

FSc Part-II · Punjab Board · English Medium

Biology 2nd Year

Complete Notes — All 12 Chapters

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FSc Part-II Biology — Punjab Board

CHAPTER 15

Homeostasis

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

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This chapter covers Homeostasis from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Every organism maintains a stable internal environment despite continuous fluctuation in its external surroundings, a property called homeostasis; living control systems achieve this through a receptor that detects change, a control centre that processes the signal, and an effector that responds, usually through negative feedback. These notes are prepared by freebooks.pk.

The chapter covers three major homeostatic processes: osmoregulation (the balance of water and solutes in cells, plants and animals across marine, fresh water and terrestrial habitats), excretion (the elimination of nitrogenous wastes, including the structures used by Hydra, Planaria, earthworm, cockroach and the human excretory system built around the nephron), and thermoregulation (how plants and animals, including humans, regulate body temperature against hot and cold extremes).

Learning Objectives

- Define homeostasis and describe the components of a living control system (receptor, control centre, effector) and negative feedback.
- Differentiate osmoconformers and osmoregulators, and describe osmoregulation in plants (hydrophytes, mesophytes, xerophytes) and animals of marine, fresh water and terrestrial habitats.
- Define excretion and relate the nature of nitrogenous excretory products (ammonia, urea, uric acid) to an animal's habitat and water availability.
- Describe excretory structures in Hydra, Planaria, earthworm and cockroach, and outline the human excretory system.
- Describe the structure of the nephron and explain filtration, reabsorption and secretion in urine formation.
- Describe common kidney disorders and their treatment, including dialysis and kidney transplant.
- Describe temperature-regulating adaptations in plants, and classify animals by their thermoregulatory strategy.
- Explain thermoregulation in humans, including the role of the hypothalamus as a thermostat and the mechanism of fever.

Key Concepts

Concepts in Homeostasis

Every species, over evolutionary history, has become adapted to a specific internal environment suited to its surroundings. Because the external environment fluctuates continuously, organisms must resist and manage these changes by keeping internal fluctuations within a narrow range, protecting the internal environment from the harms of external change; this protective regulation is called homeostasis. Homeostasis does not mean keeping the internal environment perfectly fixed - normal body functions require it to



vary within a tolerable range, adapting to lower levels under scarcity and higher levels under abundance while never approaching the extremes that would harm the organism.

Homeostatic control systems work like a physical control system such as a thermostat: a receptor (sensor) detects a change from a set point and signals a control centre, which triggers an effector to respond and correct the change. In living systems, most homeostatic control is negative feedback, in which the effector's response is opposite to the original change - for example, cooling mechanisms are triggered by a rise in temperature, and heat-conserving mechanisms by a fall. The three components most susceptible to fluctuation, and therefore most tightly regulated, are water and solute balance (osmoregulation and excretion) and internal temperature (thermoregulation).

Osmoregulation: Water Balance in Cells, Plants and Animal Habitats

Every cell is adapted to a defined internal concentration of water relative to solutes. Cells placed in a hypotonic external environment (more dilute than the cell) gain water by osmosis and become turgid, while cells in a hypertonic environment (more concentrated) lose water and shrink; an isotonic environment causes no net change. Plants show distinct water-balance adaptations depending on habitat: hydrophytes (aquatic plants) have large leaf surface area and abundant stomata on the upper leaf surface to promote water loss and prevent flooding of cells; mesophytes, with moderate water availability, open their stomata when water is plentiful and close them when it is scarce; and xerophytes, adapted to dry conditions, have small, thick leaves with a thick waxy cuticle, sunken stomata on the lower surface, and in some cases (such as cacti) shed their leaves and photosynthesise through water-storing stems instead.

Animal cells require even tighter regulation, since they cannot survive a net gain or loss of water. Some animals, called osmoconformers, keep their body fluids isotonic with the external environment (as in most marine invertebrates) and so do not need to actively regulate osmotic state; others, called osmoregulators, actively maintain an internal concentration that differs from their surroundings, discharging excess water in a hypotonic environment or excreting excess salts in a hypertonic one. Marine bony fish, being hypotonic to seawater, constantly lose water and so drink large amounts of seawater while excreting concentrated urine and actively pumping out excess salt through the gills; fresh water animals face the opposite problem, constantly gaining water and losing salts, so fresh water protozoa such as *Amoeba* use contractile vacuoles to pump out excess water while fish produce large volumes of dilute urine and actively take up salts through their gills; terrestrial animals face evaporative water loss, so they rely on waterproof body coverings (waxy insect exoskeletons, keratinized vertebrate skin), concentrated urine, and behavioural adaptations such as drinking and eating moist food, with some desert mammals surviving almost entirely on metabolic water from their food.

Excretion and the Nature of Nitrogenous Wastes

Excretion is the elimination of waste metabolites from the body, mainly nitrogenous wastes produced when amino acids are broken down (deamination), releasing an amino group that is toxic if allowed to accumulate. Depending on the animal and its habitat, this nitrogen is



excreted mainly as ammonia, urea, or uric acid. Ammonia is highly toxic and requires a large volume of water for safe removal (about 500 ml of water per gram of nitrogen), so it is used by ammonotelic animals living in a hypotonic, water-abundant environment such as fresh water. Urea is far less toxic and requires much less water (about 50 ml per gram of nitrogen), formed from ammonia in the liver via the urea cycle, and is excreted by ureotelic animals such as terrestrial mammals that have a restricted water supply. Uric acid is the least toxic and can be excreted almost solid, needing only about 1 ml of water per gram of nitrogen, making it the excretory product of uricotelic animals such as reptiles and birds living in arid environments where water conservation is critical.

Plants excrete very differently from animals: their main metabolic waste products are carbon dioxide and water, along with various organic and inorganic compounds that are stored rather than immediately released. Large plant cell vacuoles store these wastes, sometimes as crystals, and whole organs such as leaves may act as excretophores - leaves accumulate wastes and toxic materials such as heavy metals over the growing season and are then shed, as in the case of autumn leaf fall. Some trees deposit waste chemicals in old, disused xylem tissue (as in the black heartwood of ebony), and some plants actively secrete waste compounds into the soil, occasionally using them as chemical weapons against competing plants.

Excretory Structures in Invertebrates and the Human Excretory Organs

Different animal groups show a clear evolutionary progression in excretory structures. Hydra, a simple cnidarian, has no specialised excretory organs at all - wastes simply diffuse out into its isosmotic aquatic surroundings. Planaria (a flatworm) has a tubular protonephridium, a network of closed tubules capped by ciliated flame cells whose beating cilia (resembling a flickering flame) draw interstitial fluid into the tubule system, which drains to the exterior through nephridiopores. The earthworm has a more advanced tubular system, the metanephridium, one pair per body segment, with an internal ciliated funnel (the nephrostome) that collects coelomic fluid; as the fluid passes along the tubule, useful salts are reabsorbed into surrounding blood capillaries, and the remaining fluid is expelled as urine. The cockroach and other insects use Malpighian tubules, which extract nitrogenous waste directly from the haemolymph and empty it into the hind gut, where the rectum reabsorbs most of the water and salts, leaving nitrogenous waste to be excreted as solid uric acid crystals mixed with faeces - the only case among animals of a direct link between excretory and digestive systems.

In humans, the liver and kidneys are the primary excretory organs. The liver, the body's central metabolic clearing house, converts toxic ammonia into urea via the urea cycle (in which two molecules of ammonia and one of carbon dioxide combine with the amino acid ornithine, forming citrulline and then arginine, which is split by the enzyme arginase to release urea and regenerate ornithine for the next cycle); the liver also detoxifies many other harmful chemicals and performs numerous other homeostatic functions of synthesis, storage, conversion and recycling. The kidneys, in turn, filter urea and other nitrogenous wastes from the blood: a pair of human kidneys contains millions of nephrons, and although the kidneys make up less than one percent of body weight, they receive about twenty



percent of the blood pumped with every heartbeat, reflecting their critical role in maintaining blood composition.

The Nephron and Urine Formation

The nephron is the functional unit of the kidney, arranged along two regions: an outer cortex and an inner medulla. Cortical nephrons lie mostly in the cortex, while juxtamedullary nephrons have long loops that dip deep into the medulla and are specifically responsible for producing concentrated urine. Each nephron begins with a cup-shaped Bowman's capsule surrounding a knot of capillaries called the glomerulus, which receives blood via an afferent arteriole and drains it via an efferent arteriole into a further network of peritubular capillaries (and, in juxtamedullary nephrons, the vasa recta). The capsule continues as a long, highly convoluted tube consisting of the proximal tubule, the loop of Henle, and the distal tubule, which drains into a collecting tubule that eventually empties into the renal pelvis.

Urine formation involves three processes. Filtration occurs only at the glomerulus, where high blood pressure forces plasma (minus large proteins and blood cells) through the porous capillary walls into Bowman's capsule as glomerular filtrate. Reabsorption occurs mainly in the proximal tubule, where nearly all useful substances - glucose, amino acids, most salts and about 99.5 percent of filtered water - are reclaimed back into the blood, so that fluid leaving the proximal tubule is mostly nitrogenous waste. Secretion adds further substances, mainly hydrogen ions, from the blood directly into the tubule fluid to help regulate blood pH. The final concentration of urine is fine-tuned by a counter-current multiplier mechanism in the loop of Henle, which builds up a high solute concentration in the medulla, and by hormones: aldosterone (from the adrenal cortex) promotes active sodium reabsorption in the ascending loop of Henle, while antidiuretic hormone, ADH (from the posterior pituitary), increases water reabsorption in the distal tubule and collecting duct, allowing the kidney to produce urine of varying concentration depending on the body's water status.

Kidney Disorders and Their Treatment

Several disorders can impair kidney function. Kidney stones form when substances such as calcium oxalate (about 70 percent of all stones, linked to hypercalcemia and hyperoxaluria), calcium phosphate, or uric acid precipitate out during urine formation and accumulate in the renal pelvis, causing obstruction and often infection; the non-surgical treatment lithotripsy uses focused shock waves (commonly extracorporeal shock wave lithotripsy) directed from outside the body to break stones into small fragments or sand that can be passed in the urine. Renal failure occurs when pathological or chemical damage progressively destroys nephrons, particularly the glomeruli, causing a dangerous rise in blood urea and other nitrogenous wastes along with complications such as high blood pressure and anaemia.

When the kidneys can no longer clear nitrogenous waste, dialysis is used to clean the blood artificially. In hemodialysis, blood is passed through an external machine called a dialyzer (artificial kidney), where it flows on one side of a thin membrane while dialysis fluid flows on the other, allowing wastes and excess water to diffuse out of the blood into the fluid. In peritoneal dialysis, dialysis fluid is introduced directly into the patient's peritoneal cavity through a catheter, and wastes diffuse across the peritoneum (the lining of the abdominal



cavity) into the fluid, which is later drained and replaced. Dialysis can only be used as a temporary or repeated measure; in severe, end-stage renal failure (uremia), a kidney transplant from a matching donor is the only permanent treatment.

Thermoregulation in Plants and Animal Temperature Classification

Plants cope with temperature stress in different ways. High temperature denatures enzymes and damages metabolism, so plants rely on evaporative cooling through transpiration, though hot, dry conditions that force stomatal closure to conserve water reduce this cooling and cause heat stress; many plants respond by synthesising heat-shock proteins that protect enzymes and other proteins from denaturation. Low temperature reduces membrane fluidity and can lock membrane lipids into rigid crystalline arrangements; plants adapted to cold increase the proportion of unsaturated fatty acids in their membranes to resist this, and some cold-region plants alter their cytosol's solute composition so that it can super-cool without forming damaging ice crystals inside the cell, even though ice may form harmlessly in the cell walls.

Animals are classified by their thermoregulatory strategy in two overlapping ways. By whether body temperature fluctuates with the environment, animals are poikilotherms (body temperature varies with ambient temperature - most invertebrates, fish, amphibians and reptiles) or homeotherms (body temperature is kept relatively constant - birds and mammals), though this scheme has exceptions, such as some deep-sea fish that keep a constant temperature and some lizards that behaviourally regulate theirs. A more precise classification is based on the source of body heat: endotherms generate their own body heat as a by-product of metabolism (most birds, mammals, some fish and flying insects), ectotherms produce little metabolic heat and instead rely mainly on absorbing heat from the environment (most invertebrates, fish, amphibians and reptiles), and heterotherms can vary their degree of endothermic heat production but do not keep body temperature within as narrow a range as typical endotherms (such as bats and hummingbirds). Animals regulate heat exchange through structural adaptations (insulating fur, fat and pelage, sweat glands, panting), physiological adaptations (adjusting metabolic rate, vasodilation and vasoconstriction), and behavioural adaptations (moving to a more favourable microhabitat, basking, or adjusting body posture to change exposed surface area).

Thermoregulation in Humans and Fever

Mammals, including humans, are endotherms that maintain body temperature within a narrow range of about 36 to 38 degrees Celsius, giving them a high, stable metabolic rate and the ability to remain active in a wide range of environments. Heat production is increased through shivering thermogenesis (increased muscle contraction) and non-shivering thermogenesis (hormonally triggered, including through specialised brown fat in some mammals); excess heat is lost through increased blood flow to the skin and evaporative cooling (sweating in humans, panting in dogs). In cold conditions, mammals reduce heat loss through vasoconstriction of skin blood vessels, raising fur to trap insulating air, or relying on a layer of subcutaneous fat (or, in marine mammals such as whales and seals, a thick layer of blubber); in warm conditions, vasodilation increases blood flow to the



skin for heat loss, and evaporative cooling through sweating or panting becomes the main cooling strategy.

In humans, body temperature is regulated by a homeostatic thermostat in the hypothalamus, set at about 37 degrees Celsius. When temperature rises above this set point, warm-sensitive thermoreceptors in the skin, hypothalamus and elsewhere trigger increased blood flow to the skin and activation of sweat glands, cooling the body through evaporation. When temperature falls below the set point, cold receptors trigger constriction of superficial blood vessels and both shivering and non-shivering heat-production mechanisms, conserving and generating heat. During bacterial or viral infection, white blood cells and pathogens release chemicals called pyrogens, which raise the hypothalamic set point above 37 degrees Celsius, producing fever (pyrexia); this elevated temperature is believed to help stimulate the body's protective immune mechanisms against the infection.

Important Definitions

Term	Definition
Homeostasis	The maintenance of a stable internal environment within a narrow, tolerable range despite continuous fluctuation in the external environment.
Osmoregulation	The regulation of solute concentration and the gain or loss of water in an organism, keeping internal water and salt balance within a tolerable range.
Osmoconformer	An animal that keeps its body fluids isotonic with its external environment and so does not need to actively regulate its internal osmotic state.
Excretion	The elimination of waste metabolites from the body, mainly nitrogenous wastes such as ammonia, urea and uric acid.
Deamination	The removal of the amino group from an amino acid during its catabolism, releasing ammonia that must be excreted or converted to a less toxic form.
Nephron	The structural and functional unit of the kidney, consisting of Bowman's capsule, the glomerulus, and a tubular system that filters blood and forms urine.
Dialysis	The artificial removal of nitrogenous wastes and excess water from the blood of a patient with kidney failure, by hemodialysis or peritoneal dialysis.
Ectotherm	An animal that produces little metabolic heat and relies mainly on absorbing heat from its external environment to regulate its body temperature.

Key Facts

Item	Fact
Human body temperature set point	The hypothalamic thermostat is set at about 37 degrees Celsius; normal range is about 36-38 degrees Celsius.
Water needed to excrete ammonia	About 500 ml of water is required to excrete 1 gram of nitrogen as ammonia.
	About 50 ml of water is required to excrete 1 gram of nitrogen as urea.

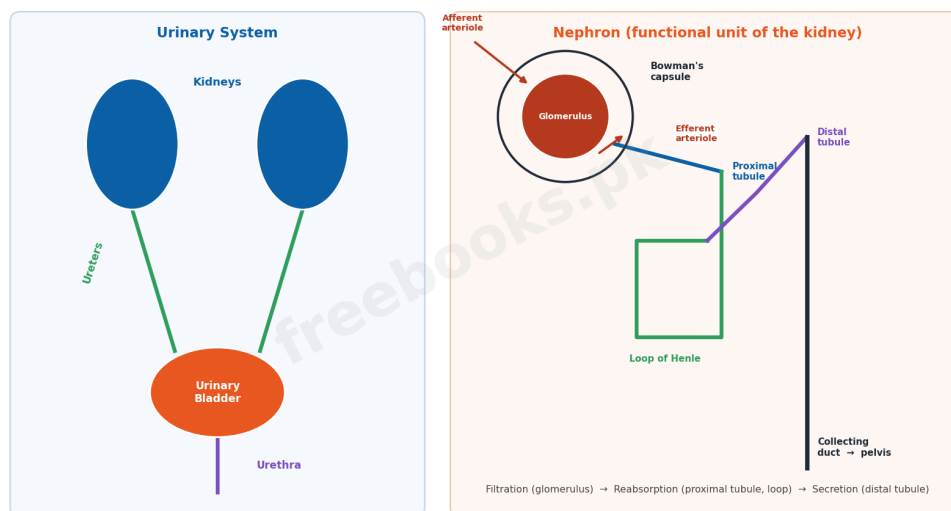


Item	Fact
Water needed to excrete urea	
Water needed to excrete uric acid	About 1 ml of water is required to excrete 1 gram of nitrogen as uric acid.
Glomerular filtrate reabsorption	Mammalian kidneys, including human, reabsorb over 99.5% of glomerular filtrate.
Kidney blood supply	Kidneys are under 1% of body weight but receive about 20% of blood pumped with each heartbeat.
Calcium oxalate stone share	Calcium oxalate stones make up about 70% of all kidney stones; calcium phosphate about 15%, uric acid about 10%.
Cardiac cycle reference	One heartbeat cycle used as a homeostatic reference for blood/kidney flow takes about 0.8 seconds.

Diagrams & Illustrations

Human Urinary System and Nephron Structure: a labelled diagram of the human urinary system (kidney, ureter, urinary bladder, urethra) alongside a detailed nephron showing Bowman's capsule, glomerulus, proximal tubule, loop of Henle, distal tubule and collecting duct.

Human Urinary System and Nephron Structure

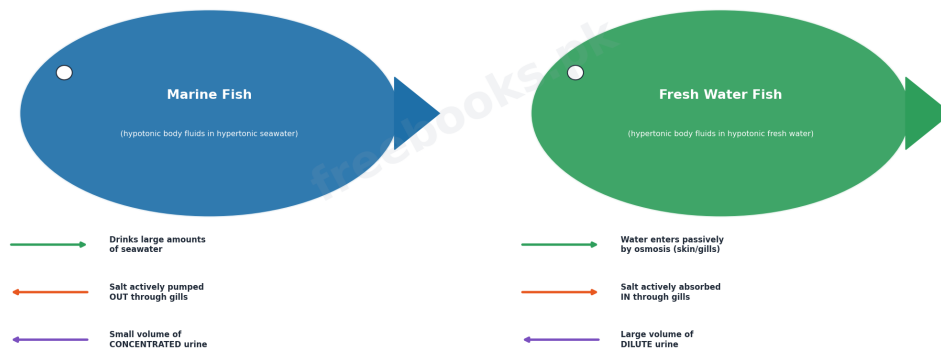


Human Urinary System and Nephron Structure

Osmoregulation in Marine and Fresh Water Fish: a comparison diagram showing a marine bony fish (drinking seawater, excreting salt through gills, producing concentrated urine) and a fresh water fish (not drinking, absorbing salt through gills, producing large volumes of dilute urine).



Osmoregulation in Marine and Fresh Water Fish

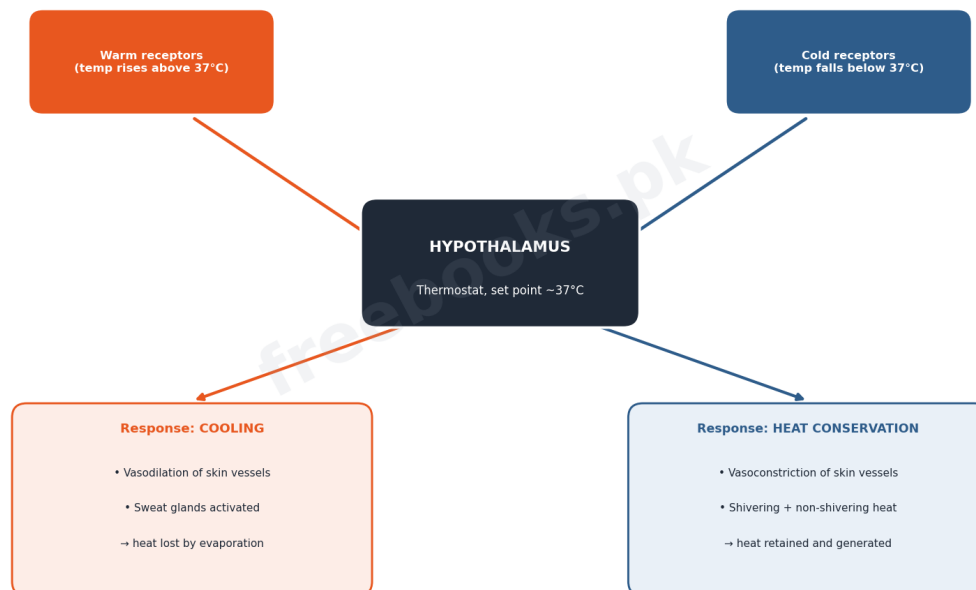


Osmoregulation in Marine and Fresh Water Fish

Human Thermoregulation: Feedback Control by the Hypothalamus: a diagram showing the hypothalamic thermostat receiving input from warm and cold receptors and controlling effectors (sweat glands, skin blood vessels, shivering muscles) through negative feedback to maintain body temperature near 37 degrees Celsius.

Human Thermoregulation: Hypothalamus Feedback Control

Negative feedback: each response acts opposite to the original change, restoring body temperature to the set point.



Human Thermoregulation: Feedback Control by the Hypothalamus

Short Questions & Answers

Q1. Differentiate osmoconformers and osmoregulators.

Ans. Osmoconformers keep their body fluids isotonic with the external environment and so do not need to actively regulate their internal osmotic state (most marine invertebrates); osmoregulators actively maintain an internal solute concentration different from their



surroundings, expending energy to discharge excess water or excrete excess salts as needed.

Q2. Why are reptiles and birds in arid habitats uricotelic?

Ans. Uric acid can be excreted as a semi-solid paste using only about 1 ml of water per gram of nitrogen, far less than ammonia or urea require; this allows reptiles and birds living in water-scarce, arid environments to eliminate nitrogenous waste while conserving water.

Q3. Why does filtration occur only at the glomerulus and nowhere else in the nephron?

Ans. Only the glomerular capillary walls are porous enough to allow blood plasma to be forced out under blood pressure, and only there does the incoming afferent arteriole create the necessary filtration pressure; the rest of the nephron tubule is not exposed to this filtration pressure and instead carries out reabsorption and secretion.

Q4. What are the two main types of dialysis?

Ans. Hemodialysis, in which blood is passed through an external machine (dialyzer) containing a membrane that separates blood from dialysis fluid so wastes diffuse out; and peritoneal dialysis, in which dialysis fluid is introduced into the patient's peritoneal cavity and wastes diffuse across the peritoneum into the fluid.

Q5. Differentiate poikilotherms and homeotherms.

Ans. Poikilotherms are animals whose body temperature fluctuates with the ambient temperature of their environment (most invertebrates, fish, amphibians, reptiles); homeotherms maintain a relatively constant body temperature despite changes in ambient temperature (birds and mammals).

Q6. What causes fever (pyrexia)?

Ans. During bacterial or viral infection, increased white blood cells and the pathogens themselves release chemicals called pyrogens, which raise the hypothalamic thermostat's set point above the normal 37 degrees Celsius, producing fever, which is thought to help stimulate the body's protective mechanisms against infection.

Long Questions & Answers

Q1: Explain the concept of homeostasis and describe how a living control system operates using negative feedback.

Homeostasis is the maintenance of a stable internal environment within a narrow, tolerable range despite continuous change in the external environment. Every species has, through evolutionary history, become adapted to a specific set of internal conditions suited to its way of life, and because external conditions such as temperature, water availability and solute concentration fluctuate constantly, organisms must actively resist and manage these changes rather than simply being overwhelmed by them. Importantly, homeostasis does not mean holding the internal environment perfectly fixed; rather, the internal environment is allowed to vary within a physiologically tolerable range, shifting toward the lower end under conditions of scarcity and the higher end under conditions of abundance, while control systems prevent it from reaching genuinely harmful extremes in either direction. This



regulation operates at both the level of the whole organism and at the level of individual cells, where the intracellular environment is kept comparatively stable relative to a more variable extracellular environment. The living control systems that achieve this regulation work on the same basic logic as any physical control system, such as a household thermostat: a receptor (sensor) continuously monitors some internal condition and detects any deviation from a genetically determined set point; when a deviation is detected, the receptor signals a control centre, which processes this information and activates an effector, a structure that carries out a response to correct the deviation and restore the condition toward its set point. In the overwhelming majority of homeostatic mechanisms, this correction takes the form of negative feedback, meaning the effector's response acts in the opposite direction to the original disturbance - for example, a rise in body temperature above the set point triggers cooling responses such as sweating and increased blood flow to the skin, while a fall in temperature triggers heat-conserving and heat-generating responses such as vasoconstriction and shivering. This feedback loop of detection, signalling and corrective response operates continuously and automatically, allowing organisms to buffer their internal environment against the much larger fluctuations that occur outside their bodies.

Q2: Discuss the nature of nitrogenous excretory products and explain how they relate to an animal's habitat and water availability.

The catabolism of amino acids and nucleoproteins in animals releases nitrogenous waste, primarily in the form of an amino group removed during deamination; because this waste, especially in the form of ammonia, is highly toxic if it accumulates in the body, it must be continuously eliminated, and the chemical form in which it is excreted is closely tied to how much water an animal's habitat makes available. Ammonia is the most toxic of the three main nitrogenous wastes and must be kept in very low concentration in body fluids, which requires large volumes of water for its safe removal - roughly 500 ml of water per gram of nitrogen excreted as ammonia. Because of this heavy water cost, ammonia is used as the primary excretory product only by animals with abundant access to water, chiefly aquatic animals living in fresh water, which are termed ammonotelic; these animals can rapidly dilute and flush ammonia from their bodies without risking dehydration. Animals living where water supply is more restricted, such as terrestrial mammals, cannot afford this water expenditure, so their liver converts ammonia into the far less toxic compound urea through the metabolic pathway called the urea cycle; urea requires only about 50 ml of water per gram of nitrogen for excretion, a tenfold saving compared to ammonia, and these animals are termed ureotelic. Animals living in habitats with acute water shortage, most notably reptiles and birds inhabiting arid regions, take water conservation a step further by excreting nitrogen as uric acid, a compound so insoluble that it can be voided as a semi-solid paste using only about 1 ml of water per gram of nitrogen; these animals are termed uricotelic. In this way, the evolutionary shift from ammonotelic to ureotelic to uricotelic represents a clear adaptive progression toward greater water conservation, precisely matching the water constraints of the habitats these different animal groups occupy, from water-abundant fresh water environments to increasingly water-scarce terrestrial and arid environments.



Q3: Describe the structure of the human nephron and explain how urine is formed by filtration, reabsorption and secretion.

The nephron is the basic structural and functional unit of the human kidney, and each kidney contains millions of them arranged along two regions, an outer cortex and an inner medulla. Nephrons whose tubules lie mostly within the cortex are called cortical nephrons, while juxtamedullary nephrons have unusually long loops that dip deep into the medulla and are specifically responsible for the kidney's ability to produce highly concentrated urine. Each nephron begins with a cup-shaped structure called Bowman's capsule, which encloses a dense knot of capillaries known as the glomerulus; blood enters the glomerulus through an afferent arteriole and leaves through a narrower efferent arteriole, and this difference in vessel diameter helps maintain a high blood pressure within the glomerular capillaries. Blood leaving the glomerulus flows into a further network of peritubular capillaries that closely wrap around the rest of the nephron tubule, and in juxtamedullary nephrons these extend further as the vasa recta running alongside the loop of Henle. Bowman's capsule continues as a long, highly coiled tube consisting of, in sequence, the proximal convoluted tubule, the loop of Henle (with descending and ascending limbs), and the distal convoluted tubule, which finally drains into a collecting tubule; many collecting tubules merge and eventually open into the renal pelvis, from which urine passes into the ureter. Urine formation proceeds through three distinct processes occurring at different points along this pathway. Filtration takes place exclusively at the glomerulus, where the unusually porous capillary walls, combined with the pressure generated by blood entering through the wider afferent arteriole, force plasma - water, salts, glucose, amino acids and other small molecules, but not blood cells or large proteins - out into Bowman's capsule as glomerular filtrate; nowhere else in the nephron does this kind of bulk filtration occur. Reabsorption occurs mainly, though not exclusively, in the proximal convoluted tubule, where essentially all of the filtrate's useful components - all of the glucose and amino acids, most salts, and typically well over 99 percent of the filtered water - are actively and passively reclaimed back into the surrounding peritubular capillaries, so that fluid leaving the proximal tubule is left overwhelmingly enriched in nitrogenous wastes destined for excretion. Secretion is the third process, in which the tubular epithelium, mainly along the distal parts of the nephron, actively adds selected substances from the blood directly into the tubular fluid; this is a highly selective process, principally involving the secretion of hydrogen ions, which helps the kidney fine-tune and regulate the pH of the blood. Together, filtration, reabsorption and secretion allow the nephron to process an enormous volume of blood each day while conserving nearly all useful substances and precisely regulating the final volume, concentration and composition of urine, a process further fine-tuned by the counter-current multiplier mechanism in the loop of Henle and by hormones such as aldosterone and antidiuretic hormone.

Q4: Describe the classification of animals based on thermoregulatory strategy and explain thermoregulation in humans, including the role of the hypothalamus.

Animals can be classified by their thermoregulatory strategy in two related but distinct ways. The older classification is based on whether body temperature fluctuates with the



environment: poikilotherms are animals whose body temperature tends to rise and fall along with the ambient air or water temperature, a category that includes most invertebrates along with fish, amphibians and reptiles, while homeotherms are animals that keep their body temperature relatively constant despite changes in ambient temperature, a category comprising birds and mammals. This scheme, however, runs into difficulties in several cases - some deep-sea fish maintain remarkably constant body temperature simply because their environment itself is thermally stable, some lizards behaviourally regulate their temperature quite precisely by basking and seeking shade, and numerous birds and mammals allow their body temperature to vary more than the classical definition would suggest. Because of these complications, biologists more often use a second, more mechanistically precise classification based on the actual source of body heat. Endotherms generate the bulk of their body heat internally as a by-product of their own metabolism, a category that includes birds, mammals, and additionally some fast-swimming fish and actively flying insects that generate substantial metabolic heat during flight. Ectotherms, in contrast, produce comparatively little metabolic heat of their own and instead rely mainly on absorbing heat directly from their external surroundings, a category comprising most invertebrates, fish, amphibians and reptiles. A third, intermediate category, heterotherms, includes animals such as bats and hummingbirds that are capable of substantial endothermic heat production at times but do not maintain their body temperature within as narrow and constant a range as typical endotherms, often allowing body temperature to drop considerably during rest or torpor to conserve energy. In humans, as in other mammals, thermoregulation is centred on a homeostatic thermostat located in the hypothalamus, a region of the brain, which is set at approximately 37 degrees Celsius and continuously compares the body's actual temperature against this set point using input from both central receptors in the hypothalamus itself and peripheral thermoreceptors in the skin. When body temperature rises above the set point, warm-sensitive receptors trigger a coordinated response: blood flow to the skin increases through vasodilation of superficial blood vessels, carrying heat to the body surface where it can be lost, while sweat glands are activated to increase evaporative cooling as sweat evaporates from the skin surface. When body temperature falls below the set point, cold receptors instead trigger heat-conserving and heat-generating responses: superficial blood vessels constrict, reducing blood flow to the skin and minimizing heat loss, while shivering thermogenesis (rapid, involuntary muscle contraction) and non-shivering thermogenesis (hormonally triggered metabolic heat production) both increase the rate of internal heat production. This continuous negative feedback loop, coordinated entirely through the hypothalamic thermostat, allows humans to maintain body temperature within the narrow range of about 36 to 38 degrees Celsius across a very wide range of external conditions, and the same thermostat mechanism, when its set point is deliberately raised above 37 degrees Celsius by pyrogens released during infection, produces the elevated body temperature known as fever.

Q5: Discuss common kidney disorders, their causes, and the medical treatments used to manage them.

The kidneys are vulnerable to a range of disorders that can seriously disrupt their filtering and regulatory functions. Kidney stones are one of the most common problems, forming when certain dissolved substances in the urine precipitate out of solution during urine



formation and gradually accumulate into hard deposits, most often lodging in the renal pelvis where they can cause painful urinary obstruction and are frequently complicated by secondary infections. The chemical composition of kidney stones varies: calcium oxalate stones are by far the most common, accounting for roughly 70 percent of all cases, and are strongly associated with hypercalcemia (abnormally high circulating blood calcium, often resulting from other underlying diseases) and hyperoxaluria (abnormally high blood levels of oxalates, which are naturally present in foods such as green vegetables and tomatoes); calcium phosphate stones account for roughly 15 percent of cases, and uric acid stones for roughly 10 percent. Historically, kidney stones were removed only through invasive surgery, but the modern non-surgical treatment of choice is lithotripsy, most commonly performed as extracorporeal shock wave lithotripsy, in which focused shock waves of high-intensity ultrasound or X-ray energy are generated by a machine positioned outside the patient's body and directed precisely at the stone, fragmenting it into tiny pieces or sand-like particles that can then be passed out of the body naturally in the urine, avoiding the need for surgical incision. A more severe category of kidney disorder is renal failure, in which various pathological processes or chemical insults progressively destroy functioning nephrons, especially damaging their glomeruli, so that the kidney's filtering capacity steadily declines; as this progresses, nitrogenous wastes such as urea build up to dangerous levels in the blood plasma, and this rising urea concentration is associated with serious complications including elevated blood pressure and anaemia. When renal failure becomes severe enough that the kidneys can no longer adequately clear nitrogenous wastes from the blood on their own, dialysis becomes necessary as an artificial substitute for kidney function; this can be delivered as hemodialysis, in which the patient's blood is circulated through an external machine containing a dialyzer (an artificial kidney) with a thin semi-permeable membrane separating flowing blood on one side from a dialysis fluid on the other, allowing wastes and excess water to diffuse out of the blood and into the fluid to be discarded, or as peritoneal dialysis, in which dialysis fluid is instead introduced directly into the patient's own abdominal peritoneal cavity through a surgically implanted catheter, allowing wastes to diffuse across the patient's peritoneal membrane into the fluid, which is later drained and replaced, with this cycle repeated multiple times each day. Dialysis, however performed, is fundamentally a temporary or ongoing supportive measure rather than a cure, and in the most severe, end-stage form of renal failure, sometimes called uremia, the only remaining permanent treatment option is surgical kidney transplantation, in which a healthy kidney from a matching donor is transplanted into the patient to permanently restore normal excretory and osmoregulatory function.

MCQs with Answers

1. The protective regulation of a stable internal environment despite external fluctuation is called:

(a) excretion (b) homeostasis (c) osmoregulation (d) thermoregulation

Correct Answer: (b) homeostasis. Homeostasis is the maintenance of a stable internal environment within a tolerable range despite continuous external change.

2. An animal whose body fluids remain isotonic with its external environment, requiring no active osmotic regulation, is called a/an:



(a) osmoregulator (b) osmoconformer (c) ammonotelic animal (d) ectotherm

Correct Answer: (b) osmoconformer. Osmoconformers keep their body fluids isotonic with the external environment and do not need to actively regulate their internal osmotic state.

3. Excreting nitrogen as uric acid, which requires only about 1 ml of water per gram of nitrogen, is an adaptation typical of:

(a) fresh water fish (b) terrestrial mammals (c) reptiles and birds in arid habitats (d) marine invertebrates

Correct Answer: (c) reptiles and birds in arid habitats. Uric acid excretion (uricotelic) conserves water and is typical of reptiles and birds living in water-scarce, arid environments.

4. The excretory structures found in the earthworm, one pair per body segment, are called:

(a) protonephridia (b) Malpighian tubules (c) metanephridia (d) flame cells

Correct Answer: (c) metanephridia. Each segment of the earthworm has a pair of metanephridia, tubular excretory structures with an internal ciliated nephrostome.

5. In insects such as the cockroach, nitrogenous waste is collected from the haemolymph by:

(a) Malpighian tubules (b) metanephridia (c) protonephridia (d) nephrons

Correct Answer: (a) Malpighian tubules. Malpighian tubules remove nitrogenous waste from the haemolymph and empty it into the hind gut for excretion as uric acid with the feces.

6. Filtration of blood in the nephron occurs only at the:

(a) proximal tubule (b) loop of Henle (c) glomerulus (d) collecting duct

Correct Answer: (c) glomerulus. Filtration occurs only at the glomerulus, where porous capillary walls and blood pressure force plasma into Bowman's capsule.

7. The hormone that promotes water reabsorption in the distal tubule and collecting duct is:

(a) aldosterone (b) antidiuretic hormone (ADH) (c) insulin (d) arginase

Correct Answer: (b) antidiuretic hormone (ADH). ADH, released from the posterior pituitary, increases water reabsorption in the distal tubule and collecting duct.

8. About 70% of kidney stones are composed mainly of:

(a) uric acid (b) calcium phosphate (c) calcium oxalate (d) cystine

Correct Answer: (c) calcium oxalate. Calcium oxalate stones, associated with hypercalcemia and hyperoxaluria, make up about 70% of all kidney stones.

9. Animals that generate the bulk of their body heat internally as a metabolic by-product are called:

(a) ectotherms (b) endotherms (c) poikilotherms only (d) osmoconformers

Correct Answer: (b) endotherms. Endotherms (e.g. birds and mammals) generate their own body heat mainly as a by-product of metabolism.

10. In humans, the homeostatic thermostat that controls body temperature is located in the:



(a) medulla oblongata (b) hypothalamus (c) cerebellum (d) adrenal cortex

Correct Answer: (b) hypothalamus. The hypothalamus contains the homeostatic thermostat, set at about 37 degrees Celsius, that regulates human body temperature.

Quick Revision Summary

- Homeostasis = stable internal environment within a tolerable range despite external change. Control system = receptor -> control centre -> effector, mostly by negative feedback (response opposite to the change).
- Osmoregulation: hypotonic/hypertonic/isotonic environments. Plants: hydrophytes (large leaf area, open stomata), mesophytes (moderate), xerophytes (small thick leaves, sunken stomata, thick cuticle). Animals: osmoconformers (isotonic, no active regulation) vs osmoregulators (marine, fresh water, terrestrial adaptations).
- Excretion = elimination of nitrogenous wastes after deamination. Ammonia (needs ~500ml water/g N, ammonotelic, fresh water) -> Urea (~50ml/g N, ureotelic, terrestrial mammals, via urea cycle in liver) -> Uric acid (~1ml/g N, uricotelic, reptiles/birds in arid habitats).
- Excretory structures: Hydra (diffusion only) -> Planaria (protonephridia + flame cells) -> earthworm (metanephridia, 1 pair/segment) -> cockroach (Malpighian tubules, linked to hindgut) -> vertebrates/human (kidneys with nephrons; liver makes urea via urea cycle).
- Nephron: Bowman's capsule + glomerulus (afferent/efferent arteriole) -> proximal tubule -> loop of Henle -> distal tubule -> collecting duct -> pelvis. Filtration (glomerulus only) -> Reabsorption (mainly proximal tubule, >99.5% water) -> Secretion (H⁺ ions, mainly distal). Hormones: aldosterone (Na⁺ reabsorption), ADH (water reabsorption).
- Kidney disorders: stones (70% calcium oxalate) treated by lithotripsy (shock waves, non-surgical); renal failure treated by dialysis (hemodialysis via external dialyzer, or peritoneal dialysis via abdominal catheter) or, in end-stage disease, kidney transplant.
- Thermoregulation: plants use heat-shock proteins (heat) and unsaturated fatty acids/solute changes (cold). Animals: poikilotherm/homeotherm (temperature stability) and ectotherm/endotherm/heterotherm (heat source) classifications. Humans: hypothalamic thermostat (~37°C), vasodilation+sweating (warm), vasoconstriction+shivering (cold), fever = pyrogens raise the set point. Notes by freebooks.pk.

Exam Tips

- Learn the receptor -> control centre -> effector -> negative feedback loop as a single labelled flow diagram; examiners often ask you to apply it to a new example, not just define it.
- Build a clear water-cost table for ammonia/urea/uric acid (500 ml, 50 ml, 1 ml per gram of nitrogen) and link each directly to a habitat (fresh water, terrestrial, arid) and animal group - this is a very common short question.



- Memorise the excretory-structure progression Hydra -> Planaria (flame cells) -> earthworm (metanephridia) -> cockroach (Malpighian tubules) with one labelled feature for each; diagram questions often ask you to identify the structure from a description.
- Practice labelling a full nephron diagram from memory (Bowman's capsule, glomerulus, afferent/efferent arteriole, proximal tubule, loop of Henle, distal tubule, collecting duct) and be ready to state exactly where filtration, reabsorption and secretion each occur.
- Separate the two thermoregulation classification schemes clearly in your notes: poikilotherm/homeotherm (temperature stability) is not the same axis as ectotherm/endotherm/heterotherm (heat source) - many students confuse these.
- Know both types of dialysis (hemodialysis vs peritoneal dialysis) with one distinguishing feature each, and be able to explain why dialysis is temporary while a transplant is the permanent option.
- For the human thermoregulation long question, structure your answer around the hypothalamus as the thermostat, then split your response into 'response to rise in temperature' and 'response to fall in temperature' as two clearly separate halves.

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FSc Part-II Biology — Punjab Board

CHAPTER 16

Support and Movement

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

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This chapter covers Support and Movement from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Both plants and animals need support against gravity and mechanical stress, though only animals show true locomotion; plants achieve support through specialised cells (parenchyma, collenchyma, sclerenchyma) and secondary growth, while animals rely on hydrostatic, exo- or endoskeletons combined with muscle. These notes are prepared by freebooks.pk.

The chapter covers support and movement in plants (supporting tissues, autonomic and paratonic movements, and the role of plant hormones), the three types of animal skeleton and the structure of the human skeleton and joints, common skeletal deformities and disorders, the structure and physiology of muscle (including the sliding filament model of contraction), and locomotion across representative invertebrates and vertebrates.

Learning Objectives

- Describe the tissues (parenchyma, collenchyma, sclerenchyma) that provide support in plants, and explain secondary growth.
- Differentiate autonomic and paratonic plant movements, with examples of each type.
- Differentiate hydrostatic skeleton, exoskeleton and endoskeleton, and describe ecdysis in arthropods.
- Describe the axial and appendicular divisions of the human skeleton and the major types of joints.
- Describe common skeletal deformities and disorders and how broken bones are repaired.
- Describe the structure of skeletal muscle and explain the sliding filament model of muscle contraction.
- Explain how calcium ions control the actin-myosin interaction and describe the source of energy for contraction.
- Describe locomotion in representative invertebrates (Euglena, Paramecium, Amoeba, earthworm, cockroach, starfish) and vertebrates (fish, amphibians, reptiles, birds, mammals).

Key Concepts

Support in Plants and Types of Plant Movement

Plants achieve mechanical support through several specialised cell types. Parenchyma cells of the epidermis, cortex and pith take up water by osmosis, generating an internal hydrostatic turgor pressure that keeps them rigid; loss of this turgidity causes herbaceous stems to wilt. Sclerenchyma cells have thick, lignin-impregnated secondary walls that make them tough and mostly non-living, occurring as fibres (long, cylindrical, found in xylem or as bundle caps), sclereids (shorter, found in seed coats and nut shells) and vessels (long tubular water-conducting cells); collenchyma cells, by contrast, have only angular thickening of their primary walls, remain living, and provide flexible support to young, growing



herbaceous parts. In woody plants, secondary growth - thickening due to cell division in the vascular cambium (producing secondary xylem and secondary phloem) and cork cambium - forms visible annual growth rings, with the outer, still-conducting sapwood surrounding the inactive, often chemically protected heartwood.

Plants cannot relocate, so instead of true locomotion they show movements of their organs, classified as autonomic (spontaneous, due to internal causes) or paratonic (due to external causes). Autonomic movements include tactic movements (locomotion of a whole free-living cell or organelle, such as phototactic chloroplast movement), turgor movements (rapid, reversible movements from changes in cell turgor, such as the sleep movements of bean leaves or the rapid leaflet-folding of Mimosa, both centred on the swollen pulvinus), and growth movements (from unequal growth on two sides of an organ, such as epinasty, hyponasty and the zig-zag nutation of a growing shoot tip). Paratonic movements include tropic movements (directional growth curvature toward or away from a stimulus, such as phototropism, thigmotropism, chemotropism, hydrotropism and geotropism) and nastic movements (non-directional responses to a stimulus, such as photonasty and thermonasty in flower opening, or the haptanastic snap of the Venus flytrap). Plant hormones control these movements: auxin drives phototropism and gravitropism (inhibiting root cell growth on the lower side while stimulating stem cell growth on the lower side, producing opposite curvature responses), while nastic movements depend on the balance between growth inhibitors such as abscisic acid and growth stimulators such as gibberellins.

Types of Skeleton in Animals

Animals rely on three main types of skeleton for support and movement. A hydrostatic skeleton, found in cnidarians, annelids and other soft-bodied invertebrates, uses a fluid-filled cavity against which surrounding muscles contract; in the earthworm, fluid-filled, septum-separated compartments allow circular muscle contraction to elongate a segment and longitudinal muscle contraction to shorten it, producing waves of movement aided by setae. An exoskeleton is a hardened, non-living outer covering secreted by the ectoderm, consisting of an outer, waterproof epicuticle and a thicker procuticle (exocuticle plus endocuticle) made of chitin and protein, further hardened by sclerotization or calcium carbonate deposition; the simplest exoskeletons are molluscan shells, while arthropods have the most complex exoskeletons, modified with flexible joints, sensory bristles and structures for gas exchange, but with the drawback that periodic shedding and replacement (ecdysis, controlled by the hormone ecdysone) is required for growth.

An endoskeleton, found in vertebrates, is built mainly of bone and cartilage, both living connective tissues embedded in a collagen-based matrix. Bone, the most rigid connective tissue, has its collagen fibres hardened by calcium phosphate deposits, with a dense outer layer of compact bone and a lighter, porous interior of spongy bone containing blood-cell-forming marrow; three cell types are involved - bone-forming osteoblasts, mature osteocytes, and bone-dissolving osteoclasts, which together remodel bone throughout life. Cartilage is softer, avascular, and secreted by living chondrocytes into a flexible collagen matrix; hyaline cartilage (the most abundant type, found at movable joints), elastic cartilage (found in the external ear and epiglottis) and fibrocartilage (found in intervertebral discs and pubic symphysis) are its three main types.



The Human Skeleton: Axial and Appendicular Divisions

The human skeleton is divided into the axial skeleton (skull, vertebral column, ribs and sternum, forming the body's central axis) and the appendicular skeleton (the limbs and their girdles). The skull consists of the cranium (8 bones - 4 unpaired: frontal, occipital, sphenoid and ethmoid; and 2 paired: parietal and temporal - protecting the brain) and 14 facial bones (6 paired: maxilla, zygomatic, nasal, lacrimal, palatine and inferior concha; and 2 unpaired: mandible and vomer). The vertebral column, extending from skull to pelvis and protecting the spinal cord, consists of 33 vertebrae grouped as 7 cervical (neck, including the atlas and axis), 12 thoracic, 5 lumbar, and 9 pelvic vertebrae fused into the sacrum (5) and coccyx (4); its natural curvatures give it more strength than a straight column would have. The rib cage comprises 12 pairs of ribs, of which 10 pairs connect to the sternum (directly or via costal cartilage) and the lower 2 pairs are 'floating ribs' with no sternal attachment, together enclosing the chest cavity.

The appendicular skeleton consists of the pectoral girdle and forelimbs, and the pelvic girdle and hindlimbs. The pectoral girdle comprises the scapula and clavicle (which connects the scapula to the sternum); the forelimb consists of the humerus, radius and ulna, 8 carpals, 5 metacarpals and 14 phalanges, with the humerus forming a ball-and-socket joint with the scapula and a hinge joint with the radius and ulna at the elbow. The pelvic girdle consists of two coxal bones, each formed by fusion of the ilium, ischium and pubis, attaching the hindlimb to the vertebral column; the hindlimb consists of the femur, tibia and fibula, 7 tarsals, 5 metatarsals and 14 phalanges, with the femur forming a ball-and-socket hip joint proximally and a hinge knee joint distally.

Joints, Skeletal Deformities and Bone Repair

Joints, where bones meet, are classified by the movement they allow (immovable, slightly movable, or freely movable) or by structure. Fibrous joints (e.g. between skull bones) are held by short collagen fibres and allow no movement; cartilaginous joints (e.g. between vertebrae) allow little movement; and synovial joints contain a fluid-filled cavity enclosed by a fibrous capsule and synovial membrane, allowing free movement - the hinge joint (e.g. elbow, knee), permitting movement in essentially one plane, and the ball-and-socket joint (e.g. hip, shoulder), permitting movement in multiple directions, being the two major types. Skeletal deformities have varied causes: genetic causes include cleft palate and microcephaly; hormonal causes include osteoporosis (bone resorption outpacing deposition, common in postmenopausal women due to reduced estrogen); and nutritional causes include osteomalacia and rickets (softened, deformed bones from inadequate calcium or vitamin D). Other disorders include a slipped (herniated) intervertebral disc, in which the annulus fibrosus ruptures and the nucleus pulposus protrudes, potentially compressing the spinal cord or nerves; sciatica, stabbing pain from sciatic nerve injury; and arthritis, inflammatory or degenerative joint disease including osteoarthritis, rheumatoid arthritis and gouty arthritis.

A broken bone is treated by reduction (closed, manually realigning the bone; or open, surgically securing it with pins or wires) followed by immobilisation in a cast, with healing typically taking 8 to 12 weeks. Repair proceeds through four phases: hematoma formation,



in which torn blood vessels form a clot at the fracture site and nearby bone cells begin to die; soft callus formation (3 to 4 weeks), in which capillaries and fibroblasts/osteoblasts invade the hematoma and begin building new bone; bony callus formation, in which osteoblasts and osteoclasts convert the soft callus into a firm bony union over 2 to 3 months; and remodeling, in which excess material is removed over several months until the repaired bone closely resembles the original structure.

Muscle Types and the Structure of Skeletal Muscle

Vertebrates possess three kinds of muscle cells. Smooth muscle is unstriated, spindle-shaped with a single nucleus, involuntary, and found in the walls of blood vessels and the digestive tract. Cardiac muscle, found only in the heart, is striated but involuntary, made of branched, interconnected cells each with its own nucleus. Skeletal muscle is striated (alternating light and dark bands) and voluntary, attached to bone via tendons, and responsible for moving the skeleton. Each skeletal muscle fibre is a large, multinucleated cylindrical cell bounded by the sarcolemma, containing sarcoplasm rich in glycogen and the oxygen-storing pigment myoglobin, and packed with parallel myofibrils built from repeating contractile units called sarcomeres. Along each myofibril, the dark A band (containing thick filaments) alternates with the light I band (containing only thin filaments, bisected by the Z line); the lighter H zone in the middle of the A band is bisected by the M line, and a sarcomere is defined as the region between two successive Z lines.

Each myofibril's myofilaments are of two types. Thick filaments (about 16 nm in diameter) are composed of myosin, a protein whose tail terminates in two globular heads, called cross bridges, which link to the thin filaments during contraction. Thin filaments (7 to 8 nm in diameter) are composed chiefly of two twisted chains of actin, wound around by two strands of tropomyosin, with the regulatory protein troponin (which binds actin, tropomyosin and calcium ions respectively via its three subunits) positioned at intervals along the filament. Each myosin filament is surrounded by six actin filaments, and it is the precisely ordered, overlapping arrangement of these thick and thin filaments that gives skeletal muscle its striped, striated appearance under the microscope.

The Sliding Filament Model and Control of Muscle Contraction

The sliding filament model, proposed by Huxley and Huxley in 1954, explains muscle contraction as the thin (actin) filaments sliding past the thick (myosin) filaments without either filament changing length, so the zones of overlap increase: the I band shortens, the H zone disappears, and successive Z lines are pulled closer together, shortening the whole sarcomere and hence the whole muscle fibre. In this process, the myosin cross bridges repeatedly attach to specific binding sites on the actin filament, bend to pull the actin filament toward the centre of the sarcomere, detach (using ATP hydrolysis), and reattach further along, in a repeating cycle. At rest, tropomyosin physically blocks these myosin-binding sites on actin, preventing contraction.

Muscle contraction is triggered by a nerve impulse at the neuromuscular junction, which travels deep into the muscle fibre via T-tubules to the adjacent sarcoplasmic reticulum, releasing calcium ions into the cytosol. These calcium ions bind to troponin, causing a



conformational shift that displaces tropomyosin and exposes the myosin-binding sites on actin, allowing cross bridges to form and the sliding filament cycle to proceed - each fibre contracts according to an 'all or none' principle, with the overall strength of a muscle's contraction depending on how many of its fibres are simultaneously activated. ATP is essential not just for the power stroke but also to break the link between myosin and actin at the end of each cycle; after death, falling ATP levels leave the cross bridges permanently locked, causing the muscle stiffness known as rigor mortis. Ongoing ATP supply during life comes primarily from the aerobic breakdown of glucose (from stored glycogen) and creatine phosphate, with anaerobic glycolysis (producing lactic acid) supplementing this during oxygen deficiency or intense activity; excess lactic acid buildup contributes to muscle fatigue, a state of physiological inability to contract effectively, distinct from tetany (muscle twitching and spasm from low blood calcium) and cramp (a sudden, painful, sustained involuntary contraction).

Muscle Arrangement and Locomotion in Invertebrates

A skeletal muscle has three functional parts: the origin, the fixed end that does not move when the muscle contracts; the insertion, the end attached to the bone that is moved; and the belly, the thick, contractile middle portion. Muscles connect to bones via non-elastic tendons, while ligaments (slightly elastic) connect bone to bone across a joint. Because a single muscle can only pull, never push, movable joints depend on antagonistic muscle pairs, in which one muscle's contraction is reversed by the contraction of its partner - the classic example being the biceps brachii (which bends, or flexes, the arm at the elbow) and the triceps (which straightens, or extends, it), which never contract simultaneously.

Invertebrates and protoctists show a remarkable diversity of locomotory mechanisms. Euglena moves by lashing an anterior flagellum, whose spiral, whip-like beating pulls the organism forward, aided by contractile myonemes that allow direction change (Euglenoid movement). Paramecium moves by the coordinated, wave-like beating of many short cilia, each performing an effective stroke (rapid bend) followed by a recovery stroke (straightening), powered by ATP. Amoeba moves by extending finger-like pseudopodia in the direction of cytoplasmic flow, causing the whole cell body to follow. Jellyfish use jet propulsion, drawing water into their bell-shaped body and then forcefully expelling it to drive themselves forward. The earthworm uses an accordion-like peristaltic movement, alternating contraction of circular muscles (which elongates and thins segments) and longitudinal muscles (which shortens and thickens segments), anchored at each stage by setae. The cockroach walks using alternating tripod support from its six legs and can also fly using its posterior wing pair, while the starfish moves using water-powered tube feet arranged along each arm, extending, attaching by suction, and then contracting to pull the body along.

Locomotion in Vertebrates

Vertebrate locomotion shows adaptations specific to each medium and habitat. Fish are propelled by muscular contractions passing along the body from anterior to posterior, producing S-shaped lashing movements; their streamlined, mucus-coated bodies minimise friction, with unpaired dorsal and ventral fins providing stability, paired pectoral and pelvic fins used for steering, the caudal fin providing forward thrust, and a swim bladder



maintaining buoyancy in bony fish. Amphibians combine a fish-like body with limbs, either wriggling on the belly using segmental muscles or, in frogs and toads, using powerful hind limbs for swimming and jumping. Reptiles show a more ossified, better-supported skeleton adapted for walking and running, with a modified atlas-axis complex allowing greater head rotation; some prehistoric reptiles were bipedal, freeing the front limbs for prey capture or eventually flight.

Birds have a skeleton highly modified for flight: bones with large air spaces reduce weight, the sternum is expanded into a keel for the attachment of powerful flight muscles, and the body is covered in feathers that both provide lift surface and insulation. Flight may be passive (gliding, using the wing as an aerofoil to generate lift from airflow) or active (flapping, in which faster airflow over the curved upper wing surface than the lower surface creates a net upward lifting pressure). Mammals show three modes of limb-based locomotion: plantigrade (walking flat on the sole, as in humans and bears), digitigrade (walking on the digits, faster, as in dogs and rodents), and unguligrade (walking on hoof-modified toe tips, the fastest, as in deer and horses); in running mammals, the spine itself flexes and extends with each stride to increase stride length and power. Across land vertebrates (tetrapods), a common pentadactyl limb plan and a firmly sacrum-attached pelvic girdle (built from the ilium, ischium and pubis meeting at the acetabulum, which articulates with the femur) underlie the diverse locomotory adaptations seen from walking and running to the independently evolved flight of pterodactyls, birds and bats.

Important Definitions

Term	Definition
Turgor pressure	The internal hydrostatic pressure that develops in a plant cell as water enters the vacuole by osmosis, keeping the cell rigid and resistant to bending.
Sclerenchyma	Plant support tissue composed of cells with thick, lignin-impregnated secondary walls, mostly non-living, including fibres, sclereids and vessels.
Ecdysis	The periodic shedding and replacement of the exoskeleton in arthropods, allowing growth, controlled by the hormone ecdysone.
Sarcomere	The region of a myofibril between two successive Z lines, and the smallest contractile unit of a skeletal muscle fibre.
Antagonism	The relationship between a pair of muscles at a joint in which the contraction of one reverses the action of the other, such as the biceps and triceps.
Tropism	A directional growth movement of a plant organ toward or away from an external stimulus such as light, gravity or touch.
Nastic movement	A non-directional movement of a plant part in response to an external stimulus, such as the opening and closing of a flower with light or temperature.
Rigor mortis	The stiffening of the body after death caused by falling ATP levels, which leaves myosin-actin cross bridges permanently locked in place.

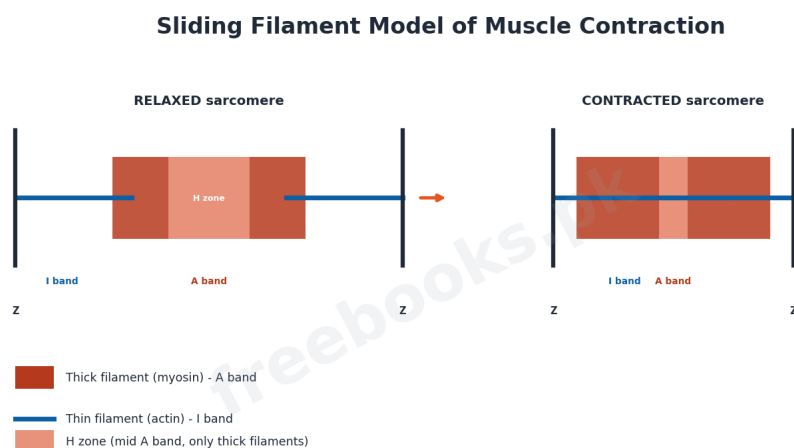


Key Facts

Item	Fact
Cranium bones	8 cranial bones (4 unpaired: frontal, occipital, sphenoid, ethmoid; 2 paired: parietal, temporal).
Vertebral column	33 vertebrae: 7 cervical, 12 thoracic, 5 lumbar, and 9 pelvic (5 fused as sacrum, 4 fused as coccyx).
Rib pairs	12 pairs of ribs; 10 pairs attach to the sternum, the lower 2 pairs are floating ribs.
Forelimb bones	Humerus, radius, ulna, 8 carpals, 5 metacarpals, 14 phalanges.
Hindlimb bones	Femur, tibia, fibula, 7 tarsals, 5 metatarsals, 14 phalanges.
Total skeletal muscles	About 650 muscles occur in the human body, most arranged in antagonistic pairs.
Filament diameters	Thick (myosin) filaments ~16 nm diameter; thin (actin) filaments ~7-8 nm diameter.
Bone healing time	Simple fractures typically heal in about 8-12 weeks, longer in elderly patients.

Diagrams & Illustrations

Sliding Filament Model of Muscle Contraction: a diagram of a sarcomere at rest and during contraction, showing the Z lines, A band, I band and H zone, and the thick (myosin) and thin (actin) filaments sliding past each other to shorten the sarcomere.



During contraction, thin filaments slide toward the center (filaments do not shorten):

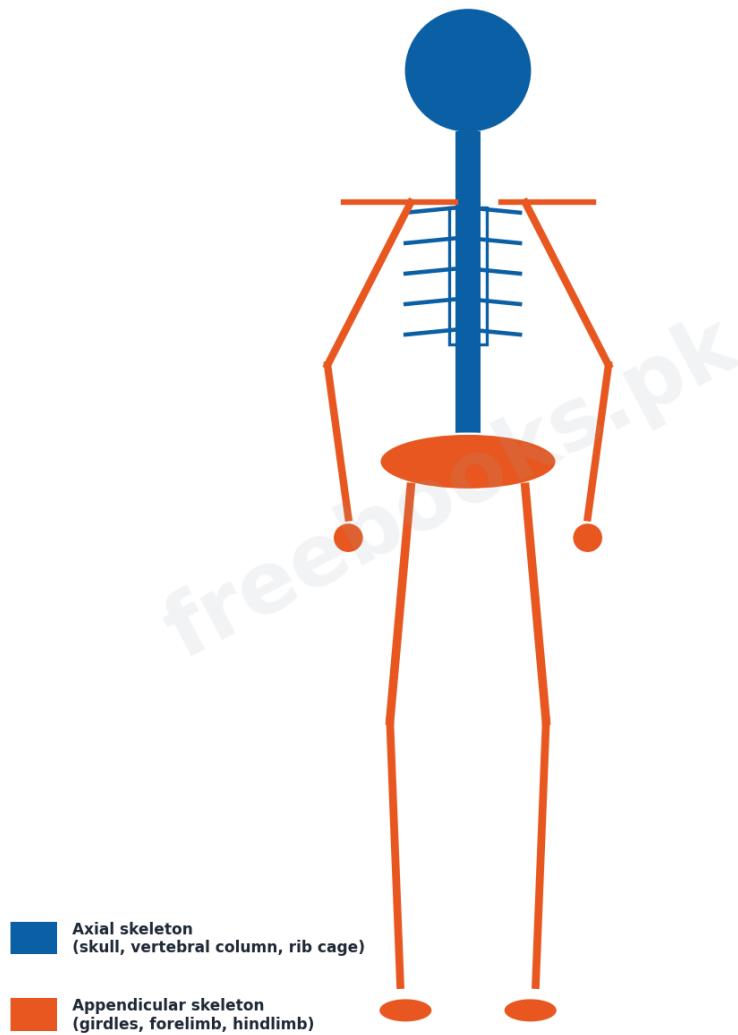
I band shortens - H zone disappears - Z lines pulled closer together - sarcomere shortens

Sliding Filament Model of Muscle Contraction

Human Skeleton: Axial and Appendicular Divisions: a labelled diagram of the human skeleton with the axial skeleton (skull, vertebral column, rib cage) and appendicular skeleton (pectoral girdle, forelimb, pelvic girdle, hindlimb) shown in different colours.



Human Skeleton: Axial and Appendicular Divisions

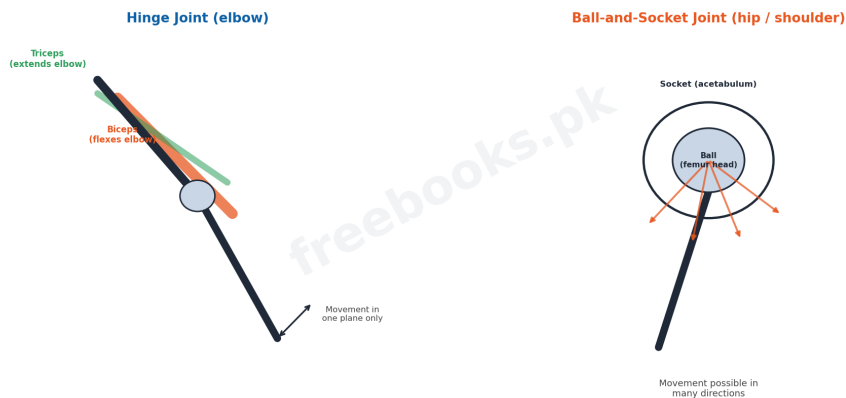


Human Skeleton: Axial and Appendicular Divisions

Types of Joints: Hinge and Ball-and-Socket: a comparison diagram of a hinge joint (elbow, with biceps and triceps as an antagonistic pair) and a ball-and-socket joint (hip or shoulder, showing its wider range of movement).



Types of Joints: Hinge and Ball-and-Socket



Types of Joints: Hinge and Ball-and-Socket

Short Questions & Answers

Q1. Differentiate sclerenchyma and collenchyma cells.

Ans. Sclerenchyma cells have thick, lignified secondary walls, are mostly non-living, and provide rigid support to mature plant parts; collenchyma cells have only angular thickening of their primary walls, remain living, and provide flexible support to young, growing herbaceous parts.

Q2. What is ecdysis, and why is it necessary?

Ans. Ecdysis is the periodic shedding and replacement of the exoskeleton in arthropods, controlled by the hormone ecdysone; it is necessary because the hardened, non-living exoskeleton cannot grow, so it must be shed and replaced with a larger one to allow the animal to increase in size.

Q3. Differentiate a hinge joint and a ball-and-socket joint, with one example each.

Ans. A hinge joint allows movement in essentially one plane, such as at the elbow or knee; a ball-and-socket joint allows movement in multiple directions and planes, providing much greater flexibility, such as at the hip or shoulder.

Q4. What is the sliding filament model of muscle contraction?

Ans. The sliding filament model states that during muscle contraction, the thin (actin) filaments slide past the thick (myosin) filaments without either filament shortening, increasing their overlap, which shortens the I band, causes the H zone to disappear, and pulls successive Z lines closer together, shortening the sarcomere.

Q5. What role does calcium play in muscle contraction?

Ans. Calcium ions released from the sarcoplasmic reticulum bind to troponin on the thin filament, causing a shift that displaces tropomyosin and exposes the myosin-binding sites on actin, allowing cross bridges to form and the contraction cycle to proceed.

Q6. Differentiate plantigrade and digitigrade locomotion, with an example of each.

Ans. In plantigrade locomotion, the sole, wrist/heel and digits all rest on the ground while walking, as in humans and bears; in digitigrade locomotion, the animal walks on its digits



only (with the first digit often reduced or lost), allowing faster movement, as in dogs and rodents.

Long Questions & Answers

Q1: Describe the three main types of skeleton found in animals, with examples.

Animals depend on one of three basic types of skeletal support. A hydrostatic skeleton relies on a fluid-filled body cavity against which surrounding muscles can contract, converting muscular force into changes in body shape and length without any rigid skeletal elements; it is found in cnidarians such as the sea anemone, whose contraction of circular muscles pressurises its water-filled cavity to maintain an upright form, and in annelids such as the earthworm, whose fluid-filled compartments (separated by septa) allow circular muscle contraction to elongate a segment and longitudinal muscle contraction to shorten it, producing the alternating waves of elongation and contraction (aided by setae) that move the animal through soil. An exoskeleton is a hardened, non-living covering secreted externally by the ectoderm, consisting of an outer waterproof epicuticle and a thicker procuticle made of chitin and protein, further toughened by sclerotization or, in some molluscs, calcium carbonate; the simplest exoskeletons are seen in molluscs such as snails and bivalves, while arthropods (such as insects and crustaceans) have the most elaborate exoskeletons, modified with flexible joints for movement, sensory bristles, and structures permitting gas exchange, though because this rigid, non-living covering cannot grow with the animal, arthropods must periodically undergo ecdysis - shedding the old exoskeleton and secreting a larger new one - a hormonally controlled process during which the animal is briefly vulnerable to predators. An endoskeleton, found in vertebrates, is an internal framework built of living connective tissues, chiefly bone (rigid, hardened by calcium phosphate deposits in a collagen matrix, with a dense compact outer layer and a lighter, porous spongy interior housing blood-cell-producing marrow) and cartilage (softer, avascular, and secreted by chondrocytes into a flexible collagen matrix, found at joints and in structures such as the outer ear); because an endoskeleton grows along with the animal's own tissues, it does not impose the same size restriction that an exoskeleton does, and it also provides an internal framework for muscle attachment that can support the greater size typical of many vertebrates.

Q2: Describe the structure of skeletal muscle from the whole muscle down to the level of the myofilaments.

A skeletal muscle is composed of bundles of individual muscle fibres, each of which is a single, remarkably large, multinucleated cylindrical cell, typically 10 to 100 micrometres in diameter, bounded by a specialised cell membrane called the sarcolemma; its cytoplasm, the sarcoplasm, is distinguished from that of ordinary cells by large stores of glycogen and by myoglobin, a red, oxygen-binding pigment that supplies oxygen to the fibre's numerous mitochondria. Within each fibre, running the entire length of the cell in parallel array, are large numbers of thread-like myofibrils, each 1 to 2 micrometres in diameter, and it is these myofibrils, viewed under high magnification, that reveal the alternating dark and light



banding responsible for skeletal muscle's characteristic striped appearance: the dark A bands (so named because they are anisotropic, or capable of polarising light) alternate with the light I bands (isotropic, non-polarising); within each A band is a lighter central H zone, itself bisected by a dark M line, while each I band is bisected by a dense Z line. The region of a myofibril lying between two successive Z lines is called a sarcomere, the fundamental repeating contractile unit of the entire muscle fibre, and each sarcomere is built from two types of myofilaments arranged with remarkable precision: thick filaments, about 16 nanometres in diameter and composed of the protein myosin - each myosin molecule having a long tail of two coiled polypeptide chains terminating in two globular heads, or cross bridges, that project outward to interact with neighbouring thin filaments - occupy the entire length of the A band; and thin filaments, only 7 to 8 nanometres in diameter and composed chiefly of two twisted chains of the globular protein actin, wound about by two helical strands of the regulatory protein tropomyosin, with the three-part regulatory protein complex troponin (one subunit binding actin, one binding tropomyosin, and one binding calcium ions) positioned at intervals along its length, extend across the I band and partway into the neighbouring A bands, with each thick filament typically surrounded by six thin filaments in the region of overlap. It is the sliding of these two types of interdigitated filaments past one another, driven by the repeated attachment, power-stroke and detachment cycling of the myosin cross bridges against binding sites on actin (a cycle regulated by calcium ions displacing tropomyosin, and powered by ATP hydrolysis), that produces the shortening of each sarcomere and, multiplied across millions of sarcomeres in series and parallel throughout the muscle, the visible contraction and force generation of the whole muscle.

Q3: Explain the sliding filament model of muscle contraction and describe how calcium ions and ATP regulate the process.

The sliding filament model, put forward by Huxley and Huxley in 1954, remains the accepted explanation of how skeletal muscle shortens during contraction. According to this model, neither the thick (myosin) filaments nor the thin (actin) filaments of a sarcomere change in length during contraction; instead, the thin filaments are actively pulled inward, sliding past the stationary thick filaments so that the two sets of filaments come to overlap over a greater proportion of their length. This increasing overlap has several visible consequences at the level of the sarcomere: the I band, which contains only thin filaments, progressively shortens as thin filaments slide further into the A band region; the H zone, the central region of the A band that normally contains no overlapping thin filaments, narrows and eventually disappears as thin filaments from either side meet in the middle; and, because both I bands attached to a given A band are shortening symmetrically, the two Z lines bounding that sarcomere are drawn closer together, shortening the sarcomere as a whole, and this shortening, repeated over many thousands of sarcomeres arranged end to end along each myofibril, produces the visible shortening of the entire muscle fibre and ultimately the whole muscle. This filament sliding is driven directly by the myosin cross bridges, the globular heads projecting from the thick filament, which cyclically attach to specific binding sites on the adjacent actin filament, bend (the power stroke) to drag the thin filament a short distance toward the centre of the sarcomere, detach, and then reattach further along the actin filament to repeat the cycle - but this cycle can only proceed if the myosin-binding sites on actin are physically accessible, and at rest they are not, being blocked by the regulatory



protein tropomyosin, which winds along the actin filament precisely covering these sites. The trigger that removes this block is a nerve impulse arriving at the neuromuscular junction, which is conducted deep into the muscle fibre via the T-tubule system to the closely associated sarcoplasmic reticulum, causing it to release stored calcium ions into the surrounding cytosol; these calcium ions bind to troponin, the regulatory protein complex positioned along the thin filament, causing a conformational change that physically displaces tropomyosin away from the myosin-binding sites on actin, at last permitting the cross bridges to attach and the sliding cycle to begin. ATP is essential to this process at two distinct points: it powers the myosin cross bridge's ability to detach from actin after each power stroke, resetting it to bind further along the filament and repeat the cycle, and it is also required to actively pump calcium ions back into the sarcoplasmic reticulum once the stimulating nerve impulse ceases, allowing tropomyosin to re-cover the binding sites and the muscle to relax; when ATP becomes unavailable after death, cross bridges that have already attached to actin cannot detach and so remain permanently locked in place, producing the total-body muscular stiffness known as rigor mortis.

Q4: Describe the axial and appendicular divisions of the human skeleton in detail.

The human skeleton is organised into two major divisions, the axial skeleton and the appendicular skeleton, which together provide the body's complete bony framework. The axial skeleton forms the central, vertical axis of the body and consists of the skull, vertebral column, ribs and sternum. The skull itself is composed of two sets of bones: the cranium, made up of eight bones - four unpaired (the frontal, occipital, sphenoid and ethmoid bones) and two paired (the parietal and temporal bones) - which together enclose and protect the brain, and the facial skeleton, made up of fourteen bones, six paired (the maxilla, zygomatic, nasal, lacrimal, palatine and inferior concha bones) and two unpaired (the mandible, the only movable skull bone, and the vomer). Below the skull, the vertebral column extends down to the pelvis, encasing and protecting the delicate spinal cord within its central canal, and is built from thirty-three individual vertebrae grouped into four named regions - seven cervical vertebrae in the neck (the first two of which, the atlas and axis, are specially modified to support and rotate the head), twelve thoracic vertebrae in the upper back (each articulating with a pair of ribs), five lumbar vertebrae in the lower back, and nine pelvic vertebrae that fuse during development into two solid structures, the sacrum (from five vertebrae) and the coccyx, or tailbone (from four vertebrae) - with the column's natural forward-and-backward curvatures giving it substantially greater mechanical strength than a perfectly straight column of the same material would have. Completing the axial skeleton, the rib cage consists of twelve pairs of ribs that articulate posteriorly with the thoracic vertebrae; anteriorly, the upper ten pairs connect, directly or via a shared costal cartilage arch, to the flat sternum in the midline of the chest, while the lowest two pairs, lacking any sternal attachment, are termed floating ribs, and together this bony cage encloses and protects the semi-vacuum chest cavity housing the heart and lungs. The appendicular skeleton, by contrast, consists of the bones of the limbs and the girdles that attach them to the axial skeleton. The pectoral girdle, comprising the scapula (shoulder blade) and clavicle (collarbone, which anchors the scapula to the sternum), attaches the forelimb, which itself consists of a single long humerus (forming a highly mobile ball-and-socket joint with the



scapula at the shoulder, and a hinge joint with the forearm bones at the elbow), the paired radius and ulna of the forearm, eight small wrist bones called carpals, five metacarpals forming the framework of the palm, and fourteen phalanges arranged in five digits. The pelvic girdle, consisting of two coxal bones (each itself formed by the fusion of three separate bones, the ilium, ischium and pubis), firmly attaches the hindlimb to the base of the vertebral column and supports the weight of the pelvic region; the hindlimb consists of a single femur (forming a ball-and-socket hip joint proximally with the coxal bone, and a hinge knee joint distally with the shin bones), the paired tibia and fibula of the lower leg, seven tarsal bones of the ankle, five metatarsals forming the framework of the foot, and fourteen phalanges of the toes, mirroring the structural plan of the forelimb in accordance with the shared pentadactyl body plan of tetrapod vertebrates.

Q5: Compare locomotion in fish, birds and mammals, highlighting the key adaptations of each group.

Locomotion in vertebrates has been shaped by the very different physical demands of moving through water, air and on land, producing three strikingly different sets of adaptations in fish, birds and mammals. Fish are propelled almost entirely by muscular contractions that pass rhythmically along the body from anterior to posterior, with alternating contraction of muscle blocks on either side of the body producing a characteristic lashing, S-shaped wave of motion that drives the animal forward, a pattern especially clear in cartilaginous fish such as sharks and dogfish; this propulsive mechanism is supported by a strongly streamlined, tapered body shape that minimises drag as water flows over it, further aided by mucus or oily secretions that lubricate the body surface (over scales in bony fish, or dermal denticles in cartilaginous fish) to reduce friction still further, while the fins serve distinct stabilising and steering roles - the unpaired dorsal and ventral fins resist rolling and yawing to keep the fish stable, the paired pectoral and pelvic fins are used for fine steering, balance and braking, and the caudal (tail) fin, working with body undulations, provides the main forward thrust - and buoyancy in bony fish is finely regulated by an internal gas-filled swim bladder, allowing the fish to remain suspended at a chosen depth with minimal muscular effort. Birds, by contrast, are adapted for locomotion through air, an environment that offers little support and requires the generation of active lift; their skeleton is extensively lightened by bones containing large internal air spaces, while their forelimbs have evolved into wings and their sternum has been dramatically enlarged and keeled to provide a greatly expanded surface area for the attachment of the massive pectoral flight muscles needed to power the wingbeat, and the body is covered by feathers that both enlarge the aerodynamic surface of the wing and provide the insulation needed to sustain the very high metabolic rate flight demands; birds achieve flight either passively, by gliding with wings held as aerofoils to extract lift from oncoming or rising air currents, or actively, by flapping the wings so that air is forced to flow faster over their curved upper surface than beneath them, lowering pressure above the wing relative to below it and so generating a continuous net upward lift force. Mammals, finally, remain fundamentally adapted for locomotion on solid ground (with notable secondary adaptations to water, air and burrowing in particular lineages), and show a graded series of limb postures reflecting different balances of stability versus speed: plantigrade mammals such as humans and bears place the entire sole of the foot, including wrist or heel and digits, flat on the ground with each



step, a stable but comparatively slow gait; digitigrade mammals such as dogs and rodents walk balanced on their digits alone, with the first digit often reduced or absent, gaining speed at some cost to stability; and unguligrade mammals such as deer and horses walk on the very tips of their toes, which have become modified into hardened hooves, representing the fastest and most specialised of the three gaits; in fast-running mammals generally, the vertebral column itself flexes and extends with each stride, working in concert with limb muscles to lengthen stride and add propulsive power well beyond what the limbs alone could generate.

MCQs with Answers

1. The internal hydrostatic pressure that keeps parenchyma cells rigid is called:

(a) osmotic pressure (b) turgor pressure (c) root pressure (d) wall pressure

Correct Answer: (b) turgor pressure. Turgor pressure develops as water enters the vacuole by osmosis, keeping parenchyma cells rigid and resistant to bending.

2. The rapid folding of Mimosa leaflets on touch is an example of which type of movement?

(a) tropic movement (b) nastic (turgor) movement (c) phototactic movement (d) chemotropic movement

Correct Answer: (b) nastic (turgor) movement. This is a turgor movement, a type of autonomic movement caused by rapid loss of turgor pressure in pulvinus cells.

3. Ecdysis, the periodic shedding of the exoskeleton, is controlled by the hormone:

(a) insulin (b) ecdysone (c) auxin (d) aldosterone

Correct Answer: (b) ecdysone. Ecdysone controls the hormonally regulated process of ecdysis (molting) in arthropods.

4. The human cranium is made up of how many bones?

(a) 6 (b) 8 (c) 14 (d) 22

Correct Answer: (b) 8. The cranium consists of 8 bones: 4 unpaired (frontal, occipital, sphenoid, ethmoid) and 2 paired (parietal, temporal).

5. A joint that allows movement in several directions, such as the hip or shoulder, is a/an:

(a) hinge joint (b) fibrous joint (c) ball-and-socket joint (d) cartilaginous joint

Correct Answer: (c) ball-and-socket joint. Ball-and-socket joints, found at the hip and shoulder, allow movement in multiple directions and provide maximum flexibility.

6. In a sarcomere, the zone containing only thin (actin) filaments is the:

(a) A band (b) H zone (c) I band (d) M line

Correct Answer: (c) I band. The I band is the light, isotropic zone containing only thin filaments, bisected by the Z line.

7. According to the sliding filament model, during contraction:

(a) thick and thin filaments both shorten (b) thin filaments slide past thick filaments without either shortening (c) only the thick filaments move (d) the Z lines move further apart

Correct Answer: (b) thin filaments slide past thick filaments without either



shortening. In the sliding filament model, filaments do not shorten; thin filaments slide past thick filaments, pulling Z lines closer together.

8. The muscle protein that blocks the myosin-binding sites on actin at rest is:

(a) troponin (b) tropomyosin (c) myosin (d) actin

Correct Answer: (b) tropomyosin. Tropomyosin covers the myosin-binding sites on actin at rest; it is displaced when calcium binds troponin.

9. Stiffening of the body after death, caused by depleted ATP locking cross bridges in place, is called:

(a) tetany (b) rigor mortis (c) muscle fatigue (d) cramp

Correct Answer: (b) rigor mortis. Rigor mortis occurs because falling ATP levels after death prevent myosin cross bridges from detaching from actin.

10. Mammals that walk on hoof-modified toe tips, such as deer, show which type of locomotion?

(a) plantigrade (b) digitigrade (c) unguligrade (d) hydrostatic

Correct Answer: (c) unguligrade. Unguligrade locomotion, walking on hoof-modified toe tips, is the fastest of the three mammalian limb postures.

Quick Revision Summary

- Plant support: parenchyma (turgor pressure), sclerenchyma (lignified, rigid, non-living: fibres/sclereids/vessels), collenchyma (living, flexible, young parts). Secondary growth: vascular cambium (secondary xylem/phloem) + cork cambium -> growth rings, sapwood vs heartwood.
- Plant movement: Autonomic (tactic, turgor, growth movements - internal cause) vs Paratonic (tropic, nastic - external cause). Hormones: auxin (phototropism/gravitropism), abscisic acid vs gibberellins (nastic balance).
- Animal skeletons: Hydrostatic (fluid cavity + muscle, e.g. earthworm) -> Exoskeleton (chitin, arthropods, needs ecdysis via ecdysone) -> Endoskeleton (bone + cartilage, vertebrates; osteoblast/osteocyte/osteoclast).
- Human skeleton: Axial (skull: 8 cranial + 14 facial bones; vertebral column: 33 vertebrae, 7C+12T+5L+9 pelvic; ribs: 12 pairs, 2 floating) + Appendicular (pectoral girdle + forelimb: humerus/radius/ulna/8 carpals/5 metacarpals/14 phalanges; pelvic girdle + hindlimb: femur/tibia/fibula/7 tarsals/5 metatarsals/14 phalanges).
- Joints: fibrous (immovable) / cartilaginous (slight) / synovial (free: hinge = one plane, e.g. elbow; ball-and-socket = multi-directional, e.g. hip). Deformities: genetic (cleft palate), hormonal (osteoporosis - low estrogen), nutritional (osteomalacia/rickets - low Ca/vitamin D). Fracture repair: hematoma -> soft callus -> bony callus -> remodeling (8-12 weeks).
- Muscle types: smooth (unstriated, involuntary), cardiac (striated, involuntary), skeletal (striated, voluntary). Sarcomere = Z line to Z line; A band (myosin) + I band (actin, has Z line) + H zone (mid A band). Sliding filament model (Huxley, 1954): actin slides on myosin -> I band and H zone shrink, sarcomere shortens.
- Contraction control: nerve impulse -> T-tubules -> SR releases Ca^{2+} -> Ca^{2+} binds troponin -> tropomyosin shifts -> cross bridges form -> ATP powers detachment/



reattachment. No ATP after death = rigor mortis. Energy: aerobic glycolysis + creatine phosphate, anaerobic (lactic acid) under stress -> fatigue. Locomotion: Euglena (flagellum), Paramecium (cilia), Amoeba (pseudopodia), earthworm (peristalsis+setae), fish (S-wave+fins), birds (keel+flapping/gliding), mammals (plantigrade/digitigrade/unguligrade). Notes by freebooks.pk.

Exam Tips

- Build a simple 2-column table of autonomic vs paratonic plant movements with one named example in each sub-category (tactic/turgor/growth vs tropic/nastic) - this structure matches how these questions are usually marked.
- Memorise the exact bone counts for the human skeleton (8 cranial, 14 facial, 33 vertebrae split 7-12-5-9, 12 rib pairs) - fill-in-the-blank and short questions frequently target these numbers directly.
- Learn the sarcomere diagram (Z line, I band, A band, H zone, M line) well enough to redraw it from memory in both the relaxed and contracted state, showing exactly which zones shrink or disappear.
- Walk through muscle contraction as one continuous numbered sequence (nerve impulse -> T-tubule -> Ca^{2+} release -> troponin -> tropomyosin shift -> cross bridge cycling -> ATP-dependent detachment) rather than memorising isolated facts - long questions are marked on this sequence.
- Keep hinge joint and ball-and-socket joint clearly separated with one labelled example each, and be ready to explain antagonistic muscle pairs (biceps/triceps) as the mechanism that moves a hinge joint in both directions.
- Group locomotion examples by mechanism, not just by animal name: flagellar (Euglena), ciliary (Paramecium), pseudopodial (Amoeba), jet propulsion (jellyfish), peristaltic (earthworm), tube feet (starfish) - this is a very common matching-style question.
- For plantigrade/digitigrade/unguligrade, remember the speed order (plantigrade slowest, unguligrade fastest) together with one clear example of each so you never confuse the three.

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FSc Part-II Biology — Punjab Board

CHAPTER 17

Coordination and Control

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

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This chapter covers Coordination and Control from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). All organisms must coordinate the activities of their different parts in response to internal and external stimuli; plants achieve this solely through hormones (a comparatively slow process matched to their sessile, growth-based responses), while animals use both fast nervous coordination (via neurons, nerve impulses and synapses) and slower, longer-lasting chemical coordination (via the endocrine system). These notes are prepared by freebooks.pk.

The chapter covers coordination in plants (movements, stress responses, defence against pathogens, biological clocks and plant growth hormones), the elements of nervous coordination (receptors, neurons, effectors, the nerve impulse and the synapse), the organisation of the human nervous system (CNS, PNS and the autonomic nervous system, plus common nervous disorders), the endocrine system and its major glands and hormones, and the two main categories of animal behaviour, innate and learned.

Learning Objectives

- Explain why plant coordination relies solely on hormones, and describe the major plant growth regulators (auxins, gibberellins, cytokinins, abscisic acid, ethylene).
- Describe the types of sensory receptors and the structure and types of neurons.
- Explain the resting and action membrane potentials and describe how a nerve impulse is generated and conducted.
- Describe the structure and function of a synapse and the role of neurotransmitters.
- Describe the organisation of the human nervous system, including the CNS, PNS and autonomic nervous system, and list common nervous disorders.
- Describe the major endocrine glands of mammals and the hormones they secrete.
- Explain the concept of feedback mechanism with reference to thyroid hormone regulation.
- Differentiate innate and learned behaviour, and describe the major types of learning.

Key Concepts

Coordination in Plants and Plant Growth Hormones

Plants respond to stimuli very differently from animals: because they are sessile rather than motile, plant behaviour depends chiefly on variable growth rates and changes in cell turgidity, and is controlled entirely by plant hormones rather than a nervous system, making plant responses comparatively slow. Environmental stresses affect plant health directly - plants grown without light become abnormally elongated and fail to produce chlorophyll (etiolation), while insufficient mineral nutrients cause a yellowish discolouration called chlorosis. Plants defend against pathogens (viruses, bacteria and fungi) and wounds by forming undifferentiated masses of cells called calluses, and parasite-induced growths called galls. Many organisms, including plants, also show biological rhythms: circadian (about 24-



hour) rhythms and circannual (about 365-day) rhythms, driven by a combination of an internal (endogenous) biological clock and external (exogenous) environmental cues.

Five major classes of plant hormone regulate growth and development. Auxins (such as indole acetic acid) promote cell enlargement and cambial division in stems, promote root growth at low concentration but inhibit it at high concentration, promote apical dominance, and are used commercially as selective weedkillers (e.g. 2,4-D) and rooting stimulants. Gibberellins promote cell enlargement and division, break bud and seed dormancy, and are used commercially to produce seedless grapes and stimulate malting in brewing. Cytokinins promote cell division and lateral bud growth, delay leaf senescence, and are used to keep cut flowers and leafy vegetables fresh. Abscissic acid generally inhibits growth under stress (drought, waterlogging), promotes dormancy, and closes stomata during water stress. Ethylene inhibits stem and root growth under stress, breaks bud dormancy, and is widely used commercially to ripen fruit (tomatoes, citrus) and induce flowering in pineapple.

Elements of Nervous Coordination: Receptors, Neurons and Effectors

Nervous coordination depends on three functional elements linked by neurons. Receptors detect stimuli and are classified by the type of stimulus they respond to: chemoreceptors (smell, taste, blood chemistry), mechanoreceptors (touch, pressure, hearing, equilibrium), photoreceptors (light, e.g. rods and cones in the eye), thermoreceptors (temperature) and nociceptors (pain). In human skin, at least three types of sensory endings detect five different sensations - touch, pressure, heat, cold and pain - including hair end organs, encapsulated Meissner's corpuscles (touch, in fingertip papillae) and deeper Pacinian corpuscles (pressure); pain receptors are about 27 times more abundant than cold receptors, which are themselves about 10 times more abundant than heat receptors. Neurons are the structural and functional units of the nervous system, supported by neuroglia (which nourish and protect neurons via the myelin sheath); each neuron has a cell body (soma, containing the nucleus and Nissl's granules), dendrites or a dendron (carrying impulses toward the cell body), and an axon (carrying impulses away, sometimes over a metre long). There are three functional types of neuron: sensory neurons (carry impulses from receptors), association or relay neurons (connect neurons within the CNS), and motor neurons (carry impulses to effectors).

Effectors are the structures - chiefly muscles (which contract) and glands (which secrete) - that respond to an impulse arriving via a motor neuron, and the overall flow of information from receptor to effector is best illustrated by the reflex arc, an involuntary response pathway. In a simple reflex arc such as the pain-withdrawal reflex, a sensory neuron with pain-sensitive endings in the skin carries an impulse to an association neuron in the spinal cord, which stimulates a motor neuron, whose axon carries the impulse to a muscle, causing it to contract and withdraw the affected body part - all without requiring conscious involvement of the brain, though the sensory neuron typically also relays signals to the brain via other association neurons, informing it of the event.



The Nerve Impulse, Synapse and Evolution of the Nervous System

A nerve impulse is a travelling wave of electrochemical change along a neuron's membrane. At rest, a neuron's membrane potential (about -70 mV) is more negative inside than outside, this resting potential maintained by the sodium-potassium pump (which actively transports 3 Na⁺ out for every 2 K⁺ pumped in, against their concentration gradients, using ATP), by large negatively-charged organic ions trapped inside the cell, and by the outward leakage of K⁺ ions (since the membrane is more permeable to K⁺ than to Na⁺). When a threshold stimulus is applied, sodium gates open and Na⁺ rushes in, briefly reversing the membrane potential to a positive action potential (about +50 mV) at that point; this depolarisation is quickly followed by K⁺ efflux (repolarisation) and restoration of the resting potential by the sodium-potassium pump, with the whole cycle taking only 2 to 3 milliseconds and travelling as a wave along the neuron (jumping node to node, called saltatory conduction, in myelinated neurons) - the normal speed of a human nerve impulse is about 100 metres per second, with a maximum recorded speed of about 120 metres per second.

Where the axon ending of one neuron meets the dendrites of the next, a microscopic gap called a synapse is left, since there is no direct cytoplasmic connection between neurons. An arriving impulse cannot jump this gap directly; instead, it triggers the release of a chemical neurotransmitter (such as acetylcholine, adrenaline, noradrenaline, serotonin or dopamine) from synaptic vesicles into the synaptic cleft, and this neurotransmitter binds receptors on the next neuron's membrane, potentially triggering a new action potential there. The nervous system itself shows an evolutionary progression in organisation: Hydra has a simple diffused nervous system, a network of undifferentiated neurons with no brain, nerve cords or specialised sense organs, and the whole body responds as a unit to a stimulus; Planaria, by contrast, has the beginnings of a centralised nervous system, with a bilobed 'brain' of two ganglia, differentiated sensory, association and motor neurons, simple eyes and chemoreceptors, and definite longitudinal and lateral nerves - a pattern of increasing centralisation that continues through more complex invertebrates to the elaborate centralised nervous system of vertebrates, including humans.

The Human Nervous System: CNS, PNS and Nervous Disorders

The central nervous system (CNS) consists of the brain and spinal cord, both protected by bone (cranium and vertebral neural arches), triple membranes called meninges, and cushioning cerebrospinal fluid. The brain is divided into the forebrain (comprising the thalamus, which relays sensory information; the limbic system, including the hypothalamus, amygdala and hippocampus, responsible for basic emotions, drives and long-term memory formation; and the cerebrum, the largest part, whose deeply folded outer cerebral cortex processes sensory information, directs voluntary movement and underlies thinking, with the left hemisphere controlling the right side of the body and vice versa), the midbrain (reduced in humans, containing auditory relay centres and the reticular formation, which screens sensory input before it reaches higher brain centres), and the hindbrain (comprising the medulla, which controls automatic functions such as breathing and heart rate; the pons, involved in sleep-wake transitions; and the cerebellum, which coordinates smooth, accurate movement and body position). The spinal cord, a hollow structure with inner grey matter



(cell bodies) and outer white matter (myelinated tracts), serves as both a reflex centre and a conduction pathway between the body and brain.

The peripheral nervous system (PNS) consists of 12 pairs of cranial nerves (from the brain) and 31 pairs of spinal nerves (mixed sensory and motor, from the spinal cord), organised into the somatic nervous system (voluntary control of skeletal muscle) and the autonomic nervous system (involuntary control of internal organs, glands and smooth muscle), which is itself divided into the sympathetic system (active in emergencies - the 'fight or flight' response, accelerating heart rate and inhibiting digestion) and the parasympathetic system (active during rest, promoting digestion and slowing heart rate). Common nervous disorders include Parkinson's disease (tremors and rigidity from dopamine-producing cell death, typically with onset in the 50s or 60s), epilepsy (a convulsive disorder from abnormal electrical discharges in the brain, typically with onset before age 30), and Alzheimer's disease (progressive decline in brain function and memory, with both genetic and environmental risk factors); nicotine, meanwhile, is a nervous system stimulant that mimics acetylcholine at nicotinic receptors, increasing heart rate, blood pressure and digestive tract activity.

Chemical Coordination: Hormones and the Hypothalamus-Pituitary Axis

Chemical coordination in animals is carried out by the endocrine system, a network of about 20 ductless glands and tissues that secrete hormones directly into the blood. Hormones are organic compounds - proteins (e.g. insulin), amino acid derivatives (e.g. thyroxine, adrenaline), polypeptides (e.g. ADH, oxytocin) or steroids (e.g. oestrogen, testosterone) - that regulate, rather than initiate, biochemical reactions at distant target cells, often controlling long-term processes such as growth, metabolism and sexual maturity. The hypothalamus, part of the forebrain, converts nervous stimuli into hormonal responses: its neurosecretory cells produce oxytocin and antidiuretic hormone (ADH), which travel down nerve fibres to be stored in and released from the posterior pituitary, and also produce releasing and inhibiting hormones that travel by blood to the anterior pituitary, regulating its hormone output.

The pituitary gland (hypophysis), an ovoid structure of about 0.5 g connected to the brain by the infundibulum, has three lobes. The anterior lobe, often called the master gland, secretes somatotrophin (growth hormone, causing gigantism if oversecreted in youth or dwarfism if undersecreted), thyroid-stimulating hormone (TSH, regulating the thyroid), adrenocorticotrophic hormone (ACTH, regulating the adrenal cortex), and gonadotrophic hormones (FSH, LH/ICSH and prolactin, regulating the gonads). The median lobe secretes melanophore-stimulating hormone (MSH), which darkens skin pigmentation. The posterior lobe releases the stored hormones ADH (which increases water reabsorption in the kidney nephron; its deficiency causes diabetes insipidus) and oxytocin (which stimulates uterine contraction during childbirth and milk ejection during suckling).

Other Major Endocrine Glands and the Feedback Mechanism

Several other glands complete the endocrine system. The thyroid gland produces thyroxine (T4) and tri-iodothyronine (T3), which raise the basal metabolic rate and are essential for



normal growth and brain development (their deficiency in infancy causes cretinism, and in adults causes myxoedema or goiter, while excess causes Graves' disease), and calcitonin, which lowers blood calcium; the parathyroid glands (embedded in the thyroid) produce parathormone, which raises blood calcium (its underactivity causes muscular tetany, and overactivity causes bone demineralisation and kidney stones) and is antagonistic to calcitonin. The islets of Langerhans in the pancreas contain beta cells, which secrete insulin (lowering blood glucose; its deficiency causes diabetes mellitus), and alpha cells, which secrete glucagon (raising blood glucose, antagonistic to insulin). The adrenal glands have an outer cortex (secreting cortisol, corticosterone, aldosterone and androgens, active especially under stress) and inner medulla (secreting adrenaline and noradrenaline, which raise blood pressure and reinforce the sympathetic 'fight or flight' response); the gut produces gastrin (stimulating gastric juice secretion) and secretin (stimulating pancreatic juice and bile production); and the gonads produce oestrogen and progesterone (ovary, regulating the menstrual cycle and pregnancy) or testosterone (testis, regulating male sexual development).

Feedback mechanism is the process by which a controlling system is itself regulated by the products of the reactions it controls, allowing the body to maintain balanced hormone levels through opposing accelerator and inhibitor actions. In thyroid regulation, for example, low body temperature or stress stimulates the hypothalamus to release TSH-releasing hormone, which triggers anterior pituitary release of TSH, which stimulates the thyroid to release thyroxine, which raises metabolic rate and body temperature; both the raised temperature and the raised thyroxine level then inhibit further release of the hypothalamic releasing hormone and pituitary TSH, completing a negative feedback loop that prevents overproduction. Nervous and chemical coordination share several features - both use chemical messengers, act in extracellular space, and respond to internal or external stimuli - but differ sharply in speed and duration: nervous coordination is fast (impulses at up to 120 m/s) and short-lived, acting on specific nearby target cells via electrical signals, while chemical coordination is slower but longer-lasting, with hormones travelling via the blood to reach distant target cells throughout the body.

Behaviour: Innate and Learned

Behaviour is broadly divided into innate (inherited, predetermined) and learned (modified by individual experience) types. Innate behaviour, which includes all plant behaviour, produces the same response to a given stimulus every time because it follows built-in nerve or cytoplasmic pathways shaped by natural selection for their survival value; types include orientation responses such as kinesis (undirected change in movement speed or turning rate in response to a stimulus, as in woodlice seeking moisture) and taxis (directed movement toward or away from a stimulus), as well as more complex reflexes and instincts such as courtship, mating and social behaviour. Instinctive behaviour is triggered by specific 'sign stimuli' recognised via an innate releasing mechanism, and is especially valuable for animals with short life spans and little parental care, such as the digger wasp, whose entire complex nest-provisioning behaviour is completed instinctively within a few weeks before she dies.



Learning, unlike instinct, depends on individual experience and requires a developed nervous system, so higher animals generally show a greater capacity for it. Thorpe classified learning into six types: imprinting (a brief, sensitive-period attachment to the first moving object encountered, seen in precocial birds such as ducklings); habituation (the simplest form of learning, a diminishing response to a repeated, harmless stimulus, as when a snail stops retracting into its shell after repeated harmless taps); conditioning or conditioned reflex type I (pairing an irrelevant stimulus with a natural one, as in Pavlov's dogs learning to salivate at the sound of a bell); operant conditioning or trial-and-error learning (learning through reward following random activity, as studied by Thorndike and Skinner using rats and cats in mazes or puzzle boxes); latent learning (learning that occurs without an obvious reward at the time, revealed only later, as when a rat that has previously explored a maze finds food in it more quickly); and insight learning (the highest form of learning, applying reasoning to solve a novel problem without prior trial and error, as demonstrated by Kohler's chimpanzees stacking boxes to reach suspended fruit).

Important Definitions

Term	Definition
Coordination	The integration of the activities of different parts of an organism's body in response to internal or external stimuli.
Hormone	An organic chemical messenger secreted directly into the blood (in animals) or transported within tissues (in plants) that regulates the activity of target cells.
Neuron	The basic structural and functional unit of the nervous system, specialised to generate and conduct nerve impulses.
Synapse	The microscopic gap between the axon ending of one neuron and the dendrites of the next, across which a nerve impulse is transmitted chemically.
Reflex arc	The pathway followed by a nerve impulse during an involuntary reflex action, from receptor through sensory, association and motor neurons to an effector.
Circadian rhythm	A biological rhythm with a periodicity of about 24 hours, driven by a combination of an internal biological clock and external environmental cues.
Feedback mechanism	A regulatory process in which a controlling system is itself controlled by the products of the reactions it regulates, such as hormone levels inhibiting their own further release.
Instinct	An inherited, predetermined behavioural response to a specific stimulus that is consistent within a species and not modified by individual experience.

Key Facts

Item	Fact
Nerve impulse speed	Normal human nerve impulse speed is about 100 m/s; maximum recorded speed is about 120 m/s.

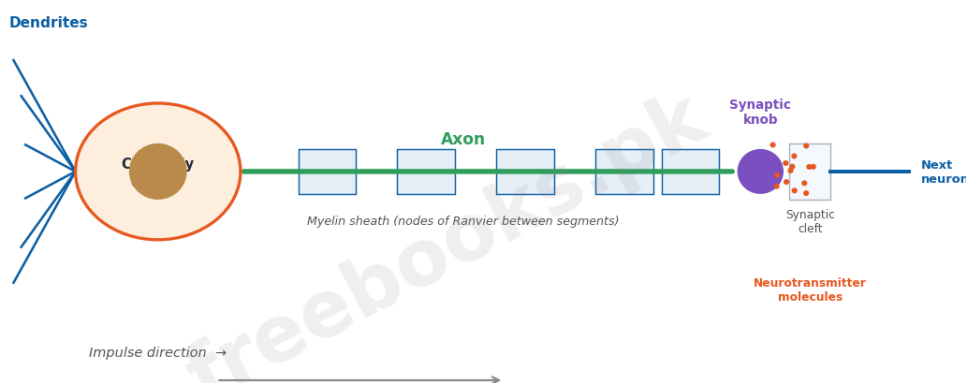


Item	Fact
Resting and action potential	Resting membrane potential is about -70 mV; action potential reaches about +50 mV.
Sodium-potassium pump ratio	For every 2 K ⁺ ions pumped in, 3 Na ⁺ ions are pumped out, both against their concentration gradients.
Cranial and spinal nerves	12 pairs of cranial nerves arise from the brain; 31 pairs of spinal nerves arise from the spinal cord.
Receptor abundance	Pain receptors are about 27 times more abundant in skin than cold receptors; cold receptors are about 10 times more abundant than heat receptors.
Pituitary gland	The pituitary gland weighs about 0.5 g in an adult and has three lobes: anterior, median and posterior.
Thyroid hormones	Thyroxine (T4) has 4 iodine atoms; tri-iodothyronine (T3) has 3 iodine atoms and a similar structure.
Action potential duration	A full action potential cycle (depolarisation to recovery) takes about 2-3 milliseconds.

Diagrams & Illustrations

Structure of a Neuron and Synapse: a labelled diagram of a motor neuron showing the cell body, dendrites, axon and myelin sheath, connecting at a synapse to the next neuron, with neurotransmitter release into the synaptic cleft.

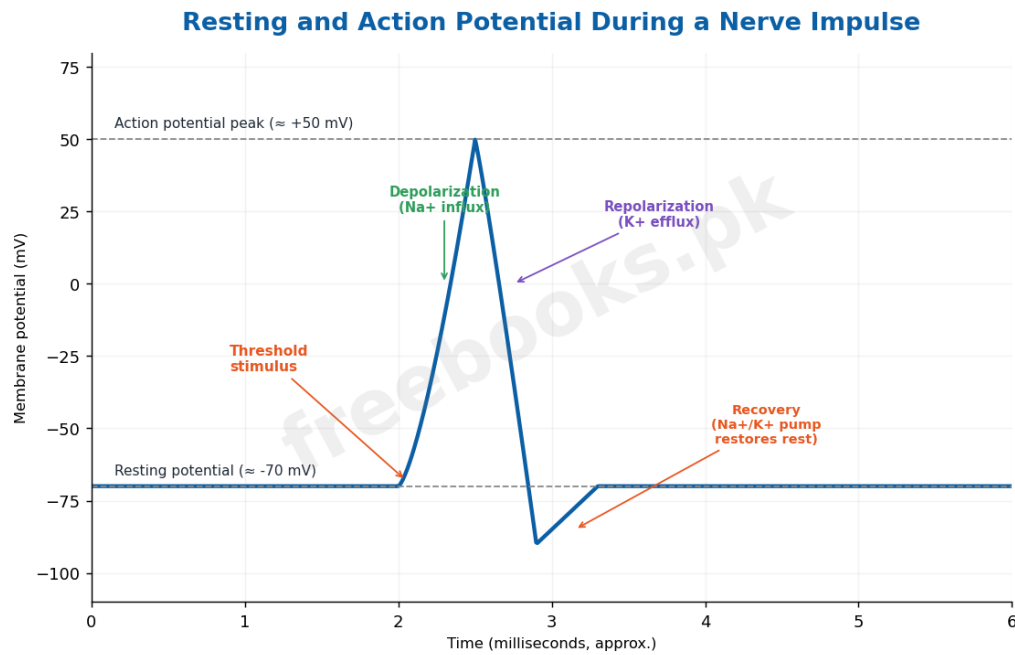
Structure of a Neuron and Synapse



Structure of a Neuron and Synapse

Resting and Action Potential: a graph showing the change in membrane potential over time during a nerve impulse, from the resting potential (about -70 mV) through depolarisation (sodium influx) to the action potential peak (about +50 mV) and repolarisation (potassium efflux) back to rest.



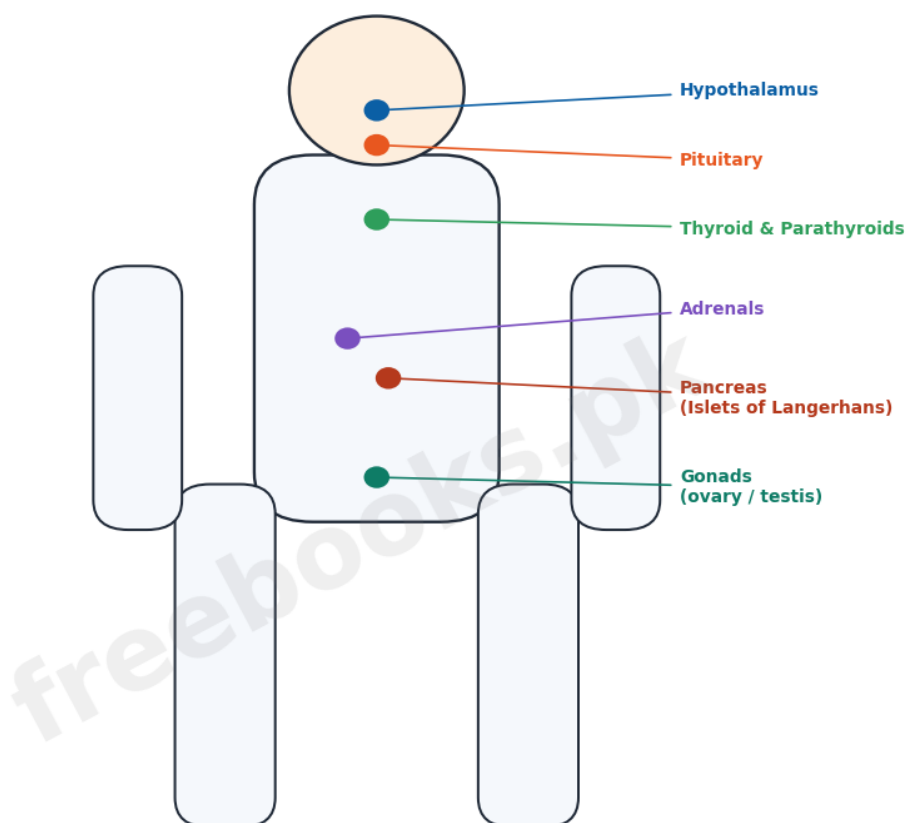


Resting and Action Potential

Human Endocrine System: Major Glands: a labelled diagram of the human body outline showing the location of the major endocrine glands: hypothalamus, pituitary, thyroid, parathyroid, adrenals, pancreas and gonads.



Human Endocrine System: Major Glands



Endocrine glands secrete hormones directly into the blood to regulate distant target cells (chemical coordination).

Human Endocrine System: Major Glands

Short Questions & Answers

Q1. Why is hormonal control in plants slower than nervous control in animals?

Ans. Plant hormones must be synthesised, released, and transported (often over some distance) to reach target cells before producing an effect, and plants lack the specialised, rapidly conducting nerve cells that animals use; since plant responses (growth, turgor changes) are themselves comparatively slow, this delay in hormonal control is not a significant disadvantage.

Q2. Differentiate the resting membrane potential and the action potential.

Ans. The resting membrane potential (about -70 mV) is the stable electrical charge difference across an unstimulated neuron's membrane, maintained by the sodium-potassium pump and K⁺ leakage; the action potential (about +50 mV) is the brief, localised reversal of



this charge that occurs when a threshold stimulus opens sodium gates, allowing Na^+ to rush in and depolarise the membrane, which is the physical basis of a nerve impulse.

Q3. How is the nervous system of Planaria more advanced than that of Hydra?

Ans. Unlike Hydra's simple diffused network of undifferentiated neurons with no brain, Planaria has the beginning of a centralised nervous system (a bilobed 'brain' of two ganglia), differentiated sensory, association and motor neurons, simple eyes and chemoreceptors, and definite longitudinal and lateral nerves.

Q4. Differentiate the sympathetic and parasympathetic nervous systems.

Ans. The sympathetic system is active during emergencies (the 'fight or flight' response), accelerating heart rate, dilating pupils and inhibiting digestion; the parasympathetic system is active during rest, promoting digestion, contracting pupils and slowing heart rate; both are divisions of the autonomic nervous system and act automatically on internal organs.

Q5. What is the feedback mechanism, and how does it regulate thyroid hormone levels?

Ans. Feedback mechanism is a regulatory process in which a controlling system is itself controlled by the products of the reactions it regulates; in thyroid regulation, rising thyroxine levels and body temperature inhibit further release of hypothalamic releasing hormone and pituitary TSH, preventing thyroxine overproduction (negative feedback).

Q6. Differentiate habituation and imprinting as types of learning.

Ans. Habituation is the simplest form of learning, a gradual decrease in response to a repeated, harmless stimulus (such as a snail no longer retracting after repeated harmless taps); imprinting is a rapid, sensitive-period attachment to the first moving object encountered shortly after birth or hatching, typically seen in precocial birds such as ducklings.

Long Questions & Answers

Q1: Describe the mechanism of nerve impulse generation and conduction, including the resting and action membrane potentials.

A nerve impulse is fundamentally a travelling wave of electrochemical change along the length of a neuron's membrane, and understanding it begins with the resting membrane potential, the stable electrical charge difference of about -70 millivolts that exists across the membrane of an unstimulated neuron, with the inside of the cell more negatively charged relative to the outside. This resting potential is maintained by three main factors working together: first, and most importantly, the sodium-potassium pump, an active transport mechanism powered by ATP hydrolysis that is embedded in every neuron's membrane and continuously pumps three sodium ions out of the cell for every two potassium ions it pumps in, both moving against their natural concentration gradients, with the effect that sodium becomes about tenfold more concentrated outside the cell while potassium becomes about twentyfold more concentrated inside; second, large, negatively charged organic ions such as proteins and organic acids are present in far higher concentration inside the neuron than outside, contributing directly to the more negative internal charge; and third, because the resting membrane is selectively more permeable to potassium than to other ions, some



potassium continuously leaks out of the cell by diffusion, further adding to the net negative charge left behind inside. When an appropriate threshold stimulus is applied to one point on the neuron, this stable resting state is dramatically and briefly disrupted: specific sodium gates in the membrane at that point open, and because sodium is so much more concentrated outside the cell, it rushes rapidly inward by diffusion, a process called depolarisation, which reverses the local membrane potential so sharply that the inside becomes electrically positive relative to the outside, reaching a peak of about positive 50 millivolts - this reversed state is called the action potential, or active membrane potential, and represents the physical form of the nerve impulse itself. This state is extremely brief, lasting only a fraction of a millisecond at any one point, because the sodium gates rapidly close again and potassium gates open, allowing potassium to diffuse back out of the cell (repolarisation) and restore the negative resting state, with the sodium-potassium pump then working to restore the original ion concentration gradients fully, a recovery process that together with depolarisation takes only about 2 to 3 milliseconds in total. Critically, this local reversal and recovery of membrane potential does not stay confined to a single point but triggers the same sequence of events in the immediately adjacent portion of the membrane, and then the portion beyond that, so that the action potential propagates as a continuously self-regenerating wave along the entire length of the neuron until it reaches the synapse at its terminal end; in myelinated neurons, this process is greatly sped up because the insulating myelin sheath forces the impulse to jump directly from one node of Ranvier to the next in a process called saltatory conduction, allowing human nerve impulses to travel at speeds of up to 100 metres per second under normal conditions, with a maximum recorded speed of about 120 metres per second.

Q2: Describe the structure and functions of the different parts of the human brain.

The human brain, protected by the cranium, meninges and cerebrospinal fluid, is organised into three major regions - the forebrain, midbrain and hindbrain - each with distinct structures and functions. The forebrain is further divided into three functional parts: the thalamus, which acts as a central relay station carrying sensory information (from the auditory and visual pathways, the skin, and internal body sensors) onward to the limbic system and cerebrum; the limbic system, an arc of structures between the thalamus and cerebrum comprising the hypothalamus, amygdala and hippocampus (together with nearby cerebral regions), which produces basic, largely unconscious emotions and drives such as fear, rage, hunger, thirst and sexual response, with the hypothalamus specifically acting as a major coordinating centre for body temperature, hunger, water balance and the sleep-wake cycle through both hormonal and neural connections, the amygdala generating sensations of pleasure, punishment, fear and rage, and the hippocampus playing a critical role in forming long-term memories and enabling learning; and the cerebrum, the largest part of the brain, divided into two cerebral hemispheres connected by the corpus callosum, whose deeply folded outer layer, the cerebral cortex, contains primary sensory areas that receive and convert raw sensory input into subjective impressions, association areas that interpret this information and are involved in speech, touch interpretation, and higher functions such as intelligence, reasoning and judgement, and motor areas that direct voluntary muscle movement, with the important cross-lateral arrangement in which the left hemisphere



controls the right side of the body and the right hemisphere controls the left side. The midbrain, comparatively reduced in size in humans relative to other vertebrates, contains an auditory relay centre, a centre controlling reflex eye movements, and the reticular formation, a relay network connecting the hindbrain to the forebrain that plays an important role in filtering and screening incoming sensory information before it reaches higher brain centres, preventing sensory overload. The hindbrain comprises three structures: the medulla, positioned at the base of the brain and continuous with the spinal cord, which controls essential automatic, life-sustaining functions such as breathing rate, heart rate, blood pressure and swallowing; the pons, situated above the medulla, whose neurons influence the transition between sleep and wakefulness as well as the rate and pattern of breathing; and the cerebellum, which is responsible for coordinating smooth, precisely timed body movements and maintaining posture and balance, is also involved in motor learning and memory for learned movement patterns, and is particularly well developed in birds, reflecting the exceptional coordination demands of powered flight.

Q3: Describe the anterior, median and posterior lobes of the pituitary gland and the hormones each secretes.

The pituitary gland, or hypophysis cerebri, is a small ovoid endocrine structure weighing only about half a gram in an adult human, suspended from the base of the brain by a short stalk called the infundibulum, and organised into three distinct lobes, each with its own characteristic hormonal output. The anterior lobe is frequently termed the body's 'master gland' because, in addition to secreting hormones with direct effects of their own, it produces a set of tropic hormones that in turn control hormone secretion by several other endocrine glands throughout the body; its secretions include somatotrophin, or growth hormone, whose oversecretion during childhood produces excessive skeletal growth known as gigantism (or, if oversecretion begins only after normal bone growth has ceased in adulthood, the abnormal enlargement of hands, feet and jaw known as acromegaly), while its undersecretion in childhood produces dwarfism; thyroid-stimulating hormone (TSH), whose release is itself regulated by circulating thyroxine levels through a hypothalamic feedback loop, and which acts directly on the thyroid gland to increase both the number and secretory activity of its cells; adrenocorticotrophic hormone (ACTH), whose release is triggered by stress signals such as cold, pain, fright or infection acting on the hypothalamus, and which regulates the secretory activity of the adrenal cortex; and the gonadotrophic hormones - follicle-stimulating hormone (FSH), luteinising hormone (LH, also called interstitial cell-stimulating hormone or ICSH in males) and prolactin - which together regulate development of the ovarian follicles and testicular germinal epithelium, oestrogen secretion, ovulation, and (in the case of prolactin) milk production. The median lobe, by contrast, secretes only a single hormone of note, melanophore-stimulating hormone (MSH), whose release is itself governed by the hypothalamus and by external light levels, and which acts on melanocytes in the skin to stimulate production of the pigment melanin, darkening the skin - notably to an excessive degree in Addison's disease. The posterior lobe does not itself synthesise any hormones but instead stores and releases two hormones that are actually produced by neurosecretory cells in the hypothalamus and transported down nerve fibres for storage there: antidiuretic hormone (ADH, or vasopressin), released in response to falling blood pressure, blood volume or rising blood osmotic pressure as detected by hypothalamic



osmoreceptors, which acts on the distal nephron and collecting duct of the kidney to increase water reabsorption (with its deficiency producing the excessive dilute urination and thirst characteristic of diabetes insipidus); and oxytocin, released in response to cervical distension, falling blood progesterone, and neural stimuli during childbirth and suckling, which acts on uterine smooth muscle to stimulate the powerful contractions of labour and on the mammary glands to trigger milk ejection.

Q4: Compare nervous coordination and chemical coordination, describing both their similarities and differences.

Nervous coordination and chemical (hormonal) coordination are the two principal mechanisms by which animals integrate the activities of their body in response to internal and external stimuli, and although they achieve broadly the same overall purpose, they do so through markedly different mechanisms with correspondingly different characteristics. The two systems share several underlying similarities: both nerve cells and hormone-producing cells synthesise and release chemical messenger molecules; both release these messengers into extracellular spaces within the body rather than directly into target cells; both systems function specifically in response to internal or external stimuli; both play an essential role in overall bodily coordination; and both contribute importantly to the maintenance of homeostasis. Despite these shared features, the two systems differ sharply in their structural basis, their range of action, their speed, and the duration of their effects. Structurally, nervous coordination depends on neurons (of sensory, association and motor types) supported by neuroglial cells providing nutrition and protection, whereas chemical coordination depends on hormone-producing endocrine cells and neurosecretory cells such as those in the hypothalamus. In terms of range, the chemical messengers released by neurons (neurotransmitters) act only extremely locally, over the microscopic width of a single synapse, affecting only the one or few cells directly connected to that synapse, whereas hormones are released into the bloodstream and are carried indiscriminately throughout the entire body, bathing millions of cells even though only those specific target cells bearing the appropriate receptors will actually respond, meaning a single hormone can potentially act simultaneously on distant target tissues throughout the body. In terms of speed, the electrical nature of nerve conduction, with impulses travelling at speeds of up to 120 metres per second in humans, allows nervous coordination to produce essentially immediate, near-instantaneous responses to a stimulus, whereas chemical coordination, dependent on the comparatively slow physical transport of hormone molecules through the circulatory system, acts far more slowly, though certain hormones such as insulin can still produce relatively rapid effects. Finally, in terms of duration, neurotransmitters released at a synapse are rapidly broken down and cleared after their release, so the resulting effects of nervous coordination tend to be brief and short-lived, whereas hormones circulating in the bloodstream typically remain active for considerably longer periods, meaning that chemical coordination, while slower to begin, tends to produce effects of much longer duration - well suited to controlling gradual, long-term processes such as growth, metabolic rate and sexual maturation rather than the instantaneous, moment-to-moment responses that nervous coordination is specialised to provide.



Q5: Describe the six types of learning behaviour identified by Thorpe, with an example of each.

Thorpe classified learning, defined as adaptive modification of behaviour resulting from individual experience, into six distinct types, each illustrated by classic examples from animal behaviour research. The first, imprinting, is a rapid and highly specific form of learning best documented in precocial birds such as geese, ducks and chickens, in which newly hatched young pass through a brief, biologically sensitive period during which they become permanently attached to, and will subsequently follow, the first suitably moving object they encounter - normally their own mother, whose appearance they thereby learn very rapidly, though in her absence a young bird may instead imprint on another species, a human, or even an inanimate object. The second, habituation, is considered the simplest form of learning, involving a gradual, adaptive decrease in an organism's behavioural response to a stimulus that is repeated often enough to prove harmless or irrelevant, usefully conserving the animal's energy and attention for genuinely significant stimuli - classically illustrated by a snail crawling on a glass surface, which initially retracts fully into its shell whenever the glass is tapped but responds progressively less strongly to repeated taps, eventually ceasing to respond to the stimulus at all once it has, in effect, learned that the tapping carries no real threat. The third, conditioning or conditioned reflex type I, involves the deliberate pairing of an originally irrelevant, neutral stimulus with a natural stimulus that already reliably triggers some automatic reflex response, until the neutral stimulus alone comes to trigger that same response - most famously demonstrated by Pavlov, who repeatedly rang a bell immediately before presenting food to dogs (which naturally salivate at the sight or smell of food) until the dogs eventually began salivating at the sound of the bell alone, even without any food being present. The fourth, operant conditioning, or conditioned reflex type II, also called trial-and-error learning and studied extensively by Thorndike and later by B. F. Skinner, is a more complex form of learning in which an animal's initially random exploratory activity is gradually and selectively shaped, through the rewarding consequences that some of those actions happen to produce, into a consistent, goal-directed behavioural pattern - demonstrated experimentally by rats and cats that learn, through repeated accidental trial and error, to navigate a maze to reach food or to press a lever to escape a puzzle box, with the behaviour that leads to reward becoming progressively more frequent and reliable with repetition. The fifth, latent learning, describes learning that occurs in the absence of any obvious or immediate reward at the time it takes place, becoming evident only later when circumstances change - illustrated by a rat that is allowed to wander freely and explore a maze with no food present, apparently learning the maze's layout with no incentive to do so, and subsequently demonstrating this hidden, previously unrewarded learning by navigating directly to a food reward when one is later introduced into the same maze. The sixth and highest form, insight learning, involves the direct application of reasoning to solve an entirely novel problem without relying on any prior trial-and-error experience with that specific problem, and was famously investigated by Kohler in his experiments with chimpanzees, one of which, presented with fruit suspended out of reach from the ceiling of its cage together with several movable boxes of different sizes scattered on the floor, was observed to pause, apparently 'thinking' the problem through, before deliberately stacking the boxes on top of one another and climbing them to reach and retrieve the fruit - behaviour interpreted as genuine reasoning rather than blind



trial and error, since the correct solution appeared suddenly and directly rather than emerging gradually through repeated failed attempts.

MCQs with Answers

1. Etiolation, the abnormal elongation and lack of chlorophyll in plants, is caused by:

(a) excess water (b) absence of light (c) excess minerals (d) high temperature

Correct Answer: (b) absence of light. Plants grown without light become etiolated: abnormally long and unable to form chlorophyll.

2. Which plant hormone is used commercially as a selective weedkiller against broad-leaved (dicot) weeds?

(a) gibberellin (b) cytokinin (c) 2,4-D (a synthetic auxin) (d) ethylene

Correct Answer: (c) 2,4-D (a synthetic auxin). 2,4-D, a synthetic auxin, is used as a selective weedkiller that kills broad-leaved dicot weeds without harming cereal crops.

3. The resting membrane potential of a typical neuron is approximately:

(a) +50 mV (b) -70 mV (c) 0 mV (d) -120 mV

Correct Answer: (b) -70 mV. The resting membrane potential of a typical neuron is about -70 mV, with the inside more negative than the outside.

4. The chemical released at a synapse that transmits a nerve impulse to the next neuron is called a:

(a) hormone (b) neurotransmitter (c) enzyme (d) receptor protein

Correct Answer: (b) neurotransmitter. Neurotransmitters, such as acetylcholine, are released at synapses and bind receptors on the next neuron to transmit the impulse.

5. Which brain region is chiefly responsible for coordinating smooth, accurate body movements and balance?

(a) medulla (b) cerebellum (c) thalamus (d) hypothalamus

Correct Answer: (b) cerebellum. The cerebellum coordinates smooth, accurate movements and maintains body position and balance.

6. The autonomic nervous system division associated with the 'fight or flight' response is the:

(a) somatic nervous system (b) parasympathetic system (c) sympathetic system (d) central nervous system

Correct Answer: (c) sympathetic system. The sympathetic system is active in emergencies, producing the 'fight or flight' response by accelerating heart rate and other changes.

7. Antidiuretic hormone (ADH) is released from the posterior pituitary and acts mainly on the:

(a) thyroid gland (b) kidney nephron (c) adrenal cortex (d) pancreas

Correct Answer: (b) kidney nephron. ADH increases water reabsorption in the distal nephron and collecting duct of the kidney.

8. Insulin and glucagon are secreted by which endocrine gland?



(a) thyroid (b) adrenal medulla (c) islets of Langerhans (pancreas) (d) parathyroid

Correct Answer: (c) islets of Langerhans (pancreas). The islets of Langerhans in the pancreas secrete insulin (beta cells) and glucagon (alpha cells).

9. In thyroid hormone regulation, rising thyroxine levels inhibiting further TSH release is an example of:

(a) positive feedback (b) negative feedback (c) operant conditioning (d) habituation

Correct Answer: (b) negative feedback. This is negative feedback: the product (thyroxine) inhibits further release of the hormone (TSH) that stimulated its own production.

10. A dog salivating at the sound of a bell after repeated pairing with food is an example of:

(a) habituation (b) imprinting (c) conditioning (conditioned reflex type I) (d) insight learning

Correct Answer: (c) conditioning (conditioned reflex type I). This is Pavlov's classic example of conditioning (conditioned reflex type I), pairing a neutral stimulus with a natural one.

Quick Revision Summary

- Plant coordination: hormones only (slow). Etiolation (no light) vs chlorosis (mineral deficiency). Hormones: auxins (cell elongation, apical dominance), gibberellins (bolting, dormancy break), cytokinins (cell division, delay senescence), abscisic acid (stress/dormancy/stomatal closure), ethylene (fruit ripening).
- Nervous coordination elements: Receptors (chemo/mechano/photo/thermo/nociceptors) -> Neurons (sensory/association/motor; dendrites+axon+cell body) -> Effectors (muscles/glands). Reflex arc = fast involuntary pathway.
- Nerve impulse: resting potential $\sim -70\text{mV}$ (Na^+/K^+ pump, 3 Na^+ out : 2 K^+ in) -> stimulus opens Na^+ gates -> action potential $\sim +50\text{mV}$ (depolarization) -> K^+ efflux (repolarization) -> pump restores rest. Speed: 100 m/s (max 120 m/s). Synapse: neurotransmitter (acetylcholine etc.) bridges gap between neurons.
- Nervous system evolution: Hydra (diffuse net, no brain) -> Planaria (bilobed brain, differentiated neurons) -> vertebrates (centralized CNS). Human CNS: forebrain (thalamus/limbic system/cerebrum) + midbrain (reticular formation) + hindbrain (medulla/pons/cerebellum) + spinal cord. PNS: 12 cranial + 31 spinal nerve pairs; somatic (voluntary) + autonomic (sympathetic=fight/flight, parasympathetic=rest).
- Endocrine: Hypothalamus -> Pituitary (anterior: STH/TSH/ACTH/gonadotrophins; median: MSH; posterior: ADH/oxytocin, stored not made there). Thyroid (T_3/T_4 , calcitonin), Parathyroid (parathormone), Pancreas (insulin/glucagon), Adrenal (cortex: cortisol/aldosterone; medulla: adrenaline/noradrenaline), Gut (gastrin/secretin), Gonads (oestrogen/progesterone/testosterone).
- Feedback mechanism: product inhibits its own stimulus (e.g., thyroxine inhibits TSH/releasing hormone) = negative feedback. Nervous vs chemical: nervous=fast/local/short-lived; chemical=slow/widespread/long-lasting.
- Behaviour: Innate (inherited, fixed - kineses, taxes, instincts, e.g. digger wasp) vs Learned (from experience - needs developed nervous system). Thorpe's 6 types of learning: imprinting (ducklings), habituation (snail), conditioning type I (Pavlov's



dogs), operant/trial-error (Skinner's rats), latent learning (unrewarded maze exploration), insight learning (Kohler's chimps, highest form). Notes by freebooks.pk.

Exam Tips

- Build a simple 5-hormone table (auxin/gibberellin/cytokinin/abscisic acid/ethylene) with one growth effect and one commercial use for each - exam questions frequently ask for exactly this pairing.
- Learn the resting-to-action-potential sequence as five numbered steps (resting -> Na⁺ gates open/depolarize -> Na⁺ gates close/K⁺ gates open -> K⁺ efflux/repolarize -> pump restores rest) so you can both describe and label a graph of it.
- Keep Hydra vs Planaria nervous system differences as a clean point-by-point list (centralization, neuron differentiation, sense organs, nerves) - this comparison is asked almost every year in some form.
- Group the human brain by division (forebrain/midbrain/hindbrain) and know one clear function per structure (thalamus=relay, hypothalamus=homeostasis, cerebrum=voluntary+thinking, cerebellum=coordination, medulla=automatic functions) rather than memorising isolated facts.
- For each endocrine gland, memorise hormone name + one clear effect + one named disorder (e.g. thyroid: thyroxine, raises metabolic rate, deficiency = cretinism/goiter) - this pattern covers most short and long questions on this topic.
- Practice explaining the thyroid negative feedback loop as a five-step numbered sequence exactly as given in the textbook (temperature drop -> hypothalamus -> TSH -> thyroxine -> inhibits hypothalamus/pituitary) since it is commonly asked to be described or diagrammed.
- Memorise Thorpe's six learning types with exactly one named example each (imprinting=ducklings, habituation=snail, conditioning=Pavlov's dogs, operant=Skinner's rats/cats, latent=maze rat, insight=Kohler's chimps) - matching-style questions test this directly.

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FSc Part-II Biology — Punjab Board

CHAPTER 18

Reproduction

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

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This chapter covers Reproduction from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Reproduction is the mechanism that produces new generations and maintains a species population, and every species reproduces by one or both of two fundamentally different strategies: asexual reproduction, requiring only a single parent and producing genetically identical offspring by mitosis, and sexual reproduction, usually requiring two parents whose meiotically produced gametes fuse to form a genetically variable offspring. These notes are prepared by freebooks.pk.

The chapter covers reproduction in plants (life cycles, parthenocarpy, seed dormancy, fruit set and ripening, photoperiodism and vernalisation), asexual reproduction in animals (parthenogenesis, tissue culturing and cloning, identical twins), the general biology of sexual reproduction and fertilization patterns (oviparous, viviparous, ovoviviparous), and human reproduction in detail, including the male and female reproductive systems, the menstrual cycle, pregnancy and birth, test tube babies, and sexually transmitted diseases.

Learning Objectives

- Differentiate asexual and sexual reproduction, and describe the common methods of each.
- Describe seed plant reproductive adaptations: parthenocarpy, seed dormancy, and fruit set and ripening.
- Explain photoperiodism and vernalisation and their role in synchronising plant reproduction with the environment.
- Describe asexual reproduction in animals: parthenogenesis, tissue culturing and cloning, and the formation of identical twins.
- Differentiate oviparous, viviparous and ovoviviparous patterns of animal development.
- Describe the structure and function of the human male and female reproductive systems.
- Describe the hormonal control of the human menstrual cycle and the process of pregnancy and birth.
- Describe test tube babies and common sexually transmitted diseases.

Key Concepts

Asexual and Sexual Reproduction: An Overview

Reproduction is of two fundamental types. Asexual reproduction requires only a single parental organism, which gives rise to offspring by mitotic cell division, so that the total chromosome content of the cell is exactly replicated and passed on to daughter cells, making the offspring genetically identical to the parent; its common methods are fission, sporulation, budding, vegetative propagation, artificial propagation, parthenogenesis and apomixis. Sexual reproduction usually involves two parents, and a fertilized egg is produced through the union of meiotically produced specialized sex cells (egg and sperm) from each parent; meiosis, or reduction division, gives rise to gametes in a process called



gametogenesis, in which the chromosome number is halved (haploid) and reshuffling of genes produces genetic recombination, an important factor in the survival and adaptation of a species. In plants that show alternation of generations between a diploid sporophyte and a haploid gametophyte, meiosis occurs during spore formation, called sporogenesis.

Although asexual reproduction allows a very rapid increase in the number of genetically alike individuals from a single parent, it is not an adaptive method and may, at some stage, jeopardize the survival of a species facing a changing environment. Humans have favoured asexual reproduction for their own purposes, commonly in plants, and now tissue culture technique in plants and cloning in animals are being adopted to produce organisms of valuable characteristics without any change in their genetic makeup; however, cloning's disadvantages, such as rapid aging and low resistance to environmental stress and disease, remain limitations for commercial ventures, and cloning is also still not fully accepted socially and morally.

Reproduction in Plants: Life Cycles, Parthenocarpy, Seed Dormancy and Fruit Development

In plants, both sexual and asexual reproduction occur; layering, grafting and budding are common artificial modes of asexual reproduction, while in sexual reproduction plants show a diplohaplontic life cycle, alternating between diploid sporophyte and haploid gametophyte generations, which may be isomorphic (vegetatively similar) or heteromorphic (dissimilar). Seed plants are predominant around us due to their superior sexual reproduction: modification of the flower and inflorescence for pollination, gamete transfer by pollen tubes, food storage for the developing embryo, protection by seed coats, and dispersal aided by fruit formation in angiosperms; seeds can also endure unfavourable conditions in a dormant form and germinate once conditions become favourable. The evolution of the pollen tube, which safely transports the male gametes to the female gamete in the ovule under hostile land conditions, was a key step in land adaptation by seed plants (spermatophytes), evolving in parallel with the seed itself.

Parthenocarpy is the development of fruit without fertilization and hence without seed formation, seen in banana, pineapple, and some varieties of orange and grape, and is caused by hormonal imbalance, usually high auxin levels in the ovary; it can also be induced artificially for commercial purposes by adding auxins to crops such as tomato and pepper. Seed dormancy is a special resting condition that enables an embryo to survive long periods of unfavourable environmental conditions such as water scarcity or low temperature, during which the embryo ceases or limits its growth, of great survival importance since it prevents a dormant seed from germinating prematurely in response to a brief accidental stimulus such as a warm winter spell. Germinating pollen is a rich source of auxin, which is necessary for fruit set, the retention of the ovary that becomes the fruit after fertilization (without it, abscission of flowers normally occurs, leading to low fruit yield); after fertilization the developing seeds continue to produce auxins, gibberellins and cytokinins, which stimulate fruit development, and fruit ripening is often accompanied by a burst of respiratory activity called the climacteric, associated with ethylene production.



Photoperiodism and Vernalisation

Photoperiodism is the response of plants to variations in day length (photoperiod), affecting flowering, fruit and seed production, bud and seed dormancy, leaf fall and germination; it was first studied in 1920 by Garner and Allard, who found that tobacco flowers only after exposure to a series of short days and classified flowering plants into short-day plants (requiring short days for flowering), long-day plants (requiring long days) and day-neutral plants (flowering independent of photoperiod). Later studies revealed that it is really the length of the uninterrupted dark period, not the day length, that is critical, so short-day plants are more accurately described as long-night plants: if the long night is interrupted by a short flash of light, flowering is prevented in short-day plants but promoted in long-day plants. The pigment responsible for detecting light and dark is phytochrome, which exists in two interconvertible forms, P660 (absorbs red light at 660 nm, converted to P730) and P730 (absorbs far-red light at 730 nm, converted back to P660); P660 to P730 conversion occurs in daylight and P730 to P660 conversion occurs in darkness, so the rate of this reversion provides the plant with a biological 'clock' for measuring the duration of darkness, ultimately triggering production of the flowering hormone florigen in the leaves, which travels through the phloem to the floral buds to initiate flowering.

Vernalisation is the stimulation of flowering in biennial and perennial plants by exposure to low temperature, received by the shoot apex of a mature stem or the embryo of a seed (unlike photoperiodism, which is detected by the leaves); the required chilling duration varies from four days to three months, with temperatures around 4 degrees Celsius being especially effective, and low temperature is believed to stimulate production of a hormone called vernalin, now generally believed to be a form of gibberellin. Together, photoperiodism and vernalisation synchronise the reproductive behaviour of plants with their environment, ensuring reproduction occurs at favourable times of year and that members of the same species flower simultaneously, encouraging cross-pollination and genetic variability.

Asexual Reproduction in Animals: Parthenogenesis, Cloning and Twins

Asexual reproduction is less common in animals than in plants, but still occurs by binary fission, multiple fission (as in animal-like protists), budding (Hydra), parthenogenesis, tissue culturing, cloning and the formation of identical twins. Parthenogenesis is the development of an egg without fertilization, seen in ants, bees and wasps; in honeybees, males (drones) develop from unfertilized haploid eggs (haploid parthenogenesis) laid by the queen, who stores sperm received from a drone in a pouch and can choose whether or not to fertilize each egg she lays, while in some organisms such as aphids, diploid parthenogenesis occurs, in which egg-producing cells undergo a modified meiosis with total non-disjunction, retaining the diploid chromosome number so the diploid egg develops directly into a young female; parthenogenesis has the advantage of accelerating the normal reproductive rate.

In tissue culturing, cambium tissue excised from a plant can be stimulated with nutrients, cytokinins and auxin (IAA) to grow continuously and differentiate into a new plant genetically identical to the parent, a technique widely used for rapid propagation of desired varieties, with similar techniques now developed for animal cell tissue culture; in flowering plants, one form of parthenogenesis called apomixis allows a diploid cell of the ovule (from the nucellus



or megaspore) to develop directly into a functional embryo without a male gamete. Organisms produced from a single cell by subculturing are called clones; in vertebrates, a somatic cell nucleus is transplanted into an egg cell whose own nucleus has been destroyed by ultraviolet radiation, and the resulting egg develops into an organism genetically identical to the nucleus donor, useful for cloning desirable animals (such as prize bulls or racehorses) and for quantitative study of hormone, drug and antibody action on cells, though its application to humans raises serious moral questions, and cloned populations lack genetic diversity, making them vulnerable if an environmental hazard such as a disease outbreak occurs. In higher vertebrates including man, if the two blastomeres of a two-celled embryo separate and each develops independently, the result is two genetically identical individuals called identical twins (produced mitotically, i.e. asexually); if instead more than one egg is independently fertilized, the resulting individuals are called fraternal twins or triplets, each with a different genetic combination (produced sexually).

Sexual Reproduction: Gamete Evolution and Fertilization Patterns

Asexual reproduction is thought to be a more primitive form of reproduction than sexual reproduction; over evolutionary time, mechanisms evolved for the production and union of gametes, with meiosis and genetic recombination driving the development of more complex life forms and gamete types, from identical gametes (isogametes) to the heterogametic condition of motile male gametes (sperm or antherozoid) and non-motile female gametes (eggs or ova). Sexual reproduction, though slower to increase population size than asexual reproduction, has the advantage of producing genetically variable offspring through genetic recombination, a crucial factor for adaptation to changing environments; organisms may be unisexual (having one sex) or hermaphrodite/bisexual (having both sexes), and while advanced sexual reproduction favours unisexuality in animals, bisexuality is generally retained in plants, and even bisexual animals such as tapeworm and earthworm ensure cross-fertilization to preserve the benefits of genetic recombination.

Fertilization, the union of gametes, may occur outside the body (external fertilization) or inside the female's body (internal fertilization). External fertilization occurs in an aquatic environment, where male gametes can swim toward female gametes in the surrounding water, and development is also typically external due to the relatively stable conditions of water, as in frogs and fish. In terrestrial animals, fertilization is internal, with sperm lodged inside the female body; this may still be followed by external development, as in reptiles and birds, which lay shelled eggs to protect the developing embryo from harsh terrestrial conditions (such animals are called oviparous). In mammals, internal fertilization is followed by internal development inside the female body, culminating in live birth (viviparous); in a few mammals such as the duck-billed platypus and spiny anteater, internal fertilization leads to internal development of a young one inside a shelled egg, which is laid and then hatches (ovoviviparous). Viviparous and ovoviviparous animals provide substantially more protection to their developing young, with nourishment supplied either through food stored in the egg or, in viviparous mammals, through the placenta.



The Human Male Reproductive System and Spermatogenesis

Reproduction in man involves separate male and female reproductive systems. The male reproductive system consists of external genitalia, including a pair of testes lying outside the body in the sac-like scrotum, and the male copulatory organ used to transfer sperm into the female reproductive tract. Each testis consists of a highly complex duct system called the seminiferous tubules, in which repeated mitotic division of the germinal epithelium produces spermatogonia; these increase in size and differentiate into primary spermatocytes, which undergo meiotic division to form secondary spermatocytes and then spermatids, which eventually differentiate into mature sperm, with fluid secreted by Sertoli cells providing a liquid medium, protection and nourishment for the developing sperm within the tubules. Mature sperm are transferred to the main duct of the male reproductive tract, the vas deferens (formed from the highly convoluted epididymis), before passing through the urinogenital duct and being discharged out of the body.

Between the seminiferous tubules lie interstitial cells (Leydig cells) that secrete the hormone testosterone, which is essential for the successful production of sperm and also controls the development of male secondary sexual characteristics during puberty, such as facial hair growth, voice deepening and increased muscle mass.

The Human Female Reproductive System and the Menstrual Cycle

The female reproductive system consists of a pair of ovaries lying within the body cavity, oviducts (fallopian tubes), the uterus, and the external genitalia. Germ cells in the ovary produce numerous oogonia, which divide mitotically to form primary oocytes, enclosed in groups of follicle cells; each primary oocyte divides meiotically into a haploid secondary oocyte and a first polar body, and the second meiotic division proceeds only as far as metaphase, remaining incomplete until the oocyte is actually fertilized by a sperm. In humans, normally only one ovum is discharged from the ovary at a time, a process called ovulation; the ovum is then transferred to the oviduct (fallopian or uterine tube), which opens into the uterus, and fertilization, when it occurs, takes place in the proximal part of the oviduct, with the resulting zygote entering and implanting in the uterus, where a placenta forms between the uterine and foetal tissues to exchange oxygen, carbon dioxide, waste and nutrients; the uterus opens into the vagina through the cervix.

In females, unlike the continuous gamete production of males, egg production is cyclic: the periodic reproductive cycle, called the menstrual cycle, is completed in approximately 28 days and involves both the ovaries (ovarian cycle) and the uterus (uterine cycle), regulated by pituitary gonadotrophins in five key steps. First, at puberty the pituitary releases follicle stimulating hormone (FSH), stimulating the development of several primary follicles, of which normally only one continues to grow while the rest degenerate through follicle atresia. Second, under FSH stimulation the growing ovarian follicle produces oestrogen, which stimulates and vascularises the endometrium (uterine lining) while simultaneously inhibiting further pituitary FSH secretion. Third, the resulting fall in FSH and rise in oestrogen triggers the pituitary to secrete luteinizing hormone (LH), which induces ovulation, the release of the ovum from the follicle. Fourth, the ruptured follicle cells transform into the corpus luteum, a yellowish glandular structure that secretes progesterone, which further develops the



endometrium and makes it receptive to implantation of a zygote. Fifth, if fertilization does not occur, the corpus luteum degenerates, progesterone secretion falls, the spongy endometrium breaks down, and the resulting discharge of blood and cell debris is called menstruation, usually lasting 3 to 7 days, after which the cycle begins again; the permanent cessation of the menstrual cycle, called menopause, marks the end of ovum production in a woman's life.

Pregnancy, Birth, Test Tube Babies and Sexually Transmitted Diseases

The total human gestation period (pregnancy) is usually about 280 days. Once established, the placenta secretes progesterone, which maintains the pregnancy (any disturbance in its secretion may cause premature birth or miscarriage), while the embryo remains enclosed in the protective, shock-absorbing amniotic fluid within the amniotic sac; from the beginning of the third month, the embryo is termed a foetus, with most major organs formed by the twelfth week and the rest of gestation devoted to growth. Birth is now understood to involve substantial foetal involvement in its timing: ACTH released from the foetal pituitary stimulates the foetal adrenal gland to release corticosteroids, which cross the placental barrier into the maternal circulation and cause a decrease in progesterone production; this progesterone decline stimulates the maternal pituitary to release oxytocin, which induces labour by causing rhythmic contractions of the uterine wall, pushing the baby downward through the dilating cervix until delivery; within 10 to 45 minutes after birth, the uterus contracts further to separate and expel the placenta (the 'afterbirth'), with bleeding controlled by contraction of smooth muscle surrounding the uterine blood vessels, and average blood loss of about 350 cubic centimetres.

Test tube babies (in vitro fertilization) help parents who are unable to conceive naturally due to physiological or physical abnormalities in either parent: sperm and ovum are fertilized in vitro (outside the female body), and the resulting zygote is implanted into the mother's uterus, where the placenta establishes itself and the remaining development proceeds normally to birth. Sexually transmitted diseases (STDs) are spread through sexual contact from carriers to healthy partners; gonorrhoea, caused by the bacterium *Neisseria gonorrhoeae*, mainly affects the mucous membrane of the urinogenital tract and can cause serious eye infections in newborns delivered through an infected birth canal; syphilis, caused by the spirochaete *Treponema pallidum*, damages the reproductive organs, eyes, bones, joints, central nervous system, heart and skin; genital herpes, caused by herpes simplex virus type 2, produces genital soreness and ulcers and can be transmitted to an infant during birth, damaging the eyes and central nervous system; and AIDS (Acquired Immune Deficiency Syndrome) is also commonly spread by sexual contact. All of these diseases can be controlled and prevented by avoiding sexual contact with an infected or carrier individual and maintaining hygienic conditions, with long-term medication available for treatment except, at present, for AIDS.

Important Definitions

Term	Definition
Parthenocarpy	



Term	Definition
	The development of fruit without fertilization and without seed formation, caused by hormonal imbalance (usually high auxin), as seen in banana and some varieties of grape and orange.
Seed dormancy	A special resting condition that enables a plant embryo to survive long periods of unfavourable environmental conditions, during which growth ceases or is greatly limited.
Photoperiodism	The response of a plant's growth and flowering to the relative length of day and night (photoperiod).
Vernalisation	The stimulation of flowering in biennial and perennial plants by prior exposure to a period of low temperature.
Parthenogenesis	The development of an egg into a new individual without fertilization by a sperm.
Oviparous	Describes animals, such as reptiles and birds, that lay shelled eggs in which the embryo develops externally after internal fertilization.
Viviparous	Describes animals, such as most mammals, in which the embryo develops fully inside the mother's body and is born alive.
Menstruation	The periodic discharge of blood and endometrial tissue from the uterus that occurs when fertilization does not take place, marking the end of one menstrual cycle.

Key Facts

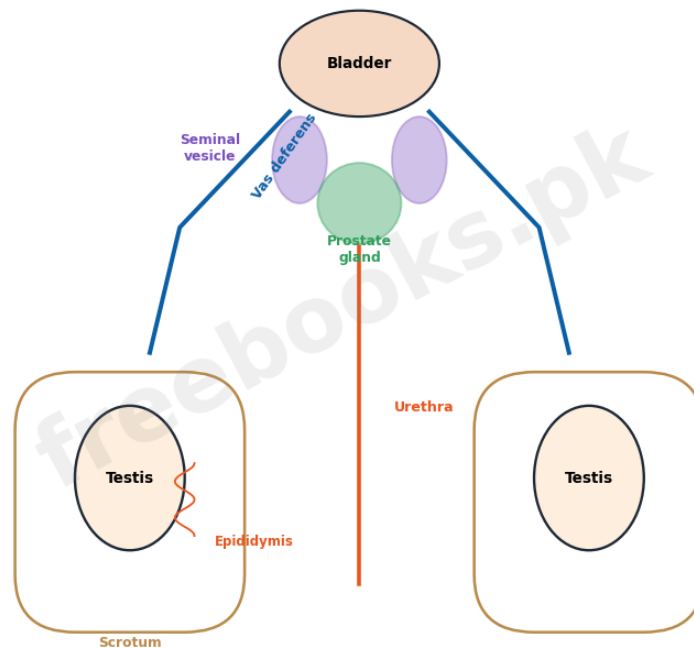
Item	Fact
Menstrual cycle length	The human menstrual cycle is completed in approximately 28 days (with individual variation).
Menstruation duration	Menstrual bleeding usually lasts 3 to 7 days.
Gestation period	Total human pregnancy (gestation) is usually about 280 days.
Average blood loss at birth	Average blood loss during afterbirth/placental separation is about 350 cm ³ .
Phytochrome forms	P660 absorbs red light (660 nm) and converts to P730; P730 absorbs far-red light (730 nm) and converts back to P660.
Vernalisation temperature	Around 4°C is found to be the most effective temperature for vernalisation; chilling duration required ranges from 4 days to 3 months.
Major foetal organs formed	Most major organs of the human foetus are formed by the 12th week of pregnancy.
Placental separation time	The placenta typically separates from the uterine wall and is expelled within 10-45 minutes after birth.



Diagrams & Illustrations

The Human Male Reproductive System: a simplified labelled diagram showing the testis (within the scrotum), epididymis, vas deferens, seminal vesicle, prostate gland and urethra of the human male reproductive system.

The Human Male Reproductive System (simplified)

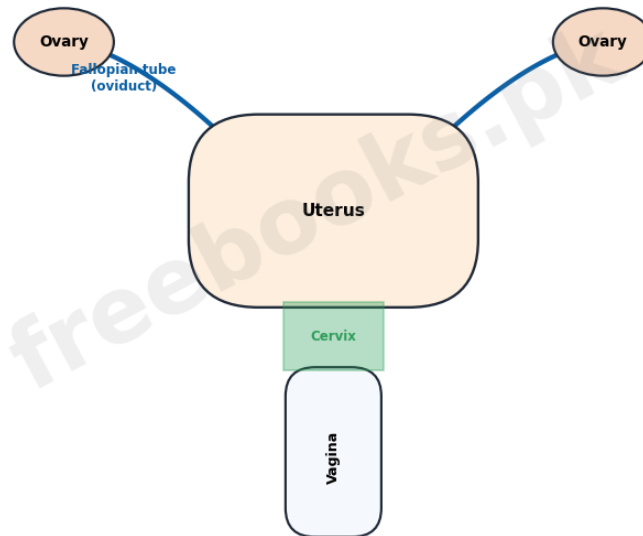


The Human Male Reproductive System

The Human Female Reproductive System: a simplified labelled diagram showing the ovaries, fallopian tubes (oviducts), uterus, cervix and vagina of the human female reproductive system.

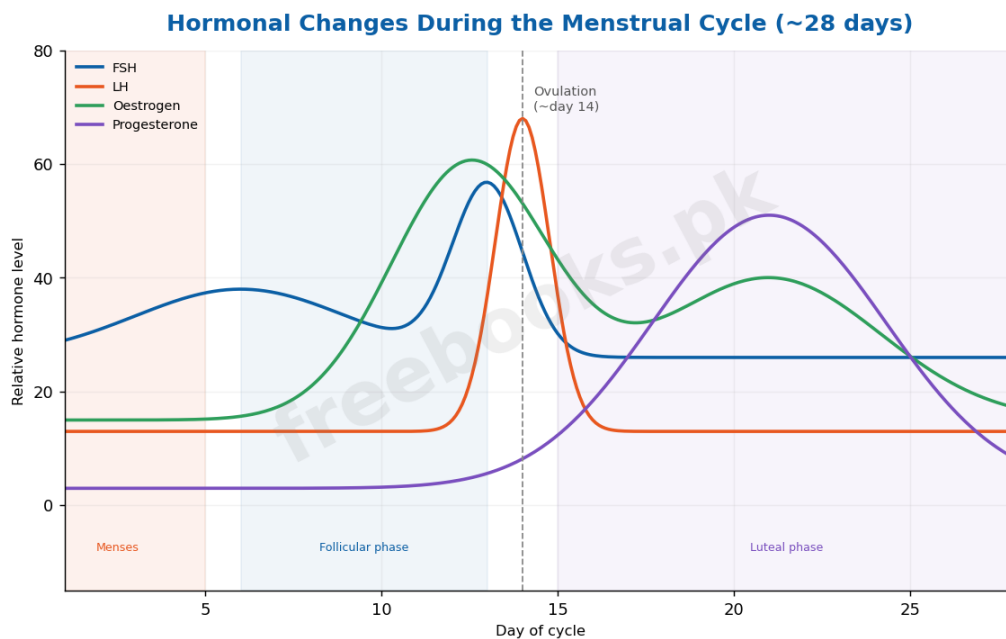


The Human Female Reproductive System (simplified)



The Human Female Reproductive System

Hormonal Changes During the Menstrual Cycle: a graph showing the relative levels of FSH, LH, oestrogen and progesterone across the approximately 28-day human menstrual cycle, aligned with the follicular, ovulation and luteal phases.



Hormonal Changes During the Menstrual Cycle



Short Questions & Answers

Q1. Differentiate asexual and sexual reproduction in terms of parent number and genetic outcome.

Ans. Asexual reproduction requires only one parent and produces offspring genetically identical to that parent via mitosis, with no gametes or meiosis involved; sexual reproduction usually requires two parents whose meiotically produced haploid gametes fuse at fertilization, producing genetically variable offspring through genetic recombination.

Q2. What is parthenocarpy, and give two examples of fruits that commonly show it.

Ans. Parthenocarpy is the development of fruit without fertilization and without seed formation, caused by hormonal imbalance (usually high auxin levels in the ovary); banana and pineapple are common natural examples, and it can also be artificially induced in tomato and pepper.

Q3. Differentiate short-day plants and long-day plants in terms of their flowering requirement.

Ans. Short-day plants flower when the uninterrupted dark period exceeds a critical length (effectively requiring long nights, e.g. cocklebur, tobacco), while long-day plants flower when the dark period is shorter than a critical length (effectively requiring short nights, e.g. henbane, spinach); day-neutral plants flower independently of photoperiod altogether.

Q4. What is parthenogenesis, and how does it differ in honeybees and aphids?

Ans. Parthenogenesis is the development of an egg without fertilization; in honeybees it is haploid parthenogenesis, where unfertilized haploid eggs develop into haploid male drones, while in aphids it is diploid parthenogenesis, where a modified meiosis with total non-disjunction retains the diploid chromosome number, so the diploid egg develops into a young female.

Q5. Differentiate oviparous and viviparous animals with one example each.

Ans. Oviparous animals, such as reptiles and birds, undergo internal fertilization but lay shelled eggs in which the embryo develops externally; viviparous animals, such as most mammals, undergo internal fertilization followed by internal development of the embryo inside the mother's body, culminating in live birth.

Q6. List, in order, the five key hormonal steps of the human menstrual cycle.

Ans. (1) Pituitary FSH stimulates development of primary follicles; (2) the growing follicle secretes oestrogen, which builds the endometrium and inhibits further FSH; (3) falling FSH and rising oestrogen trigger a pituitary LH surge, inducing ovulation; (4) the ruptured follicle becomes the corpus luteum, secreting progesterone to prepare the endometrium for implantation; (5) if fertilization does not occur, the corpus luteum degenerates, progesterone falls, and the endometrium breaks down as menstruation.



Long Questions & Answers

Q1: Describe the structure and function of the human male reproductive system, including the process of sperm formation.

The human male reproductive system is built around a pair of testes, which lie outside the main body cavity within the sac-like scrotum, an arrangement that keeps the testes at a slightly lower temperature than the rest of the body, a condition essential for normal sperm production, together with the male copulatory organ, which is used to transfer sperm into the female reproductive tract during mating. Within each testis lies a highly complex, tightly coiled duct system called the seminiferous tubules, and it is here that spermatogenesis, the formation of mature sperm, takes place: repeated mitotic division of cells in the germinal epithelium lining the tubules produces spermatogonia, which grow in size and differentiate into primary spermatocytes; each primary spermatocyte then undergoes the first meiotic division to form two secondary spermatocytes, and each of these undergoes a second meiotic division to form spermatids, so that each original primary spermatocyte ultimately gives rise to four haploid spermatids, which then differentiate through a process of extensive structural remodelling (developing a head, midpiece and tail) into mature, motile sperm. Throughout this process, specialised Sertoli cells within the seminiferous tubules secrete a nourishing fluid that provides the developing sperm cells with a protective liquid medium and essential nourishment while they mature within the tubules. Once mature, sperm are transferred out of the seminiferous tubules into the epididymis, a highly convoluted duct in which sperm complete their maturation and are stored, before passing into the vas deferens, the main duct of the male reproductive tract, and ultimately through the urinogenital duct to be discharged from the body during ejaculation. In addition to their role in physically producing sperm, the testes also have a vital endocrine function: scattered between the seminiferous tubules are interstitial cells, also called Leydig cells, which secrete the steroid hormone testosterone; this hormone is essential for successful, ongoing sperm production and is also responsible for controlling the development of male secondary sexual characteristics that emerge at puberty, such as the growth of facial and body hair, deepening of the voice, and increased muscle mass, distinguishing testosterone's role as both a reproductive and a developmental hormone.

Q2: Describe the five key hormonal steps of the human menstrual cycle, and explain what happens if fertilization does not occur.

The human menstrual cycle is a periodic reproductive cycle completed in approximately 28 days that coordinates cyclic changes in both the ovaries (the ovarian cycle) and the uterus (the uterine cycle), and unlike the continuous gamete production seen in males, it ensures that egg production and release in females occurs only once per cycle, regulated throughout by pituitary gonadotrophin hormones acting in a precise five-step sequence. The cycle begins when, from puberty onward, the pituitary gland releases follicle stimulating hormone (FSH), which stimulates several primary follicles within the ovary to begin developing simultaneously, although normally only a single dominant follicle continues to mature with its primary oocyte while the remaining follicles undergo a degenerative process called follicle atresia and break down. In the second step, the single growing follicle, under continued FSH



stimulation, itself begins producing the hormone oestrogen, which has two important simultaneous effects: it stimulates and vascularises the endometrium, the internal lining of the uterine wall, preparing it for a possible pregnancy, while at the same time inhibiting further secretion of FSH from the pituitary gland through negative feedback. In the third step, this combination of falling FSH and steadily rising oestrogen levels eventually triggers the pituitary gland to release a surge of luteinizing hormone (LH), and this LH surge is what actually induces ovulation, the rupture of the mature follicle and release of the ovum from the ovary. In the fourth step, following the release of the egg, the ruptured follicle cells do not simply degenerate but instead transform into a distinctive yellowish glandular structure called the corpus luteum, which begins secreting the hormone progesterone; progesterone continues the work oestrogen began, further developing the endometrium and specifically making it receptive to the implantation of a fertilized zygote, effectively preparing the uterus for a potential pregnancy. The fifth and final step depends entirely on whether fertilization has actually occurred during this cycle: if it has not, the corpus luteum, receiving no signal to persist, begins to degenerate on its own, causing progesterone secretion to fall sharply; without progesterone's continued support, the thickened, spongy endometrium can no longer be maintained and undergoes breakdown, and the resulting discharge of blood and cellular debris from the uterus through the vagina is what is experienced as menstruation, typically lasting 3 to 7 days, after which the entire five-step cycle begins again with a fresh round of FSH release; if fertilization has occurred, by contrast, the corpus luteum persists and progesterone secretion is maintained, sustaining the endometrium and supporting the establishment of pregnancy instead.

MCQs with Answers

1. Asexual reproduction produces offspring that are:

(a) genetically variable (b) genetically identical to the parent (c) always haploid (d) always sterile

Correct Answer: (b) genetically identical to the parent. Asexual reproduction occurs by mitosis, so offspring are exact genetic copies of the single parent.

2. Parthenocarpy, seen in bananas and pineapples, results in fruit development:

(a) with normal seed formation (b) without fertilization and without seed formation (c) only after vernalisation (d) only in short-day plants

Correct Answer: (b) without fertilization and without seed formation. Parthenocarpy is fruit development without fertilization, so no seeds are formed; it is caused by hormonal imbalance (usually high auxin).

3. A short-day plant will fail to flower if its long night is interrupted by a brief flash of which colour of light?

(a) blue light (b) green light (c) red light (d) far-red light alone

Correct Answer: (c) red light. Red light interrupting the long night prevents flowering in short-day plants; far-red light can reverse this effect.

4. Vernalisation refers to the stimulation of flowering by prior exposure to:

(a) long days (b) low temperature (c) high humidity (d) darkness alone

Correct Answer: (b) low temperature. Vernalisation is the stimulation of flowering in



biennial/perennial plants by a period of low (chilling) temperature, detected by the shoot apex.

5. In honeybees, male drones develop through which process?

- (a) diploid parthenogenesis (b) haploid parthenogenesis (c) normal sexual reproduction (d) apomixis

Correct Answer: (b) haploid parthenogenesis. Honeybee drones develop from unfertilized haploid eggs, a process called haploid parthenogenesis.

6. Animals such as reptiles and birds that undergo internal fertilization but lay shelled eggs for external development are called:

- (a) viviparous (b) ovoviviparous (c) oviparous (d) parthenogenetic

Correct Answer: (c) oviparous. Oviparous animals fertilize internally but lay shelled eggs in which the embryo develops externally, protected by the shell.

7. Sperm cells mature and are produced within which structure of the testis?

- (a) interstitial (Leydig) cells (b) seminiferous tubules (c) epididymis (d) vas deferens

Correct Answer: (b) seminiferous tubules. Spermatogenesis occurs within the seminiferous tubules of the testis, lined by germinal epithelium and Sertoli cells.

8. The hormone that induces ovulation by triggering the rupture of the mature ovarian follicle is:

- (a) FSH (b) oestrogen (c) LH (luteinizing hormone) (d) progesterone

Correct Answer: (c) LH (luteinizing hormone). A surge of luteinizing hormone (LH), triggered by falling FSH and rising oestrogen, induces ovulation.

9. The corpus luteum, formed from the ruptured follicle after ovulation, mainly secretes:

- (a) FSH (b) LH (c) oestrogen only (d) progesterone

Correct Answer: (d) progesterone. The corpus luteum secretes progesterone, which develops the endometrium and prepares it for implantation.

10. Which sexually transmitted disease is caused by the bacterium *Neisseria gonorrhoeae*?

- (a) Syphilis (b) Genital herpes (c) Gonorrhoea (d) AIDS

Correct Answer: (c) Gonorrhoea. Gonorrhoea is caused by the gram-negative bacterium *Neisseria gonorrhoeae*, affecting the mucous membrane of the urinogenital tract.

Quick Revision Summary

- Two reproduction types: Asexual (1 parent, mitosis, identical offspring: fission/ sporulation/budding/vegetative propagation/parthenogenesis/apomixis) vs Sexual (2 parents, meiosis+gamete fusion, genetically variable offspring).
- Plant reproduction: Parthenocarpy (fruit w/o fertilization, high auxin, banana/ pineapple) | Seed dormancy (survival rest state) | Fruit set/ripening (auxin/ gibberellin/cytokinin -> climacteric -> ethylene ripens).
- Photoperiodism: SDP (long-night plants, e.g. tobacco) vs LDP (short-night plants, e.g. henbane) vs DNP (independent). Phytochrome: P660 (red light) <-> P730 (far-red light); P660->P730 in day, reverse at night = biological clock -> florigen ->



flowering. Vernalisation: low temp ($\sim 4^{\circ}\text{C}$) stimulates flowering via vernalin/gibberellin, sensed by shoot apex.

- Animal asexual reproduction: Parthenogenesis (haploid=honeybee drones; diploid=aphids), Tissue culturing/cloning (somatic nucleus $\rightarrow$ enucleated egg $\rightarrow$ clone), Identical twins (2-cell stage splits, mitotic/asexual) vs Fraternal twins (multiple eggs fertilized, sexual).
- Fertilization patterns: External (aquatic, e.g. frog/fish) vs Internal (terrestrial). Oviparous (shelled egg, external development - reptiles/birds) vs Viviparous (internal development, live birth - mammals) vs Ovoviviparous (shelled egg develops internally, e.g. platypus).
- Human male system: testes (scrotum) $\rightarrow$ seminiferous tubules (spermatogonia $\rightarrow$ primary spermatocyte $\rightarrow$ secondary spermatocyte $\rightarrow$ spermatid $\rightarrow$ sperm) $\rightarrow$ epididymis $\rightarrow$ vas deferens $\rightarrow$ urinogenital duct. Sertoli cells nourish sperm; interstitial (Leydig) cells secrete testosterone.
- Human female system + menstrual cycle (~ 28 days, 5 steps): FSH (grows follicle) $\rightarrow$ oestrogen (builds endometrium, inhibits FSH) $\rightarrow$ LH surge (ovulation) $\rightarrow$ corpus luteum/progesterone (prepares endometrium) $\rightarrow$ if no fertilization: corpus luteum degenerates $\rightarrow$ menstruation (3-7 days). Gestation ~ 280 days; birth triggered by fetal ACTH $\rightarrow$ corticosteroids $\rightarrow$ falling progesterone $\rightarrow$ oxytocin $\rightarrow$ labour. Notes by freebooks.pk.

Exam Tips

- Build a two-column comparison table (asexual vs sexual reproduction) exactly as in Table 18.2 of the textbook - parent number, gametes, meiosis, offspring identity, occurrence, reproduction speed - this comparison is a very common exam question.
- Memorise the phytochrome conversion pair as one clean rule: P660 $\rightarrow$ (red light, day) $\rightarrow$ P730 $\rightarrow$ (far-red light, night) $\rightarrow$ P660, and link it directly to flowering promotion/inhibition in SDPs vs LDPs.
- Keep parthenogenesis examples paired precisely: honeybee = haploid parthenogenesis (drones), aphid = diploid parthenogenesis (females) - exam questions often test this exact pairing.
- Learn the oviparous/viviparous/ovoviviparous distinction with one animal example each (bird, mammal/human, platypus) rather than just the definitions alone.
- Write out spermatogenesis as a five-step numbered chain (spermatogonia $\rightarrow$ primary spermatocyte $\rightarrow$ secondary spermatocyte $\rightarrow$ spermatid $\rightarrow$ sperm) and be ready to state which steps are mitotic vs meiotic.
- Memorise the menstrual cycle as a five-step numbered sequence with hormone names in order (FSH $\rightarrow$ oestrogen $\rightarrow$ LH $\rightarrow$ progesterone $\rightarrow$ menstruation) - this is one of the most frequently asked long questions in this chapter.
- For STDs, build a compact 3-column table (disease, causative organism, key effect) for gonorrhoea, syphilis and genital herpes - this format matches how the question is usually asked.



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FSc Part-II Biology — Punjab Board

CHAPTER 19

Growth and Development

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

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This chapter covers Growth and Development from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). In the course of its life cycle, an organism changes from a fertilized egg into an adult, and this progressive sequence of changes that occurs before it acquires its adult form constitutes embryonic development; growth itself is the permanent, irreversible increase in size that occurs as an organism matures. These notes are prepared by freebooks.pk.

The chapter covers growth and development in plants (meristems, phases of growth, external and internal growth conditions, differentiation, and growth correlations such as apical dominance), growth and development in animals using the chick as a model system (fertilization, cleavage, blastula, gastrulation, notochord and mesoderm formation, neurulation), the underlying mechanisms of development (the roles of nucleus and cytoplasm, embryonic induction), and finally aging, regeneration and abnormal development.

Learning Objectives

- Differentiate growth and development, and describe the concept of open growth in plants.
- Describe the types of plant meristems (apical, intercalary, lateral) and the four phases of plant growth.
- Describe the external and internal factors that influence plant growth, and explain growth correlation and apical dominance.
- Describe the early stages of chick development: fertilization, cleavage, morula, blastula and gastrulation.
- Describe notochord and mesoderm formation and neurulation in the chick embryo.
- Explain the roles of the nucleus and cytoplasm in development using classic experiments (Dietrich, Spemann, Haemmerling).
- Define embryonic induction and describe Spemann and Mangold's primary organizer experiment.
- Describe the processes of aging, regeneration, and the causes of abnormal development.

Key Concepts

Growth and Development in Plants: Meristems and Phases of Growth

In plants, growth and development involve cell division, elongation, and differentiation of cells into tissues and then organs; growth is an irreversible increase in size, while development is a programmed series of stages from a simpler to a more complex form, accompanied by cellular differentiation of structure and function. Plants show a growth pattern called open growth: throughout life, a plant continues adding new organs such as branches, leaves and roots, enlarging from the tips of roots and shoots, though the rate of growth is not uniform, starting slow, becoming rapid, reaching a maximum, and then gradually slowing. In vascular plants, growth occurs through the activity of meristems, young



tissues or groups of cells that retain the potential to divide; in lower plants the entire plant body can grow, but in higher plants growth is limited to specific growing points. There are three types of meristem: apical meristems, found at the tips of roots and shoots, are perpetual growth zones primarily responsible for primary growth (increase in length); intercalary meristems are parts of apical meristem separated from the apex by permanent tissue, situated at the bases of internodes, playing an important but temporary role in leaf and flower production; and lateral meristems, cylinders of dividing cells present in dicots and gymnosperms (vascular and cork cambium), are responsible for secondary growth (increase in diameter), with some structures being determinate (grow to a certain size and stop, e.g. leaves, flowers, fruits) and others indeterminate (continually replenished, remaining youthful, e.g. vegetative roots and stems).

The growth of a multicellular plant is divided into four phases. During cell division, the number of cells increases by mitosis at the tips of root and shoot, where cells are small with centrally located spherical nuclei in non-vacuolated cytoplasm. A short distance from the apex lies the zone of elongation, only a few millimetres long, where cell volume increases up to 150-fold due to water uptake as cell wall plasticity increases and wall pressure decreases. During maturation, cells attain their final size: some, like pith and cortex cells, do not elongate further, while others, like fibres and tracheids, elongate lengthwise more than in other directions. Once cell enlargement ceases, differentiation begins: cell walls thicken and become pitted, xylem vessel walls develop thickenings, and cells of various tissues acquire distinct spatial dimensions and structural features; differentiation itself proceeds through five recognisable stages, from formation of the embryo, through recognition of shoot and root apical meristems and of the cambium, to production of leaf and root primordia, and finally the formation of fully differentiated tissues including xylem, phloem, leaves, shoots and roots.

Conditions for Plant Growth and Growth Correlations

Plant growth rate is influenced by both external and internal factors. Among external factors, temperature influences growth rate within a range of 0-35 degrees Celsius, with an optimum of 25-30 degrees Celsius, minimal growth at 5-10 degrees Celsius, and growth stopping (potentially fatally) above 35-40 degrees Celsius; light influences growth through its intensity (more intensity increases cell division), quality (red light favours cell elongation, blue light enhances division but retards enlargement, and ultraviolet light retards elongation), and duration (affecting vegetative and reproductive structures and flowering, a phenomenon called photoperiodism); oxygen is necessary for the metabolic activity underlying growth, though excess oxygen inhibits growth; carbon dioxide is essential for photosynthesis but retards growth at very high concentrations; water enables cell elongation by absorption, with growth ceasing entirely in its absence; and nutrition supplies energy for growth, with growth increasing as nutrition increases and slowing as it decreases. Among internal factors, hormones such as indole-3-acetic acid (IAA, an auxin) cause cell elongation, while vitamins, organic compounds synthesised within the plant in the presence of light, are essential for continued growth, since plants grown in the dark develop vitamin deficiencies that halt growth.



The development of a plant is usually correlated with its growth, with different organs growing at different rates and in different directions in a reciprocal relationship known as correlation. One of the most important correlative effects is apical dominance, in which only the apical bud grows actively while growth in the lower axillary buds is suppressed; when the apical bud is experimentally removed, growth in the lower buds is released from inhibition, showing that the active shoot apex controls lateral bud development. Thimann and Skoog demonstrated in 1934 that apical dominance is caused by auxin diffusing from the apical bud and inhibiting lateral shoot growth (the inhibitory effect), while removal of the apex releases the lateral buds from this inhibition (the compensatory effect); later research showed that cytokinins also play a role, since applying cytokinin directly to an inhibited bud can release it from apical dominance, and plants with dense lateral branching typically show very little apical dominance. Practically, apical dominance is important in tap root development and is exploited commercially by applying synthetic auxin to potato tubers to inhibit sprouting of the eyes, extending storage time from one to three years.

Development of the Chick: Fertilization, Cleavage and Blastula Formation

Embryology is the study of the growth and differentiation an organism undergoes in developing from a single fertilized egg into a complex, independent living being resembling its parents; development is an ordered sequence of irreversible steps, each setting up the conditions for the next, and because all animals are related through evolution, their early development shows broad similarities, commonly studied using the chick as a basic model applicable to all vertebrates. In the chick, fertilization is internal, occurring just as the ovum enters the oviduct, and the shell is secreted as the egg passes through the shell gland (uterus); development ceases once the egg is laid unless its temperature is kept near the mother's body temperature, and artificial incubators are typically regulated at 36-38 degrees Celsius, at which the chick completes development and hatches on the twenty-first day.

Immediately after fertilization, the egg undergoes a series of mitotic divisions called cleavage; in the bird's egg, this cell division is confined to a small disc of protoplasm on the surface of the yolk at the animal pole, a pattern called discoidal cleavage, with the first two cleavage planes vertical and the third running horizontally, separating the dividing cytoplasm from the underlying yolk, after which successive cleavages become increasingly irregular. Cleavage produces the morula, a rounded, closely packed mass of blastomeres forming a disc-shaped blastoderm two or more layers thick, with smaller, well-defined cells at the centre and flattened, larger cells at the periphery; this short-lived stage soon transitions into the blastula, characterised by a fluid-filled segmentation cavity called the blastocoel beneath the discoidal blastoderm, with the marginal zone where cells remain attached to the yolk called the zone of junction. Gastrulation follows, characterised by extensive cell movement and rearrangement: the blastoderm splits into an upper epiblast layer (presumptive ectoderm and mesoderm) and a lower hypoblast layer (presumptive endoderm, which grows outward and then downward around the yolk to form the endodermal lining of the yolk sac), and the central region of the blastoderm separates from the yolk with a pool of fluid developing beneath it, producing a translucent area called the area pellucida, in contrast to the peripheral area opaca, where cells remain attached to the yolk.



Notochord and Mesoderm Formation, and Neurulation

In the chick, mesodermal cells migrate medially and caudally from both sides of the blastoderm, creating a midline thickening called the primitive streak, which grows rapidly in length as more presumptive mesodermal cells aggregate, changing the blastoderm's shape from circular to pear-shaped. The anterior end of the primitive streak is occupied by an aggregation of primitive node (notochordal) cells, while the rest consists of mesodermal cells, so the primitive streak effectively represents the dorsal and both lateral lips of the blastopore; continuous cell migration between the epiblast and hypoblast forms a groove along the length of the primitive streak (the primitive groove), flanked by thickened primitive ridges, with a special local thickening at the cephalic end called Hensen's node marking the site of a specialised type of invagination. Shortly after the primitive streak forms and the endoderm is established, cells migrate inward from Hensen's node to form the rod-like notochord in the midline beneath the ectoderm; from Hensen's node, dorsal mesoderm is also organised into somites (seen in 25-26 hour embryos as compact cell masses lateral to the neural folds), while the lateral plate mesoderm splits into somatic and splanchnic mesoderm layers separated by the coelom.

Neurulation begins on the dorsal surface of the gastrula, over the notochord, where a band of presumptive neural ectoderm thickens to form the neural plate as the gastrula elongates; by 21-22 hours, longitudinal folding establishes the neural groove in the mid-dorsal line, flanked by neural folds, and by 24 hours this folding is clearly visible, with the embryo now termed a neurula. The anterior end of the neural groove, the widest part, forms the future brain, while the rest becomes the future spinal cord; the neural plate sinks as the neural folds grow toward one another, meet in the mid-dorsal line, fuse, and convert the neural groove into the neural tube (with small anterior and posterior neuropore openings at each end that close later), giving rise to the central nervous system and enclosing a cavity called the neurocoel - this entire process is called neurulation.

Mechanisms of Development: The Roles of Nucleus and Cytoplasm

A single-celled zygote develops into a multicellular individual using the complete genetic information present in its chromosomes, inherited from egg and sperm; during cleavage, every resulting cell receives a full set of chromosomes and complete genetic instructions, yet during differentiation some genes remain active while others switch off. Classic experiments revealed the relative roles of nucleus and cytoplasm in this process. In 1892, Hans Driesch separated a two-celled sea urchin embryo into two individual cells, and both halves developed into normal larvae, showing that each cell contained all the genetic information of the original zygote. Spemann divided a salamander zygote with a fine hair ligature into two halves, one containing the nucleus and one without; cleavage proceeded normally only in the nucleated half until, at the 16-cell stage, one nucleus crossed the narrow cytoplasmic bridge into the anucleate half, which then immediately began dividing too, showing that a nucleus was essential for cleavage to begin in any cytoplasm. In a further experiment, Spemann separated two nucleated halves of an embryo and found both developed into complete embryos (even a single cell from a 16-cell embryo could form a complete embryo), but occasionally a nucleated half developed only into an unorganised mass, and this was traced to the presence or absence of the grey crescent, a pigment-free



area appearing at fertilization; halves lacking the grey crescent failed to develop further, from which Spemann concluded that all cells contain identical nuclear information, but the cytoplasm of the grey crescent region contains information essential for development.

Because all cells share the same nuclear information, differentiation must depend on how cells become committed to different developmental fates, which occurs through cytoplasmic segregation of determinants during cleavage and through induction, or interaction with neighbouring cells. The role of cytoplasm was demonstrated in the ascidian egg, whose cytoplasm of five different colours segregates into different blastomeres during cleavage, with clear cytoplasm producing larval epidermis, yellow cytoplasm producing muscle cells, grey vegetal cytoplasm producing gut, and grey equatorial cytoplasm producing notochord and neural tube. The role of the nucleus itself was shown in the multicellular alga *Acetabularia*, which has a single nucleus in its rhizoid, a long stalk, and an umbrella-shaped cap whose shape differs between species (*A. mediterranea* has a regular cap, *A. crenulata* an irregular one); Haemmerling grafted a rhizome (containing the nucleus) of one species onto the stalk of another, and found that the regenerated cap always matched the species of the nucleus, not the cytoplasm/stalk, proving that the nucleus determines cap structure regardless of which species' cytoplasm surrounds it. Together, these experiments established that the nucleus contains all the genes determining an individual's characteristics, while the cytoplasm plays the role of selectively activating specific genes.

Concept of Differentiation and Embryonic Induction

A fertilized egg contains cytoplasmic components unequally distributed within it, believed to carry morphogenetic determinants controlling the function of specific cell types, a process now called differentiation; although the zygote contains complete information for developing an individual, understanding exactly how cells differentiate required further experimentation. Spemann investigated this using amphibian embryos: when he removed a piece of ectoderm from a frog embryo and grew it separately, the embryo it came from developed a defective nervous system while the isolated ectoderm piece developed no structures at all, despite remaining healthy; in a further experiment, separating the mesoderm underlying the ectoderm and then folding the ectoderm flap back onto its original position also resulted in no nervous system forming, proving that the underlying mesoderm has a specific inductive effect on the overlying ectoderm, stimulating it to form nervous tissue.

The capacity of some cells to evoke a specific developmental response in others is a widespread phenomenon called embryonic induction, first reported by Hans Spemann and Hilde Mangold in 1924. They removed a piece of dorsal blastopore lip from one salamander gastrula and transplanted it into the ventral or lateral position of a second gastrula; this transplanted tissue invaginated and developed into a notochord and somites, and remarkably also induced the surrounding host tissue to form a complete second neural tube and nervous system at the graft site, so that the resulting embryo carried both a normal and an induced (secondary) nervous system. Because only cells from the dorsal blastopore lip (corresponding to the presumptive notochord, somites, and prechordal plate) were capable of this effect, Spemann designated this region the primary organizer, and the phenomenon itself became known as primary induction.



Aging

Aging is an inevitable, ongoing process, defined as the negative physiological changes that accumulate in the body over time; signs of old age, not all of which need be present in any individual, include loss of hair pigment, development of small pigmented skin areas on the face and arms, dryness and wrinkling of skin, loss of agility, weight gain due to fat, poor vision, forgetfulness, general weakness and decreased immunity, alongside degeneration of specific organs and tissues, such as cartilage degeneration causing arthritis in joints, or degeneration of elastic tissue in blood vessel walls causing arteriosclerosis and coronary blood clotting. The exact mechanism of aging remains unknown, but several contributing factors are recognised: cells have only a finite number of possible mitotic divisions, so tissues such as the nervous system show fewer cells and declining mental activity and memory in old age once this limit is approached; intracellular substances change with age, such as collagen developing increased cross-linkages and elastic tissue losing elasticity, causing hardening and loss of resilience in connective tissue and cartilage; and spontaneous mutations may cause progressive cell loss and tissue degeneration.

The process of aging can be slowed through better nutrition and living conditions, such as regular meals, regular exercise, adequate sleep, avoiding smoking, and maintaining an ideal weight, which together can prolong life by an average of 11 years. Gerontology, the study of aging, has become an area of great interest as the number of older individuals rises: the human lifespan is judged to have a maximum of about 120-125 years, and the present goal of gerontology is not necessarily to increase overall lifespan but to increase health span, the period of life spent in good health.

Regeneration and Abnormal Development

Regeneration is the ability to regain or recover a lost or injured part of the body. Sponges, due to their simple organisation, show great regenerative power, with any piece of the body capable of growing into a complete sponge, though the process is very slow, taking months or years; other examples include a lobster regenerating a lost pincer claw, a starfish's central disc (and sometimes its detached arm pieces) developing into complete new individuals, an earthworm regenerating a removed head, and salamanders readily regenerating limbs throughout life (more rapidly when young), as well as lizards regenerating a discarded tail. Healing of a bone fracture and repair of a skin wound are further, more familiar, examples of regeneration; in plants, regeneration underlies plant propagation, since almost any part or fragment, even a single tissue cell, can develop into a full plant. During regeneration, missing cell types are typically replaced by differentiation of unspecialised reserve cells (such as neoblasts in flatworms and planaria, which migrate to the amputation site and differentiate into needed cell types), while in organisms such as salamanders, specialised cells near the wound instead dedifferentiate (become less specialised) before redifferentiating into the needed cell types.

Abnormal development, studied by the branch of biology called teratology, occurs when normal developmental processes are disturbed by inherited abnormalities, chromosomal or genetic defects, environmental factors, or metabolic defects. Inherited abnormalities arise from defective genes, including genes on sex chromosomes (as in haemophilia, which affects



mainly males), depending on whether the gene is dominant or recessive and homozygous or heterozygous; chromosomal abnormalities arise when a sex chromosome is missing or extra, producing syndromes such as Klinefelter's syndrome (XXY, a trisomy) or Turner's syndrome (XO, a monosomy), or the XYY condition, associated with tallness, aggressiveness, and antisocial behaviour. Environmental factors causing abnormal development are called teratogens, including ionizing radiation (such as X-rays, which damage or mutate genes in developing gametes), nutritional deficiencies (of vitamins or trace elements), and toxins or drugs ingested by the mother, all of which can affect foetal tissue differentiation and, in severe cases, cause foetal death; metabolic defects during organogenesis can cause an organ or body part to be missing, duplicated, or malformed, producing conditions such as microcephaly (an abnormally small skull) or cleft palate/harelip.

Important Definitions

Term	Definition
Growth	The permanent and irreversible increase in size that occurs as an organism matures.
Meristem	A young tissue or group of cells, located at growing points such as root and shoot tips, that retains the capacity for continued cell division.
Apical dominance	The phenomenon in which the actively growing apical bud, through auxin, suppresses the growth of lower axillary (lateral) buds.
Gastrulation	The stage of early embryonic development characterised by extensive movement and rearrangement of cells to form the germ layers.
Neurulation	The process by which the neural plate folds and fuses to form the neural tube, giving rise to the central nervous system.
Embryonic induction	The capacity of one group of cells (the organizer) to evoke a specific developmental response in an adjacent group of cells.
Aging	The inevitable, progressive accumulation of negative physiological changes in the body over time.
Regeneration	The ability of an organism to regain or recover a lost or injured part of its body.

Key Facts

Item	Fact
Optimum growth temperature	Optimum temperature for maximum plant growth is 25-30°C; growth is minimal at 5-10°C and stops (may be fatal) above 35-40°C.
Cell elongation increase	During elongation, cell volume can increase up to 150-fold due to water uptake.
Chick incubation temperature and hatching	Artificial incubators are regulated at 36-38°C; the chick hatches on the 21st day of incubation.
Somite appearance in chick	Somites are seen in chick embryos at 25-26 hours of development.



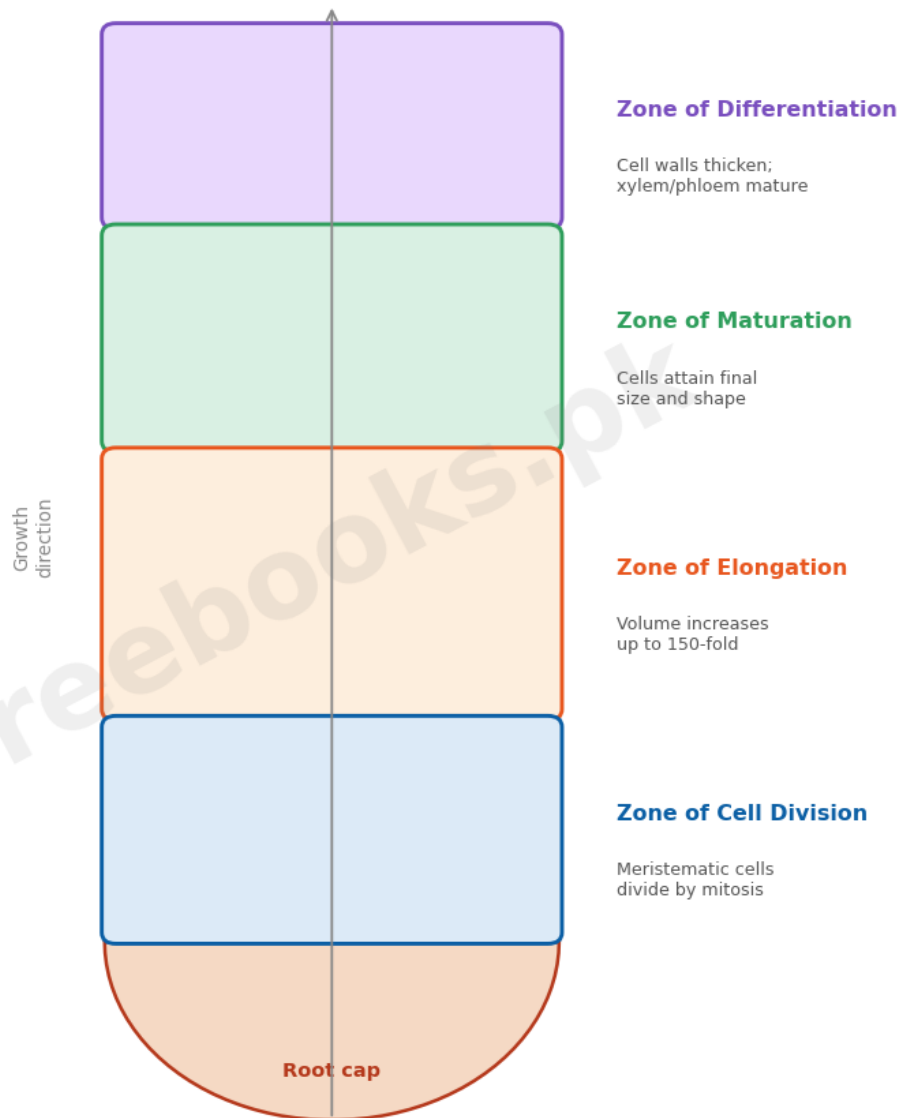
Item	Fact
Neurula stage timing	The neural groove is established by 21-22 hours; folding is clearly visible by 24 hours (the embryo is then called a neurula).
Effect of healthy habits on lifespan	Regular meals, exercise, adequate sleep, no smoking and ideal weight can prolong life by an average of 11 years.
Human lifespan limit	The human lifespan is judged to have a maximum of about 120-125 years.
Klinefelter's and Turner's syndromes	Klinefelter's syndrome = XXY (trisomy); Turner's syndrome = XO (monosomy of a sex chromosome).

Diagrams & Illustrations

Zones of Growth in a Root Tip: a labelled longitudinal diagram of a root tip showing the root cap and the four zones of growth: cell division, elongation, maturation and differentiation.



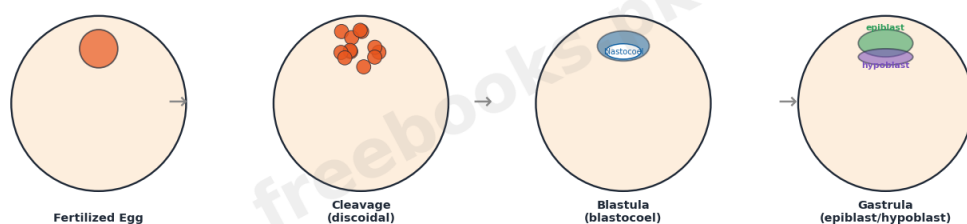
Zones of Growth in a Root Tip



Zones of Growth in a Root Tip

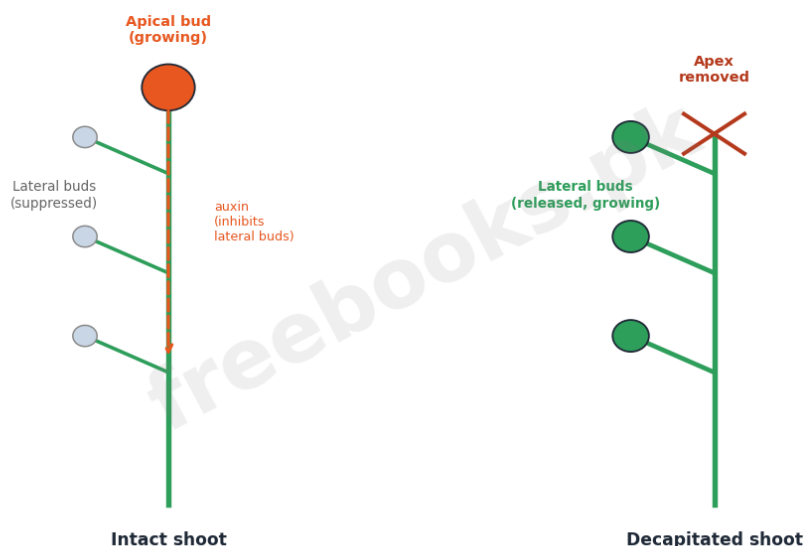
Early Chick Development: Cleavage to Gastrulation: a simplified schematic showing the progression of early chick development from the fertilized egg through cleavage, morula, blastula (with blastocoel) to the gastrula stage (epiblast and hypoblast layers).

Early Chick Development: Cleavage to Gastrulation



Apical Dominance: The Influence of Auxin: a diagram comparing an intact shoot (apical bud growing, lateral buds suppressed by auxin diffusing downward) with a decapitated shoot (apex removed, lateral buds released and growing).

Apical Dominance: The Influence of Auxin



Apical Dominance: The Influence of Auxin

Short Questions & Answers

Q1. Differentiate apical, intercalary and lateral meristems.

Ans. Apical meristems occur at root and shoot tips and drive primary growth (length); intercalary meristems are temporary, separated portions of apical meristem at the base of internodes, involved in leaf and flower production; lateral meristems (vascular and cork cambium) are cylinders of dividing cells in dicots/gymnosperms responsible for secondary growth (increase in diameter).

Q2. What is apical dominance, and how did Thimann and Skoog explain it?

Ans. Apical dominance is the suppression of lateral (axillary) bud growth by the actively growing apical bud; Thimann and Skoog (1934) showed it is caused by auxin diffusing down from the apical bud, inhibiting lateral buds (inhibitory effect), while removing the apex releases lateral buds from this inhibition (compensatory effect).

Q3. Differentiate the epiblast and hypoblast layers formed during chick gastrulation.

Ans. The epiblast is the upper layer of the blastoderm, mainly presumptive ectoderm and mesoderm; the hypoblast is the lower layer, mainly presumptive endoderm, which grows outward and downward over the yolk to form the endodermal lining of the yolk sac.

Q4. What did Hans Driesch's sea urchin experiment demonstrate about the nucleus?



Ans. Driesch separated a two-celled sea urchin embryo into individual cells and found both developed into normal larvae, demonstrating that each cell contained a complete, identical set of genetic information from the original zygote.

Q5. What is embryonic induction, and who first demonstrated it?

Ans. Embryonic induction is the capacity of one group of cells to evoke a specific developmental response in adjacent cells; it was first demonstrated by Hans Spemann and Hilde Mangold (1924), who showed that a transplanted dorsal blastopore lip could induce formation of a second nervous system in a host salamander embryo.

Q6. Differentiate Klinefelter's syndrome and Turner's syndrome.

Ans. Klinefelter's syndrome (XXY) is a trisomy of the sex chromosomes, occurring in males with an extra X chromosome; Turner's syndrome (XO) occurs in females missing one of their two X chromosomes (monosomy).

Long Questions & Answers

Q1: Describe the four phases of plant growth and the external factors that influence plant growth rate.

The growth of a multicellular plant proceeds through four distinct, sequential phases, each with characteristic cellular activity. The first phase, cell division, occurs at the very tips of the root and shoot, where cells are small, contain centrally positioned spherical nuclei, and have non-vacuolated cytoplasm; here the number of cells increases through repeated mitosis, and each daughter cell begins synthesising new cytoplasm and cell wall material in preparation for the next phase. A short distance back from the apex, typically only a few millimetres, lies the second phase, the zone of elongation, where cells dramatically increase in volume, by as much as 150-fold, largely due to the uptake of water; this rapid expansion is made possible by an increase in the plasticity of the cell wall and a corresponding decrease in wall pressure, while synthesis of new cytoplasm and wall material continues throughout. In the third phase, maturation, cells attain their final size appropriate to their eventual tissue type: cells destined to become pith, cortex, or similar tissues cease elongating along the plant's axis, while other cell types, notably fibres and tracheids, continue to elongate lengthwise considerably more than in other directions, establishing their characteristic elongated shape. Finally, once cell enlargement has ceased entirely, the fourth phase, differentiation, begins: cell walls thicken and in many cases become pitted, distinctive thickening patterns appear on the walls of xylem vessels, and cells belonging to different tissues increasingly diverge in their spatial dimensions and develop the specific new structural features required for their final specialised function. This entire four-phase sequence is, in turn, strongly influenced by a range of external environmental factors. Temperature affects growth rate across a working range of roughly 0 to 35 degrees Celsius, with growth rate generally rising as temperature increases and falling as it decreases, reaching an optimum at 25 to 30 degrees Celsius, becoming minimal at 5 to 10 degrees Celsius, and ceasing altogether (potentially fatally to the plant) at very high temperatures of 35 to 40 degrees Celsius. Light influences growth through three distinct properties: its intensity (with greater light intensity increasing the rate of cell division), its quality or wavelength (red light specifically favours cell elongation, blue



light enhances cell division while simultaneously retarding cell enlargement, and ultraviolet light retards elongation), and its duration, which affects the growth of both vegetative and reproductive structures and plays a central role in inducing or suppressing flowering, a phenomenon known as photoperiodism. Beyond light and temperature, a regular supply of oxygen is essential, since no metabolic activity and hence no growth is possible without it, although an excessively high oxygen supply can actually inhibit growth; carbon dioxide is likewise essential for the photosynthesis that ultimately powers growth, yet becomes growth-retarding at very high concentrations; water enables the cell elongation central to the growth process by allowing cells to take up water and expand, with growth ceasing entirely in its absence; and adequate nutrition supplies the energy required for continued growth, so that increasing nutrient availability increases growth while decreasing it causes growth retardation.

Q2: Describe Spemann and Mangold's primary organizer experiment and explain its significance for understanding embryonic induction.

Embryonic induction refers to the widespread developmental phenomenon in which certain cells possess the capacity to evoke a specific developmental response in neighbouring cells, and this phenomenon was first rigorously demonstrated through a landmark experiment reported by Hans Spemann and Hilde Mangold in 1924, using salamander embryos at the gastrula stage of development. Working with two separate salamander gastrula embryos, they carefully excised a small piece of tissue from the dorsal lip of the blastopore of the first embryo, a region known to correspond to the presumptive fate map area destined to form the notochord, the somites, and the prechordal plate, and then surgically transplanted this excised piece of dorsal blastopore lip tissue into a distinctly different location, the ventral or lateral position, of a second, separate host salamander gastrula. Once transplanted into its new position, the grafted tissue behaved remarkably in two related ways simultaneously: first, true to its own original developmental fate, it invaginated into the host embryo exactly as it would have in its original location, and proceeded to differentiate autonomously into a proper notochord and associated somites, exactly as programmed by its cell-autonomous determinants. Second, and far more strikingly, this same grafted tissue additionally induced the surrounding host tissue, tissue that under normal circumstances would never have contributed to forming any part of a nervous system, to itself organise and form an entirely new, complete neural tube, effectively assembling a second, fully formed nervous system at the ectopic site of the graft. The resulting experimental embryo was therefore left possessing both its own original, normal nervous system in its usual anatomical position, together with this entirely separate, secondary induced nervous system that had formed specifically around and in response to the transplanted graft tissue, combining both the directly grafted donor tissue and the newly induced host tissue into one composite structure. Through further careful experimentation, Spemann and Mangold established that this remarkable inductive capacity was not a general property shared by tissue from just anywhere in the donor embryo, but was instead a highly specific property belonging exclusively to cells originating from the dorsal lip of the blastopore, corresponding precisely to the presumptive areas of the notochord, the somites, and the prechordal plate. On the basis of this specificity, Spemann designated this uniquely powerful dorsal lip region the primary organizer, recognising it as the only tissue in the entire embryo capable of inducing the development of



a complete secondary embryonic axis when transplanted into a host, and the overall phenomenon this experiment revealed became known more broadly as primary induction. The experiment's significance for developmental biology was profound: it provided the first clear, direct experimental proof that embryonic development is not simply a matter of each cell autonomously executing its own predetermined genetic programme in isolation, but instead depends critically on ongoing inductive signalling and interaction between different groups of cells within the developing embryo, establishing embryonic induction as one of the central organising principles underlying how complex, correctly patterned multicellular organisms are able to reliably assemble themselves from a single fertilized egg.

MCQs with Answers

1. Meristems responsible primarily for increase in length (primary growth) are located at the:

(a) base of internodes (b) root and shoot tips (apical) (c) vascular cambium only (d) cork cambium only

Correct Answer: (b) root and shoot tips (apical). Apical meristems, found at root and shoot tips, are primarily responsible for primary growth (increase in length).

2. During which phase of plant growth does cell volume increase up to 150-fold due to water uptake?

(a) cell division (b) elongation (c) maturation (d) differentiation

Correct Answer: (b) elongation. During the elongation phase, cell volume increases up to 150-fold as water is taken up and wall plasticity increases.

3. Apical dominance, in which the apical bud suppresses lateral bud growth, is primarily caused by:

(a) gibberellin (b) auxin diffusing from the apical bud (c) cytokinin alone (d) ethylene

Correct Answer: (b) auxin diffusing from the apical bud. Thimann and Skoog (1934) showed apical dominance is caused mainly by auxin diffusing down from the apical bud, inhibiting lateral bud growth.

4. In chick development, the type of cleavage confined to a small disc of protoplasm on the yolk surface is called:

(a) holoblastic cleavage (b) discoidal cleavage (c) radial cleavage (d) spiral cleavage

Correct Answer: (b) discoidal cleavage. Bird eggs undergo discoidal cleavage, confined to the disc of protoplasm (blastoderm) at the animal pole, rather than dividing the whole yolk.

5. The fluid-filled cavity characteristic of the blastula stage in the chick is called the:

(a) neurocoel (b) coelom (c) blastocoel (d) archenteron

Correct Answer: (c) blastocoel. The blastula is characterized by the blastocoel, a segmentation cavity beneath the discoidal blastoderm.

6. Hans Driesch's sea urchin experiment (1892), in which a two-celled embryo was separated into individual cells, demonstrated that:



(a) only one cell contains genetic information (b) each cell contains all the genetic information of the zygote (c) cytoplasm alone controls development (d) cleavage cannot occur without both cells together

Correct Answer: (b) each cell contains all the genetic information of the zygote.

Both separated cells developed into normal larvae, showing each contained the complete genetic information of the original zygote.

7. In Haemmerling's Acetabularia grafting experiment, the shape of the regenerated cap was determined by the:

(a) cytoplasm/stalk species (b) nucleus (rhizome) species (c) amount of light received (d) age of the alga

Correct Answer: (b) nucleus (rhizome) species. The regenerated cap always matched the species of the grafted nucleus-containing rhizome, proving the nucleus determines cap structure.

8. The tissue Spemann designated the 'primary organizer', capable of inducing a secondary nervous system when transplanted, is the:

(a) ventral ectoderm (b) dorsal blastopore lip (c) yolk sac endoderm (d) notochord of the host only

Correct Answer: (b) dorsal blastopore lip. Spemann and Mangold identified the dorsal blastopore lip as the primary organizer, uniquely capable of inducing formation of a secondary embryonic axis.

9. Klinefelter's syndrome, a trisomy of the sex chromosomes, has the genotype:

(a) XO (b) XYY (c) XXY (d) XXX

Correct Answer: (c) XXY. Klinefelter's syndrome is XXY, a trisomy condition affecting males with an extra X chromosome.

10. The branch of biology that studies abnormal development and its causes is called:

(a) gerontology (b) embryology (c) teratology (d) cytology

Correct Answer: (c) teratology. Teratology is the branch of biology dealing with abnormal development and its causes (teratogens).

Quick Revision Summary

- Plant growth: Open growth (continuous, non-uniform rate). Meristems: Apical (tips, primary growth/length) | Intercalary (internode base, temporary, leaves/flowers) | Lateral (vascular/cork cambium, secondary growth/width). 4 growth phases: cell division -> elongation (up to 150x volume) -> maturation -> differentiation.
- Growth conditions: External (temperature 25-30°C optimum, light intensity/quality/duration, O₂, CO₂, water, nutrition) + Internal (hormones e.g. IAA, vitamins). Growth correlation: Apical dominance = auxin from apical bud inhibits lateral buds (Thimann & Skoog 1934); cytokinin can release inhibition. Commercial use: auxin on potato eyes prevents sprouting (storage 1->3 years).
- Chick development sequence: Fertilization (internal, in oviduct) -> Cleavage (discoidal, 21 days to hatch @ 36-38°C) -> Morula -> Blastula (blastocoel, blastoderm) -> Gastrulation (epiblast=ectoderm+mesoderm; hypoblast=endoderm);



area pellucida vs area opaca) -> Primitive streak/Hensen's node -> Notochord + somites (25-26h) -> Neurulation (neural plate -> neural groove -> neural tube, 21-24h) = CNS forms.

- Nucleus vs cytoplasm experiments: Driesch (1892, sea urchin, 2-cell separation) = each cell has full genetic info. Spemann (salamander hair ligature) = nucleus needed to start cleavage; grey crescent cytoplasm essential for development. Ascidian egg = 5 cytoplasm colors -> different tissues (cytoplasmic determinants). Haemmerling (Acetabularia graft) = nucleus determines structure, not cytoplasm/stalk species.
- Differentiation: unequal cytoplasmic determinants + induction (neighboring cell interaction). Embryonic induction: Spemann & Mangold 1924, dorsal blastopore lip transplant -> induces 2nd nervous system = 'primary organizer' / 'primary induction'.
- Aging: irreversible negative physiological changes (finite mitotic divisions, collagen cross-linking, mutations). Slowed by good nutrition/exercise/sleep/no smoking (+11 yrs avg). Max human lifespan ~120-125 yrs. Gerontology = study of aging; goal = increase health span.
- Regeneration: sponges (slow, whole body), lobster claw, starfish arm/disc, earthworm head, salamander limb (best when young), lizard tail. Mechanism: neoblasts (planaria) or dedifferentiation (salamander). Abnormal development (teratology): inherited genes, chromosomal (Klinefelter's XXY, Turner's XO, XYY), teratogens (radiation, nutrition deficiency, drugs), metabolic defects (microcephaly, cleft palate). Notes by freebooks.pk.

Exam Tips

- Build a simple 3-row table for meristem types (apical/intercalary/lateral) with location + growth type (primary vs secondary) - this comparison is asked almost every year.
- Memorise the four growth phases in strict order (division -> elongation -> maturation -> differentiation) with one key fact per phase (especially the 150-fold volume increase in elongation) since sequence questions are common.
- Learn apical dominance as a cause-effect chain: auxin from apex -> inhibits lateral buds -> remove apex -> auxin gone -> lateral buds grow (compensatory effect). Also remember the potato-tuber commercial application.
- Sequence chick development as a clean numbered list (fertilization -> cleavage -> morula -> blastula -> gastrulation -> primitive streak -> notochord/somites -> neurulation) - long questions often ask to 'describe in detail'.
- Pair each classic development experiment with its one-line conclusion (Driesch = each cell has full genome; Spemann hair ligature = nucleus needed for cleavage + grey crescent essential; Haemmerling = nucleus controls structure) rather than memorising procedural detail alone.
- Keep 'embryonic induction' and 'primary organizer' as one linked fact: dorsal blastopore lip = primary organizer, and its induction of a second nervous system when transplanted = primary induction (Spemann & Mangold, 1924).



- For abnormal development, group causes into exactly four categories (inherited genes, chromosomal, environmental/teratogens, metabolic defects) with one named example condition for each - this structure directly matches how exam questions are framed.

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FSc Part-II Biology — Punjab Board

CHAPTER 20

Chromosomes and DNA

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

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This chapter covers Chromosomes and DNA from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Chromosomes are thread-like structures that appear inside the nucleus at cell division, first observed by Walther Flemming in 1882; found in all eukaryotic cells, their number varies widely between species (humans have 46, in 23 pairs), and each chromosome carries hundreds or thousands of genes essential for normal development and survival. These notes are prepared by freebooks.pk.

The chapter covers chromosome structure and composition, the chromosomal theory of inheritance (Sutton, Morgan), the classic experiments proving DNA is the hereditary material (Griffith, Avery-MacLeod-McCarty, Hershey-Chase), the chemical nature and double helical structure of DNA (Levene, Chargaff, Franklin, Watson and Crick), semi-conservative DNA replication (Meselson-Stahl) and the replication process, the concept of the gene (Garrod, Beadle and Tatum's one gene/one polypeptide hypothesis), the central dogma of gene expression (transcription, the genetic code, and translation), and mutations.

Learning Objectives

- Describe the structure, composition and types of chromosomes, and explain karyotype.
- Describe the chromosomal theory of inheritance and the evidence provided by Sutton and Morgan.
- Describe the classic experiments (Griffith, Avery, Hershey-Chase) that established DNA as the hereditary material.
- Describe the chemical composition and double helical structure of DNA (Levene, Chargaff, Franklin, Watson and Crick).
- Explain semi-conservative DNA replication and the Meselson-Stahl experiment, and describe the replication process.
- Explain the concept of a gene using Garrod's and Beadle and Tatum's work (one gene/one polypeptide hypothesis).
- Describe the central dogma of gene expression: transcription, the genetic code, and translation.
- Describe the types and significance of mutations.

Key Concepts

Chromosome Structure, Composition and the Chromosomal Theory of Inheritance

Chromosomes are thread-like structures that appear inside the nucleus at cell division, first observed by the German embryologist Walther Flemming in 1882 in dividing salamander larvae cells; found in all eukaryotes, their number varies widely between species (Penicillium has one pair, some ferns over 500 pairs, mosquito 6, honeybee 32, corn 20, sugarcane 80, frog 26, mouse 40, and humans 46, in 23 pairs), and each carries hundreds or thousands of genes essential for normal development, so losing part or all of a chromosome has serious, often fatal, consequences. A typical chromosome consists of chromatids, a centromere



(primary constriction), and a secondary constriction; chromosomes vary in size, staining properties, centromere position, and arm length, and the particular array of chromosomes an individual possesses is called its karyotype. Based on centromere position, chromosomes are classified as telocentric, acrocentric, submetacentric or metacentric, and acquire characteristic I, J or V shapes at anaphase during cell division. Chromosomes are composed of roughly 40% DNA and 60% protein, with associated RNA (since they are sites of RNA synthesis); a typical human chromosome's DNA contains about 140 million nucleotides and would measure about 5 centimetres if stretched out, yet is tightly coiled to fit inside the nucleus. Every 200 nucleotides, DNA coils around a core of eight positively charged histone proteins to form a nucleosome (resembling a string of beads), with further coiling into supercoils; permanently condensed, non-expressed chromatin is called heterochromatin, while chromatin that condenses only during cell division (and is otherwise open and expressible) is called euchromatin.

A central role for chromosomes in heredity was first suggested in 1900 by Karl Correns, and the chromosomal theory of inheritance was formulated in 1902 by Walter Sutton, based on evidence that gametes (with little cytoplasm) must carry hereditary material in their nuclei, that diploid individuals have two copies of each chromosome (matching Mendel's model of two gene copies) while gametes have one, and that chromosome pairs segregate and assort independently during meiosis, just as Mendelian traits do. A puzzle remained: organisms show far more independently assorting traits than chromosome pairs. In 1910, Thomas Hunt Morgan, studying the fruit fly *Drosophila melanogaster*, found a mutant white-eyed male; crossing it with a normal red-eyed female produced all red-eyed F1 offspring, but crossing F1 flies together produced F2 offspring in which all white-eyed flies were male, an unexpected result unexplained by simple Mendelian theory. A test cross of F1 females with the original white-eyed male produced a 1:1:1:1 ratio of white and red-eyed males and females, showing white-eyed females could exist; the explanation was that the white-eye gene resides only on the X chromosome (absent from Y), making it sex-linked - a trait determined by a gene on the X chromosome. This experiment provided the first clear evidence that Mendelian genes reside on chromosomes, confirming the chromosomal theory of inheritance.

DNA as Hereditary Material: Griffith, Avery, and Hershey-Chase

The first evidence of DNA's hereditary role came from British microbiologist Frederick Griffith, working with *Streptococcus pneumoniae*. The virulent S strain (smooth colonies, polysaccharide coat) killed infected mice, while the mutant R strain (rough colonies, no coat) did not; dead S bacteria alone were harmless, but a mixture of dead S bacteria and live, harmless R bacteria killed the mice, and live virulent S bacteria were recovered from their blood. Griffith concluded that genetic information specifying the polysaccharide coat had passed from the dead S bacteria to the living R bacteria, permanently transforming them into the virulent S form - a process he called transformation, the transfer of genetic material between cells altering the recipient's genetic makeup. The identity of the 'transforming principle' remained unknown until 1944, when Oswald Avery, Colin MacLeod and Maclyn McCarty purified Griffith's transforming material to 99.98% protein-free purity without any loss of transforming activity; protein- and RNA-digesting enzymes had no effect on this



activity, but the DNA-digesting enzyme DNase destroyed it completely, identifying DNA as the transforming principle.

Further confirmation came in 1952 from Alfred Hershey and Martha Chase, working with bacteriophage T2 viruses. They labelled viral DNA with radioactive phosphorus (^{32}P) in one experiment and viral protein coats with radioactive sulphur (^{35}S) in another; after infecting bacteria and violently agitating the mixture to strip off the empty protein coats, nearly all the ^{35}S label was removed from the bacteria, while the ^{32}P label had entered the bacterial cells and was later found in the next generation of viruses. This proved that the hereditary information transmitted into the bacteria to direct new virus production was DNA, not protein, providing strong independent confirmation of Avery's earlier conclusion.

Chemical Nature and Double Helical Structure of DNA

DNA was first discovered in 1869 by German chemist Friedrich Miescher, who extracted a substance he called 'nuclein' (later 'nucleic acid') from cell nuclei and fish sperm; its function remained unknown for 50 years. In the 1920s, biochemist P.A. Levene determined that DNA contains three components - phosphate groups, five-carbon sugars, and nitrogen-containing bases (purines adenine and guanine; pyrimidines thymine and cytosine, with uracil replacing thymine in RNA) - joined into repeating units called nucleotides, in which the base attaches to carbon 1 of the sugar and phosphate to carbon 5, with a free hydroxyl group at carbon 3; the 5' phosphate and 3' hydroxyl groups allow nucleotides to join via phosphodiester bonds (formed by dehydration synthesis) into long chains, always leaving a free 5' phosphate at one end and a free 3' hydroxyl at the other. Erwin Chargaff later showed that in any DNA sample, the amount of adenine always equals thymine, and guanine always equals cytosine, so purines (A+G) and pyrimidines (C+T) occur in equal proportion, a pattern later called Chargaff's rule.

The significance of Chargaff's rule became clear when British chemist Rosalind Franklin, working in Maurice Wilkins's laboratory, produced an X-ray diffraction pattern of DNA fibres, revealing a helical structure with a diameter of 2 nm and a complete turn every 3.4 nm. Learning informally of Franklin's results before their 1953 publication, James Watson and Francis Crick at Cambridge University rapidly worked out the now-accepted DNA structure: a double helix of two antiparallel strands (one running 3' to 5', the other 5' to 3'), with bases pointing inward and pairing such that a large purine always pairs with a small pyrimidine, keeping the helix diameter constant at 2 nm; adenine forms two hydrogen bonds with thymine, and guanine forms three hydrogen bonds with cytosine (explaining Chargaff's equal A=T and G=C ratios), with base pairs stacked 0.34 nm apart, stabilised by hydrophobic interactions.

Semi-conservative DNA Replication and the Meselson-Stahl Experiment

The Watson-Crick model immediately suggested that DNA replication relies on complementarity: if the double helix is 'unzipped,' each exposed single strand can serve as a template for assembling a new complementary strand, producing two daughter duplexes each identical in sequence to the original. This mechanism, in which each daughter duplex contains one original (parental) strand and one newly synthesised strand, is called semi-



conservative replication, since the original sequence is conserved but the original duplex itself is not (its two strands separate to form parts of two different new duplexes). Two rival hypotheses were also proposed: the conservative model, in which the original duplex would remain fully intact and generate an entirely separate new duplex, and the dispersive model, in which each strand of every daughter molecule would be a patchwork mixture of old and new DNA.

These three hypotheses were tested in 1958 by Matthew Meselson and Franklin Stahl. They grew bacteria in a medium containing heavy nitrogen (^{15}N), labelling their DNA, then transferred the bacteria to a medium with normal, lighter nitrogen (^{14}N) and collected DNA samples at intervals, separating them by density using cesium chloride density-gradient ultracentrifugation. DNA collected immediately after transfer was uniformly dense (all ^{15}N); after one round of replication in ^{14}N medium, all the DNA had an intermediate density; after a second round, two density classes appeared, one intermediate and one matching pure ^{14}N DNA. This pattern was exactly as predicted by semi-conservative replication: after the first round, every daughter duplex is a hybrid of one heavy and one light strand, and when a hybrid duplex itself replicates, it produces one new hybrid duplex and one new fully light duplex, definitively confirming the Watson-Crick model's semi-conservative replication mechanism and ruling out the conservative and dispersive models.

The Replication Process: Enzymes and Mechanism

DNA replication begins at specific origin sequences on the DNA molecule, where DNA polymerase III and associated enzymes catalyse addition of nucleotides to growing complementary strands. Bacteria have three DNA polymerases (I, II and III); DNA polymerase I plays a small supporting role, while DNA polymerase III, a large dimeric enzyme, is the true replicating enzyme, threading DNA through itself at about 1000 nucleotides per second. DNA polymerase III can only extend an existing nucleotide chain already paired with the template, so it cannot initiate synthesis alone; instead, the enzyme primase first constructs a short RNA primer (about 10 nucleotides) complementary to the template, which DNA polymerase III then extends with DNA nucleotides, with the RNA primer nucleotides later replaced by DNA.

DNA polymerase III can only add nucleotides to the 3' end of a strand, so replication always proceeds in the 5' to 3' direction; because the two parental strands are antiparallel, the two new strands must be synthesised differently. The leading strand, elongating toward the replication fork, is synthesised continuously by simply adding nucleotides to its growing 3' end. The lagging strand, elongating away from the replication fork, is synthesised discontinuously as a series of short Okazaki fragments (about 100-200 nucleotides in eukaryotes, 1000-2000 in prokaryotes), each begun with its own RNA primer and synthesised 5' to 3' away from the fork; when DNA polymerase III reaches the previous fragment, DNA ligase joins the fragments together, while the enzyme jumps ahead to begin the next fragment as the DNA continues to unwind.



What Is a Gene? Garrod and the One Gene/One Polypeptide Hypothesis

In 1902, Archibald Garrod and William Bateson found certain diseases clustering in particular families, behaving as simple recessive Mendelian traits; investigating alkaptonuria, in which patients' urine darkens on exposure to air due to accumulated homogentisic acid, Garrod concluded that affected patients lacked the enzyme needed to break this substance down, and speculated that many inherited diseases might reflect similar enzyme deficiencies - implying that chromosomal DNA specifies particular enzymes, though this was not definitively established until 1941. Stanford geneticists George Beadle and Edward Tatum irradiated *Neurospora* (bread mould) spores with X-rays to induce mutations, then grew the progeny on a 'minimal' medium containing only basic nutrients; mutants unable to synthesise a required compound failed to survive unless that specific compound was added back, allowing precise identification of each mutant's biochemical deficiency. Adding arginine, for example, rescued several mutant strains ('arg mutants'), whose mutations clustered at three distinct chromosomal locations, one for each enzyme in the arginine biosynthetic pathway.

Since each enzyme defect traced to a mutation at a single, distinct chromosomal site, Beadle and Tatum concluded that genes act by specifying enzyme structure, with each gene encoding one enzyme - the one gene/one enzyme hypothesis, now more commonly called one gene/one polypeptide, since many enzymes consist of multiple polypeptide subunits each encoded by a separate gene. Since enzymes catalyse the assembly of all cellular components (nucleic acids, proteins, carbohydrates, lipids), DNA's control of enzyme structure ultimately specifies the structure of the organism itself. In 1953, Frederick Sanger sequenced the amino acids of insulin, proving proteins are definable, ordered chains of amino acids; in 1956, Vernon Ingram showed sickle cell anaemia results from a single amino acid change (glutamic acid to valine) in haemoglobin, caused by a single DNA base change (thymine to adenine) - establishing that a gene is the sequence of nucleotides that determines the amino acid sequence of a protein.

Central Dogma: Transcription and the Genetic Code

All organisms follow the same basic mechanism for reading and expressing genes, called the central dogma: genetic information flows from DNA to RNA (transcription) and then from RNA to protein (translation). Transcription begins when RNA polymerase binds a promoter sequence upstream of a gene, then moves along the DNA synthesising a complementary mRNA strand until it reaches a stop signal and releases the newly made RNA; only one DNA strand (the template or antisense strand) is transcribed, while the other (coding or sense strand) matches the mRNA sequence. Prokaryotes have a single RNA polymerase making all three RNA types, while eukaryotes have three: RNA polymerase I (rRNA), II (mRNA), and III (tRNA). In eukaryotes, the newly made mRNA is modified with a 7-methyl-GTP cap at the 5' end and a poly-A tail at the 3' end, protecting it during its journey from nucleus to ribosome and stabilising it against degradation.

There are three major classes of RNA: ribosomal RNA (rRNA), which forms part of the ribosome and provides the site of polypeptide assembly; transfer RNA (tRNA), which transports amino acids to the ribosome and positions them correctly on the growing



polypeptide (humans have about 45 different tRNAs); and messenger RNA (mRNA), transcribed from DNA and carrying the code for protein synthesis to the ribosome. The genetic code consists of three-nucleotide codons, since a two-nucleotide code ($4^2 = 16$ combinations) cannot specify all 20 common amino acids, while a three-nucleotide code ($4^3 = 64$ combinations) provides more than enough; the code was fully determined in the mid-1960s through experiments by Marshall Nirenberg, Philip Leder and Har Gobind Khorana. Of the 64 codons, three (UAA, UAG, UGA) are nonsense/stop codons that terminate translation, while AUG serves as the universal start codon (encoding methionine); the genetic code is nearly universal across all organisms (allowing genes to be transferred between species and still function), though minor exceptions exist in mitochondrial DNA, where, for example, UGA codes for tryptophan rather than acting as a stop codon.

Translation and Mutations

Translation begins when the initial portion of an mRNA binds to a ribosome, exposing one codon at a time at the ribosome's peptidyl (P) site; a tRNA molecule carrying the complementary anticodon and its specific attached amino acid binds each exposed codon in turn, with aminoacyl-tRNA synthetase enzymes (one for each of the 20 amino acids) ensuring each tRNA carries the correct amino acid. Translation begins with formation of an initiation complex, in which a special initiator tRNA carrying methionine binds the small ribosomal subunit at the P site, positioned by initiation factors, before the complex binds the mRNA's AUG start codon; the large ribosomal subunit then joins, and successive aminoacyl-tRNAs bind the exposed codon at the adjacent A (aminoacyl) site, with each new amino acid joined to the growing chain by a peptide bond as the ribosome translocates three nucleotides along the mRNA (5' to 3') for each cycle, shifting the growing chain to the P site and ejecting the spent tRNA at the E (exit) site; elongation continues until a nonsense (stop) codon is reached, which is recognised not by a tRNA but by release factor proteins that free the completed polypeptide from the ribosome.

If the DNA in all cells of an adult human were laid end to end, it would stretch nearly 100 billion kilometres, roughly 60 times the Earth-Jupiter distance, so even small changes (mutations), whether from replication errors or damage to the genetic message, can have significant effects; mutations in somatic cells are not inherited and have limited evolutionary consequence, while mutations in germ-line cells are passed to offspring, providing the raw material for evolutionary change through natural selection. Mutations are broadly classified as chromosomal aberrations, large-scale changes such as an extra or missing chromosome, or structural changes like deletions, insertions or inversions (causing syndromes such as Down's syndrome or Klinefelter's syndrome), and point mutations, small changes affecting only one or a few DNA base pairs, arising either from spontaneous replication errors or from damage by mutagens such as radiation or chemicals. Sickle cell anaemia (a single glutamic acid to valine substitution in haemoglobin) and phenylketonuria (a defective phenylalanine hydroxylase enzyme, causing toxic phenylalanine accumulation and mental retardation if untreated) are classic, well-studied examples of point mutations with serious clinical consequences.



Important Definitions

Term	Definition
Karyotype	The particular array of chromosomes (number, size, shape) that characterizes an individual or species.
Transformation	The transfer of genetic material from one cell to another, altering the genetic makeup of the recipient cell (demonstrated by Griffith).
Semi-conservative replication	The mode of DNA replication in which each daughter duplex contains one original (parental) strand and one newly synthesized strand.
Okazaki fragment	A short DNA segment (100-200 nucleotides in eukaryotes) synthesized discontinuously on the lagging strand during DNA replication.
Gene	The sequence of nucleotides in DNA that determines the amino acid sequence of a protein (or specifies a functional RNA).
Transcription	The process by which an RNA copy of a gene's DNA sequence is synthesized by RNA polymerase.
Translation	The process by which the nucleotide sequence of mRNA is used by ribosomes to direct synthesis of a polypeptide's amino acid sequence.
Point mutation	A mutation involving a change in only one or a few base pairs in the DNA coding sequence.

Key Facts

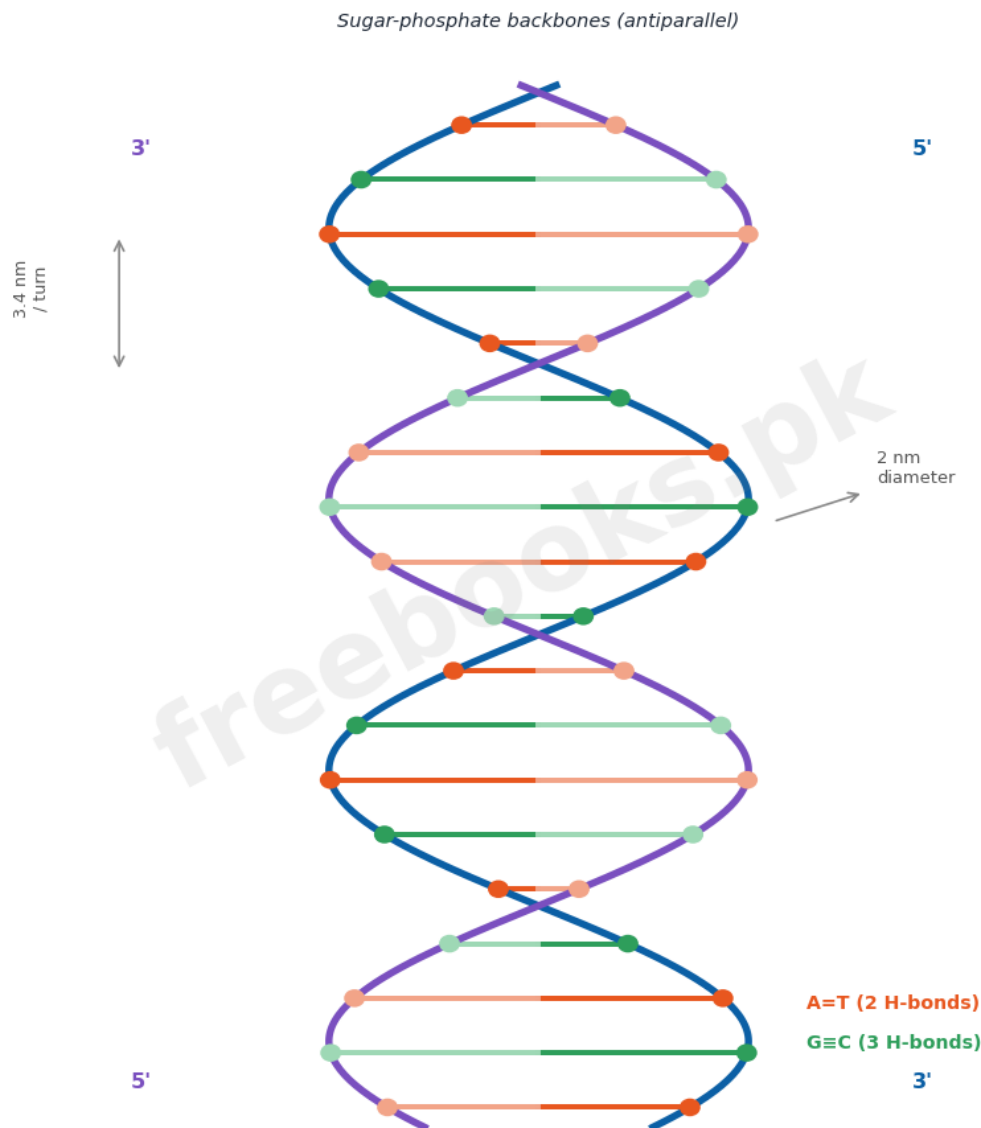
Item	Fact
Human chromosome number	Human cells have 46 chromosomes, in 23 homologous pairs.
DNA content per human chromosome	A typical human chromosome contains about 140 million (1.4×10^8) nucleotides, about 5 cm long if stretched out.
Nucleosome spacing	The DNA duplex coils around a core of 8 histone proteins every 200 nucleotides, forming a nucleosome.
DNA helix dimensions	The DNA double helix has a diameter of 2 nm, with a complete turn every 3.4 nm; base pairs stack 0.34 nm apart.
Base pairing (hydrogen bonds)	Adenine pairs with thymine via 2 hydrogen bonds; guanine pairs with cytosine via 3 hydrogen bonds.
DNA polymerase III speed	DNA polymerase III adds nucleotides at a rate of about 1000 nucleotides per second.
Genetic code	The genetic code is a triplet (3-nucleotide) code; $4^3 = 64$ possible codons specify 20 amino acids, with 3 stop codons (UAA, UAG, UGA) and 1 start codon (AUG = methionine).
tRNA diversity	Human cells contain about 45 different kinds of tRNA molecules.



Diagrams & Illustrations

The Double Helical Structure of DNA: a labelled diagram of the Watson-Crick DNA double helix, showing the antiparallel sugar-phosphate backbones, complementary base pairing (A=T with 2 hydrogen bonds, G≡C with 3 hydrogen bonds), and helix dimensions (2 nm diameter, 3.4 nm per turn).

The Double Helical Structure of DNA

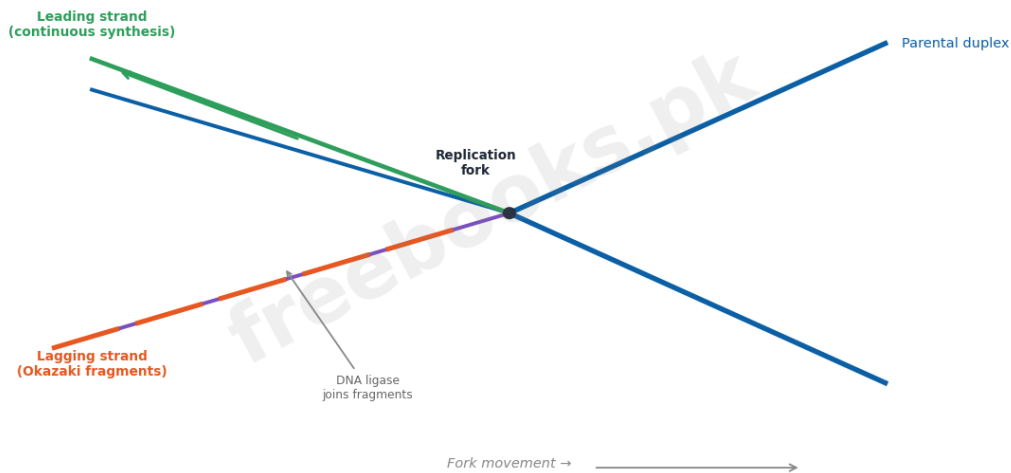


The Double Helical Structure of DNA

The DNA Replication Fork: a labelled diagram of a DNA replication fork showing the leading strand (synthesized continuously toward the fork) and lagging strand (synthesized discontinuously as Okazaki fragments, joined by DNA ligase, away from the fork).



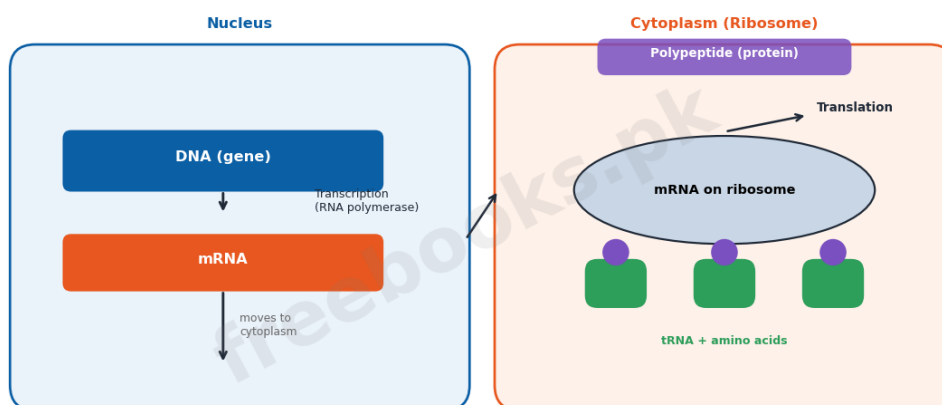
The DNA Replication Fork



The DNA Replication Fork

The Central Dogma: Transcription and Translation: a flow diagram showing the central dogma of gene expression: DNA is transcribed into mRNA (transcription) in the nucleus, and mRNA is translated into a polypeptide chain by ribosomes and tRNA (translation) in the cytoplasm.

The Central Dogma: Transcription and Translation



The Central Dogma: Transcription and Translation

Short Questions & Answers

Q1. What is a karyotype, and what features of chromosomes does it describe?

Ans. A karyotype is the particular array of chromosomes an individual or species possesses; it describes chromosome number, size, staining properties, centromere position, and relative arm lengths, and can differ markedly even among individuals of the same species.

Q2. Briefly describe Griffith's transformation experiment and its significance.



Ans. Griffith found that mixing dead virulent S bacteria with live harmless R bacteria killed mice, and live virulent S bacteria were recovered from them; he concluded genetic information had passed from the dead S bacteria to the living R bacteria (transformation), providing the first evidence that a hereditary 'transforming principle' exists, later identified as DNA by Avery.

Q3. How did the Hershey-Chase experiment confirm DNA (not protein) is the hereditary material?

Ans. By labelling viral DNA with radioactive ^{32}P and viral protein coats with radioactive ^{35}S , Hershey and Chase showed that only the ^{32}P (DNA) label entered infected bacteria and appeared in the next generation of viruses, while the ^{35}S (protein) label stayed outside, proving DNA carries the hereditary information.

Q4. State Chargaff's rule and explain how it relates to the Watson-Crick base pairing model.

Ans. Chargaff's rule states that in DNA, the amount of adenine always equals thymine, and guanine always equals cytosine; this is explained by Watson-Crick base pairing, in which adenine always pairs specifically with thymine (2 H-bonds) and guanine always pairs specifically with cytosine (3 H-bonds), so the two bases in each pair must always occur in equal amounts.

Q5. Differentiate the leading strand and lagging strand during DNA replication.

Ans. The leading strand elongates continuously toward the replication fork, with nucleotides added directly to its growing 3' end; the lagging strand elongates away from the fork and is synthesized discontinuously as short Okazaki fragments, each requiring its own RNA primer, later joined together by DNA ligase.

Q6. Differentiate a chromosomal aberration and a point mutation, with one example of each.

Ans. A chromosomal aberration is a large-scale change, such as an extra or missing chromosome or a deletion/insertion/inversion of a chromosome segment (e.g. Down's syndrome); a point mutation is a small change affecting only one or a few DNA base pairs (e.g. sickle cell anaemia, caused by a single base change altering one amino acid in haemoglobin).

Long Questions & Answers

Q1: Describe the Meselson-Stahl experiment and explain how it demonstrated that DNA replicates semi-conservatively.

The Watson-Crick model of DNA structure immediately suggested a natural mechanism for copying genetic information: if the two strands of the double helix were separated, each could serve as a template along which a new complementary strand could be assembled, producing two daughter duplexes each identical in sequence to the original parent molecule; this proposed mechanism was called semi-conservative replication, because while the original nucleotide sequence would be faithfully conserved across generations, the original physical duplex itself would not remain intact, since each of its two strands would end up as part of a different new duplex. However, semi-conservative replication was not the only



hypothesis proposed to explain how DNA might be copied: the conservative model held that the entire original parental double helix would remain completely intact after replication, with an entirely new, separate daughter duplex generated alongside it, while the dispersive model predicted an even more thorough mixing, in which the parental DNA would become fully dispersed throughout all the daughter molecules, so that every single strand in every daughter duplex would actually be a patchwork mixture of old, original DNA and newly synthesized DNA. To distinguish decisively between these three competing hypotheses, Matthew Meselson and Franklin Stahl, working at the California Institute of Technology, designed an elegant experiment in 1958 using different isotopes of nitrogen as density labels. They first grew several generations of bacteria in a growth medium containing only the heavy isotope of nitrogen, ^{15}N , which became incorporated throughout the nitrogen-containing bases of all the bacterial DNA, making that DNA measurably denser than normal DNA; once the bacterial DNA was uniformly heavy, they abruptly transferred the bacterial culture into a fresh medium containing only the ordinary, lighter isotope of nitrogen, ^{14}N , and then carefully collected samples of the bacterial DNA at successive time intervals as the bacteria continued to grow and divide, replicating their DNA using the now-available lighter nitrogen. To measure the density of the DNA collected at each interval, they dissolved each sample in a concentrated cesium chloride solution and spun it at extremely high speed in an ultracentrifuge; the intense centrifugal force caused the heavy cesium ions themselves to migrate toward the bottom of the tube, establishing a stable density gradient within the tube, and any given DNA molecule would migrate through this gradient and come to rest at exactly the point where its own density matched the surrounding cesium chloride solution, with denser ^{15}N -containing DNA settling further down the tube than lighter ^{14}N -containing DNA. The results were striking and unambiguous: the DNA sample collected immediately at the moment of transfer into the ^{14}N medium was uniformly dense, forming a single band at the position expected for pure ^{15}N DNA, exactly as expected since no replication had yet occurred in the new medium. However, after the bacteria had completed exactly one full round of DNA replication in the ^{14}N medium, all of the resulting DNA now formed a single band at an intermediate density, exactly halfway between the density expected for pure ^{15}N DNA and pure ^{14}N DNA, a result immediately inconsistent with the conservative model (which would have predicted two separate bands, one still fully heavy and one fully light, rather than a single uniform intermediate band). Then, after the bacteria completed a second full round of replication, two distinct density bands appeared simultaneously: one band still at the intermediate density observed after the first round, and a second, new band at the density of pure, fully light ^{14}N DNA, a result that decisively ruled out the dispersive model as well, since dispersive replication would have predicted that all the DNA converge toward a single density approaching pure ^{14}N DNA rather than splitting cleanly into two distinct density classes. Meselson and Stahl correctly interpreted this precise pattern as the direct signature of semi-conservative replication: after the first round of replication, every single daughter DNA duplex was necessarily a hybrid molecule, containing exactly one original heavy ^{15}N strand paired with one newly synthesized light ^{14}N strand, which is why all the DNA appeared at a single, uniform intermediate density at that stage; then, when each of these hybrid duplexes itself underwent a second round of replication, each hybrid duplex separated into its two individual strands, with the original heavy ^{15}N strand serving as a template to synthesize a new light partner strand (regenerating another hybrid,



intermediate-density duplex), while the light ^{14}N strand from the first round separately served as a template to synthesize its own new light partner strand (producing an entirely new, fully light duplex) - together producing exactly the two density bands actually observed, providing clear, direct experimental confirmation of the semi-conservative replication mechanism originally predicted by the Watson-Crick model.

Q2: Describe the process of transcription in detail, and explain how the genetic code specifies the sequence of amino acids in a protein.

Transcription is the first step of the central dogma of gene expression, the process by which the genetic information encoded in a gene's DNA sequence is copied into a complementary strand of messenger RNA (mRNA), and it proceeds through a precise, well-regulated sequence of molecular events. Only one of the two DNA strands making up a gene actually serves as the template for RNA synthesis at any given time, and this strand is specifically called the template strand or antisense strand, while the opposite, non-transcribed DNA strand, which carries the same sequence as the resulting mRNA (except for using thymine in place of uracil), is called the coding strand or sense strand. The process begins when the enzyme RNA polymerase specifically recognizes and binds to a particular DNA sequence located just upstream of the gene itself, called the promoter; in prokaryotes, this promoter region contains two short, specific binding sequences that have a particular affinity for RNA polymerase, one located around position -35 (with the consensus sequence TTGACA) and another around position -10 (with the consensus sequence TATAAT), while in eukaryotic promoters, functionally analogous binding sites are instead found further upstream, at approximately positions -75 and -25. Once RNA polymerase has bound correctly to the promoter, guided in bacteria by a specialized subunit called the sigma factor (which is responsible specifically for ensuring correct initiation of transcription and is subsequently released once transcription is properly underway), the remaining core enzyme complex proceeds to move steadily along the template strand of the gene; as it advances, the two strands of the DNA double helix are locally and transiently separated or 'unzipped' at the exact point where the enzyme is actively working, creating a small, characteristic bubble-like structure called the transcription bubble, which itself progressively moves down the length of the gene as transcription proceeds, with the newly synthesized RNA strand visibly protruding from the moving bubble as it lengthens. RNA polymerase continues synthesizing RNA in a fixed 5' to 3' direction, continuously adding nucleotides that are complementary to the template DNA strand, until it eventually reaches a specific stop or termination sequence positioned at the far end of the gene; in many cases, this termination sequence consists of a stretch of GC-rich base pairs immediately followed by a stretch of AT-rich base pairs, and the RNA transcript itself, once synthesized from this particular region, is able to fold back on itself to form a stable hairpin loop structure, followed immediately by a run of four or more uracil ribonucleotides, and this specific combination of a hairpin structure followed by U residues causes RNA polymerase to physically stall, disengage completely from the DNA template, and release the finished RNA transcript. Once this newly transcribed mRNA molecule has been produced, its genetic information is subsequently decoded and converted into a specific sequence of amino acids according to the genetic code, a universal biological cipher in which each successive, non-overlapping group of exactly three nucleotides, called a codon, specifies one particular amino acid to be incorporated into the growing protein chain;



three nucleotides are required for this coding system specifically because a code based on only two nucleotides at a time could generate at most 4 squared, or 16, distinct combinations, which is insufficient to uniquely specify all 20 amino acids commonly found in proteins, whereas a three-nucleotide code generates 4 cubed, or a full 64 distinct possible combinations, more than enough to comfortably cover all 20 amino acids with some redundancy remaining. Of these 64 possible codons, 61 each specify one of the 20 standard amino acids (with most amino acids therefore specified by more than one alternative codon), while the remaining three codons, UAA, UAG and UGA, do not correspond to any amino acid at all and instead function specifically as stop or nonsense codons that signal the definitive end of the coding sequence and terminate protein synthesis; in addition, one particular codon, AUG, serves the important dual role of both specifying the amino acid methionine and simultaneously acting as the universal start codon that marks precisely where translation of every protein-coding sequence must begin. Because this fundamental three-nucleotide codon system, and the specific assignment of particular codons to particular amino acids, is very nearly identical and universally shared across almost all known organisms, from simple bacteria through to complex eukaryotes such as humans, it becomes possible in principle to experimentally transfer a functioning gene from one organism into an entirely different host organism and still have that transferred gene correctly transcribed and translated into the very same intended protein by the new host's own cellular machinery, a fact of tremendous practical importance underlying essentially the entire modern field of genetic engineering and biotechnology.

MCQs with Answers

1. Chromosomes were first observed by Walther Flemming while examining dividing cells of:

(a) fruit flies (b) salamander larvae (c) bacteria (d) pea plants

Correct Answer: (b) salamander larvae. Flemming first observed chromosomes in 1882 while examining rapidly dividing cells of salamander larvae.

2. The chromosomal theory of inheritance was first formulated in 1902 by:

(a) Karl Correns (b) Thomas Hunt Morgan (c) Walter Sutton (d) Gregor Mendel

Correct Answer: (c) Walter Sutton. Walter Sutton formulated the chromosomal theory of inheritance in 1902, based on parallels between chromosome behavior and Mendelian inheritance.

3. Griffith's experiment demonstrating 'transformation' used which bacterium?

(a) Escherichia coli (b) Streptococcus pneumoniae (c) Neurospora crassa (d) Salmonella typhi

Correct Answer: (b) Streptococcus pneumoniae. Griffith worked with Streptococcus pneumoniae (then Pneumococcus), using virulent (S) and non-virulent (R) strains.

4. The Hershey-Chase experiment used radioactive isotopes ^{32}P and ^{35}S to label, respectively:

(a) protein and DNA (b) DNA and protein (c) RNA and DNA (d) protein and RNA

Correct Answer: (b) DNA and protein. ^{32}P labelled phage DNA (phosphate-containing) and ^{35}S labelled phage protein coats (sulfur-containing amino acids).



5. According to Chargaff's rule, in any DNA sample the amount of adenine always equals the amount of:

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

Correct Answer: (c) thymine. Chargaff's rule states A always equals T, and G always equals C, in double-stranded DNA.

6. In the DNA double helix, guanine pairs with cytosine via how many hydrogen bonds?

(a) one (b) two (c) three (d) four

Correct Answer: (c) three. Guanine pairs with cytosine via three hydrogen bonds, while adenine pairs with thymine via two.

7. The Meselson-Stahl experiment confirmed that DNA replication is:

(a) conservative (b) dispersive (c) semi-conservative (d) non-replicative

Correct Answer: (c) semi-conservative. Meselson and Stahl's density-gradient results matched the predictions of semi-conservative replication, ruling out conservative and dispersive models.

8. On the lagging strand, DNA is synthesized discontinuously as short segments called:

(a) primers (b) Okazaki fragments (c) nucleosomes (d) codons

Correct Answer: (b) Okazaki fragments. The lagging strand is synthesized as short Okazaki fragments, later joined together by DNA ligase.

9. Beadle and Tatum's experiments on Neurospora led to which hypothesis?

(a) one gene/one chromosome (b) one gene/one polypeptide (c) one gene/one codon (d) one codon/one nucleotide

Correct Answer: (b) one gene/one polypeptide. Beadle and Tatum's arginine mutant studies established the one gene/one enzyme (now one gene/one polypeptide) hypothesis.

10. Which of the following is a stop (nonsense) codon in the genetic code?

(a) AUG (b) UGG (c) UAA (d) AUA

Correct Answer: (c) UAA. UAA is one of three stop/nonsense codons (along with UAG and UGA) that terminate translation; AUG is the start codon.

Quick Revision Summary

- Chromosome basics: humans = 46 (23 pairs). Structure: chromatid + centromere + secondary constriction. Types by centromere position: telocentric/acrocentric/submetacentric/metacentric. Composition: ~40% DNA + 60% protein. Nucleosome = DNA + 8 histones (every 200 nucleotides). Heterochromatin (permanently condensed) vs Euchromatin (condenses only during division).
- Chromosomal theory: Sutton (1902, chromosome-gene parallel) -> Morgan (1910, Drosophila white-eye = sex-linked, gene on X chromosome) = proved genes are ON chromosomes.
- DNA = hereditary material: Griffith (1928, transformation, dead S + live R -> live S) -> Avery/MacLeod/McCarty (1944, DNase destroys transforming activity = DNA is



the agent) -> Hershey-Chase (1952, 32P-DNA enters bacteria, 35S-protein stays outside) = confirmed DNA.

- DNA structure: Miescher (1869, discovered 'nuclein') -> Levene (1920s, nucleotide = sugar+phosphate+base) -> Chargaff (A=T, G=C) -> Franklin (X-ray diffraction, helix, 2nm diameter/3.4nm turn) -> Watson & Crick (1953, double helix, antiparallel strands, A=T 2 H-bonds, G≡C 3 H-bonds).
- Replication: Semi-conservative (Meselson-Stahl 1958, 15N/14N density gradient, confirmed hybrid bands). Process: origin -> primase makes RNA primer -> DNA polymerase III extends 5'->3' (1000 nt/sec) -> Leading strand (continuous) vs Lagging strand (Okazaki fragments + DNA ligase).
- Gene concept: Garrod (1902, alkaptonuria = enzyme deficiency) -> Beadle & Tatum (1941, Neurospora, arg mutants) = one gene/one polypeptide. Sanger (1953, insulin sequence) + Ingram (1956, sickle cell = Glu->Val mutation) = gene defines protein sequence.
- Central dogma: DNA -> (transcription, RNA polymerase, promoter) -> mRNA -> (translation, ribosome+tRNA) -> protein. 3 RNA types: mRNA/tRNA/rRNA. Genetic code: triplet, 64 codons, AUG=start, UAA/UAG/UGA=stop, nearly universal. Mutations: Chromosomal aberration (large-scale, e.g. Down's) vs Point mutation (1-few bases, e.g. sickle cell/PKU). Notes by freebooks.pk.

Exam Tips

- Memorise the three DNA-is-the-hereditary-material experiments as a linked chain with one key result each: Griffith (transformation happens) -> Avery (DNase destroys it = it's DNA) -> Hershey-Chase (32P/DNA enters cells, 35S/protein doesn't).
- Keep Chargaff's rule and Watson-Crick base pairing as one linked fact: A=T (2 H-bonds), G=C (3 H-bonds) - this single fact answers many 'why' questions about DNA structure and replication.
- Draw and label the semi-conservative replication diagram from memory (parent duplex -> two hybrid duplexes -> one hybrid + one fully new duplex) - this is one of the most commonly asked long questions.
- Build a 2-column comparison table for leading vs lagging strand (continuous vs discontinuous, toward vs away from fork, no fragments vs Okazaki fragments) rather than memorising as separate facts.
- Learn the one gene/one polypeptide chain of evidence in order: Garrod (enzyme deficiency idea) -> Beadle & Tatum (Neurospora proof) -> Sanger (protein = amino acid sequence) -> Ingram (sickle cell = 1 amino acid change).
- Memorise the central dogma as a simple flow: DNA --transcription--> mRNA --translation--> Protein, and know which RNA polymerase makes which RNA in eukaryotes (I=rRNA, II=mRNA, III=tRNA).
- For the genetic code, remember the '4-16-64' logic (4 bases, 2-letter code=16 combos insufficient, 3-letter code=64 combos sufficient) rather than just memorising 'triplet code' as an isolated fact - this explains 'why triplet' questions.





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FSc Part-II Biology — Punjab Board

CHAPTER 21

Cell Cycle

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

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This chapter covers the Cell Cycle from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). A cell undergoes a regular sequence of changes involving a period of growth, replication of DNA, and cell division, together called the cell cycle, comprising interphase (the period of non-apparent division) and the mitotic phase (the period of division); each of these phases is further subdivided into distinct sub-phases. These notes are prepared by freebooks.pk.

The chapter covers interphase (G1, S and G2 phases), mitosis (karyokinesis with its prophase, metaphase, anaphase and telophase stages, followed by cytokinesis, including differences between plant and animal cells), the importance of mitosis and the biology of cancer, meiosis (the substages of prophase I, and meiosis I and II, plus its importance), meiotic errors (non-disjunction and the resulting syndromes such as Down's, Klinefelter's and Turner's), and finally the two forms of cell death, necrosis and apoptosis.

Learning Objectives

- Define the cell cycle and describe the sub-phases of interphase (G1, S, G2, G0).
- Describe the stages of mitosis (prophase, metaphase, anaphase, telophase) and cytokinesis, including plant-animal differences.
- Explain the importance of mitosis and describe how uncontrolled cell division leads to cancer.
- Describe the substages of prophase I of meiosis (leptotene through diakinesis) and the role of crossing over.
- Describe meiosis I and meiosis II and explain the biological importance of meiosis.
- Define chromosomal non-disjunction and describe Down's, Klinefelter's and Turner's syndromes.
- Differentiate necrosis and apoptosis as forms of cell death.

Key Concepts

The Cell Cycle and Interphase

A cell undergoes a regular sequence of changes involving a period of growth, DNA replication, and cell division, together called the cell cycle, comprising two main phases: interphase, the period of non-apparent division, and the mitotic phase, the period of actual division. Interphase, sometimes misleadingly called the 'resting phase', is actually a period of intense biochemical activity, divided into three sub-phases. G1 (Gap 1) is a period of extensive metabolic activity in which the cell grows in size, synthesises specific enzymes, and accumulates DNA base units for upcoming DNA synthesis; a post-mitotic cell can exit the cycle during G1 into a resting state called G0, remaining there for days, weeks, or (in cells such as nerve cells and eye lens cells) even the organism's entire lifetime without further division. G1 is followed by the S-phase (synthesis phase), during which DNA is replicated (chromosomes duplicated), which then initiates G2 (the pre-mitotic phase), during which the cell prepares further for division by storing energy for chromosome movement and synthesising mitosis-specific proteins, RNA, and microtubule subunits for the spindle fibres.



At each stage of the cell cycle, specific checkpoints determine whether the cell proceeds to the next phase based on its internal state, and the length of each phase varies considerably between cell types: in a typical human cell, the full cycle takes about 24 hours, with mitosis taking about 30 minutes, G1 about 9 hours, S-phase about 10 hours, and G2 about 4.5 hours, while the full cycle in yeast cells takes only about 90 minutes.

Mitosis: Karyokinesis (Prophase through Telophase)

Mitosis is the type of cell division that ensures the daughter cells receive the same number of chromosomes as the parent cell; it occurs in haploid or diploid cells throughout nearly all parts of the body as needed, and although a continuous process, it is conventionally divided into karyokinesis (division of the nucleus) and cytokinesis (division of the whole cell). At the start of mitosis in an animal cell, the centriole pairs (already duplicated during interphase) separate and migrate to opposite sides of the nucleus, establishing bipolarity; three sets of microtubules radiate from each pair of centrioles - astral microtubules (forming the aster), kinetochore microtubules (attaching to chromosomes at their kinetochores), and polar microtubules (interdigitating with polar microtubules from the opposite pole) - together forming the mitotic apparatus, a structure larger than the nucleus, designed to capture, align and separate chromosomes to ensure their equal distribution. Karyokinesis is itself conventionally divided into four stages. During prophase, the fine chromatin network condenses into visible, increasingly thick chromosomes (each showing two sister chromatids joined at the centromere), the nuclear envelope and nucleoli disappear, releasing nuclear material into the cytoplasm, and the mitotic apparatus organises as the cytoplasm becomes more viscous.

During metaphase, each duplicated chromosome (two sister chromatids joined at the centromere, which bears a specialised kinetochore region) has kinetochore fibres from each spindle pole attach to its kinetochore, aligning all the chromosomes at the equator of the spindle to form the metaphase (equatorial) plate. Anaphase is the most critical phase, ensuring equal distribution of chromatids: kinetochore fibres contract toward their poles while polar microtubules elongate, separating the sister chromatids at the centromere so that half travel to each pole. Telophase begins once the chromosomes reach the poles: they decondense back into chromatin, the mitotic apparatus disassembles, and the nuclear membrane and nucleoli reorganise around each set of chromosomes, forming two new nuclei. During late telophase, cytokinesis begins as astral microtubules signal the cell's equatorial region, activating actin and myosin to form a contractile ring, which produces a cleavage furrow that deepens inward, ultimately dividing the parent cell into two daughter cells.

Mitosis in Plant Cells and the Importance of Mitosis

Mitotic events in plant cells broadly resemble those in animal cells but show important differences: most higher plants lack visible centrioles, instead having an analogous region from which spindle microtubules radiate, and the rigid cell wall prevents the plant cell from changing shape as dramatically as an animal cell does during division. At cytokinesis, instead of a contractile ring, plant cells form a membrane structure called the phragmoplast, built from Golgi-derived vesicles that originate during metaphase, line up at the cell's centre,



and fuse at the end of telophase; these vesicle membranes become the new plasma membrane of the daughter cells, while their contents (including cellulose and pectin precursors) form the new cell wall material.

Mitosis is essential because it equally distributes hereditary material to daughter cells; since there is no crossing over or recombination, genetic information remains unchanged from generation to generation of cells, ensuring continuity. Mitosis underlies asexual reproduction in many plants and animals, regeneration, wound healing, replacement of aging cells, and the orderly growth and development of multicellular organisms, and it is also essential for tissue culture and cloning techniques; because of its importance, mitosis must be carefully managed and controlled, since malfunction can result in tumours and lethal diseases such as cancer.

Cancer: Uncontrolled Cell Division

Normal cell multiplication is carefully regulated and responsive to the body's specific needs, balancing cell death and birth to maintain a steady state; when this regulatory control breaks down, a cell may begin growing and dividing in an unregulated fashion without regard for the body's actual need for more cells of its type, and its unrestrained proliferation produces an unwanted clone of cells called a tumour, which can expand indefinitely. Tumours are of two basic types: benign tumours are small, localised, and generally behave like normal cells with little harmful effect (except through physical interference or hormone-like secretions), while malignant tumours (cancers) divide more rapidly, invade surrounding tissue, enter the circulatory system, and establish secondary growth sites away from the original tumour, a process called metastasis. Cancer cells can be distinguished from normal cells by being less differentiated, showing characteristics of rapid growth such as a high nucleus-to-cytoplasm ratio, prominent nucleoli, and frequent mitosis, with invading cells in otherwise normal tissue indicating malignancy.

Cancer is caused mainly by mutations in somatic cells, typically accumulating from as few as three to as many as twenty mutations in genes that regulate cell division; these mutations produce two fundamental changes in cancer cells: first, metastatic cells break contact with neighbouring cells and overcome the normal restrictions on cell movement imposed by the basal lamina and other barriers, allowing them to invade other body regions; second, they proliferate without limit, ignoring the body's normal regulatory checks and programmes.

Meiosis I: Prophase I and the Significance of Crossing Over

Meiosis is a specialised type of cell division that reduces the chromosome number in daughter cells to half that of the parent cell, occurring during gamete formation in animals and spore formation in plants; because it involves two consecutive divisions (meiosis I and meiosis II) after a single round of DNA replication, each diploid cell produces four haploid cells. Meiosis I is the reduction division, while meiosis II resembles mitosis; both are divided into prophase, metaphase, anaphase and telophase stages (numbered I and II respectively). Prophase I is a notably prolonged phase that differs from mitotic prophase because homologous chromosomes (similar but not necessarily identical chromosome pairs, one from each parent) pair up; it is itself divided into five substages. In leptotene, chromosomes



become visible, shorten and thicken, and homologous chromosomes begin approaching each other. In zygotene, synapsis (the highly specific pairing of homologous chromosomes) begins, forming a paired structure called a bivalent or tetrad. In pachytene, pairing is completed, chromosomes thicken further, and each bivalent (with four chromatids) undergoes crossing over, in which non-sister chromatids exchange segments at points called chiasmata, reshuffling genetic material and producing recombination; pachytene may last days, weeks, or even years, while leptotene and zygotene last only a few hours.

In diplotene, the paired homologous chromosomes begin to repel and separate from one another, though separation remains incomplete since they stay joined at their chiasmata (points of exchange). In diakinesis, chromosome condensation reaches its maximum, the separation begun in diplotene completes (though the chromosomes typically remain joined at one point, often near the ends), and the nucleoli disappear. In metaphase I, the nuclear membrane disassembles, spindle fibres form, and kinetochore fibres attach to the kinetochore of each homologous chromosome from opposite poles, aligning the bivalents at the equator, with the two sister chromatids of each chromosome behaving as a single unit. In anaphase I, unlike mitotic anaphase, sister chromatids remain joined: kinetochore fibres contract and polar fibres elongate, pulling each whole chromosome (still with two chromatids) to its respective pole, so each pole receives half the total chromosome number - the actual reduction step. In telophase I, the nuclear membrane and nucleoli reform around each set of chromosomes, producing two nuclei each with half the original chromosome number, after which the cytoplasm divides, completing the first meiotic division; chromosomes may decondense at this stage.

Meiosis II and the Importance of Meiosis

After telophase I, the two daughter cells undergo a brief interphase, but unlike mitotic interphase, no further chromosome replication occurs. Prophase II, metaphase II, anaphase II and telophase II closely resemble the corresponding mitotic phases: chromosomes condense, the mitotic apparatus forms, chromosomes align at the equator, and sister chromatids separate and move to opposite poles, ultimately producing four nuclei (two from each of the two cells formed after meiosis I); cytokinesis then produces four haploid cells, each with half the original chromosome number.

Meiosis's importance rests on two key phenomena: crossing over, in which parental chromosomes exchange segments to produce a large number of new gene combinations (recombinations), and the random assortment of homologous chromosomes during anaphase I, which produces a very wide variety of possible gamete combinations; together these processes generate genetic variation, providing both the raw material for evolution and the basis for each individual's unique characteristics, meaning even siblings from the same parents are never genetically identical. Meiosis occurs during gamete or spore formation, halving the chromosome number so that it is restored to the normal diploid number upon fertilization, keeping the chromosome number constant across generations; without meiosis, chromosome number would double with every generation, an unsustainable outcome.



Meiotic Errors: Non-disjunction and Chromosomal Syndromes

Although meiosis is normally an orderly process, errors sometimes occur; one important abnormality is chromosomal non-disjunction, in which chromosomes fail to segregate properly during anaphase and telophase, resulting in an unequal distribution of chromosomes among daughter nuclei and causing an increase or decrease in chromosome number, with serious physical, social and mental consequences; non-disjunction may affect autosomes or sex chromosomes. Down's syndrome (mongolism) results from autosomal non-disjunction of chromosome 21, producing a gamete with 24 chromosomes that, upon fertilization with a normal gamete, yields an individual with 47 chromosomes (trisomy 21, $2n+1$); it appears to occur mainly in the ovum and is strongly linked to maternal age (roughly 1 in several thousand for teenage mothers, 1 in 100 by age 40, and about three times greater risk by age 45), producing a flat, broad face, squint eyes with an inner eyelid fold, a protruding tongue, mental retardation, and defective central nervous system development; non-disjunction of chromosomes other than 21 usually causes miscarriage or very early death.

Klinefelter's syndrome results from an additional sex chromosome, typically 47 chromosomes (44 autosomes + XXY); affected individuals are phenotypically male but frequently show enlarged breasts, tendency toward tallness and obesity, small testes with no sperm production, and underdeveloped secondary sexual characteristics (rarer variants include XXXY, XXXXY and XYY karyotypes). Turner's syndrome results from a missing X chromosome, giving only 45 chromosomes (44 autosomes + X); many affected pregnancies do not survive to term, while those that do survive have a female appearance with short stature, a webbed neck, absent ovaries, and complete absence of germ cells.

Necrosis and Apoptosis: Two Forms of Cell Death

Cells rely on various extracellular and intracellular signals to regulate their activities, such as division, differentiation, morphogenesis and motility, and even a cell's death can be a predetermined, programmed event. Programmed cell death is essential for properly controlled multicellular development, sometimes eliminating an entire structure (such as the tail of a developing human embryo) or part of one (such as the tissue between developing fingers), and also regulates cell numbers, since most neurons in the human body actually die during normal development. Cell death in multicellular organisms occurs in two fundamentally different ways: a cell may commit 'suicide' in the absence of survival signals (trophic factors), or it may be actively 'murdered' by killing signals from other cells.

The internal programme of events and morphological changes by which a cell commits suicide is collectively called apoptosis (from the Greek for 'dropping off' or 'falling off'); during apoptosis, the dying cell shrinks and condenses, eventually splitting into small, membrane-bound apoptotic bodies that are generally engulfed (phagocytosed) by neighbouring cells, so intracellular contents are never released freely into the surrounding tissue, avoiding damage to neighbouring cells. In contrast, necrosis is cell death resulting from tissue damage, during which the dying cell swells and bursts, releasing its intracellular contents into the surrounding tissue, which can damage neighbouring cells and trigger inflammation.



Important Definitions

Term	Definition
Cell cycle	The regular sequence of changes a cell undergoes, comprising growth, DNA replication, and cell division, divided into interphase and the mitotic phase.
Interphase	The period of the cell cycle between two consecutive divisions, comprising G1, S and G2 phases, characterized by intense biochemical activity.
Mitosis	The type of cell division that ensures daughter cells receive the same number of chromosomes as the parent cell.
Synapsis	The highly specific pairing of homologous chromosomes that occurs during zygotene of meiotic prophase I.
Crossing over	The exchange of chromosome segments between non-sister chromatids of homologous chromosomes during pachytene, producing genetic recombination.
Non-disjunction	The failure of chromosomes to segregate properly during anaphase and telophase, resulting in an abnormal chromosome number in daughter cells.
Apoptosis	The internally programmed sequence of events by which a cell commits controlled 'suicide,' shrinking and fragmenting into membrane-bound bodies that are phagocytosed.
Necrosis	Cell death resulting from tissue damage, in which the cell swells and bursts, releasing its contents and potentially damaging neighboring tissue.

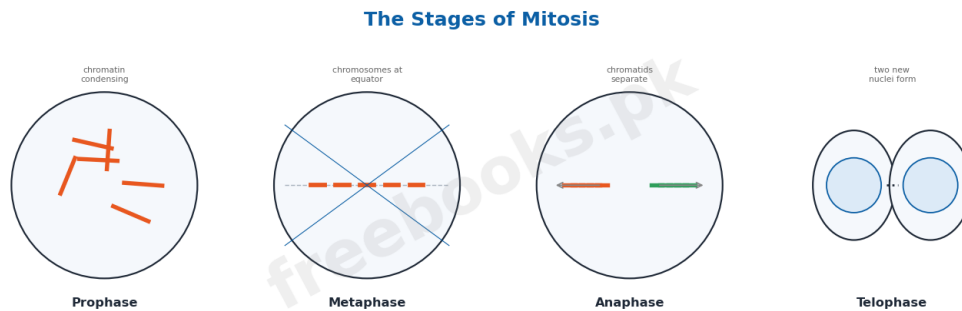
Key Facts

Item	Fact
Human cell cycle timing	Average human cell cycle $\approx$ 24 hours: G1 $\approx$ 9 hrs, S-phase $\approx$ 10 hrs, G2 $\approx$ 4.5 hrs, mitosis $\approx$ 30 minutes.
Yeast cell cycle timing	Full cell cycle in yeast cells takes only about 90 minutes.
Meiosis chromosome outcome	One diploid ($2n$) cell after meiosis produces 4 haploid (n) cells (2 divisions after 1 DNA replication).
Down's syndrome (trisomy 21)	Down's syndrome = 47 chromosomes ($2n+1$), non-disjunction of chromosome 21.
Klinefelter's syndrome	Klinefelter's syndrome = 47 chromosomes (44 autosomes + XXY).
Turner's syndrome	Turner's syndrome = 45 chromosomes (44 autosomes + X, one X missing).
Down's syndrome maternal age risk	Risk of Down's syndrome: $\sim$ 1 in several thousand (teenage mother) $\rightarrow$ $\sim$ 1 in 100 (age 40) $\rightarrow$ $\sim$ 3x greater by age 45.
Cancer mutation accumulation	Cancer typically results from accumulation of about 3 to 20 mutations in cell-division-regulating genes.



Diagrams & Illustrations

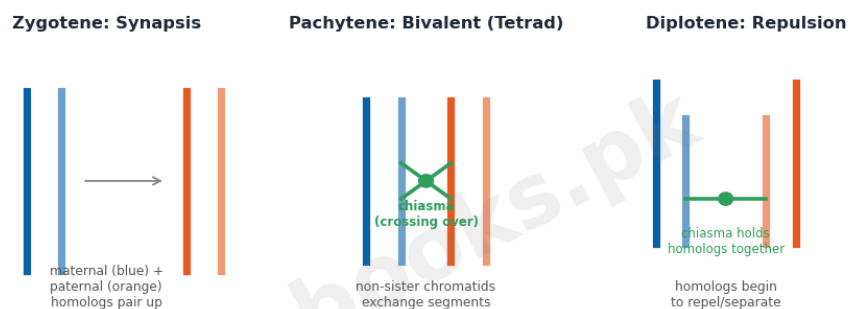
The Stages of Mitosis: a panel diagram showing the sequential stages of mitosis in an animal cell: prophase (chromosomes condense), metaphase (chromosomes align at the equatorial plate), anaphase (sister chromatids separate to poles), and telophase (two new nuclei form).



The Stages of Mitosis

Homologous Chromosome Pairing and Crossing Over in Meiosis I: a diagram showing synapsis of homologous chromosomes to form a bivalent (tetrad) during zygotene/pachytene, and crossing over between non-sister chromatids at a chiasma during prophase I.

Homologous Chromosome Pairing and Crossing Over (Prophase I)

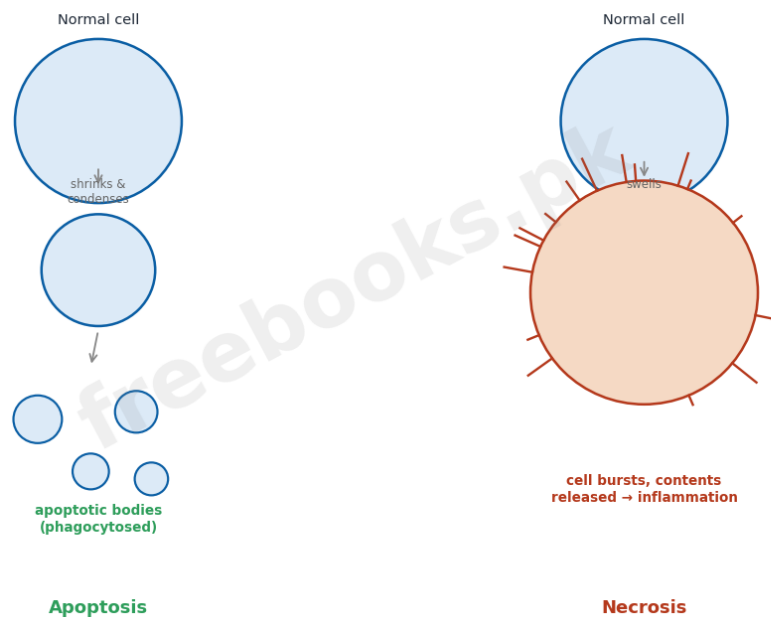


Homologous Chromosome Pairing and Crossing Over in Meiosis I

Apoptosis versus Necrosis: a comparative diagram showing apoptosis (cell shrinks, condenses, and fragments into phagocytosed apoptotic bodies) alongside necrosis (cell swells and bursts, releasing contents and causing inflammation).



Apoptosis versus Necrosis



Apoptosis versus Necrosis

Short Questions & Answers

Q1. Differentiate G1, S and G2 phases of interphase.

Ans. G1 is a period of metabolic activity and cell growth in which enzymes are synthesized and DNA precursors accumulate; the S-phase is when DNA is actually replicated (chromosomes duplicated); G2 is the pre-mitotic phase in which the cell synthesizes mitosis-specific proteins, RNA and microtubule subunits in preparation for division.

Q2. What is the mitotic apparatus, and what is its function?

Ans. The mitotic apparatus is the specialized microtubule structure (aster + spindle) formed from centriole-derived microtubules during mitosis; it attaches to and captures chromosomes at their kinetochores, aligns them at the metaphase plate, and separates them to ensure equal chromosome distribution to daughter cells.

Q3. How does mitosis differ between plant and animal cells?

Ans. Most higher plants lack visible centrioles (having an analogous spindle-organizing region instead), plant cell shape changes little during division due to the rigid cell wall, and plant cytokinesis forms a phragmoplast from Golgi-derived vesicles (rather than an animal cell's actin-myosin contractile ring), which becomes the new plasma membrane and cell wall material.

Q4. Differentiate anaphase I of meiosis from anaphase of mitosis.

Ans. In mitotic anaphase, sister chromatids separate and move individually to opposite poles; in anaphase I of meiosis, sister chromatids remain joined and whole homologous chromosomes (each with two chromatids) separate and move to opposite poles, which is the actual chromosome-number-reducing step.

Q5. What is non-disjunction, and give one example of a resulting syndrome.



Ans. Non-disjunction is the failure of chromosomes to segregate properly during anaphase/telophase, causing an abnormal chromosome number in daughter cells; Down's syndrome (trisomy 21, 47 chromosomes) is a well-known example, caused by non-disjunction of chromosome 21.

Q6. Differentiate apoptosis and necrosis.

Ans. Apoptosis is programmed cell 'suicide' in which the cell shrinks, condenses, and fragments into membrane-bound apoptotic bodies that are phagocytosed without releasing contents; necrosis is cell death from tissue damage in which the cell swells and bursts, releasing its contents and causing inflammation and damage to neighboring cells.

Long Questions & Answers

Q1: Describe in detail the four stages of karyokinesis (prophase, metaphase, anaphase and telophase) during mitosis.

Mitosis, though a continuous process, is conventionally divided into four distinct stages for study, and it begins with prophase, during which the fine, thread-like chromatin network that is invisible during interphase begins to condense through progressive folding, gradually becoming visible as increasingly thick chromosome structures ranging from about 0.25 to 50 micrometres in length; as prophase advances, each chromosome becomes clearly visible as a duplicated structure consisting of two sister chromatids joined together at a single point called the centromere, and toward the end of prophase several other major changes occur simultaneously - the nuclear envelope breaks down entirely and releases the nuclear material directly into the surrounding cytoplasm, the nucleoli disappear, the mitotic apparatus (comprising the aster and spindle, built from microtubules radiating out from the now-separated centriole pairs at opposite poles of the cell) becomes fully organized, and the cytoplasm itself becomes noticeably more viscous in preparation for the mechanical work of chromosome separation that is to follow. The cell then enters metaphase, in which each chromosome, still consisting of its two sister chromatids joined at the centromere, becomes attached to the mitotic spindle through its kinetochore, a specialized region located at the centromere with a particular arrangement of DNA sequences and associated proteins specifically adapted to bind the kinetochore microtubules of the spindle apparatus; critically, each kinetochore receives exactly two microtubule fibres, one originating from each of the two opposite spindle poles, and this precisely balanced, bipolar attachment is what allows all of the chromosomes in the cell to become aligned together along a single plane at the very centre of the spindle, roughly equidistant between the two poles, forming what is called the equatorial plate or metaphase plate, a configuration that must be achieved correctly before the cell is permitted to proceed further. Anaphase, widely regarded as the single most critical and consequential phase of the entire mitotic process, follows immediately once every chromosome has become properly and completely attached to spindle fibres from both poles; during this phase, the kinetochore fibres of the spindle apparatus begin to actively contract and shorten, physically pulling toward their respective poles, while at the very same time the polar microtubules, which run between the two poles rather than attaching to chromosomes, begin to elongate and push the two poles further apart, and the combined mechanical effect of these two simultaneous processes generates enough force to physically



break the connection joining each pair of sister chromatids at the centromere, so that the two sister chromatids of every chromosome are pulled cleanly and completely apart from one another, with exactly one full set of chromatids, now considered individual daughter chromosomes in their own right, travelling steadily toward each of the two opposite poles of the dividing cell, thereby guaranteeing that each future daughter cell will receive a genetically complete and identical set of chromosomes. Once the separated chromosomes have fully reached their respective poles at opposite ends of the cell, anaphase is considered complete and the cell enters the final stage, telophase, during which the entire sequence of structural changes seen earlier during prophase is essentially reversed in order to reconstruct two separate, fully functional nuclei: the tightly condensed chromosomes at each pole begin to decondense and unfold, gradually losing their compact, visible chromosome structure and reverting back into the loosely dispersed, essentially invisible chromatin form characteristic of interphase, while simultaneously the mitotic apparatus itself completely disassembles and disappears, a brand new nuclear membrane reforms and reorganizes around each of the two separated sets of decondensing chromosomes, and the nucleoli, which had disappeared back during prophase, now reappear within each newly forming nucleus - together, these coordinated changes result in the formation of two genetically identical, fully reconstituted nuclei positioned at opposite poles of what remains, at this point, still a single, undivided cell, setting the stage for the subsequent physical division of the cytoplasm itself during cytokinesis, which finally separates this one cell into two completely independent daughter cells.

Q2: Describe the substages of prophase I of meiosis and explain the biological significance of crossing over and random chromosome assortment.

Prophase I of meiosis is a notably prolonged and considerably more elaborate phase than the corresponding prophase of ordinary mitosis, distinguished above all by the fact that homologous chromosomes, meaning the two versions of each type of chromosome present in a diploid cell, one originally inherited from the mother and one from the father, actively come together and pair with one another in a highly organized way, and for the purposes of detailed study this single extended phase is conventionally broken down into five sequential and clearly recognizable substages. The first of these, leptotene, is the stage during which chromosomes, previously invisible as diffuse chromatin during interphase, first become visible as they progressively shorten and thicken, while at the same time the overall size of the nucleus itself increases and the various homologous chromosome pairs present in the cell begin gradually moving closer to one another in preparation for the pairing process that is about to follow. This leads directly into zygotene, the stage in which the single most essential defining event of meiosis actually begins to take place: the highly specific pairing of each homologous chromosome with its partner, a precise process known as synapsis, which despite being remarkably exact in how closely and completely the two homologous partners eventually align is nevertheless not restricted to any single fixed starting point along the chromosome's length, and once this pairing process is underway, each resulting paired (though still physically distinct and unfused) structure formed by the two homologous chromosomes together is specifically referred to as a bivalent, or alternatively a tetrad, in recognition of the fact that it ultimately contains four individual chromatids in total. The cell



then progresses into pachytene, the substage during which the pairing of homologous chromosomes that began in zygotene finally reaches full completion, while the chromosomes themselves continue to become progressively thicker and more condensed, and it is specifically during this pachytene stage that each fully formed bivalent, now clearly containing four tightly wrapped chromatids in total, undergoes the single most genetically consequential event of the entire meiotic process: individual non-sister chromatids belonging to the two different homologous chromosomes physically exchange corresponding segments of DNA with one another at specific points of contact called chiasmata, in a precisely regulated process known as crossing over, which has the critical effect of extensively reshuffling and recombining the genetic material originally inherited separately from the two parents, thereby generating substantial new genetic recombination; notably, this particular pachytene substage, unlike the comparatively brief leptotene and zygotene stages that typically last only a matter of hours, can itself persist for an extended and highly variable length of time, ranging anywhere from several days to several weeks or, in certain organisms and circumstances, even for a period of years. Following pachytene, the cell enters diplotene, the stage in which the two homologous chromosomes making up each bivalent, having completed their crossing over, now begin to actively repel one another and separate apart, although this separation process remains distinctly incomplete at this stage, since the two homologous partners continue to remain physically joined together specifically at the precise points where genetic exchange previously occurred, these persistent points of connection being the chiasmata themselves, with every bivalent retaining at least one such point of continued attachment even as the chromatids elsewhere along their length become visibly separated from one another. The final substage, diakinesis, is characterized by chromosome condensation reaching its very maximum level of compactness throughout the entire cell, while the separation process of the homologous chromosomes that had originally begun back during diplotene now finally reaches its full completion, though the homologous pairs typically still remain joined together at one single remaining point of contact, quite often located specifically near the very ends of the chromosomes, and it is also during this final diakinesis substage that the nucleoli, which had been clearly visible up to this point, now finally disappear entirely from the cell, marking the definitive end of prophase I and signalling that the cell is now fully prepared to proceed onward into metaphase I. The profound biological significance of both crossing over and the subsequent random assortment of homologous chromosome pairs during the following anaphase I cannot be overstated: crossing over itself directly generates enormous numbers of new genetic recombinations by physically exchanging chromosome segments between the maternally and paternally inherited homologous chromosomes, while entirely independently of this, the random and unpredictable orientation with which each different pair of homologous chromosomes happens to align itself along the metaphase plate, and is consequently separated during the subsequent anaphase I, produces an extraordinarily wide range of possible different combinations of maternal and paternal chromosomes ultimately being distributed into the resulting gametes; taken together, these two entirely distinct genetic mechanisms combine to generate the vast pool of heritable variation that serves as the essential, indispensable raw material upon which the entire process of evolution by natural selection depends, while at the very same time ensuring that every single individual



organism produced through sexual reproduction, even full siblings sharing the very same two parents, invariably ends up being genetically unique and distinct from one another.

MCQs with Answers

1. The period of the cell cycle in which DNA is actually replicated is called the:

(a) G1 phase (b) S phase (c) G2 phase (d) M phase

Correct Answer: (b) S phase. DNA replication (chromosome duplication) occurs during the S (synthesis) phase of interphase.

2. A post-mitotic cell that exits the cell cycle and stops dividing (e.g. a nerve cell) enters a phase called:

(a) G0 (b) G1 (c) S (d) G2

Correct Answer: (a) G0. Cells that exit the cycle during G1 and stop proliferating enter the G0 (resting) phase, sometimes permanently.

3. During which stage of mitosis do chromosomes align at the equatorial (metaphase) plate?

(a) prophase (b) metaphase (c) anaphase (d) telophase

Correct Answer: (b) metaphase. Metaphase is characterized by chromosome alignment at the spindle equator, forming the metaphase plate.

4. In plant cell cytokinesis, the structure formed from Golgi-derived vesicles (in place of an animal contractile ring) is the:

(a) kinetochore (b) phragmoplast (c) aster (d) centromere

Correct Answer: (b) phragmoplast. Plant cells form a phragmoplast from Golgi vesicles at cytokinesis, which becomes the new plasma membrane and cell wall material.

5. The spread of cancer cells to establish secondary growth sites away from the original tumor is called:

(a) mitosis (b) apoptosis (c) metastasis (d) synapsis

Correct Answer: (c) metastasis. Metastasis is the spread of malignant tumor cells to establish new growth sites elsewhere in the body.

6. The pairing of homologous chromosomes during meiotic prophase I is called:

(a) crossing over (b) synapsis (c) disjunction (d) cytokinesis

Correct Answer: (b) synapsis. Synapsis is the specific pairing of homologous chromosomes, beginning during zygotene of prophase I.

7. Crossing over between non-sister chromatids occurs during which substage of prophase I?

(a) leptotene (b) zygotene (c) pachytene (d) diakinesis

Correct Answer: (c) pachytene. Crossing over occurs during pachytene, when non-sister chromatids exchange segments at chiasmata.

8. Down's syndrome results from non-disjunction of which chromosome, producing 47 total chromosomes?



(a) chromosome 13 (b) chromosome 18 (c) chromosome 21 (d) the X chromosome

Correct Answer: (c) chromosome 21. Down's syndrome (trisomy 21) results from non-disjunction of chromosome 21, giving 47 total chromosomes ($2n+1$).

9. An individual with karyotype 44 autosomes + XXY has which syndrome?

(a) Turner's syndrome (b) Klinefelter's syndrome (c) Down's syndrome (d) Jacobs syndrome

Correct Answer: (b) Klinefelter's syndrome. Klinefelter's syndrome results from an extra sex chromosome, typically 44 autosomes + XXY (47 total).

10. Programmed cell 'suicide,' in which the cell shrinks and fragments into phagocytosed bodies, is called:

(a) necrosis (b) apoptosis (c) metastasis (d) mitosis

Correct Answer: (b) apoptosis. Apoptosis is programmed cell death in which the cell shrinks, condenses, and fragments into apoptotic bodies that are phagocytosed.

Quick Revision Summary

- Cell cycle = Interphase (G1 growth → S DNA replication → G2 pre-mitotic prep) + Mitotic phase. Human cycle ~24h (G1=9h, S=10h, G2=4.5h, M=30min); yeast ~90 min. G0 = resting/non-dividing exit point.
- Mitosis (karyokinesis): Prophase (chromatin condenses, nuclear envelope breaks down, spindle forms) → Metaphase (chromosomes align at equator/metaphase plate) → Anaphase (sister chromatids separate to poles) → Telophase (2 nuclei reform). Cytokinesis: animal = contractile ring; plant = phragmoplast (Golgi vesicles).
- Importance of mitosis: growth, repair, regeneration, asexual reproduction, tissue culture/cloning. Cancer = uncontrolled division (mutations in cell-cycle genes) → benign (localized) vs malignant/cancer (invasive, metastasis).
- Meiosis I (reduction division): Prophase I = 5 substages (Leptotene → Zygotene/ synapsis → Pachytene/crossing over at chiasmata → Diplotene/separation begins → Diakinesis/max condensation) → Metaphase I (bivalents align) → Anaphase I (homologous chromosomes separate, NOT sister chromatids) → Telophase I (2 haploid nuclei, still 2 chromatids each).
- Meiosis II (like mitosis, no DNA replication before it): Prophase II → Metaphase II → Anaphase II (sister chromatids separate) → Telophase II = 4 haploid cells total. Importance: crossing over + random assortment = genetic variation = basis of evolution + individual uniqueness. Restores chromosome number after fertilization.
- Non-disjunction: chromosomes fail to segregate properly. Down's syndrome = trisomy 21 (47, $2n+1$), linked to maternal age. Klinefelter's = 44+XXY (47). Turner's = 44+X (45, monosomy). Table: Down 1/700 births, Klinefelter 1/1500, Turner 1/6000 births (Down: also 1/40 abortions, etc.).
- Cell death: Apoptosis (programmed 'suicide', cell shrinks/fragments, phagocytosed, no content leakage) vs Necrosis (damage-induced, cell swells/bursts, releases contents, causes inflammation). Notes by freebooks.pk.



Exam Tips

- Memorise the human cell cycle timing numbers exactly (24h total: G1=9h, S=10h, G2=4.5h, M=30min) - these are frequently tested as direct recall or fill-in-the-blank questions.
- Draw the 4 mitotic stages (prophase/metaphase/anaphase/telophase) as a simple 4-panel sketch with one key event labelled per panel - this both helps memory and directly answers 'describe mitosis' long questions.
- Keep the key mitosis vs meiosis I anaphase distinction as one sharp fact: mitosis anaphase separates SISTER chromatids; meiosis anaphase I separates HOMOLOGOUS chromosomes (sister chromatids stay together) - this is a very common exam trap.
- Memorise prophase I's 5 substages in strict order using a mnemonic (Leptotene-Zygotene-Pachytene-Diplotene-Diakinesis = 'L-Z-P-D-D') and attach exactly one key event to each (thickening / synapsis / crossing over / chiasmata separate / max condensation).
- Build a 3-row comparison table for Down's/Klinefelter's/Turner's syndromes (chromosome count, sex chromosome pattern, key physical signs) rather than memorising each in isolation.
- Keep apoptosis vs necrosis as a clean opposite-pair: apoptosis = controlled/shrink/fragment/phagocytosed/no damage; necrosis = damage-induced/swell/burst/leak contents/inflammation.
- For 'importance of meiosis' questions, always mention both crossing over AND random assortment as the two separate sources of variation, plus the chromosome-number-restoring role at fertilization - examiners look for all three points.

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FSc Part-II Biology — Punjab Board

CHAPTER 22

Variation and Genetics

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

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This chapter covers Variation and Genetics from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Hereditary characteristics pass from parents to offspring through genes carried in gametes; a gene is the basic unit of biological information, a segment of DNA occupying a specific position (locus) on a chromosome, and paired alleles on homologous chromosomes may be identical or different, producing the inherited resemblances and variations seen across generations. These notes are prepared by freebooks.pk.

The chapter covers Mendel's experiments and laws of inheritance (segregation and independent assortment), the four dominance relations (complete, incomplete, codominance, overdominance) illustrated through human and other blood group systems (MN, ABO, Rh), epistasis and pleiotropy, continuously varying (polygenic) traits, gene linkage and crossing over, the chromosomal patterns of sex determination, sex linkage in *Drosophila* and humans (haemophilia, colour blindness, X-linked dominant and Y-linked traits, sex-limited and sex-influenced traits), and the genetic basis of diabetes mellitus.

Learning Objectives

- Define gene, allele, locus, phenotype, genotype and gene pool.
- Describe Mendel's monohybrid cross and state the law of segregation, including the test cross.
- Describe Mendel's dihybrid cross and state the law of independent assortment, including the product rule.
- Differentiate complete dominance, incomplete dominance, codominance and overdominance with examples.
- Describe the ABO, MN and Rh blood group systems and their genetic and clinical significance.
- Explain epistasis (Bombay phenotype), pleiotropy, and polygenic (continuously varying) inheritance.
- Explain gene linkage, crossing over, and recombination frequency.
- Describe the chromosomal patterns of sex determination and sex linkage in *Drosophila* and humans.

Key Concepts

Genes, Alleles, Gene Pool and Mendel's Experimental Approach

A gene is the basic unit of biological information, a segment of DNA whose base sequence encodes hereditary information; its position on a chromosome is its locus. Genes form pairs on pairs of homologous chromosomes, with one member of the pair (allele) on each homologue; alleles at a locus may be identical or different. Phenotype is the observable form of a trait, while genotype is the genetic constitution underlying it; a gene pool is the total genetic information (all genes/alleles) present in a breeding population at a given time - conceptualised as a 'beanbag' of individually segregating, randomly assorting alleles. Gregor Johann Mendel (1822-1884) laid the foundation of classical genetics through eleven years



(1854-1865) of breeding experiments on the garden pea (*Pisum sativum*), a plant well suited to the task: easy to cultivate, normally self-fertilizing but capable of cross-fertilization, with a short generation time and seven sharply contrasting trait pairs (such as round versus wrinkled seeds), allowing him to establish true-breeding lines before beginning his crosses.

Mendel crossed true-breeding plants differing in a single trait (monohybrid cross), such as round-seeded and wrinkled-seeded plants; all F1 offspring were round, showing complete dominance of round over wrinkled, with wrinkled (the masked trait) called recessive. Self-fertilizing F1 monohybrids produced F2 offspring in a consistent 3:1 ratio (round to wrinkled) across all seven traits he studied, and further self-fertilization to produce F3 revealed that one-third of F2 round plants bred true (like the P1 parent) while two-thirds behaved like heterozygous F1 plants.

Mendel's Interpretation and the Law of Segregation

Mendel proposed that each contrasting trait form was governed by paired hereditary factors (later renamed genes by Johannsen), one from each parent, designated with capital letters for dominant and small letters for recessive forms (e.g. R for round, r for wrinkled); an organism with identical alleles at a locus is homozygous, while one with different alleles is heterozygous. He inferred that allele pairs separate (segregate) during gamete formation, so each gamete receives only one allele per trait, with fertilization restoring the pair randomly - the true-breeding round parent (RR) and wrinkled parent (rr) thus produced a heterozygous F1 (Rr), phenotypically round but genotypically a monohybrid; self-fertilizing F1 produced F2 in a 1 RR : 2 Rr : 1 rr genotypic ratio, matching the observed 3:1 phenotypic ratio. This led Mendel to formulate the law of segregation: the two alleles for a trait in an individual separate from each other during meiosis, so each gamete receives only one, and alleles reunite randomly at fertilization.

Mendel devised the test cross to determine whether an individual showing a dominant phenotype is homozygous or heterozygous, by crossing it with a homozygous recessive individual: if the tested parent is homozygous dominant (RR), all offspring show the dominant phenotype; if heterozygous (Rr), offspring appear in a 1:1 ratio of dominant to recessive phenotypes, with even a single recessive offspring proving heterozygosity in the parent.

Dihybrid Cross and the Law of Independent Assortment

Mendel also studied inheritance of two traits simultaneously (e.g. seed shape and colour) using a dihybrid cross: crossing true-breeding round-yellow with true-breeding wrinkled-green plants produced all round-yellow F1 (dihybrids); self-fertilizing these F1 dihybrids produced F2 offspring showing not just the two parental combinations (round-yellow, wrinkled-green) but also two new recombinant combinations (round-green, wrinkled-yellow), in a clear 9:3:3:1 phenotypic ratio. This indicated the alleles for seed shape and colour assort independently into gametes rather than staying in fixed parental combinations, forming four gamete types (RY, Ry, rY, ry) in equal 1:1:1:1 proportions, leading Mendel to formulate the law of independent assortment: when two trait pairs are followed together, their alleles assort into gametes independently of each other.



Probability, the chance of an event occurring, underlies this law: since seed shape and seed colour are independent events, the joint probability of any combined phenotype equals the product of their individual probabilities (the product rule) - e.g. round ($3/4$) x yellow ($3/4$) = round-yellow ($9/16$). Independent assortment of genes actually depends on independent assortment of the chromosomes bearing them; genes on the same chromosome (linked genes) do not assort independently, while genes on different (non-homologous) chromosomes do. Mendel presented his findings in 1865 (published 1866), but his work lay neglected for 34 years until its rediscovery in 1900 by Correns, de Vries and Tschermak.

Dominance Relations: Complete, Incomplete, Codominance and Overdominance

There are four recognised dominance relations between alleles. In complete dominance (shown by all seven of Mendel's pea traits), one allele fully masks its partner, so the heterozygote is phenotypically identical to the dominant homozygote. In incomplete dominance, discovered by Carl Correns in the 4 O'clock plant, the heterozygote shows an intermediate phenotype between the two homozygotes (e.g. crossing true-breeding red and white flowers produces pink F₁, with F₂ segregating 1 red : 2 pink : 1 white) - since neither allele is truly dominant, both are denoted with the same letter, distinguished by superscript (R¹, R²). In codominance, both alleles are expressed independently and simultaneously in the heterozygote, each producing its own distinct product, rather than blending; the human MN blood group system illustrates this, with genotype LM LN individuals expressing both M and N antigens on their red blood cells.

In overdominance, the heterozygote's phenotypic expression actually exceeds that of either homozygote, as seen in *Drosophila* eye pigment, where the heterozygote (w⁺/w) shows more fluorescent pigment than either the wild-type or white-eyed homozygote. Gene mutations may also produce multiple alleles, more than two alternative forms of a gene (some genes have up to 300); any diploid individual carries at most two of these, while a haploid gamete carries only one. The ABO blood group system, discovered by Karl Landsteiner (1901) and genetically explained by Bernstein (1925), is encoded by three multiple alleles (I^A, I^B, i) of a single gene on chromosome 9: I^A and I^B are codominant with each other (producing type AB when both present) but both are dominant to i (recessive), so genotypes I^AI^A/I^Ai give type A, I^BI^B/I^Bi give type B, and ii gives type O; O individuals are universal donors (no A or B antigen) and AB individuals are universal recipients (no anti-A or anti-B antibodies).

Rh Blood Group System, Epistasis and Pleiotropy

The Rh blood group system, named after the Rhesus monkey in which its antigen was first found (Landsteiner, 1930s), is defined primarily by the D locus: allele D (dominant, produces Rh factor, Rh⁺) and allele d (recessive, no Rh factor, Rh⁻); unlike ABO antibodies, anti-Rh antibody production requires prior exposure to Rh antigen. Erythroblastosis foetalis (haemolytic disease of the newborn) occurs when an Rh⁻ mother carrying an Rh⁺ foetus is exposed to foetal Rh antigen (often at a prior birth), producing maternal anti-Rh antibodies that cross the placenta in a later pregnancy and destroy the foetal red blood cells, causing anaemia, jaundice, and potentially death; this is prevented by giving the Rh⁻ mother an Rh



antiserum injection during pregnancy and immediately after birth, destroying any foetal Rh+ cells before they can stimulate her own antibody production.

Epistasis is gene interaction in which an allele at one locus interferes with or masks the effect of a gene at a different locus (distinct from dominance, which involves alleles at the same locus); the Bombay phenotype illustrates this, in which a recessive hh genotype at the H locus (chromosome 19) prevents attachment of A or B antigens to red blood cells even in individuals who genetically carry IA or IB alleles, making them phenotypically (but not genotypically) type O. Pleiotropy is the phenomenon in which a single gene affects two or more apparently unrelated traits (a pleiotropic gene); for example, the dominant W allele in cats causes both pure white fur and deafness, since the underlying melanocyte defect disrupts both fur pigmentation and the inner ear hair cells that detect sound.

Continuously Varying (Polygenic) Traits, Gene Linkage and Crossing Over

While traits like pea seed shape show discontinuous, qualitative variation (sharply distinct phenotypes controlled by one gene), many traits, such as human height, weight, skin colour, and wheat grain colour, show continuous, quantitative variation across a smooth range of phenotypes; such polygenic traits are controlled by multiple genes (polygenes) at different loci, each contributing a small additive positive or negative effect. Nilsson-Ehle's classic wheat grain colour study found that crossing true-breeding dark red and white grain plants produced intermediate light-red F1, and F2 grains showed seven distinct shades in a 1:6:15:20:15:6:1 ratio, explained by three independently assorting gene pairs (Aa, Bb, Cc) whose combined 'dose' of red-pigment alleles determines shade; environmental factors further smooth the distribution of phenotypes, producing the bell-shaped curve typical of traits like human height.

Because chromosome number is limited relative to the number of genes, each chromosome carries many genes, all linked together as a linkage group (humans have 23 linkage groups); linked genes do not assort independently, reducing genetic recombination among offspring. However, crossing over, the exchange of chromosome segments between non-sister chromatids of homologous chromosomes during meiosis, can separate linked genes, producing recombinant gamete types alongside parental types; the closer two loci are, the less likely they are to be separated by crossing over. Recombination frequency, the proportion of recombinant types among all gamete combinations, is directly proportional to the physical distance between linked gene loci, allowing genes to be mapped along a chromosome (1% recombination frequency = 1 map unit).

Chromosomal Patterns of Sex Determination and Sex Linkage in Drosophila

T.H. Morgan (1911) discovered that Drosophila's fourth chromosome pair differs between sexes: females have two similar rod-shaped X chromosomes, while males have one X and one differently shaped Y, together called sex chromosomes (all other chromosomes are autosomes); humans similarly have 22 autosome pairs and one sex chromosome pair (XX in females, XY in males), with the SRY gene (Sex-determining Region of Y) at the tip of the Y chromosome's short arm triggering male development. Three common sex determination patterns exist: in the XO-XX type (grasshopper, Protenor bug), males lack a second sex



chromosome entirely (XO, heterogametic, producing X-bearing or nullo gametes) while females are XX (homogametic); in the XY-XX type (*Drosophila*, humans, most mammals), males (XY) are heterogametic and females (XX) homogametic, giving a 1:1 sex ratio; in the ZZ-ZW type (birds, moths, butterflies, discovered by Seiler in 1914), the pattern is reversed - females (ZW) are heterogametic and males (ZZ) homogametic. Despite sharing the XY-XX pattern, *Drosophila* and humans differ mechanistically: an XO individual is a sterile male in *Drosophila* but a sterile female (Turner's syndrome) in humans, while XXY is a fertile female in *Drosophila* but sterile male (Klinefelter's syndrome) in humans, since *Drosophila* sex depends on the ratio of X chromosomes to autosome sets rather than the presence of Y (as in humans, where SRY is decisive).

T.H. Morgan (1910) provided key experimental support for the chromosomal theory of inheritance through his discovery of sex linkage in *Drosophila*, an organism well suited to genetics due to its easy culture, sexual dimorphism, two-week generation time, large number of distinct traits, and just eight chromosomes (four pairs). When Morgan's colleague Calvin Bridges found a mutant white-eyed male fly and Morgan crossed it with a wild-type red-eyed female, all F1 offspring had red eyes (showing red is dominant); F1 x F1 crosses produced F2 in which all white-eyed flies were male, a result inconsistent with simple autosomal Mendelian inheritance. Morgan concluded the eye-colour gene is located on the X chromosome with no corresponding allele on Y, so males (hemizygous, having just one X) express even a single recessive allele, while females (with two X chromosomes) can be homozygous or heterozygous; a subsequent test cross of the white-eyed P1 male with his heterozygous red-eyed F1 daughter confirmed this hypothesis, producing red-eyed and white-eyed offspring of both sexes in a 1:1 ratio each.

Sex Linkage in Humans, Sex-limited/Sex-influenced Traits, and Diabetes Genetics

A trait whose gene lies on the X chromosome is X-linked (sex-linked); such traits pass in a characteristic crisscross fashion from maternal grandfather through a carrier daughter to a grandson, never directly from father to son (since a son inherits only Y from his father). X-linked recessive traits in humans include haemophilia (types A and B, affecting blood clotting factors VIII and IX respectively; type C is autosomal) and red-green colour blindness (caused by mutations in the X-linked red or green opsin genes); such traits affect males more often than females, since a male needs only one recessive allele to be affected while a female needs two. X-linked dominant traits, such as hypophosphatemic (vitamin D-resistant) rickets, follow a different pattern: all daughters of an affected father are affected while none of his sons are, and an affected heterozygous mother passes the trait to half her children of both sexes. Y-linked traits pass only from father to son (since only sons inherit the Y chromosome), with maleness itself (via the SRY gene) being the clearest example.

Sex-limited traits (such as milk yield in dairy cattle or beard growth in humans) are expressed in only one sex due to anatomical differences, even though the underlying genes may be carried and transmitted by both sexes; sex-influenced traits (such as pattern baldness) occur in both sexes but are expressed differently due to hormonal differences, with the same allele behaving as dominant in one sex and recessive in the other (so a heterozygous man goes bald while a heterozygous woman does not). Diabetes mellitus, a



hereditary disorder of elevated blood sugar, has two major types: Type I (insulin-dependent, juvenile-onset, an autoimmune disorder in which the immune system destroys insulin-producing pancreatic beta cells, requiring lifelong insulin treatment) and Type II (non-insulin-dependent, accounting for 90% of cases, typically arising after age 40 and associated with obesity-driven insulin resistance, involving multifactorial polygenic inheritance combined with environmental influence); MODY (maturity-onset diabetes of the young), an early-onset autosomal dominant form, is caused about half the time by mutations in the glucokinase gene.

Important Definitions

Term	Definition
Gene	The basic unit of biological information; a DNA segment occupying a specific locus on a chromosome that encodes hereditary information.
Allele	One of the alternative forms of a gene occupying the same locus on homologous chromosomes.
Genotype	The genetic constitution of an individual for a particular trait, as distinct from its observable phenotype.
Test cross	A cross between an individual showing a dominant phenotype and a homozygous recessive individual, used to determine the dominant individual's genotype.
Codominance	A dominance relation in which both alleles of a heterozygote are expressed independently and simultaneously, each producing a distinct product.
Epistasis	Gene interaction in which an allele at one locus masks or interferes with the phenotypic effect of a gene at a different locus.
Linkage group	The set of genes located together on the same chromosome, which do not assort independently during meiosis.
Recombination frequency	The proportion of recombinant-type gametes (or offspring) relative to the total, used to estimate the map distance between two linked gene loci.

Key Facts

Item	Fact
Monohybrid F2 ratio	Mendel's monohybrid cross ($Rr \times Rr$) gives F2 phenotypic ratio 3 (dominant) : 1 (recessive), genotypic ratio 1:2:1 ($RR:Rr:rr$).
Dihybrid F2 ratio	Mendel's dihybrid cross gives F2 phenotypic ratio 9:3:3:1 (two parental + two recombinant phenotype classes).
Product rule	Joint probability of two independent events = product of their individual probabilities (e.g. $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$ for round-yellow).
Recombination frequency formula	Recombination frequency (%) = $\left(\frac{\text{Recombinant types}}{\text{Sum of all combinations}} \right) \times 100$.
Map distance	



Item	Fact
	1% recombination frequency = 1 map unit of distance between two linked gene loci.
Down's/Klinefelter's/Turner's chromosome counts	Down's = 47 (trisomy 21); Klinefelter's = 47 (44+XXY); Turner's = 45 (44+X).
Wheat grain colour F2 ratio	Nilsson-Ehle's trihybrid polygenic wheat cross gives F2 ratio 1:6:15:20:15:6:1 across 7 colour shades (3 gene pairs, 6 alleles).
Sex ratio in XY-XX and ZZ-ZW systems	All common sex determination patterns (XO-XX, XY-XX, ZZ-ZW) produce an expected male:female sex ratio of 1:1.

Diagrams & Illustrations

Monohybrid Cross: Law of Segregation: a Punnett square diagram of Mendel's Rr x Rr monohybrid cross, showing the F2 genotypic ratio 1 RR : 2 Rr : 1 rr and phenotypic ratio 3 round : 1 wrinkled.

Monohybrid Cross: Law of Segregation (Rr x Rr)

Parents: Rr (round) x Rr (round)

Gametes from each parent: R or r

	R	r
R	RR	Rr
r	Rr	rr

Round (R₋): 3

Wrinkled (rr): 1

F2 phenotypic ratio = 3 round : 1 wrinkled
F2 genotypic ratio = 1 RR : 2 Rr : 1 rr

Monohybrid Cross: Law of Segregation



Dihybrid Cross: Law of Independent Assortment: a Punnett square diagram of Mendel's dihybrid cross ($RrYy \times RrYy$) showing the F2 phenotypic ratio 9:3:3:1, including two new recombinant phenotype classes.

Dihybrid Cross: Law of Independent Assortment ($RrYy \times RrYy$)

Gametes: RY, Ry, rY, ry (each 1/4)

	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

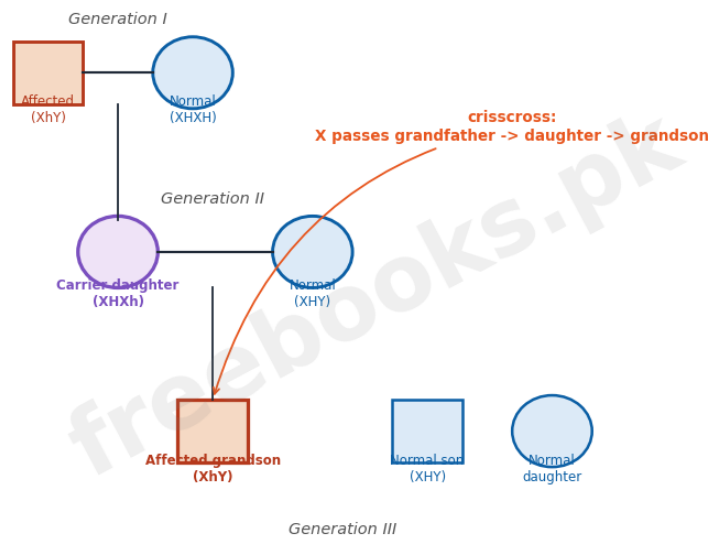
 Round Yellow (9)	 Round Green (3)	 Wrinkled Yellow (3)
 Wrinkled Green (1)	F2 ratio = 9:3:3:1	

Dihybrid Cross: Law of Independent Assortment

Sex-linked Inheritance: The Crisscross Pattern: a diagram illustrating the crisscross inheritance pattern of an X-linked recessive trait, passing from an affected maternal grandfather through a phenotypically normal carrier daughter to an affected grandson.



Sex-linked Inheritance: The Crisscross Pattern



Sex-linked Inheritance: The Crisscross Pattern

Short Questions & Answers

Q1. Differentiate phenotype and genotype.

Ans. Phenotype is the observable form or appearance of a trait (e.g. red or white flowers); genotype is the underlying genetic constitution (allele combination) responsible for that phenotype (e.g. RR, Rr, or rr).

Q2. What is a test cross, and why is it useful?

Ans. A test cross mates an individual showing a dominant phenotype with a homozygous recessive individual; it reveals whether the dominant individual is homozygous (all offspring show the dominant phenotype) or heterozygous (offspring appear in a 1:1 dominant:recessive ratio), since even one recessive offspring proves heterozygosity.

Q3. Differentiate incomplete dominance and codominance.

Ans. In incomplete dominance, the heterozygote shows a single intermediate phenotype blending both parental traits (e.g. pink from red x white 4 O'clock flowers); in codominance, both alleles are expressed fully and independently in the heterozygote, producing two distinct, separately visible products rather than a blend (e.g. MN blood type showing both M and N antigens).

Q4. What is epistasis, and how does it differ from dominance?

Ans. Epistasis is interaction between genes at different loci, where one gene's effect masks or interferes with another gene's effect (e.g. the Bombay phenotype, where hh at the H locus masks IA/IB expression at the ABO locus); dominance, by contrast, is a relationship between alleles of the same gene at the same locus.



Q5. What is crossing over, and how does it relate to recombination frequency?

Ans. Crossing over is the exchange of chromosome segments between non-sister chromatids of homologous chromosomes during meiosis, which can separate linked genes; recombination frequency (the proportion of recombinant gamete types) is directly proportional to the distance between the linked loci, allowing genes to be mapped along a chromosome.

Q6. Why do X-linked recessive traits appear more often in males than in females?

Ans. Males are hemizygous for X-linked genes (having only one X chromosome), so a single recessive allele is sufficient to express the trait; females have two X chromosomes and so need two copies of the recessive allele (homozygous recessive) to express the same trait, making them far more likely to be unaffected carriers instead.

Long Questions & Answers

Q1: Describe Mendel's dihybrid cross experiment and explain how it led to the law of independent assortment.

After thoroughly working out the pattern of inheritance for each of his seven pea traits studied one at a time, Mendel took the logical next step of investigating what would happen when two different traits were followed together simultaneously within the very same cross, choosing to examine seed shape (round versus wrinkled) and seed colour (yellow versus green) together as his test case. He began, exactly as in his earlier monohybrid work, by crossing two true-breeding parental lines that differed from each other in both of these traits at once: a true-breeding plant producing seeds that were both round and yellow was crossed with a true-breeding plant producing seeds that were both wrinkled and green, and because round and yellow had each already been separately established as the dominant phenotype for their respective trait, every single F1 offspring produced by this cross, referred to as dihybrids because they were heterozygous for two different gene pairs simultaneously, displayed the completely dominant round and yellow phenotype for both traits. Mendel's crucial next step, the one that actually defined this as a true dihybrid cross rather than merely two separate monohybrid crosses run in parallel, was to allow these F1 dihybrid plants to self-fertilize with each other and then carefully examine the full range of phenotypes that appeared among their F2 offspring, and the results he obtained here proved genuinely surprising and highly informative: the resulting F2 seeds were not restricted to reappearing in only the original two parental combinations of round-yellow and wrinkled-green, but instead also included two entirely new phenotypic combinations that had never actually been present in either of the original true-breeding parental lines, namely round-green seeds and wrinkled-yellow seeds, and when Mendel carefully counted out the relative proportions of all four of these phenotype classes among his F2 population, he consistently found them occurring in a remarkably clean and highly reproducible ratio of 9 round-yellow to 3 round-green to 3 wrinkled-yellow to 1 wrinkled-green, a characteristic pattern now universally known as the classic 9:3:3:1 dihybrid ratio. The unmistakable appearance of these two entirely new, non-parental recombinant phenotype classes among the F2 generation provided Mendel with clear and compelling evidence that some genuine process of shuffling or reshuffling must have taken place involving the alleles for these two different



traits at some specific point during the process of gamete formation in the F1 dihybrid plants, since there was simply no way for genuinely new trait combinations like round-green to have arisen at all if the alleles for seed shape and the alleles for seed colour had instead remained forever locked together in only their original parental combinations throughout the entire process. Mendel correctly identified and named the precise underlying mechanism responsible for generating this reshuffling as the independent assortment of alleles into gametes, and from this he drew the broader and highly significant conclusion that the allele for seed shape carried by any given plant and the allele for seed colour carried by that very same plant were not permanently bound together in their original parental combination, meaning that the allele 'R' for roundness was not eternally forced to travel together specifically with the allele 'Y' for yellowness, nor was the allele 'r' for wrinkledness permanently bound only to the allele 'y' for greenness; rather, during the process of meiotic gamete formation in the doubly heterozygous F1 dihybrid, the two members of each individual allele pair were now understood to separate from each other and become distributed into gametes completely independently of how the members of the other, entirely separate allele pair happened to be simultaneously distributing themselves, so that the R allele had exactly as much chance of ending up paired together with either the Y allele or the y allele in any given gamete, and likewise the r allele had exactly as much chance of pairing with either Y or y. Working through the direct genetic consequence of this principle of independent assortment, Mendel correctly determined that an F1 dihybrid plant with the genotype RrYy would actually produce four genetically distinct types of gametes rather than merely the two parental gamete types one might otherwise naively expect, with these four gamete types specifically being RY, Ry, rY and ry, and critically, because of the truly independent nature of this assortment process, all four of these possible gamete types would be produced by the dihybrid plant in exactly equal proportions relative to one another, in a precise 1:1:1:1 ratio. When Mendel then worked through the full mathematical consequences of allowing all four of these equally frequent gamete types to combine with each other entirely at random during the process of self-fertilization, which is most conveniently and systematically visualized using a sixteen-box Punnett square constructed by crossing all four possible types of female gametes against all four possible types of male gametes, the resulting mathematical combinations reliably and predictably generated precisely the observed 9:3:3:1 phenotypic ratio among the F2 offspring, thereby providing full and complete theoretical justification and explanation for the actual experimental results Mendel had originally observed. On the basis of this entire body of dihybrid cross evidence, Mendel went on to formally state what has become permanently known as his law of independent assortment, which holds specifically that whenever two different, separately contrasting pairs of traits are simultaneously followed together within the very same genetic cross, the alleles governing each of those two traits will assort themselves into the resulting gametes in a manner that is genuinely independent of how the alleles governing the other trait happen to be simultaneously assorting themselves, meaning in practical terms that the particular way in which any one specific trait pair, such as seed shape, distributes its own alleles into gametes has absolutely no influence whatsoever upon how a second, entirely separate and different trait pair, such as seed colour, happens to distribute its own alleles into those very same gametes.



Q2: Discuss the chromosomal patterns of sex determination found in different organisms, and compare sex determination in *Drosophila* and humans.

The scientific search to properly understand the underlying genetic mechanism responsible for the inheritance of biological sex began in earnest shortly after the rediscovery and widespread acceptance of Mendel's original work around 1900, but it was really only with the subsequent discovery of specialized sex chromosomes that biologists finally obtained a genuinely clear and complete picture of exactly how sex determination actually operates at the genetic level, and this understanding revealed that there are, in practice, three broad chromosomal patterns of sex determination that occur most commonly across different groups of organisms. The first of these common patterns is known as the XO-XX type, characteristically found in organisms such as grasshoppers and the Protenor bug, in which the male of the species possesses only a single X chromosome and is described as XO because the second member of what would normally be a matched sex chromosome pair is simply entirely absent from his genome altogether; because of this, the male is considered heterogametic, since the process of meiosis in his body actually produces two genuinely different types of sperm cells in equal number, with exactly half of all his sperm carrying a single X chromosome and the other half instead carrying no sex chromosome whatsoever (a so-called nullo gamete), while the corresponding female of the species, possessing two complete X chromosomes and therefore properly described as XX, is by contrast homogametic, since every single egg cell she produces is entirely uniform and invariably carries exactly one X chromosome; the eventual sex of any given offspring in this system is therefore determined entirely by which specific type of paternal sperm happens to fertilize the maternal egg, with an X-bearing sperm producing an XX daughter and a nullo sperm instead producing an XO son, and this mechanism reliably yields the expected overall 1:1 sex ratio between male and female offspring across the population as a whole. The second, and by far most broadly familiar, pattern is the XY-XX type, characteristically exhibited by *Drosophila*, by humans, and indeed by the great majority of other mammalian species, in which the male is XY and is therefore the heterogametic sex, producing two distinct types of sperm in equal proportion (half bearing an X chromosome, half instead bearing a Y chromosome), while the female, being XX, is homogametic and produces only a single uniform type of egg, each invariably carrying one X chromosome; here, an X-bearing sperm fertilizing the egg will reliably produce an XX female zygote, whereas a Y-bearing sperm fertilizing that same egg will instead reliably produce an XY male zygote, and this mechanism again reliably yields the familiar overall 1:1 sex ratio observed between sons and daughters. The third recognized pattern, discovered specifically by J. Seiler working with moths back in 1914, is the ZZ-ZW type, characteristically found in birds, in butterflies, and in moths, and this particular pattern represents essentially a direct mechanistic reversal of the more familiar XY-XX pattern described above, since in this specific case it is instead the female of the species who is heterogametic, described as ZW, while it is the corresponding male who is homogametic and described as ZZ; here it is specifically the type of egg produced by the mother, rather than the type of sperm produced by the father, that ultimately determines the resulting sex of any given offspring, since the male in this system produces only a single uniform type of sperm (each invariably carrying a Z chromosome),



while the female instead produces two genuinely different types of egg in equal number, one type carrying a Z chromosome and the other type instead carrying a W chromosome, so that fertilization of a Z-bearing egg by the uniform sperm produces a male (ZZ) offspring while fertilization of a W-bearing egg instead produces a female (ZW) offspring, once again yielding the expected overall 1:1 sex ratio. Although both *Drosophila* and humans happen to share this same broadly similar XY-XX chromosomal pattern of sex determination on the surface, there nevertheless exists a fundamentally important underlying mechanistic difference in precisely how sex is actually determined at a deeper biological level between these two particular organisms: in the specific case of humans, the mere physical presence of a single copy of the highly specific SRY gene, located right at the very tip of the short arm of the Y chromosome, is itself absolutely essential and sufficient to actively trigger the entire developmental cascade leading toward maleness, meaning that the simple absence of any Y chromosome (and therefore the absence of SRY) in a human individual will, by default, always lead the developing embryo down the alternative female developmental pathway regardless of how many X chromosomes happen to be present; this SRY-dependent mechanism specifically explains why a human individual with only a single X chromosome and no Y chromosome at all, described as XO and clinically corresponding to Turner's syndrome, is invariably female (albeit typically sterile), while conversely a human individual carrying an additional extra X chromosome alongside a normal Y chromosome, described as XXY and clinically corresponding to Klinefelter's syndrome, is invariably still recognizably male (though again typically sterile) purely because that necessary Y chromosome bearing the crucial SRY gene remains present. In striking contrast, *Drosophila* sex determination does not actually depend directly upon the simple presence or absence of the Y chromosome as such at all, but instead depends specifically upon the overall numerical ratio existing between the total number of X chromosomes present in a given fly's genome relative to the total number of complete sets of autosomes also present in that same genome, an arrangement generally referred to as the X-chromosome-to-autosome balance system; under this alternative balance-based mechanism, an X-to-autosome ratio of 1.00 or higher will reliably produce female development, whereas a ratio of 0.5 or lower will instead reliably produce male development, and this fundamentally different underlying mechanism directly explains why the very same XO chromosomal constitution that reliably produces a sterile female in humans instead reliably produces a sterile male in *Drosophila* (since a single X against two full sets of autosomes yields a low X:autosome ratio of 0.5), while conversely that same XXY chromosomal constitution that reliably produces a sterile male in humans instead reliably produces an entirely fertile female fly in *Drosophila* (since two X chromosomes against two full sets of autosomes yields a full X:autosome ratio of 1.0), demonstrating clearly and conclusively that superficially identical chromosomal constitutions can nevertheless correspond to dramatically different final sexual phenotypes whenever the two organisms being compared actually rely upon two genuinely different underlying molecular mechanisms to translate raw chromosome number into the final observed developmental outcome of biological sex.



MCQs with Answers

1. Partners of a gene pair occupying the same locus on homologous chromosomes are called:

- (a) genotypes (b) alleles (c) phenotypes (d) loci

Correct Answer: (b) alleles. Alleles are the alternative forms of a gene occupying the same locus on homologous chromosomes.

2. Mendel's monohybrid cross ($Rr \times Rr$) produces an F₂ phenotypic ratio of:

- (a) 1:1 (b) 1:2:1 (c) 3:1 (d) 9:3:3:1

Correct Answer: (c) 3:1. The monohybrid F₂ phenotypic ratio is 3 dominant : 1 recessive (genotypic ratio 1:2:1).

3. A test cross is used to determine whether a dominant-phenotype individual is:

- (a) male or female (b) homozygous or heterozygous (c) diploid or haploid (d) linked or unlinked

Correct Answer: (b) homozygous or heterozygous. A test cross (crossing with a homozygous recessive) reveals whether the tested individual is homozygous or heterozygous dominant.

4. In incomplete dominance, the heterozygote phenotype is:

- (a) identical to one homozygote (b) intermediate between the two homozygotes (c) a novel, unrelated phenotype (d) always lethal

Correct Answer: (b) intermediate between the two homozygotes. Incomplete dominance produces a heterozygote phenotype intermediate between the two homozygous parental phenotypes.

5. The ABO blood group system has how many multiple alleles at its single gene locus?

- (a) two (b) three (c) four (d) five

Correct Answer: (b) three. The ABO system has three multiple alleles: I^A, I^B, and i.

6. Erythroblastosis foetalis results from incompatibility of which blood group system between mother and foetus?

- (a) ABO (b) MN (c) Rh (d) Bombay

Correct Answer: (c) Rh. Erythroblastosis foetalis results from Rh incompatibility between an Rh⁻ mother and an Rh⁺ foetus.

7. The Bombay phenotype is an example of which genetic phenomenon?

- (a) codominance (b) epistasis (c) pleiotropy (d) overdominance

Correct Answer: (b) epistasis. The Bombay phenotype results from epistasis: the hh genotype at the H locus masks expression of I^A/I^B alleles at the ABO locus.

8. A quantitative trait controlled by multiple genes at different loci, each with a small additive effect, is called:

- (a) a monogenic trait (b) an epistatic trait (c) a polygenic trait (d) a sex-limited trait

Correct Answer: (c) a polygenic trait. Polygenic (continuously varying) traits are controlled by multiple genes (polygenes) at different loci with additive effects.



9. In the XY-XX sex determination pattern (e.g. humans), which sex is heterogametic?

(a) female (b) male (c) both equally (d) neither

Correct Answer: (b) male. In the XY-XX system, the male (XY) is heterogametic, producing two types of sperm (X-bearing and Y-bearing).

10. X-linked recessive traits such as haemophilia typically pass from:

(a) father directly to son (b) mother directly to daughter only (c) maternal grandfather through a carrier daughter to a grandson (d) father to daughter only, never sons

Correct Answer: (c) maternal grandfather through a carrier daughter to a grandson. X-linked recessive traits show a crisscross pattern, passing from maternal grandfather through a carrier daughter to a grandson.

Quick Revision Summary

- Basics: Gene=basic hereditary unit; allele=alternative form at a locus; genotype=genetic makeup; phenotype=observable trait; gene pool=all alleles in a breeding population. Mendel: pea plant, 7 traits, true-breeding lines, monohybrid cross.
- Law of Segregation: $Rr \times Rr \rightarrow F_2 = 3:1$ phenotype (1:2:1 genotype). Alleles separate at meiosis, reunite randomly at fertilization. Test cross = dominant phenotype $\times$ homozygous recessive, reveals genotype.
- Law of Independent Assortment: dihybrid cross $RrYy \times RrYy \rightarrow F_2 = 9:3:3:1$ (2 parental + 2 recombinant classes). Product rule: joint probability = product of individual probabilities. Genes on different chromosomes (or far apart) assort independently.
- Dominance relations: Complete (heterozygote=dominant homozygote) | Incomplete (heterozygote=intermediate blend, e.g. 4 O'clock pink) | Codominance (both alleles expressed separately, e.g. MN blood group) | Overdominance (heterozygote exceeds both homozygotes, e.g. Drosophila eye pigment).
- Blood groups: ABO = 3 multiple alleles (I^A , I^B codominant; i recessive) $\rightarrow A/B/AB/O$; O =universal donor, AB =universal recipient. Rh = D (dominant, Rh+) vs d (recessive, Rh-); erythroblastosis foetalis = Rh- mother + Rh+ foetus $\rightarrow$ maternal anti-Rh antibodies attack foetal RBCs; prevented by Rh antiserum injection.
- Epistasis (different loci interact, e.g. Bombay phenotype: hh masks I^A/I^B) vs Pleiotropy (1 gene affects multiple traits, e.g. cat W allele = white fur + deafness). Polygenic traits (height, skin colour, wheat grain colour) = continuous variation, multiple genes with additive small effects + environment.
- Gene linkage: genes on same chromosome = linkage group (23 in humans), don't assort independently. Crossing over separates linked genes $\rightarrow$ recombinant gametes. Recombination frequency % = map distance (1%=1 map unit). Sex determination: XO-XX (grasshopper), XY-XX (Drosophila/humans, male heterogametic), ZZ-ZW (birds/moths, female heterogametic) - all give 1:1 sex ratio. Sex linkage: X-linked recessive (haemophilia, colour blindness) = crisscross inheritance, more common in males. Notes by freebooks.pk.



Exam Tips

- Master the Punnett square for both monohybrid (4-box, 3:1) and dihybrid (16-box, 9:3:3:1) crosses by practicing drawing them from memory - almost every exam includes at least one cross-based numerical question.
- Keep the four dominance relations as a clean comparison table (complete/incomplete/codominant/overdominant) with one example organism/trait for each - this is a very common 'differentiate' or 'define with example' question.
- Memorise the ABO genotype-phenotype mapping as a compact table ($I^A I^A / I^A i = A$, $I^B I^B / I^B i = B$, $I^A I^B = AB$, $ii = O$) alongside universal donor (O) and universal recipient (AB) facts.
- Learn epistasis vs pleiotropy as opposite directions: epistasis = one gene affects/masks another gene's trait; pleiotropy = one gene affects multiple traits. Attach exactly one example to each (Bombay phenotype / cat white fur+deafness).
- For sex determination, build a 3-row table (XO-XX / XY-XX / ZZ-ZW) with example organism + which sex is heterogametic - and separately memorise the Drosophila vs human XO/XXY outcome differences as a 2x2 grid.
- Practice the crisscross X-linked recessive inheritance pattern as a 3-generation diagram (affected grandfather -> carrier daughter -> affected grandson) - this exact pattern is tested repeatedly for haemophilia and colour blindness questions.
- Distinguish X-linked recessive, X-linked dominant, Y-linked, sex-limited, and sex-influenced traits with one identifying rule each (recessive=more common in males; dominant=all daughters of affected father affected; Y-linked=father to son only; sex-limited=expressed in one sex only; sex-influenced=dominant in one sex, recessive in other) - exam questions frequently mix these up deliberately.

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FSc Part-II Biology — Punjab Board

CHAPTER 23

Biotechnology

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

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This chapter covers Biotechnology from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Since Mendel's work was rediscovered in 1900, geneticists have made startling advances leading to a new era of DNA technology, enabling the production of substances such as human insulin, drugs and vaccines, environmental clean-up bacteria, and genetically improved plants and animals; gene therapy in humans is now undergoing clinical trials. These notes are prepared by freebooks.pk.

The chapter covers recombinant DNA technology (cloning a gene, obtaining genes, restriction endonucleases, vectors, genomic libraries), the polymerase chain reaction (PCR) and DNA analysis techniques (DNA fingerprinting, gene sequencing), the Human Genome Project, biotechnology products from transgenic bacteria, plants and animals, cloning of transgenic animals, gene therapy, and tissue culture techniques and their applications in agriculture.

Learning Objectives

- Describe the components and process of recombinant DNA technology (gene of interest, restriction enzymes, vectors, DNA ligase).
- Explain the concept of a genomic library and how a specific gene can be located within it using probes.
- Describe the polymerase chain reaction (PCR) and its applications in DNA analysis and forensic science.
- Explain gene sequencing methods and the two primary goals of the Human Genome Project.
- Describe biotechnology products derived from transgenic bacteria, plants and animals.
- Explain the cloning of transgenic animals, using Dolly the sheep as an example.
- Describe gene therapy, including ex vivo and in vivo methods, with examples.
- Describe tissue culture techniques (micropropagation, meristem culture, protoplast culture, anther culture) and their applications.

Key Concepts

Recombinant DNA Technology: Obtaining Genes and Molecular Tools

Cloning of a gene produces many identical copies; recombinant DNA technology (genetic engineering) is used when a large quantity of a gene is required, while the polymerase chain reaction (PCR) can create copies more quickly within a laboratory test tube. Recombinant DNA technology aims to synthesise recombinant DNA containing DNA from two different sources, requiring: a gene of interest to be cloned, molecular scissors to cut it out, a molecular carrier (vector) on which to place it, and an expression system into which the gene-vector combination is introduced to produce a specific product. There are three ways to obtain a gene of interest: isolating it directly from a chromosome (using restriction endonucleases to cut at flanking sites), synthesising it chemically in the laboratory (for small



genes), or synthesising complementary DNA (cDNA) from messenger RNA using the enzyme reverse transcriptase.

Restriction endonucleases (restriction enzymes) are natural bacterial enzymes that cut viral DNA to protect the bacterium from infection, without harming the bacterium's own chromosome; Hamilton O. Smith isolated the first restriction enzyme in 1970, and over 400 have since been identified (about 20 in common use), each cutting DNA at specific palindromic sequences (symmetrical 4-6 nucleotide sequences). EcoRI, a commonly used restriction enzyme, cuts double-stranded DNA to leave single-stranded, complementary overhangs called 'sticky ends,' which can bind to any DNA cut by the same enzyme through complementary base pairing, facilitating insertion of foreign DNA into a vector. A vector is the means by which recombinant DNA is introduced into a host cell; a common vector is the plasmid, a natural, extra-chromosomal, circular DNA molecule (discovered while studying *Escherichia coli*) that often carries antibiotic-resistance genes - plasmid pSC101 carries tetracycline resistance, while pBR322 carries both tetracycline and ampicillin resistance, enabling selection of bacteria that have taken up a modified plasmid.

Building Recombinant DNA and Genomic Libraries

To prepare recombinant DNA, a plasmid is cut with the same restriction enzyme used to isolate the gene of interest, and the gene is then joined to the plasmid's sticky ends using the enzyme DNA ligase, which seals the foreign DNA into the vector, producing recombinant (chimaeric) DNA. A clone is a large number of identical molecules, cells, or organisms derived from one original; bacterial cells, especially when treated with calcium chloride to increase membrane permeability, readily take up recombinant plasmids, and as the bacterium reproduces, each resulting cell in the bacterial clone carries at least one copy of the plasmid (and hence the gene of interest), allowing the cloned gene or its protein product to be isolated. Besides plasmids, bacterial viruses (such as lambda phage) can also serve as vectors: after the phage infects a bacterium, the recombinant DNA it carries directs production of many new viruses, each carrying a copy of the cloned gene.

A genomic library is a collection of bacterial or bacteriophage clones, each carrying a different DNA segment from a source organism, together representing that organism's entire genome; it is made by slicing an organism's DNA into fragments and inserting them into vectors taken up by host bacteria. A specific gene can be located within a genomic library using a probe, a single-stranded, radioactively or fluorescently labelled nucleotide sequence that hybridises (base-pairs) specifically with its complementary target DNA sequence, allowing bacterial colonies carrying the gene of interest to be identified, isolated, and further analysed or cloned.

The Polymerase Chain Reaction (PCR) and DNA Analysis

Kary B. Mullis developed the polymerase chain reaction (PCR) in 1983, providing a fast, inexpensive way to create millions of copies of a specific DNA sequence directly in a test tube, so precise that it can amplify a target present at less than one part per million in a DNA sample; PCR takes its name from DNA polymerase, the enzyme that repeatedly carries out replication to generate millions of copies, though it does not replace gene cloning when large



quantities of protein product are needed. Before PCR, primers (about 20-base sequences complementary to the DNA flanking the target region) must be prepared, since DNA polymerase can only extend, not initiate, a DNA strand; the temperature-insensitive (thermostable) Taq polymerase, extracted from the hot-spring bacterium *Thermus aquaticus*, allows repeated heating cycles (to separate DNA strands) without needing to add fresh enzyme, and PCR is now performed automatically using a thermocycler.

DNA fingerprinting analyses an individual's entire genome using restriction enzymes to produce a unique collection of differently sized DNA fragments (restriction fragment length polymorphisms, RFLPs), separated by size using gel electrophoresis and visualised as a distinctive banding pattern using genetic marker probes recorded on X-ray film; since DNA is inherited, a person's fingerprint resembles that of their parents, enabling applications such as identifying remains, resolving disputed parentage cases (a child's bands must match both biological parents), and forensic criminal investigation (matching suspect DNA to evidence from a crime scene). PCR amplification and DNA analysis are also used to diagnose viral infections, genetic disorders and cancer, to trace human evolutionary history, and even to sequence DNA from ancient specimens, such as a 76,000-year-old mummified human brain and a 17-20 million-year-old plant fossil.

Gene Sequencing and the Human Genome Project

Methods developed in the late 1970s allow the nucleotide sequence of a purified DNA fragment to be determined by generating DNA pieces of different sizes (all starting from the same point but ending at different points), separating them by size on agarose gel, and reading the sequence directly from the gel; Sanger's method uses dideoxynucleoside triphosphates to terminate DNA synthesis at specific points, while the Maxam-Gilbert method chemically cuts DNA into fragments of different sizes. Modern automated sequencing uses chain-terminating nucleotides labelled with different coloured fluorescent dyes, allowing all four synthesis reactions in one tube; a laser-based detector reads the fluorescent colour of each band as it passes, and a computer records the resulting sequence - this automation has enabled sequencing of the genomes of many organisms, including bacteria, yeasts, *Drosophila*, *Arabidopsis*, mouse and human.

The Human Genome Project, a massive international effort originally funded by the U.S. government, has two primary goals: constructing a genetic map showing the sequence of genes along each chromosome (achieved for human chromosome 22 in 1999 and for the entire genome by 2001, revealing a genome 25 times larger than any previously sequenced), often relying on RFLPs to help pinpoint disease-causing genes (since a particular RFLP and a nearby defective gene, such as the one causing Huntington's disease, are often inherited together); and constructing a complete base-sequence map of all three billion base pairs of the human genome (equivalent to roughly 200 volumes of a 1000-page encyclopaedia), a goal that has now been fully achieved.

Biotechnology Products: Transgenic Bacteria and Transgenic Plants

Organisms with a foreign gene inserted into them are called transgenic organisms. Transgenic bacteria, grown in large vats called bioreactors, are used to produce



biotechnology products such as insulin, human growth hormone, tissue plasminogen activator, haemophilia factor VIII, and hepatitis B vaccine; other transgenic bacteria have been engineered to protect plants from frost damage (frost-minus bacteria), protect corn roots from insects (via an insect toxin gene), clean up oil spills and toxic waste, act as biofilters against airborne pollutants, remove sulfur from coal, and even extract metals such as copper, uranium and gold through enhanced bioleaching.

Transgenic plants are produced by introducing foreign genes into immature embryos or into protoplasts (plant cells with the cell wall removed), often using an electric current to create temporary pores in the plasma membrane for DNA entry; foreign genes have made cotton, corn and potato pest-resistant (via an insect toxin) and soybeans herbicide-resistant, with transgenic crops planted on over 70 million acres worldwide by 1999. Since regenerating cereal grains from protoplasts is difficult, other methods are used for crops like corn and wheat: the bacterium *Agrobacterium* (which naturally infects plants) can be engineered to carry a recombinant plasmid into plant cells, and the 'particle gun' developed by Sanford and Klein (1987) bombards plant tissue with DNA-coated microscopic metal particles. Plants have also been engineered to produce biodegradable plastic, human hormones, clotting factors, and antibodies (e.g. in corn and soybean seeds) for medical use.

Transgenic Animals and Cloning of Transgenic Animals

Techniques for inserting genes into animal eggs (by micro-injection or vortex mixing with silicon-carbide needles) have produced transgenic fish, cows, pigs, rabbits and sheep, many carrying the gene for bovine growth hormone to increase size; genetically engineered fish are kept in escape-proof ponds due to ecological concerns. 'Gene pharming,' the use of transgenic farm animals to produce pharmaceuticals secreted in their milk, is being pursued for treatments of cystic fibrosis, cancer, and blood diseases; antithrombin III, used to prevent blood clots during surgery, is currently produced by a herd of transgenic goats. Researchers have also engineered mice to secrete human growth hormone in their urine rather than milk, since urine offers practical advantages (produced by all animals from birth, unlike milk, which only mature females produce).

Cloning a transgenic animal (asexual reproduction using only that one animal's genes) is the preferred way to obtain identical copies once a useful transgenic animal has been produced; although it was long believed adult vertebrates could not be cloned (since specialised cells turn off most of their genes), scientists at the Roslin Institute in Scotland announced the successful cloning of an adult sheep, Dolly, in 1997, followed by cloned calves and goats. The technique involves injecting an enucleated egg with a diploid (2n) nucleus from an adult somatic cell (e.g. cumulus cells, which cling to the egg after ovulation), then chemically stimulating the egg to begin dividing; the resulting offspring has the genotype and phenotype of the nucleus donor. Human cloning is currently prohibited by presidential order in the United States, though some other countries continue related research.

Gene Therapy

Gene therapy is the insertion of genetic material into human cells to treat a disorder, either by supplying healthy genes to compensate for faulty ones or by using genes to treat



conditions such as cancer and cardiovascular disease; it uses two main approaches, *ex vivo* (cells are removed, modified, and returned to the patient) and *in vivo* (genetic material is delivered directly into the patient's body). In *ex vivo* therapy for severe combined immunodeficiency syndrome (SCID), caused by a missing adenosine deaminase (ADA) enzyme needed for T and B cell maturation, bone marrow stem cells are removed, infected with a retrovirus carrying a normal ADA gene, and returned to the patient, producing sustained improvement in immune function. Similarly, for familial hypercholesterolemia (a liver receptor deficiency causing dangerously high blood cholesterol), a portion of excised liver tissue is infected with a retrovirus carrying the normal receptor gene, lowering serum cholesterol in several patients.

In vivo gene therapy is being tested for cystic fibrosis (caused by a missing chloride ion channel gene), using liposomes coated with the therapeutic gene sprayed into the nostrils, though limited gene transfer has so far restricted its success; gene therapy is also used to make cancer patients more tolerant of chemotherapy or make tumours more vulnerable to it, and a plasmid-coated balloon catheter carrying a vascular endothelial growth factor gene has been used during coronary angioplasty to promote blood vessel growth around obstructed arteries. Future applications may include treating haemophilia (via cells with normal clotting-factor genes, possibly in implanted organoids) and Parkinson's disease (via grafted dopamine-producing cells).

Tissue Culture and Genetic Engineering of Plants for Improved Traits

Tissue culture is the growth of tissue in an artificial liquid culture medium; German botanist Gottlieb Haberlandt proposed in 1902 that plant cells are totipotent (each cell retains the full genetic potential of the organism), and in 1958 Cornell botanist F.C. Steward confirmed this by growing a complete carrot plant from a small piece of phloem tissue, whose dividing cells first formed an undifferentiated callus before differentiating into shoots and roots. Tissue culture has led to micropropagation, the commercial mass production of genetically identical (clonal) seedlings, often via meristem culture (using auxin and cytokinin to stimulate new shoot growth from a shoot tip), which has the added benefit of producing virus-free plants, since meristem tissue itself is naturally virus-free. Protoplasts (cell-wall-free plant cells) can also regenerate a new wall, divide, and be manipulated into somatic embryos, sometimes encapsulated as shippable 'artificial seeds' and mass-produced in bioreactors for crops like tomato and celery and ornamentals like lilies; anther culture allows haploid plants to be generated from pollen grain cells, useful for producing homozygous diploid plants (after chromosome doubling) that directly express recessive traits, while cell suspension cultures (e.g. of *Cinchona ledgeriana* for quinine, or *Digitalis lanata* for digitoxin) can produce valuable plant chemicals without farming the whole plant.

Traditional hybridisation (crossing different plant varieties) has long been used to combine desirable traits, but modern genetic engineering allows direct gene transfer into a plant protoplast, using high-voltage electric pulses to create temporary membrane pores for DNA entry (demonstrated early on by inserting the firefly luciferase gene into tobacco, making the plants glow under luciferin). Since cereal protoplasts are difficult to regenerate, alternative methods are used for crops like corn and wheat: the *Agrobacterium* bacterium can carry a recombinant plasmid into intact plant cells, or the 'particle gun' can bombard



plant callus tissue with DNA-coated metal particles. Genetic engineering has produced crops with improved agricultural traits (herbicide, salt, drought and cold tolerance, improved yield) and improved food quality traits (altered fatty acid, protein, starch and amino acid content, disease resistance); notable achievements include salt-tolerant Arabidopsis (engineered to sequester excess sodium in vacuoles) and soybeans producing modified, healthier oleic acid-based oils, with ongoing research aiming to introduce the more heat- and drought-efficient C4 photosynthetic pathway into rice.

Important Definitions

Term	Definition
Recombinant DNA	DNA formed by joining DNA segments from two different sources, such as a gene of interest inserted into a plasmid vector.
Restriction endonuclease	A bacterial enzyme that cuts DNA at specific palindromic sequences, used as a molecular scissor in recombinant DNA technology.
Vector	The means (such as a plasmid or virus) by which recombinant DNA is introduced into a host cell.
Genomic library	A collection of bacterial or bacteriophage clones, each carrying a different DNA fragment, that together represent an organism's entire genome.
Polymerase chain reaction (PCR)	A laboratory technique that rapidly creates millions of copies of a specific DNA sequence using repeated cycles of DNA polymerase-driven replication.
Transgenic organism	An organism that has had a foreign gene inserted into its genome.
Gene therapy	The insertion of genetic material into human cells to treat a disorder, either by supplying healthy genes or using genes therapeutically.
Totipotent	Describes a cell (such as a plant cell) that retains the full genetic potential to develop into a complete organism.

Key Facts

Item	Fact
First restriction enzyme discovery	Hamilton O. Smith isolated the first restriction enzyme in 1970; over 400 have since been identified, about 20 in common use.
PCR development	Kary B. Mullis developed PCR in 1983; PCR can amplify a target present at less than 1 part per million of total DNA.
Taq polymerase source	Taq polymerase (thermostable) is extracted from the hot-spring bacterium <i>Thermus aquaticus</i> .
Human genome size	The human genome contains about 3 billion base pairs, about 25 times larger than any other genome sequenced at the time.
Chromosome 22 and full genome sequencing dates	Human chromosome 22 was sequenced in 1999; the full human genome was published in 2001.



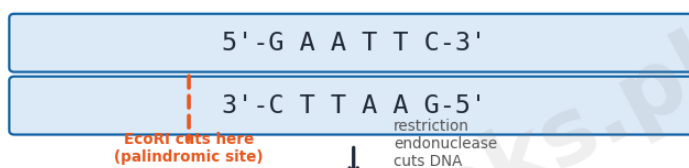
Item	Fact
First cloned mammal	Dolly the sheep, cloned at the Roslin Institute, Scotland, was announced in 1997 - the first cloned adult vertebrate.
Transgenic crop acreage (1999)	Transgenic crops were planted on more than 70 million acres worldwide in 1999.
Ancient DNA sequencing examples	PCR has enabled sequencing of DNA from a 76,000-year-old mummified human brain and a 17-20 million-year-old plant fossil.

Diagrams & Illustrations

Restriction Enzyme Action: Creating Sticky Ends: a diagram showing a restriction enzyme (e.g. EcoRI) cutting double-stranded DNA at a palindromic recognition sequence to produce complementary single-stranded 'sticky ends' that can bind foreign DNA cut by the same enzyme.

Restriction Enzyme Action: Creating Sticky Ends (EcoRI)

Before cutting:



After cutting - sticky ends produced:



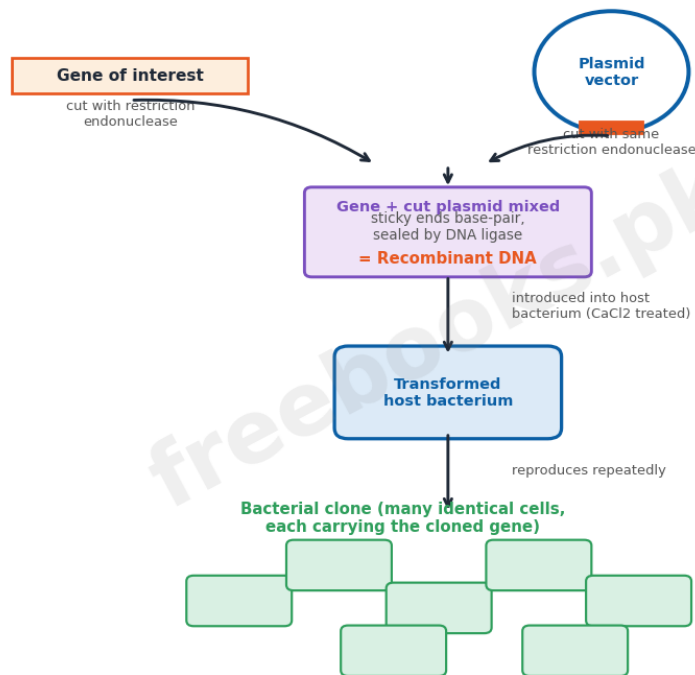
Complementary sticky ends allow foreign DNA cut by the same enzyme to base-pair and join with the vector.

Restriction Enzyme Action: Creating Sticky Ends

Cloning a Gene: Recombinant DNA Technology: a flow diagram showing the steps of gene cloning: cutting the gene of interest and a plasmid vector with the same restriction enzyme, joining them with DNA ligase to form recombinant DNA, and introducing this into a host bacterium to form a bacterial clone.



Cloning a Gene: Recombinant DNA Technology

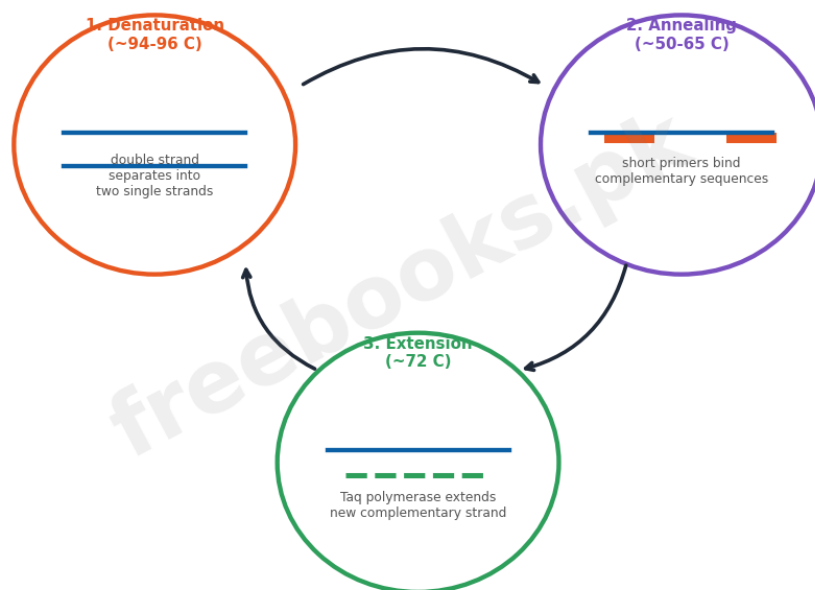


Cloning a Gene: Recombinant DNA Technology

The Polymerase Chain Reaction (PCR) Cycle: a diagram showing the three repeating steps of a PCR cycle: denaturation (heating to separate DNA strands), annealing (primers bind complementary sequences), and extension (Taq polymerase synthesizes new complementary strands), doubling the DNA with each cycle.

The Polymerase Chain Reaction (PCR) Cycle

Each completed cycle doubles the amount of target DNA
(~25-35 cycles -> millions of copies)



Short Questions & Answers

Q1. What is a restriction endonuclease, and why is it called a 'molecular scissor'?

Ans. A restriction endonuclease is a bacterial enzyme that cuts DNA at specific palindromic sequences; it is called a molecular scissor because it precisely cuts out or opens DNA at defined sites, enabling a gene of interest and a vector to be cut and later joined together in recombinant DNA technology.

Q2. What is a vector, and give one example.

Ans. A vector is the means by which recombinant DNA is introduced into a host cell; a common example is a plasmid, a natural, circular, extra-chromosomal bacterial DNA molecule that can carry a gene of interest into a host bacterium.

Q3. What is a genomic library, and how is a specific gene located within it?

Ans. A genomic library is a collection of bacterial or bacteriophage clones, each carrying a different DNA fragment, together representing an organism's entire genome; a specific gene is located using a labelled probe, a single-stranded nucleotide sequence that hybridizes specifically with its complementary target sequence.

Q4. Why is Taq polymerase essential for PCR?

Ans. Taq polymerase, extracted from the heat-tolerant bacterium *Thermus aquaticus*, is thermostable and can withstand the high temperatures used to separate DNA strands during each PCR cycle, so it does not need to be replaced between cycles, allowing PCR to be automated in a thermocycler.

Q5. What is DNA fingerprinting, and name one of its applications.

Ans. DNA fingerprinting is a technique that analyzes an individual's unique pattern of restriction fragment length polymorphisms (RFLPs) using restriction enzymes and gel electrophoresis; applications include forensic criminal identification, resolving disputed parentage cases, and identifying human remains.

Q6. What is meristem culture, and why does it produce virus-free plants?

Ans. Meristem culture is a tissue culture technique in which new shoots are grown from a shoot tip using auxin and cytokinin in liquid medium; it produces virus-free plants because meristem tissue itself is naturally free of plant viruses, unlike other plant tissues.

Long Questions & Answers

Q1: Describe the complete methodology for producing recombinant DNA to be used in gene cloning.

Producing recombinant DNA for the purpose of gene cloning follows a carefully sequenced series of steps, each depending on a specific molecular tool, and understanding the full methodology requires tracing this process from the initial identification of the gene of interest all the way through to its expression inside a living host cell. The process begins with obtaining the gene of interest itself, which can be accomplished in one of three distinct



ways: it can be directly isolated from a chromosome by cutting out the DNA on either flanking side of the gene using specific restriction endonuclease enzymes; if the gene happens to be relatively small, it can instead simply be synthesized chemically from scratch in a laboratory setting; or, in what is actually one of the most common approaches used in practice, it can be synthesized indirectly starting from a purified sample of the corresponding messenger RNA molecule, using the specialized enzyme reverse transcriptase to work backward from RNA to produce a complementary DNA molecule, generally referred to simply as cDNA. Once the gene of interest has been successfully obtained through whichever of these three methods proves most suitable, the next essential step involves selecting an appropriate vector, meaning the specific molecular carrier that will actually be used to transport this gene of interest into a living host cell where it can subsequently be replicated and expressed; one of the most commonly used types of vector for this purpose is a bacterial plasmid, which is a naturally occurring, small, circular loop of DNA that exists separately from a bacterium's main chromosome and that frequently carries useful marker genes of its own, such as genes conferring resistance to particular antibiotics, which later prove extremely valuable for identifying and selecting successfully transformed bacterial colonies. With both the isolated gene of interest and the chosen plasmid vector now available, the critical step of actually constructing the recombinant DNA molecule itself can begin, and this is accomplished by treating both the plasmid vector and the DNA containing the gene of interest with the exact same specific type of restriction endonuclease enzyme; because restriction enzymes cut DNA at highly specific palindromic recognition sequences in a characteristically staggered fashion, this treatment leaves both the cut plasmid and the excised gene fragment with matching single-stranded overhanging ends, commonly referred to as 'sticky ends,' precisely because their exposed, complementary bases readily allow them to bind back together again through ordinary complementary base pairing wherever they happen to meet. Once the gene of interest and the opened plasmid vector have been mixed together and allowed to associate through this sticky-end base pairing, a second essential enzyme, DNA ligase, is then introduced into the reaction mixture, and this enzyme performs the crucial final sealing step by permanently joining the sugar-phosphate backbones of the two DNA pieces together at the point where they meet, thereby covalently uniting what were originally two entirely separate pieces of DNA, derived from two genuinely different biological sources, into one single, continuous, unified molecule that is now properly termed recombinant DNA, sometimes also called chimaeric DNA in recognition of its hybrid, composite origin. With the recombinant DNA molecule now fully assembled, the final major step in the overall methodology involves successfully introducing this newly constructed recombinant plasmid into an appropriate living host cell, most commonly a bacterium such as *Escherichia coli*, a process that is typically made significantly more efficient by first treating the host bacterial cells with calcium chloride, which has the effect of temporarily increasing the permeability of their outer cell membrane and thereby substantially improving the efficiency with which the bacterial cells will subsequently take up the recombinant plasmid DNA from the surrounding solution. Once a given host bacterium has successfully taken up a copy of the recombinant plasmid, that single transformed bacterial cell will then begin to reproduce and divide repeatedly in the ordinary way, and because the plasmid itself is able to replicate independently within the bacterium alongside its own normal chromosome, every single one of the many new daughter bacterial cells produced through



this ongoing division will likewise inherit and continue to carry at least one complete copy of that same recombinant plasmid, thereby collectively forming what is properly termed a bacterial clone; critically, because the originally inserted gene of interest remains fully intact and functional within this recombinant plasmid throughout this entire process, every single bacterium making up this expanding clone population will now also carry, and importantly will actively express, that same gene of interest, meaning the clone as a whole will now reliably manufacture whatever specific protein product that particular gene happens to encode, and this desired protein product, or alternatively simply many additional purified copies of the cloned gene itself, can then finally be successfully harvested, isolated and purified directly from this rapidly growing bacterial clone population for whatever further practical, medical or research purpose was originally intended.

Q2: Explain the polymerase chain reaction (PCR), describing how it is carried out to produce multiple copies of a DNA segment, and discuss its major applications.

The polymerase chain reaction, universally known simply by its abbreviation PCR, was originally developed by the American biochemist Kary B. Mullis back in 1983, and it represented an absolutely revolutionary advance in molecular biology precisely because it provided researchers, for the very first time, with the ability to rapidly and inexpensively generate literally millions of identical copies of one single, specific, targeted sequence of DNA directly within an ordinary laboratory test tube, entirely replacing the far slower, more cumbersome and considerably more expensive earlier methods that had previously been available for obtaining multiple copies of a particular DNA sequence of interest. The overall technique takes its distinctive name quite directly from DNA polymerase, which is specifically the same natural cellular enzyme that is ordinarily responsible for carrying out the entire process of DNA replication within any living cell, and PCR is properly described as a 'chain reaction' specifically because this same DNA polymerase enzyme is made to repeatedly and continuously carry out fresh rounds of replication over and over again in immediate succession, with each successive round essentially doubling the total quantity of the specific target DNA sequence present, until an extraordinarily large number, potentially many millions, of identical copies of that original target sequence have ultimately been produced within the reaction tube. Before the actual PCR amplification process itself can even begin, however, it is first absolutely essential to have prepared and made available a pair of short synthetic DNA sequences known as primers, each one typically only about twenty nucleotide bases in length, and these primers must be specifically designed and synthesized so that they are precisely complementary to the two short stretches of known DNA sequence that lie directly on either flanking side of the particular target DNA region that is actually intended to be amplified; these primers turn out to be genuinely indispensable to the entire procedure because DNA polymerase itself, despite being perfectly capable of extending an already-existing strand of nucleotides, is nevertheless completely incapable of spontaneously initiating brand new DNA synthesis entirely from scratch on its own, meaning it absolutely requires a short, pre-existing, already double-stranded starting point, provided specifically by these bound primers, from which it can then begin extending. The actual PCR procedure itself, once all necessary primers, template DNA, free nucleotides and DNA polymerase enzyme have been properly combined together within the reaction tube,



proceeds through a repeating cycle made up of three distinct, precisely temperature-controlled steps that are carried out automatically and repeatedly using a specialized piece of laboratory equipment called a thermocycler: first, during the denaturation step, the entire reaction mixture is briefly heated to a very high temperature, typically somewhere in the region of 94 to 96 degrees Celsius, which has the direct physical effect of breaking apart the hydrogen bonds holding the two original strands of the template DNA double helix together, thereby fully separating them into two individual single strands; second, during the subsequent annealing step, the temperature of the reaction mixture is then rapidly lowered to a considerably cooler temperature, typically somewhere around 50 to 65 degrees Celsius, which allows the short synthetic primer sequences present in great excess within the tube to specifically locate, bind to, and base-pair with their exactly complementary target sequences on each of the two now-separated single template DNA strands; and third, during the final extension step, the reaction temperature is then raised once again to an intermediate working temperature, typically around 72 degrees Celsius, which represents the optimal working temperature for the specific heat-tolerant DNA polymerase enzyme employed in the reaction, allowing that enzyme to actively bind at each primer site and then proceed to synthesize an entirely new, complementary DNA strand by progressively adding individual nucleotides one at a time, extending outward from each bound primer along the length of the template strand. This entire three-step cycle of denaturation, annealing and extension is then simply repeated over and over again, typically for something in the range of twenty-five to thirty-five full repeated cycles in total, and because each successive completed cycle has the direct mathematical effect of precisely doubling the total number of copies of the specific target DNA sequence that are present within the reaction tube relative to the number present just before that particular cycle began, this repeated cyclical doubling process rapidly and predictably generates an enormously exponential increase in the overall quantity of the desired target DNA sequence, typically yielding many millions of essentially identical copies after only a relatively modest total number of completed cycles, usually requiring in practice only a few hours total to complete the entire automated procedure from start to finish. A particularly crucial practical enabling factor underlying the entire modern PCR technique is specifically the use of a special thermostable variant of DNA polymerase, most commonly a form known as Taq polymerase, which is originally naturally extracted directly from *Thermus aquaticus*, a distinctive bacterium that is naturally found thriving in extremely hot natural springs; because this particular thermostable form of the enzyme is able to comfortably withstand the very high denaturation temperatures used repeatedly throughout the PCR cycling process without itself becoming permanently damaged or destroyed by that repeated heating, it conveniently never needs to be freshly added again between each successive PCR cycle, which is precisely the specific technical feature that first made full automation of the entire PCR process practically possible in the first place. In terms of its now extraordinarily widespread and diverse practical applications, PCR technology is very commonly employed for numerous important purposes across many different fields, including the rapid diagnosis of active viral infections, inherited genetic disorders and various forms of cancer directly from small clinical samples; for forensic scientific investigations, where it is routinely used to successfully identify criminal suspects, missing persons or unidentified human remains from only very minute biological samples such as tiny traces of blood, hair or skin cells recovered from a crime scene; and additionally for



detailed evolutionary and archaeological research purposes, where its remarkable sensitivity has famously enabled successful genetic sequencing efforts even on extremely old and degraded biological samples, including notably a human brain sample recovered from a naturally mummified body estimated to be around 76,000 years old, as well as an ancient fossilized plant specimen judged to be somewhere between roughly 17 and 20 million years old.

MCQs with Answers

1. Restriction endonucleases cut DNA at specific sequences called:

(a) codons (b) primers (c) palindromic sequences (d) introns

Correct Answer: (c) palindromic sequences. Restriction enzymes cut DNA at specific palindromic (symmetrical) recognition sequences.

2. A common type of vector used to introduce recombinant DNA into a host bacterium is a:

(a) ribosome (b) plasmid (c) mitochondrion (d) centriole

Correct Answer: (b) plasmid. Plasmids, natural circular extra-chromosomal DNA molecules, are commonly used as vectors in recombinant DNA technology.

3. The enzyme that seals a gene of interest into a cut vector, forming recombinant DNA, is called:

(a) DNA polymerase (b) restriction endonuclease (c) DNA ligase (d) reverse transcriptase

Correct Answer: (c) DNA ligase. DNA ligase joins (seals) the sticky ends of a gene of interest and a cut vector to form recombinant DNA.

4. A single-stranded, labelled nucleotide sequence used to locate a specific gene in a genomic library is called a:

(a) primer (b) probe (c) vector (d) plasmid

Correct Answer: (b) probe. A probe is a labelled single-stranded sequence that hybridizes with its complementary target gene sequence to locate it.

5. The polymerase chain reaction (PCR) was developed in 1983 by:

(a) Hamilton O. Smith (b) Kary B. Mullis (c) Fred Sanger (d) Karl Landsteiner

Correct Answer: (b) Kary B. Mullis. Kary B. Mullis developed PCR in 1983, revolutionizing rapid DNA amplification.

6. The thermostable DNA polymerase used in PCR, extracted from *Thermus aquaticus*, is called:

(a) DNA ligase (b) Taq polymerase (c) reverse transcriptase (d) restriction endonuclease

Correct Answer: (b) Taq polymerase. Taq polymerase, extracted from the heat-loving bacterium *Thermus aquaticus*, withstands PCR's high denaturation temperatures.

7. DNA fingerprinting relies on differences between individuals in their:

(a) codon usage (b) restriction fragment length polymorphisms (RFLPs) (c) ribosome number (d) chromosome shape

Correct Answer: (b) restriction fragment length polymorphisms (RFLPs). DNA fingerprinting exploits restriction fragment length polymorphisms (RFLPs), unique fragment patterns produced by restriction enzyme digestion.



8. The first mammal successfully cloned from an adult somatic cell nucleus was:

(a) a mouse named Snuppy (b) a sheep named Dolly (c) a goat named Bessie (d) a cow named Daisy

Correct Answer: (b) a sheep named Dolly. Dolly the sheep, cloned at the Roslin Institute in Scotland (announced 1997), was the first mammal cloned from an adult cell nucleus.

9. Ex vivo gene therapy for SCID (severe combined immunodeficiency) targets a deficiency of which enzyme?

(a) insulin (b) adenosine deaminase (ADA) (c) DNA ligase (d) Taq polymerase

Correct Answer: (b) adenosine deaminase (ADA). SCID patients lack adenosine deaminase (ADA), essential for T and B cell maturation; ex vivo gene therapy restores a functional ADA gene via bone marrow stem cells.

10. Meristem culture is favoured for micropropagation partly because meristem tissue is naturally:

(a) virus-free (b) haploid (c) resistant to herbicides (d) salt-tolerant

Correct Answer: (a) virus-free. Meristem tissue is naturally free of plant viruses, so plants propagated via meristem culture are also virus-free.

Quick Revision Summary

- Recombinant DNA basics: Gene of interest + Molecular scissors (restriction endonuclease, e.g. EcoRI, cuts at palindromic sequences -> sticky ends) + Vector (plasmid/virus) + DNA ligase (seals gene into vector) = Recombinant/chimaeric DNA. 3 ways to get a gene: isolate from chromosome, synthesize chemically, make cDNA from mRNA (reverse transcriptase).
- Cloning: transformed bacteria (CaCl₂ treated) take up recombinant plasmid -> reproduce -> bacterial clone, all expressing gene of interest. Genomic library = collection of clones covering whole genome; probe (labelled complementary sequence) locates specific gene.
- PCR (Mullis, 1983): primers (~20 bases) + Taq polymerase (thermostable, from *Thermus aquaticus*) + thermocycler = millions of copies via denaturation -> annealing -> extension cycles. DNA fingerprinting: restriction enzymes -> RFLPs -> gel electrophoresis -> probe hybridization -> banding pattern (forensics, paternity, identification).
- Gene sequencing: Sanger's dideoxy method / Maxam-Gilbert method -> automated fluorescent sequencing. Human Genome Project: 2 goals = genetic map (gene locations, RFLPs help find disease genes) + base sequence map (3 billion bp); chromosome 22 sequenced 1999, full genome 2001.
- Transgenic organisms = foreign gene inserted. Transgenic bacteria (bioreactors) -> insulin, growth hormone, vaccines, oil-spill cleanup. Transgenic plants -> pest/herbicide resistant crops (*Agrobacterium*, particle gun methods), improved traits table (herbicide/salt/drought/cold tolerant, improved yield/quality).
- Transgenic animals: gene inserted into eggs -> larger fish/livestock; gene pharming (drugs in milk/urine, e.g. antithrombin III from goats). Cloning of transgenic animals:



enucleated egg + adult somatic cell nucleus (e.g. cumulus cells) -> Dolly the sheep (1997, Roslin Institute) = first cloned adult vertebrate.

- Gene therapy: Ex vivo (cells removed, modified with retrovirus, returned - e.g. SCID/ADA deficiency, familial hypercholesterolemia) vs In vivo (direct delivery - e.g. cystic fibrosis via liposomes, angioplasty balloon with VEGF gene). Tissue culture: totipotency (Haberlandt 1902, Steward 1958 carrot) -> callus -> micropropagation/meristem culture (virus-free clones), protoplast/somatic embryos, anther culture (haploid->homozygous diploid), cell suspension culture (quinine, digitoxin). Notes by freebooks.pk.

Exam Tips

- Memorise the 4-component recombinant DNA technology checklist in order (gene of interest -> molecular scissors -> vector -> expression system) - this exact sequence structures most 'describe recombinant DNA technology' long questions.
- Keep restriction enzyme + DNA ligase as a paired 'cut and paste' fact: restriction endonuclease CUTS DNA at palindromic sites (sticky ends), DNA ligase SEALS/joins DNA pieces together - these are commonly confused in exams.
- Learn the PCR three-step cycle (denaturation -> annealing -> extension) with one temperature-related fact for each step, plus why Taq polymerase specifically is essential (thermostable, survives repeated heating).
- Build a simple 2-column table distinguishing gene cloning (bacterial-based, large protein quantities) from PCR (test-tube based, fast DNA copies, no protein product) since exams often test this distinction directly.
- Remember Dolly the sheep as one linked fact: 1997, Roslin Institute (Scotland), first cloned adult vertebrate, made from an enucleated egg + adult cumulus cell nucleus.
- For gene therapy, keep ex vivo vs in vivo as opposite directions with one named disease example each (ex vivo = SCID/ADA deficiency and familial hypercholesterolemia; in vivo = cystic fibrosis via liposomes, angioplasty/VEGF).
- Memorise the tissue culture technique-to-purpose pairing (micropropagation=mass clonal seedlings, meristem culture=virus-free clones, anther culture=haploid/homozygous plants, cell suspension culture=chemical production like quinine) rather than the definitions alone.

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FSc Part-II Biology — Punjab Board

CHAPTER 24

Evolution

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

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This chapter covers Evolution from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Questions of the origins of the earth and of life on it have occupied human minds since prehistoric times: how old is the planet earth, how long has life existed on it, and how did particular species come into existence? Evolution refers to the processes that have transformed life on earth from its earliest forms to the vast diversity we observe today, based mainly on interactions between populations of organisms and their environments. These notes are prepared by freebooks.pk.

The chapter covers the historical concept of evolution versus special creation, the evolution of eukaryotic cells from prokaryotic ancestors, Lamarck's theory of inheritance of acquired characteristics, Darwin's theory of natural selection and the modern evolutionary synthesis (Neo-Darwinism), the major evidences of evolution (biogeography, fossil record, comparative anatomy, comparative embryology, molecular biology), natural and artificial selection, population genetics (gene pools, allele and genotype frequencies), the Hardy-Weinberg theorem, and endangered species.

Learning Objectives

- Contrast the theory of special creation with the theory of evolution by natural selection.
- Describe the two major hypotheses (endosymbiont and membrane invagination) for the evolution of eukaryotic cells from prokaryotic ancestors.
- Explain Lamarck's theory of inheritance of acquired characteristics and why it is now rejected.
- State Darwin's two main points from *The Origin of Species*: descent with modification and natural selection.
- Describe at least five categories of evidence supporting evolution, with an example of each.
- Differentiate between homologous and analogous structures, and between natural and artificial selection.
- Define population, gene pool, and allele/genotype frequency, and state the Hardy-Weinberg theorem.
- Explain the factors that alter gene frequency in a population and describe the concept of endangered and threatened species.

Key Concepts

Concept of Evolution versus Special Creation

In a bid to explain the diversity of life and the interrelationships among living organisms, two schools of thought emerged in the early nineteenth century: creationists believed in the Theory of Special Creation, holding that all living things came into existence in their present forms, specially and specifically created by Nature, while evolutionists believed in the Theory of Natural Selection. Among scientists who believed in divine creation was Carolus Linnaeus (1707-1778), who nonetheless sought and found order in the diversity of life and introduced



binomial nomenclature for naming species. The idea that organisms might evolve through time, with one type giving rise to another, is an ancient one, existing since the days of Aristotle, who recognized that organisms ranged from relatively simple to very complex structures; however, the present-day concept of evolution is based on a known history of contributions from several scientists, including Lamarck (1744-1829, published his theory of evolution), Malthus (1766-1834, published an essay on the Principle of Population), Cuvier (1769-1832, explained Earth's history by catastrophism), Lyell (1797-1875, published Principles of Geology), Darwin (1809-1882, voyage of the Beagle and On the Origin of Species), Mendel (1822-1884, published papers on inheritance), and Wallace (1823-1913, sent his own theory of natural selection to Darwin).

Carolus Linnaeus, in the eighteenth century, classified organisms by grouping similar species in the same genus and similar genera in one family, but as a natural theologian he believed species were permanent creations; a century later, his taxonomic system became a focal point in Darwin's arguments for evolution.

Evolution from Prokaryotes to Eukaryotes

One speculation explaining the origin of life is that it may have begun deep in the oceans, in underwater hot springs called hydrothermal vents, which could have supplied energy and raw materials for the origin and survival of early life forms; a group of bacteria called archaeobacteria, which tolerate temperatures up to 120 degrees Celsius and seem to have undergone less evolutionary change than any other living species, supports this vent hypothesis. The first photosynthetic organisms probably used hydrogen sulfide as a source of hydrogen for reducing carbon dioxide to sugars; later, water served this purpose, and oxygen liberated by photosynthesis began accumulating in the atmosphere, eventually building enough protective ozone (about 420 million years ago) to make life on land possible. The first cells were most likely simple prokaryotic forms that may have arisen more than 3.5 billion years ago, while eukaryotes are thought to have first appeared about 1.5 billion years ago.

The eukaryotic cell might have evolved when a large anaerobic amoeboid prokaryote ingested small aerobic bacteria and stabilized them instead of digesting them, an idea known as the endosymbiont hypothesis, first proposed by Lynn Margulis; according to this hypothesis, the aerobic bacteria developed into mitochondria, the sites of aerobic respiration in eukaryotic cells, while ingestion of prokaryotes resembling present-day cyanobacteria could have led to the endosymbiotic development of chloroplasts in plants. An alternative hypothesis, membrane invagination, proposes that the prokaryotic cell membrane folded inward to enclose copies of its genetic material, resulting in the formation of several double-membrane-bound organelles within a single cell, which could then have evolved into the mitochondrion, nucleus, and chloroplast. Whatever the exact mechanism, the formation of the eukaryotic cell led to a dramatic increase in the complexity and diversity of life, with some eukaryotic cells later evolving into multicellular organisms with cells specialized into tissues and organs.



Lamarckism and Darwin's Theory of Natural Selection

Jean Baptiste Lamarck (1744-1829) published his theory of evolution in 1809, the year Darwin was born, arguing that body parts used extensively to cope with the environment become larger and stronger, while unused parts deteriorate; his second idea, the inheritance of acquired characteristics, held that modifications an organism acquires during its lifetime can be passed to its offspring, such as the giraffe's neck lengthening gradually as the cumulative product of generations of ancestors stretching for leaves. However, we now know that acquired characteristics cannot be inherited. Charles Darwin, born in Shrewsbury, England in 1809, joined the expedition of the Beagle to the South American coastline, where he collected thousands of specimens and noticed that the fauna and flora of different regions had a definite South American character; a particularly puzzling case was the fauna of the Galapagos Islands, including 13 types of finches that, though quite similar, seemed to be different species, some unique to individual islands.

After returning to Britain in 1836, Darwin perceived the origin of new species and adaptations as closely related processes, with a new species arising from an ancestral form by gradual accumulation of adaptations to different environments, separated by geographical barriers. By the early 1840s Darwin had worked out the major features of his theory of natural selection, but before he could publish, Alfred Wallace, a young naturalist working in the East Indies, independently developed an essentially identical theory; both were presented to the Linnaean Society of London in 1858, and Darwin published *The Origin of Species* the following year. In it, Darwin developed two main points: descent with modification (all organisms are related through descent from a common ancestor, with the history of life resembling a branching tree) and natural selection and adaptation, based on the observations that populations produce more individuals than the environment can support (leading to a struggle for existence), that survival is not random but depends partly on hereditary constitution (individuals best fitted to their environment leave more offspring), and that this unequal ability to survive and reproduce leads to gradual change in a population as favourable characteristics accumulate over generations, ultimately leading to the evolution of new species.

Neo-Darwinism and the Evidences of Evolution

The Origin of Species convinced most biologists that species are products of evolution. An important turning point was the birth of population genetics, which emphasizes extensive genetic variation within populations; with progress in population genetics in the 1930s, Mendelism and Darwinism were reconciled, producing a comprehensive theory known as the modern synthesis or Neo-Darwinism, developed in the early 1940s by integrating discoveries from paleontology, taxonomy, biogeography and population genetics. Evolution leaves several kinds of observable evidence. Biogeography, the geographical distribution of species, was what first suggested the idea of evolution to Darwin; islands have many species that are endemic yet closely related to species of the nearest mainland, such as armadillos, armored mammals that live only in America, whose fossil ancestors confirm this pattern. The fossil record provides a strong evidence in favour of evolution, with the oldest known fossils being prokaryotes (consistent with molecular evidence placing prokaryotes as ancestors of all life) and with vertebrate classes appearing in a chronological sequence in the fossil record



- fish, then amphibians, then reptiles, then mammals and birds - consistent with the history of vertebrate descent.

Comparative anatomy shows that the same skeletal elements make up the forelimbs of humans, cats, whales and bats, although these appendages perform very different functions; similarity resulting from common ancestry is called homology, and such anatomical signs of evolution are called homologous structures - functionally different but structurally alike, as seen in divergent evolution. Analogous organs, by contrast, are functionally alike but structurally different, such as the wings of bats, birds and insects, examples of convergent evolution. Vestigial organs are historical remnants of structures that had important functions in ancestors but are no longer essential, such as the pelvic and leg bones retained by whales and some snakes, the vermiform appendix in carnivores, or ear muscles in humans. Comparative embryology shows that closely related organisms go through similar stages in embryonic development, such as the gill pouches present in all vertebrate embryos, which become gills in fish but modify into structures such as the eustachian tube in terrestrial vertebrates. Molecular biology provides strong evidence too: if two species have genes and proteins with closely matching sequences, the sequences must have been copied from a common ancestor, and a common genetic code and shared proteins (such as cytochrome c, found in all aerobic species) support the unity and diversity of life.

Natural Selection and Artificial Selection

Natural selection occurs through an interaction between the environment and the variability inherent in any population. Darwin found supporting evidence in artificial selection, the breeding of domesticated plants and animals, in which humans modify other species over many generations by selecting individuals with desired traits as breeding stock, so the plants and animals grown for food bear little resemblance to their wild ancestors; from the changes achieved by artificial selection within a relatively short period, Darwin postulated that natural selection operating over vast spans of time could account for the entire diversity of life. A population is a group of interbreeding individuals belonging to a particular species and sharing a common geographic area.

Natural selection can amplify or diminish only variations that are heritable - adaptations an organism acquires through its own actions during its lifetime are not heritable. The specifics of natural selection are regional and timely, since environmental factors vary from place to place and from time to time, and an adaptation favourable in one situation may be useless or even detrimental in other circumstances; a well-known example of natural selection in action is the evolution of antibiotic resistance in bacteria.

Population, Gene Pool, Allele and Genotype Frequencies

A population is a localized group of individuals belonging to the same species; a species is defined as a group of populations that have the potential to interbreed in nature. Each species has a geographical range within which individuals are concentrated in several localized populations rather than spread evenly, and a population may be isolated from others of the same species, exchanging genetic material only rarely, particularly common for populations confined to widely separated islands, unconnected lakes, or mountain ranges



separated by lowlands. The total aggregate of genes in a population at any one time is called the population's gene pool, consisting of all alleles at all gene loci in all individuals of the population; for a diploid species, each locus is represented twice in the genome of an individual, who may be homozygous or heterozygous.

If all members of a population are homozygous for the same allele, that allele is said to be fixed in the gene pool; more often, there are two or more alleles for a gene, each with a relative frequency in the gene pool. For example, in an imaginary wildflower population of 500 plants with a dominant pink-flower allele A and a recessive white-flower allele a: 20 plants are homozygous recessive (aa, white), 320 are homozygous dominant (AA, pink), and 160 are heterozygous (Aa, pink). With 1000 total gene copies for flower colour (500 plants $\times$ 2 alleles), the dominant allele A accounts for 800 of these copies ($320 \times 2 + 160 \times 1$), giving allele frequency of A = 0.8 (80%) and of a = 0.2 (20%); the corresponding genotype frequencies are AA = 0.64 (64%), Aa = 0.32 (32%), and aa = 0.04 (4%).

Hardy-Weinberg Theorem and Factors Affecting Gene Frequency

The frequencies of genotypes in non-evolving populations are described by the Hardy-Weinberg theorem, named for the two scientists who derived the principle independently in 1908; it states that the frequencies of alleles and genotypes in a population's gene pool remain constant over generations unless acted upon by agents other than sexual recombination, meaning that the shuffling of alleles due to meiosis and random fertilization alone has no effect on the overall genetic structure of a population. For a gene locus with only two alleles, population geneticists use p to represent the frequency of one allele and q for the other, where $p + q = 1$; when gametes combine to form zygotes, the probability of an AA genotype is p-squared, of aa is q-squared, and of heterozygous Aa is 2pq, so that $p\text{-squared} + 2pq + q\text{-squared} = 1$ (a binomial expansion of $(p+q)\text{-squared}$). In the wildflower example, $p = 0.8$ and $q = 0.2$, giving $p\text{-squared} = 0.64$ (AA), $2pq = 0.32$ (Aa), and $q\text{-squared} = 0.04$ (aa), which together sum to 1.

Five factors can alter gene frequency enough to produce significant deviations from Hardy-Weinberg proportions: mutation (the ultimate source of all changes, though individual mutations occur so rarely that mutation alone does not change allele frequency much), migration (a potent agent of change through emigration and immigration disturbing the gene pool, while also acting locally to prevent populations that exchange members from diverging from one another), genetic drift (a chance-based change in allele frequency, especially significant in small populations where fluctuations may lead to loss of particular alleles), non-random mating (such as inbreeding, which does not alter allele frequency but lessens the proportion of heterozygous individuals), and selection (whether artificial, where breeders select for desired characters, or natural, where the environment plays this role), where some individuals leave behind more progeny than others due to their inherited characteristics.

Endangered Species

Extinction has been the fate of most plant and animal species and is a natural process that will continue; however, in recent years the threat to wild plants and animals has increased



dramatically, mostly as a result of habitat destruction. Tropical rain forests, the most threatened areas on earth, have been reduced to 44% of their original extent, and in certain areas such as Ecuador, forest coverage has been reduced by 95%; this decrease in habitat has resulted in tens of thousands of extinctions, with the true number impossible to estimate accurately since taxonomists have not even described most species in areas like rain forests. Other causes of extinction include climate change, pollution, and invasions from foreign species, and habitats other than rain forest, such as grasslands, marshes, deserts, and coral reefs, are also seriously threatened.

An endangered species is in imminent danger of extinction throughout its range, while a threatened species is likely to become endangered in the near future; saving species requires preserving a large diversity of genes within species groups to promote survival in changing environments, which requires large populations, not just a few remnant individuals. A multifaceted conservation plan includes a global system of national parks and wildlife corridors, protected landscapes and multiple-use areas that allow controlled private activity while retaining wildlife habitat value, and zoos and botanical gardens to save species whose extinction is imminent. In Pakistan, the cheetah, tiger, Asian lion, Indian rhino, cheer pheasant, crocodile and gharial (Gavial) have been declared extinct, while the Indus dolphin, blackbuck, common leopard, great Indian bustard, houbara bustard, white-headed duck and marbled teal are among the species near extinction, with deserts, sub-mountainous tracts and wetlands identified as habitats in peril and more than 500 endangered plant species recorded.

Important Definitions

Term	Definition
Evolution	The processes that have transformed life on earth from its earliest forms to the vast diversity observed today, based on interactions between populations and their environments.
Natural selection	The process by which individuals whose inherited characteristics best fit them to their environment tend to survive and leave more offspring, gradually changing a population over generations.
Endosymbiont hypothesis	The hypothesis, proposed by Lynn Margulis, that the eukaryotic cell evolved when a large anaerobic prokaryote ingested and stabilized small aerobic bacteria, which developed into mitochondria.
Homologous structures	Anatomical structures that are functionally different but structurally alike due to common ancestry, such as the forelimbs of humans, bats, and whales.
Analogous structures	Anatomical structures that are functionally alike but structurally different, arising through convergent evolution, such as the wings of bats, birds and insects.
Gene pool	The total aggregate of genes (all alleles at all gene loci) present in all individuals of a population at a given time.
Hardy-Weinberg theorem	



Term	Definition
	The principle that allele and genotype frequencies in a population's gene pool remain constant across generations unless acted upon by agents other than sexual recombination.
Endangered species	A species that is in imminent danger of extinction throughout its range.

Key Facts

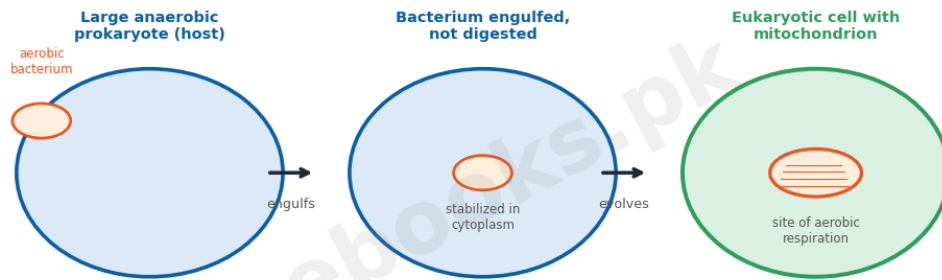
Item	Fact
Hardy-Weinberg equation	$p^2 + 2pq + q^2 = 1$, where p^2 = frequency of AA, $2pq$ = frequency of Aa, q^2 = frequency of aa, and $p + q = 1$.
Age of first prokaryotes	The first prokaryotic cells are thought to have arisen more than 3.5 billion years ago.
Age of first eukaryotes	Eukaryotes are thought to have first appeared about 1.5 billion years ago.
Hardy-Weinberg year	The Hardy-Weinberg theorem was derived independently by two scientists in 1908.
Darwin & Wallace presentation	Wallace's and Darwin's independently developed theories of natural selection were presented to the Linnaean Society of London on 1 July 1858.
Publication of Origin of Species	Charles Darwin published On the Origin of Species in 1859.
Rain forest reduction	Tropical rain forests have been reduced to 44% of their original extent worldwide; in Ecuador, by 95%.
Ozone and life on land	About 420 million years ago, enough protective ozone had built up in the atmosphere to make life on land possible.

Diagrams & Illustrations

The Endosymbiont Hypothesis: Origin of Mitochondria: a diagram showing the endosymbiont hypothesis for the evolution of the eukaryotic cell: a large anaerobic prokaryote engulfing a small aerobic bacterium, which is stabilized rather than digested and gradually develops into a mitochondrion within the host cell.



The Endosymbiont Hypothesis: Origin of Mitochondria



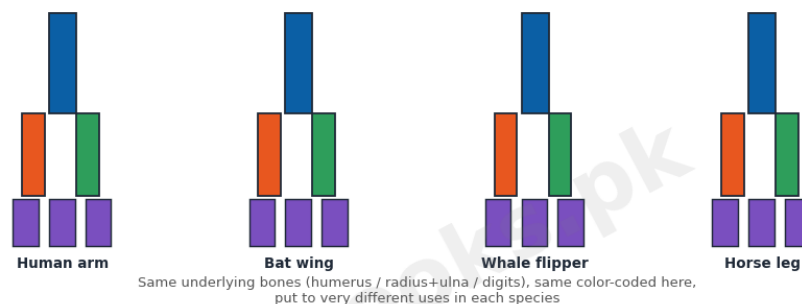
Similarly, ingestion of cyanobacteria-like prokaryotes is proposed to have led to the endosymbiotic development of chloroplasts in plants.

The Endosymbiont Hypothesis: Origin of Mitochondria

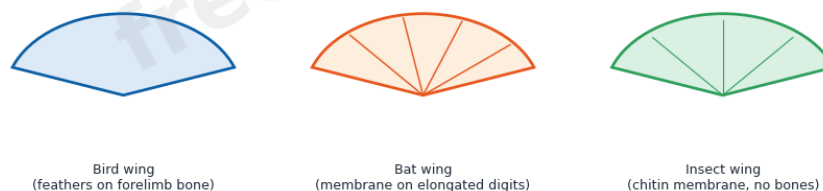
Homologous vs Analogous Structures: a comparison diagram showing homologous structures (the forelimb bones of a human, bat, whale and horse, structurally alike but functionally different, from divergent evolution) alongside analogous structures (the wings of a bird, bat and insect, functionally alike but structurally different, from convergent evolution).

Homologous vs Analogous Structures

HOMOLOGOUS STRUCTURES (structurally alike, functionally different - divergent evolution)



ANALOGOUS STRUCTURES (functionally alike, structurally different - convergent evolution)



All three fly, but each wing evolved independently from very different structures.

Homologous vs Analogous Structures



Hardy-Weinberg Equilibrium: Genotype Frequencies: a diagram illustrating the Hardy-Weinberg equation ($p^2 + 2pq + q^2 = 1$) applied to the wildflower population example, showing the genotype frequencies of AA (0.64), Aa (0.32), and aa (0.04) as proportional segments.

Hardy-Weinberg Equilibrium: Genotype Frequencies

$$p^2 + 2pq + q^2 = 1 \quad (p = \text{frequency of A} = 0.8, q = \text{frequency of a} = 0.2)$$



500 wildflower population example (320 AA, 160 Aa, 20 aa)

Phenotype summary:

- Pink (AA): 320 plants
- Pink (Aa): 160 plants
- White (aa): 20 plants

Allele frequency:
 p (A) = 0.8 (80%)
 q (a) = 0.2 (20%)
 $p + q = 1$

A non-evolving population's allele & genotype frequencies stay constant across generations, unless acted on by mutation, migration, drift, non-random mating, or selection.

Hardy-Weinberg Equilibrium: Genotype Frequencies

Short Questions & Answers

Q1. What are hydrothermal vents, and why are they relevant to the origin of life?

Ans. Hydrothermal vents are underwater hot springs that could have supplied the energy and raw materials needed for the origin and survival of early life forms; archaeobacteria, which tolerate temperatures up to 120 degrees Celsius, support this vent hypothesis for the origin of life.

Q2. State the endosymbiont hypothesis.

Ans. The endosymbiont hypothesis, proposed by Lynn Margulis, states that the eukaryotic cell evolved when a large anaerobic amoeboid prokaryote ingested small aerobic bacteria and stabilized rather than digested them; these bacteria developed into mitochondria, the sites of aerobic respiration in eukaryotic cells.

Q3. Explain the term homology with a suitable example.

Ans. Homology is similarity in characteristics resulting from common ancestry; anatomical signs of evolution called homologous structures are functionally different but structurally alike, such as the forelimb bones of humans, cats, whales and bats, which are all built from the same skeletal elements despite performing very different functions.

Q4. What are vestigial organs? Give two examples.



Ans. Vestigial organs are rudimentary structures that had important functions in ancestors but are of marginal or no use to the organism today; examples include the pelvic and leg bones retained by whales and some snakes, the vermiform appendix in carnivores, and ear muscles in humans.

Q5. State the Hardy-Weinberg theorem.

Ans. The Hardy-Weinberg theorem states that the frequencies of alleles and genotypes in a population's gene pool remain constant over generations unless acted upon by agents other than sexual recombination, meaning shuffling of alleles by meiosis and random fertilization alone has no effect on a population's genetic structure.

Q6. What is the difference between an endangered species and a threatened species?

Ans. An endangered species is in imminent danger of extinction throughout its range, whereas a threatened species is likely to become endangered in the near future.

Long Questions & Answers

Q1: Describe the evidences of evolution from any five branches of biology, explaining how each supports the theory of evolution.

Evolution, unlike a directly observable single event, is nevertheless supported by an extraordinarily wide and mutually reinforcing body of observable evidence drawn from many entirely different branches of biological science, and examining several of these branches in turn makes clear just how consistently they all point toward the same underlying conclusion that living species share common ancestry and have changed gradually over immense spans of time. The first major branch of evidence is biogeography, the study of the geographical distribution of species, which was in fact the very branch of evidence that first suggested the idea of evolution to Darwin himself during his voyage on the Beagle; islands, he observed, characteristically harbour many species of plants and animals that are found nowhere else in the world, and yet these endemic island species are consistently found to be closely related to species inhabiting the nearest mainland or a neighbouring island, exactly the pattern one would expect if the islands had originally been colonized by mainland species that subsequently diversified in isolation, a pattern strikingly illustrated by armadillos, armoured mammals that live only in the Americas, whose fossil record confirms that earlier armadillo-like ancestors did indeed occupy these same continents. The second major branch of evidence is the fossil record, which provides a strong and often startlingly complete visual record of the successive forms through which particular evolutionary lineages have passed over time; the fossil record's own internal chronology turns out to be entirely consistent with independent evolutionary predictions, since the oldest known fossils recovered anywhere in the geological record are consistently prokaryotic in nature, exactly as would be expected if prokaryotes truly are the evolutionary ancestors of all subsequent life, and similarly the different classes of vertebrate animals appear in the fossil record in a clear chronological sequence, with fossil fishes as the earliest vertebrates, followed in turn by amphibians, then reptiles, and only much later by mammals and birds, a sequence that corresponds precisely with the independently reconstructed history of vertebrate descent. The third major branch



of evidence is comparative anatomy, which examines the anatomical similarities shared between species that are grouped together within the same taxonomic category; a particularly clear example is the observation that the very same underlying set of skeletal elements is used to construct the forelimbs of humans, cats, whales, bats, and indeed all other mammals, even though these superficially very different-looking appendages have subsequently been put to radically different functional uses in each lineage, ranging from grasping to swimming to flying, a basic similarity that is best explained as the direct consequence of common descent from a shared mammalian ancestor, with such anatomically similar but functionally divergent structures properly termed homologous structures, a concept that stands in useful contrast to purely superficial similarities such as the wings of birds, bats and insects, which are functionally alike but structurally quite different and are instead properly termed analogous structures, arising through the entirely separate process of convergent evolution rather than through shared ancestry. The fourth major branch of evidence is comparative embryology, which reveals that closely related organisms characteristically pass through remarkably similar stages during their own individual embryonic development, even in cases where the fully grown adult forms of those same organisms subsequently end up looking extremely different from one another; a particularly striking example is that all vertebrate embryos, without exception, pass through an early developmental stage in which they possess gill pouches located on the sides of their throat region, structures that in fish go on to develop directly into functional gills, but that in terrestrial vertebrates instead become substantially modified during later development to serve entirely different purposes, such as forming the eustachian tube that connects the middle ear to the throat in humans, a pattern of shared early development that is again most readily and economically explained by shared evolutionary ancestry. The fifth major branch of evidence is molecular biology, which examines evolutionary relationships as they are directly reflected within the genes and gene products, meaning the DNA and protein sequences, of different species; when two different species are found to possess genes or proteins whose monomer sequences match one another unusually closely, the most probable explanation is that those matching sequences were originally copied down, with only minor subsequent modification, from a single shared common ancestor, and indeed the fact that essentially all known living organisms share the same fundamental genetic code, along with the fact that taxonomically very remote organisms such as humans and bacteria nevertheless still share certain specific proteins in common, such as the respiratory protein cytochrome c which is found in essentially all aerobic species, together provide particularly strong and compelling molecular-level evidence in direct support of evolution as the fundamental basis underlying both the unity and the diversity that we observe throughout all of life.

Q2: Explain Darwin's theory of natural selection as the mechanism of evolution, and describe how the modern evolutionary synthesis (Neo-Darwinism) built upon it.

Charles Darwin's theory of natural selection represents one of the single most influential and thoroughly well-supported explanatory frameworks in the entire history of biological science, and properly understanding both the theory itself and the way it was subsequently extended and refined requires tracing the argument carefully through each of its component



observations and logical inferences in turn. Darwin's own thinking on this subject was shaped very substantially by his personal experiences during the voyage of the Beagle, during which he collected thousands of specimens of the diverse fauna and flora of South America and personally observed that the living species inhabiting different regions of that continent consistently displayed a definite and unmistakably South American character, quite distinct from the character of equivalent life forms found in Europe, while the South American fossil specimens that he collected, although clearly representing extinct and different species from those living today, nevertheless still bore a distinctly South American resemblance to the modern plants and animals of that same continent; a particularly puzzling case that especially struck Darwin was the highly unusual fauna of the Galapagos Islands, most of which live nowhere else in the entire world despite closely resembling related species found living on the nearby South American mainland, exactly the pattern one would expect if these islands had originally been colonized by stray mainland organisms that had subsequently diversified along separate evolutionary paths on the different individual islands, a phenomenon strikingly illustrated by the thirteen distinct types of Galapagos finches that Darwin collected, some confined to individual islands and others more widely distributed. After returning to Great Britain in 1836, Darwin came to perceive the origin of new species and the origin of new adaptations as two closely related aspects of the very same underlying evolutionary process, in which an entirely new species would gradually arise from some pre-existing ancestral form through the slow, cumulative accumulation of successive adaptations to a new and different environment, a process typically initiated and sustained by geographical separation from the original ancestral population; over the course of many successive generations, two populations that had originally been separated from one another in this way could plausibly become sufficiently dissimilar from each other to properly warrant being designated as entirely separate species, apparently exactly what had happened among the various populations of Galapagos finches that Darwin had personally observed and collected. By the early 1840s Darwin had already privately worked out the major essential features of his eventual theory of natural selection as the fundamental underlying mechanism driving the entire process of evolutionary change, though before he was able to publish his ideas the young naturalist Alfred Wallace, working independently in the East Indies, developed an essentially identical theory of natural selection entirely on his own; the two men's respective findings were jointly presented together to the Linnaean Society of London in 1858, and Darwin quickly completed and published his now-famous book *The Origin of Species* the following year, in which he laid out two central and closely interrelated points, namely descent with modification, the idea that all living organisms are ultimately related to one another through shared descent from some common ancestor that lived in the remote evolutionary past, and natural selection and adaptation, the proposal that populations of individual species gradually become progressively better adapted to their particular local environments specifically through the ongoing operation of natural selection, a process grounded in three closely linked underlying observations: first, that any given population characteristically produces substantially more offspring individuals than the surrounding environment can actually support, which inevitably leads to an ongoing struggle for existence among the individual members of that population, with only some fraction of the total offspring produced actually managing to survive through to reproduce in each successive generation; second, that survival within this ongoing struggle for existence is



emphatically not a purely random matter, but instead depends at least partly upon each individual's own particular hereditary constitution, meaning that those specific individuals whose inherited characteristics happen to fit them relatively better to their local environment are correspondingly more likely to survive and to leave behind a correspondingly larger number of surviving offspring than their comparatively less well-adapted fellow individuals; and third, that this resulting unequal ability of different individuals to successfully survive and reproduce will, purely as an inevitable logical consequence, progressively lead to a gradual cumulative change in the overall genetic composition of the population as a whole, as those particular favourable heritable characteristics steadily accumulate in frequency over the course of many successive generations, ultimately giving rise over sufficiently long spans of time to the evolution of an entirely new species. Following the initial publication of *The Origin of Species*, an important subsequent turning point for the further development and refinement of evolutionary theory more broadly was the later birth of the distinct field of population genetics, which placed particular scientific emphasis specifically upon the extensive genetic variation that is characteristically found to exist within essentially all natural populations, and which additionally recognized the particular importance of quantitative, continuously varying hereditary characters; with substantial further scientific progress subsequently made within the field of population genetics specifically during the 1930s, the previously apparently conflicting theoretical frameworks of Mendelian genetics and classical Darwinian natural selection were at last successfully reconciled with one another, with the underlying genetic basis both of heritable variation itself and of the specific process of natural selection acting upon that variation being worked out in considerably greater mechanistic detail than Darwin himself had originally been able to achieve; the resulting comprehensive and substantially more mechanistically complete theory of evolution that emerged from this reconciliation became subsequently known as the modern evolutionary synthesis, or more commonly simply as Neo-Darwinism, and was fully developed during the early 1940s specifically by successfully integrating relevant discoveries and ideas drawn from several previously largely separate scientific fields, including palaeontology, taxonomy, biogeography, and, of course, the newly developed field of population genetics itself.

MCQs with Answers

1. Who introduced binomial nomenclature for naming species?

(a) Charles Darwin (b) Carolus Linnaeus (c) Jean Baptiste Lamarck (d) Alfred Wallace

Correct Answer: (b) Carolus Linnaeus. Carolus Linnaeus (1707-1778) introduced binomial nomenclature and sought order in the diversity of life, though he believed species were permanent creations.

2. The idea that mitochondria evolved from engulfed aerobic bacteria is called the:

(a) membrane invagination hypothesis (b) endosymbiont hypothesis (c) special creation hypothesis (d) catastrophism hypothesis

Correct Answer: (b) endosymbiont hypothesis. The endosymbiont hypothesis, proposed by Lynn Margulis, holds that mitochondria evolved from aerobic bacteria engulfed and stabilized by a host prokaryote.



3. Lamarck's theory that modifications acquired during an organism's lifetime can be passed to offspring is called:

- (a) natural selection (b) genetic drift (c) inheritance of acquired characteristics (d) descent with modification

Correct Answer: (c) inheritance of acquired characteristics. Lamarck's theory of inheritance of acquired characteristics proposed that traits acquired during an organism's life could be inherited by offspring; this is now known to be incorrect.

4. Darwin and Wallace's theories of natural selection were jointly presented to the Linnaean Society of London in:

- (a) 1836 (b) 1844 (c) 1858 (d) 1908

Correct Answer: (c) 1858. Wallace's paper and extracts from Darwin's unpublished essay were jointly presented to the Linnaean Society of London on 1 July 1858.

5. Structures that are functionally different but structurally alike due to common ancestry are called:

- (a) analogous structures (b) vestigial structures (c) homologous structures (d) convergent structures

Correct Answer: (c) homologous structures. Homologous structures, such as the forelimbs of humans, bats and whales, are structurally alike but functionally different due to shared common ancestry (divergent evolution).

6. Wings of bats, birds and insects, which are functionally similar but structurally different, are examples of:

- (a) homologous structures (b) analogous structures (c) vestigial organs (d) genetic drift

Correct Answer: (b) analogous structures. Analogous structures are functionally alike but structurally different, arising through convergent evolution rather than shared ancestry.

7. The total aggregate of all genes in a population at a given time is called its:

- (a) genotype (b) phenotype (c) gene pool (d) gene locus

Correct Answer: (c) gene pool. The gene pool is the total aggregate of all alleles at all gene loci in all individuals of a population.

8. In the Hardy-Weinberg equation $p^2 + 2pq + q^2 = 1$, the term $2pq$ represents the frequency of:

- (a) homozygous dominant individuals (AA) (b) homozygous recessive individuals (aa) (c) heterozygous individuals (Aa) (d) the total population

Correct Answer: (c) heterozygous individuals (Aa). $2pq$ represents the frequency of heterozygous (Aa) individuals in a population at Hardy-Weinberg equilibrium.

9. Which of the following is NOT one of the five major factors that alter gene frequency?

- (a) Mutation (b) Genetic drift (c) Photosynthesis (d) Non-random mating

Correct Answer: (c) Photosynthesis. The five major factors affecting gene frequency are mutation, migration, genetic drift, non-random mating, and selection; photosynthesis is not one of them.

10. A species that is in imminent danger of extinction throughout its range is called:



(a) a threatened species (b) an endangered species (c) an invasive species (d) a keystone species

Correct Answer: (b) an endangered species. An endangered species is in imminent danger of extinction throughout its range, while a threatened species is likely to become endangered in the near future.

Quick Revision Summary

- Evolution vs special creation: Creationists (Special Creation) vs Evolutionists (Natural Selection). Key historical scientists: Linnaeus (binomial nomenclature), Lamarck (theory of evolution, 1809), Malthus (Principle of Population), Cuvier (catastrophism), Lyell (Principles of Geology), Darwin (Origin of Species, 1859), Mendel (inheritance), Wallace (independent natural selection theory).
- Prokaryotes -> eukaryotes: prokaryotes >3.5 billion years ago, eukaryotes ~1.5 billion years ago. Endosymbiont hypothesis (Margulis): aerobic bacteria -> mitochondria; cyanobacteria-like -> chloroplasts. Alternative: membrane invagination hypothesis.
- Lamarckism (inheritance of acquired characteristics, rejected) vs Darwinism (natural selection). Darwin's Origin of Species (1859) 2 main points: Descent with modification + Natural selection/adaptation (overproduction -> struggle for existence -> differential survival -> gradual change).
- Neo-Darwinism = Mendelism + Darwinism (1930s-40s), via population genetics. 5 evidences of evolution: Biogeography, Fossil record, Comparative anatomy (homologous vs analogous structures, vestigial organs), Comparative embryology (gill pouches), Molecular biology (cytochrome c, genetic code).
- Natural selection (environment selects) vs Artificial selection (humans select, e.g. breeding). Population = interbreeding group sharing geographic area. Gene pool = total alleles at all loci in a population.
- Hardy-Weinberg theorem: $p + q = 1$, $p^2 + 2pq + q^2 = 1$ (non-evolving population). Derived 1908. 5 factors altering gene frequency: Mutation, Migration, Genetic drift, Non-random mating, Selection.
- Endangered species = imminent extinction risk; Threatened species = likely to become endangered. Pakistan extinct: cheetah, tiger, Asian lion, Indian rhino, cheer pheasant, crocodile, gharial. Conservation: national parks, protected landscapes, zoos/botanical gardens. Notes by freebooks.pk.

Exam Tips

- Build a simple timeline of the 8 key historical scientists (Linnaeus -> Lamarck -> Malthus -> Cuvier -> Lyell -> Darwin -> Mendel -> Wallace) with one achievement each - this exact list appears repeatedly in short-question format.
- Keep the endosymbiont hypothesis and membrane invagination hypothesis as a clearly separated pair: endosymbiont = engulfed bacteria become organelles; invagination = membrane folds inward to form organelles.



- Memorise Darwin's 2 main points from Origin of Species as a fixed pair (descent with modification + natural selection/adaptation), and be ready to list the 3 underlying observations behind natural selection in order.
- Build a homologous vs analogous 2-column comparison table with one example each (homologous = forelimbs of man/bat/whale, divergent evolution; analogous = wings of bat/bird/insect, convergent evolution) - a very common exam question.
- Memorise the Hardy-Weinberg equation $p^2 + 2pq + q^2 = 1$ alongside the wildflower numeric example ($p=0.8$, $q=0.2 \rightarrow AA=0.64$, $Aa=0.32$, $aa=0.04$) so you can both state and apply the theorem.
- Learn the 5 factors affecting gene frequency as a fixed list (Mutation, Migration, Genetic drift, Non-random mating, Selection) - exams often ask you to name and briefly describe all five.
- Keep endangered vs threatened species as a clear distinction (endangered = imminent extinction; threatened = likely to become endangered soon), and memorise at least 3 Pakistan-specific extinct species examples (cheetah, tiger, Asian lion).

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FSc Part-II Biology — Punjab Board

CHAPTER 25

Ecosystem

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

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This chapter covers Ecosystem from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). The term ecology comes from the Greek words oikos, meaning 'the family household,' and logy, meaning 'the study of'; it was coined by the German zoologist Ernst Haeckel in 1866, who called it oecologic and defined it as the study of the relationship of animals (organisms) to their environment. Environment includes not only physical but also biological conditions under which an organism lives. These notes are prepared by freebooks.pk.

The chapter covers the concept of the ecosystem and its biotic and abiotic components, the biosphere, habitat and ecological niche, autecology and synecology, the roles of producers, consumers and decomposers, food chains and food webs and trophic levels, ecological succession (primary and secondary, including the stages of xerosere), interspecies relationships (predation, parasitism, symbiosis, mutualism, commensalism, and grazing), biogeochemical cycles with a focus on the nitrogen cycle, and the flow of energy through an ecosystem's food chain.

Learning Objectives

- Define ecology, ecosystem, biosphere, habitat, and ecological niche.
- Differentiate between autecology and synecology, and describe the three levels of ecological integration.
- Describe the biotic and abiotic components of an ecosystem and the roles of producers, consumers, and decomposers.
- Explain food chains, food webs, and trophic levels, and describe how food web diversity maintains ecosystem stability.
- Describe ecological succession, distinguishing primary from secondary succession and outlining the stages of xerosere.
- Explain predation, parasitism, symbiosis, mutualism, commensalism, and grazing, with examples of each.
- Describe the nitrogen cycle, including ammonification, nitrification, assimilation, and denitrification.
- Explain how energy flows through an ecosystem's food chain, including gross and net primary production.

Key Concepts

Introduction to Ecology, Ecosystem, Biosphere and Niche

The term ecology comes from the Greek oikos ('the family household') and logy ('the study of'); it was coined by German zoologist Ernst Haeckel in 1866, who called it oecologic and defined it as the study of the relationship of organisms to their environment, including both physical conditions and interactions with members of other species and the same species. The major unit of ecology is the ecosystem: organisms interact with their environment within the confines of the ecosystem, which consists of two basic interacting components, the living or biotic and the physical or abiotic factors. Biotic components consist of animals, plants,



fungi and micro-organisms, while abiotic components are atmosphere, climate, soil and water. A population is a group of interbreeding individuals of the same species occurring together in space and time, and all populations within an ecosystem, interconnected with one another, are known as a community. Major types of ecosystems that occupy broad geographical regions are called biomes, each characterized by a uniform life-form of vegetation such as grass or coniferous trees; combined, the biomes of earth together form the planetary ecosystem.

The biosphere is a thin layer of earth in which all living organisms exist; organisms within it not only adapt to the environment but also interact to modify and control its chemical and physical conditions. The actual location or place where an organism lives is called its habitat. In 1917, Joseph Grinnell, an American ornithologist, first proposed the term niche in ecology; a niche is the ultimate distributional unit within which a species is restrained by the limitations of its physical structure and physiology. Charles Elton considered the niche the basic role of an organism in the community - what it does in and for the living community, its relationship to its food and enemies - essentially defining niche as the species' occupation. A niche includes all physical factors of the environment necessary for survival, such as range of temperature, humidity, and pH of water and soil, as well as an organism's predators, prey, competitors, behaviour and interactions.

Autecology and Synecology

Ecology is the study of the relationship of living organisms to their environment. When studying a single population's relationship to its environment, this is called autecology; for example, studying 50 to 100 soybean plants to know the effect of water pollution on their growth and yield is autecology, since it examines a single population. Growth responses of individual organisms to their environment are complex, since various environmental factors interact with and aggravate one another, and the complexity of environment depends on the combination of these various factors.

The study of the relationship of different communities (groupings of populations) to their environment is called synecology, or community ecology. When you study only one population at different places in an environment, it is autecology; when you study all the populations together at the same time and place, it is synecology. In synecology you must consider various aspects of the community, including its origin, structure, composition, history and dynamics, since a community is not a fixed entity but changes over time. While studying the community, we encounter three levels of integration: individual, population, and community.

Components of the Ecosystem: Producers, Consumers and Decomposers

The ecosystem can be divided into two main components. Biotic components include all living organisms - plants and animals - supported by the biosphere, which is spread out over the surface of the planet earth, extending about 8-10 kilometres into the upper atmosphere and a similar distance into the depths of oceans. Abiotic components include all non-living components: air, water and soil, referred to ecologically as the atmosphere (atmo - air,



sphere - place), hydrosphere (hydro - water, sphere - place), and lithosphere (litho - earth/soil, sphere - place).

The main processes occurring in an ecosystem include feeding and the circulation of chemical elements, together with the flow of energy through the ecosystem. An ecosystem is made up of three main components concerned with these processes: producers, consumers and decomposers. Producers are the autotrophs - green photosynthetic plants - which capture and bring light energy into the ecosystem, manufacturing organic food from simpler inorganic substances. Consumers are all the organisms, primarily animals, which obtain energy directly or indirectly from producers as ready-made organic food; they are mainly heterotrophic organisms. Decomposers are mainly fungi and bacteria, which obtain their energy from dead and decaying plants and animals, releasing chemical elements as ions such as nitrates, ammonia, phosphates, potassium and calcium. In a basic food chain, all animals ultimately depend on plants for food - for example, an eagle may eat a blue bird, the blue bird eats insects like caterpillars, and the caterpillar feeds on grass or green leaves.

Food Webs and Trophic Levels

A food web is the combination of many food chains; food webs are not as simple as a single linear chain because most animals eat more than one type of food at different times - for instance, a fox does not feed entirely on rabbits but also takes beetles, rats and other prey. All food chains and food webs begin with a green plant (producer) and may consist of three to five links, or trophic levels: T1, the first trophic (producer) level, includes all green plants, grass and phytoplankton; T2, the second trophic level, consists of primary consumers; T3, the third trophic level, consists of secondary consumers; and T4, the fourth trophic level, consists of tertiary consumers.

The variety of pathways in a food web helps maintain the stability of the ecosystem. For example, owls prey on rabbits and mice; if a disease reduces the rabbit population, fewer plants are consumed, so the larger plant population produces more fruits and seeds, which in turn support a larger mouse population, and the increased number of mice becomes the major food source for the owls; the rabbit population then gradually increases and once again becomes a food source for owls, so nature maintains a balance through these interconnected pathways.

Ecological Succession

Succession is a sequence of changes in the community structure of an ecosystem over a period of time; community changes alter the ecosystem in ways that favour competitor species to replace their predecessors in a somewhat predictable manner, until a stable, self-sustaining climax community is reached. Succession is a kind of 'community relay' in which assemblages of plants and animals replace earlier ones in a sequence that is at least somewhat predictable; it is initiated by a few hardy invaders called pioneers and ends with a diverse and relatively stable climax community. Succession on dry land takes two major forms: primary succession, in which an ecosystem is forged from bare rock, sand or a clear glacial pool where there was no trace of previous life (a process often requiring thousands of years), and secondary succession, in which a new ecosystem develops after an existing



ecosystem is disturbed, as in the case of a forest fire or an abandoned farm field; secondary succession happens much more rapidly than primary succession because the previous community has left its mark in the form of improved soil and seeds.

Primary succession starting in a pond is called hydrosere, and that on dry soil or habitat is called xerosere; plants growing in xeric conditions are called xerophytes, able to withstand prolonged periods of water shortage. Xerosere passes through several stages: the crustose lichen stage, in which special lichens impregnate the substratum as a crust and remain quiescent or dormant, desiccated during dry seasons, absorbing water during rain and dew; the foliage lichen stage, in which lichens resemble crumpled leaves attached at one point, shading and reducing the growth of crustose lichens as the area becomes rougher with fissures and depressions (examples include *Dermatocarpon* and *Parmelia*); the moss stage, with mosses such as *Polytrichum* and *Tortula* competing with lichens for water while penetrating deeper into the soil and adding more humus; the herbaceous plant stage, in which small seedlings of herbaceous plants establish due to increased moisture, humus and soil for anchorage; the shrub stage, in which shrubby plants dominate and shadow herbaceous plants, which die and add more humus to the soil; and finally the climax forest stage, in which improved soil allows woody plants to establish, whose shade inhibits growth of most other plants (leaving only mosses, lichens and a few ferns), forming a stable climax stage that persists unless the environmental balance is upset.

Interspecies Relationships: Predation, Parasitism, Symbiosis, Mutualism, Commensalism and Grazing

An animal that preys on other animals is a predator, itself a type of consumer; the animal caught and eaten is the prey, and the overall process is called predation. The sizes of predator and prey populations are related to each other in a cycle: if the number of prey is large, predator numbers increase; as predators feed on prey, prey numbers fall; as prey becomes scarce, predator numbers also decrease due to reduced food supply; and as predators decrease, prey numbers begin to increase again. Examples include cat/mouse, fox/rabbit, seal/fish, frog/mosquito, and hawk/small birds. Parasitism is an association between a host and a parasite in which the host provides the parasite with food, protection and conditions for survival, and the parasite may or may not harm the host; diseases caused by parasites are called infestations. Parasites may be ectoparasites, living outside the host's body (e.g. fungi causing dandruff), or endoparasites, living inside the host's body (e.g. tapeworm in the human intestine).

Symbiosis is an association between two organisms that brings benefit to both. In root nodules, legume plants such as pea and bean host symbiont bacteria in their roots, which fix nitrogen from the air into amino acids that the host uses, while the host provides the bacteria food and protection; in mycorrhiza, an association between plant roots in acid soil and certain fungi (host plants include pine, beech or heather), the host provides the fungus an enzyme to digest carbohydrates in leaf litter, while the fungus passes mineral ions from the soil to the host. Mutualism is a relationship in which both organisms benefit, such as lichens (a mutualistic association between a fungus and an alga, growing on exposed rock surfaces and important colonizers of bare ground) or the relationship between insects and flowering plants (the insect gets nectar, and the flower is pollinated). Commensalism is a



relationship in which only one organism benefits and the other is unaffected, such as remoras attached to sharks, picking up feeding scraps without affecting the shark. Grazing is the feeding mode of animals like rabbits, goats, sheep, cows, buffaloes and horses on grasses in pastureland; moderate grazing is helpful for maintaining a grassland ecosystem by destroying competitors and helping grass grow well, but overgrazing tramples the soil into a hard, impermeable layer, causing rainwater runoff and topsoil loss, ultimately transforming grassland into barren land or desert.

Biogeochemical Cycles and the Nitrogen Cycle

Chemical elements essential for life are called biogenic or nutrient elements; macronutrients are elements required in large amounts, such as water, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur and calcium, while micronutrients are required in small or trace amounts, such as zinc, molybdenum, iron and iodine. Nutrient cycles are also called biogeochemical cycles, as nutrients move from living to non-living to living portions of the ecosystem in a cyclic manner. The chief reservoir of nitrogen is the atmosphere, which is 78 percent nitrogen gas; however, most living things cannot use elemental atmospheric nitrogen directly to make amino acids and other nitrogen-containing compounds, so they depend on nitrogen present in soil minerals, making nitrogen shortage in soil often the major limiting factor in plant growth. The nitrogen cycle has three principal stages: ammonification, nitrification, and assimilation.

Much soil nitrogen results from decomposition of organic materials (proteins, amino acids, nucleic acids and nucleotides), rapidly decomposed by soil-dwelling bacteria and fungi into simpler compounds; these microorganisms release excess ammonia or ammonium ions, a process called ammonification. Several soil bacteria then oxidize ammonia or ammonium ions, a process called nitrification. Although plants can utilize ammonium directly, nitrate is the main form in which nitrogen moves from soil into plant roots; once inside the plant cell, nitrate is reduced back to ammonium, a process called assimilation, which (unlike nitrification) requires energy, and the resulting ammonium ions are transferred to carbon-containing compounds to produce amino acids and other nitrogenous organic compounds the plant needs.

Nitrogen Depletion and the Flow of Energy in the Food Chain

Although the nitrogen cycle appears complete and self-sustaining, nitrates are steadily lost through soil erosion, fire, and water percolating through soil, as well as through the activity of certain soil bacteria that, in the absence of oxygen, break down nitrates and release nitrogen back into the atmosphere while using the oxygen for their own respiration - a process called denitrification, occurring in poorly drained (poorly aerated) soils. The cycle is maintained despite these losses primarily by nitrogen-fixing bacteria, which incorporate gaseous nitrogen from the air into organic nitrogen-containing compounds; just as all organisms ultimately depend on photosynthesis for energy, they all depend on nitrogen fixation for nitrogen. Soil nitrogen resources are also strengthened by the addition of nitrogen fertilizers by humans.



Energy in the form of radiant heat and light from the sun flows through an ecosystem, passing through different trophic levels and eventually radiating back into outer space. The total amount of energy fixed by plants is gross primary production; the energy remaining after plants meet their own respiratory needs is net primary production, which shows up as plant biomass. About 1% of the total solar energy is trapped by producers in an ecosystem, while the remaining 99% is used to evaporate water, heat soil, and is lost to outer space. As energy is transferred from one trophic level to the next - from producer to primary consumer, and onward - between 80 and 90% of the energy is lost as heat, a by-product of respiration; however, the continuous flux of energy from the sun prevents the ecosystem from running down. A short food chain of two or three links supports a community more efficiently than a long chain of five links, where much of the original energy from producers would never reach organisms at higher trophic levels; decomposers obtain energy by converting plant and animal tissues and waste into inorganic mineral ions.

Important Definitions

Term	Definition
Ecology	The study of the relationship of organisms to their environment, coined by Ernst Haeckel in 1866 from the Greek oikos (household) and logy (study of).
Ecosystem	A unit of ecology consisting of two interacting components - the living (biotic) and the physical (abiotic) - within which organisms interact with their environment.
Habitat	The actual location or place where an organism lives.
Ecological niche	The role a species plays in a community, including its behaviour, food and enemy relationships, and influence, as well as the physical environmental factors it requires.
Autecology	The study of a single population's relationship to its environment.
Synecology	The study of the relationship of different communities (groupings of populations) to their environment, also called community ecology.
Succession	A sequence of predictable changes in the community structure of an ecosystem over time, beginning with pioneer species and ending in a stable climax community.
Biogeochemical cycle	The cyclic movement of nutrient elements from living to non-living to living portions of an ecosystem.

Key Facts

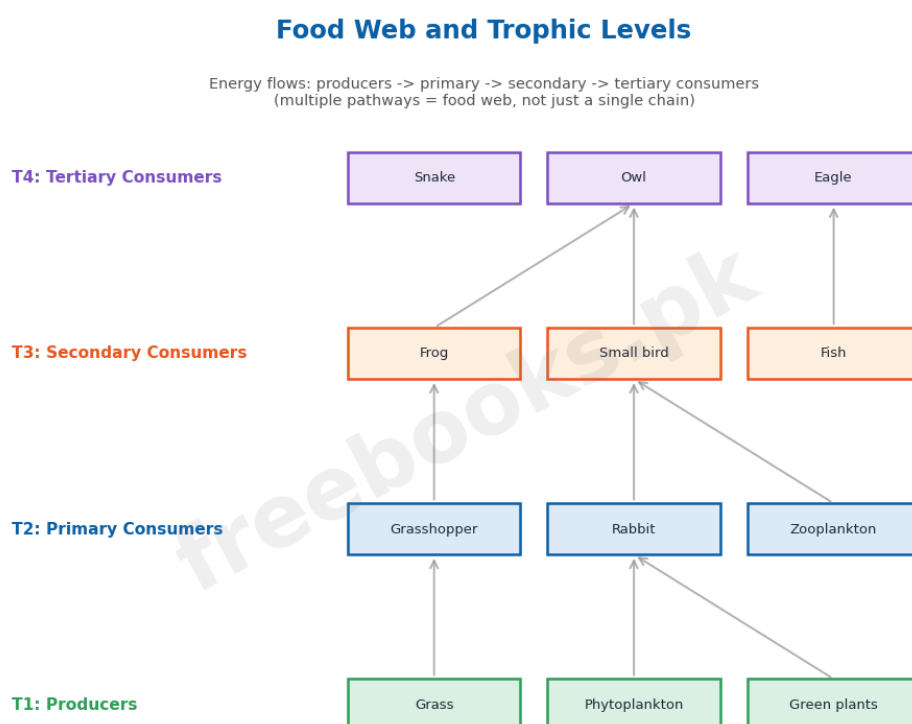
Item	Fact
Coining of ecology	Ernst Haeckel, German zoologist, coined the term 'oecologic' (ecology) in 1866.
Coining of niche	Joseph Grinnell, American ornithologist, first proposed the term 'niche' in ecology in 1917.



Item	Fact
Biosphere extent	The biosphere extends about 8-10 kilometres into the upper atmosphere and a similar distance into ocean depths.
Atmospheric nitrogen	Nitrogen makes up 78 percent of the gases in the atmosphere, the chief reservoir of nitrogen.
3 stages of nitrogen cycle	Ammonification, nitrification, and assimilation are the three principal stages of the nitrogen cycle.
Solar energy capture	About 1% of total solar energy is trapped by producers in an ecosystem; the remaining 99% is lost as heat or used to evaporate water.
Energy loss between trophic levels	Between 80% and 90% of energy is lost as heat (a by-product of respiration) when transferred from one trophic level to the next.
Food chain trophic levels	Food chains/webs typically consist of three to five links or trophic levels (T1 producers, T2 primary consumers, T3 secondary consumers, T4 tertiary consumers).

Diagrams & Illustrations

Food Web and Trophic Levels: a diagram showing a food web with multiple interconnected food chains, illustrating the four trophic levels: T1 producers (green plants), T2 primary consumers, T3 secondary consumers, and T4 tertiary consumers.

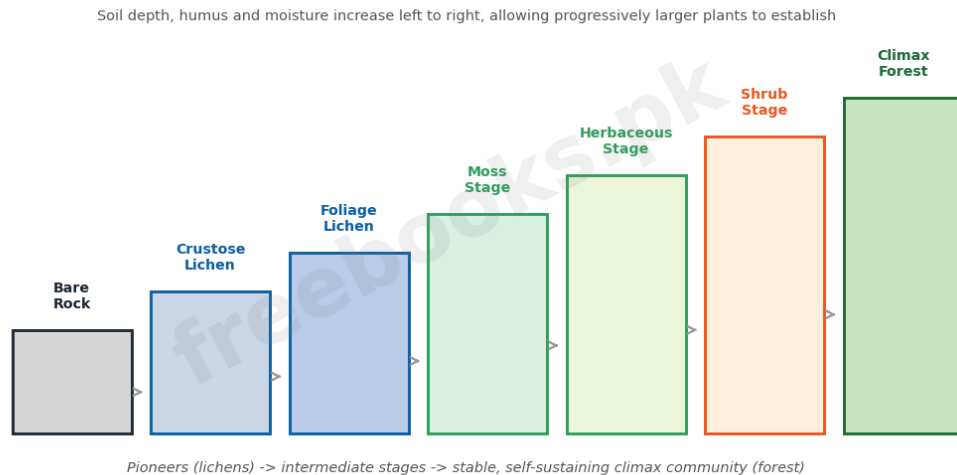


Food Web and Trophic Levels



Ecological Succession: Stages of Xerosere: a diagram showing the sequential stages of xerosere (primary succession on dry land): crustose lichen stage, foliage lichen stage, moss stage, herbaceous stage, shrub stage, and climax forest stage.

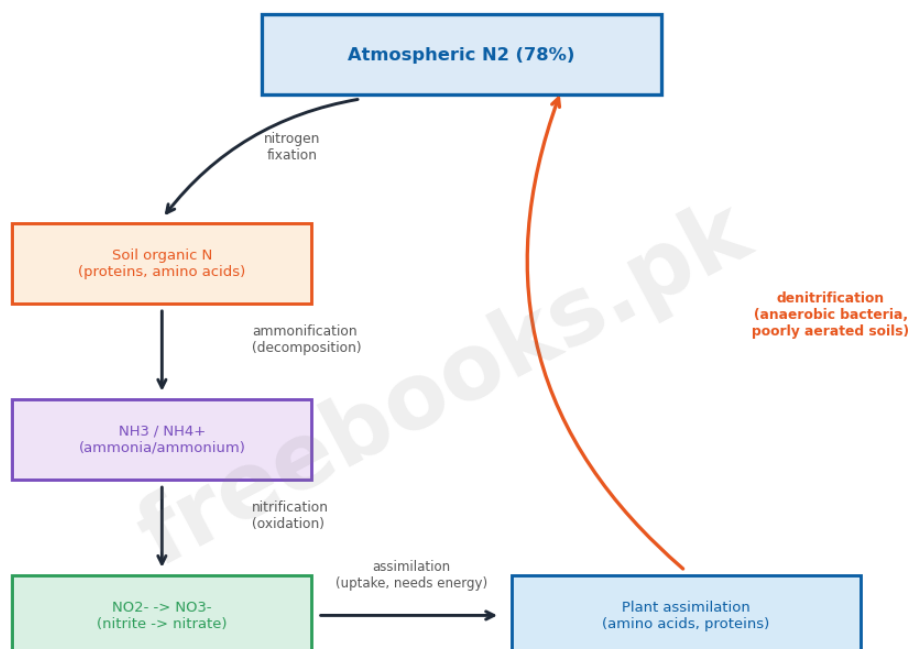
Ecological Succession: Stages of Xerosere



Ecological Succession: Stages of Xerosere

The Nitrogen Cycle: a diagram showing the nitrogen cycle: atmospheric nitrogen, nitrogen fixation, ammonification (decomposition to ammonia), nitrification (ammonia to nitrites to nitrates), assimilation by plants, and denitrification (nitrates back to atmospheric nitrogen).

The Nitrogen Cycle



Short Questions & Answers

Q1. What are the biogeochemical cycles?

Ans. Biogeochemical cycles are the cyclic movements of essential chemical (nutrient) elements from the living to the non-living to the living portions of an ecosystem, such as the nitrogen cycle, carbon cycle, and water cycle.

Q2. Sketch/describe the three main steps in the nitrogen cycle.

Ans. The three principal stages of the nitrogen cycle are ammonification (decomposition of organic nitrogen compounds into ammonia/ammonium ions by soil bacteria and fungi), nitrification (oxidation of ammonia/ammonium into nitrates by soil bacteria), and assimilation (uptake of nitrate by plant roots, reduction back to ammonium, and conversion into amino acids).

Q3. Define grazing.

Ans. Grazing is the mode of feeding in which animals such as rabbits, goats, sheep, cows, buffaloes and horses feed on grasses in pastureland; moderate grazing helps maintain grassland ecosystems, while overgrazing can transform grassland into barren land.

Q4. What percentage of the sun's energy reaches producers, and what happens to the rest?

Ans. About 1% of the total solar energy reaching earth is trapped by producers (green plants) in an ecosystem; the remaining 99% is used to evaporate water, heat up soil, and is eventually lost to outer space.

Q5. What is autecology?

Ans. Autecology is the study of a single population's relationship to its environment, such as studying the effect of water pollution on the growth and yield of one population of soybean plants.

Q6. Define synecology.

Ans. Synecology, or community ecology, is the study of the relationship of different communities (groupings of populations) to their environment, considering the origin, structure, composition, history and dynamics of the community.

Long Questions & Answers

Q1: Discuss ecological succession, distinguishing primary from secondary succession and describing the stages of xerosere.

Ecological succession represents one of the most fundamental and thoroughly documented processes shaping the long-term structure and composition of ecological communities over time, and properly understanding the concept requires examining both its two major underlying forms and the specific sequence of stages through which one of these forms, xerosere, characteristically proceeds. Succession itself is most usefully defined as a sequence of changes occurring within the community structure of a given ecosystem over an



extended period of time, in which ongoing changes within the community progressively alter the ecosystem in ways that favour certain competitor species, allowing them to gradually replace their predecessor species in a manner that is at least somewhat predictable, continuing in this fashion until an eventual stable, self-sustaining climax community is finally reached; succession is therefore often usefully described as a kind of ongoing 'community relay,' in which one assemblage of plants and animals is progressively replaced by the next in a broadly predictable sequence, a process that in every case is initiated by a small number of hardy pioneer invader species and that eventually terminates in a diverse and comparatively stable climax community. Succession occurring on dry land characteristically takes one of two major distinct forms, namely primary succession and secondary succession, and distinguishing carefully between these two forms is essential to understanding the overall concept properly. Primary succession refers specifically to the case in which an entirely new ecosystem is gradually forged essentially from scratch, starting from bare rock, bare sand, or a newly formed clear glacial pool in which there was previously no trace whatsoever of prior biological life, a demanding process that consequently often requires many thousands of years to fully complete; secondary succession, by contrast, refers to the quite different case in which a new ecosystem instead develops specifically after some pre-existing, already-established ecosystem has been significantly disturbed or disrupted in some way, such as by an intervening forest fire or by the abandonment of a previously cultivated farm field, and secondary succession consequently proceeds very considerably more rapidly than primary succession precisely because the previously established community has already left behind its own significant biological mark on the site, particularly in the form of already meaningfully improved soil conditions and an already-present bank of viable seeds. When primary succession specifically begins within a body of water such as a pond, the resulting successional sequence is given the specific technical name hydrosere, whereas primary succession beginning instead on dry soil or a comparable dry habitat is given the specific technical name xerosere, and the particular xerophytic plants able to tolerate and grow successfully in such markedly dry conditions are correspondingly termed xerophytes, plants specifically adapted to withstand prolonged periods of significant water shortage. The xerosere successional sequence itself proceeds through a series of clearly recognizable and sequentially ordered stages: it begins with the crustose lichen stage, in which specially adapted crustose lichens become physically impregnated directly into the bare rock substratum in the form of a thin protective crust, remaining largely quiescent or fully dormant and significantly desiccated throughout dry seasons while absorbing whatever moisture becomes available during periods of rain or morning dew; this is followed by the foliage lichen stage, in which a different type of lichen, now resembling a loose cluster of crumpled leaves attached to the rock surface at only a single point, begins to cast increasing shade over the earlier crustose lichens, thereby progressively reducing their growth, while the immediate surrounding area simultaneously becomes considerably rougher in texture as more numerous fissures and small depressions gradually develop within it; the sequence then proceeds to the moss stage, in which true mosses become established and begin actively competing with the earlier lichens for available water while additionally penetrating considerably deeper into the developing soil layer than the lichens had previously managed, in the process contributing substantially more organic humus material to the accumulating soil; this is followed in turn by the herbaceous plant stage, in which small seedlings of



various herbaceous plant species are now finally able to successfully establish themselves, made possible specifically by the by-now considerably greater availability of adequate moisture, accumulated humus, and sufficient soil depth to provide secure anchorage for root systems; the sequence then progresses further to the shrub stage, in which larger, woody shrub species begin actively growing and progressively come to dominate and cast shade over the smaller herbaceous plants growing beneath them, which correspondingly die back and in doing so contribute still further additional humus to the continuously improving soil; and the xerosere sequence finally culminates in the climax forest stage, in which the by-now substantially improved soil conditions are sufficient to permit the successful establishment and growth of full-sized woody trees, whose dense overhead shade in turn effectively inhibits the successful growth of most other plant species apart from a limited number of shade-tolerant mosses, lichens, and ferns, so that the resulting woody forest comes to dominate the site and this particular stage of the succession accordingly remains essentially unchanged and stable for as long as nothing subsequently occurs within the surrounding environment to meaningfully upset this newly achieved ecological balance, precisely the defining characteristic that qualifies the woody forest as the true climax stage for that particular region.

Q2: Describe the nitrogen cycle in detail, explaining ammonification, nitrification, assimilation, and denitrification, along with the causes and remedies of nitrogen depletion.

The nitrogen cycle represents one of the most ecologically essential of all the various biogeochemical cycles operating within the biosphere, precisely because nitrogen itself constitutes an absolutely indispensable structural component of amino acids, proteins, nucleic acids and numerous other biologically essential nitrogen-containing compounds required by every living organism, and properly understanding this particular cycle in its entirety requires carefully tracing the movement of nitrogen atoms as they pass in turn through each of the cycle's several interconnected principal stages. The single chief reservoir of nitrogen anywhere on the planet is unquestionably the atmosphere itself, within which nitrogen gas alone makes up a substantial 78 percent of the total volume of atmospheric gases present; however, despite this considerable atmospheric abundance, the great majority of living organisms are nevertheless entirely unable to make any direct biological use whatsoever of this elemental atmospheric nitrogen gas in order to manufacture amino acids or other essential nitrogen-containing biological compounds, and as a direct consequence, most organisms instead remain critically dependent upon whatever nitrogen happens to already be present within the soil in the form of various soil mineral compounds, a basic biological constraint that helps explain why an underlying shortage of usable nitrogen within the soil so frequently turns out to be the principal factor actually limiting plant growth in a great many natural and agricultural environments alike, quite independent of the vast, but biologically inaccessible, atmospheric nitrogen reserve. The overall nitrogen cycle itself can be most usefully broken down into three clearly distinguishable principal successive stages, namely ammonification, nitrification, and assimilation, each of which is carried out by a different specialized set of microorganisms and which together convert nitrogen progressively from one chemical form into the next as it moves through the cycle. The first stage, ammonification, begins with the simple



observation that a substantial proportion of the total nitrogen actually present within ordinary soil originates directly from the ongoing decomposition of pre-existing organic materials, materials that are initially present in the relatively complex chemical forms of proteins, amino acids, nucleic acids and nucleotides; these various complex nitrogenous organic compounds are then typically decomposed comparatively rapidly into much simpler chemical compounds through the combined metabolic activity of various soil-dwelling microorganisms, chiefly ordinary soil bacteria together with various soil fungi, and these particular microorganisms characteristically make direct metabolic use of the available proteins and amino acids for their own nutritional purposes while simultaneously releasing a corresponding excess quantity of either ammonia gas or, alternatively, dissolved ammonium ions back into the surrounding soil environment as a direct metabolic by-product, and this particular overall process is accordingly given the specific technical name ammonification. The second principal stage, nitrification, subsequently involves several further specialized types of soil bacteria that are metabolically capable of chemically oxidizing this previously produced ammonia or ammonium, in the specific technical sense of chemical oxidation, converting these particular nitrogen-containing compounds progressively into nitrite and ultimately into nitrate ions, with this particular subsequent oxidation process accordingly given the specific technical name nitrification. The third principal stage, assimilation, then follows, in which, although growing plants are in fact fully capable of directly utilizing ammonium ions when these happen to be available, it is instead nitrate that actually constitutes the predominant chemical form in which the great majority of soil nitrogen is ultimately transported from the surrounding soil directly into plant root systems; once any given nitrate ion has successfully entered a living plant cell, it is then promptly chemically reduced back down into ammonium once again, and this particular assimilation process, in clear contrast to the immediately preceding nitrification process, specifically requires a net metabolic input of energy on the part of the plant in order to proceed, following which the resulting ammonium ions are then further metabolically transferred onto various carbon-containing organic compounds already present within the plant in order to successfully produce the various amino acids and other essential nitrogenous organic compounds that the growing plant specifically requires for its own biological functioning. Beyond these three principal forward-moving stages, the nitrogen cycle additionally includes a further, distinctly different process known as denitrification, occurring specifically within poorly drained or otherwise poorly aerated soils, in which yet another group of specialized soil bacteria, operating characteristically under conditions of low or entirely absent oxygen availability, instead actively break down existing soil nitrates, in the process releasing the resulting nitrogen gas directly back into the surrounding atmosphere while simultaneously making metabolic use of the oxygen atoms thereby liberated to support their own cellular respiration; more generally, despite the nitrogen cycle's overall appearance of forming an essentially complete and fully self-sustaining natural loop, soil nitrates are nevertheless continuously and steadily lost from the soil through several additional distinct pathways beyond denitrification alone, including ordinary soil erosion, the periodic occurrence of fire, and the simple physical process of water gradually percolating downward through the soil profile and carrying dissolved nitrates away with it; however, despite this ongoing, continuous loss of soil nitrogen through these several combined pathways, the overall nitrogen cycle nevertheless continues to be successfully maintained over time, primarily



through the essential ongoing biological activity of specialized nitrogen-fixing bacteria, which are uniquely capable of directly incorporating otherwise biologically inaccessible gaseous atmospheric nitrogen into various usable organic nitrogen-containing compounds, meaning that, in a directly analogous fashion to the way in which essentially all living organisms remain ultimately dependent upon ongoing photosynthesis as their fundamental original source of usable biological energy, all living organisms similarly remain simultaneously and equally dependent upon ongoing biological nitrogen fixation as their fundamental original source of usable biological nitrogen; finally, in modern agricultural practice, existing soil nitrogen resources are additionally and very substantially further supplemented and reinforced through the widespread deliberate human application of manufactured nitrogen-based chemical fertilizers, a practical human intervention specifically intended to help compensate for the various natural nitrogen losses described above and thereby to help sustain adequate soil nitrogen levels for continued successful crop production.

MCQs with Answers

1. The term 'ecology' was coined in 1866 by the German zoologist:

(a) Charles Darwin (b) Ernst Haeckel (c) Joseph Grinnell (d) Charles Elton

Correct Answer: (b) Ernst Haeckel. Ernst Haeckel coined the term 'oecologic' (ecology) in 1866, defining it as the study of the relationship of organisms to their environment.

2. The term 'niche' in ecology was first proposed in 1917 by:

(a) Ernst Haeckel (b) Charles Elton (c) Joseph Grinnell (d) Charles Darwin

Correct Answer: (c) Joseph Grinnell. Joseph Grinnell, an American ornithologist, first proposed the term 'niche' in ecology in 1917.

3. The study of a single population's relationship to its environment is called:

(a) synecology (b) autecology (c) biogeography (d) phytogeography

Correct Answer: (b) autecology. Autecology is the study of a single population's relationship to its environment, as opposed to synecology, which studies communities.

4. Organisms that manufacture their own organic food from inorganic substances are called:

(a) consumers (b) decomposers (c) producers (d) parasites

Correct Answer: (c) producers. Producers are autotrophs, mainly green photosynthetic plants, that manufacture organic food from simple inorganic substances.

5. In a food web, the second trophic level (T2) consists of:

(a) green plants (b) primary consumers (c) secondary consumers (d) decomposers

Correct Answer: (b) primary consumers. T2, the second trophic level, consists of primary consumers, which feed directly on producers (T1).

6. Primary succession beginning in a pond is called:

(a) xerosere (b) hydrosere (c) lithosere (d) psammosere

Correct Answer: (b) hydrosere. Primary succession starting in a pond is called hydrosere, while that on dry soil is called xerosere.

7. The first stage of xerosere, in which lichens form a crust on bare rock, is called the:



(a) foliage lichen stage (b) moss stage (c) crustose lichen stage (d) climax stage

Correct Answer: (c) crustose lichen stage. The crustose lichen stage is the first stage of xerosere, in which crustose lichens become impregnated as a crust on the bare rock substratum.

8. An association between two organisms that brings benefit to both is called:

(a) parasitism (b) commensalism (c) predation (d) mutualism

Correct Answer: (d) mutualism. Mutualism is a relationship in which both organisms benefit, such as the lichen association between a fungus and an alga.

9. The process by which soil bacteria oxidize ammonia or ammonium ions into nitrates is called:

(a) ammonification (b) nitrification (c) denitrification (d) assimilation

Correct Answer: (b) nitrification. Nitrification is the oxidation of ammonia/ammonium ions into nitrites and nitrates by soil bacteria, the second stage of the nitrogen cycle.

10. Approximately what percentage of total solar energy reaching earth is trapped by producers in an ecosystem?

(a) 1% (b) 10% (c) 50% (d) 90%

Correct Answer: (a) 1%. About 1% of the total solar energy reaching earth is trapped by producers; the remaining 99% is used to evaporate water, heat soil, or is lost to space.

Quick Revision Summary

- Ecology (Haeckel, 1866) = study of organisms & environment. Ecosystem = biotic (living) + abiotic (non-living) components. Biosphere = thin layer of earth with all life. Habitat = where organism lives; Niche (Grinnell, 1917) = role/occupation of species in community.
- Autecology = study of ONE population. Synecology = study of communities (multiple populations). 3 levels of integration: individual -> population -> community.
- Ecosystem components: Producers (autotrophs, e.g. green plants) -> Consumers (heterotrophs) -> Decomposers (fungi/bacteria, release nutrient ions). Food chain -> Food web (many food chains) -> Trophic levels T1 (producers) to T4 (tertiary consumers).
- Succession = predictable community change over time, pioneers -> climax community. Primary succession (bare rock/pond, from scratch, slow) vs Secondary succession (after disturbance, faster). Hydrosere (pond) vs Xerosere (dry land) - 6 stages: crustose lichen -> foliage lichen -> moss -> herbaceous -> shrub -> climax forest.
- Interspecies relationships: Predation (predator-prey cycle), Parasitism (ecto/endoparasites, host harmed or not), Symbiosis (root nodules, mycorrhiza - both benefit), Mutualism (lichens, insect-flower - both benefit), Commensalism (remora-shark - one benefits, other unaffected), Grazing (moderate = healthy grassland; overgrazing = desertification).
- Nitrogen cycle: atmosphere = 78% N₂ (chief reservoir, but unusable directly). 3 stages: Ammonification (organic N -> NH₃/NH₄⁺ by bacteria/fungi) -> Nitrification



($\text{NH}_3/\text{NH}_4^+$ $\rightarrow$ nitrites $\rightarrow$ nitrates, oxidation) $\rightarrow$ Assimilation (nitrate $\rightarrow$ ammonium $\rightarrow$ amino acids in plant, needs energy). Denitrification = nitrates $\rightarrow$ N_2 gas (poorly aerated soil).

- Energy flow: Sun $\rightarrow$ $\sim 1\%$ trapped by producers (99% lost/used for evaporation/heat). Gross primary production (total fixed) vs Net primary production (after plant respiration = biomass). 80-90% energy lost as heat between trophic levels $\rightarrow$ short food chains (2-3 links) more efficient than long ones (5 links). Notes by freebooks.pk.

Exam Tips

- Memorise the 3 key historical figures with their contributions: Haeckel (1866, coined ecology), Grinnell (1917, coined niche), Elton (defined niche as species' occupation/role) - commonly asked as short questions.
- Keep autecology (ONE population) vs synecology (communities/MULTIPLE populations) as a clean opposite pair - a very frequently tested distinction.
- Build a 3-row table for producers/consumers/decomposers with one defining feature each (autotrophic/heterotrophic/release nutrient ions) rather than memorising prose definitions alone.
- Memorise the 6 xerosere stages in strict order (crustose lichen $\rightarrow$ foliage lichen $\rightarrow$ moss $\rightarrow$ herbaceous $\rightarrow$ shrub $\rightarrow$ climax forest) - exams often ask you to sequence or name all six stages.
- Build a 2-column comparison table for interspecies relationships (predation/parasitism/symbiosis/mutualism/commensalism/grazing) with one example and one 'who benefits' note for each - this structure directly answers most related exam questions.
- Memorise the nitrogen cycle's 3 forward stages in order (ammonification $\rightarrow$ nitrification $\rightarrow$ assimilation) plus denitrification as the reverse process, and note which stage requires energy (assimilation).
- Remember the energy flow numbers as a pair: $\sim 1\%$ of solar energy trapped by producers, and 80-90% lost as heat between each trophic level - together they explain why food chains rarely exceed 4-5 links.

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FSc Part-II Biology — Punjab Board

CHAPTER 26

Some Major Ecosystems

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

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This chapter covers Some Major Ecosystems, the final chapter from the 2nd Year (FSc Part-II) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Life on earth, especially on land, is affected by both weather and climate: weather refers to short-term fluctuations in temperature, humidity, cloud cover, wind and precipitation over hours or days, while climate refers to overall patterns of weather that prevail from year to year or even century to century in a particular region. Building on the general concept of the ecosystem from the previous chapter, this chapter discusses aquatic and terrestrial ecosystems in detail. These notes are prepared by freebooks.pk.

The chapter covers the aquatic (hydrospheric) ecosystem and its productivity, the three life zones of fresh water lakes (littoral, limnetic and profundal) and human-caused eutrophication, the terrestrial (lithospheric) ecosystem and its adaptations, and Pakistan's major terrestrial ecosystems: temperate deciduous forests, coniferous alpine and boreal forests (taiga), grassland ecosystems, desert ecosystems, and the tundra ecosystem, concluding with a discussion of human impact on ecosystems.

Learning Objectives

- Distinguish between weather and climate.
- Describe the hydrospheric (aquatic) ecosystem and the factors determining its productivity.
- Identify the three life zones of a fresh water lake (littoral, limnetic, profundal) and describe eutrophication.
- Describe the terrestrial (lithospheric) ecosystem, the factors influencing life on land, and adaptations for land life.
- List the major divisions of the terrestrial ecosystem and identify Pakistan's major ecosystems and their locations.
- Describe the climate, plant life, animal life and human impact of temperate deciduous forests and coniferous (taiga) forests.
- Describe the climate, plant life, animal life and human impact of grassland and desert ecosystems.
- Describe the tundra ecosystem and summarize the overall impact of humans on natural ecosystems.

Key Concepts

Climate and the Aquatic (Hydrospheric) Ecosystem

Weather refers to short-term fluctuations in temperature, humidity, cloud cover, wind and precipitation over periods of hours or days, while climate refers to overall patterns of weather that prevail from year to year, even century to century, in a particular region. The hydrospheric ecosystem is a system in water where living and non-living components exchange materials and energy transfer also takes place within water. Salt-water oceans and seas are the largest ecosystems on earth, forming about 71% of its surface, while fresh water ecosystems cover less than 1%. The unique properties of water give aquatic



ecosystems some common features: water changes temperature more slowly than air, so aquatic temperatures are more moderate for supporting life; although water appears transparent, it absorbs considerable light energy, and light intensity decreases rapidly with depth, so at depths of 600 feet or more little light remains to power photosynthesis; nutrients tend to concentrate near bottom sediments where light levels are often too low for photosynthesis; and water, abundantly available with appropriate temperature, is essential for all metabolic processes, with energy and nutrients being the major factors determining the quantity and type of life present.

The productivity of an aquatic ecosystem can be indicated by consumption of carbon dioxide and evolution of oxygen during photosynthesis, and is basically determined by light and nutrients; light intensity and quality vary with water depth, so primary productivity also varies with light, while nutrient amounts change with season, and productivity varies from zone to zone. Aquatic environments can be broadly classified into fresh water and marine (salty) water.

Fresh Water Lakes: Life Zones and Human Impact

Fresh water lakes vary tremendously in size, depth and nutrient content, including distinct life zones and temperature stratification; the distribution of life in lakes depends on access to light, nutrients, and a place for attachment, dividing the lake ecosystem into three main zones. The littoral zone (near-shore) has shallow water where plants find abundant light, anchorage and nutrients from bottom sediments; plant communities here are the most diverse, including water lilies and submerged vascular plants and algae, and this zone also has the greatest diversity of animals, including plankton (microscopic organisms divided into phytoplankton - photosynthetic protista, bacteria and algae - and zooplankton - protozoa and tiny crustaceans), along with littoral invertebrates (small crustaceans, insect larvae, snails, flatworms, Hydra) and vertebrates (frogs, aquatic snakes, turtles). As water depth increases away from shore, plants can no longer anchor while still collecting enough light, dividing the open water area into the upper limnetic zone, where enough light penetrates for photosynthesis (with cyanobacteria as phytoplankton producers, eaten by protozoa and small crustaceans, which are in turn consumed by fish), and the lower profundal zone, where light is insufficient for photosynthesis and organisms are nourished mainly by detritus falling from the littoral and limnetic zones and incoming sediment, inhabited by decomposers and detritus feeders such as snails, certain insect larvae, bacteria, fungi and fish.

Human activities may greatly accelerate eutrophication, since nutrients are carried into lakes from farm feedlots and sewage; even after solid wastes are removed, water discharged from sewage treatment plants is often rich in phosphates and nitrates, and rainwater washes fertilizer and cattle manure runoff into lakes, enriching the water and supporting excessive growth of phytoplankton. Producers like blue-green algae form a surface scum, depriving submerged plants of sunlight, causing them to die; the dead plant bodies are decomposed by bacteria that use up dissolved oxygen, causing fish, snails and insect larvae to die from oxygen deprivation, and their decaying bodies fuel further bacterial growth, further depleting oxygen; even without oxygen, certain foul-smelling-gas-producing bacteria thrive, so a polluted lake, while full of life and nutrients, smells bad, with most trophic levels including fish eliminated and bacteria and blue-green algae dominating the community. Another



serious cause of polluted water is acid produced by the burning of fossil fuels, posing a different threat, as few organisms can withstand the low pH of acidified lakes.

The Terrestrial (Lithospheric) Ecosystem: Factors and Adaptations

The ecosystem present on land or soil is called the terrestrial or lithospheric ecosystem, which receives plenty of light and abundant soil nutrients, but water is limited and very unevenly distributed in both place and time. Temperature, like water, is very unevenly distributed on land in place and time: at the poles, average temperature is below freezing; in temperate zones, favourable temperatures occur only during certain seasons; but tropical zones have uniformly warm, moist climates. In the terrestrial ecosystem, air is in constant motion, so its composition (including oxygen and carbon dioxide levels) is more uniform and beneficial throughout.

Plants and animals shifting from water to land developed various adaptations for terrestrial life, including supporting tissues - vascular bundles (xylem-phloem) in plants and a skeleton in animals - to support them against gravity, and mechanisms for conservation of water, such as homeostasis, and temperature regulation, such as bark in plants and skin in animals. The terrestrial ecosystem can be divided into several main types: the forest ecosystem (further sub-divided into tropical rain forests, temperate deciduous forests, and coniferous alpine and boreal forests), the grassland ecosystem, the desert ecosystem, and the tundra ecosystem.

Pakistan's Ecosystems and the Temperate Deciduous Forests

Pakistan has a wide variety of seasons and climates, ranging from hot and dry in the plains to cold and snowy in the mountains, and hosts a range of major terrestrial ecosystems: temperate deciduous forests (Shogran and Neelum valley), coniferous alpine and boreal forests (northern mountains of Kaghan, Malam Jabba/Swat, Dir and Chilas), grassland ecosystem (Gilgit, Kashmir, Waziristan, lower Chitral and North Kalat), desert ecosystem (Mianwali, Bhakkar; Fort Abbas, Bahawalnagar, Yazman, Bahawalpur, Khanpur and Rahim Yar Khan; and Sindh), and tundra ecosystem (the Karakoram and Hindu Kush mountains).

In Pakistan, temperate deciduous forests occur in the Neelum valley and Shogran; worldwide, these forests originally covered India, Southeast Asia, eastern North America, Europe, China, Australia, Japan, and North and South America. Farther from the equator, rainfall is not constant, with pronounced wet and dry (summer and winter) seasons; during dry seasons trees cannot get enough water from the soil to compensate for evaporation from their leaves, so they have adapted by shedding leaves to minimize water loss, delaying new leaf formation if rains fail to return on schedule. Average rainfall is 750-1500 mm, with moderate temperatures ranging from 4 to 30 degrees Celsius; dominant plants include *Taxus baccata*, *Pinus wallichiana*, and *Berberis lyceum*, with herbs and shrubs up to 5 metres, grasses, ferns and other herbaceous plants forming the field layer, and mosses, liverworts and lichens at the litter-covered floor. Common animals include the rhesus monkey (*Macaca mulatta*), black bear (*Selenarctos thibetanus*), leopard cat (*Felis bengalensis*), deer, and wolves, alongside microorganisms such as bacteria, fungi and earthworms that convert litter into organic matter. The soil is grayish-brown, very fertile and rich in organic matter with



maximum water-holding capacity; human impact through lumber harvesting for agriculture has reduced many deciduous forests worldwide, and large predators such as black bear, deer, wolves, bobcats and mountain lions have been largely wiped out by humans.

Coniferous Alpine and Boreal Forests (Taiga)

In Pakistan, coniferous forests occur in upper Kaghan, Dir and Chilas, and Malam Jabba in the Swat valley; worldwide, they stretch across Eurasia and North America, just south of the tundra, and are also called taiga. Conditions in the taiga are harsher than in temperate deciduous forest, with longer, colder winters and a shorter growing season too brief for trees to regrow foliage each year; as a result, evergreen coniferous trees with small waxy needles dominate this forest type, their waxy coating and small surface area reducing water loss by evaporation during cold months, allowing needles to remain on trees year-round. Coniferous forests at high altitude are called alpine, while those at high latitude are called boreal.

The taiga has a constant cover of snow characterized by long, severe winters, with temperatures ranging from below freezing up to 10 degrees Celsius; because of the harsh climate, biodiversity is much lower than in deciduous forest. Large mammals present include bison, wolf, black bear, deer, and Marco Polo sheep, alongside smaller animals such as the Kashmir flying squirrel, snowshoe hare, wolverine, and crossbills; plant life includes *Pinus wallichiana*, *Pinus roxburghii*, *Abies pindrow*, *Picea smithiana*, and *Cedrus deodara*. Due to the severity of the climate and remoteness of these regions, most coniferous forests remain relatively undisturbed, though they are a major source of lumber for construction, leading to clearing of these forests in various parts of the world.

The Grassland Ecosystem

Grassland ecosystems in Pakistan are found in Gilgit, Kashmir, Waziristan, lower Chitral and North Kalat; worldwide, a large grassland region occurs in the center of the Eurasian continent. Grasslands in temperate climates, lacking woody plants, are called prairies (such as the Prairies of North America and the Pampas of Argentina), while grasslands in tropical climates with woody trees are called savannas. Grasslands typically face severe droughts, with annual rainfall of about 250-750 mm (reaching about 1500 mm in tropical and subtropical grasslands), occurring in regions where mean annual rainfall is midway between forest and desert conditions, generally featuring a continuous grass cover with virtually no trees except along rivers; water and fire are the crucial factors in the competition between grasses and trees.

The dominant plant species are graminoids (grasses and grass-like plants), along with certain forbs such as composites and legumes. Grasslands show characteristic layering: tall grasses (*Andropogon*, *Panicum*) form the first layer, mid-high grasses (*Stipa*, *Sporobolus*, *Oryzopsis*) form the second layer, and short grasses, forbs, mosses and lichens form the third layer. Soil moisture is limited due to low precipitation and high evaporation; the upper soil layer where grasses are rooted is normally moist, but deeper layers remain constantly dry, and the soil tends to be impermeable with excessive salinity. Dominant animal species are herbivores, with numerous invertebrates including insects (grasshoppers can become numerous enough to compete with other herbivores for plant foliage); predators include



reptiles, amphibians and mammals such as lizards, toads, turtles, foxes and wolves; decomposers include bacteria, actinomycetes and fungi (molds, yeasts, mushrooms, bracket fungi); and large animals like zebras, wild horses and bison are also significant. Primary production in temperate grassland is about 700-1500 g/m² annually, exceeding 4000 g/m² in sub-humid tropical grassland; human impact includes crop production and livestock management, with only a small fraction of the world's grasslands cultivated due to acidic climatic conditions, soil erosion and salinity, and overgrazing causing herbage reduction, soil erosion, and desertification.

The Desert Ecosystem

In Pakistan, the desert ecosystem is found in western Punjab (Mianwali and Bhakkar), known as 'Thal', and in southern Punjab (Fort Abbas, Bahawalnagar, Yazman, Bahawalpur/Cholistan, Khanpur and Rahim Yar Khan); in Sindh, this desert ecosystem is called 'Thar'. Deserts are found on every continent, often around 20 to 30 degrees north and south latitude and in the rain shadows of major mountain ranges, and include a variety of environments - at one extreme, areas of the Sahara or Chile where it virtually never rains and there is no vegetation at all; more commonly, deserts are characterized by widely spaced vegetation and large areas of bare ground.

Deserts receive less than 25-50 cm (10-20 inches) of rainfall or none at all; plants are often evenly spaced, frequently as bushes or cacti with large shallow root systems, covered with waterproof waxy coatings to prevent water evaporation, and storing water in thick stems (as in cacti and Euphorbia, which have fleshy stems for water storage during drought). Animals are also specially adapted to survive on little water; most deserts appear almost devoid of animal life during the day, as animals seek relief from sun and heat in cool underground burrows, emerging in the dark as the desert cools, with horned lizards, snakes and other reptiles feeding alongside mammals such as kangaroo rats and birds such as the burrowing owl. Most smaller animals survive without ever drinking, obtaining water from food and cellular respiration, while large animals such as desert bighorn sheep and camels depend on permanent water holes during the driest times. Human activities are causing the spread of deserts, a process called desertification; a dramatic example is occurring in the Sahel, bordering the southern edge of the Sahara in Africa, where twenty-five years of below-average rainfall coupled with rapid human population growth have caused a steady southward spread of desert, exceeding the land's carrying capacity and resulting in nearly irreversible productivity loss and massive famines, such as occurred in Ethiopia in the mid-1980s.

The Tundra Ecosystem and Human Impact on Ecosystems

The last biome before reaching the polar ice caps is the arctic tundra, a vast treeless region bordering the Arctic Ocean, describing vegetation types in treeless high latitudes between taiga and polar ice caps, as well as high altitudes above the timberline, such as the Karakoram and Hindu Kush mountains in Pakistan. Arctic tundra stretches across northern North America, northern Europe, and Siberia. The ground is carpeted with small perennial flowers and dwarf willows no more than a few centimetres tall, often with large lichen called reindeer moss; standing pools provide superb mosquito habitat, and mosquitoes and other



insects provide food for numerous migratory birds (ducks and geese) that travel long distances to nest and raise young during the brief summer. Tundra vegetation supports lemmings, which are eaten by wolves, snowy owls, arctic foxes, and even grizzly bears.

The tundra is perhaps the most fragile of all biomes because of its short growing season - a willow just 10 centimetres (4 inches) tall may have a trunk 7 centimetres (3 inches) in diameter and be 50 years old - meaning human activities in the tundra leave scars that persist for centuries; fortunately, civilization's impact remains largely localized around oil drilling sites, pipelines, mines and military bases. More broadly, the expanding human population has left relatively few ecosystems undisturbed; our impact on natural ecosystems is so diverse and wide-ranging that it far exceeds the scope of any single chapter, and ecosystems dominated by people tend to be simpler, with fewer species and fewer community interactions than an undisturbed ecosystem.

Important Definitions

Term	Definition
Weather	Short-term fluctuations in temperature, humidity, cloud cover, wind and precipitation over periods of hours or days.
Climate	The overall patterns of weather that prevail from year to year, even century to century, in a particular region.
Littoral zone	The near-shore zone of a lake with shallow water, abundant light, anchorage and nutrients, hosting the most diverse plant and animal communities.
Eutrophication	The process by which excessive nutrient enrichment of a water body (often from human activity) leads to excessive algal growth, oxygen depletion, and death of aquatic life.
Taiga	Northern coniferous forest, found across Eurasia and North America just south of the tundra, dominated by evergreen conifers adapted to harsh, cold winters.
Prairie	Temperate grassland lacking woody plants, such as the Prairies of North America or the Pampas of Argentina.
Savanna	Tropical grassland containing woody trees, distinguished from temperate treeless prairies.
Desertification	The process by which human activities and/or climatic factors cause the spread of desert conditions into previously non-desert land.

Key Facts

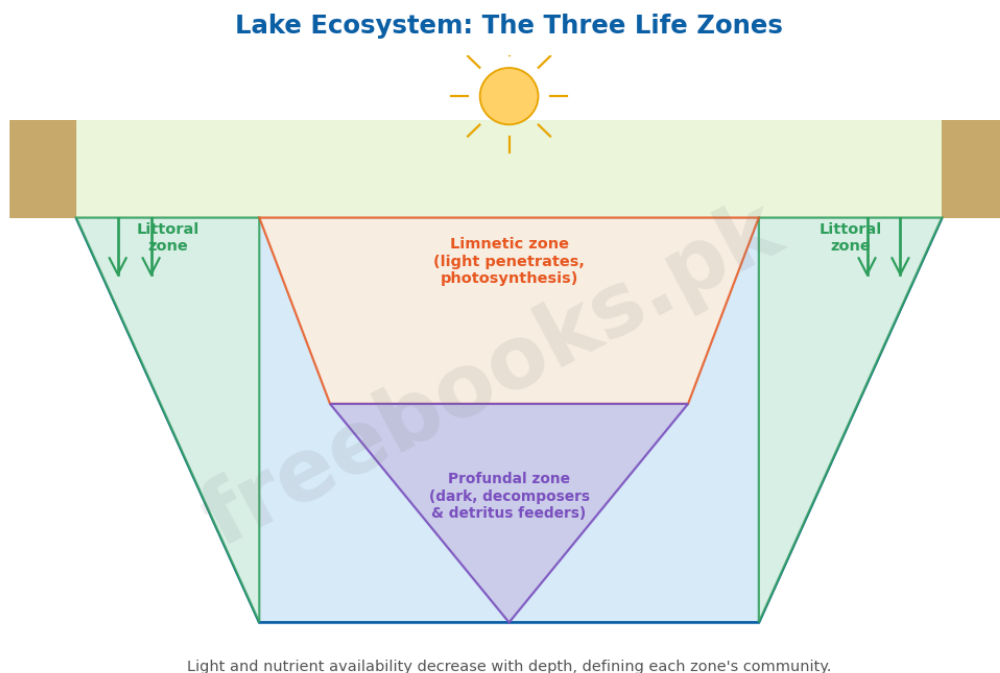
Item	Fact
Ocean/sea surface coverage	Salt-water oceans and seas cover about 71% of Earth's surface; fresh water ecosystems cover less than 1%.
Light penetration depth for photosynthesis	At depths of 600 feet (about 180 m) or more, little light remains to power photosynthesis in aquatic ecosystems.



Item	Fact
Temperate deciduous forest rainfall & temperature	Average rainfall 750-1500 mm; temperature ranges from 4°C to 30°C.
Grassland annual rainfall	Temperate grassland: about 250-750 mm annually; tropical/subtropical grassland: up to about 1500 mm (60 inches).
Grassland primary production	Temperate grassland: 700-1500 g/m ² annually; sub-humid tropical grassland: more than 4000 g/m ² annually.
Desert rainfall	Deserts receive less than 25-50 cm (10-20 inches) of rainfall annually, or none at all.
3 lake life zones	A lake ecosystem has three main life zones: littoral (near-shore), limnetic (open water, upper), and profundal (open water, deep).
Desert & grassland latitude band	Many of the world's major deserts and grasslands occur around 20° to 30° north and south latitude.

Diagrams & Illustrations

Lake Ecosystem: The Three Life Zones: a cross-section diagram of a fresh water lake showing the three life zones: the littoral (near-shore) zone with rooted plants, the limnetic (open water, upper) zone with phytoplankton, and the profundal (deep, dark) zone with decomposers.

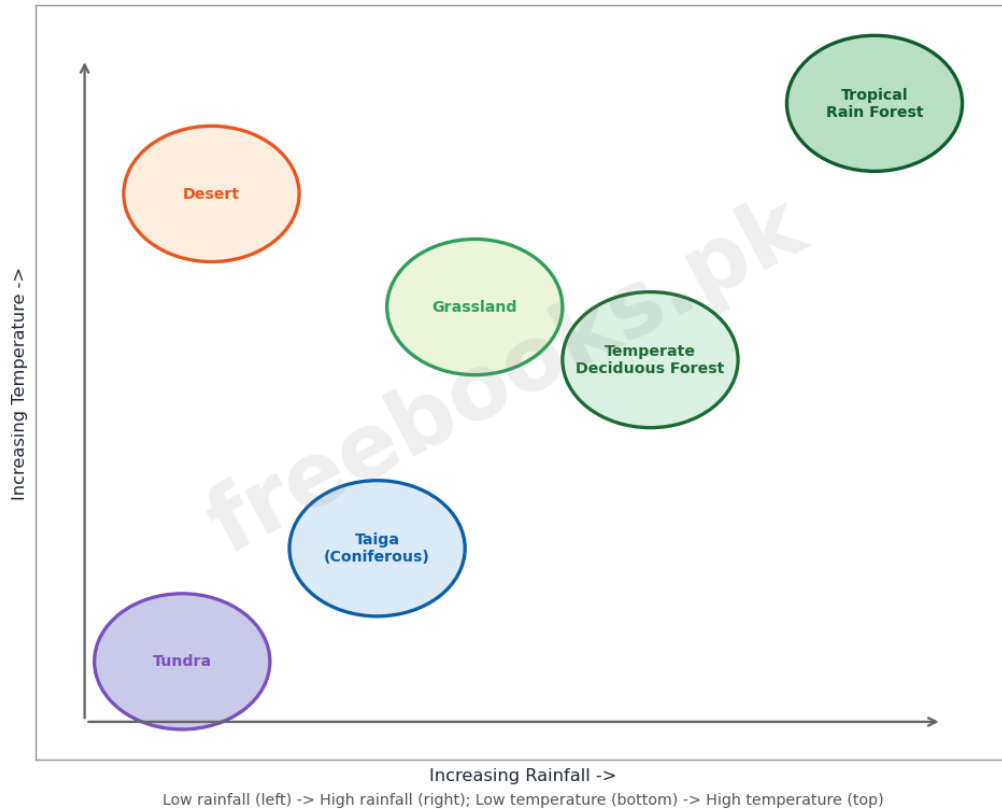


Lake Ecosystem: The Three Life Zones

Terrestrial Biomes: Temperature and Rainfall: a diagram plotting the major terrestrial biomes (tundra, taiga/coniferous forest, temperate deciduous forest, grassland, desert) on axes of temperature and rainfall, showing how each biome's characteristic climate conditions determine its position.



Terrestrial Biomes: Temperature and Rainfall

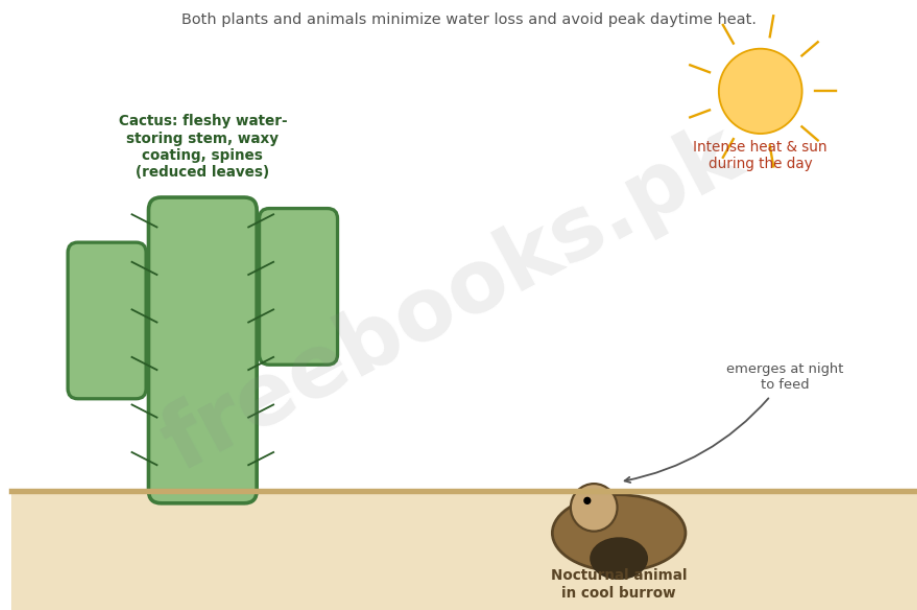


Terrestrial Biomes: Temperature and Rainfall

Desert Plant and Animal Adaptations: a diagram showing desert survival adaptations: a cactus with a thick, water-storing fleshy stem and waxy coating and reduced leaves (spines), alongside a burrowing nocturnal animal emerging from an underground burrow at night to avoid daytime heat.

Desert Plant and Animal Adaptations

Both plants and animals minimize water loss and avoid peak daytime heat.



Short Questions & Answers

Q1. Define productivity of an ecosystem.

Ans. Productivity of an ecosystem is the rate at which producers convert light energy into organic matter through photosynthesis, indicated by the consumption of carbon dioxide and evolution of oxygen; in aquatic ecosystems it is determined mainly by light and nutrient availability.

Q2. List four adaptations in plants and animals for terrestrial life.

Ans. Terrestrial adaptations include supporting tissues (vascular bundles/xylem-phloem in plants, skeletons in animals) to withstand gravity, water conservation mechanisms such as homeostasis, temperature regulation structures such as bark in plants and skin in animals, and waterproof coverings to reduce water loss.

Q3. Name the three zones in a lake ecosystem.

Ans. The three zones in a lake ecosystem are the littoral zone (near-shore, shallow, most diverse), the limnetic zone (open water, upper, supports photosynthesis), and the profundal zone (open water, deep, insufficient light for photosynthesis, dominated by decomposers).

Q4. Name five major biomes found in the world.

Ans. Five major biomes include temperate deciduous forest, coniferous forest (taiga), grassland, desert, and tundra; tropical rain forest is another major biome.

Q5. Give the names of some major ecosystems on land in Pakistan.

Ans. Major terrestrial ecosystems in Pakistan include temperate deciduous forests (Shogran, Neelum valley), coniferous alpine and boreal forests (Kaghan, Swat, Dir, Chilas), grassland (Gilgit, Kashmir, Waziristan), desert (Thal in Punjab, Thar in Sindh, Cholistan), and tundra (Karakoram and Hindu Kush mountains).

Q6. What causes eutrophication of lakes, and what are its effects?

Ans. Eutrophication is caused by excess nutrients (phosphates and nitrates) entering lakes from sewage, farm feedlots and fertilizer runoff, leading to excessive algal growth that blocks sunlight to submerged plants; when algae and plants die and decompose, bacteria deplete dissolved oxygen, killing fish and other aquatic life.

Long Questions & Answers

Q1: Distinguish between the three different zones in a lake ecosystem, describing the light, organisms and productivity characteristic of each.

A fresh water lake, despite superficially appearing to be a single uniform body of water, is in fact ecologically organized into three clearly distinguishable life zones, each defined primarily by its differing degree of access to sunlight, dissolved nutrients, and suitable surfaces for anchorage, and properly understanding the overall ecology of a lake requires examining each of these three zones carefully in turn, moving progressively outward and downward from the shoreline toward the deepest open water. The first and shallowest of



these three zones is the littoral zone, situated immediately near the shoreline, where the water remains comparatively shallow throughout and where rooted plants consequently find abundant available sunlight, secure anchorage directly in the bottom sediments, and an adequate ongoing supply of nutrients likewise drawn from those same bottom sediments; plant communities within the littoral zone are consistently found to be the most diverse of any zone within the lake, characteristically including floating water lilies together with fully submerged vascular plants and various forms of algae, and the plants rooted within this particular zone additionally perform the valuable ecological function of physically trapping sediment carried into the lake by inflowing streams, thereby further increasing the already substantial nutrient content of this region over time; living among these anchored littoral plants are numerous microscopic planktonic organisms, conventionally subdivided into phytoplankton (a term derived from the Greek for 'drifting plants,' encompassing various photosynthetic protists, bacteria and algae) and zooplankton (correspondingly 'drifting animals,' encompassing protozoa and various tiny crustaceans), and the littoral zone additionally supports the single greatest overall diversity of animal life found anywhere within the lake, including littoral invertebrates such as small crustaceans, various insect larvae, snails, flatworms and Hydra, together with vertebrates such as frogs, aquatic snakes and turtles. As the water progressively increases in depth moving farther away from the shoreline, rooted plants eventually become physically unable to simultaneously maintain anchorage to the lake bottom while still collecting sufficient sunlight to sustain active photosynthesis, and this deeper open-water portion of the lake is accordingly further subdivided into two additional, vertically stacked zones: the upper limnetic zone, in which sufficient sunlight still penetrates the water column to actively support ongoing photosynthesis, supporting phytoplankton, including cyanobacteria (commonly known as blue-green algae), functioning here as the zone's primary producers, which are in turn consumed by protozoa and small crustaceans, which are themselves subsequently consumed by fish; and the considerably deeper profundal zone lying directly beneath it, in which the available sunlight has by this depth become far too weak or insufficient to support any meaningful photosynthesis whatsoever, meaning that organisms inhabiting this deepest zone must instead obtain their nourishment primarily from detritus (organic debris) continuously falling downward from the littoral and limnetic zones above, together with incoming sediment, so that the profundal zone is consequently characteristically inhabited mainly by decomposers and various detritus-feeding organisms, including snails, certain specialized insect larvae, bacteria, fungi and bottom-dwelling fish species. Taken together, these three vertically and horizontally distinct zones, the shallow, sunlit, biologically diverse littoral zone; the intermediate, still photosynthetically active limnetic zone; and the deep, dark, detritus-dependent profundal zone, collectively illustrate how a single lake ecosystem's overall productivity and species diversity are fundamentally organized and structured according to the underlying availability of light, nutrients, and secure surfaces for anchorage at each successive depth.

Q2: Compare the climate, plant adaptations, and animal life of the grassland and desert ecosystems, and describe the human impact on each.

Grassland ecosystems and desert ecosystems, although both are broadly classified as terrestrial biomes and although both are frequently found occurring within roughly similar



latitudinal bands around the globe, nevertheless differ from one another quite substantially and instructively in terms of their characteristic climate, in the specific survival adaptations exhibited by their resident plant and animal life, and in the particular nature of the various human impacts to which each biome type has historically been subjected, and examining each of these three dimensions of comparison in turn helps to make the underlying ecological contrast between these two important biome types considerably clearer. In terms of underlying climate, grassland ecosystems, found in Pakistan specifically in regions such as Gilgit, Kashmir, Waziristan, lower Chitral and North Kalat, characteristically experience an annual rainfall total of roughly 250 to 750 millimetres in temperate grassland regions, rising to as much as approximately 1500 millimetres in tropical and sub-tropical grassland regions, occurring specifically in those geographic regions where the overall mean annual rainfall total happens to fall roughly midway between the generally much higher rainfall totals characteristic of forest ecosystems and the generally much lower rainfall totals characteristic of true desert ecosystems; desert ecosystems, by clear contrast, found in Pakistan specifically in regions such as the Thal desert of western Punjab and the Thar desert of Sindh, characteristically receive substantially less rainfall overall, typically amounting to less than roughly 25 to 50 centimetres annually, and in certain particularly extreme desert regions such as parts of the Sahara or the Atacama desert in Chile, virtually no meaningful rainfall occurs at all. In terms of characteristic plant adaptations, grassland vegetation is overwhelmingly dominated by graminoids, meaning true grasses together with various grass-like plants, frequently supplemented by scattered herbaceous forbs such as various composite and legume species, with grassland vegetation additionally displaying a distinctive layered vertical structure, comprising an uppermost layer of taller grass species, a middle layer of intermediate-height grass species, and a lowest layer made up of shorter grasses together with forbs, mosses and lichens; desert plant life, by contrast, has instead evolved a substantially different and more specialized suite of adaptations specifically oriented toward minimizing water loss and maximizing water storage under conditions of severe and prolonged water scarcity, including a distinctive waterproof waxy surface coating that helps to significantly reduce evaporative water loss, together with specialized fleshy, thickened stems, as seen in cacti and various Euphorbia species, specifically adapted to store substantial reserves of water internally for later use during extended drought periods, along with typically widely spaced individual plant distribution patterns and comparatively large but very shallow root systems specifically adapted to rapidly capture whatever limited rainfall does occasionally occur. In terms of characteristic animal life, grassland ecosystems typically support comparatively large overall populations of herbivorous animals, together with numerous associated invertebrate species, including grasshoppers, which can at times become numerous enough to directly compete with larger herbivores for available plant foliage, together with various predatory reptiles, amphibians and mammals such as lizards, toads, foxes and wolves, and with larger characteristic grassland animals including zebras, wild horses and bison; desert animal life, by contrast, has instead evolved a substantially different and more specialized set of behavioural and physiological adaptations specifically oriented toward avoiding the most extreme daytime heat and conserving the limited available water, with the great majority of desert animal species accordingly remaining concealed within cool underground burrows throughout the heat of the day and instead emerging to actively feed only after nightfall, once temperatures have meaningfully cooled,



including horned lizards, snakes and various other reptile species together with mammals such as kangaroo rats and birds such as the burrowing owl, with many smaller desert animal species additionally managing to survive entirely without ever directly drinking any water at all, instead obtaining all of the water they require metabolically from their food and from the water produced internally as a natural by-product of ordinary cellular respiration. Finally, in terms of characteristic human impact, grassland ecosystems have historically been very extensively impacted by widespread crop cultivation and livestock grazing activity, with excessive overgrazing in particular characteristically leading directly to significant reduction of the natural herbage cover, substantially increased soil erosion, and, in especially severe cases, eventual outright desertification of previously productive grassland; desert ecosystems, by contrast, face the somewhat different but closely related human-driven threat of desertification actively spreading outward from existing desert regions into adjacent, previously non-desert land, a process dramatically illustrated by the historical experience of the Sahel region bordering the southern edge of the Sahara desert in Africa, where a sustained twenty-five-year period of below-average rainfall, combined with rapid ongoing human population growth substantially exceeding the land's underlying ecological carrying capacity, together produced a steady, ongoing southward spread of desert conditions, ultimately resulting in a largely irreversible loss of ecosystem productivity and, tragically, in severe associated famines, such as the catastrophic famine that occurred in Ethiopia during the mid-1980s.

MCQs with Answers

1. Salt-water oceans and seas cover approximately what percentage of Earth's surface?

(a) 25% (b) 50% (c) 71% (d) 90%

Correct Answer: (c) 71%. Salt-water oceans and seas are the largest ecosystems on earth, covering about 71% of its surface; fresh water ecosystems cover less than 1%.

2. Which lake zone has the greatest diversity of plants and animals?

(a) Limnetic zone (b) Profundal zone (c) Littoral zone (d) Benthic zone

Correct Answer: (c) Littoral zone. The littoral (near-shore) zone has abundant light, anchorage and nutrients, making it the most diverse zone of a lake in both plant and animal life.

3. The process by which excess nutrients cause algal overgrowth and oxygen depletion in a lake is called:

(a) denitrification (b) eutrophication (c) desertification (d) nitrification

Correct Answer: (b) eutrophication. Eutrophication is the process by which nutrient enrichment (often from sewage or fertilizer runoff) leads to excessive algal growth, followed by decomposition that depletes dissolved oxygen.

4. Northern coniferous forest, found across Eurasia and North America just south of the tundra, is also called:

(a) savanna (b) prairie (c) taiga (d) chaparral

Correct Answer: (c) taiga. Northern coniferous forests are also called taiga; those at high altitude are called alpine, and those at high latitude are called boreal.



5. Temperate grasslands lacking woody plants, such as those of North America, are called:

(a) savannas (b) prairies (c) taigas (d) tundras

Correct Answer: (b) prairies. Temperate grasslands without woody plants are called prairies (e.g. the Prairies of North America, the Pampas of Argentina); tropical grasslands with woody trees are called savannas.

6. In Sindh, Pakistan, the desert ecosystem is known as:

(a) Thal (b) Thar (c) Cholistan (d) Sahel

Correct Answer: (b) Thar. In Sindh, the desert ecosystem is called 'Thar', while in western Punjab (Mianwali, Bhakkar) it is called 'Thal'.

7. The Sahel region, where desertification has caused severe famine, borders which desert?

(a) Thar Desert (b) Atacama Desert (c) Sahara Desert (d) Gobi Desert

Correct Answer: (c) Sahara Desert. The Sahel borders the southern edge of the Sahara Desert in Africa, where below-average rainfall and population growth caused desertification and famine, notably in Ethiopia in the mid-1980s.

8. Which of the following is a key adaptation of desert plants such as cacti?

(a) Broad thin leaves for maximum photosynthesis (b) Thick, water-storing fleshy stems
(c) Deep taproots reaching the water table (d) Deciduous leaf-shedding in winter

Correct Answer: (b) Thick, water-storing fleshy stems. Desert plants such as cacti and Euphorbia have thick, fleshy stems that store water for use during drought, along with waterproof waxy coatings to reduce evaporation.

9. The tundra biome is bordered by which two regions?

(a) Desert and grassland (b) Taiga and polar ice caps (c) Temperate forest and taiga (d) Savanna and desert

Correct Answer: (b) Taiga and polar ice caps. Tundra describes treeless vegetation in high latitudes between taiga (coniferous forest) and the polar ice caps, and at high altitudes above the timberline.

10. Which mountain ranges in Pakistan host the tundra ecosystem?

(a) Sulaiman and Kirthar (b) Margalla Hills (c) Karakoram and Hindu Kush (d) Salt Range

Correct Answer: (c) Karakoram and Hindu Kush. In Pakistan, the tundra ecosystem occurs at high altitude in the Karakoram and Hindu Kush mountain ranges.

Quick Revision Summary

- Weather (short-term) vs Climate (long-term patterns). Hydrospheric ecosystem: oceans/seas = 71% of Earth surface, fresh water <1%. Aquatic features: moderate temperature, light decreases with depth (little light below 600 ft), nutrients concentrate at bottom.
- Lake ecosystem = 3 zones: Littoral (near-shore, most diverse, rooted plants + plankton) -> Limnetic (open water, upper, photosynthesis) -> Profundal (deep, dark, decomposers/detritus feeders). Eutrophication: excess nutrients (sewage/fertilizer) -> algal bloom -> death -> bacterial decomposition -> oxygen depletion -> fish kill.



- Terrestrial ecosystem: plenty light + nutrients, but limited/uneven water. Adaptations: supporting tissues (xylem-phloem/skeleton), water conservation (homeostasis), temperature regulation (bark/skin). Division: Forest (tropical rain/temperate deciduous/coniferous) + Grassland + Desert + Tundra.
- Pakistan ecosystems: Temperate deciduous forest (Shogran, Neelum valley) | Coniferous/taiga (Kaghan, Swat, Dir, Chilas) | Grassland (Gilgit, Kashmir, Waziristan) | Desert (Thal-Punjab, Thar-Sindh, Cholistan) | Tundra (Karakoram, Hindu Kush).
- Temperate deciduous forest: rainfall 750-1500mm, temp 4-30C, deciduous (sheds leaves in dry season), fertile grayish-brown soil. Taiga/coniferous: harsh cold winters, evergreen waxy-needle conifers, low biodiversity, major lumber source.
- Grassland: rainfall 250-750mm (up to 1500mm tropical), prairie (temperate, no trees) vs savanna (tropical, has trees), 3-layer structure (tall/mid/short grasses), overgrazing -> desertification. Desert: <25-50cm rainfall, waxy/fleshy water-storing plants, nocturnal animals, desertification (e.g. Sahel/Sahara).
- Tundra: treeless, between taiga & polar ice caps (also high altitude e.g. Karakoram/Hindu Kush), dwarf plants + reindeer moss, lemmings/wolves/arctic foxes, most fragile biome (slow growth, scars persist centuries). Human impact overall: simplifies ecosystems (fewer species/interactions). Notes by freebooks.pk.

Exam Tips

- Keep weather (hours/days, short-term) vs climate (years/centuries, long-term pattern) as a clean opposite pair - a frequently tested basic distinction.
- Memorise the 3 lake zones in order from shore to deep water (littoral -> limnetic -> profundal) along with one defining feature each (most diverse / photosynthesis / decomposers) rather than just definitions.
- Build a Pakistan-ecosystem location table (5 rows: forest/coniferous/grassland/desert/tundra with their specific regions) - this exact mapping is commonly tested in short and extensive questions.
- Keep prairie (temperate, no trees) vs savanna (tropical, has trees) as a clear opposite pair when discussing grasslands.
- Memorise the key numeric ranges for each biome (temperate forest: 750-1500mm rainfall, 4-30C; grassland: 250-750mm; desert: <25-50cm) as they are commonly tested as fill-in-the-blank or short-answer facts.
- Build a simple 2-column adaptation table for desert plants vs desert animals (waxy coating/fleshy stems vs nocturnal behaviour/burrows) to directly answer common extensive questions.
- Remember 3 concrete named examples of desertification/human impact (Sahel/Sahara famine, overgrazing in grasslands, tundra oil/pipeline scars) as ready-made exam examples.

