

O Level and IGCSE Biology: full syllabus summary notes

These notes cover the whole Cambridge O Level Biology 5090 and IGCSE Biology 0610 course in syllabus order. They are written for the last weeks before the examination: every section lists what must be known, the definitions that examiners expect word for word are set out in boxes, and each calculation has a worked example. Use the key terms table and the quick check at the end to test yourself. Where a point is only in the IGCSE 0610 extended (supplement) papers it is marked **(extended)**. O Level 5090 has no core and extended split, so a 5090 student should learn the marked points as well.

Cells

Cell structure

- All living organisms are made of cells. A cell is the smallest unit of life that can carry out all the life processes.
- **Animal cells** contain a cell membrane, cytoplasm, a nucleus, mitochondria and ribosomes.
- **Plant cells** contain all of these plus a cellulose cell wall, a large permanent vacuole containing cell sap, and (in green parts) chloroplasts.
- **Bacterial cells** have a cell wall (not cellulose), a cell membrane, cytoplasm, ribosomes, a single circular chromosome of DNA lying free in the cytoplasm, and often small rings of DNA called plasmids. There is no nucleus and no mitochondria.

Structure	Function
Cell membrane	Partially permeable; controls what enters and leaves the cell
Cytoplasm	Jelly-like fluid where most chemical reactions take place
Nucleus	Contains the chromosomes (DNA); controls cell activities and cell division
Mitochondria	Site of aerobic respiration; release energy; numerous in active cells such as muscle and sperm
Ribosomes	Site of protein synthesis
Cell wall	Made of cellulose in plants; fully permeable; gives support and prevents bursting
Chloroplasts	Contain chlorophyll; site of photosynthesis
Vacuole	Stores cell sap (water, sugars, salts); keeps the cell turgid

Specialised cells

- **Ciliated cell**: hair-like cilia beat to move mucus up the trachea and bronchi.
- **Root hair cell**: long extension gives a large surface area for absorbing water and mineral ions.
- **Palisade mesophyll cell**: packed with chloroplasts, column-shaped and near the upper leaf surface for photosynthesis.



- **Neurone:** long fibre carries electrical impulses quickly over long distances.
- **Red blood cell:** biconcave disc, no nucleus, full of haemoglobin to carry oxygen.
- **Sperm cell:** tail for swimming, many mitochondria, acrosome containing enzymes to enter the egg, haploid nucleus.
- **Egg cell:** large, with food stores in the cytoplasm, a jelly coat and a haploid nucleus.

Levels of organisation

- **Cell → tissue → organ → organ system → organism.**
- A tissue is a group of similar cells working together to perform a shared function (for example muscle tissue).
- An organ is a structure made of several tissues working together to perform a function (the heart, a leaf).
- An organ system is a group of organs with related functions (the digestive system).

Magnification

Magnification = image size ÷ actual size. Both sizes must be in the same unit before dividing. 1 mm = 1000 micrometres (µm).

Worked example. A drawing of a red blood cell measures 35 mm across. The real cell is 7 µm wide. Find the magnification.

Convert the image size to micrometres: 35 mm × 1000 = 35 000 µm.

Magnification = 35 000 ÷ 7 = **×5000**.

Second example. A photograph of a cell at ×400 shows the cell as 20 mm long. Actual size = image size ÷ magnification = 20 ÷ 400 = 0.05 mm = **50 µm**.

Exam tip: magnification has no units; write it as ×5000. Always show the conversion of units as a separate line.

Classification

Characteristics of living organisms

All living organisms show seven characteristics, remembered as MRS GREN.

- **Movement:** an action by an organism or part of an organism causing a change of position or place.
- **Respiration:** the chemical reactions in cells that break down nutrient molecules and release energy for metabolism.
- **Sensitivity:** the ability to detect or sense stimuli in the internal or external environment and to make appropriate responses.
- **Growth:** a permanent increase in size and dry mass.
- **Reproduction:** the processes that make more of the same kind of organism.
- **Excretion:** the removal of the waste products of metabolism and substances in excess of

requirements.

- **Nutrition:** the taking in of materials for energy, growth and development.

Species and the binomial system

- A **species** is a group of organisms that can reproduce to produce fertile offspring.
- The **binomial system** gives each species a two-part Latin name: the genus (capital letter) followed by the species (lower case), written in italics or underlined, for example *Homo sapiens*.
- Classification groups organisms by shared features. Traditionally morphology (form) and anatomy were used; today the base sequences of DNA are compared. Species with more similar DNA sequences share a more recent common ancestor (**extended**).

The kingdoms and main groups

- **Animals:** multicellular, no cell walls, no chloroplasts, feed on other organisms.
- **Plants:** multicellular, cellulose cell walls, chloroplasts, make their food by photosynthesis.
- **Fungi:** cell walls (not cellulose), no chlorophyll, feed by secreting enzymes onto food and absorbing the products (saprophytic nutrition), mostly made of thread-like hyphae; yeast is single-celled.
- **Prokaryotes** (bacteria): single cells with no nucleus, circular DNA, cell walls.
- **Protoctists:** mostly single-celled organisms with a nucleus, such as *Amoeba* and *Plasmodium*; some photosynthesise.
- **Viruses** are not in any kingdom and are not usually classed as living. They are a protein coat around a strand of DNA or RNA and can only reproduce inside a host cell.

Vertebrates (animals with a backbone):

Class	Key features
Fish	Scales, gills, fins, lay eggs in water, cold-blooded
Amphibians	Moist smooth skin, lungs as adults and gills as larvae, eggs without shells laid in water
Reptiles	Dry scaly skin, lungs, soft-shelled eggs laid on land
Birds	Feathers, beak, wings, hard-shelled eggs, warm-blooded
Mammals	Hair or fur, mammary glands produce milk, external ears, warm-blooded, give birth to live young

Arthropods (jointed legs, exoskeleton, segmented body):

- **Insects:** three body parts (head, thorax, abdomen), six legs, usually two pairs of wings, one pair of antennae.
- **Arachnids:** two body parts, eight legs, no antennae, no wings.
- **Crustaceans:** more than four pairs of legs, two pairs of antennae, hard chalky exoskeleton, mostly aquatic.
- **Myriapods:** many similar segments, each with one or two pairs of legs, one pair of antennae.

Plants: ferns have roots, stems and fronds and reproduce by spores; flowering plants reproduce by

seeds made in flowers. **Monocotyledons** have one seed leaf, parallel leaf veins, and flower parts in multiples of three; **dicotyledons** have two seed leaves, branching (network) veins, and flower parts in fours or fives.

Dichotomous keys

- A key is a series of paired statements; each pair gives a choice that leads to another pair or to a name.
- Use visible features that do not vary with age or season (number of legs, leaf shape), not size or colour alone.

Movement in and out of cells

Diffusion

Diffusion is the net movement of particles from a region of their higher concentration to a region of their lower concentration, down a concentration gradient, as a result of their random movement.

- Needs no energy from the cell; the energy comes from the random (kinetic) movement of particles.
- Examples: oxygen into cells and carbon dioxide out; carbon dioxide into the leaf through stomata.
- Rate increases with a steeper concentration gradient, higher temperature, larger surface area and a shorter distance (thinner membrane).

Osmosis

Osmosis is the net movement of water molecules from a region of higher water potential (a dilute solution) to a region of lower water potential (a concentrated solution), through a partially permeable membrane.

- Water enters plant cells by osmosis when the surrounding solution is more dilute than the cell sap: the vacuole swells, the cytoplasm presses on the cell wall and the cell becomes **turgid**. Turgor pressure supports leaves and young stems.
- In a concentrated solution water leaves the cell: it becomes **flaccid**, and if more water is lost the cytoplasm pulls away from the wall (**plasmolysis**). The plant wilts.
- Animal cells have no wall. In pure water they swell and burst (lysis); in a concentrated solution they shrink and become crenated.
- Osmosis is how water is absorbed by root hair cells and how water passes from cell to cell across the root.

Worked example: percentage change in mass. A potato strip had a mass of 5.0 g before being placed in a salt solution and 4.6 g afterwards.

Change in mass = $4.6 - 5.0 = -0.4$ g.

Percentage change = $(\text{change} \div \text{original mass}) \times 100 = (-0.4 \div 5.0) \times 100 = -8\%$.

The strip lost water by osmosis, so the salt solution had a lower water potential than the potato cells. Always divide by the original value, and give the sign.

Active transport

Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration (against a concentration gradient), using energy from respiration.

- Needs carrier proteins in the membrane and ATP from respiration, so cells doing active transport have many mitochondria.
- Examples: uptake of mineral ions (nitrate) by root hair cells from dilute soil water; absorption of glucose by the villi of the small intestine and by the kidney tubules.
- Anything that stops respiration (lack of oxygen, cyanide, low temperature) stops active transport but not diffusion.

Biological molecules

The main nutrients

Molecule	Elements	Made of	Examples and uses
Carbohydrates	C, H, O	Simple sugars (glucose) join to form starch, glycogen and cellulose	Energy source; starch is the plant store, glycogen the animal store, cellulose makes cell walls
Fats and oils (lipids)	C, H, O	One glycerol and three fatty acids	Energy store, insulation, cell membranes
Proteins	C, H, O, N (sometimes S)	Long chains of amino acids	Growth and repair, enzymes, haemoglobin, antibodies, hormones such as insulin

- The sequence of amino acids decides the shape of a protein, and the shape decides its function (an enzyme's active site, an antibody's binding site) (**extended**).
- **Water** is the solvent in which reactions happen and in which substances are transported in blood, cytoplasm, xylem and phloem, and it is needed in digestion and excretion.

Food tests

Test for	Reagent and method	Positive result
Starch	Add iodine solution	Orange-brown turns blue-black
Reducing sugar (glucose)	Add Benedict's solution and heat in a water bath	Blue turns green, yellow, orange then brick-red (more sugar gives a redder colour)
Protein	Add biuret solution	Blue turns purple (lilac)
Fat	Shake with ethanol, then pour into water (ethanol emulsion test)	Clear solution turns cloudy white

Vitamin C	Add the food juice drop by drop to blue DCPIP	DCPIP turns colourless
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Enzymes

A **catalyst** is a substance that increases the rate of a chemical reaction and is not changed by the reaction.

Enzymes are proteins that are involved in all metabolic reactions, where they function as biological catalysts.

How enzymes work

- Each enzyme has an **active site** with a shape that fits only one substrate (or a group of similar substrates), like a lock and key. The substrate binds to the active site to form an enzyme-substrate complex, the reaction happens, and the products leave. The enzyme is unchanged and can be used again.
- Enzymes are **specific**: amylase breaks down starch only; protease breaks down protein only.
- Enzymes are needed because without them metabolic reactions would be too slow at body temperature to keep an organism alive.

Temperature and pH

- As temperature rises, molecules move faster, so collisions between enzyme and substrate are more frequent and the rate rises. The rate is highest at the **optimum temperature** (about 37 °C for human enzymes).
- Above the optimum the enzyme vibrates so much that bonds holding its shape break, the active site changes shape and the substrate no longer fits. The enzyme is **denatured**; this is permanent.
- Each enzyme has an optimum pH. Away from it the active site changes shape and activity falls; a large change in pH denatures the enzyme. Pepsin in the stomach works best at about pH 2; amylase in the mouth and small intestine at about pH 7; trypsin in the small intestine at about pH 8.
- Low temperatures do not denature enzymes; they only slow them down.

Exam tip: never write that an enzyme is "killed". Write that it is denatured because the shape of the active site has changed so the substrate can no longer fit.

Plant nutrition

Photosynthesis

Photosynthesis is the process by which plants synthesise carbohydrates from raw materials using energy from light.

Word equation: carbon dioxide + water → glucose + oxygen (in the presence of light and chlorophyll)

Balanced equation (**extended**): $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

- Chlorophyll in chloroplasts absorbs light energy and transfers it into chemical energy in glucose.
- Uses of the glucose made: respiration; converted to starch for storage; made into cellulose for cell walls; converted to sucrose for transport in the phloem; combined with nitrate ions to make amino acids and proteins; made into fats and oils.
- Testing a leaf for starch: boil in water to kill the cells and soften the leaf; boil in ethanol in a water bath to remove the chlorophyll; rinse in warm water to soften; add iodine solution. Blue-black shows starch. A plant must be destarched (kept in the dark for 48 hours) before an experiment on the need for light or carbon dioxide.

Mineral requirements

- **Nitrate ions:** to make amino acids and proteins. Deficiency gives stunted growth and yellow older leaves.
- **Magnesium ions:** to make chlorophyll. Deficiency gives yellow leaves between the veins (chlorosis).

Limiting factors

A **limiting factor** is something present in the environment in such short supply that it restricts life processes.

- Light intensity, carbon dioxide concentration and temperature can each limit the rate of photosynthesis. On a graph the rate rises with the factor, then levels off when a different factor becomes limiting (**extended**).
- Glasshouse growers raise the rate by adding carbon dioxide (from burning paraffin), using heaters and artificial lighting.

Leaf structure

- **Waxy cuticle** on the upper epidermis reduces water loss; the epidermis is transparent so light reaches the mesophyll.
- **Palisade mesophyll:** tightly packed cells with many chloroplasts near the upper surface.
- **Spongy mesophyll:** loosely packed cells with air spaces that allow gases to diffuse to all cells.
- **Stomata** (mostly on the lower surface) are pores between pairs of **guard cells**; they let carbon dioxide in and oxygen and water vapour out. Guard cells open the stoma when they are turgid.
- **Vascular bundles** (veins) contain xylem bringing water and mineral ions, and phloem taking sucrose and amino acids away.
- Leaves are broad and thin for a large surface area and a short diffusion distance.

Transport in plants

Xylem and phloem

- **Xylem** carries water and mineral ions from roots to leaves and supports the plant. Xylem vessels are dead, hollow tubes with no end walls and thick walls strengthened with lignin.

- **Phloem** carries sucrose and amino acids from where they are made or stored to where they are used. Phloem sieve tubes are living, with sieve plates between cells and companion cells alongside.
- In a root the xylem is in the centre; in a stem the vascular bundles are arranged in a ring near the outside; in a leaf they form the midrib and veins.

Water uptake

- Root hair cells absorb water by osmosis and mineral ions by active transport. Their shape gives a large surface area.
- Pathway of water: root hair → root cortex cells → xylem → stem xylem → leaf xylem → mesophyll cells → evaporation into air spaces → diffusion out through stomata.

Transpiration

Transpiration is the loss of water vapour from leaves. Water evaporates from the surfaces of mesophyll cells into the air spaces and then diffuses out through the stomata.

- Water molecules are attracted to one another (cohesion), so as water is lost from the leaf a continuous column is pulled up the xylem: the transpiration pull (**extended**).
- Rate increases with higher temperature (faster evaporation and diffusion), lower humidity (steeper water vapour gradient), higher wind speed (removes humid air) and brighter light (stomata open).
- Wilting happens when water loss exceeds uptake; cells lose turgor and the leaf droops, which reduces the surface exposed to the sun (**extended**).

Translocation

Translocation is the movement of sucrose and amino acids in the phloem, from regions of production (sources) to regions of storage or of use in respiration or growth (sinks).

- A leaf is a source in summer; a potato tuber is a sink while it fills and a source when it sprouts in spring (**extended**).

Human nutrition

Diet

A **balanced diet** contains all the nutrients in the correct amounts and proportions for the needs of the individual: carbohydrates, fats, proteins, vitamins, mineral ions, fibre and water.

Nutrient	Good sources	Needed for	Deficiency
Vitamin C	Citrus fruit, fresh vegetables	Healthy skin and gums, holding tissues together	Scurvy: bleeding gums, poor wound healing
Vitamin D	Oily fish, eggs, made in skin in sunlight	Absorbing calcium, strong bones	Rickets: soft, bent bones

Calcium	Milk, cheese	Bones and teeth, blood clotting	Rickets, brittle bones
Iron	Red meat, liver, spinach	Making haemoglobin	Anaemia: tiredness, pale skin
Fibre (roughage)	Wholegrain cereals, vegetables	Keeps food moving by peristalsis, prevents constipation	Constipation

- Diet depends on age, sex and activity: growing children and pregnant women need more protein, calcium and iron; active people need more energy foods.
- Too much energy intake leads to obesity, linked to heart disease, diabetes and joint problems. Too little protein in children causes kwashiorkor; too little food causes marasmus (starvation).

The alimentary canal

- **Ingestion:** taking substances (food and drink) into the body through the mouth.
- **Physical (mechanical) digestion:** the breakdown of food into smaller pieces without chemical change to the food molecules.
- **Chemical digestion:** the breakdown of large insoluble molecules into small soluble molecules.
- **Absorption:** the movement of small food molecules and ions through the wall of the intestine into the blood.
- **Assimilation:** the movement of digested food molecules into the cells of the body where they are used, becoming part of the cells.
- **Egestion:** the passing out of food that has not been digested or absorbed, as faeces, through the anus.

- **Mouth:** teeth chew the food (physical digestion); saliva from the salivary glands contains amylase (starch → maltose) and lubricates the food.
- **Oesophagus:** muscular tube; **peristalsis** (waves of contraction of circular and longitudinal muscle) pushes the bolus to the stomach.
- **Stomach:** muscular walls churn the food; gastric juice contains pepsin (a protease) and hydrochloric acid. The acid kills bacteria and gives the low pH pepsin needs.
- **Small intestine:** the duodenum receives pancreatic juice (amylase, trypsin, lipase) and bile; the ileum completes digestion (maltase on its wall turns maltose into glucose) and absorbs the products.
- **Pancreas:** makes pancreatic juice containing amylase, protease (trypsin) and lipase, and the hormones insulin and glucagon.
- **Liver** makes bile; the **gall bladder** stores it and releases it into the duodenum through the bile duct.
- **Large intestine:** the colon absorbs water; the rectum stores faeces, which leave through the anus.

Teeth (5090 and older 0610 syllabuses)

- Incisors bite and cut, canines tear, premolars and molars crush and grind. Enamel is the hard

outer layer, dentine beneath it, pulp in the centre with nerves and blood vessels, and cement holds the root in the jaw.

- Tooth decay: bacteria in plaque feed on sugar and produce acid that dissolves enamel.
Prevention: less sugar, brushing with fluoride toothpaste, regular dental checks.

Chemical digestion

Enzyme	Where made	Substrate → product
Amylase	Salivary glands, pancreas	Starch → maltose
Maltase (extended)	Wall of small intestine	Maltose → glucose
Protease (pepsin, trypsin)	Stomach, pancreas	Protein → amino acids
Lipase	Pancreas	Fats → fatty acids and glycerol

- **Bile** is alkaline, so it neutralises the acidic chyme from the stomach and gives the optimum pH for the enzymes in the small intestine. It also **emulsifies** fats (breaks large drops into small droplets), increasing the surface area for lipase (**extended**).

Absorption

- The small intestine is long and its inner wall is folded and covered with millions of finger-like **villi**, each with **microvilli**, giving a very large surface area.
- Each villus has a thin wall (one cell thick), a network of blood capillaries (absorb glucose and amino acids, carried in the hepatic portal vein to the liver) and a **lacteal** (absorbs fatty acids and glycerol into the lymph).
- Absorption is by diffusion and active transport. Water is absorbed mainly in the small intestine and the rest in the colon.

Gas exchange

Gas exchange surfaces

- Features of a good gas exchange surface: large surface area, thin (short diffusion distance), good blood supply, well ventilated (in mammals), moist so gases can dissolve.
- Pathway of air: nose and mouth → larynx → trachea → bronchi → bronchioles → alveoli.
- Rings of cartilage hold the trachea and bronchi open. The airways are lined with **goblet cells** that make mucus (traps dust and pathogens) and **ciliated cells** whose cilia sweep the mucus up to the throat.
- In the **alveoli** oxygen diffuses into the blood in the capillaries and carbon dioxide diffuses out, each down its concentration gradient. Breathing and the blood flow keep the gradients steep.

Breathing

- **Inhalation**: the external intercostal muscles contract and pull the ribs up and out; the diaphragm muscle contracts and flattens. The volume of the thorax increases, pressure inside falls below atmospheric pressure and air is pushed in.

- **Exhalation:** the external intercostal muscles relax, the ribs fall, the diaphragm relaxes and domes upwards. Volume decreases, pressure rises and air is forced out. Forced exhalation uses the internal intercostal muscles (**extended**).

Gas	Inspired air	Expired air
Oxygen	21 %	16 %
Carbon dioxide	0.04 %	4 %
Nitrogen	78 %	78 %
Water vapour	Variable	Saturated

- Carbon dioxide is tested with **limewater**, which turns milky (cloudy), or with hydrogencarbonate indicator, which turns from red to yellow.
- During exercise the rate and depth of breathing increase to supply more oxygen to muscles and remove more carbon dioxide. The rise in carbon dioxide concentration in the blood is detected by the brain, which sends more impulses to the breathing muscles (**extended**).
- Tobacco smoke: tar causes cancer and damages cilia so mucus builds up (chronic bronchitis); smoke destroys alveolar walls (emphysema), reducing the surface area; nicotine is addictive and raises blood pressure; carbon monoxide binds to haemoglobin and lowers oxygen transport.

Respiration

Aerobic respiration is the chemical reactions in cells that use oxygen to break down nutrient molecules to release energy.

glucose + oxygen → carbon dioxide + water; $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (**extended**)

Anaerobic respiration is the chemical reactions in cells that break down nutrient molecules to release energy without using oxygen.

In muscles: glucose → lactic acid. In yeast: glucose → ethanol + carbon dioxide; $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (**extended**)

- Energy released by respiration is used for muscle contraction, protein synthesis, cell division, active transport, growth, the passage of nerve impulses and maintaining a constant body temperature.
- Anaerobic respiration releases much less energy per glucose molecule than aerobic respiration because glucose is not completely broken down.
- During hard exercise muscles respire anaerobically because oxygen cannot be supplied fast enough. Lactic acid builds up, causing fatigue. After exercise the lactic acid is carried in the blood to the liver, where it is broken down using oxygen. The extra oxygen needed is the **oxygen debt**, which is why breathing and heart rate stay high after exercise (**extended**).
- Investigations: germinating seeds in a flask with a thermometer show a temperature rise; hydrogencarbonate indicator turns yellow in a tube with respiring organisms; yeast in sugar solution produces bubbles of carbon dioxide.

Transport in humans

The circulatory system

- The circulatory system is a system of blood vessels with a pump (the heart) and valves to ensure one-way flow.
- Humans have a **double circulation**: blood passes through the heart twice in each circuit. The right side pumps deoxygenated blood to the lungs (pulmonary circulation); the left side pumps oxygenated blood to the body (systemic circulation). This keeps oxygenated and deoxygenated blood separate and lets blood to the body be pumped at a higher pressure (**extended**). Fish have a single circulation.

The heart

- Four chambers: right and left atria (thin walls, receive blood), right and left ventricles (thick walls, pump blood out). The **septum** separates the two sides.
- The left ventricle wall is thicker than the right because it pumps blood all round the body, against greater resistance; the right pumps only to the lungs.
- Vessels: vena cava (body → right atrium), pulmonary artery (right ventricle → lungs), pulmonary vein (lungs → left atrium), aorta (left ventricle → body). The coronary arteries supply the heart muscle itself.
- Valves: atrioventricular valves (tricuspid on the right, bicuspid on the left) stop backflow into the atria; semilunar valves at the start of the aorta and pulmonary artery stop backflow into the ventricles.
- One heartbeat: atria contract and push blood into the ventricles; ventricles contract, the atrioventricular valves close, and blood is forced into the arteries; the ventricles relax, the semilunar valves close (**extended**).
- Heart rate can be measured by the pulse, by an ECG, or from a stethoscope. During exercise the heart rate rises so that more oxygen and glucose reach the muscles and more carbon dioxide is removed; adrenaline also raises the rate.

Coronary heart disease

- Fatty deposits (cholesterol) build up in the coronary arteries, narrowing them; a blood clot can block one, so part of the heart muscle gets no oxygen and dies: a heart attack.
- Risk factors: diet high in saturated fat and salt, smoking, stress, lack of exercise, genetic factors, age, sex (men more at risk), obesity.
- Prevention and treatment: healthy diet, exercise, stopping smoking; drugs such as aspirin and statins; a stent to hold the artery open; a bypass graft (**extended**).

Blood vessels

Vessel	Structure	Function
Artery	Thick muscular and elastic wall, narrow lumen, no valves	Carries blood away from the heart at high pressure; the elastic wall stretches and recoils with each pulse
Vein	Thin wall, wide lumen, valves	Returns blood to the heart at low pressure; valves and the squeezing of skeletal muscles prevent backflow

Capillary	Wall one cell thick, very narrow, very numerous	Exchange of substances between blood and tissues; the thin wall gives a short diffusion distance
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- Named vessels to learn: renal artery and vein (kidneys), hepatic artery and vein (liver), hepatic portal vein (small intestine to liver), pulmonary artery and vein, aorta, vena cava.

Blood

- Red blood cells:** carry oxygen as oxyhaemoglobin; biconcave shape gives a large surface area; no nucleus leaves room for haemoglobin.
- White blood cells:** **phagocytes** engulf and digest pathogens (phagocytosis); **lymphocytes** produce antibodies.
- Platelets:** cell fragments that start clotting. At a wound, soluble fibrinogen is converted to insoluble fibrin fibres, which trap red cells to form a clot; this stops blood loss and keeps pathogens out (**extended**).
- Plasma:** the liquid part; transports blood cells, ions, soluble nutrients (glucose, amino acids), hormones, carbon dioxide (as hydrogen carbonate), urea and heat.
- Tissue fluid forms when plasma is forced out of capillaries; the lymphatic system returns it to the blood and contains lymphocytes (**extended**).

Disease and immunity

A **pathogen** is a disease-causing organism.

A **transmissible disease** is a disease in which the pathogen can be passed from one host to another.

Transmission

- Direct contact:** through blood or other body fluids (HIV, hepatitis B), or touching an infected person (athlete's foot).
- Indirect:** contaminated surfaces, food and water (cholera, typhoid), droplets in the air (influenza, tuberculosis), animal vectors (mosquitoes carry malaria, houseflies carry pathogens on their feet).

Body defences

- Mechanical barriers:** skin, hairs in the nose.
- Chemical barriers:** mucus in the airways, hydrochloric acid in the stomach, tears and saliva (lysozyme).
- Cells:** phagocytes engulf pathogens; lymphocytes make antibodies.
- Antibodies** are proteins that bind to **antigens** on the surface of a pathogen. Each pathogen has its own antigens, and the antibody has a complementary shape so it binds to one antigen only. Binding marks the pathogen for destruction by phagocytes or causes pathogens to clump together, and some antibodies neutralise toxins (**extended**).

Immunity

- **Active immunity:** the defence against a pathogen by antibody production in the body. It is gained by infection or by vaccination and is long-lasting because **memory cells** remain, which respond faster and make more antibody on a second exposure (**extended**).
- **Vaccination:** a harmless form of the pathogen (dead, weakened, or its antigens) is given; lymphocytes make antibodies and memory cells. When most of a population is vaccinated the pathogen cannot spread easily (herd immunity).
- **Passive immunity:** short-term defence by antibodies made by another organism, for example antibodies passed from mother to baby across the placenta and in breast milk. No memory cells are made, so it does not last (**extended**).
- **Type 1 diabetes** is an example of the immune system attacking the body's own cells (the insulin-producing cells of the pancreas); it is treated with insulin injections (**extended**).

Controlling the spread of disease

- Clean water supply; hygienic food preparation; good personal hygiene (hand washing); waste disposal; proper sewage treatment so pathogens do not enter drinking water.
- Cholera: the bacterium produces a toxin that makes the cells of the small intestine secrete chloride ions into the gut; water follows by osmosis, giving severe diarrhoea and dehydration (**extended**).

Excretion

Excretion is the removal of the waste products of metabolism and substances in excess of requirements.

- Products excreted: **carbon dioxide** from respiration (lungs); **urea** made in the liver from excess amino acids (kidneys, in urine); excess water and ions (kidneys, skin).
- The liver breaks down excess amino acids by **deamination**: the nitrogen-containing amino group is removed and converted into urea, and the rest is used for energy or stored. The liver also breaks down alcohol, drugs and old hormones (**extended**).
- Urea must be removed because it is toxic in high concentration and is not needed by the cells.

The kidneys

- Each kidney receives blood from a **renal artery**; cleaned blood leaves in the **renal vein**; urine passes down the **ureter** to the **bladder**, which empties through the **urethra**.
- The kidney has an outer **cortex**, an inner **medulla** and a central space (the pelvis) leading to the ureter.
- Each kidney contains about a million **nephrons**. In the **glomerulus**, a knot of capillaries inside the **Bowman's capsule**, high pressure forces water, glucose, ions and urea out of the blood into the capsule (filtration). Blood cells and proteins are too large to pass through (**extended**).
- As the filtrate flows along the tubule, all the glucose, most of the water and some ions are reabsorbed into the blood (selective reabsorption), partly by active transport. What remains (water, urea, excess ions) is urine, which collects in the collecting duct (**extended**).
- The volume and concentration of urine depend on water intake, temperature and exercise: more

water drunk gives a larger volume of dilute urine.

Coordination and response

The nervous system

- The **central nervous system (CNS)** is the brain and spinal cord; the **peripheral nervous system** is the nerves running to and from it. The nervous system coordinates and regulates body functions using fast electrical impulses.
- **Sensory neurones** carry impulses from receptors to the CNS; **relay neurones** in the CNS connect sensory to motor neurones; **motor neurones** carry impulses from the CNS to effectors (muscles and glands).
- A **reflex action** is a fast, automatic, protective response to a stimulus that does not involve conscious thought. Reflex arc: stimulus → receptor → sensory neurone → relay neurone (spinal cord) → motor neurone → effector → response. Example: pulling the hand away from a hot object.
- A **synapse** is the junction between two neurones. An impulse arriving at the end of the first neurone causes vesicles to release **neurotransmitter** molecules, which diffuse across the gap and bind to receptor proteins on the next neurone, starting a new impulse. Synapses ensure impulses travel in one direction only. Many drugs act at synapses (**extended**).

Sense organs and the eye

- Sense organs are groups of receptor cells responding to specific stimuli: light (eye), sound (ear), touch, temperature and pain (skin), chemicals (tongue, nose).
- Eye structure: **cornea** refracts (bends) light; **iris** controls how much light enters; **pupil** is the hole; **lens** focuses light onto the retina; **retina** contains the light receptors (rods for dim light, cones for colour, concentrated at the **fovea**); **optic nerve** carries impulses to the brain; the **blind spot** is where the optic nerve leaves and has no receptors.
- **Pupil reflex**: in bright light the circular muscles of the iris contract and the radial muscles relax, so the pupil narrows; in dim light the radial muscles contract and the circular relax, so the pupil widens. This is a reflex that protects the retina (**extended**).
- **Accommodation (extended)**: to focus on a near object the ciliary muscles contract, the suspensory ligaments slacken and the lens becomes fatter (more curved); for a distant object the ciliary muscles relax, the ligaments tighten and the lens is pulled thinner.

Hormones

A **hormone** is a chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs.

Hormone	Gland	Effects
Adrenaline	Adrenal glands	"Fight or flight": raises heart rate and breathing rate, widens pupils, raises blood glucose concentration, diverts blood to muscles

Insulin	Pancreas	Lowers blood glucose by making liver and muscle cells take up glucose and store it as glycogen
Glucagon (extended)	Pancreas	Raises blood glucose by making the liver convert glycogen to glucose
Testosterone	Testes	Male secondary sexual characteristics, sperm production
Oestrogen	Ovaries	Female secondary sexual characteristics, rebuilds the uterus lining

- Nervous control is fast, electrical, short-lived and acts on a precise area; hormonal control is slower, chemical, longer-lasting and can affect many organs.

Homeostasis

Homeostasis is the maintenance of a constant internal environment.

- Control is by **negative feedback**: a change from the set point is detected and a response returns the value towards the set point (**extended**).
- **Blood glucose**: after a meal glucose rises; the pancreas secretes insulin; liver and muscle store glucose as glycogen. When glucose falls, glucagon is released and the liver converts glycogen back to glucose (**extended**). In type 1 diabetes the pancreas makes too little insulin; symptoms are high blood glucose, glucose in the urine, thirst and tiredness; treatment is insulin injections and diet control.
- **Temperature**: the skin has receptors, hairs, sweat glands, fatty tissue (insulation) and blood vessels. The hypothalamus in the brain monitors blood temperature. When too hot: sweating (evaporation removes heat), **vasodilation** (arterioles near the surface widen so more blood flows through surface capillaries and more heat is lost), hairs lie flat. When too cold: shivering (muscle contractions release heat), **vasoconstriction** (arterioles narrow, less blood near the surface), hairs raised to trap air, less sweating (**extended**).

Exam tip: capillaries cannot widen or narrow; it is the arterioles leading to them that change. Never write "blood vessels move to the surface".

Tropisms

Gravitropism is a response in which parts of a plant grow towards or away from gravity.

Phototropism is a response in which parts of a plant grow towards or away from the direction of the light source.

- Shoots are positively phototropic and negatively gravitropic (grow up, towards light for photosynthesis); roots are positively gravitropic and negatively phototropic (grow down to anchor the plant and find water).
- **Auxin** is a plant hormone made at the shoot tip. It moves down the shoot and stimulates cell elongation. In one-sided light auxin accumulates on the shaded side, cells there grow longer, and the shoot bends towards the light (**extended**).
- Investigations use seedlings in a clinostat (removes the effect of gravity) or a box with a slit for light.

Reproduction

Asexual reproduction is a process resulting in the production of genetically identical offspring from one parent.

Sexual reproduction is a process involving the fusion of the nuclei of two gametes (sex cells) to form a zygote and the production of offspring that are genetically different from each other.

Fertilisation is the fusion of the nuclei of gametes.

- Asexual reproduction (bacteria dividing, potato tubers, runners, bulbs): fast, needs one parent, good features kept, but no variation so the whole population may be wiped out by one disease.
- Sexual reproduction: variation lets a population adapt to change and survive, but it is slower and needs two parents.

Flowering plants

- Flower parts: **sepals** protect the bud; **petals** attract insects; **stamen** = anther (makes pollen grains, which contain the male gametes) + filament; **carpel** = stigma (receives pollen) + style + ovary containing ovules (which contain the female gametes).
- **Pollination** is the transfer of pollen grains from the anther to the stigma. Self-pollination is within one flower or plant; cross-pollination is to a different plant of the same species, which gives more variation (**extended**).

Feature	Insect-pollinated	Wind-pollinated
Petals	Large, brightly coloured, scented, with nectar	Small, dull or absent
Anthers	Inside the flower, firmly attached	Hanging outside, loosely attached
Stigma	Inside the flower, sticky	Feathery, hanging outside
Pollen	Larger, sticky or spiky, smaller amounts	Small, smooth, light, huge amounts

- After pollination a **pollen tube** grows down the style into the ovary and enters the ovule; the male nucleus fuses with the female nucleus (fertilisation). The ovule becomes the **seed** and the ovary becomes the **fruit**.
- A seed has a **testa** (coat), a **micropyle** (hole letting in water), cotyledons (food store) and the embryo (radicle and plumule).
- **Germination** needs water (to activate enzymes and swell the seed), oxygen (for aerobic respiration) and a suitable warm temperature (for enzymes). Light is not needed.

Human reproduction

- **Male**: testes make sperm and testosterone; scrotum keeps them slightly below body temperature; sperm ducts carry sperm; prostate gland and seminal vesicles add fluid to make semen; urethra in the penis carries semen or urine.
- **Female**: ovaries release an egg about every 28 days and make oestrogen and progesterone; oviducts (fallopian tubes) carry the egg and are where fertilisation happens; uterus with a

muscular wall where the embryo develops; cervix at the neck of the uterus; vagina.

- Sperm are small, many, mobile with a tail and many mitochondria; eggs are large, few, immobile with food stores and a jelly coat.
- **Puberty**: testosterone and oestrogen cause the secondary sexual characteristics (body hair, voice deepening, breast development, start of the menstrual cycle).
- **Menstrual cycle** (about 28 days): days 1 to 5 the uterus lining breaks down (menstruation); the lining rebuilds; **ovulation** on about day 14; the lining stays thick ready for implantation; if no fertilisation the cycle repeats. Oestrogen rebuilds the lining and triggers ovulation; progesterone (from the corpus luteum, later the placenta) maintains the lining. FSH stimulates egg development and LH triggers ovulation (**extended**).
- Fertilisation in the oviduct produces a **zygote**, which divides by mitosis into an **embryo** and implants in the uterus lining. The **fetus** is surrounded by the **amniotic sac** containing **amniotic fluid**, which protects it from knocks and drying out.
- The **placenta** is where the mother's and the fetus's blood come close but do not mix. Oxygen and nutrients diffuse to the fetus; carbon dioxide and urea diffuse back; the **umbilical cord** carries the blood between fetus and placenta. The placenta also acts as a barrier to some toxins and pathogens, but not to all (rubella virus, nicotine, alcohol can cross) (**extended**).
- Breast milk vs formula milk: breast milk contains antibodies, is at the right temperature, free and sterile; formula lets others feed the baby and its content can be measured.

Birth control and STIs

- Natural methods: abstinence, rhythm method (avoiding intercourse around ovulation). Barrier: condom, femidom, diaphragm (also protect against STIs for condoms). Chemical: contraceptive pill, implant, injection (hormones stop ovulation), IUD. Surgical: vasectomy, female sterilisation (tying the oviducts).
- Fertility treatments: hormone (FSH) injections to stimulate ovulation; artificial insemination; IVF (eggs fertilised outside the body and embryos placed in the uterus) (**extended**).
- A **sexually transmitted infection (STI)** is an infection transmitted through sexual contact. **HIV** is a virus passed in body fluids (sexual contact, shared needles, blood transfusion, mother to baby). It infects lymphocytes, weakening the immune system so that other infections become serious (AIDS). Spread is reduced by condoms, screening blood, not sharing needles and antiviral drugs.

Inheritance

DNA, chromosomes and genes

Inheritance is the transmission of genetic information from generation to generation.

A **chromosome** is a thread-like structure of DNA, carrying genetic information in the form of genes.

A **gene** is a length of DNA that codes for a protein.

An **allele** is an alternative form of a gene.

- DNA is a **double helix** of two strands joined by pairs of **bases**: A always pairs with T, and C with G.
- The sequence of bases in a gene decides the sequence of amino acids in a protein. The DNA stays in the nucleus; a copy of the gene (mRNA) passes to a ribosome, where amino acids are joined in the order it specifies. Different cells express different genes, which is why a muscle cell and a nerve cell differ although they carry the same DNA (**extended**).
- Human body cells have 46 chromosomes (23 pairs): a **diploid** nucleus. Gametes have 23: a **haploid** nucleus. Fertilisation restores the diploid number.
- Sex determination**: females are XX, males XY. A mother passes an X to every child; a father passes X or Y, giving a 1 : 1 ratio of girls to boys.

Cell division

Mitosis is nuclear division giving rise to genetically identical cells.

Meiosis is reduction division in which the chromosome number is halved from diploid to haploid, resulting in genetically different cells.

- Mitosis is used for growth, repair of damaged tissues, replacement of cells (skin, blood) and asexual reproduction. Before mitosis each chromosome is copied exactly; the copies separate into the two daughter cells (**extended**). **Stem cells** are unspecialised cells that divide by mitosis to produce daughter cells that can become specialised.
- Meiosis makes gametes in the testes, ovaries, anthers and ovules. One cell gives four haploid cells, each with a different combination of alleles, so meiosis produces variation.

Monohybrid inheritance

- Genotype**: the genetic make-up of an organism in terms of the alleles present.
- Phenotype**: the observable features of an organism.
- Homozygous**: having two identical alleles of a particular gene; two identical homozygous individuals that breed together will be pure-breeding.
- Heterozygous**: having two different alleles of a particular gene; not pure-breeding.
- Dominant allele**: an allele that is expressed if it is present.
- Recessive allele**: an allele that is only expressed when there is no dominant allele of the gene present.

Worked example: a monohybrid cross. In pea plants the allele for tall (T) is dominant to the allele for short (t). Two heterozygous tall plants are crossed. Predict the offspring.

Parents' phenotypes: tall × tall. Parents' genotypes: Tt × Tt. Gametes: T or t from each parent.

	T	t
T	TT (tall)	Tt (tall)
t	Tt (tall)	tt (short)

Offspring genotypes: 1 TT : 2 Tt : 1 tt. Offspring phenotypes: 3 tall : 1 short. The probability of a short plant is 1 in 4, or 25 %.

A **test cross** finds out whether a tall plant is TT or Tt: cross it with a short plant (tt). If any short offspring appear, the tall parent was Tt; if all offspring are tall, it was probably TT.

- Always set out: parental phenotypes, parental genotypes, gametes (circled), the Punnett square, offspring genotypes and phenotypes with the ratio. Ratios are predictions; actual numbers vary because fertilisation is random.
- **Codominance (extended)**: both alleles are expressed in the heterozygote. Human ABO blood groups: alleles I^A , I^B and I^O ; I^A and I^B are codominant, both dominant to I^O . Genotypes $I^A I^O$ (group A), $I^B I^O$ (group B), $I^A I^B$ (group AB), $I^O I^O$ (group O).
- **Sex-linked characteristics (extended)**: a gene carried on the X chromosome, such as red-green colour blindness (X^b recessive). A male has only one X, so $X^b Y$ is colour blind; a female needs $X^b X^b$ and $X^B X^b$ is a carrier. Males are affected more often than females.
- Pedigree diagrams: squares are males, circles females, shaded symbols show the characteristic. If two unaffected parents have an affected child, the characteristic is recessive and both parents are heterozygous.

Variation and selection

Variation is differences between individuals of the same species.

Mutation is genetic change. A **gene mutation** is a random change in the base sequence of DNA.

An **adaptive feature** is an inherited feature that helps an organism to survive and reproduce in its environment.

- **Continuous variation** gives a range of phenotypes between two extremes with no distinct groups (height, body mass); it is caused by both genes and the environment and is shown on a histogram. **Discontinuous variation** gives a limited number of distinct phenotypes with no intermediates (blood group, sex); it is caused by genes alone and is shown on a bar chart.
- Variation arises from mutation, from meiosis (new combinations of alleles) and from random fertilisation. Mutation rate is increased by ionising radiation and some chemicals.
- Sickle cell anaemia is caused by a gene mutation in the haemoglobin gene; red cells become sickle-shaped and carry less oxygen. Heterozygotes (sickle cell trait) are more resistant to malaria, so the allele stays common where malaria occurs (**extended**).
- Adaptive features of hydrophytes (water plants): air spaces for buoyancy, stomata on the upper surface, little xylem. Xerophytes (dry habitats): thick cuticle, few sunken stomata, rolled or spiny leaves, deep or spreading roots, water storage tissue (**extended**).

Natural selection (the process to learn in order):

1. Within a population there is variation caused by mutation and sexual reproduction.
2. Organisms produce more offspring than can survive, so there is competition for food, mates, space and so on (a struggle for survival).
3. Individuals with features best suited to the environment survive and reproduce more (survival of

the fittest).

4. They pass on the alleles for those features to the next generation.
5. Over many generations the advantageous alleles become more common; the population becomes better adapted. This is **evolution**: the change in adaptive features of a population over time as a result of natural selection.
 - Example: antibiotic resistance in bacteria. A random mutation makes a bacterium resistant; when the antibiotic is used, the non-resistant bacteria die, the resistant ones survive and reproduce, and the resistant strain spreads.
 - **Artificial selection (selective breeding)**: humans choose individuals with the desired features, breed them together, select the best offspring and repeat over many generations. Examples: cows with high milk yield, wheat with high yield and disease resistance, dogs with particular shapes. Compared with natural selection, humans do the selecting and it is much faster, but it reduces variation.

Biotechnology and genetic modification

Why bacteria are used

- Bacteria reproduce rapidly, can make complex molecules, have few ethical concerns about their growth, and have plasmids that can be used to carry genes from other organisms. They can also be grown cheaply on waste materials (**extended**).

Uses of micro-organisms and enzymes

- **Yeast** respire anaerobically to produce ethanol and carbon dioxide. In **bread-making** the carbon dioxide makes the dough rise (the ethanol evaporates in baking). In **biofuel** production yeast ferments sugar from crops such as sugar cane or maize to make ethanol for fuel.
- **Pectinase** breaks down pectin in cell walls, so more juice is released from fruit and the juice is clearer.
- **Biological washing powders** contain proteases and lipases that digest protein and fat stains into soluble products at low temperatures, saving energy.
- **Lactase** is used to break down lactose in milk to glucose and galactose, making lactose-free milk for people who cannot digest lactose (**extended**).
- **Fermenters** are large vessels for growing micro-organisms, for example to make the antibiotic **penicillin** from the fungus *Penicillium*. Conditions controlled: temperature (cooling jacket), pH, oxygen (sterile air pumped in), nutrient supply, stirring (paddles), and everything is sterilised to prevent contamination (**extended**).

Genetic modification

Genetic modification is changing the genetic material of an organism by removing, changing or inserting individual genes.

- Examples: bacteria given the human insulin gene make human insulin for diabetics; crops given genes for herbicide resistance or insect resistance (Bt maize); crops with extra vitamins (golden rice).

- Process for human insulin (**extended**): the insulin gene is cut out of human DNA using **restriction enzymes**, which leave sticky ends; a bacterial **plasmid** is cut with the same restriction enzyme; the gene is joined into the plasmid with **DNA ligase**; the recombinant plasmid is inserted into bacteria; the bacteria multiply in a fermenter and make insulin, which is extracted and purified.
- Advantages of GM crops: higher yields, less pesticide, better nutrition, growth in poor conditions. Disadvantages: possible spread of genes to wild plants, effects on insects and biodiversity, dependence on seed companies, uncertainty about long-term health effects (**extended**).

Organisms and their environment

Energy flow and food chains

- **Food chain**: shows the transfer of energy from one organism to the next, beginning with a producer.
 - **Food web**: a network of interconnected food chains.
 - **Producer**: an organism that makes its own organic nutrients, usually using energy from sunlight, through photosynthesis.
 - **Consumer**: an organism that gets its energy by feeding on other organisms.
 - **Herbivore**: an animal that gets its energy by eating plants. **Carnivore**: an animal that gets its energy by eating other animals.
 - **Decomposer**: an organism that gets its energy from dead or waste organic material.
 - **Trophic level**: the position of an organism in a food chain, food web or ecological pyramid.
 - **Ecosystem**: a unit containing the community of organisms and their environment, interacting together.
 - **Population**: a group of organisms of one species, living in the same area, at the same time.
 - **Community**: all of the populations of different species in an ecosystem.
- The Sun is the principal source of energy input to biological systems. Light energy is trapped by producers and passed along the chain as chemical energy in food.
 - Energy is lost at each level as heat from respiration, in uneaten parts, in faeces and in urea. Only about 10 % passes to the next level, so food chains rarely have more than five links and the number of organisms usually falls along the chain.
 - Eating plants directly is more efficient than eating animals fed on plants, because fewer transfers mean less energy is wasted (**extended**).
 - **Pyramids of numbers** show how many organisms are at each level; they can be inverted (one tree feeding many insects). **Pyramids of biomass** show the dry mass at each level and are usually a true pyramid shape. **Pyramids of energy** show the energy transferred at each level per unit area per year and are always pyramid-shaped (**extended**).
 - Removing one organism from a food web affects the others: if a predator is removed its prey increases, then the prey's food decreases.

The carbon cycle

- Carbon dioxide is removed from the air by **photosynthesis** and becomes carbohydrate, fat and protein in plants.
- Carbon passes to animals by **feeding**. It returns to the air as carbon dioxide by **respiration** of plants, animals and decomposers, by **combustion** of wood and fossil fuels, and by **decomposition** of dead material.
- Fossilisation locks carbon away in coal, oil and gas over millions of years. Burning fossil fuels and deforestation (less photosynthesis, more combustion) are raising the carbon dioxide concentration of the atmosphere.

The nitrogen cycle (extended)

- Plants cannot use nitrogen gas. They absorb **nitrate ions** by active transport and use them to make amino acids and proteins; animals obtain protein by feeding.
- **Decomposition**: bacteria and fungi break down proteins in dead organisms, faeces and urea into **ammonium ions**.
- **Nitrification**: nitrifying bacteria convert ammonium ions to nitrite and then to nitrate ions.
- **Nitrogen fixation**: nitrogen-fixing bacteria in the soil and in the root nodules of legumes (peas, beans, clover) convert nitrogen gas into ammonium ions or amino acids. Lightning also fixes nitrogen.
- **Denitrification**: denitrifying bacteria in waterlogged, airless soil convert nitrate back into nitrogen gas.
- Farmers add nitrogen by using fertilisers, growing legumes in crop rotation, and ploughing in manure.

Populations

- Factors affecting population size: food supply, predation, disease, competition, space.
- Growth curve of a population in a new habitat (sigmoid curve) (**extended**): **lag phase** (few organisms, slow increase while they adjust and reproduce); **exponential (log) phase** (rapid growth, plenty of food, little competition); **stationary phase** (birth rate equals death rate; a limiting factor such as food or waste has been reached; the population is at the carrying capacity); **death phase** (food runs out or waste builds up and the population falls).
- The human population has grown exponentially because of more food, better medicine and hygiene, and lower death rates. Consequences: more land for housing and farming, more waste, more pollution, more resources used.

Human influences on ecosystems

- **Food supply** has been increased by agricultural machinery, chemical fertilisers, insecticides and herbicides, and selective breeding. Monocultures (one crop over a large area) and intensive livestock production reduce biodiversity and encourage pests and disease; fertiliser run-off causes eutrophication (**extended**).
- **Habitat destruction** happens through clearing land for farming, housing and industry, extracting resources (mining, quarrying), marine pollution and draining wetlands. It reduces biodiversity.
- **Deforestation** causes extinction of species, loss of soil (erosion, as there are no roots to hold it), flooding (less water taken up and transpired), and more carbon dioxide in the air (less

photosynthesis and burning of the wood).

- **Water pollution by sewage and fertilisers (eutrophication) (extended):** nitrate and phosphate enter the water → algae grow rapidly (algal bloom) → algae block light, so plants below die → bacteria decompose the dead material and multiply → bacteria use up the dissolved oxygen in respiration → fish and other animals die.
- **Non-biodegradable plastics** stay in the environment for hundreds of years, choke and poison animals on land and at sea, and break into microplastics that enter food chains.
- **The greenhouse effect:** carbon dioxide and methane in the atmosphere trap heat radiated from the Earth. Increased concentrations from burning fossil fuels, deforestation, cattle and rice paddies are increasing the effect, causing climate change: rising sea levels, melting ice, extreme weather, changed distributions of species.

Conservation (extended)

A **sustainable resource** is one which is produced as rapidly as it is removed from the environment so that it does not run out.

Sustainable development is development providing for the needs of an increasing human population without harming the environment.

- Some resources (forests, fish stocks) can be maintained by education, legal quotas, closed seasons, protected areas, re-stocking and replanting, and by controlling net mesh size so young fish escape.
- Reasons to conserve species and habitats: maintaining biodiversity and ecosystems, protecting the Earth's resources, protecting the plants and animals that might provide food and medicines, and ethical and cultural reasons.
- Methods: monitoring and protecting species and habitats, captive breeding programmes, seed banks, national parks, and laws against hunting and trade in endangered species. Endangered species can be saved by these methods and reintroduced into the wild.
- Recycling paper, glass, metals and plastics, and treating sewage before it is released, reduce pollution and the use of raw materials.

Key terms

Term	Meaning
Absorption	Movement of small food molecules and ions through the wall of the intestine into the blood
Active transport	Movement of particles through a membrane against a concentration gradient using energy from respiration
Adaptive feature	An inherited feature that helps an organism to survive and reproduce in its environment
Aerobic respiration	Chemical reactions in cells that use oxygen to break down nutrient molecules to release energy
Allele	An alternative form of a gene

Alveolus	Tiny air sac in the lung where gas exchange takes place
Anaerobic respiration	Chemical reactions in cells that break down nutrient molecules to release energy without using oxygen
Antibody	Protein made by lymphocytes that binds to a specific antigen
Antigen	A substance, usually on the surface of a pathogen, that triggers antibody production
Artery	Vessel carrying blood away from the heart under high pressure
Assimilation	Movement of digested food molecules into the cells of the body where they are used
Auxin	Plant hormone made at the shoot tip that stimulates cell elongation
Balanced diet	A diet with all nutrients in the correct amounts and proportions for the individual
Bile	Alkaline liquid made by the liver that neutralises stomach acid and emulsifies fats
Binomial system	Naming each species with a genus name and a species name
Catalyst	A substance that increases the rate of a reaction and is not changed by it
Chlorophyll	Green pigment in chloroplasts that absorbs light energy
Chromosome	A thread-like structure of DNA carrying genetic information in the form of genes
Codominance	Both alleles are expressed in a heterozygote
Community	All the populations of different species in an ecosystem
Consumer	Organism that gets its energy by feeding on other organisms
Deamination	Removal of the amino group from an amino acid in the liver to form urea
Decomposer	Organism that gets its energy from dead or waste organic material
Denatured	An enzyme whose active site has changed shape so it no longer works
Diffusion	Net movement of particles from higher to lower concentration due to random movement
Diploid	A nucleus with two sets of chromosomes
Dominant	An allele that is expressed if it is present
Ecosystem	A unit containing the community of organisms and their environment, interacting together
Egestion	Passing out of undigested food as faeces through the anus
Enzyme	A protein that functions as a biological catalyst
Eutrophication	Enrichment of water with nutrients leading to algal growth and loss of oxygen
Excretion	Removal of the waste products of metabolism and substances in excess of requirements
Fertilisation	The fusion of the nuclei of gametes
Food chain	Transfer of energy from one organism to the next, beginning with a producer
Gene	A length of DNA that codes for a protein

Genetic modification	Changing the genetic material of an organism by removing, changing or inserting genes
Genotype	The genetic make-up of an organism in terms of the alleles present
Gravitropism	Growth of part of a plant towards or away from gravity
Haploid	A nucleus with a single set of chromosomes
Heterozygous	Having two different alleles of a particular gene
Homeostasis	Maintenance of a constant internal environment
Homozygous	Having two identical alleles of a particular gene
Hormone	A chemical made by a gland, carried in the blood, that alters the activity of specific target organs
Ingestion	Taking food and drink into the body through the mouth
Inheritance	Transmission of genetic information from generation to generation
Limiting factor	Something in such short supply that it restricts life processes
Lymphocyte	White blood cell that produces antibodies
Magnification	Image size divided by actual size
Meiosis	Reduction division halving the chromosome number, producing genetically different cells
Mitosis	Nuclear division giving rise to genetically identical cells
Mutation	Genetic change; a gene mutation is a random change in the base sequence of DNA
Natural selection	Survival and reproduction of the best-adapted individuals, passing on their alleles
Nephron	The filtering unit of the kidney
Osmosis	Net movement of water from higher to lower water potential through a partially permeable membrane
Oxygen debt	Extra oxygen needed after exercise to break down lactic acid
Pathogen	A disease-causing organism
Peristalsis	Waves of muscle contraction that move food along the gut
Phagocyte	White blood cell that engulfs and digests pathogens
Phenotype	The observable features of an organism
Phloem	Living tissue that transports sucrose and amino acids
Photosynthesis	Process by which plants synthesise carbohydrates from raw materials using light energy
Phototropism	Growth of part of a plant towards or away from the direction of light
Plasmolysis	Cytoplasm pulling away from the cell wall after water loss by osmosis
Pollination	Transfer of pollen grains from the anther to the stigma

Population	A group of organisms of one species living in the same area at the same time
Producer	Organism that makes its own organic nutrients, usually by photosynthesis
Recessive	An allele only expressed when no dominant allele of the gene is present
Reflex action	A fast, automatic response to a stimulus not involving conscious thought
Sexual reproduction	Fusion of the nuclei of two gametes to form a zygote, giving genetically different offspring
Species	A group of organisms that can reproduce to produce fertile offspring
Sustainable resource	One produced as rapidly as it is removed so that it does not run out
Synapse	Junction between two neurones where a neurotransmitter crosses the gap
Translocation	Movement of sucrose and amino acids in the phloem from source to sink
Transmissible disease	A disease in which the pathogen can be passed from one host to another
Transpiration	Loss of water vapour from leaves
Trophic level	Position of an organism in a food chain, food web or pyramid
Turgid	A plant cell full of water with the cytoplasm pressing on the cell wall
Variation	Differences between individuals of the same species
Xylem	Dead, lignified tubes that carry water and mineral ions and support the plant
Zygote	The diploid cell formed by fertilisation

Quick check

1. State three structures found in a plant cell but not in an animal cell.
2. A drawing of a cheek cell is 60 mm wide. The actual cell is 60 μm wide. Calculate the magnification.
3. State the two features used to place an animal in the class Mammalia, and name the group of arthropods with eight legs and no antennae.
4. Explain why a potato strip placed in distilled water gains mass.
5. Describe how you would test a food sample for reducing sugar and state the positive result.
6. Explain why an enzyme stops working above 60 °C.
7. Write the word equation for photosynthesis and state why a plant short of magnesium has yellow leaves.
8. Describe three ways in which a leaf is adapted for photosynthesis.
9. State three environmental conditions that increase the rate of transpiration, giving a reason for one of them.
10. Describe the function of bile in digestion.
11. Explain how the villi adapt the small intestine for absorption.
12. Compare aerobic respiration with anaerobic respiration in muscle, giving two differences.

13. Explain why the wall of the left ventricle is thicker than the wall of the right ventricle.
14. Describe how vaccination gives long-lasting immunity.
15. Name the substance made from excess amino acids in the liver, and the organ that removes it from the blood.
16. Write out the pathway of a reflex arc from stimulus to response.
17. Explain how the body reduces its temperature when it is too hot.
18. In humans the allele for brown eyes (B) is dominant to the allele for blue eyes (b). A brown-eyed man who is heterozygous has children with a blue-eyed woman. Use a Punnett square to find the probability of a blue-eyed child.
19. Describe the process of natural selection using the example of antibiotic resistance in bacteria.
20. Explain why only about 10 % of the energy at one trophic level passes to the next.

1. Cell wall (cellulose), chloroplasts, large permanent vacuole containing cell sap.
2. Convert to the same unit: $60 \text{ mm} = 60\,000 \text{ }\mu\text{m}$. Magnification = image size $\div$ actual size = $60\,000 \div 60 = \times 1000$.
3. Mammals have hair or fur and mammary glands that produce milk (also accept external ears, warm-blooded, give birth to live young). Arthropods with eight legs and no antennae are arachnids.
4. Distilled water has a higher water potential than the cell sap of the potato cells. Water moves into the cells by osmosis through the partially permeable cell membranes, down the water potential gradient, so the cells become turgid and the strip gains mass.
5. Crush the sample and mix with water, add Benedict's solution and heat in a boiling water bath for a few minutes. A positive result is a colour change from blue to green, yellow, orange or brick-red; the more reducing sugar, the closer to brick-red.
6. At high temperature the enzyme molecule vibrates violently and the bonds that hold its three-dimensional shape break. The active site changes shape, so the substrate is no longer complementary and cannot bind. The enzyme is denatured, and this change is permanent.
7. Carbon dioxide + water $\rightarrow$ glucose + oxygen, with light energy absorbed by chlorophyll. Magnesium ions are needed to make chlorophyll, so a plant short of magnesium cannot make enough chlorophyll and its leaves turn yellow.
8. Any three: broad and flat for a large surface area to absorb light; thin for a short diffusion distance for carbon dioxide; palisade cells near the upper surface packed with chloroplasts; air spaces in the spongy mesophyll let gases reach all cells; stomata allow carbon dioxide to diffuse in; xylem in the veins supplies water; transparent epidermis lets light through.
9. Higher temperature, lower humidity, higher wind speed, brighter light. Reason, for example: higher temperature gives water molecules more kinetic energy, so evaporation from the mesophyll cells and diffusion through the stomata are faster. Or: lower humidity gives a steeper water vapour concentration gradient between the air spaces and the outside air, so diffusion is faster.
10. Bile is alkaline and neutralises the acidic chyme from the stomach, giving the optimum pH for the pancreatic and intestinal enzymes. It emulsifies fats, breaking large drops into small droplets, which increases the surface area for lipase to act on. Bile contains no enzymes.

11. Millions of villi, each with microvilli, give a very large surface area. The wall of each villus is one cell thick, giving a short diffusion distance. Each villus has a dense capillary network to carry away glucose and amino acids and maintain a steep concentration gradient, and a lacteal to absorb fatty acids and glycerol. Mitochondria in the epithelial cells provide energy for active transport.

12. Aerobic respiration uses oxygen; anaerobic does not. Aerobic produces carbon dioxide and water; anaerobic in muscle produces lactic acid. Aerobic releases much more energy per molecule of glucose, because glucose is completely broken down. Anaerobic respiration builds up an oxygen debt.

13. The left ventricle pumps blood through the aorta to the whole body, so it must generate a much higher pressure to push blood through the long systemic circuit against greater resistance. The right ventricle pumps blood only to the nearby lungs at lower pressure, which also avoids damaging the delicate alveolar capillaries.

14. A vaccine contains a harmless form of the pathogen or its antigens (dead, weakened or part of the pathogen). Lymphocytes recognise the antigens and produce complementary antibodies. Memory cells are also made and remain in the blood. If the real pathogen later enters, the memory cells respond quickly and produce a large amount of antibody before the pathogen can cause disease. This is active immunity.

15. Urea, made by deamination of excess amino acids in the liver. It is removed from the blood by the kidneys and excreted in urine.

16. Stimulus → receptor → sensory neurone → (synapse) relay neurone in the spinal cord → (synapse) motor neurone → effector (muscle or gland) → response.

17. The hypothalamus detects the rise in blood temperature. Sweat glands secrete more sweat; as the water evaporates from the skin it takes heat from the body. Vasodilation: arterioles leading to the skin capillaries widen, so more blood flows near the surface and more heat is lost by radiation. Hairs lie flat so less air is trapped as insulation. The person may also become less active.

18. Parental phenotypes: brown eyes × blue eyes. Parental genotypes: Bb × bb. Gametes: B or b from the father; b only from the mother.

	B	b
b	Bb (brown)	bb (blue)
b	Bb (brown)	bb (blue)

Offspring genotypes 1 Bb : 1 bb; phenotypes 1 brown : 1 blue. The probability of a blue-eyed child is 1 in 2, or 50 %, for every child.

19. In a population of bacteria there is variation caused by random mutation; a mutation gives a few bacteria resistance to the antibiotic. When the antibiotic is used, the bacteria without the resistance allele are killed, while the resistant bacteria survive. They reproduce and pass the resistance allele to their offspring. Over many generations the proportion of resistant bacteria rises until the antibiotic no longer works against that population.

20. Energy is lost from each level before it can be passed on: most is released as heat by

respiration; some is in parts of the organism that are not eaten (bones, roots); some is in undigested material lost as faeces; and some leaves in excretory products such as urea. Only the energy stored in the tissues that are eaten and digested is available to the next trophic level, which is roughly 10 %.