

Organisms (Interaction and interdependence)

revision notes

How the parts of a multicellular organism work together, and how the body defends itself against pathogens. Nerves, hormones and the blood integrate organs into one system, feedback loops regulate heart rate and ventilation, and at HL phytohormones coordinate plant growth. The second topic covers primary defences, innate and adaptive immunity, HIV, antibiotics, zoonoses, vaccines and herd immunity.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

1 Integration of body systems **Spec C3.1**

System integration and the hierarchy of subsystems **Spec C3.1.1, C3.1.2, C3.1.3**

System integration is a necessary process in living systems. Coordination is needed for the component parts of a system to collectively perform an overall function. Without it, organs would work independently and the organism could not respond to its environment as a whole.

A hierarchy of subsystems

A multicellular organism is built as a **hierarchy of subsystems**: cells form tissues, tissues form organs, and organs form body systems. Each level is integrated with the others. Integration gives **emergent properties**: abilities of the whole organism that no single part has on its own.

A **cheetah** becomes an effective predator by integration of its body systems. Its eyes detect prey, the brain processes the information and plans the chase, motor neurons stimulate skeletal muscles to contract in sequence, the skeleton provides levers, and the heart, lungs and blood supply oxygen and glucose to the muscles. No single organ can hunt; the whole integrated organism can.

How organs are integrated in animals

Nervous and endocrine signalling compared		
Feature	Nervous system	Endocrine system
Signal	Electrical impulses along neurons, chemical (neurotransmitter) across synapses	Hormones secreted by glands into the blood
Route	Along neurons to specific cells	Carried by the blood to all parts of the body; only target cells with receptors respond
Speed	Very fast (milliseconds)	Slower (seconds to hours)
Duration of effect	Usually short	Usually longer lasting
Example	Withdrawal of the hand from a painful stimulus	Epinephrine preparing the body for vigorous activity

The **blood system** integrates organs by **transporting materials and energy** between them. For example, glucose absorbed in the small intestine is carried to the liver and to muscles; oxygen from the lungs is

carried to every respiring tissue; urea from the liver is carried to the kidneys; heat from active muscles is distributed around the body. The blood also carries hormones from endocrine glands to their target organs.

Exam tip: When asked to distinguish nervous and hormonal signalling, give paired points (nerve impulses vs hormones in blood; fast vs slow; short-lived vs long-lasting; specific route vs reaches all cells).

The brain, spinal cord, neurons and nerves Spec C3.1.4, C3.1.5, C3.1.6, C3.1.7, C3.1.8

The brain as the central integration organ

The brain receives impulses from many receptors at once, for example the eyes, ears and skin. It **processes information combined from several inputs**, compares it with stored information, and decides on a response. The brain is also the organ of **learning and memory**: experiences cause lasting changes in the connections between neurons, so information can be stored and recalled to modify later behaviour.

The spinal cord and unconscious processes

The **spinal cord** is an integrating centre for **unconscious processes**, such as reflexes. **Conscious processes** are those we are aware of and can control voluntarily, such as deciding to pick up a cup; they are coordinated by the cerebral hemispheres. **Unconscious processes** happen without awareness or deliberate decision, such as withdrawing a hand from a sharp object; they can be coordinated by the spinal cord without involving the brain.

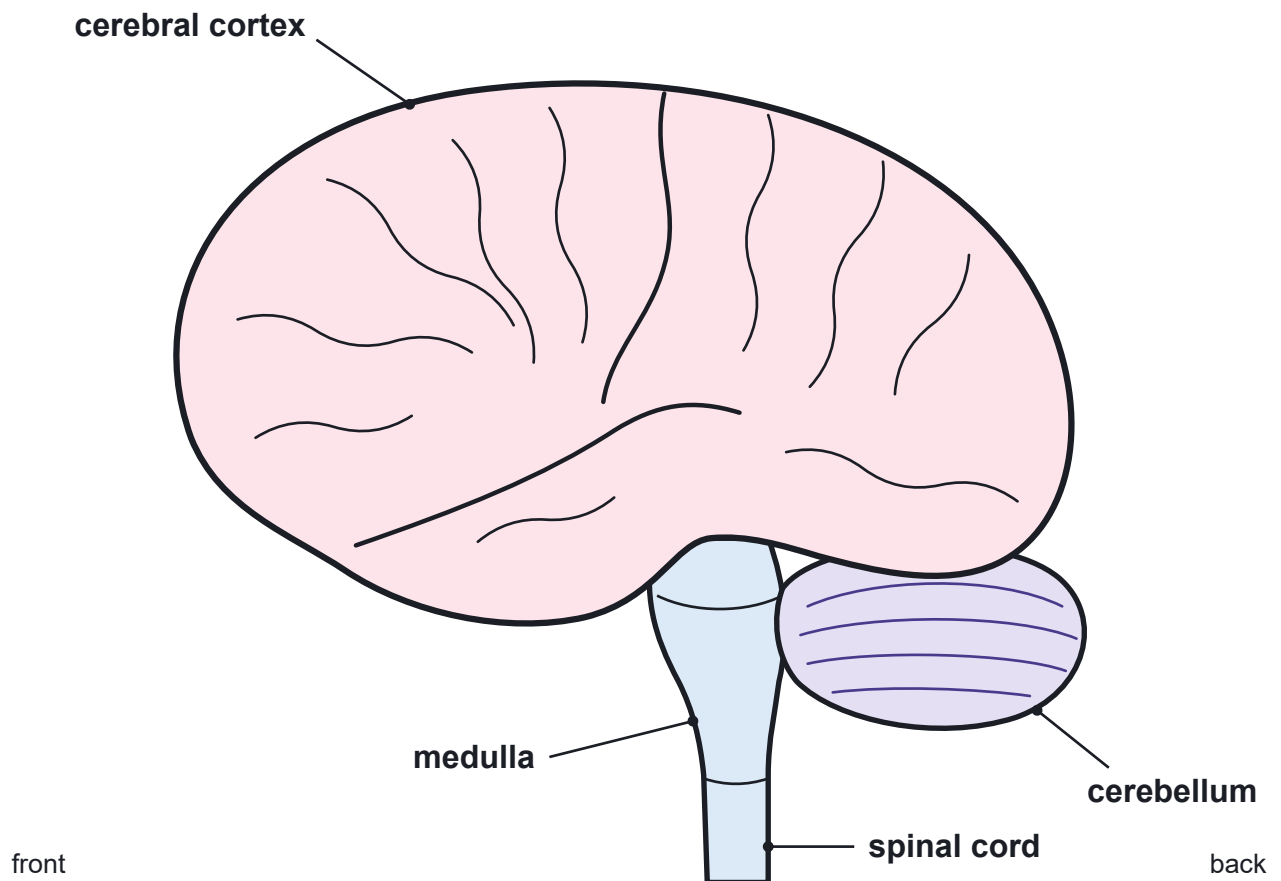
In a transverse section of the spinal cord, the central **grey matter** contains cell bodies of neurons, interneurons and synapses; the outer **white matter** contains myelinated nerve fibres that carry impulses up and down the cord.

Sensory and motor neurons

- **Sensory neurons** convey messages from receptor cells to the central nervous system (CNS): input to the spinal cord and to the cerebral hemispheres.
- **Motor neurons** carry output from the cerebral hemispheres (and the spinal cord) to muscles, which are stimulated to contract.

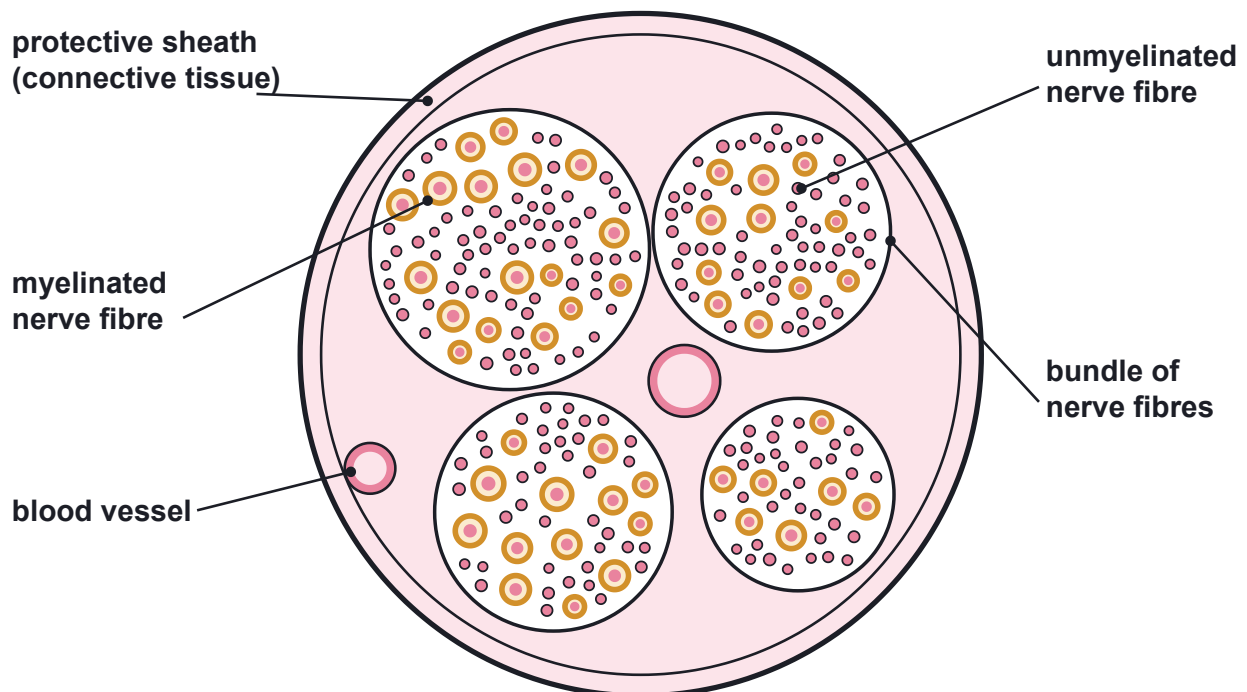
Nerves

A **nerve** is a bundle of nerve fibres (axons) of both sensory and motor neurons, surrounded by a **protective sheath** of connective tissue. A transverse section of a nerve shows many fibres; some are **myelinated** (surrounded by a myelin sheath, which speeds conduction) and some are **unmyelinated**. Blood vessels supply the fibres.



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The **cerebral cortex** (outer layer of the cerebral hemispheres) integrates conscious processes, the **cerebellum** coordinates movement and the **medulla** controls heart rate and ventilation.



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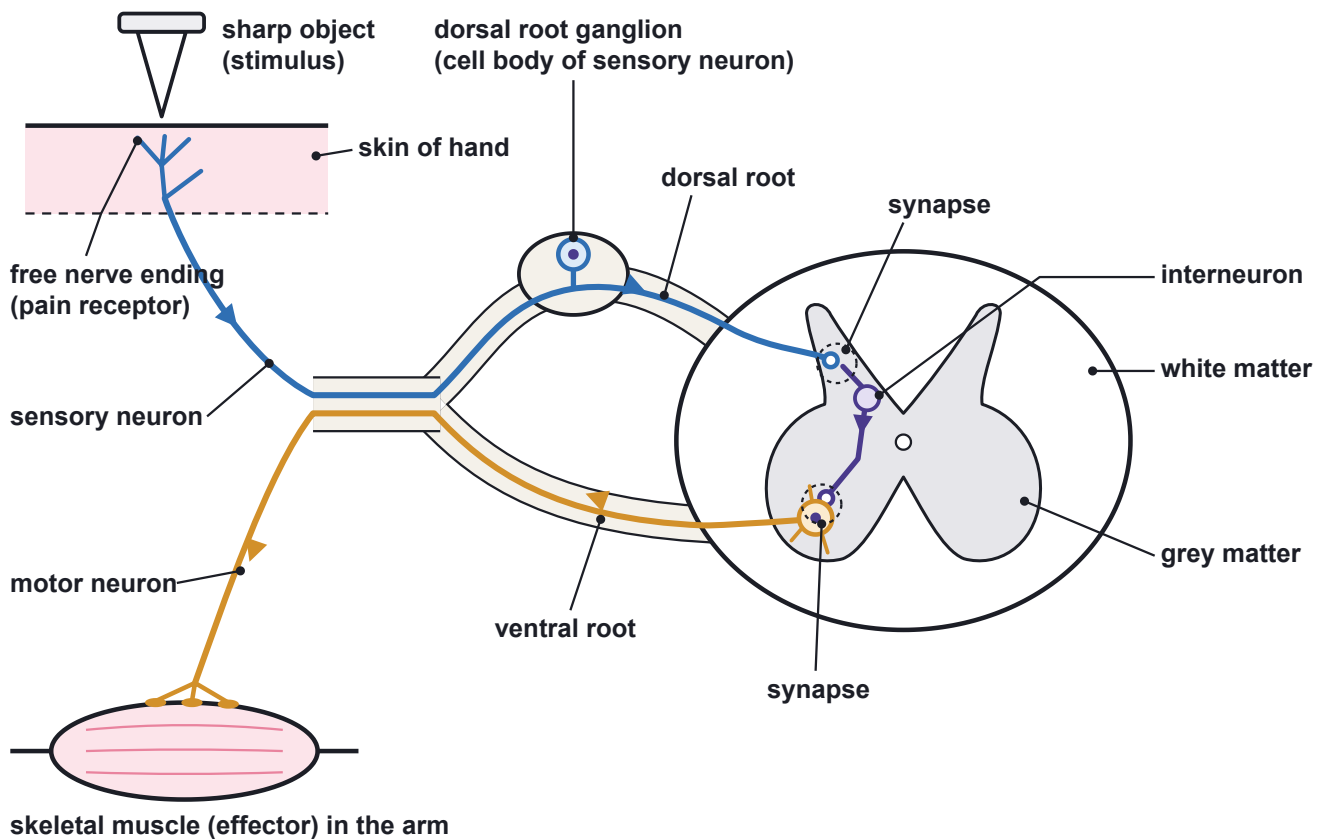
Transverse section of a nerve: a nerve contains **fibres of both sensory and motor neurons**, some myelinated and some unmyelinated, inside a protective sheath.

Pain reflex arcs and the cerebellum Spec C3.1.9, C3.1.10

A **reflex** is a rapid, involuntary response to a stimulus. The pain reflex arc is an example of an involuntary response with **skeletal muscle as the effector**. Because the spinal cord, not the brain, processes the signal, the response is fast and does not need a conscious decision.

1. A sharp object pricks the hand. A **free sensory nerve ending** of a sensory neuron acts as the pain receptor and generates nerve impulses.
2. The sensory neuron carries impulses to the spinal cord, entering through the dorsal root.
3. In the grey matter of the spinal cord, the sensory neuron synapses with a single **interneuron**.
4. The interneuron synapses with a motor neuron, which carries impulses out of the spinal cord through the ventral root.
5. The motor neuron stimulates a skeletal muscle (for example the biceps) to contract, pulling the hand away.

Other interneurons also pass impulses up the spinal cord to the brain, so the pain is felt consciously, but only after the withdrawal has already begun.



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The pain reflex arc: sensory neuron → **interneuron** in the grey matter → motor neuron → skeletal muscle. Arrows show the direction of the impulse.

The cerebellum

The **cerebellum**, at the back of the brain below the cerebral hemispheres, coordinates skeletal muscle contraction and balance. It receives information about body position from muscles, joints, the inner ear and the eyes, and adjusts the timing and strength of muscle contractions so that movements are smooth and accurate and posture is maintained. It is important in learned motor skills such as walking, riding a bicycle or writing.

Common mistake: The cerebellum does not start voluntary movements; the cerebral hemispheres do. The cerebellum coordinates them and keeps the body balanced.

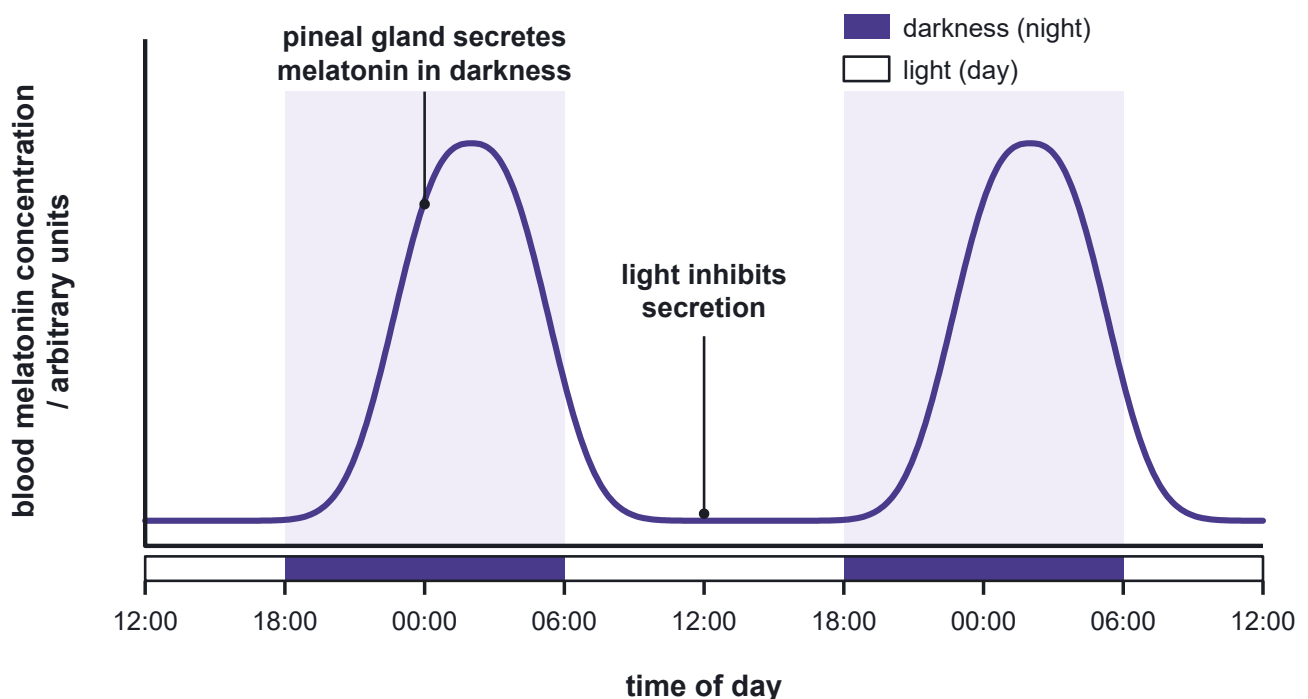
Melatonin, epinephrine and control by the hypothalamus and pituitary

Spec C3.1.11, C3.1.12, C3.1.13

Melatonin and circadian rhythms

Circadian rhythms are cycles in body activity that repeat about every 24 hours. **Melatonin** is secreted by the **pineal gland** in the brain with a diurnal pattern: secretion increases in the evening as it gets dark, stays high during the night and falls to a low level in the morning. Light detected by the retina is signalled to the hypothalamus, which inhibits melatonin secretion during the day.

High melatonin levels promote sleepiness and a fall in body temperature; low levels in the morning allow waking. In this way melatonin modulates sleep patterns and helps to establish a cycle of sleeping and waking. Shifting the light-dark cycle, as in jet lag or night-shift work, disrupts this pattern.



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Melatonin secretion over two days (illustrative): the pineal gland secretes melatonin **in darkness**; light inhibits secretion.

Epinephrine (adrenaline)

Epinephrine is secreted by the **adrenal glands** to prepare the body for vigorous activity, for example in response to danger or before a race. It has widespread effects, which together supply skeletal muscles with the oxygen and glucose they need for intense contraction:

- heart rate and stroke volume increase, so more blood is pumped per minute
- arterioles to skeletal muscles dilate; arterioles to the gut and skin constrict, diverting blood to the muscles
- airways (bronchioles) widen and ventilation rate increases, so more oxygen is absorbed
- glycogen in the liver is broken down to glucose, raising blood glucose concentration
- pupils dilate and mental alertness increases

The hypothalamus and pituitary gland

The endocrine system is controlled by the **hypothalamus and pituitary gland**. The **hypothalamus**, at the base of the brain, links the nervous and endocrine systems: it receives information from the nervous system and from the blood, and responds by sending signals (releasing hormones and nerve impulses) to the pituitary gland. The **pituitary gland**, below the hypothalamus, then secretes hormones that travel in the blood and regulate other endocrine glands and organs, for example thyroid-stimulating hormone (TSH), FSH and LH, growth hormone and ADH.

Exam tip: You only need a general understanding of hypothalamus–pituitary control. Differences between the anterior and posterior pituitary are not required.

Feedback control of heart rate and ventilation rate Spec C3.1.14, C3.1.15

Receptors and their location

Sensory input for heart rate and ventilation control		
Receptor	What it monitors	Location
Baroreceptors	Blood pressure (stretch of the artery wall)	Walls of the aorta (aortic arch) and the carotid arteries (carotid sinus)
Peripheral chemoreceptors	Blood pH and concentrations of oxygen and carbon dioxide	Aortic bodies and carotid bodies
Central chemoreceptors	pH (and so carbon dioxide concentration)	Brainstem (medulla)

Control of heart rate

The **medulla** (in the brainstem) coordinates the response. It sends nerve impulses to the heart through two nerves: impulses along a **sympathetic nerve** increase heart rate and the force of contraction (stroke volume); impulses along the **vagus nerve** (parasympathetic) decrease heart rate. Both act on the pacemaker (sinoatrial node); sympathetic impulses also act on the ventricle walls to increase the force of contraction.

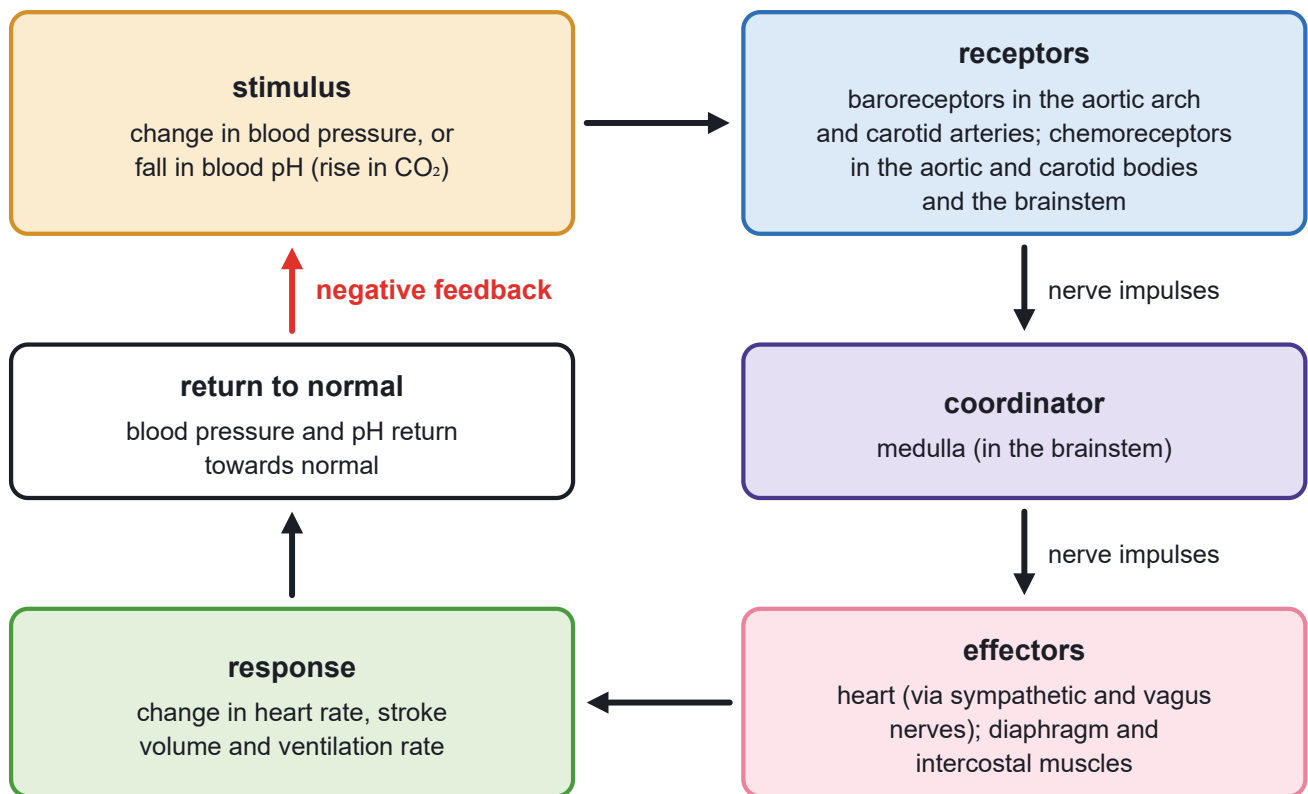
1. During exercise, muscles respire faster, so blood carbon dioxide rises and pH falls; blood oxygen may fall.
2. Chemoreceptors detect the change and send impulses to the medulla.
3. The medulla sends more impulses along the sympathetic nerve to the heart: heart rate and stroke volume increase.
4. More blood flows to the lungs and muscles, removing carbon dioxide and supplying oxygen, so pH returns towards normal.
5. If blood pressure rises too high, baroreceptors are stretched more and send more impulses to the medulla, which sends impulses along the vagus nerve to slow the heart: **negative feedback**.

Control of ventilation rate

Blood pH changes mainly because of carbon dioxide. Carbon dioxide reacts with water to form carbonic acid, which dissociates into hydrogen ions and hydrogencarbonate ions: $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-$. So when respiration increases, more CO_2 enters the blood and **blood pH falls**. Lactic acid from anaerobic respiration in muscles can lower pH further.

Chemoreceptors in the brainstem detect the fall in pH and the medulla sends more nerve impulses to the **diaphragm** and **intercostal muscles**. These contract more often and more strongly, so the

ventilation rate and depth increase. More CO₂ is exhaled, blood pH rises back towards normal, and the stimulus is reduced: negative feedback.



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Control of heart rate and ventilation rate by **negative feedback**: the response removes the stimulus.

Common mistake: Ventilation rate is mainly driven by a rise in CO₂ (fall in pH), not by a fall in O₂. Write 'chemoreceptors detect a fall in blood pH' rather than 'the body detects a lack of oxygen'.

Maths skill: Exercise data often ask for a percentage change: $(\text{new value} - \text{original value}) \div \text{original value} \times 100$. A heart rate rising from 70 to 140 beats per minute is a 100% increase.

Control of peristalsis by the CNS and enteric nervous system Spec C3.1.16

Peristalsis is the coordinated contraction and relaxation of circular and longitudinal smooth muscle in the wall of the gut. Contraction of circular muscle behind the food squeezes it forward; the wave of contraction travels along the gut.

Control of the digestive system is shared between two parts of the nervous system:

Voluntary and involuntary control of movement through the gut		
Stage	Type of control	Controlled by
Initiation of swallowing	Voluntary	Central nervous system (CNS)
Peristalsis from oesophagus to rectum	Involuntary	Enteric nervous system (ENS)
Egestion of faeces	Voluntary	Central nervous system (CNS)

The **enteric nervous system** is a network of neurons in the wall of the gut, from the oesophagus to the anus. It detects stretching of the gut wall by food and coordinates waves of peristalsis without input from the brain. The action of the ENS ensures that the passage of material through the gut is **coordinated**, so food spends long enough in each region for digestion and absorption.

Exam tip: Linking question: the ENS forms a net-like (reticulate) network in the gut wall, while neurons branch in a dendritic pattern. Be ready to give these as examples of patterns of organization.

Tropic responses in seedlings and positive phototropism Spec C3.1.17, C3.1.18 HL only

A **tropism** is a directional growth response to a directional stimulus. **Positive phototropism** is a directional growth response to lateral light in plant shoots: the shoot grows towards the side the light comes from. This places leaves where they absorb more light for photosynthesis.

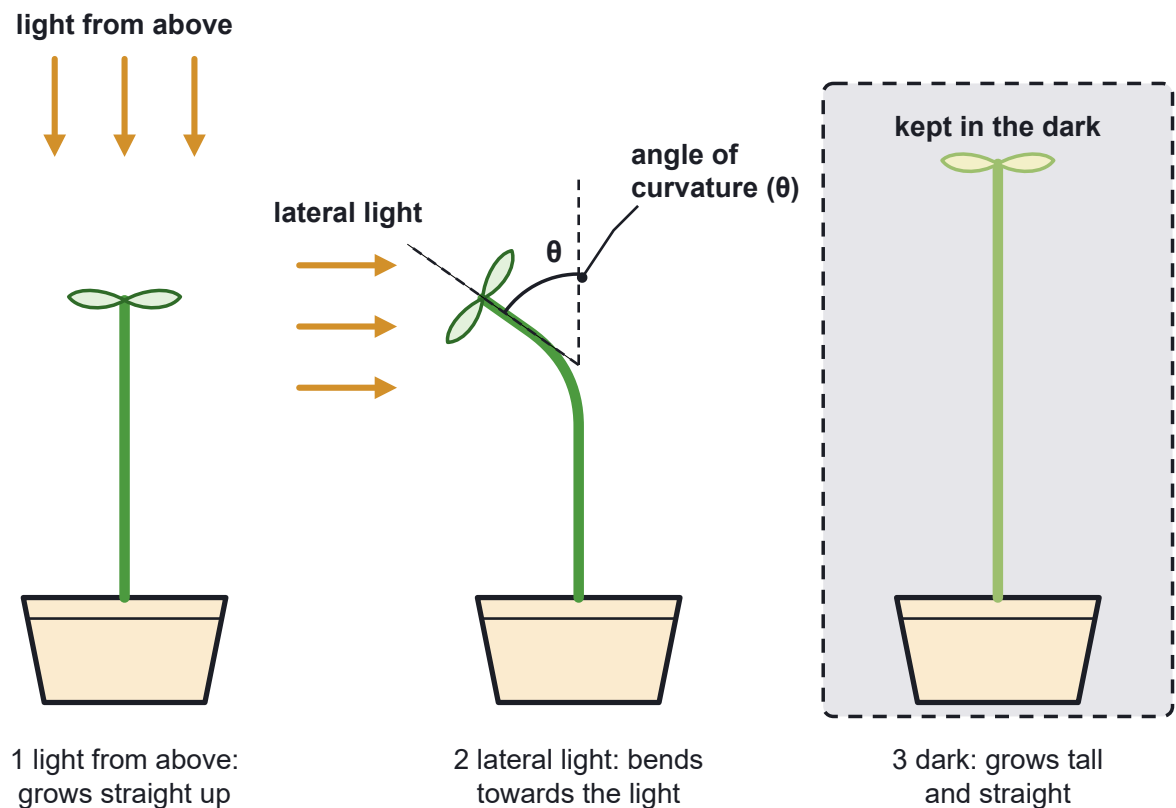
*Practical skill: Grow seedlings (for example cress, mustard or oat) in a box lit from one side, with controls lit from above or kept in the dark. Record qualitative data with labelled diagrams; collect quantitative data by measuring the **angle of curvature** of each seedling with a protractor or from a photograph.*

Qualitative and quantitative observations

- **Qualitative** observations describe without numbers: for example a drawing showing that shoots bend towards the light.
- **Quantitative** observations are measurements: for example the angle of curvature in degrees after 24 hours.

Precision, accuracy and reliability

- Precision is limited by the resolution of the protractor and by deciding exactly where the curved shoot begins. Photographing seedlings against a grid and measuring angles with image-analysis software increases precision.
- Accuracy is improved by measuring from a fixed reference line (the original vertical) and photographing from directly side-on.
- Reliability is improved by using many seedlings per treatment, repeating the experiment and calculating means; controlling light intensity, temperature and water.



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Seedlings after 24 hours. The **angle of curvature (θ)** is measured from the original vertical to a line along the bent tip.

Exam tip: You only need phototropism. Specific examples of other tropisms are not required.

Phytohormones, auxin efflux carriers and cell growth Spec C3.1.19, C3.1.20, C3.1.21 HL only

Phytohormones are signalling chemicals controlling growth, development and response to stimuli in plants. A variety of chemicals are used as phytohormones, including auxin, cytokinins, gibberellins, abscisic acid and ethylene. They are produced in small amounts and act on target cells, often some distance from where they are made.

Auxin efflux carriers

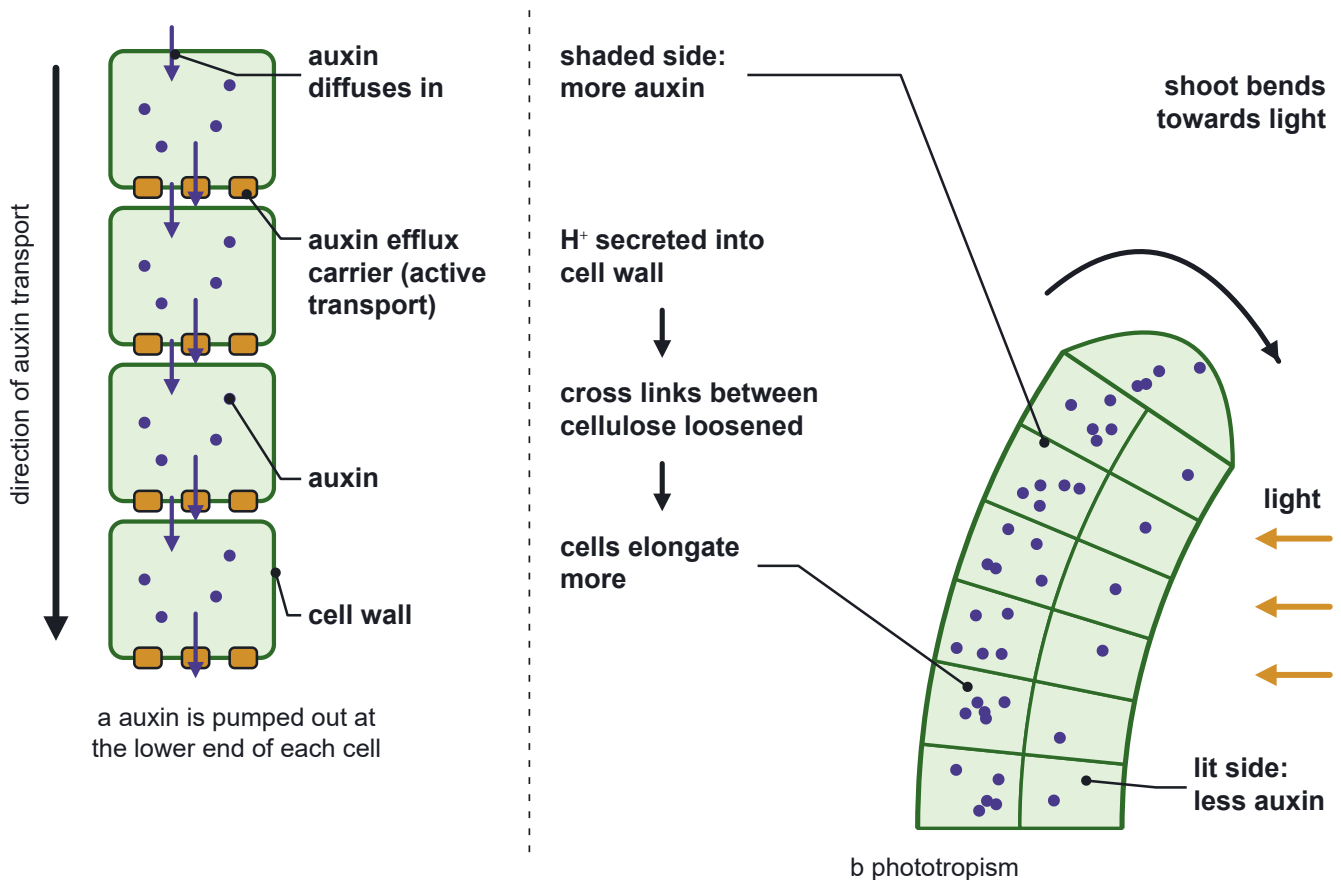
Auxin can diffuse freely into plant cells but not out of them. To leave a cell it must be moved by **auxin efflux carriers**, membrane proteins that pump auxin out. These carriers can be positioned in the cell membrane on one side of the cell only. If all cells coordinate to concentrate their efflux carriers on the same side, auxin is actively transported from cell to cell through the tissue in one direction, and becomes concentrated in part of the plant. This is how plants maintain concentration gradients of phytohormones.

Promotion of cell growth by auxin

1. Auxin binds to receptors in target cells and promotes the secretion of hydrogen ions (by proton pumps) into the apoplast (cell wall).
2. The cell wall becomes **acidified**.
3. The low pH loosens cross links between cellulose molecules in the cell wall.
4. Water enters the cell by osmosis and turgor pressure stretches the loosened wall, so the cell elongates.

How auxin causes phototropism

Auxin is produced in the shoot tip. When light comes from one side, efflux carriers are repositioned so that more auxin is transported to the **shaded side**. Concentration gradients of auxin cause the differences in growth rate needed for phototropism: cells on the shaded side elongate faster than cells on the lit side, so the shoot bends towards the light.



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(a) Auxin efflux carriers on one side of each cell move auxin in one direction. (b) More auxin on the **shaded side** makes those cells elongate more, so the shoot bends towards the light.

Common mistake: Auxin does not 'diffuse away from the light'. It is actively transported to the shaded side by efflux carriers. The evidence shows that auxin is moved sideways, not that light destroys it on the lit side.

Auxin and cytokinin interactions, and ethylene in fruit ripening

Spec C3.1.22, C3.1.23

HL only

Auxin and cytokinin

Root tips produce **cytokinin**, which is transported to the shoots in the xylem. Shoot tips produce **auxin**, which is transported to the roots (from cell to cell by efflux carriers, and in the phloem). Each hormone signals the state of the other part of the plant, and the two hormones often have opposite effects in the same tissue:

- In the roots, auxin arriving from the shoots promotes the formation of new lateral roots, while cytokinin inhibits it. More auxin from a growing shoot system therefore favours root growth.
- In the shoots, auxin from the shoot tip inhibits the growth of side buds (apical dominance), while cytokinin arriving from the roots promotes cell division and side-bud growth. More cytokinin from a growing root system therefore favours shoot growth.

- So it is the balance (ratio) of auxin to cytokinin that matters: a high auxin to cytokinin ratio favours root growth, and a low ratio favours shoot growth. In plant tissue culture, changing this ratio makes a callus form roots or shoots.

These interactions help to ensure that root and shoot growth are **integrated**: the roots can supply enough water and mineral ions for the leaves, and the leaves can supply enough sugars for the roots.

Ethylene and fruit ripening

Ethylene (IUPAC name: ethene) is a gaseous phytohormone. It stimulates the changes that occur in fruits during ripening, such as conversion of starch to sugars, softening of the flesh and change of colour. Ripening also stimulates increased production of ethylene. This is **positive feedback**: the response increases the stimulus. It happens in fruits such as bananas, apples and tomatoes, which show a burst of ethylene production as they ripen.

1. A fruit starts to produce ethylene.
2. Ethylene stimulates ripening changes in the fruit.
3. Ripening stimulates the fruit to produce even more ethylene.
4. Ethylene, a gas, also diffuses to neighbouring fruits and triggers their ripening.

The benefit is that fruit ripening is **rapid and synchronized**: all the fruits on a plant ripen at about the same time, which makes them attractive to seed-dispersing animals together.

Exam tip: Linking question: positive feedback amplifies change and moves a system away from its starting state, so it suits one-off events such as ripening. Contrast it with the negative feedback that keeps heart rate and blood pH stable.

Quick check

1. What is meant by an emergent property, and what example does the IB guide use?
2. Which part of the nervous system is an integrating centre for unconscious processes?
3. Where are baroreceptors located?
4. Which gland secretes melatonin, and when is secretion highest?
5. **HL only** How does auxin make cells elongate?

2 Defence against disease Spec C3.2

Pathogens as the cause of infectious diseases Spec C3.2.1

A **pathogen** is a disease-causing organism. Pathogens are the cause of **infectious diseases**: diseases that can be passed from one host to another. A broad range of organisms can infect humans, but the term pathogen is typically reserved for four groups.

Groups of pathogen	
Group	Example disease
Viruses	COVID-19, HIV/AIDS, rabies
Bacteria	Tuberculosis, cholera
Fungi	Athlete's foot
Protists	Malaria

Archaea are not known to cause any diseases in humans, even though many live in and on the human body.

Nature of science: careful observation

Careful observation can lead to important progress. In 19th-century Vienna, a doctor observed that childbed fever (an infection after childbirth) was far more common on a ward where doctors came straight from dissecting bodies; making them wash their hands in a chlorinated solution cut deaths sharply. In London, mapping cholera cases during an epidemic showed that they clustered around one water pump, linking the disease to contaminated water. Both led to breakthroughs in the control of infectious disease.

Skin, mucous membranes and blood clotting Spec C3.2.2, C3.2.3

Primary defence

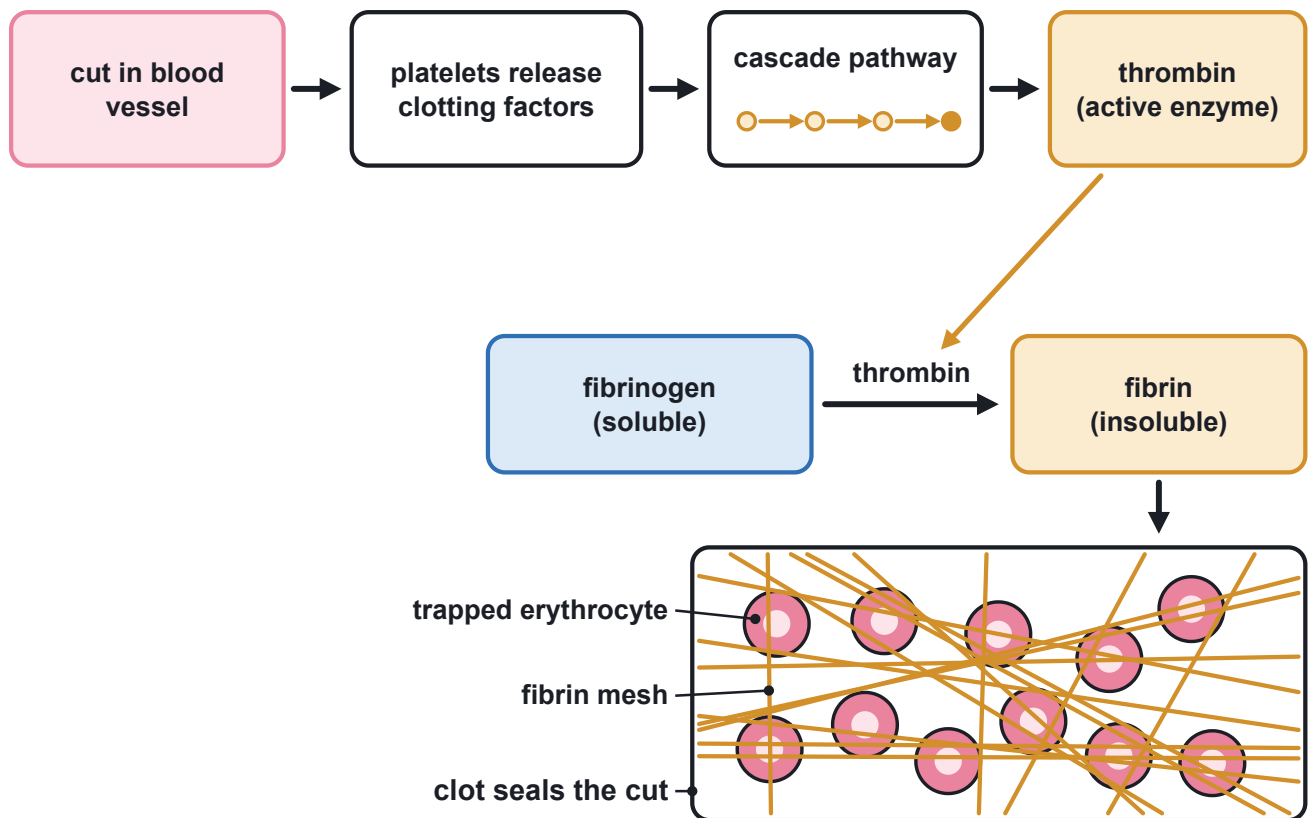
The **primary defence** stops pathogens entering the body in the first place.

- **Skin as a physical barrier:** the outer layer is made of tough, dead cells packed with keratin, which pathogens cannot easily penetrate. Dead cells are constantly shed, taking microorganisms with them.
- **Skin as a chemical barrier:** secretions from sebaceous and sweat glands contain fatty acids and lactic acid, making the skin surface acidic, and contain antimicrobial chemicals that inhibit the growth of many bacteria and fungi.
- **Mucous membranes** line the airways, gut, urinary and reproductive tracts. They are thinner than skin but secrete sticky mucus that traps pathogens. In the airways, cilia sweep mucus up to the throat to be swallowed. Mucus, tears and saliva contain lysozyme, an enzyme that digests bacterial cell walls.

Sealing of cuts by blood clotting

A cut in the skin breaks the primary barrier, so it must be sealed quickly. **Blood clotting** does this.

1. Platelets at the site of the cut release clotting factors.
2. The clotting factors start a cascade pathway: a series of reactions, each activating the next, which amplifies the signal.
3. The cascade produces active **thrombin**, an enzyme.
4. Thrombin rapidly converts soluble fibrinogen (a plasma protein) into insoluble **fibrin**.
5. Fibrin forms a mesh of fibres that traps erythrocytes, forming a clot that seals the cut.



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Blood clotting: a cascade produces **thrombin**, which converts soluble fibrinogen into insoluble fibrin.

Exam tip: Students are not required to draw or label diagrams of skin, and no further clotting details beyond platelets, clotting factors, the cascade, thrombin, fibrinogen, fibrin and trapped erythrocytes are required.

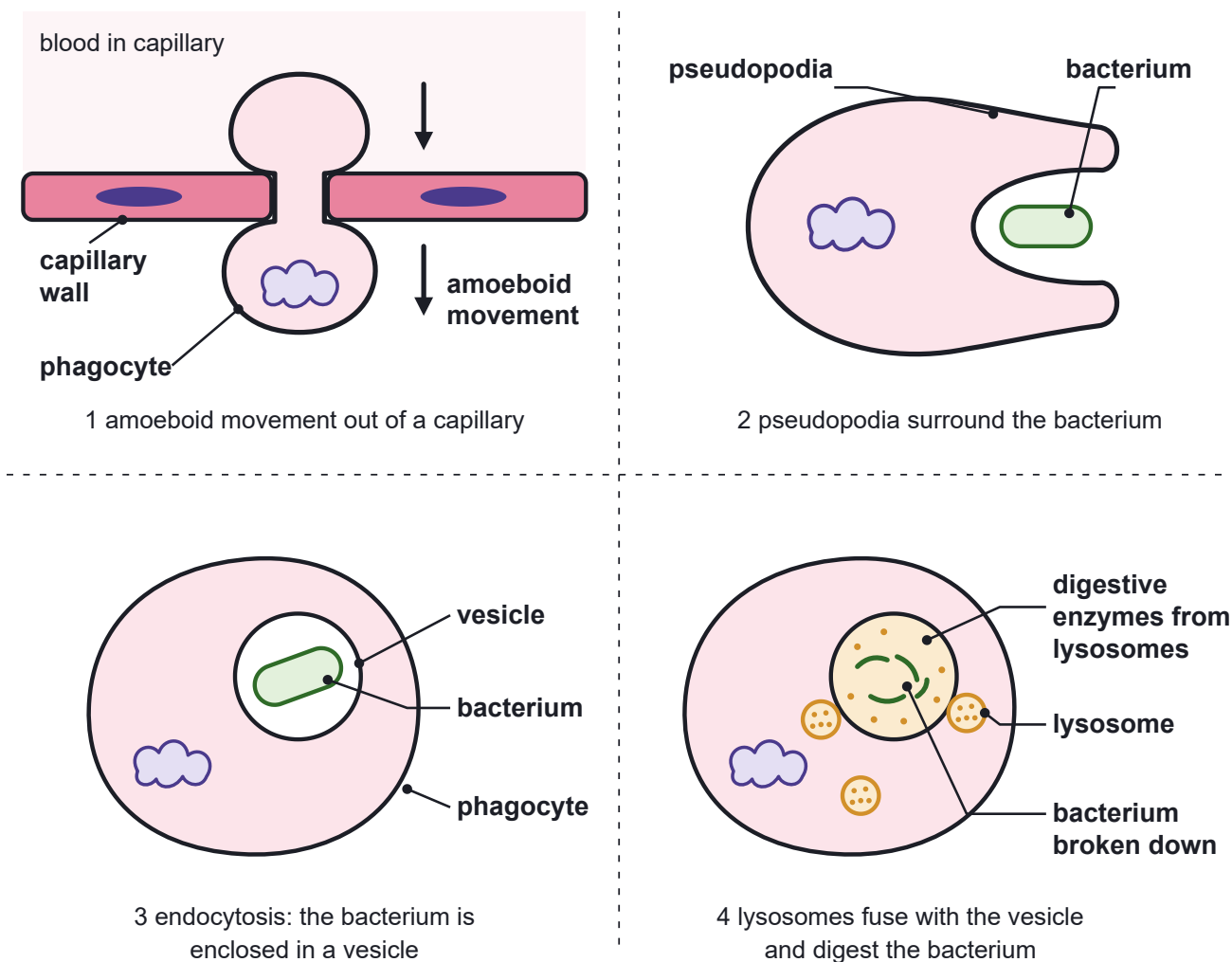
Innate and adaptive immunity, and phagocytes Spec C3.2.4, C3.2.5

Innate and adaptive immune systems		
Feature	Innate immune system	Adaptive immune system
What it responds to	Broad categories of pathogen	Particular pathogens, in a specific way
Change during life	Does not change during an organism's life	Builds up a memory of pathogens encountered
Effect of a second infection	Same response as the first time	Response becomes faster and more effective
Cells	Phagocytes	Lymphocytes (B-cells and T-cells)

Both systems work together: the innate system responds immediately to any infection, while the adaptive system takes longer the first time but produces a targeted response with long-term **memory**.

Infection control by phagocytes

1. Phagocytes circulate in the blood. At a site of infection they squeeze out of capillaries through gaps between the wall cells by **amoeboid movement**.
2. They move through the tissue to the pathogens and recognize them as foreign.
3. The phagocyte engulfs the pathogen by **endocytosis**, enclosing it in a vesicle.
4. Lysosomes fuse with the vesicle and release enzymes that digest the pathogen.



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Phagocytosis: **amoeboid movement**, engulfing by **endocytosis**, then digestion by enzymes from **lysosomes**.

Exam tip: Phagocytes are the only components of the innate immune system you need to know. Use the words **amoeboid movement**, **endocytosis** and **lysosomes** in answers.

Lymphocytes, antigens and antibody production Spec C3.2.6, C3.2.7, C3.2.8, C3.2.9

Lymphocytes

Lymphocytes are the cells of the adaptive immune system. They both circulate in the blood and are contained in lymph nodes. An individual has a very large number of different **B-lymphocytes** (B-cells), each able to make one specific type of antibody. Lymphocytes cooperate to produce antibodies.

Antigens

An **antigen** is a recognition molecule that triggers antibody production. Most antigens are glycoproteins or other proteins, usually located on the outer surfaces of pathogens. Each antibody has a binding site with a shape complementary to one antigen.

Antigens on the surface of erythrocytes (for example the A and B antigens of the ABO blood groups) may stimulate antibody production if transfused into a person with a different blood group. For example, a Rhesus-negative person given Rhesus-positive blood makes antibodies against the Rhesus (D) antigen. In the ABO system, a person already has antibodies against the A or B antigen they lack (a person with group A has anti-B), so a mismatched transfusion makes the donated erythrocytes clump (agglutinate).

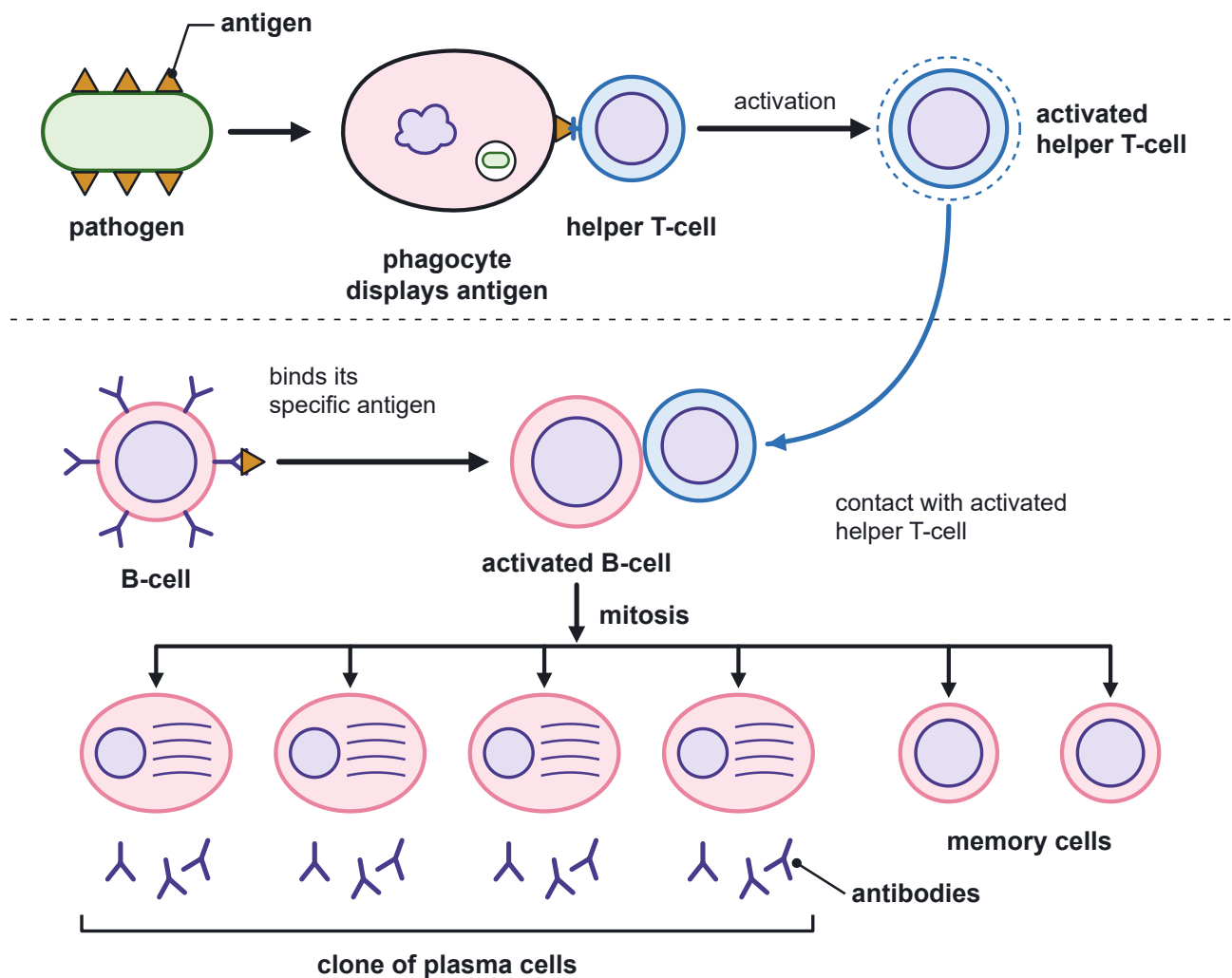
Activation of B-lymphocytes

There are antigen-specific B-cells and antigen-specific **helper T-cells**. B-cells produce antibodies and become memory cells only when they have been activated. Activation requires both:

- direct interaction of the B-cell with its specific antigen, and
- contact with a **helper T-cell** that has also become activated by the same type of antigen (helper T-cells are activated when they bind the antigen, for example displayed on the surface of a phagocyte that has engulfed the pathogen).

Clones of plasma cells

Only a relatively small number of B-cells respond to a specific antigen. To produce sufficient quantities of antibody, activated B-cells first divide by **mitosis** to produce large numbers of **plasma B-cells** (plasma cells), all capable of producing the same type of antibody. This group of identical cells is a **clone**. Plasma cells have extensive rough endoplasmic reticulum and secrete antibodies into the blood.



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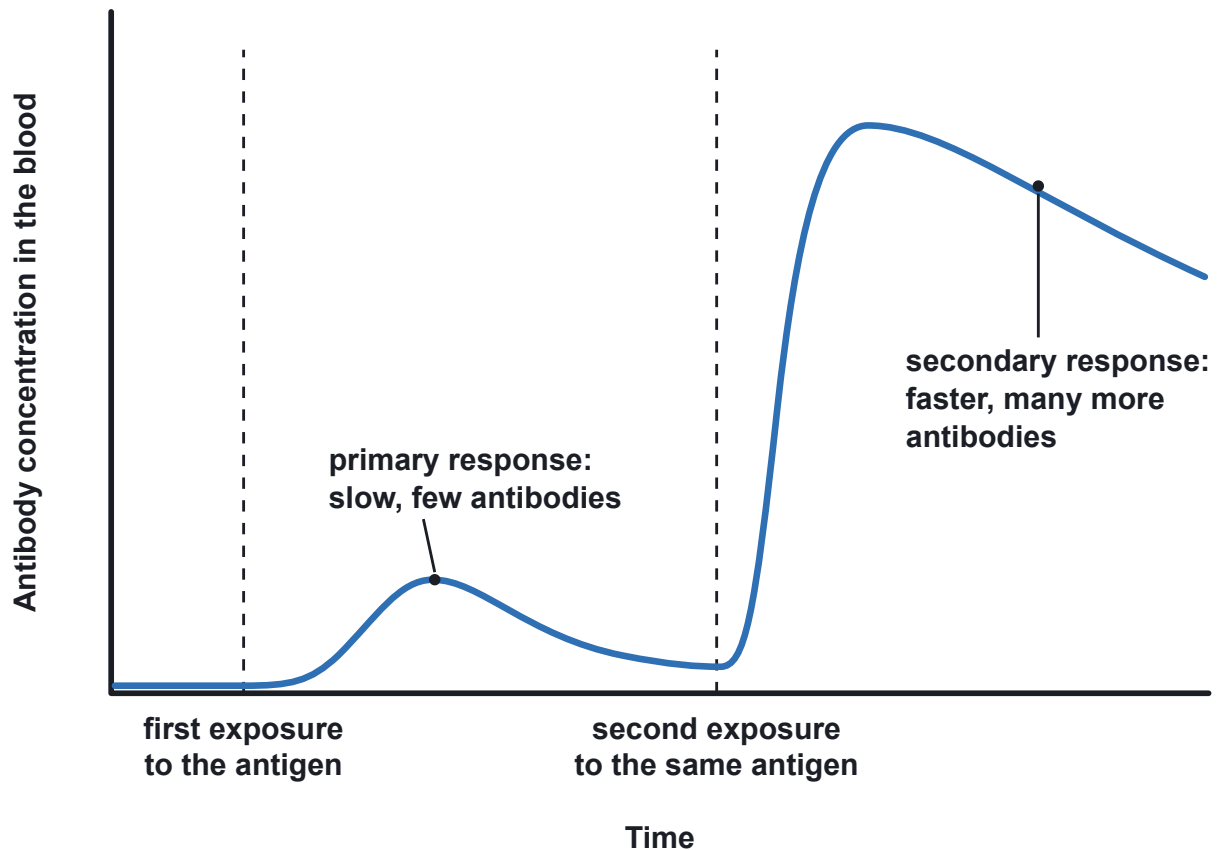
A B-cell is activated by its **specific antigen** and by contact with an **activated helper T-cell**, then divides by mitosis into a clone of plasma cells and memory cells.

Common mistake: Antibodies are made by plasma cells, not by helper T-cells or phagocytes. Helper T-cells activate B-cells but do not make antibodies.

Immunity, vaccines and herd immunity Spec C3.2.10, C3.2.16, C3.2.17

Immunity and memory cells

Immunity is the ability to eliminate an infectious disease from the body. It is due to the long-term survival of lymphocytes capable of making the specific antibodies needed to fight the infection: these are **memory cells**. On a second infection by the same pathogen, memory cells are activated quickly and divide to form plasma cells, so antibodies are produced faster and in greater quantities. The pathogen is usually eliminated before symptoms develop.



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The secondary response is faster and larger because **memory cells** survive from the first exposure.

Vaccines and immunization

A **vaccine** contains antigens, or nucleic acids (DNA or RNA) with sequences that code for antigens. Antigens may be on killed or weakened pathogens, or be purified pathogen proteins. With an mRNA vaccine, the person's own cells use the RNA to make the antigen. Either way, the vaccine stimulates a primary immune response and the development of memory cells, so the person gains immunity to a specific pathogen **without causing the disease**. Immunization is the process of making a person immune, usually by vaccination.

Herd immunity

Members of a population are interdependent in building **herd immunity**. If a sufficient percentage of a population is immune to a disease, an infected person is unlikely to meet a susceptible person, so transmission is greatly impeded and epidemics are prevented. This protects people who cannot be vaccinated, such as newborn babies or people with weakened immune systems. The more transmissible the pathogen, the higher the percentage that must be immune.

Exam tip: Nature of science: vaccines are tested rigorously and the risks of side effects are minimal but not nil. The media often report research while evaluation by other scientists is still happening, so distinguish pragmatic truths from certainty.

HIV transmission and AIDS Spec C3.2.11, C3.2.12

Transmission of HIV in body fluids

HIV does not survive long outside the body, so it is transmitted in **body fluids** that pass directly from one person into another's blood or mucous membranes. Mechanisms of transmission include:

- unprotected sexual intercourse (semen and vaginal fluids)
- sharing hypodermic needles between intravenous drug users (blood)
- transfusion of blood or blood products that have not been screened for HIV
- from mother to baby across the placenta, during childbirth or in breast milk

Infection of lymphocytes and AIDS

HIV infects only certain types of lymphocyte, mainly **helper T-cells**, which it enters and eventually kills. Over several years, the number of helper T-cells falls. Because B-cells need contact with activated helper T-cells to be activated, the reduction in these lymphocytes **limits the ability to produce antibodies**.

The person can no longer fight **opportunistic infections**: infections by pathogens that a healthy immune system would normally control, such as tuberculosis and pneumonia. This condition is AIDS (acquired immunodeficiency syndrome).

Common mistake: HIV does not infect all lymphocytes or directly destroy B-cells. Say it kills helper T-cells, so fewer B-cells are activated and fewer antibodies are made.

Antibiotics and antibiotic resistance Spec C3.2.13, C3.2.14

How antibiotics work

Antibiotics are chemicals that block processes occurring in bacteria but not in eukaryotic cells. Because these processes or structures differ between prokaryotes and eukaryotes, antibiotics can be used to treat bacterial infections without harming the patient's cells.

Examples of bacterial targets	
Process in bacteria	Why human cells are unaffected
Synthesis of the bacterial cell wall (for example blocked by penicillin)	Animal cells have no cell wall
Protein synthesis by 70S ribosomes	Human cytoplasmic ribosomes are 80S, with a different structure
Other bacterial enzymes, for example in DNA replication	Eukaryotic enzymes have different structures

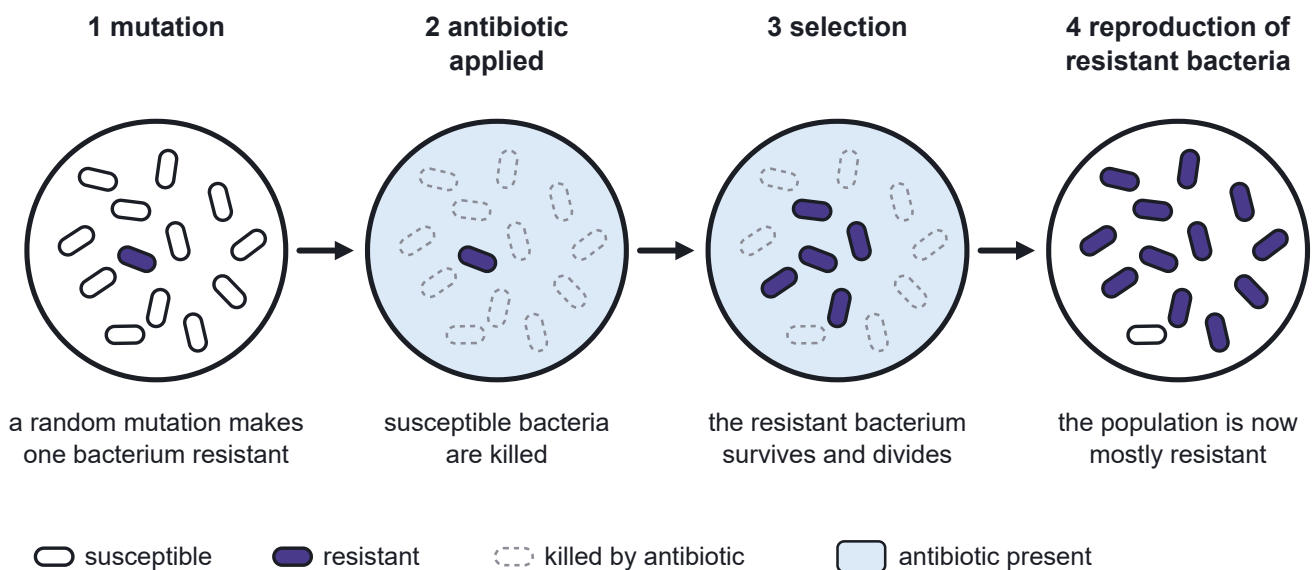
Why antibiotics fail against viruses

- Viruses have **no metabolism of their own**: they have no cell wall, no ribosomes and no enzymes for respiration or protein synthesis for antibiotics to block.
- Viruses use the host cell's own processes to replicate, and blocking these would harm the host's cells.

Evolution of resistance

1. A random mutation gives a bacterium a gene for resistance to an antibiotic, or the gene is gained from another bacterium on a plasmid.
2. When the antibiotic is used, susceptible bacteria are killed but resistant bacteria survive: **natural selection**.
3. Resistant bacteria reproduce rapidly by binary fission, passing on the resistance gene.
4. Repeated use of different antibiotics selects strains with resistance to several antibiotics: multiresistant bacteria.

Careful use of antibiotics is necessary to slow the emergence of multiresistant bacteria: prescribing them only for bacterial infections, completing the prescribed course, avoiding routine use in livestock, and good hygiene in hospitals to stop resistant strains spreading.



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Evolution of antibiotic resistance by **natural selection**: mutation, antibiotic applied, selection, reproduction of resistant bacteria.

Exam tip: Nature of science: new techniques open new avenues of research. Searching chemical libraries (large collections of compounds) is now yielding new antibiotics.

Zoonoses and evaluating COVID-19 data Spec C3.2.15, C3.2.18

Zoonoses

Zoonoses are infectious diseases that can transfer from other species to humans. Many human infectious diseases are zoonoses, and their modes of infection are varied.

Examples of zoonoses		
Disease	Pathogen	Mode of infection
Tuberculosis (bovine)	Bacterium (Mycobacterium bovis)	From cattle, through drinking unpasteurized milk or breathing in droplets from infected animals. Most human tuberculosis is now spread from person to person by a related species, Mycobacterium tuberculosis.
Rabies	Virus	Through a bite from an infected mammal, such as a dog or bat, as the virus is in the saliva
Japanese encephalitis	Virus	Through the bite of a mosquito that has fed on infected pigs or wading birds
COVID-19	Virus (SARS-CoV-2, a coronavirus)	Its closest known relatives are coronaviruses found in horseshoe bats. Most evidence points to spillover from animals, possibly through an intermediate host, but the exact route into humans has not been confirmed. It now spreads between humans in respiratory droplets and aerosols.

COVID-19 is an infectious disease that has **recently transferred from another species**, with profound consequences for humans: millions of deaths worldwide, overwhelmed health services, and major social and economic disruption. The IB guide treats it as a zoonosis; how the virus first reached people is still being investigated, so avoid stating a single proven source in answers.

Evaluating COVID-19 data

Pandemic data (cases, hospital admissions, deaths, vaccination rates) are often compared over time or between groups. Two calculations are used:

$$\text{percentage change} = (\text{final value} - \text{initial value}) \div \text{initial value} \times 100$$

$$\text{percentage difference} = |\text{value A} - \text{value B}| \div ((\text{value A} + \text{value B}) \div 2) \times 100$$

Maths skill: Percentage change compares one quantity at two times, so it has a starting value to divide by and a sign (+ for an increase, – for a decrease). Percentage difference compares two values where neither is the starting point, for example two groups or two countries at the same time, so you divide by the mean of the two and the answer is always positive. If a question says 'relative to' one value, divide by that value instead and say so.

Percentage change and percentage difference

Practice data: in one city, weekly COVID-19 hospital admissions fell from 250 to 90 over two months. In the final week, the admission rate was 12 per 100 000 among unvaccinated adults and 3 per 100 000 among vaccinated adults. Calculate the percentage change in admissions, and the percentage difference between the admission rates of the two groups.

1. Percentage change = $(90 - 250) \div 250 \times 100$
2. = $-160 \div 250 \times 100 = -64\%$
3. Mean of the two rates = $(12 + 3) \div 2 = 7.5$ per 100 000
4. Percentage difference = $|12 - 3| \div 7.5 \times 100 = 9 \div 7.5 \times 100 = 120\%$
5. Relative to unvaccinated adults only: $(3 - 12) \div 12 \times 100 = -75\%$

Answer: Admissions fell by 64%. The percentage difference between the two admission rates is 120%; put another way, the rate in vaccinated adults was 75% lower than in unvaccinated adults.

Exam tip: When evaluating pandemic data, consider sample size, how cases were tested and recorded, whether the groups differ in age or health, and that correlation does not prove causation. Linking question: false-positive and false-negative test results can distort case numbers.

Quick check

1. Which four groups of organism is the term pathogen usually reserved for?
2. Which enzyme converts fibrinogen into fibrin?
3. What two things are needed to activate a B-lymphocyte?
4. Why do antibiotics not work against viruses?
5. Name three zoonoses given in the IB guide besides COVID-19.

Quick check answers

Integration of body systems

1. A property of the whole organism that arises from integration of its parts; a cheetah becomes an effective predator through integration of its body systems.
2. The spinal cord.
3. In the walls of the aorta (aortic arch) and the carotid arteries.
4. The pineal gland; secretion is highest at night, in darkness.
5. It promotes H^+ secretion into the cell wall; the acidified wall has loosened cross links between cellulose molecules, so the cell can elongate.

Defence against disease

1. Viruses, bacteria, fungi and protists.
2. Thrombin.
3. Direct interaction with its specific antigen, and contact with a helper T-cell activated by the same antigen.
4. Viruses have no metabolism of their own, so there are no bacterial processes to block; they use the host cell's processes.
5. Tuberculosis, rabies and Japanese encephalitis.