

Coordination, Response and Gene Technology

revision notes

Coordination, Response and Gene Technology is topic 8 of Pearson Edexcel International A Level Biology (YBI11) and is examined in Unit 5. It covers how neurones, synapses, receptors, hormones and plant growth substances coordinate responses, the structure and imaging of the brain, and how recombinant DNA, microarrays and genetically modified organisms are used. It is A Level only content (IA2).

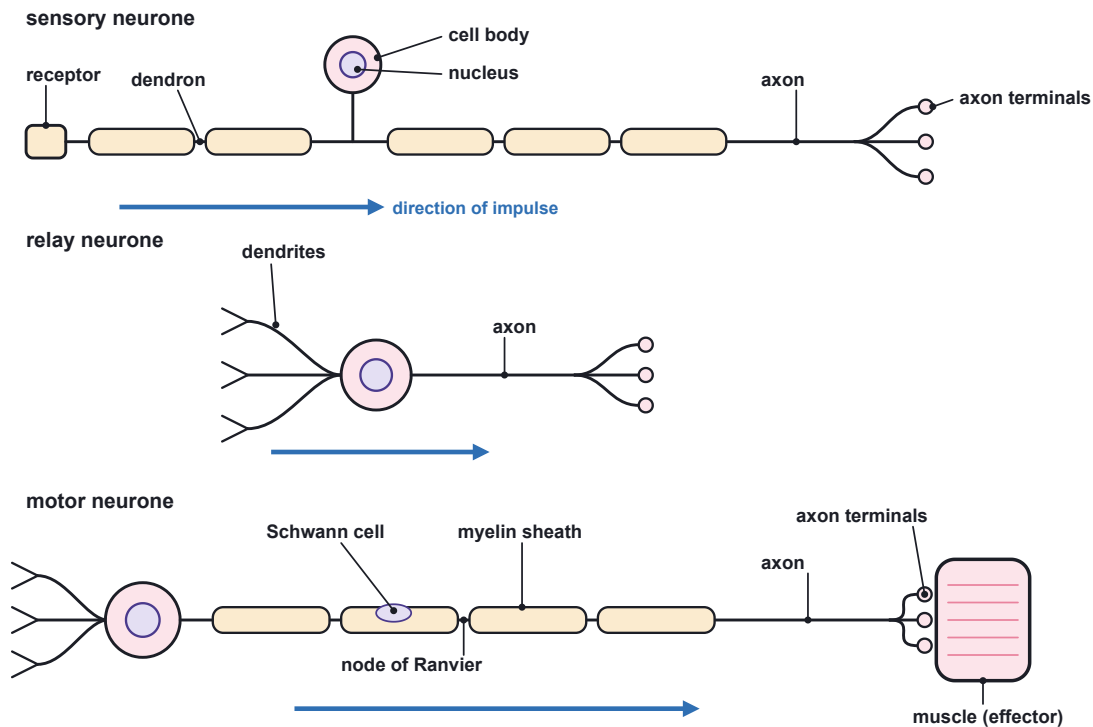
For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

1 Neurones, reflexes and the nervous system **Spec 8.1-8.3, 8.10** **A Level only**

Sensory, relay and motor neurones **Spec 8.1**

A **neurone** is a nerve cell specialised to conduct **nerve impulses** (action potentials) as rapid electrical signals. Each has a **cell body** containing the nucleus and organelles, extensions called **dendrites** or a **dendron** that carry impulses towards the cell body, and a long **axon** that carries impulses away from it. There are three types, which differ in structure because their jobs and positions in a pathway differ.

Sensory, relay and motor neurones compared			
Feature	Sensory neurone	Relay neurone	Motor neurone
Function	Carries impulses from a receptor to the central nervous system (CNS)	Carries impulses between sensory and motor neurones, entirely inside the CNS	Carries impulses from the CNS to an effector (a muscle or gland)
Position of cell body	Just outside the spinal cord, in a swelling of the dorsal root called the dorsal root ganglion; the cell body sits to one side of the long fibre	Inside the CNS, in the grey matter	Inside the CNS, in the grey matter; the cell body is at the start of the neurone
Dendrites and axon	One long dendron brings impulses from the receptor to the cell body; a shorter axon takes them into the CNS	Many short processes, with numerous dendrites and a short axon, giving many synapses	Many short dendrites on the cell body; one very long axon runs out to the effector
Myelin	Axon and dendron usually myelinated	Often unmyelinated or with a thin sheath because the distances are short	Axon usually myelinated, allowing fast conduction over a long distance



The **sensory, relay and motor neurones** of a reflex pathway; arrows show the direction of the impulse.

Schwann cells are glial cells that wrap their plasma membrane many times around an axon in the peripheral nervous system. The layers of membrane are rich in lipid, and together they form the **myelin sheath**. Myelin is an electrical insulator: ions cannot cross it. The sheath is interrupted by small gaps, about 1 mm apart, called **nodes of Ranvier**, where the axon membrane is exposed. Schwann cells also support the axon and help to repair it if it is damaged.

Exam tip: Describe the structure and the function for each neurone. A common mark is for the position of the cell body: sensory cell body in the dorsal root ganglion, relay and motor cell bodies in the grey matter of the CNS.

The nervous system and its effectors Spec 8.2, 8.10

The mammalian **nervous system** has two parts. The **central nervous system (CNS)** is the brain and spinal cord. The **peripheral nervous system (PNS)** is all the neurones outside the CNS: the cranial and spinal nerves that connect the CNS to receptors and effectors. The PNS contains sensory neurones, which bring information into the CNS, and motor neurones, which carry instructions out.

Parts of the mammalian nervous system		
Part	Made up of	Role
Central nervous system (CNS)	Brain and spinal cord	Receives and processes information, then sends out impulses; the coordinator
Peripheral nervous system (PNS)	Sensory and motor neurones in nerves outside the brain and spinal cord	Links receptors to the CNS and the CNS to effectors

Nervous systems allow an organism to respond to a **stimulus**, a change in the internal or external environment. The response follows a fixed sequence:

1. A **receptor** detects the stimulus and converts its energy into electrical energy, producing a nerve impulse.
2. A **sensory neurone** carries the impulse to the CNS.

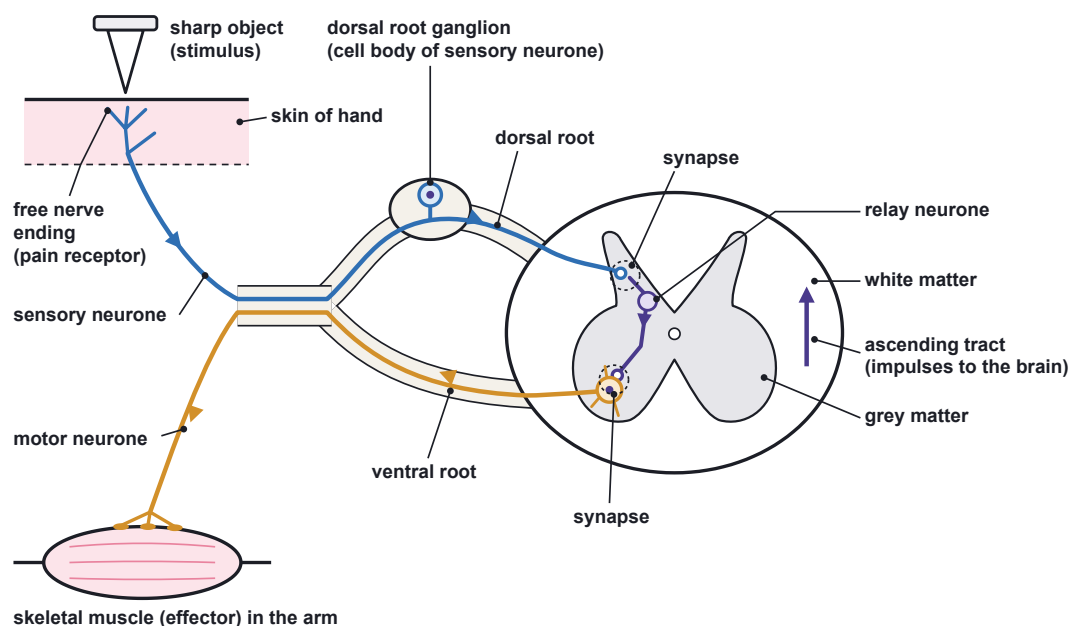
3. The CNS acts as the **coordinator**: relay neurones pass the impulse on and, in the brain, the information is processed.
4. A **motor neurone** carries impulses from the CNS to an **effector**.
5. The effector responds: a muscle contracts or a gland secretes.

Common mistake: The effector is the muscle or gland, not the motor neurone. The spinal cord is part of the CNS, but the nerves leaving it belong to the PNS.

The spinal reflex arc Spec 8.3

A **reflex** is a rapid, automatic response to a stimulus that does not involve conscious thought. The pathway is a **reflex arc**. In a **spinal reflex arc** the neurones pass through the spinal cord, so the response does not wait for the brain. This makes it fast, which is protective: for example, the withdrawal of a hand from a hot object.

In cross-section the spinal cord has an inner, butterfly-shaped region of **grey matter** surrounded by **white matter**. Grey matter contains the cell bodies of relay and motor neurones and many synapses. White matter looks pale because it consists of the myelinated axons of neurones, which run up and down the cord carrying impulses to and from the brain. A fluid-filled central canal runs through the middle.



A **reflex arc** through the spinal cord: receptor, sensory neurone, relay neurone, motor neurone, effector.

Adapted from an IB-style diagram drawn for this site.

1. A receptor (for example a pain receptor in the skin) detects a stimulus and generates an impulse.
2. The impulse passes along a sensory neurone, whose cell body lies in the dorsal root ganglion, into the spinal cord by the dorsal root.
3. In the grey matter the sensory neurone synapses with a relay neurone.
4. The relay neurone synapses with a motor neurone.
5. The motor neurone carries the impulse out by the ventral root to an effector (a muscle), which contracts to withdraw the limb.

At the same time, relay neurones pass impulses up the white matter to the brain, so you become aware of the stimulus after the response has begun. The brain can also send impulses down the cord to override some reflexes.

Exam tip: Link structure to function in a reflex: few synapses and a short pathway mean a faster response, and the response is automatic so it protects the body before pain is felt.

Quick check

1. Where is the cell body of a sensory neurone found?
2. What is myelin made from?
3. Name the two parts of the mammalian nervous system.
4. What does the white matter of the spinal cord contain?

2 Impulses, synapses and receptors

Spec 8.4-8.9

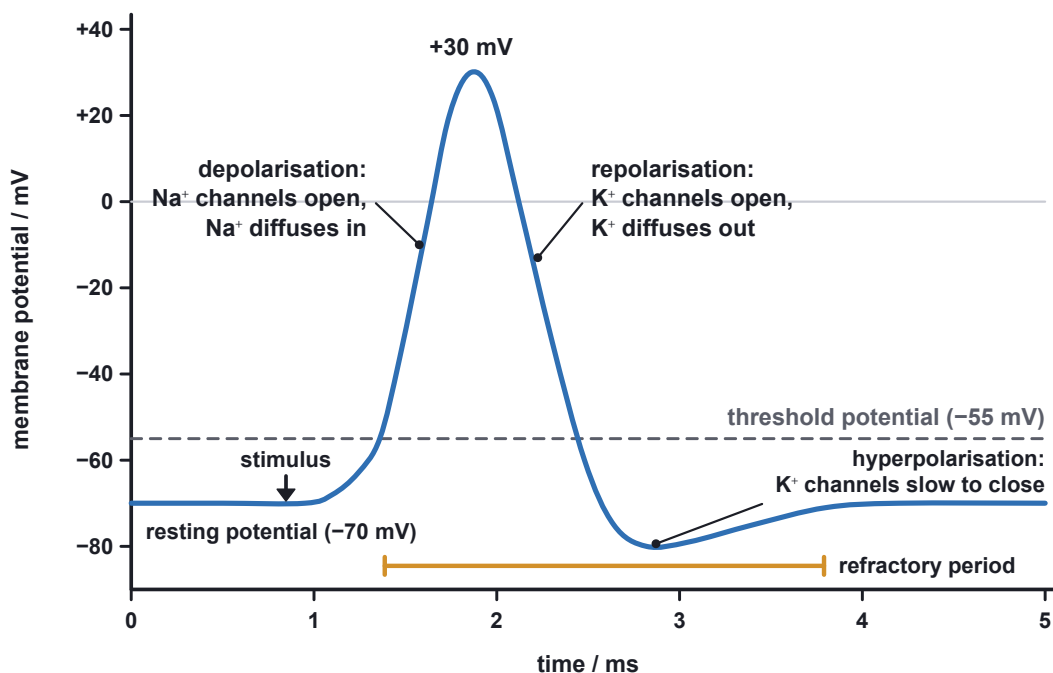
A Level only

Resting potential and action potentials Spec 8.4

At rest, the inside of an axon is negative relative to the outside. This **resting potential** is about -70 mV. It is set up by the **sodium-potassium pump**, which uses ATP to move 3 Na^+ out of the axon for every 2 K^+ moved in, and by **potassium ion channels** that leak K^+ out far more easily than Na^+ can leak in. The membrane is said to be **polarised**.

A stimulus that is strong enough opens some **voltage-gated sodium ion channels**. When the membrane potential reaches the **threshold** (about -55 mV), many more open. This is an **all-or-nothing** response: below threshold nothing happens, and above it every action potential has the same size.

1. **Depolarisation**: voltage-gated Na^+ channels open, so Na^+ diffuses in down its electrochemical gradient. The inside becomes positive, reaching about $+40$ mV.
2. At the peak the Na^+ channels close (they are inactivated) and voltage-gated **K^+ channels** open.
3. **Repolarisation**: K^+ diffuses out of the axon, so the inside becomes negative again.
4. **Hyperpolarisation**: the K^+ channels are slow to close, so the potential briefly falls below -70 mV. The K^+ channels then close and the sodium-potassium pump and K^+ leak channels restore the resting potential.



An **action potential**: depolarisation as Na^+ channels open, repolarisation as K^+ channels open, then hyperpolarisation.

During and just after an action potential the Na^+ channels are inactivated, so the region cannot respond to another stimulus. This **refractory period** means impulses travel in one direction only, do not overlap, and are separate events. The frequency of impulses, not their size, carries information about stimulus strength.

An action potential travels along the axon by **local circuits**. Na^+ entering one region diffuses sideways inside the axon, depolarising the next region to threshold, so its Na^+ channels open. The region behind is refractory, so the impulse moves forward.

Exam tip: Use the terms 'voltage-gated', 'down an electrochemical gradient' and 'permeability'. State which ion moves, in which direction, through which channel, and what happens to the potential.

Myelination and saltatory conduction Spec 8.5

In an unmyelinated axon the action potential must be regenerated at every point along the membrane, so conduction is slow (about 0.5 to 2 m s^{-1}). In a myelinated axon, the myelin sheath is an insulator, so ions can enter and leave only at the **nodes of Ranvier**. The voltage-gated Na^+ and K^+ channels are concentrated at the nodes.

1. An action potential at one node makes Na^+ enter and depolarise the node.
2. Local circuits carry the positive charge along inside the axon, through the myelinated section, to the next node.
3. The next node reaches threshold and an action potential forms there.
4. The impulse appears to **jump** from node to node. This is **saltatory conduction** (Latin saltare, to leap).

Because depolarisation occurs only at the nodes, conduction can reach about 100 m s^{-1} . Fewer ion channels need to open and fewer ions move, so less ATP is needed for the sodium-potassium pumps to restore the resting potential.

Common mistake: The impulse does not travel through the myelin. The action potential is generated at the nodes, and local circuits carry the depolarisation between them.

Conduction velocity

An impulse travels 0.45 m along a myelinated motor axon in 5.0 ms . Calculate the speed of conduction in m s^{-1} .

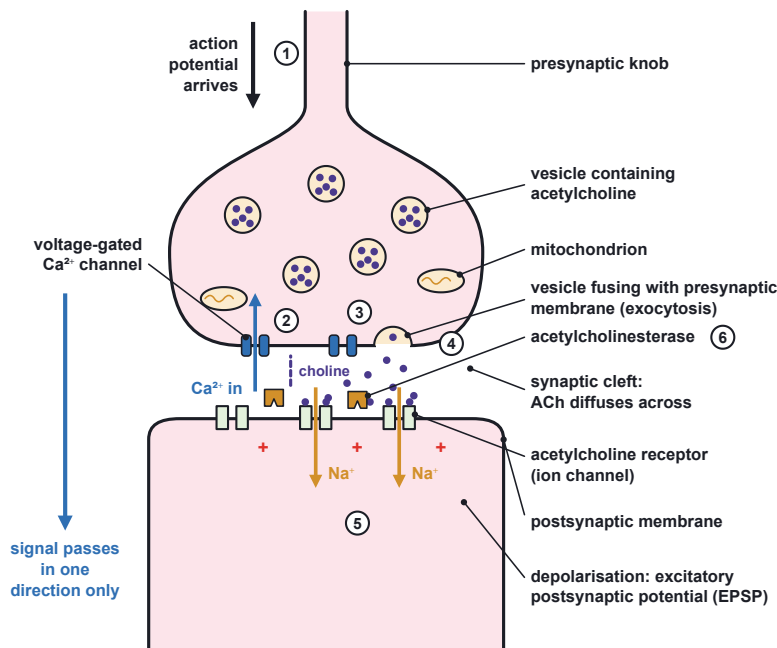
1. Convert time: $5.0 \text{ ms} = 5.0 \times 10^{-3} \text{ s}$
2. speed = distance $\div$ time = $0.45 \div 5.0 \times 10^{-3}$

Answer: 90 m s^{-1}

Maths skill: Convert to SI units before dividing: milliseconds to seconds, millimetres to metres.

Synapses and neurotransmitters Spec 8.6

A **synapse** is the junction between two neurones. A narrow gap of about 20 nm , the **synaptic cleft**, separates the **presynaptic knob** from the **postsynaptic membrane**. Impulses cannot cross the gap, so a chemical, a **neurotransmitter**, carries the signal. At a **cholinergic synapse** the neurotransmitter is **acetylcholine (ACh)**.



- ① action potential arrives and depolarises the presynaptic membrane
- ② voltage-gated Ca^{2+} channels open and Ca^{2+} diffuses into the knob
- ③ vesicles fuse with the presynaptic membrane and release ACh by exocytosis
- ④ ACh diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane
- ⑤ Na^{+} channels open and Na^{+} enters, depolarising the postsynaptic membrane; if the threshold is reached an action potential starts
- ⑥ acetylcholinesterase breaks ACh down into choline and ethanoic acid; choline is taken back into the knob and ACh is remade using ATP from the mitochondria

Transmission across a **cholinergic synapse**, in six numbered steps.

1. An action potential arrives at the presynaptic knob and opens voltage-gated **Ca^{2+} channels**. Ca^{2+} enters by facilitated diffusion.
2. Ca^{2+} makes vesicles containing ACh move to and fuse with the presynaptic membrane. ACh is released by **exocytosis**.
3. ACh diffuses across the synaptic cleft and binds to **receptors** on the postsynaptic membrane.
4. The receptors are linked to Na^{+} channels, which open. Na^{+} enters the postsynaptic neurone, so the membrane is depolarised.
5. If depolarisation reaches threshold, an action potential is set off in the postsynaptic neurone.
6. The enzyme **acetylcholinesterase** in the cleft hydrolyses ACh to choline and ethanoate (acetate), so the response stops. Choline is taken back into the presynaptic knob and used, with ATP from the mitochondria, to resynthesise ACh.

Synapses ensure **one-way transmission** because only the presynaptic knob has vesicles and only the postsynaptic membrane has receptors. A single impulse may not release enough ACh to reach threshold in the next neurone, so a synapse controls which signals are passed on.

Acetylcholine is one of many **neurotransmitters**; others include noradrenaline, dopamine and serotonin. Each binds only to receptors with a complementary shape. At an **excitatory synapse** the transmitter opens Na^{+} channels and depolarises the postsynaptic membrane. At an **inhibitory synapse** the transmitter (for example GABA) opens channels that make the postsynaptic membrane more negative (hyperpolarised), so an action potential is less likely. Whether the postsynaptic neurone fires depends on the combined effect of all the transmitter released onto it, from several synapses at once (spatial summation) or from impulses arriving in quick succession at one synapse (temporal summation).

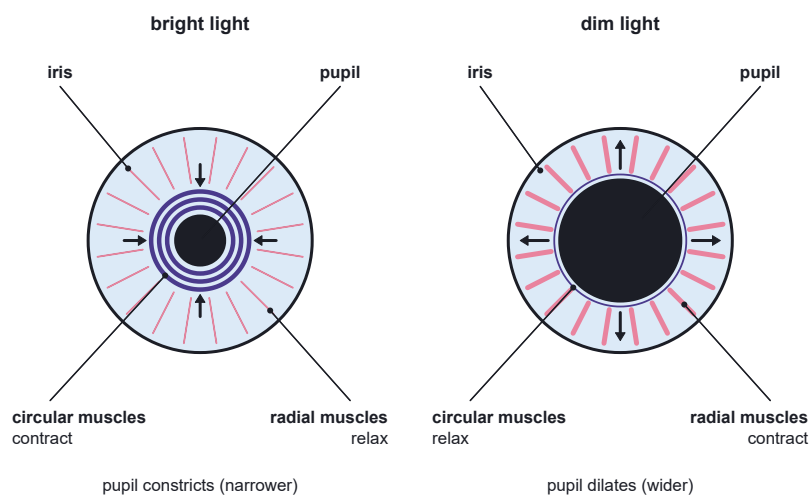
Exam tip: Name the ion (Ca^{2+} entering the presynaptic knob, Na^{+} entering the postsynaptic neurone), the process (exocytosis, diffusion) and the enzyme that breaks down ACh. Each is a mark.

How the pupil dilates and constricts Spec 8.6

The **iris** contains two sets of muscle that act as effectors, controlling the size of the **pupil** and so how much light reaches the retina. They are **antagonistic muscles**: when one contracts the other relaxes.

Pupil responses		
	Bright light	Dim light
Circular muscles	Contract	Relax
Radial muscles	Relax	Contract
Pupil	Constricts (gets smaller)	Dilates (gets larger)
Purpose	Protects the retina (the light receptors) from damage by intense light	Lets more light reach the retina so rods can detect it
Control	Parasympathetic neurones release acetylcholine onto the circular muscles	Sympathetic neurones release noradrenaline onto the radial muscles

The pupil constriction in bright light is a reflex. Light receptors in the retina send impulses along the optic nerve to the brain, and motor neurones carry impulses to the muscles of the iris. This is rapid and automatic, so it protects the retina.



In bright light the **circular muscles contract** and the pupil constricts; in dim light the **radial muscles contract** and it dilates.

Common mistake: Do not say that the iris 'opens and closes'. The pupil is the hole; the muscles in the iris change its size.

Drugs and nerve impulse transmission Spec 8.7

A drug can stimulate (an **agonist**), block (an **antagonist**) or alter the amount of neurotransmitter, so it changes transmission of impulses along axons or across synapses.

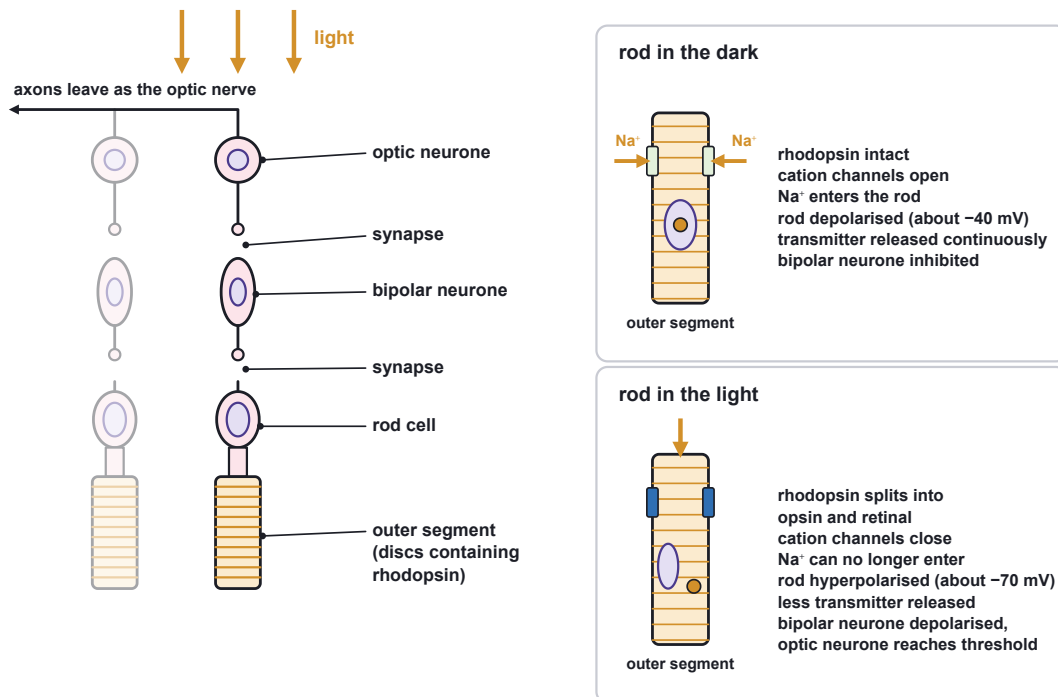
Drugs that affect nerve impulse transmission		
Drug	Action	Effect
Nicotine	Binds to acetylcholine receptors and mimics ACh, so Na ⁺ channels open and the postsynaptic neurone is depolarised. It is not broken down by acetylcholinesterase, so stimulation lasts longer.	Stimulates nerve impulses: raises heart rate and blood pressure; in the brain it also triggers release of dopamine, which contributes to addiction
Lidocaine	A local anaesthetic that blocks voltage-gated Na ⁺ channels in the axon membrane, so no depolarisation occurs and action potentials are not conducted.	Impulses from pain receptors do not reach the brain: numbness
Cobra venom alpha toxin	Binds very tightly (almost irreversibly) to acetylcholine receptors on the postsynaptic membrane, so ACh cannot bind and Na ⁺ channels do not open.	No depolarisation of the muscle: paralysis, including breathing muscles
L-DOPA	A precursor of dopamine that crosses the blood-brain barrier and is converted to dopamine in the brain. Dopamine itself cannot cross it.	Replaces dopamine lost in Parkinson's disease, reducing tremor and rigidity
MDMA (ecstasy)	Causes release of serotonin from presynaptic neurones and prevents its reuptake, so more serotonin stays in the synaptic cleft and acts on the postsynaptic membrane for longer.	Raised mood and energy; can cause overheating; serotonin stores become depleted

Exam tip: In a 'suggest how' question, name the target (receptor, channel or reuptake), say whether the drug mimics or blocks, and link it to the effect on depolarisation of the postsynaptic membrane.

Rods, rhodopsin and the optic neurone Spec 8.8

Rod cells in the retina detect light, particularly in dim conditions. Their outer segment contains the pigment **rhodopsin**, made of a protein, **opsin**, bound to **retinal**, a derivative of vitamin A.

In the retina, the rods synapse with bipolar neurones, which in turn synapse with the optic neurones whose axons form the optic nerve. The key point is that light causes hyperpolarisation, not depolarisation, of the rod cell.



Light passes through the **optic neurone** and **bipolar neurone** to the **rod cell**; in the light the rod hyperpolarises.

1. **In the dark:** cation channels in the rod membrane are open, so Na⁺ continuously enters. The rod is partly depolarised (about -40 mV) and releases an inhibitory transmitter (glutamate) onto the bipolar neurone, so the bipolar neurone is hyperpolarised and does not pass a signal on.
2. **In the light:** absorbing light changes retinal from its cis form to its trans form, so rhodopsin breaks down into opsin and retinal (bleaching). Opsin activates a cascade of reactions in the membrane (a fall in cyclic GMP, which normally keeps the channels open), so the cation channels close.
3. Na⁺ can no longer enter, but the sodium-potassium pump keeps removing it and K⁺ continues to leave, so the rod becomes more negative: **hyperpolarisation** (about -70 mV).
4. The hyperpolarised rod releases less inhibitory transmitter, so the bipolar neurone is depolarised and releases transmitter onto an **optic neurone**.
5. The optic neurone reaches threshold and action potentials pass along the optic nerve to the visual cortex of the brain.

Rods are very sensitive because one photon can close many channels. Several rods synapse with one bipolar neurone, which makes rods sensitive in dim light but gives low visual acuity, and they do not distinguish colours.

Common mistake: The rod cell itself does not fire action potentials. The action potentials are formed in the optic neurone, after the bipolar neurone is depolarised.

Habituation Spec 8.9

Habituation is a form of simple learning in which an organism gradually stops responding to a stimulus that is repeated but has no good or bad consequence. For example, a bird stops flying off at a scarecrow, or you stop noticing the sound of a clock.

1. Each repeated stimulus causes fewer voltage-gated Ca²⁺ channels to open in the presynaptic knob.
2. Less Ca²⁺ enters, so fewer vesicles release neurotransmitter.
3. The postsynaptic membrane is less depolarised and the postsynaptic neurone is less likely to reach threshold.
4. The response (for example a muscle contraction) becomes smaller and may stop.

Habituation is useful because it stops an animal wasting energy on irrelevant stimuli and keeps its attention available for new stimuli that may signal food or danger. It differs from fatigue because a different stimulus restores the full response straight away.

Practical skill: Recommended additional practical: investigate habituation to a stimulus. Choose a response that can be scored, for example the withdrawal of a snail's tentacles when touched with a thin rod, or the number of times a stimulus causes a response in set intervals. Repeat the stimulus at a regular interval; record the response each time; control the strength, interval and position of the stimulus and temperature; test a different stimulus at the end to show it is not fatigue. Ethics: use minimal stimulation, handle animals gently and return them to their habitat.

Quick check

1. What is the resting potential of an axon, approximately?
2. Which ion enters the presynaptic knob and causes vesicles to release acetylcholine?
3. What does acetylcholinesterase do?
4. What is saltatory conduction?
5. What happens to a rod cell's membrane potential when light strikes it?

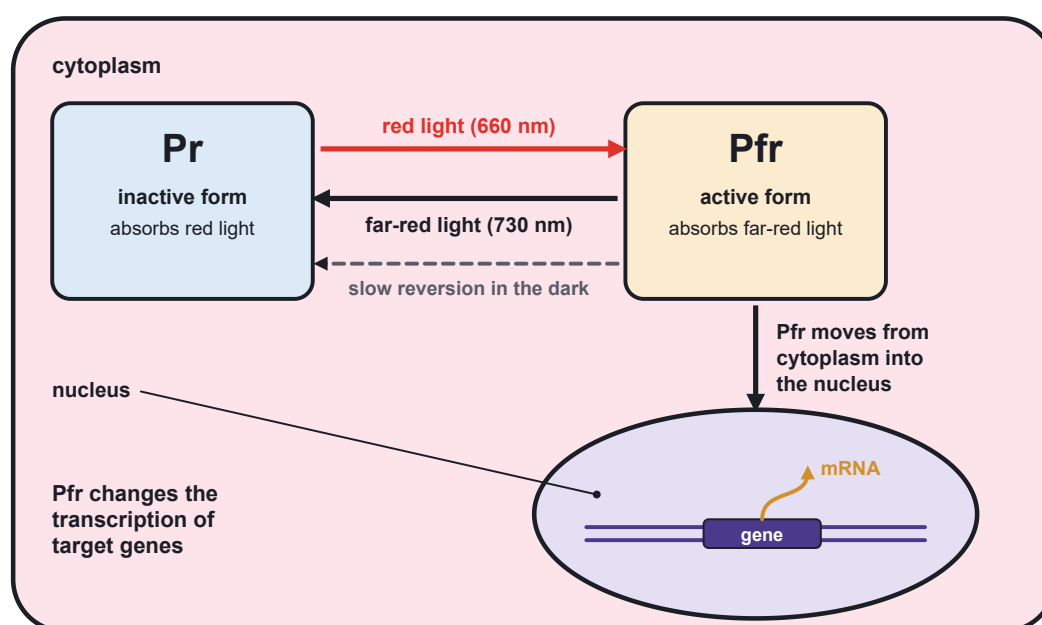
3 Plant responses Spec 8.11, 8.12 A Level only

Phytochrome Spec 8.11

Phytochrome is a pigment protein that allows plants to detect the amount and quality of light, and the length of day and night. It exists in two interconvertible forms:

The two forms of phytochrome			
Form	Absorbs	Converted to	Activity
Pr	Red light (wavelength about 660 nm)	Pfr	Inactive
Pfr	Far-red light (wavelength about 730 nm)	Pr (also slowly in the dark)	Active

In sunlight there is more red than far-red light, so most phytochrome is in the active Pfr form. Under the shade of leaves, which absorb red light, far-red light dominates and Pfr is converted to Pr.



The **phytochrome** cycle between inactive Pr and active Pfr.

Effect on transcription: active Pfr moves from the cytoplasm into the nucleus. There it interacts with **transcription factors**, proteins that control whether RNA polymerase can transcribe particular genes. This switches some genes on and others off, so the plant makes different proteins and the response changes.

- Germination:** in light-requiring seeds, red light and Pfr stimulate germination; far-red light inhibits it, so seeds buried too deep or in shade stay dormant.
- Stem elongation:** in shade, low Pfr lets stems elongate rapidly towards the light; in light, Pfr inhibits elongation, giving short, sturdy shoots with expanded leaves.
- Flowering:** short-day plants flower only when the night is longer than a critical length, and long-day plants only when it is shorter. A flash of red light in the night prevents flowering in a short-day plant, but a following flash of far-red light cancels the effect.

Exam tip: Do not say that Pfr is 'made by' far-red light. Red light converts Pr to Pfr. Link Pfr to transcription factors and gene expression to gain the mark for 'effect on transcription'.

Auxin (IAA) Spec 8.11

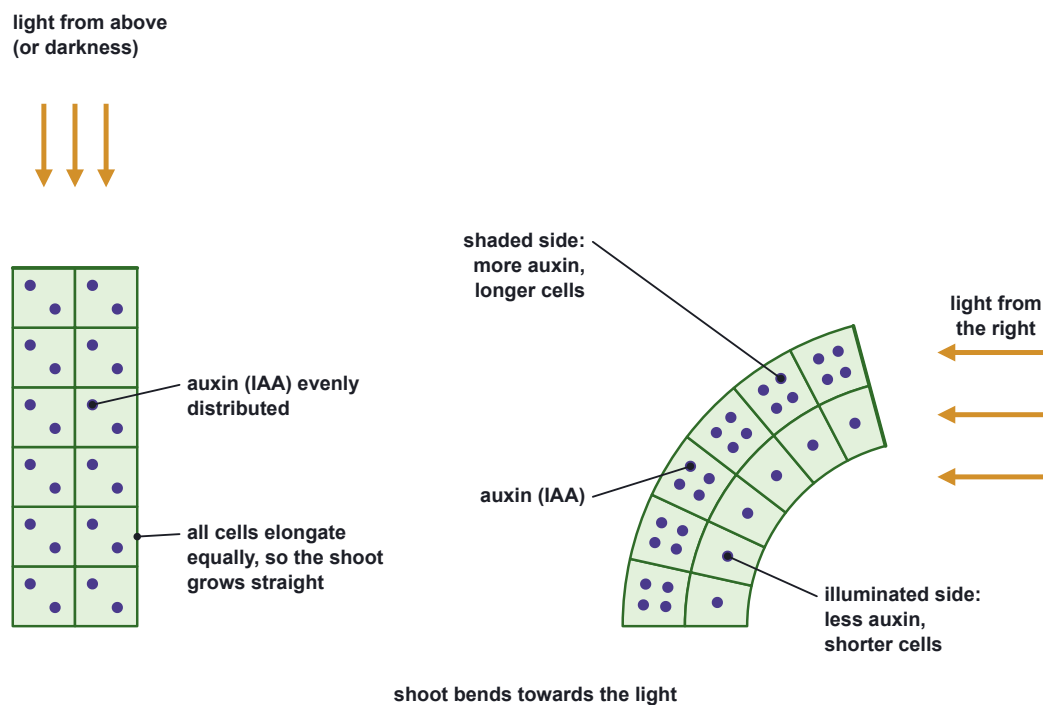
Auxin (IAA, indoleacetic acid) is made in the tip of the shoot and moves to the regions where cells are elongating. It acts on target cells by binding to receptors, which is how it affects **transcription** of genes.

Effect on cell elongation

1. Auxin binds to a receptor in a target cell. This leads to the breakdown of proteins that normally repress genes, so transcription factors are free to switch on genes for elongation.
2. Auxin stimulates the activity of proton pumps (ATPase), which move H^+ from the cytoplasm into the cell wall. The pH of the wall falls (becomes more acidic).
3. The acid conditions activate wall proteins called expansins, which loosen the hydrogen bonds linking cellulose microfibrils to other wall polysaccharides, making the wall more extensible.
4. Water enters the cell by osmosis and turgor pressure pushes the loosened wall outwards, so the cell elongates.

Phototropism and gravitropism

In **phototropism**, light causes auxin to be moved sideways to the shaded side of the shoot by carrier proteins. More auxin on the shaded side means those cells elongate more, so the shoot bends towards the light. In shoots **gravitropism** is negative: auxin accumulates on the lower side so the shoot bends upwards. In roots, the higher concentration of auxin on the lower side inhibits elongation, so the upper side grows faster and the root bends downwards (positive gravitropism).



Phototropism: more auxin on the shaded side, so those cells elongate more and the shoot bends towards the light.

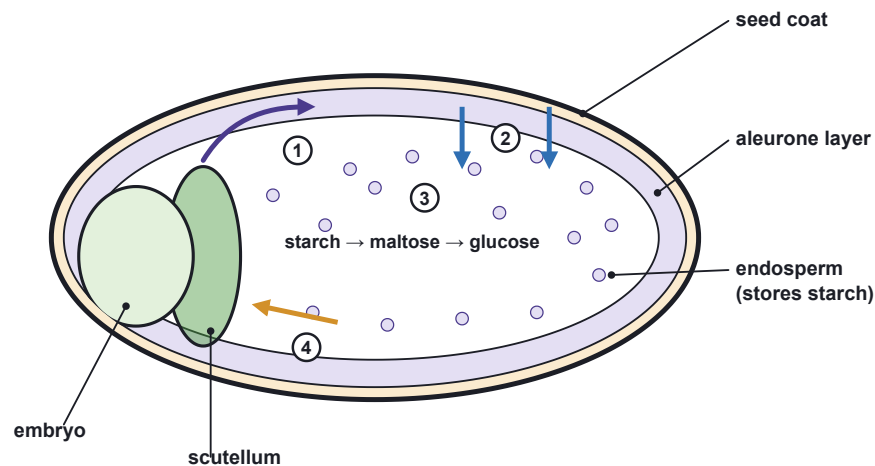
Common mistake: Light does not destroy auxin on the lit side. The auxin is redistributed to the shaded side, and cells there elongate faster.

Gibberellins Spec 8.11

Gibberellins are plant growth substances made in young leaves, shoot tips and embryos. They stimulate **stem elongation**, partly by promoting cell elongation and cell division, and trigger **germination** of seeds. Dwarf varieties of plants often make little gibberellin.

Germination of a cereal grain (such as barley)

1. The seed absorbs water and the embryo releases gibberellin.
2. Gibberellin diffuses to the **aleurone layer**, the outer layer of the endosperm, and binds to a receptor.
3. This causes breakdown of a repressor protein that normally stops transcription factors working, so the transcription factors can bind to the **amylase gene** and switch it on. Gibberellin therefore acts at the level of **transcription**.
4. The gene is transcribed and translated, so **amylase** is made and secreted into the endosperm.
5. Amylase hydrolyses starch in the endosperm to maltose, which is converted to glucose.
6. Glucose is transported to the embryo and used in respiration, releasing ATP for growth, and as a source of carbon for cellulose.



- ① the embryo releases gibberellin (GA), which diffuses to the aleurone layer
- ② GA switches on the gene for amylase in the aleurone cells; amylase is secreted into the endosperm
- ③ amylase hydrolyses starch to maltose, which is broken down to glucose
- ④ sugars move to the embryo (through the scutellum) for respiration and growth

Gibberellin from the embryo switches on amylase production in the aleurone layer.

Exam tip: A full answer links hormone, target cell, gene and enzyme: gibberellin, aleurone layer, transcription of the amylase gene, starch digestion.

Core practical 18: amylase in germinating cereal grains Spec 8.12

Core practical: Core practical 18: investigate the production of amylase in germinating cereal grains. Your teacher may use a variant of the method below, so check which apparatus and treatments you used.

The aim is to show that the germinating grain produces **amylase**, and that the embryo (through gibberellin) is needed to switch on its production.

1. Prepare agar plates containing starch, using sterile technique.
2. Surface-sterilise germinating barley grains (for example by soaking them briefly in dilute bleach and rinsing in sterile water), because bacteria and fungi on the grains also make amylase.
3. Cut the grains in half across the middle with a scalpel on a tile. One half contains the embryo, the other does not.

- Place halves cut side down on the agar. For example: embryo halves; embryo-free halves; embryo-free halves with gibberellin solution; boiled embryo halves as a control.
- Incubate at a constant temperature (for example 25 °C) for 24 to 48 hours.
- Remove the grain halves and flood the plates with iodine in potassium iodide solution for a minute, then pour the excess off.
- Starch turns blue-black. A **clear zone** where starch has been digested by amylase appears around each half. Measure the diameter of each clear zone.

Variables and controls	
Type	Detail
Independent variable	Treatment of the grain half (embryo present or absent, gibberellin added or not)
Dependent variable	Diameter, or area, of the clear zone / mm or mm ²
Controlled variables	Age, mass and type of grain; concentration and volume of starch agar; temperature; incubation time; volume and concentration of gibberellin and iodine
Controls	Boiled embryo halves (enzyme and gibberellin denatured) and agar with no grain, showing that the clear zone is caused by living tissue producing amylase
Safety	Scalpel: cut away from the body on a tile. Iodine solution stains and irritates: wear eye protection and wash spills. Sterile technique: tape the lids during incubation, open plates only briefly to remove the grains and add iodine, dispose of plates safely (for example by autoclaving) and wash hands.

To process results, measure the diameter of each clear zone in two directions at right angles and take the mean. Calculate the area from πr^2 and compare the mean area for each treatment. Repeat each treatment several times to identify anomalies and calculate a mean. Because a clear zone is only a rough measure of the amount of amylase, results are semi-quantitative.

Area of a clear zone

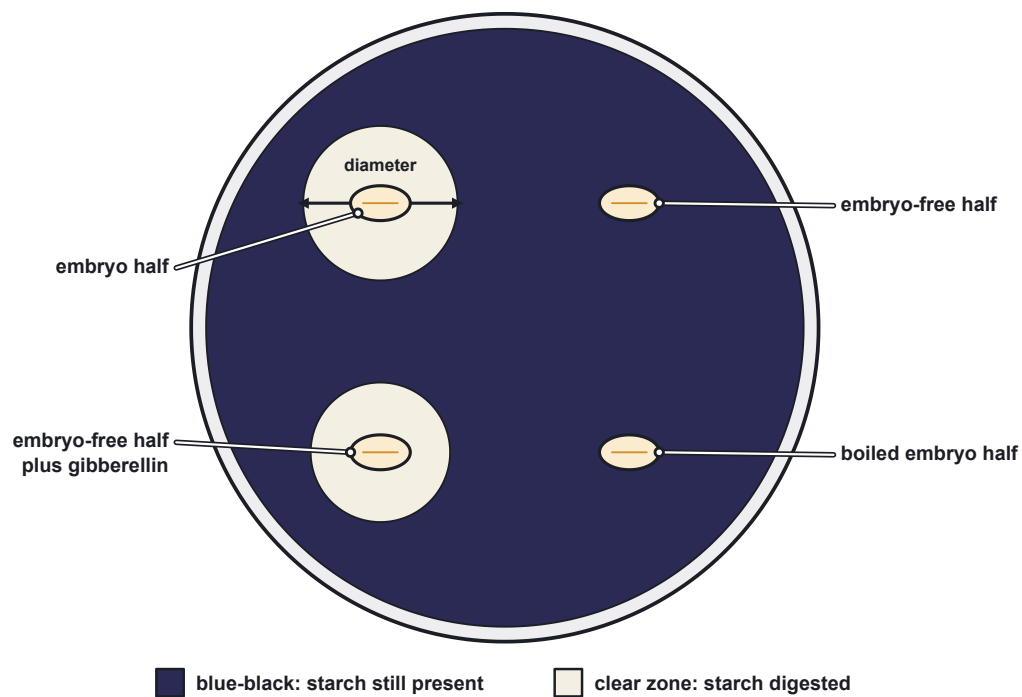
A clear zone has a mean diameter of 14 mm. Calculate its area.

$$1. \text{ radius} = 14 \div 2 = 7 \text{ mm}$$

$$2. \text{ area} = \pi r^2 = \pi \times 7^2 = \pi \times 49$$

Answer: 154 mm² (to 3 significant figures)

Maths skill: Area of a circle = πr^2 . Halve the diameter first, then square the radius, and give units (mm²).



Core practical 18: **clear zones** show where amylase has digested the starch.

Quick check

1. Which wavelength of light converts Pr to Pfr?
2. Which form of phytochrome is active?
3. How does auxin make cells elongate?
4. Where is amylase made in a germinating cereal grain?

4

The brain and hormonal control

Spec 8.13–8.16

A Level only

Nervous and hormonal coordination

Spec 8.13

Coordination means that different parts of an animal work together in response to stimuli. It is brought about by the **nervous system** and by **hormones** released by the endocrine system. The two work together: the hypothalamus is part of the brain but controls the pituitary gland.

Nervous and hormonal control compared

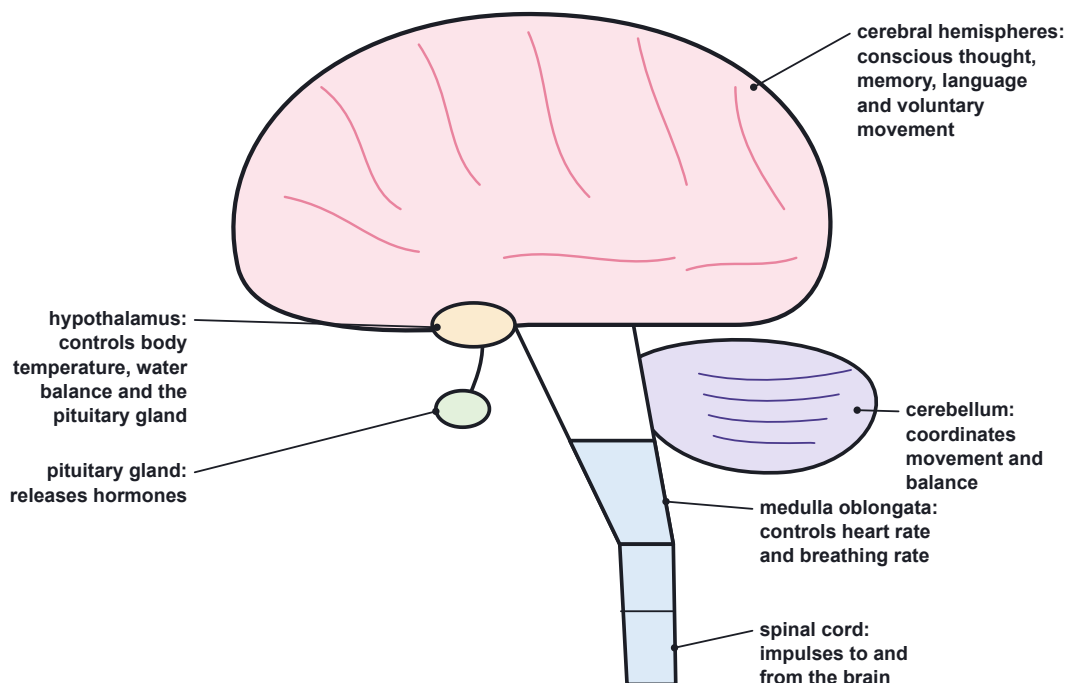
Feature	Nervous control	Hormonal control
Signal	Electrical impulses (action potentials) and neurotransmitters	Chemicals (hormones)
Transmitted by	Neurones	Blood (plasma)
Speed	Very fast (milliseconds)	Slower (seconds to hours)
Target	Specific effectors, usually one muscle or gland	Target cells with the complementary receptors, which may be widely spread
Duration	Short-lived, stops when the stimulus stops	Longer-lasting, because the hormone remains in the blood
Example	Withdrawal of a hand from a hot object	Adrenaline released from the adrenal glands

Many responses use both. In the ‘fight or flight’ response, nervous impulses from the hypothalamus stimulate the adrenal glands to release **adrenaline**. The nervous system gives a very fast response, and adrenaline then prolongs and widens it by raising heart rate, ventilation and blood glucose. The hypothalamus also detects changes in the blood and controls the **pituitary gland**, which secretes hormones that control other endocrine glands.

Exam tip: In compare questions use matching features: ‘nerves are fast, hormones are slower’ and ‘nervous effects are short-lived, hormonal effects longer-lasting’. Give a statement for both sides.

Regions of the human brain Spec 8.14

Regions of the brain you need to know		
Region	Location	Main functions
Cerebral hemispheres	Two large halves forming the upper and outer part of the brain, with a highly folded outer cortex	Sensory areas receive information from receptors; motor areas control voluntary movement; association areas are involved in conscious thought, learning, memory, language and decision-making
Hypothalamus	In the centre of the brain, below the thalamus	Monitors and regulates body temperature, water balance, hunger and thirst; makes hormones released by the posterior pituitary and controls the anterior pituitary; links the nervous and endocrine systems
Pituitary gland	Hangs from the base of the hypothalamus	Anterior lobe secretes hormones such as growth hormone and hormones controlling other glands; the posterior lobe releases ADH and oxytocin made in the hypothalamus
Cerebellum	At the back of the brain, below the cerebral hemispheres	Coordinates movement, balance and posture using information from the muscles, joints and ears; important for fine, skilled movement
Medulla oblongata	At the base of the brain, joining the spinal cord	Controls involuntary actions: heart rate, breathing (ventilation) rate and blood pressure; also swallowing and coughing reflexes



The main regions of the **brain** and what each does.

Common mistake: Do not say that the cerebellum 'starts' movement. The motor areas of the cerebral hemispheres start voluntary movements; the cerebellum coordinates them to make them smooth and balanced.

Imaging the brain: CT, MRI, fMRI and PET Spec 8.15

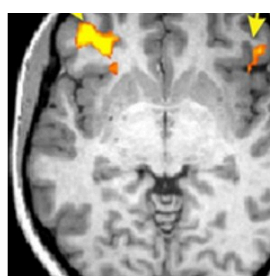
Brain imaging techniques			
Technique	How it works	What it shows and uses	Advantages and limitations
CT (computed tomography)	An X-ray source rotates around the head. Detectors measure how much is absorbed by tissues; a computer builds cross-sectional slices.	Brain structure: bone, tumours, bleeding in stroke or head injury	Quick and widely available. Uses ionising radiation; poorer soft-tissue contrast than MRI; shows structure, not activity.
MRI (magnetic resonance imaging)	A strong magnetic field aligns hydrogen nuclei in water. A pulse of radio waves knocks them out of line; they emit signals as they return, which differ between tissues.	Detailed images of soft tissue: tumours, damage to brain tissue, multiple sclerosis, structural abnormalities	No ionising radiation and high resolution. Slow, noisy, expensive; cannot be used with some metal implants or pacemakers.
fMRI (functional MRI)	MRI that detects changes in blood oxygen. Active neurones use more oxygen, so blood flow to them increases, which changes the signal.	Which parts of the brain are active during a task, such as speaking or moving a hand	Shows function as well as structure and uses no radiation. Indirect measure of activity; expensive; the person must keep still.
PET (positron emission tomography)	A radioactive tracer, such as a glucose analogue labelled with a positron emitter, is injected. Active cells take up more of it. Detectors record the gamma rays produced.	Metabolic activity, such as areas that are abnormally active or inactive in epilepsy, dementia or tumours	Shows chemical activity. Uses radioactivity; costly; the tracer has a short half-life, so it must be made close to the scanner.



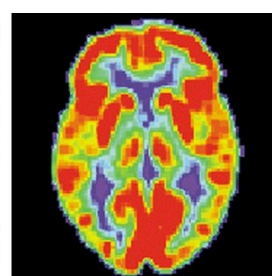
CT
bone and bleeds,
structure



MRI
soft tissue
detail



fMRI
active areas
during a task



PET
glucose uptake,
active regions

CT and MRI show structure; fMRI and PET show activity.

Images: Mikael Häggström, CC0 (CT); everyone's idle, CC BY-SA 2.0 (MRI); Ovaysikia et al., CC BY 2.5 (fMRI); US National Institute on Aging, Public domain (PET); via Wikimedia Commons

Exam tip: Choose the scan by what the question asks: structure (CT or MRI) or function (fMRI or PET). Then give a reason and a limitation, because 'evaluate' questions need both.

Brain chemicals and ill health Spec 8.16

Imbalances of brain chemicals		
	Parkinson's disease	Depression
Chemical	Dopamine	Serotonin
Imbalance	Neurones that make dopamine, in a region of the brain controlling movement, die, so dopamine is deficient	Low serotonin activity at synapses is associated with low mood
Symptoms	Tremor, muscle rigidity, slow movement, poor balance	Persistent low mood, loss of interest, changes in sleep and appetite
Treatment	L-DOPA, which is converted to dopamine in the brain; drugs that act like dopamine (agonists) or reduce its breakdown	Drugs that block the reuptake of serotonin (selective serotonin reuptake inhibitors, SSRIs), so serotonin stays in the synaptic cleft for longer

Understanding how synapses work makes it possible to **design new drugs** that act at a particular target: a receptor, an enzyme that breaks down a transmitter or the protein that takes a transmitter back up. A drug must reach the brain, so it needs to cross the blood-brain barrier, and it must be tested for effectiveness and side effects in clinical trials before it can be used.

Common mistake: The cause of depression is complex and an imbalance of serotonin is only one factor linked to it. Say 'associated with' or 'contributes to', not 'is caused by'.

Quick check

1. Which region of the brain coordinates movement and balance?
2. Which region of the brain controls heart rate and breathing rate?
3. What does fMRI show that MRI alone does not?
4. Which neurotransmitter is lacking in Parkinson's disease?

5

Gene technology

Spec 8.17-8.22

A Level only

Making recombinant DNA

Spec 8.18

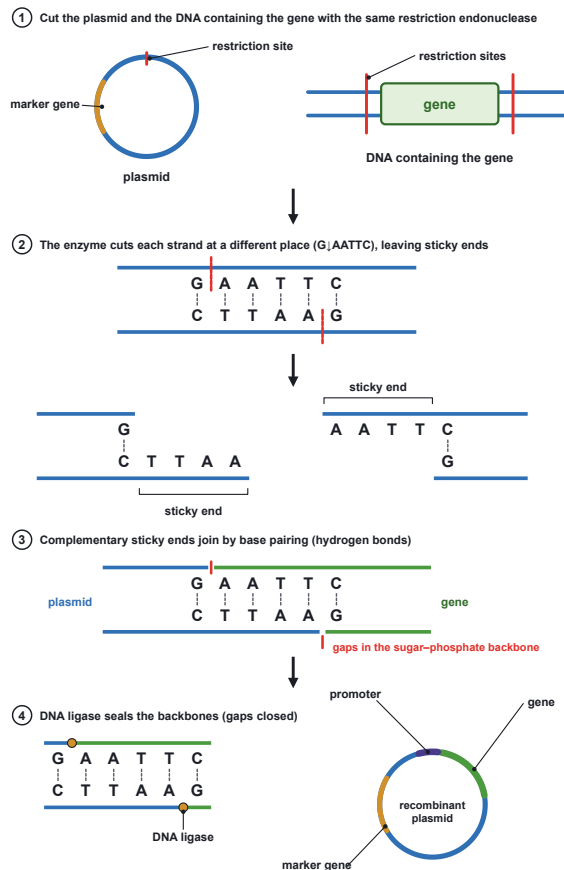
Recombinant DNA is DNA made by joining DNA from two different sources, usually from different organisms. A gene from one organism is combined with a **vector**, usually a **plasmid** (a small circular DNA molecule from bacteria), which carries the gene into a host cell.

Getting the gene

- **Using reverse transcriptase**: mRNA for the gene is extracted from cells that make a lot of it (for example, insulin mRNA from pancreatic beta cells). Reverse transcriptase makes a complementary DNA (**cDNA**) copy, and DNA polymerase makes it double-stranded. cDNA has no introns, so a bacterium can express it.
- **Using restriction endonucleases** to cut the gene out of the genome.
- **Synthesising** the gene from its known base sequence in a gene machine.

Joining the gene to the plasmid

1. A **restriction endonuclease** (restriction enzyme) cuts DNA at a specific base sequence called its **recognition site** (often a palindromic sequence). It hydrolyses the phosphodiester bonds in each strand.
2. Many restriction enzymes make staggered cuts, leaving short single-stranded ends called **sticky ends**.
3. The plasmid is cut with the **same** restriction enzyme, so its sticky ends are complementary to those on the gene.
4. The gene and plasmid are mixed. The sticky ends join by hydrogen bonds between complementary bases (annealing).
5. **DNA ligase** forms phosphodiester bonds between the sugar and phosphate groups of adjacent nucleotides (a condensation reaction), sealing the gaps in the backbone to make a **recombinant plasmid**.



Making a **recombinant plasmid** with a restriction endonuclease and DNA ligase.

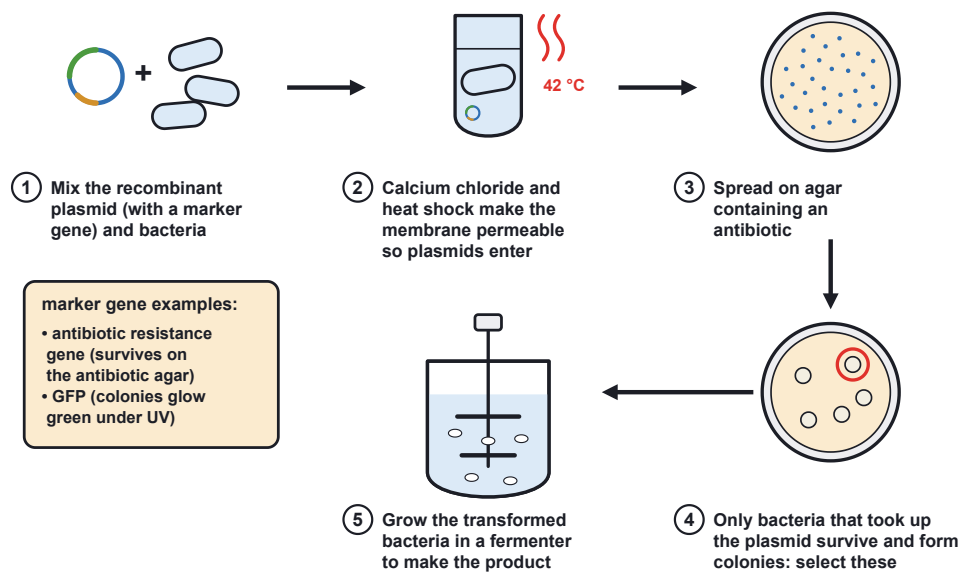
Common mistake: Restriction enzymes and ligase have opposite roles: restriction enzymes cut (hydrolysis) and ligase joins (condensation). The sticky ends are held by hydrogen bonds between bases; ligase makes the covalent bonds.

Inserting recombinant DNA into cells Spec 8.19

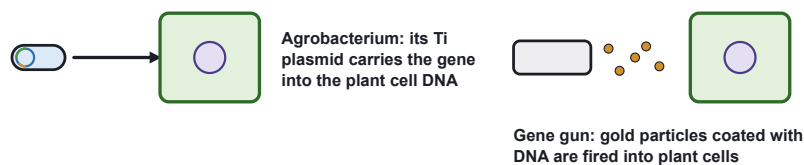
Ways of inserting recombinant DNA		
Host	Method	How it works
Bacteria	Heat shock with calcium chloride; electroporation	Cells are treated with ice-cold calcium chloride and heated briefly to about 42 °C, which makes the cell membrane permeable to plasmids. Electroporation uses a brief electrical pulse to the same effect.
Plants	Agrobacterium tumefaciens	The gene is put into the Ti plasmid of this bacterium, which naturally transfers part of its plasmid DNA into plant cells, where it is integrated into the plant genome. Whole plants are grown from the transformed cells by tissue culture.
Plants	Gene gun	Microscopic gold or tungsten particles coated with the DNA are fired into plant cells.
Animals	Microinjection	DNA is injected through a fine needle into the nucleus of a fertilised egg, which is then implanted in a surrogate mother.
Animals / human cells	Viral vectors or liposomes	A virus modified so it cannot cause disease carries the gene into cells; liposomes are lipid vesicles that fuse with the cell surface membrane.

Only a small fraction of host cells take up the DNA. **Marker genes** are included in the plasmid so that cells that took it up can be identified. These may code for antibiotic resistance (cells that survive on agar

containing the antibiotic carry the plasmid) or for a fluorescent protein such as GFP (cells glow green under UV light).



Getting a gene into plant cells



From recombinant plasmid to **transgenic bacteria**, selected using a marker gene.

Exam tip: Say why a marker gene is needed: not every cell takes up the plasmid, so a marker lets you pick out the ones that did.

Drugs from genetically modified organisms Spec 8.17

Making drugs with GMOs		
Organism	How it is used	Example
Microorganisms (bacteria, yeast)	The human gene is inserted on a plasmid; the cells are grown in large fermenters and the protein is purified from the culture	Human insulin for diabetes; human growth hormone
Plants	A human gene is inserted into plant cells, and the protein is extracted from leaves or seeds	Antibodies and vaccine antigens made in tobacco or other plant leaves
Animals	The gene is joined to a promoter that works in the mammary gland, so the protein is secreted in milk	Human antithrombin (a protein that prevents unwanted blood clotting) in the milk of transgenic goats; human clotting factor IX in the milk of transgenic sheep

Advantages of making human insulin in GM microorganisms rather than extracting it from animals:

- The insulin is identical to human insulin, so it is less likely to cause an immune response.
- It can be made in large amounts, quickly and cheaply, in fermenters.

- There are fewer ethical objections than using animals, and a reliable supply that does not depend on slaughter of animals.

Bacteria cannot remove introns and cannot modify proteins after translation in the way eukaryotic cells do (for example by adding carbohydrate groups). So a human gene for bacteria is supplied as cDNA, and proteins that need these modifications to work are made in yeast, plants or animals instead.

Exam tip: A 'how are drugs produced using GMOs' answer needs the sequence: isolate the human gene, insert it into a vector, put the vector in the host, express the gene and purify the protein.

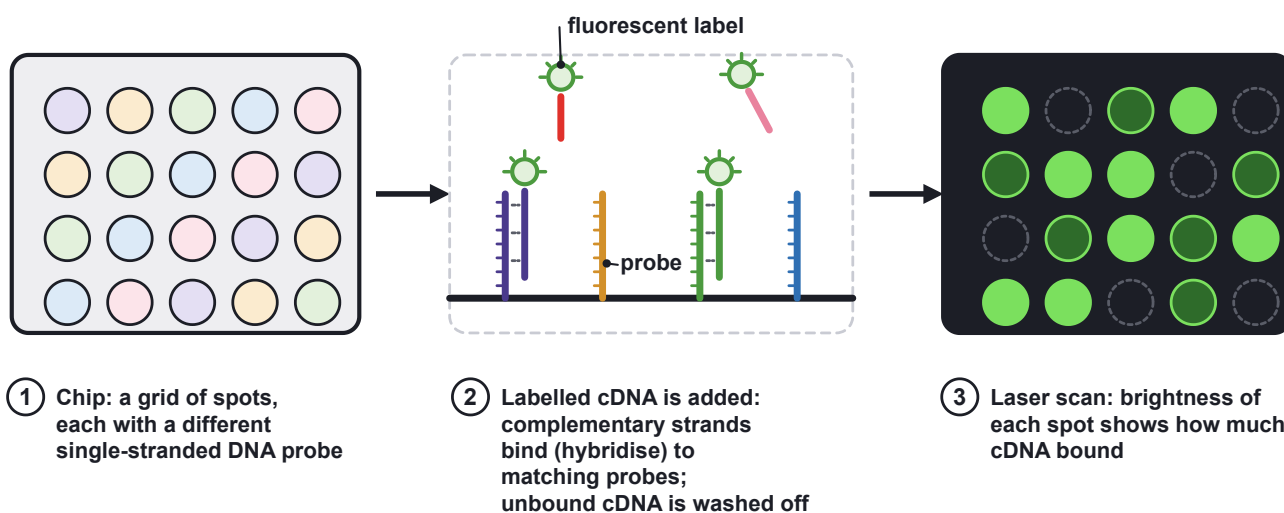
Microarrays and bioinformatics Spec 8.20, 8.21

Microarrays

A **microarray** (DNA chip) is a small slide with thousands of tiny spots in a grid. Each spot holds many copies of a single-stranded DNA **probe** from a known gene. It is used to find out which genes are active (being transcribed) in a tissue at a given time.

1. mRNA is extracted from the cells being studied (for example cancer cells and normal cells).
2. Reverse transcriptase makes cDNA from the mRNA, and a fluorescent label is added. Samples from two conditions may carry different colours.
3. The labelled cDNA is added to the microarray. It binds (hybridises) to the probes with a complementary base sequence.
4. Unbound cDNA is washed away and the array is scanned. A spot that fluoresces shows the gene was active; the brighter the spot, the more mRNA was present.

Microarrays can identify active genes in different tissues, compare healthy and diseased cells, and show how gene expression changes in response to a drug.



Key to the scan

- bright spot: a lot of cDNA bound, so the gene is highly expressed in the sample
- dull spot: a little cDNA bound, so the gene is expressed at a low level
- no spot: no cDNA bound, so the gene is not expressed in the sample

A **microarray** shows which genes are being expressed.

Bioinformatics

Bioinformatics is the use of computer science, mathematics and statistics to collect, store, analyse and interpret large sets of biological data, such as DNA base sequences, protein sequences and gene

expression data. Computers can compare sequences in databases, find genes in a genome and compare species, and so provide a way to handle the very large amount of data produced by sequencing and microarrays.

Exam tip: Define bioinformatics in terms of computers and biological data. Examples help: comparing a gene sequence in a database to identify its function.

Risks and benefits of GMOs Spec 8.22

Risks and benefits of using GMOs		
	Benefits	Risks
Agriculture	Higher yields; crops resistant to pests (such as Bt crops), herbicides, drought or disease; less pesticide used; crops with added nutrients, such as beta-carotene (which the body converts to vitamin A) in golden rice	Genes may spread to wild relatives or weeds through pollen; pests may evolve resistance; non-target insects may be harmed; reduced biodiversity if only a few GM varieties are grown
Medicine	Large amounts of pure human proteins such as insulin; vaccines and antibodies made in plants and animals	Unforeseen effects of inserted genes; welfare of transgenic animals
Health	Foods may be more nutritious or free of allergens	Possible allergic reactions to new proteins; long-term effects not fully known
Economic and ethical	Cheaper food and reliable supply; benefits for food security	Seeds are patented and costly for farmers; some people object on ethical or religious grounds to modifying organisms

In an 'evaluate' or 'discuss' question, weigh the benefits against the risks, give specific examples and reach a justified judgement. The evidence often depends on the organism, the gene and the environment, so each GMO may be judged separately.

Common mistake: Do not write that GM food 'is unsafe' or 'is safe' without evidence. Say what could happen and how it can be tested or controlled, for example by trials and monitoring.

Quick check

1. What is the role of a restriction endonuclease?
2. What does DNA ligase do?
3. Why is a marker gene included in a plasmid?
4. What does a bright spot on a microarray show?
5. What is bioinformatics?

Quick check answers

Neurones, reflexes and the nervous system

1. In the dorsal root ganglion, just outside the spinal cord.
2. Many layers of the plasma membrane of Schwann cells, which are rich in lipid.
3. The central nervous system (brain and spinal cord) and the peripheral nervous system.
4. Myelinated axons carrying impulses up and down the cord.

Impulses, synapses and receptors

1. About -70 mV (the inside is negative relative to the outside).
2. Calcium ions (Ca^{2+}).
3. It hydrolyses acetylcholine to choline and ethanoate in the synaptic cleft, ending the stimulation.
4. Conduction in which the action potential jumps from one node of Ranvier to the next along a myelinated axon.
5. It becomes hyperpolarised, because rhodopsin splits and the cation channels close.

Plant responses

1. Red light (about 660 nm).
2. Pfr.
3. It increases proton pumping into the cell wall; the acidic wall becomes more extensible and the cell takes in water.
4. In the aleurone layer, under the control of gibberellin from the embryo.

The brain and hormonal control

1. The cerebellum.
2. The medulla oblongata.
3. Which areas of the brain are active, by detecting changes in blood oxygen.
4. Dopamine.

Gene technology

1. It cuts DNA at a specific recognition sequence, leaving sticky ends.
2. It joins sugar-phosphate backbones of DNA fragments by forming phosphodiester bonds.
3. To identify the host cells that have taken up the plasmid.
4. That the gene with the matching probe is active, because mRNA from it was present.
5. The use of computers and statistics to store and analyse large sets of biological data.