



Neural signalling

Revision notes • IB Biology neural signalling: neurons, resting and action potentials, impulse speed and synapses, plus HL saltatory conduction and summation.

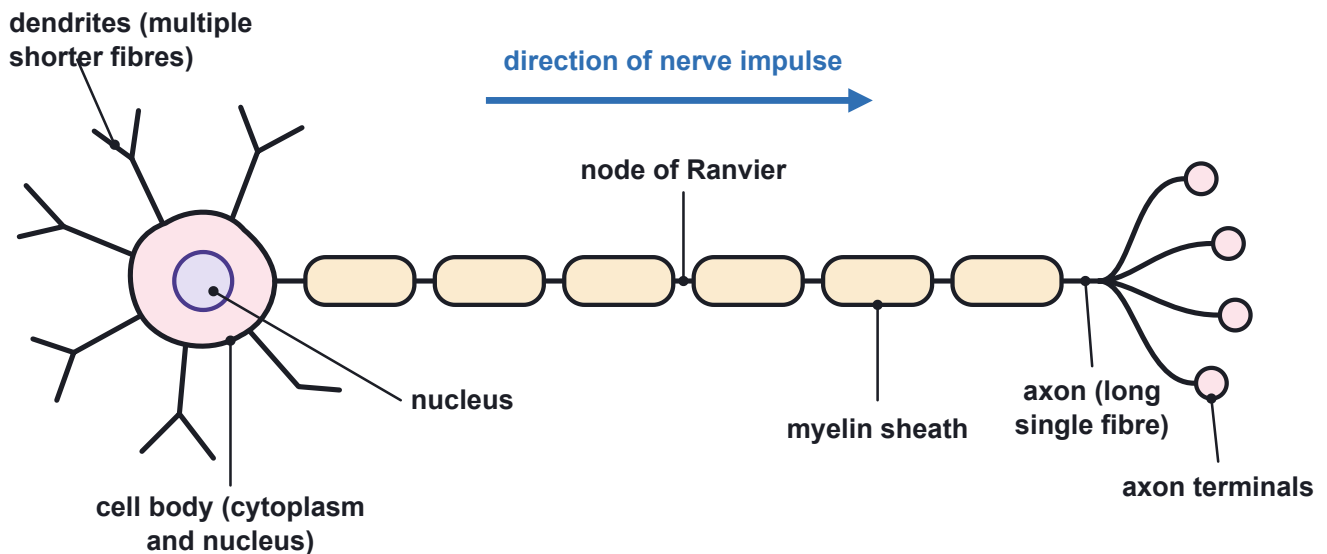
For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Neural signalling Spec C2.2

Neurons and the resting potential Spec C2.2.1, C2.2.2

Neurons are cells within the nervous system that carry electrical impulses. The **cell body** contains the cytoplasm and nucleus. Elongated nerve fibres of varying length project from it.

- **Axon:** a long single fibre that carries impulses away from the cell body. Some are over a metre long.
- **Dendrites:** multiple shorter fibres that receive signals from other neurons.
- Electrical impulses are conducted along these fibres.



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A motor neuron: impulses travel from the **dendrites** and cell body along the **axon** to the axon terminals.

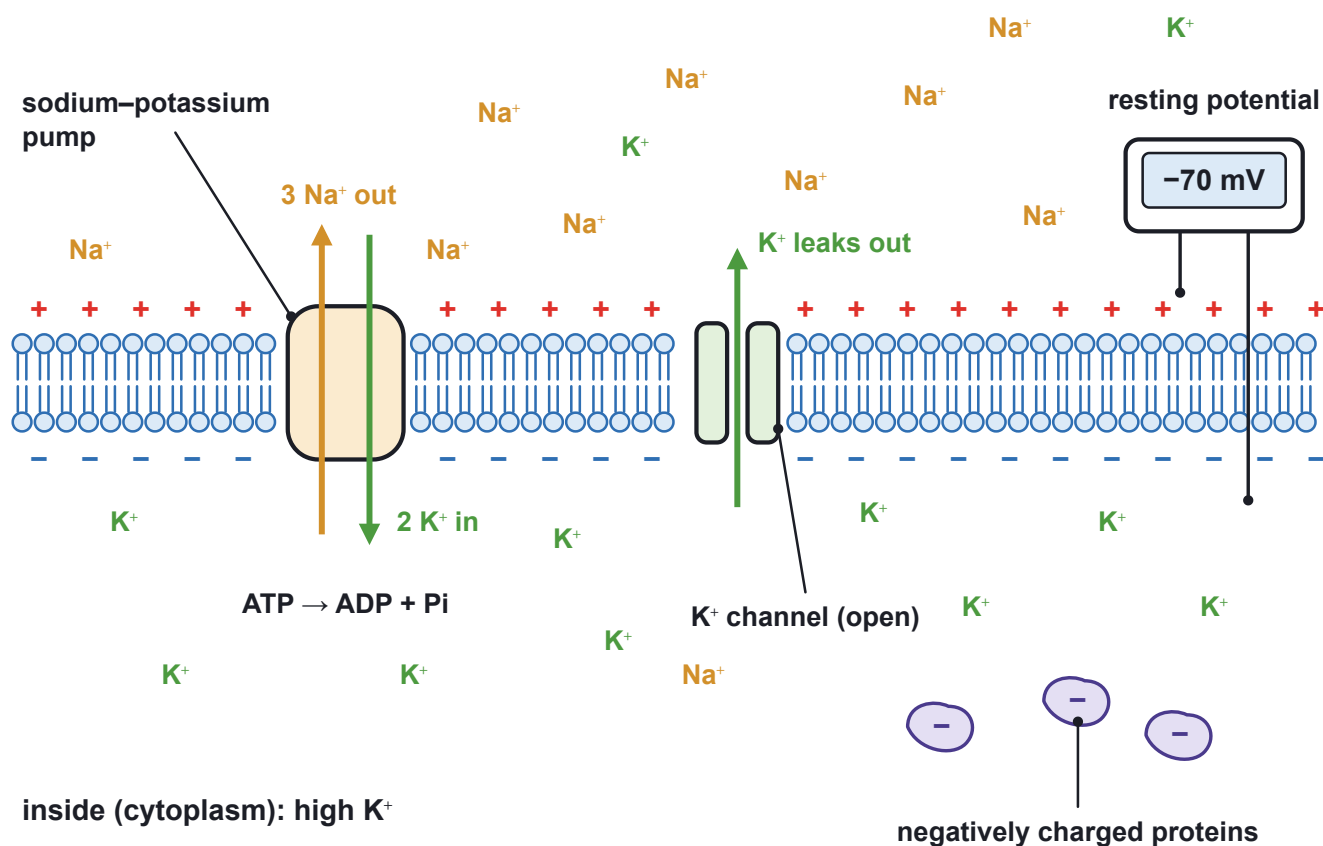
The resting potential

A **membrane potential** is the voltage across a membrane. A neuron that is not conducting an impulse is **polarized**: there is a charge difference across its plasma membrane, with the inside negative. This is the **resting potential**, typically about -70 mV.

1. Sodium-potassium pumps in the plasma membrane use energy from ATP.
 2. Each cycle pumps three Na^+ out of the neuron and two K^+ in: the two ions move in opposite directions.
 3. This establishes and maintains concentration gradients: Na^+ is more concentrated outside, K^+ more concentrated inside.
- More positive charge is pumped out than in (3 Na^+ out for 2 K^+ in).

- The membrane is much more permeable to K^+ than to Na^+ , so K^+ leaks back out through open channels faster than Na^+ leaks in.
- The cytoplasm contains many negatively charged proteins and other organic ions that cannot leave.
- Together these make the inside negative relative to the outside.

outside: high Na^+



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The **resting potential** (about -70 mV): pumps set up the Na^+ and K^+ gradients and K^+ leaks out faster than Na^+ leaks in.

Nerve impulses as action potentials Spec C2.2.3

A **nerve impulse** is an **action potential** that travels along a nerve fibre. At any one point on the fibre the action potential is a brief, rapid change in membrane potential.

- **Depolarization:** Na^+ diffuses into the fibre, so the inside becomes positive.
- **Repolarization:** K^+ diffuses out, so the inside becomes negative again.
- Each part of the fibre that depolarizes causes the next part to depolarize, so the action potential is **propagated** along the fibre.

A nerve impulse is **electrical** because it involves the movement of positively charged ions across the plasma membrane. Electrons do not flow along the axon as they do in a wire.

Common mistake: Do not write that an impulse is 'electricity flowing down the nerve'. Write that an action potential involves movement of Na^+ and K^+ ions across the membrane.

Depolarization, repolarization and oscilloscope traces Spec C2.2.8, C2.2.9, C2.2.10 HL only

Depolarization and repolarization

1. A stimulus or local current makes the membrane potential less negative. If it reaches the **threshold potential** (about -55 mV), **voltage-gated sodium channels** open. Below threshold they stay closed

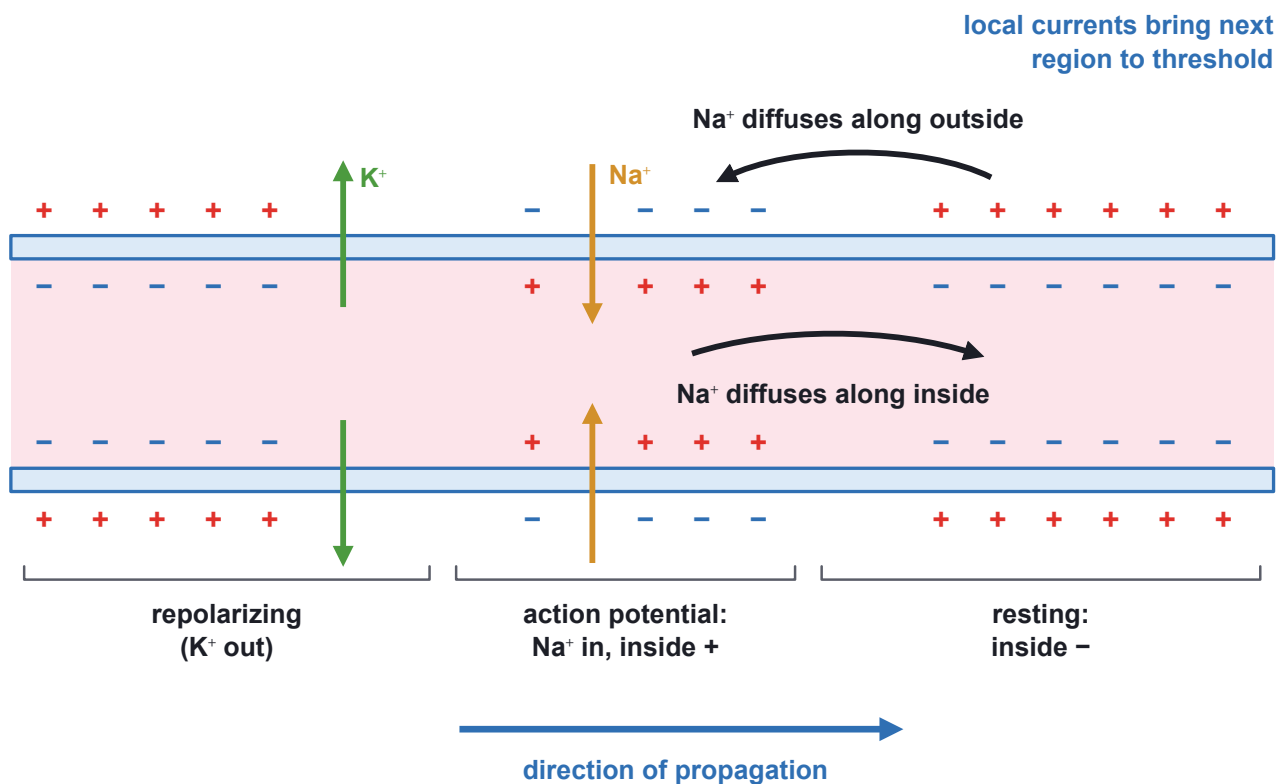
and no action potential occurs.

2. Na^+ diffuses in down its concentration gradient. The entry of Na^+ depolarizes the membrane further, opening more sodium channels, until the inside reaches about +30 mV (depolarization).
3. The sodium channels close, and **voltage-gated potassium channels** open.
4. K^+ diffuses out, making the inside negative again (repolarization). The potential briefly falls below the resting potential before the potassium channels close.
5. Sodium-potassium pumps maintain the concentration gradients, so the neuron can carry further impulses.

Propagation by local currents

Na^+ entering a depolarized region diffuses along the inside of the axon towards the next, still polarized region. Outside the membrane, Na^+ diffuses from the next region towards the depolarized region. These **local currents** make the potential in the next region less negative until the threshold potential is reached and its sodium channels open.

The region just behind the action potential is still repolarizing and its sodium channels cannot reopen yet, so the impulse travels in one direction only.



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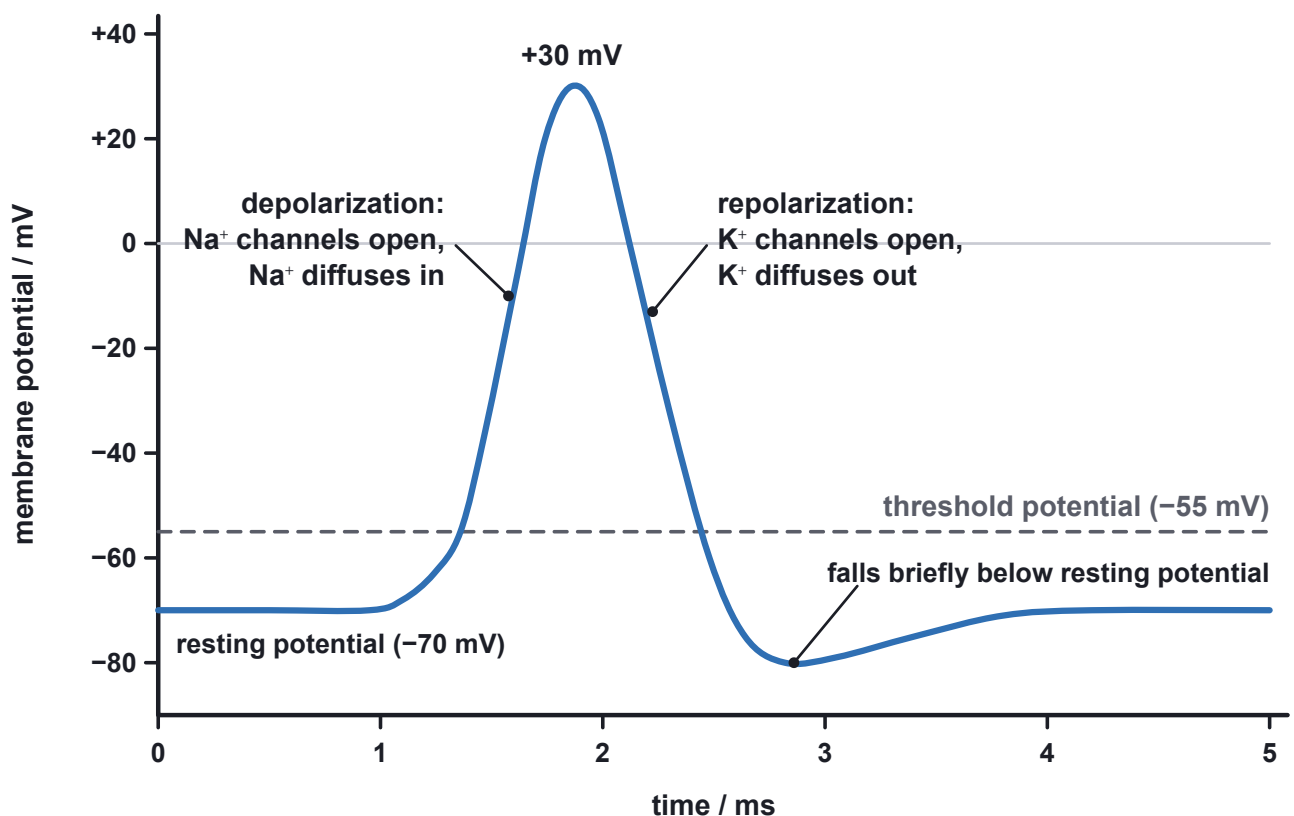
Local currents of Na^+ bring the next region of the axon to the threshold potential.

Oscilloscope traces

An oscilloscope trace plots membrane potential (mV) on the y-axis against time (ms) on the x-axis. You should link each part of the trace to events in the membrane.

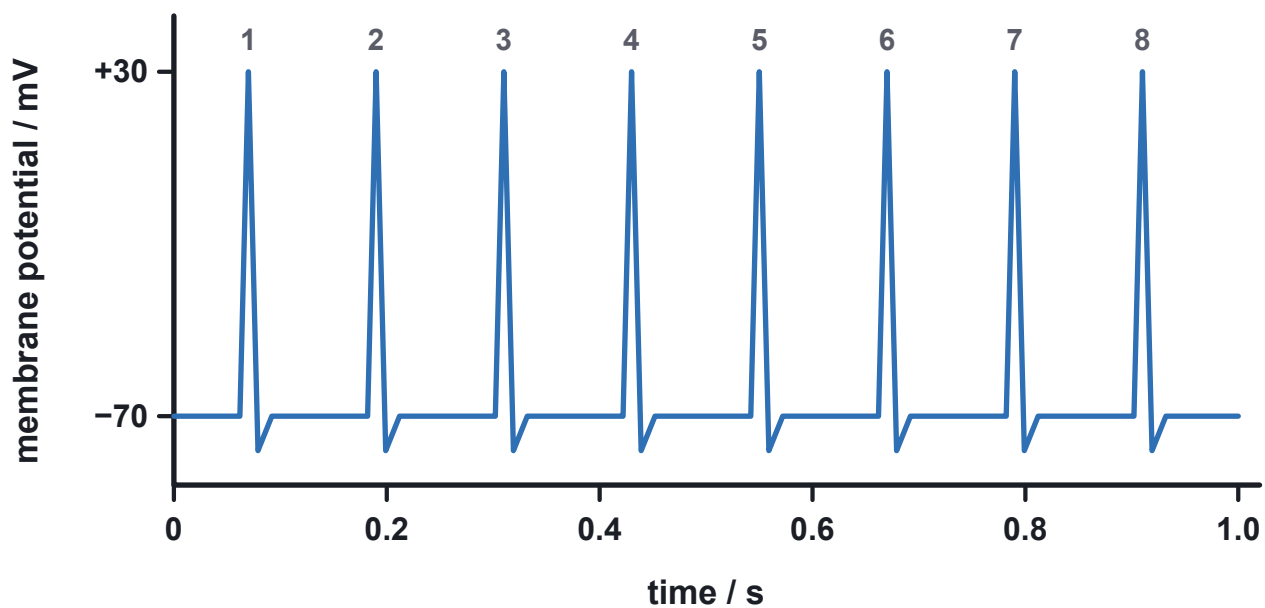
Reading an oscilloscope trace of one action potential

Part of trace	Membrane potential	Cellular event
Flat line before the spike	About -70 mV	Resting potential maintained by pumps and K^+ leak
Small rise to threshold	-70 to -55 mV	Local currents or stimulus depolarize the membrane
Steep rise	-55 to about $+30$ mV	Voltage-gated Na^+ channels open; Na^+ diffuses in
Steep fall	$+30$ mV to below -70 mV	Na^+ channels close; voltage-gated K^+ channels open; K^+ diffuses out
Return to resting level	Back to about -70 mV	K^+ channels close; resting potential restored



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Oscilloscope trace of one action potential (typical values): -70 mV resting, -55 mV threshold, peak about $+30$ mV.



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Counting impulses: eight action potentials in 1.0 s is a frequency of 8 impulses per second (illustrative trace).

Number of impulses per second

An oscilloscope trace shows 18 action potentials in a 0.30 s recording. Calculate the frequency of impulses.

1. frequency = number of impulses $\div$ time

2. = $18 \div 0.30$ s

Answer: 60 impulses per second (60 Hz)

Practical skill: Read the time scale before counting spikes. A stronger stimulus gives more impulses per second, not taller action potentials: each action potential reaches the same peak.

Speed of nerve impulses Spec C2.2.4, C2.2.11

The speed of nerve impulses varies a lot between nerve fibres. Two factors matter most: **axon diameter** and **myelination**.

Approximate conduction speeds (typical textbook values)		
Fibre	Diameter	Approximate speed
Small non-myelinated fibre	About 1 μm	About 1 m s^{-1}
Squid giant axon (non-myelinated)	Up to about 0.5-1 mm	About 25 m s^{-1}
Myelinated vertebrate fibre	About 10-20 μm	Up to about 100 m s^{-1}

- **Squid giant axons vs smaller non-myelinated fibres:** a wider axon has less resistance to the flow of ions inside it, so local currents spread further and faster. The giant axon allows a rapid escape response.
- **Myelinated vs non-myelinated fibres:** myelinated fibres conduct far faster, even when much narrower, so many fast fibres fit into a small nerve.

Correlation and the coefficient of determination

- A **positive correlation**: one variable rises as the other rises, e.g. conduction speed and axon diameter.
- A **negative correlation**: one variable falls as the other rises. The guide's example is conduction speed and animal size. Published data for this vary between groups of animals, so in an exam describe the trend that the data you are given actually show.
- The correlation coefficient, r , runs from -1 to $+1$. Values near ± 1 show a strong correlation; values near 0 show little or none.
- The coefficient of determination, R^2 , is r squared. It gives the proportion of the variation in the dependent variable that is explained by variation in the independent variable.
- Correlation does not by itself show causation.

Using r and R^2

For a set of non-myelinated axons, the correlation coefficient between axon diameter and conduction speed is $r = 0.90$. Calculate R^2 and interpret it.

1. $R^2 = r^2 = 0.90^2$
2. $R^2 = 0.81$
3. $0.81 = 81\%$: 81% of the variation in conduction speed is explained by variation in axon diameter.
4. The other 19% is due to other factors, such as temperature or measurement error.

Answer: $R^2 = 0.81$; a strong positive correlation, with 81% of the variation in speed explained by diameter

Maths skill: State the direction (positive or negative) and strength of a correlation from r . Use R^2 only to say how much of the variation is explained, and never claim it proves cause.

HL only

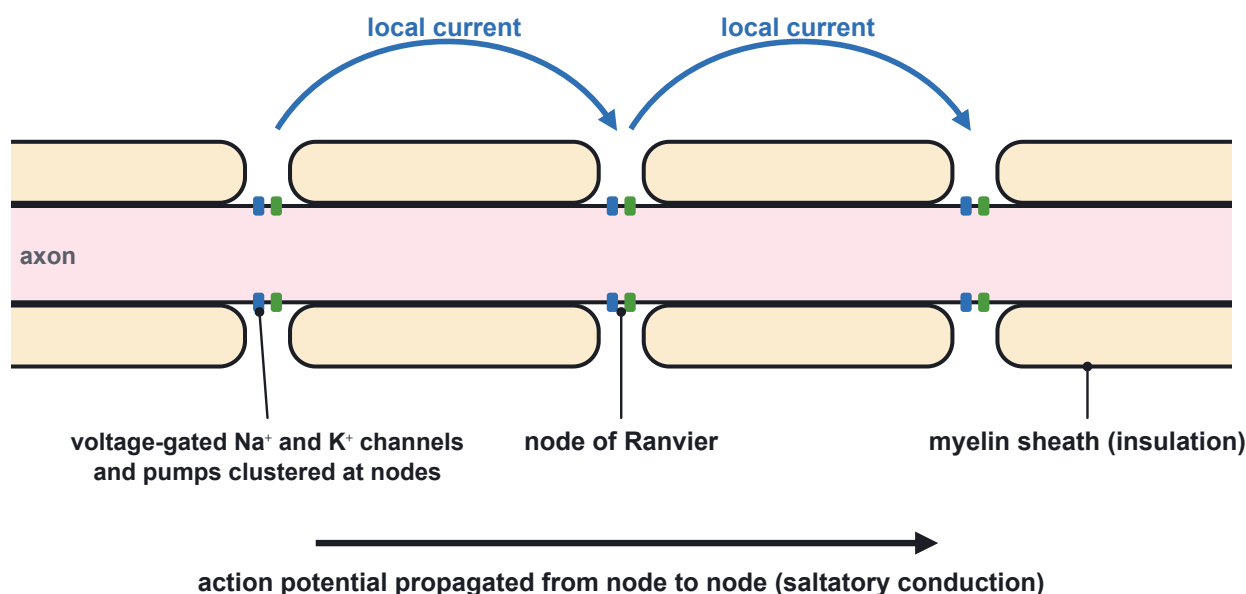
Saltatory conduction

HL only

In myelinated fibres the axon is wrapped in a **myelin sheath** that insulates it, with small gaps called **nodes of Ranvier**. The ion pumps and channels are clustered at the nodes, so an action potential can only occur there.

HL only

1. An action potential occurs at one node.
2. Local currents spread inside the axon, under the myelin, to the next node.
3. The next node reaches threshold, its voltage-gated sodium channels open and an action potential occurs there.
4. The action potential is propagated from node to node. This **saltatory conduction** is much faster than continuous propagation along the whole membrane.



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Saltatory conduction: the action potential jumps from one node of Ranvier to the next.

Synapses and excitatory postsynaptic potentials Spec C2.2.5, C2.2.6, C2.2.7

Synapses are junctions between neurons and between neurons and effector cells, such as muscle fibres at **neuromuscular junctions**. At a chemical synapse (called simply a synapse here) the cells are separated by a narrow **synaptic cleft**.

A signal can only pass in one direction across a typical synapse. Only the presynaptic neuron has vesicles of neurotransmitter, and only the postsynaptic membrane has the receptors.

Release of neurotransmitter from the presynaptic membrane

1. An action potential arrives and depolarizes the presynaptic membrane.
2. Voltage-gated calcium channels open and Ca^{2+} diffuses into the presynaptic neuron (it is more concentrated outside).
3. Inside the neuron, **calcium ions act as a signalling chemical**: they cause vesicles of neurotransmitter to move to the presynaptic membrane and fuse with it.
4. The neurotransmitter is released into the synaptic cleft by exocytosis.

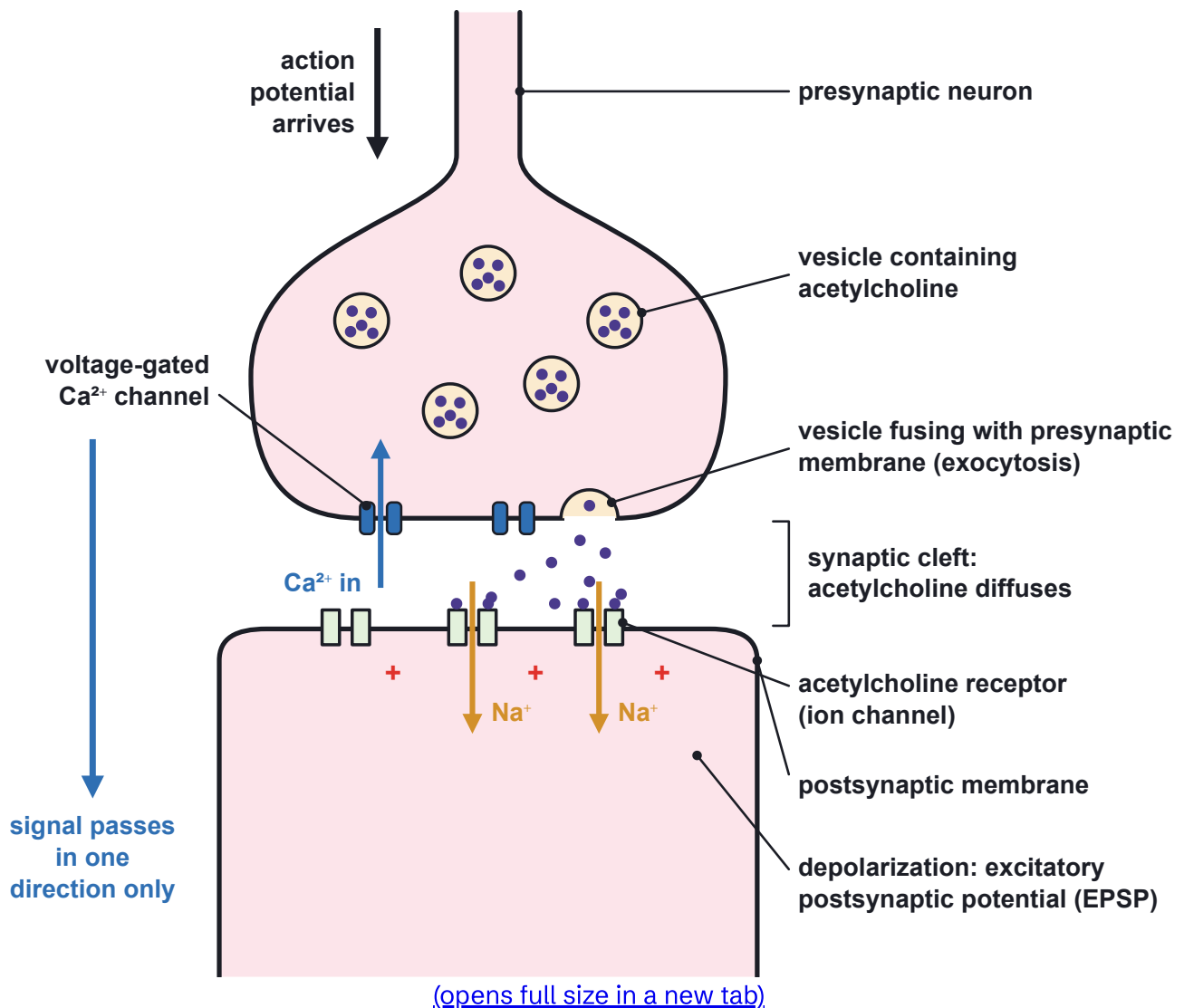
Excitatory postsynaptic potential (EPSP)

1. **Acetylcholine** diffuses across the synaptic cleft.
2. It binds to transmembrane receptors in the postsynaptic membrane.
3. The receptors open ion channels and positively charged ions, mainly Na^+ , diffuse into the postsynaptic cell.
4. The postsynaptic membrane is depolarized: an **excitatory postsynaptic potential**. If it reaches the threshold potential, an action potential starts in the postsynaptic cell.
5. The neurotransmitter is quickly removed from the synaptic cleft, so each signal is brief.

Beyond the syllabus: the guide does not name the enzyme that removes acetylcholine. It is acetylcholinesterase, which breaks acetylcholine into acetate and choline; the presynaptic neuron

reabsorbs the choline to make more acetylcholine.

Acetylcholine is used at many types of synapse, including neuromuscular junctions, where it triggers contraction of skeletal muscle fibres.



At a cholinergic synapse, Ca^{2+} entry triggers exocytosis of acetylcholine, which causes an EPSP in the postsynaptic cell.

Exam tip: Linking question: in what ways are biological systems regulated? Synapses are control points: whether a signal passes depends on how much neurotransmitter is released and how many receptors respond.

Exogenous chemicals, inhibition and summation Spec C2.2.12, C2.2.13, C2.2.14 HL only

Effects of exogenous chemicals

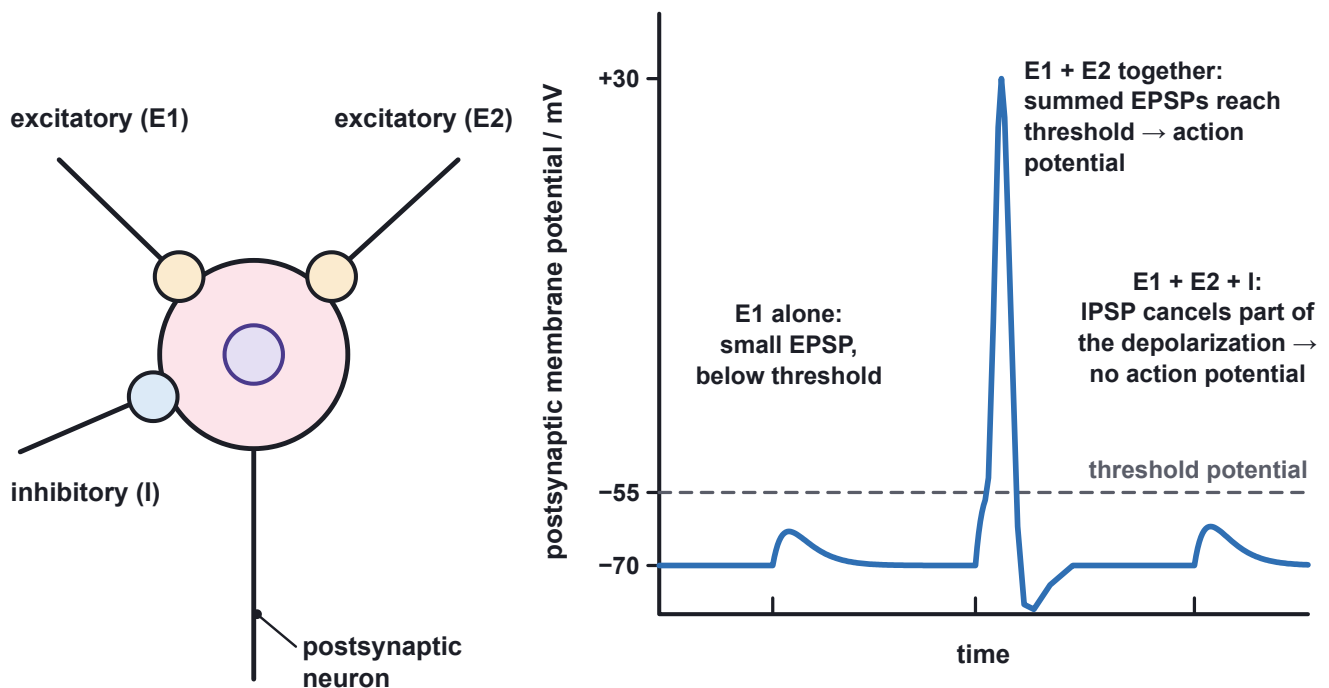
Two exogenous chemicals that affect synapses		
Chemical	Action at the synapse	Consequence
Neonicotinoids (pesticides)	Bind to acetylcholine receptors in the postsynaptic membrane of insect neurons. Unlike acetylcholine, they are not broken down by the enzyme in the synaptic cleft, so they stay bound and block synaptic transmission.	Paralysis and death of insects. They bind far more strongly to insect receptors than to mammalian ones, but they also harm useful insects such as bees.
Cocaine (drug)	Binds to the transporter proteins that take dopamine back into the presynaptic neuron, blocking reuptake of the neurotransmitter.	Dopamine builds up in the cleft and keeps stimulating postsynaptic neurons in the brain's reward pathways, causing euphoria and addiction.

Inhibitory postsynaptic potentials

Inhibitory neurotransmitters, such as GABA, bind to receptors that let negative ions (Cl^-) in or positive ions (K^+) out. The postsynaptic membrane becomes **hyperpolarized**: more negative than the resting potential. This **inhibitory postsynaptic potential** (IPSP) moves the membrane further from threshold, so an action potential is less likely.

Summation

- A postsynaptic neuron may receive synapses from many presynaptic neurons, some excitatory and some inhibitory.
- One EPSP is usually too small to reach threshold on its own.
- The effects add together (**summation**): EPSPs depolarize, IPSPs hyperpolarize, and the net change decides the outcome.
- The result is all-or-nothing: if the combined depolarization reaches the threshold potential, an action potential is generated; if not, there is no action potential.



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Summation: the neuron fires only if the combined EPSPs and IPSPs reach the threshold potential.

Exam tip: For an IPSP the guide's key word is hyperpolarized. Say the inside becomes more negative and the threshold is harder to reach.

Pain perception and consciousness Spec C2.2.15, C2.2.16 HL only

Perception of pain

1. Pain receptors are neurons with **free nerve endings** in the skin.
2. The nerve endings have **channels for positively charged ions**. They open in response to a stimulus such as high temperature, acid, or certain chemicals such as **capsaicin** in chilli peppers.
3. Positively charged ions enter the nerve ending and depolarize it until the threshold potential is reached.
4. Nerve impulses pass along the neurons to the brain.
5. Pain is perceived in the brain, not in the skin.

Capsaicin opens the same channels as high temperature, which is why chilli peppers feel hot even though they do not change the temperature of the mouth.

Consciousness as an emergent property

Consciousness is a property that **emerges** from the interaction of individual neurons in the brain. No single neuron is conscious. The property arises only from huge numbers of neurons (tens of billions in the human brain) interacting through their synapses.

Emergent properties are another example of the consequences of interaction: a whole system has properties that its parts do not have on their own, so they cannot be predicted by studying the parts separately.

Exam tip: Say pain is perceived in the brain. The receptors in the skin only generate nerve impulses.

Quick check

1. What are the two types of fibre that project from the cell body of a neuron?
2. How many sodium and potassium ions does one cycle of the sodium-potassium pump move?
3. Why can a signal only pass one way across a synapse?
4. What ion enters the presynaptic neuron and triggers neurotransmitter release?
5. **HL only** Where are ion pumps and channels clustered in a myelinated fibre?

Quick check answers

Neural signalling

1. One long axon and multiple shorter dendrites.
2. Three Na^+ out and two K^+ in, using one ATP.
3. Only the presynaptic neuron releases neurotransmitter, and only the postsynaptic membrane has receptors for it.
4. Calcium ions (Ca^{2+}).
5. At the nodes of Ranvier.