



Neural signalling

Revision notes · IB Biology neural signalling: neurons, resting and action potentials, the speed of nerve impulses and synapses.

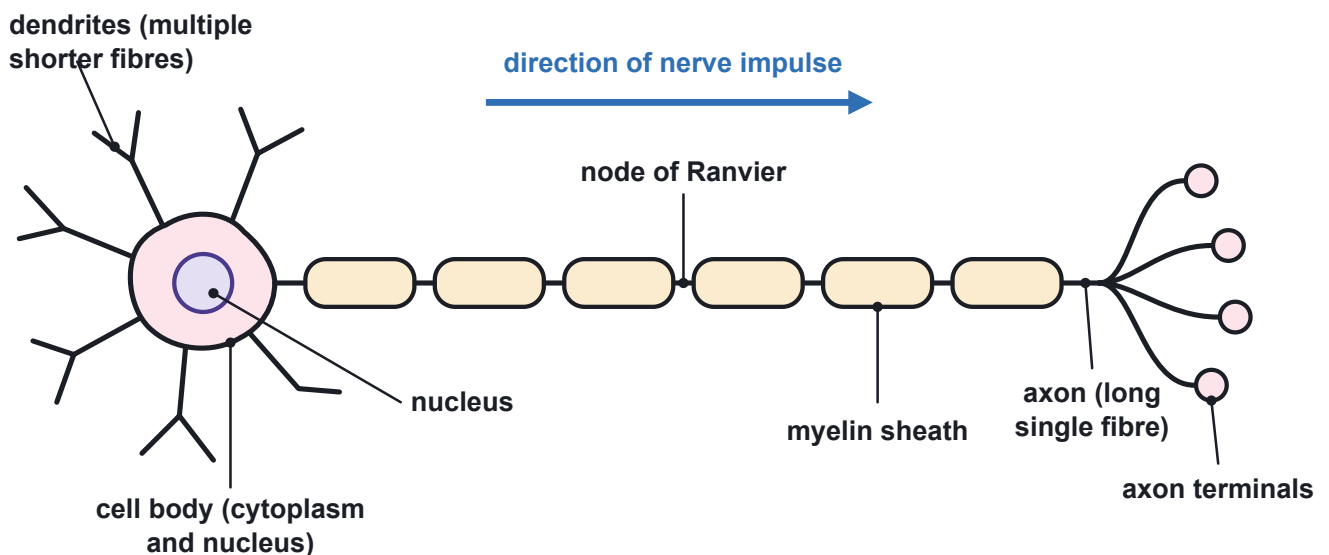
For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

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.

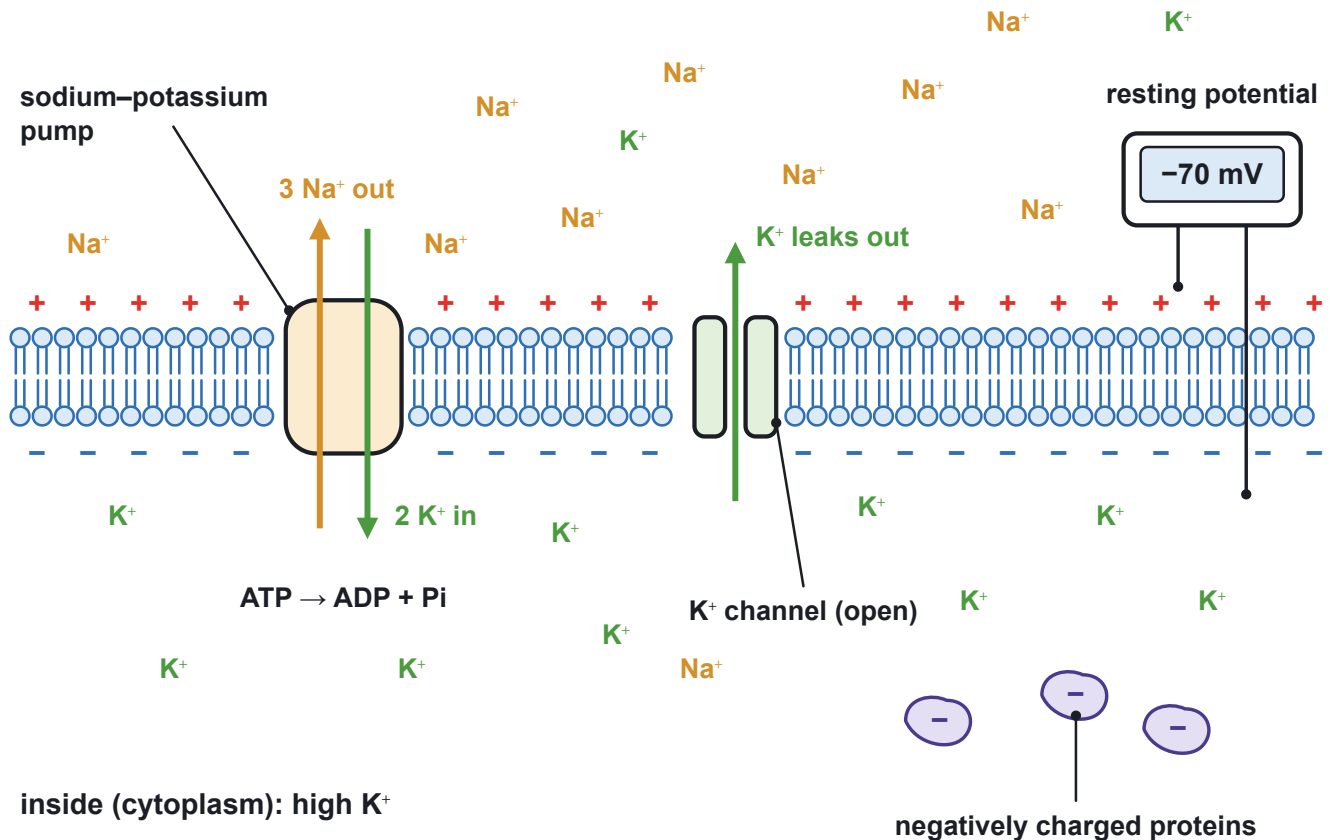
The resting potential

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^+



inside (cytoplasm): high K^+

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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.

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.

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.

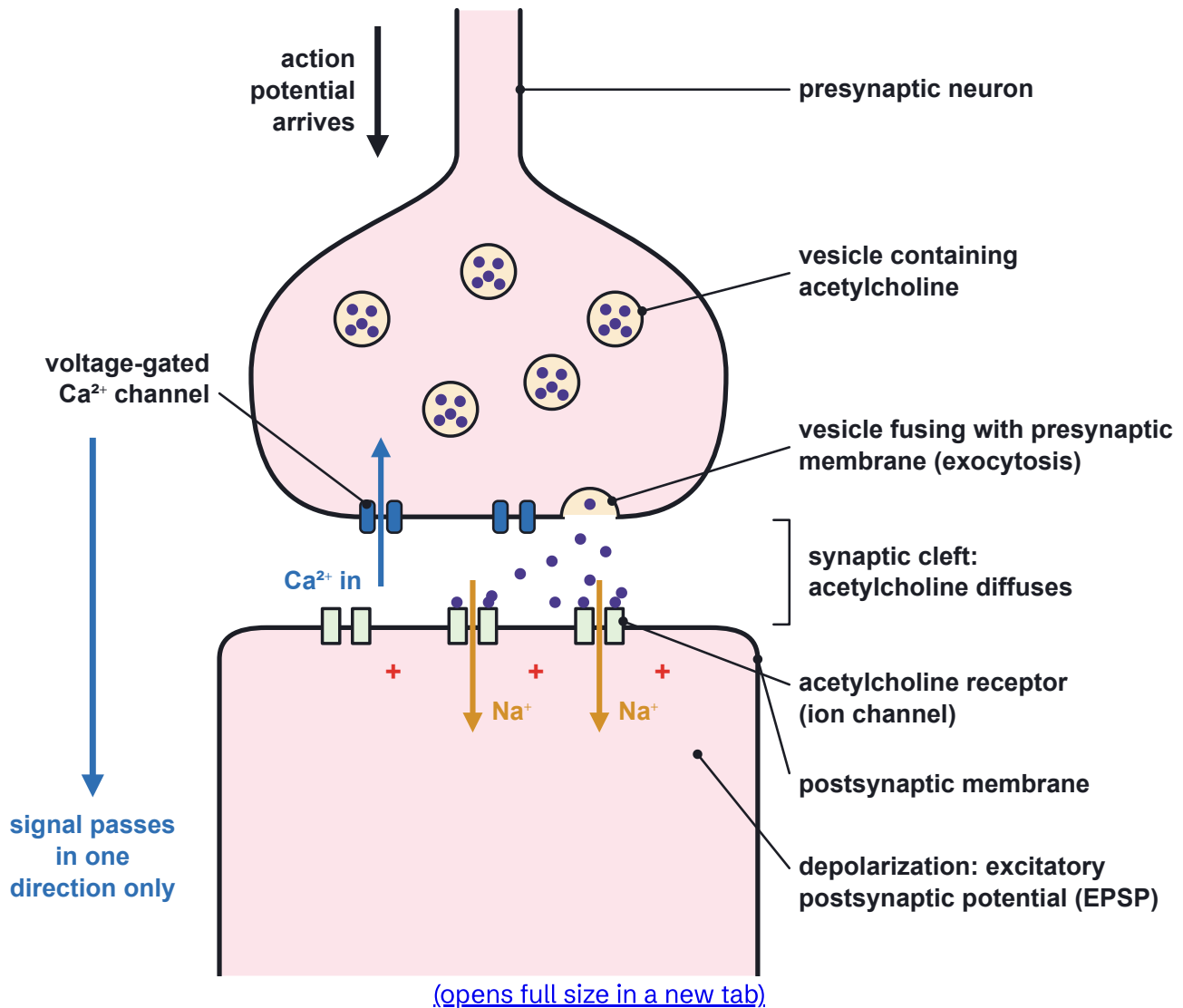
2. Voltage-gated calcium channels open and Ca^{2+} diffuses into the presynaptic neuron (it is more concentrated outside).
3. Inside the neuron, **calcium ions act as a signalling chemical**: they cause vesicles of neurotransmitter to move to the presynaptic membrane and fuse with it.
4. The neurotransmitter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

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?

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+}).