The Nervous System and Neurones

The nervous system helps organisms to respond to the environment, so you need to know a bit more about it...

The Nervous System Sends Information as Nerve Impulses

1) The **nervous system** is made up of a **complex network** of cells called **neurones**. There are **three main types** of neurone:
   - **Sensory neurones** transmit nerve impulses from **receptors** to the **central nervous system** (CNS) — the **brain** and **spinal cord**.
   - **Motor neurones** transmit nerve impulses from the **CNS** to **effectors**.
   - **Relay neurones** transmit nerve impulses **between** sensory neurones and motor neurones.

2) A stimulus is detected by **receptor cells** and a **nerve impulse** is sent along a **sensory neurone**.
3) When a **nerve impulse** reaches the end of a neurone chemicals called **neurotransmitters** take the information across to the **next neurone**, which then sends a **nerve impulse** (see p. 10).
4) The **CNS processes** the information, **decides what to do** about it and sends impulses along **motor neurones** to an **effector**.

Nerve impulses are electrical impulses. They're also called action potentials.

Stimulus	→	Receptors	→ sensory neurone →	CNS	→ motor neurone →	Effectors	→	Response
E.g. you see a friend **waving**.		**Light receptors** (photoreceptors) in your eyes **detect** the wave.		CNS **processes information** and **decides** what to do about it.		**Muscle cells** are stimulated by the motor neurones.		**Muscles contract** to make your arm **wave**.

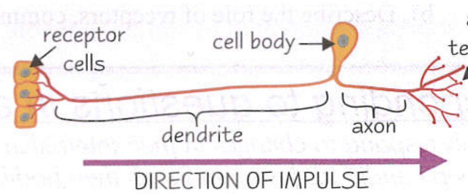
Sensory Receptors Convert Stimulus Energy into Nerve Impulses

1) **Different stimuli** have **different forms** of **energy**, e.g. light energy or chemical energy.
2) But your **nervous system** only sends information in the form of **nerve impulses** (electrical impulses).
3) **Sensory receptors convert** the energy of a **stimulus** into **electrical energy**.
4) So, sensory receptors act as **transducers** — something that **converts** one form of energy into another.
5) Here's a bit more about how receptor cells that communicate information via the **nervous system** work:

- When a nervous system receptor is in its **resting state** (not being stimulated), there's a **difference in charge** between the **inside** and the **outside** of the cell — this is generated by ion pumps and ion channels. This means there's a **voltage** across the membrane. Voltage is also known as **potential difference**.
- The **potential difference** when a cell is at **rest** is called its **resting potential**. When a stimulus is detected, the cell membrane is **excited** and becomes **more permeable**, allowing **more ions** to move **in** and **out** of the cell — **altering** the **potential difference**. The **change** in **potential difference** due to a stimulus is called the **generator potential**.
- A **bigger stimulus** excites the membrane more, causing a **bigger movement** of ions and a **bigger change** in potential difference — so a **bigger generator potential** is produced.
- If the **generator potential** is **big enough** it'll trigger an **action potential** (nerve impulse) along a neurone. An action potential is only triggered if the generator potential reaches a certain level called the **threshold** level.
- If the stimulus is **too weak** the generator potential **won't reach** the **threshold**, so there's **no action potential**.

You Need to Learn the Structure of Sensory Neurones...

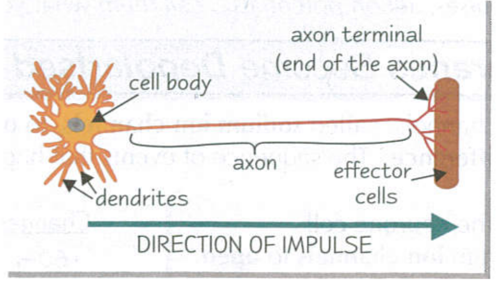
1) All neurones have a **cell body** with a **nucleus** (plus **cytoplasm** and all the other **organelles** you usually get in a cell).
2) The cell body has **extensions** that **connect** to **other neurones** — **dendrites** carry nerve impulses **towards** the **cell body**, and **axons** carry nerve impulses **away** from the **cell body**.
3) Sensory neurones have **one long dendrite** that carries nerve impulses from **receptor cells** to the **cell body**, and **one short axon** that carries nerve impulses from the **cell body** to the **CNS**.



The Nervous System and Neurones

...and Motor Neurones

Motor neurones have **many short dendrites** that carry nerve impulses from the **central nervous system** (**CNS**) to the **cell body**, and **one long axon** that carries nerve impulses from the **cell body** to **effector cells**.



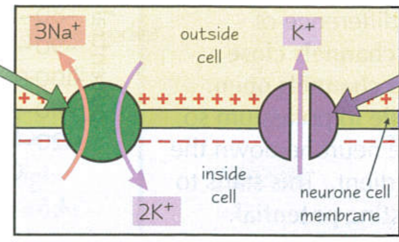
This is a non-myelinated motor neurone — see p. 9 for the structure of a myelinated one.

Neurone Cell Membranes are Polarised at Rest

1) In a neurone's **resting state** (when it's not being stimulated), the **outside** of the membrane is **positively charged** compared to the **inside**. This is because there are **more positive ions outside** the cell than inside.
2) So the membrane is **polarised** — there's a **difference in charge**.
3) The voltage across the membrane when it's at rest is called the **resting potential** — it's about **–70 mV**.
4) The resting potential is created and maintained by **sodium-potassium pumps** and **potassium ion channels** in a neurone's membrane:

Sodium-potassium pump

These pumps use **active transport** to move **three sodium ions** (Na^+) **out** of the neurone for every **two potassium ions** (K^+) moved **in**. **ATP** is needed to do this.



Potassium ion channel

These channels allow **facilitated diffusion** of **potassium ions** (K^+) **out** of the neurone, down their **concentration gradient.**

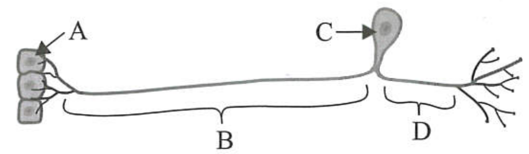
- The sodium-potassium pumps move **sodium ions out** of the neurone, but the membrane **isn't permeable** to **sodium ions**, so they **can't diffuse back in**. This creates a **sodium ion electrochemical gradient** (a **concentration gradient** of **ions**) because there are **more** positive sodium ions **outside** the cell than inside.
- The sodium-potassium pumps also move **potassium ions in** to the neurone, but the membrane **is permeable** to **potassium ions** so they **diffuse back out** through potassium ion channels.
- This makes the **outside** of the cell **positively charged** compared to the inside.

Practice Questions

Q1 What is the function of a motor neurone?

Q2 What do sensory receptors convert energy into?

Q3 Name the pumps and channels that maintain a neurone's resting potential.



Exam Question

Q1 Bright light causes circular iris muscles in an animal's eyes to contract, which constricts the pupils and protects the eyes. Describe and explain the roles of receptors and effectors for this response. [5 marks]

Q2 The diagram above is of a sensory neurone. Name parts A to D. [4 marks]

Vacancy — talented gag writer required for boring biology topics...

Actually, it's not that boring, it's just all the stuff about sensory receptors and resting potentials can be a bit tricky to get your head around. Just take your time and try scribbling it all down a few times till it starts to make some kind of sense. Then you can finish off by drawing loads of sensory and motor neurones, until you can label them in your sleep.

Action Potentials

Electrical impulses, nerve impulses, action potentials... call them what you will, you need to know how they work.

Neurone **Cell Membranes** *Become* **Depolarised** *when they're* **Stimulated**

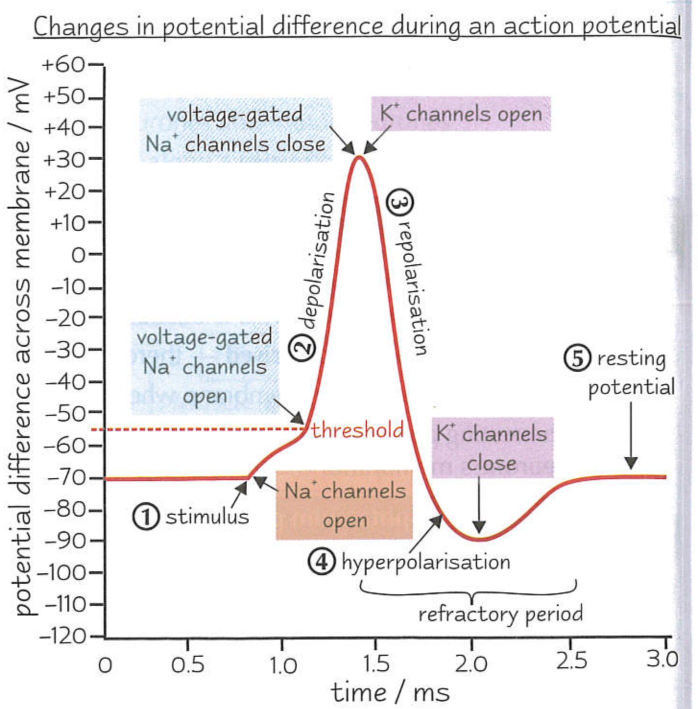
A **stimulus** triggers other ion channels, called **sodium ion channels**, to **open**. If the stimulus is big enough, it'll trigger a **rapid change** in **potential difference**. The sequence of events that happen are known as an **action potential**:

① **Stimulus** — this **excites** the neurone cell membrane, causing **sodium ion channels** to **open**. The membrane becomes **more permeable** to sodium, so **sodium ions diffuse into** the neurone down the sodium ion electrochemical gradient. This makes the **inside** of the neurone **less negative**.

② **Depolarisation** — if the potential difference reaches the **threshold** (around **–55 mV**), **voltage-gated sodium ion channels open**. **More sodium ions diffuse into** the neurone.

Voltage-gated ion channels open at a certain voltage.

③ **Repolarisation** — at a potential difference of around **+30 mV** the **sodium ion channels close** and **voltage-gated potassium ion channels open**. The membrane is **more permeable** to potassium so **potassium ions diffuse out** of the neurone down the potassium ion concentration gradient. This starts to get the membrane **back** to its **resting potential**.



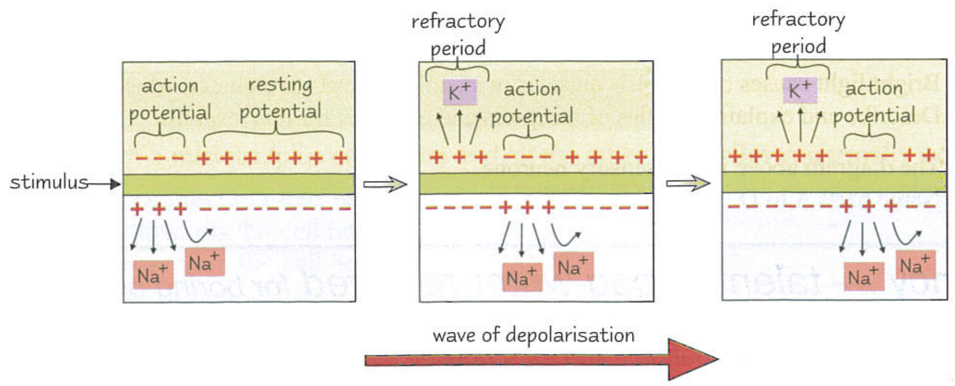
④ **Hyperpolarisation** — **potassium ion channels** are **slow to close** so there's a slight **'overshoot'** where too many potassium ions diffuse out of the neurone. The potential difference becomes **more negative** than the **resting potential** (i.e. less than –70 mV).

⑤ **Resting potential** — the ion channels are **reset**. The **sodium-potassium pump** returns the membrane to its **resting potential** and maintains it until the membrane's excited by another stimulus.

After an **action potential**, the neurone cell membrane **can't** be **excited** again straight away. This is because the ion channels are **recovering** and they **can't** be made to **open** — **sodium ion channels** are **closed** during repolarisation and **potassium ion channels** are **closed** during hyperpolarisation. This period of recovery is called the **refractory period**.

The **Action Potential** *Moves* **Along** *the* **Neurone** *as a* **Wave** *of* **Depolarisation**

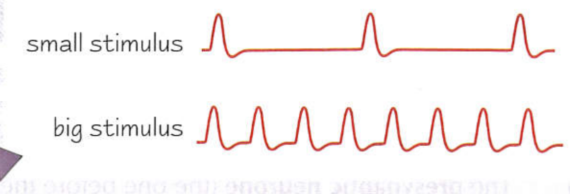
1) When an **action potential** happens, some of the **sodium ions** that enter the neurone **diffuse sideways**.
2) This causes **sodium ion channels** in the **next region** of the neurone to **open** and **sodium ions diffuse into** that part.
3) This causes a **wave of depolarisation** to travel along the neurone.
4) The **wave** moves **away** from the parts of the membrane in the **refractory period** because these parts **can't fire** an action potential.



Action Potentials

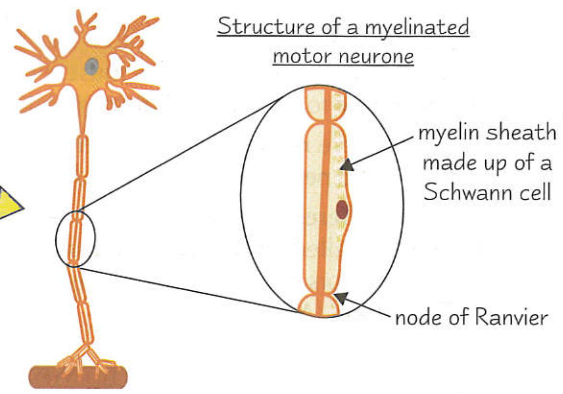
A **Bigger Stimulus** *Causes* **More Frequent Impulses**

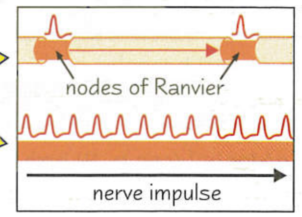
1) Once the threshold is reached, an action potential will **always fire** with the **same change in voltage**, no matter how big the stimulus is.
2) If **threshold isn't reached**, an action potential **won't fire**.
3) A **bigger stimulus** won't cause a bigger action potential, but it will cause them to fire **more frequently**.



Action Potentials *Go* **Faster** *in* **Myelinated Neurones**

1) Some neurones are **myelinated** — they have a **myelin sheath**.
2) The myelin sheath is an **electrical insulator**.
3) It's made of a type of cell called a **Schwann cell**.
4) Between the Schwann cells are tiny patches of **bare membrane** called the **nodes of Ranvier**. **Sodium ion channels** are **concentrated** at the nodes.
5) In a **myelinated** neurone, **depolarisation** only happens at the **nodes of Ranvier** (where sodium ions can get through the membrane).
6) The neurone's **cytoplasm conducts** enough electrical charge to **depolarise** the **next node**, so the impulse **'jumps'** from node to node.
7) This is called **saltatory conduction** and it's **really fast**.
8) In a **non-myelinated** neurone, the impulse travels as a **wave** along the **whole length** of the **axon membrane**.
9) This is **slower** than saltatory conduction (although it's still pretty quick).



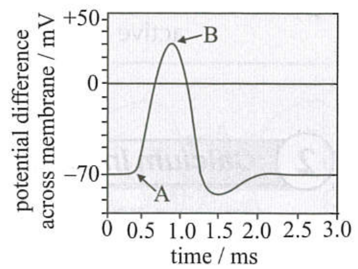


Practice Questions

Q1 Briefly describe how an action potential moves along a neurone.

Q2 What are nodes of Ranvier?

Exam Questions



Q1 The graph shows an action potential across an axon membrane following the application of a stimulus.

a) What label should be added at point A? [1 mark]

b) Explain what causes the change in potential difference between point A and point B. [3 marks]

c) A stimulus was applied at 1.5 ms, but failed to produce an action potential. Suggest why. [2 marks]

Q2 Multiple sclerosis is a disease of the nervous system characterised by damage to the myelin sheaths of neurones. Explain how this will affect the transmission of action potentials. [5 marks]

I'm feeling a bit depolarised after all that...

Action potentials are potentially confusing. The way I remember them is that polarisation is the difference in charge across the cell's membrane — during depolarisation that difference becomes smaller and during repolarisation it gets bigger again.

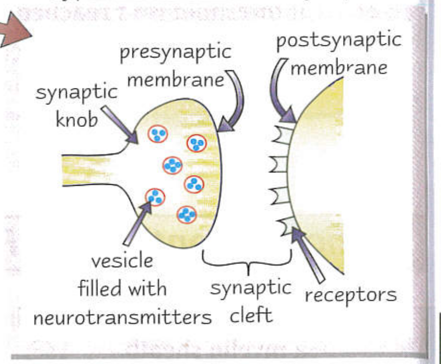
Synapses

When an action potential arrives at the end of a neurone the information has to be passed on to the next cell — this could be another neurone, a muscle cell or a gland cell.

A Synapse is a Junction Between a Neurone and the Next Cell

1) A **synapse** is the junction between a **neurone** and another **neurone**, or between a **neurone** and an **effector cell**, e.g. a muscle or gland cell.
2) The **tiny gap** between the cells at a synapse is called the **synaptic cleft**.
3) The **presynaptic neurone** (the one before the synapse) has a **swelling** called a **synaptic knob**. This contains **synaptic vesicles** filled with **chemicals** called **neurotransmitters**.
4) When an **action potential** reaches the end of a neurone it causes **neurotransmitters** to be **released** into the synaptic cleft. They **diffuse across** to the **postsynaptic membrane** (the one after the synapse) and **bind** to **specific receptors**.
5) When neurotransmitters bind to receptors they might **trigger** an **action potential** (in a neurone), cause **muscle contraction** (in a muscle cell), or cause a **hormone** to be **secreted** (from a gland cell).
6) Neurotransmitters are **removed** from the **cleft** so the **response** doesn't keep happening, e.g. they're taken back into the **presynaptic neurone** or they're **broken down** by **enzymes** (and the products are taken into the neurone).
7) There are many **different** neurotransmitters, e.g. **acetylcholine** (**ACh**) and **noradrenaline**. Synapses that use acetylcholine are called **cholinergic synapses**. Their structure is exactly the **same** as in the diagram above. They bind to receptors called **cholinergic receptors**, and they're broken down by an enzyme called **acetylcholinesterase** (**AChE**).

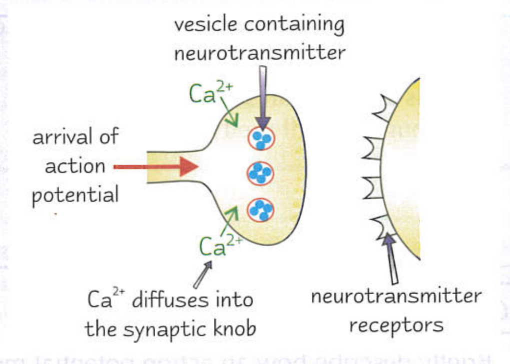
Typical structure of a synapse



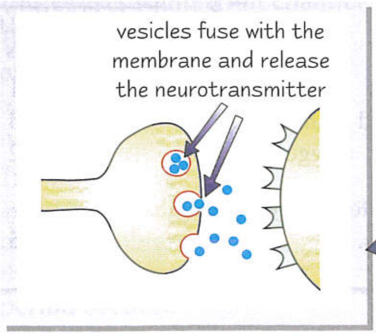
Here's How Neurotransmitters Transmit Nerve Impulses Between Neurones

1 An Action Potential Triggers Calcium Influx

1) An action potential (see p. 8) arrives at the **synaptic knob** of the **presynaptic neurone**.
2) The action potential stimulates **voltage-gated calcium ion channels** in the **presynaptic neurone** to **open**.
3) **Calcium ions diffuse into** the synaptic knob. (They're pumped out afterwards by active transport.)



2 Calcium Influx Causes Neurotransmitter Release

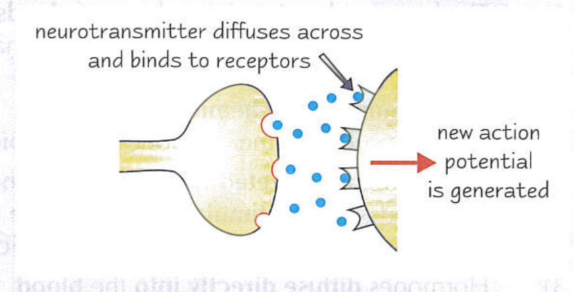


1) The influx of **calcium ions** into the synaptic knob causes the **synaptic vesicles** to **move** to the **presynaptic membrane**. They then **fuse** with the presynaptic membrane.
2) The **vesicles release** the neurotransmitter into the **synaptic cleft** — this is called **exocytosis**.

Synapses

3 The Neurotransmitter Triggers an Action Potential in the Postsynaptic Neurone

1) The neurotransmitter **diffuses** across the **synaptic cleft** and **binds** to specific **receptors** on the **postsynaptic membrane**.
2) This causes **sodium ion channels** in the **postsynaptic neurone** to **open**.
3) The **influx** of **sodium ions** into the postsynaptic membrane causes **depolarisation**. An **action potential** on the **postsynaptic membrane** is generated if the **threshold** is reached.
4) The **neurotransmitter** is **removed** from the **synaptic cleft** so the **response** doesn't keep happening.



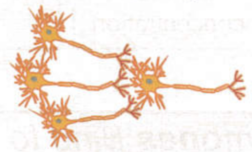
Synapses Play Vital Roles in the Nervous System

1 Synapses allow Information to be Dispersed or Amplified

1) When **one** neurone **connects** to **many** neurones information can be **dispersed** to **different parts** of the body. This is called **synaptic divergence**.
2) When **many** neurones **connect** to **one** neurone information can be **amplified** (made stronger). This is called **synaptic convergence**.

Impulses diverge

Impulses converge



2 Summation at Synapses Finely Tunes the Nervous Response

If a stimulus is **weak**, only a **small amount** of **neurotransmitter** will be released from a neurone into the synaptic cleft. This might not be enough to **excite** the postsynaptic membrane to the **threshold** level and stimulate an action potential. **Summation** is where the effect of neurotransmitter released from **many neurones** (or **one** neurone that's stimulated **a lot** in a short period of time) is **added together**.

3 Synapses make sure Impulses are Transmitted One Way

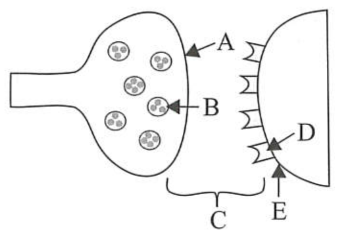
Receptors for neurotransmitters are **only** on the **postsynaptic** membranes, so synapses make sure **impulses** can only travel in **one direction**.

Practice Questions

Q1 Give one way that neurotransmitters are removed from the synaptic cleft.

Q2 What neurotransmitter do you find at cholinergic synapses?

Exam Questions



Q1 The diagram on the right shows a synapse. Label parts A-E. [5 marks]

Q2 Describe the sequence of events from the arrival of an action potential at the presynaptic membrane of a synapse to the generation of a new action potential at the postsynaptic membrane. [6 marks]

Synaptic knobs and clefts — will you stop giggling at the back...

Some more pretty tough pages here, aren't I kind to you. And lots more diagrams to have a go at drawing and re-drawing. Don't worry if you're not the world's best artist, just make sure you add labels to your drawings to explain what's happening.