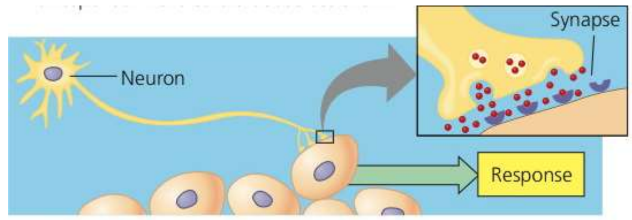
SLE 132 – Form and Function
The Nervous System

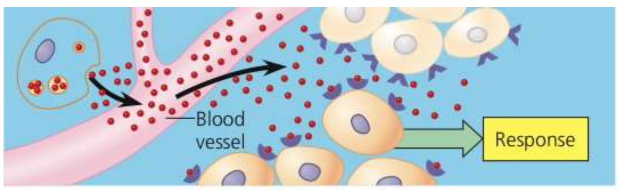
The Nervous system

- 2nd System of internal communication and regulation
- Nervous and Endocrine Systems are Structurally, chemically and functionally related
  - Neurosecretory cells of nervous system secrete many hormones
  - Several hormones are signals in both systems
  - Many body functions regulated by both

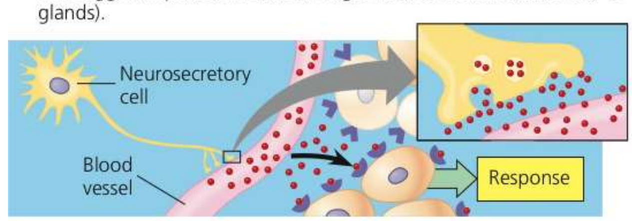
Nervous system is similar to endocrine system – both secrete chemicals



(d) In **synaptic signaling**, neurotransmitters diffuse across synapses and trigger responses in cells of target tissues (neurons, muscles, or glands).



(a) In **endocrine signaling**, secreted molecules diffuse into the bloodstream and trigger responses in target cells anywhere in the body.



(e) In **neuroendocrine signaling**, neurohormones diffuse into the bloodstream and trigger responses in target cells anywhere in the body.

Nervous and Endocrine System

Nervous System	Endocrine System
Chemicals over small distances (electrical over long distance)	Over large distances
Small amounts of chemicals released	Larger amounts of chemicals released
Fast response	Slow response
Transitory response	Prolonged response
Target is a limited number of cells	Targets all cells capable of responding

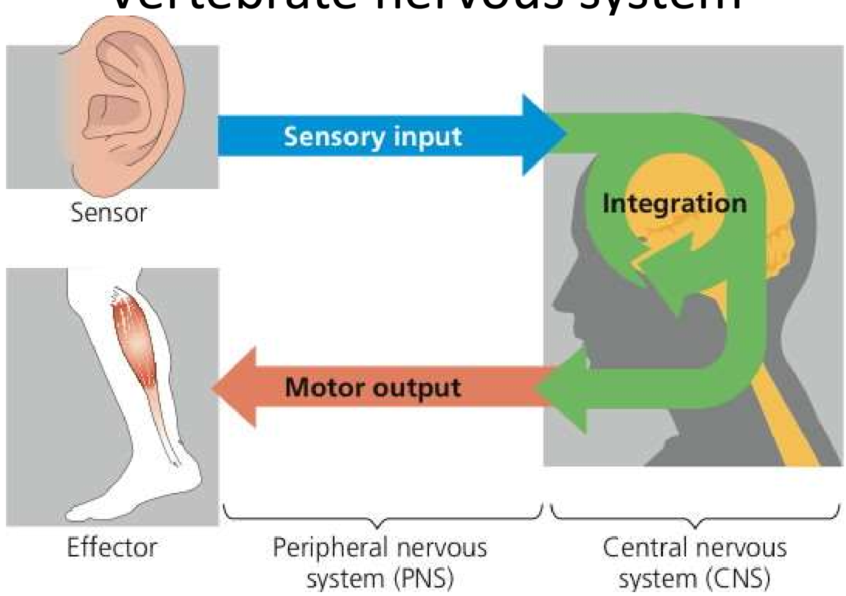
Nervous system works together with endocrine system to regulate internal body function and behaviour

STIMULUS		RESPONSE
External	→	behavioural
or internal		(external) or internal

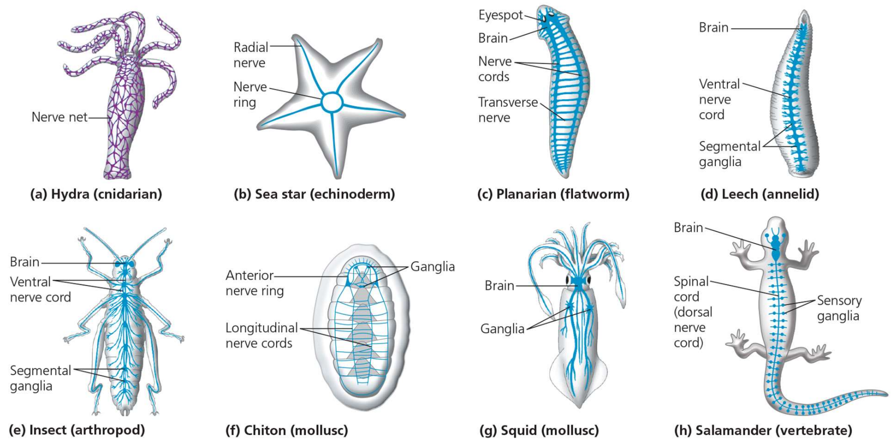
Example:

Increased blood CO_2	→	Increased breathing rate
Drop in blood pressure		increase in heart rate

Vertebrate nervous system



Most animals have a nervous system



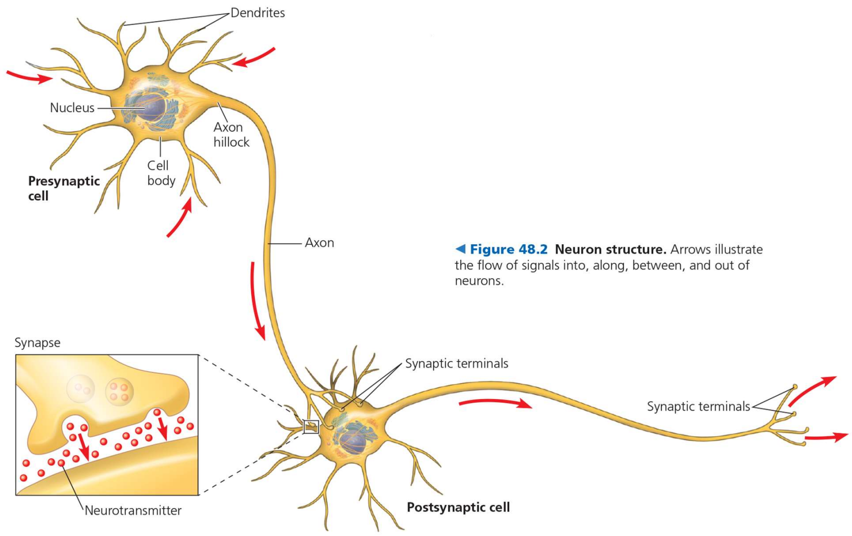
(a) Hydra (cnidarian) **(b) Sea star (echinoderm)** **(c) Planarian (flatworm)** **(d) Leech (annelid)** **(e) Insect (arthropod)** **(f) Chiton (mollusc)** **(g) Squid (mollusc)** **(h) Salamander (vertebrate)**

A network of specialised cells able to conduct an electrical signal, secretory cells and supporting cells

The basic structural unit is the neuron

- A neuron is made up of
  - **Cell body** with nucleus and other cellular organelles
  - **Dendrites** – carry signals toward cell body
  - **Axon** – carry signals away from the cell body. Also contains cytoskeletal fibres
  - **Synaptic knobs** – contain vesicles with neurotransmitter
- A bundle of neurons is called a nerve

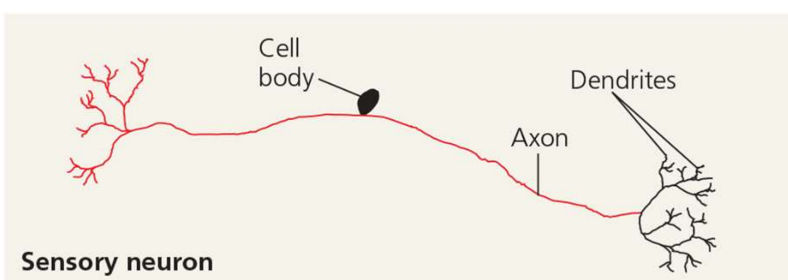
A neuron is made up of.........



◀ **Figure 48.2 Neuron structure.** Arrows illustrate the flow of signals into, along, between, and out of neurons.

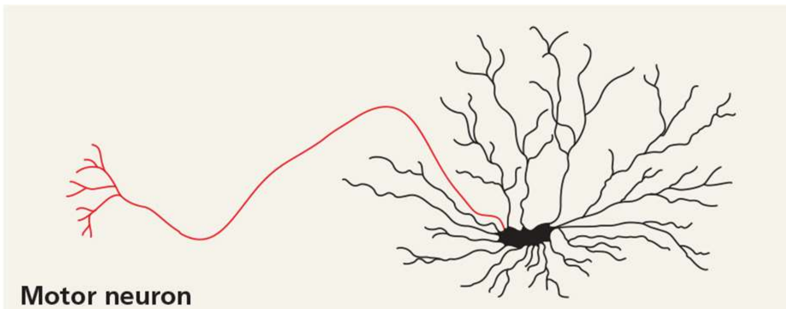
There are 3 functional types of neurons

- **Sensory Neurons**: Provide sensory input
  - Communicate information about the environment
    - both external and internal
  - from the sensory receptors to the Central Nervous System (CNS)



There are 3 functional types of neurons

- **Motor neurons**
  - Convey the signals from the CNS to the effector cells e.g. Muscle cell



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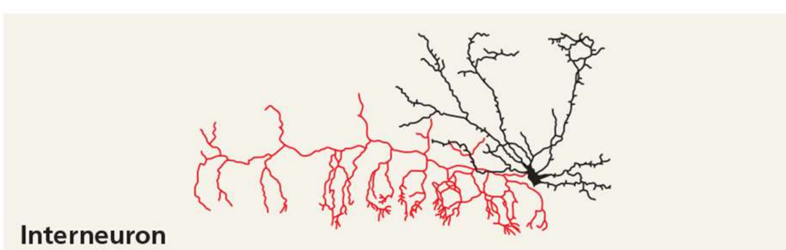
There are 3 functional types of neurons

- **Inter-neurons**
  - Located entirely within the CNS
  - The integrate the sensory input
  - relay the appropriate response to the motor neurons
    - or to other interneurons



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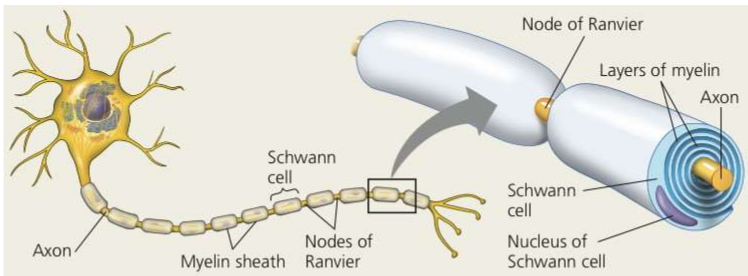
Other Cells support the neurons

Glial cells surround the neurons

- outnumber neurons by 10 – 50 times and are essential
  - Some help **nourish** the neurons
  - Others called **Schwann cells** – produce the myelin sheath which surrounds and insulates the neurons



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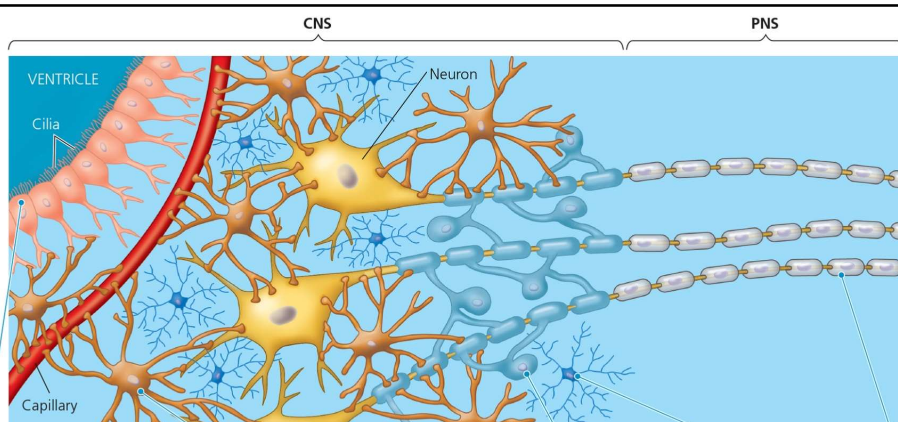

Ependymal cells line the ventricles of the brain (see Figure 49.5) and have cilia that promote circulation of the cerebrospinal fluid.

Astrocytes (from the Greek *astron*, star), found in the CNS, facilitate information transfer at synapses and in some instances release neurotransmitters. Astrocytes next to active neurons cause nearby blood vessels to dilate, increasing blood flow and enabling the neurons to obtain oxygen and glucose more quickly. Astrocytes also regulate extracellular concentrations of ions and neurotransmitters.

Oligodendrocytes myelinate axons in the CNS. Myelination greatly increases the conduction speed of action potentials.

Microglia are immune cells in the CNS that protect against pathogens.

Schwann cells myelinate axons in the PNS.

▲ **Figure 49.3** **Glia in the vertebrate nervous system.**

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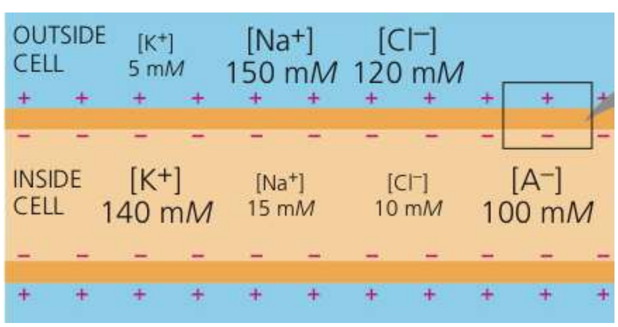
How neurons work

https://www.youtube.com/watch?v=wcdWs_sr7-Y

How does the nervous system send a message?

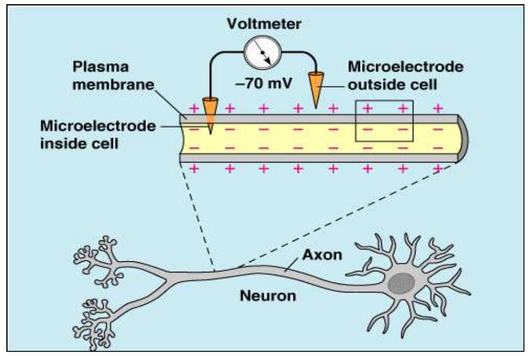
- A resting neuron is more negatively charged inside than outside



- A potential difference in charge exists across its membrane of 70 mV
- Neuron is said to have a resting membrane potential of -70mV

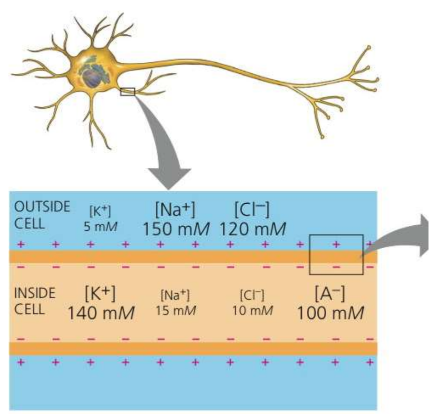
The resting membrane Potential is – 70mV

- Think of this difference in charge as a store of potential energy
- The nervous system works by altering this potential



How is this membrane potential formed?

1. **Unequal distribution of ions across the membrane**
   – Proteins (A-) inside (negative charge)
   – Na^+ (sodium) ions more concentrated outside
   – K^+ (potassium) ions are more concentrated inside



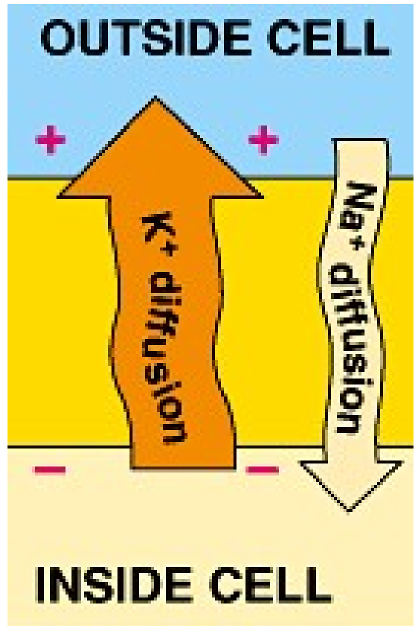
(a) The values shown represent the approximate concentrations in millimoles per liter (m*M*) for ions in the fluids within and surrounding a mammalian neuron: [K^+] = potassium concentration; [Na^+] = sodium concentration; [Cl^-] = chloride concentration; and [A^-] = other anions.

2. Differential permeability of membrane to ions

- Low permeability to Na^+
- K+ can move freely across (OUT)

Most of the membrane potential

- Movement of K+ out
- Presence of negatively charged proteins inside (can't move out)



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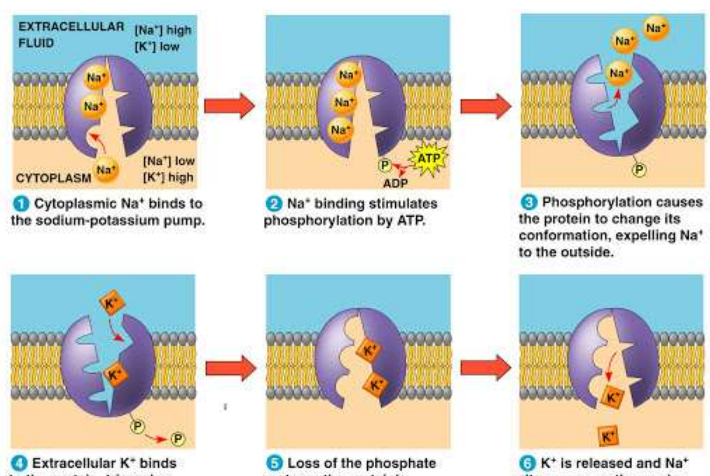
3. Sodium/Potassium Pump

- Na^+ is pumped out in exchange for K^+ which is pumped in
- Requires ATP
- This maintains the distribution across the membrane

3 Na^+ OUT

2 K^+ IN



1 Cytoplasmic Na+ binds to the sodium-potassium pump.

2 Na+ binding stimulates phosphorylation by ATP.

3 Phosphorylation causes the protein to change its conformation, expelling Na+ to the outside.

4 Extracellular K+ binds to the protein, triggering release of the phosphate group.

5 Loss of the phosphate restores the protein's original conformation.

6 K+ is released and Na+ sites are receptive again; the cycle repeats.

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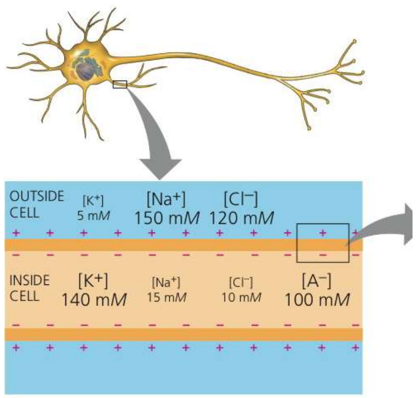
In summary…..



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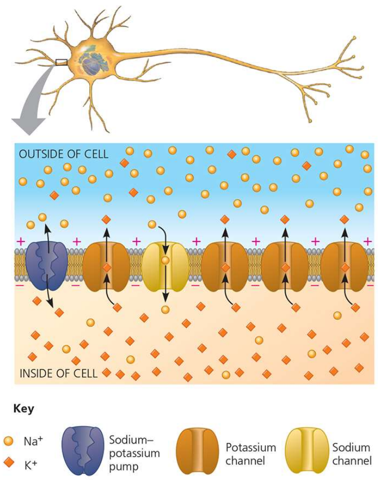


▲ **Figure 48.6 The basis of the membrane potential.** The sodium–potassium pump generates and maintains the ionic gradients of Na^+ and K^+ shown in Table 48.1. (Many such pump molecules are located in the plasma membrane of each cell.) Although there is a substantial concentration gradient of sodium across the membrane, very little net diffusion of Na^+ occurs because there are very few open sodium channels. In contrast, the many open potassium channels allow a significant net outflow of K^+. Because the membrane is only weakly permeable to chloride and other anions, this outflow of K^+ results in a net negative charge inside the cell.

Neurons have special "gated" ion channels

Na^+ and K^+ gated channels

- This is why neurons are excitable
- These channels respond to stimuli & change the neuron's membrane electrical potential
- If the stimulus is strong enough -opens the gates and triggers a dramatic change in distribution of ions (**sodium flows in**)

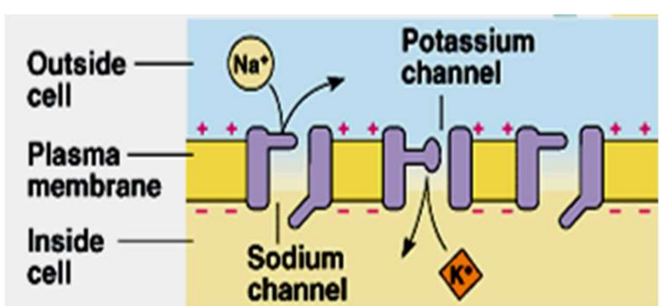


Fig. 48.13

A neuron is activated when….

- **A stimulus is applied** which opens the sodium gated ion channels and causes reversal of charge inside the membrane.
- If enough channels open, the potential reaches threshold.
- **Threshold Potential** is the depolarisation needed to generate a continuing, rapid change in membrane potential that propagates along the axon in one direction.

An activated neuron

- This rapid change in membrane potential is called an **ACTION POTENTIAL**
- Thus once threshold potential is reached, it triggers an action potential

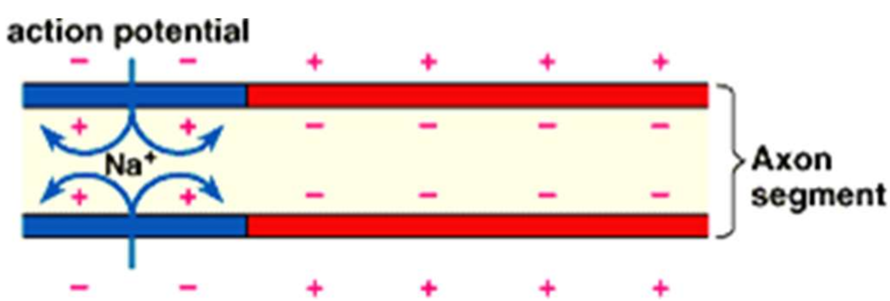
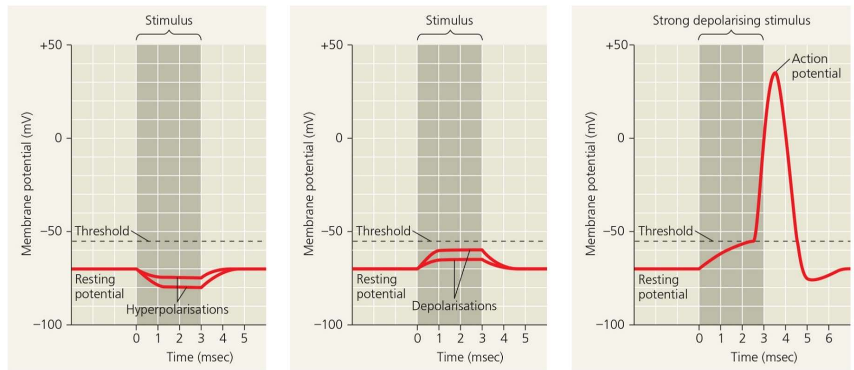


Fig. 48.14

An action potential is an **“all or none”** effect.

If threshold is reached, and action potential occurs.

If threshold is not reached there is no action potential



(a) **Graded hyperpolarisations produced by two stimuli that increase membrane permeability to K^+.** The larger stimulus produces a larger hyperpolarisation.

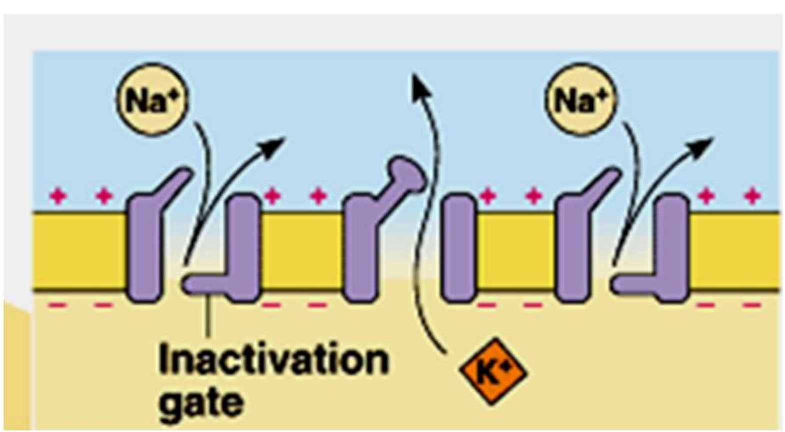
(b) **Graded depolarisations produced by two stimuli that increase membrane permeability to Na^+.** The larger stimulus produces a larger depolarisation.

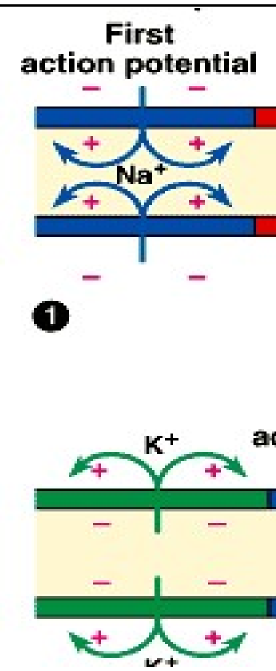
(c) **Action potential triggered by a depolarisation that reaches the threshold.**

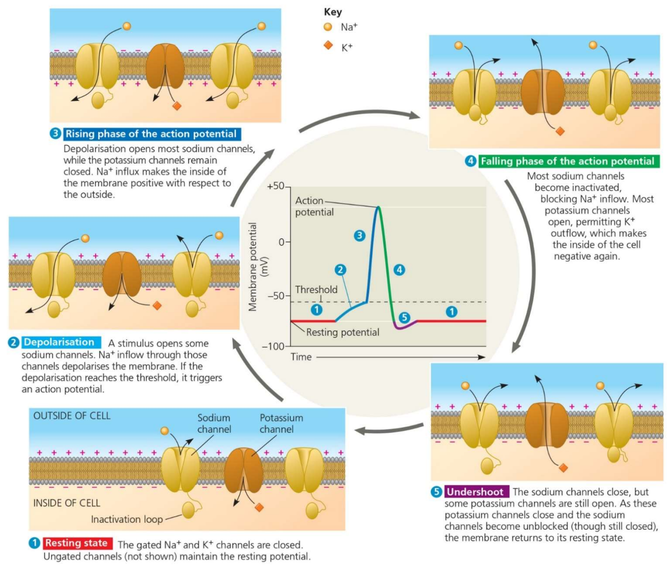
▲ **Figure 48.10 Graded potentials and an action potential in a neuron.**

DRAW IT *Redraw the graph in (c), extending the y-axis. Then label the positions of E_K and E_{Na}.*

Next:
Na^+ channels close
K^+ channels open
Membrane recovers to resting state







▲ **Figure 48.11 The role of voltage-gated ion channels in the generation of an action potential.** The circled numbers on the graph in the centre and the colours of the action potential phases correspond to the five diagrams showing voltage-gated sodium and potassium channels in a neuron's plasma membrane. (Ungated ion channels are not illustrated.)

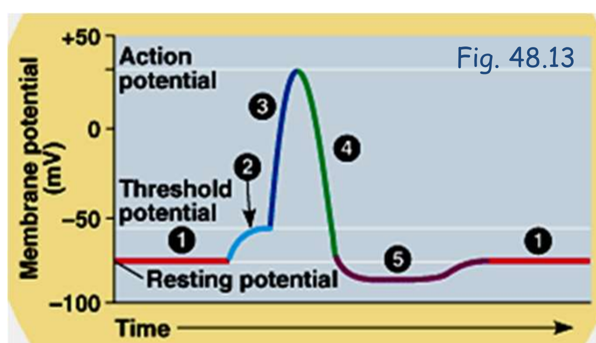
Four phases of an Action Potential

1. **Resting state** - The Na^+ and K^+ channels are both closed

2. & 3. **Depolarising state** - the potential across the membrane reverses (Gates open, Na^+ rushes in)

4. **Repolarising phase** - potential returns towards the resting level

5. **Overshoot (undershoot)** - the potential goes past the resting level briefly and returns to the resting level (prevents re stimulation for a short time)



Modelling membrane potential

- Draw a circle on a piece of paper to represent the cross section of an axon including
  - Na+/K+ pump
  - a closed Na+ gated channel
  - a closed K+ gated channel
- Place about:
  - 5 Na+ ions inside and 20 Na+ outside the cell
  - 20 K+ ions inside and 5 K+ outside the cell

How does an action potential move along an axon?

1. **Action potential present**
   - Na^+ channels open
   - Local spread of electrical charges changes to next part of membrane
2. This **opens Na^+ channels** in next part of membrane & an action potential is formed.
   - Behind the action potential, **Na^+ channels are closed & K^+ channels open** as membrane recovers.
3. **Action potential continues** to move along axon

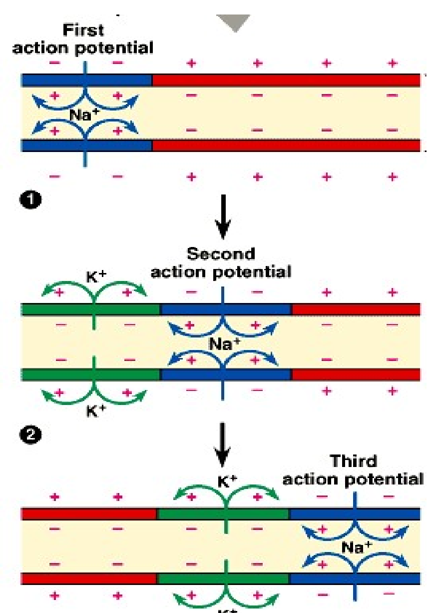
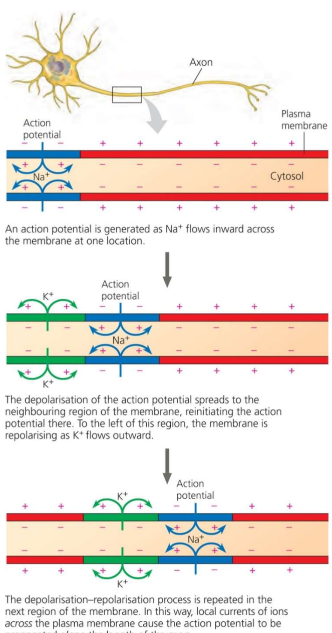


Fig. 48.14

Why doesn't the action potential move backwards?

- Action potentials only travel in one direction along the axon
- They are initiated near the cell body and spread from the site of initiation
- As they "travel" the membrane ahead is stimulated to depolarise the points behind are in **refractory period**
- In the refractory period the membrane is **insensitive to stimuli**



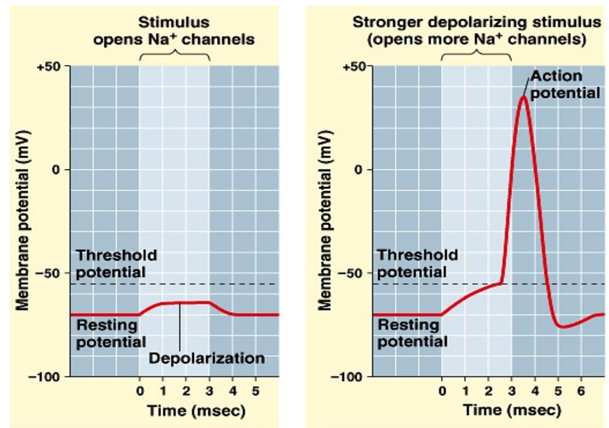
Why doesn't the action potential move backwards?

▲ **Figure 48.12 Conduction of an action potential.** This figure shows events at three successive times as an action potential passes from left to right. At each point along the axon, voltage-gated ion channels go through the sequence of changes shown in Figure 48.11. Membrane colours correspond to the action potential phases in Figure 48.11.

DRAW IT *For the axon segment shown, consider a point at the left end, a point in the middle, and a point at the right end. Draw a graph for each point showing the change in membrane potential over time at that point as a single nerve impulse moves from left to right across the segment.*

Characteristics of the action potential

- **Self-propagating** - Doesn't require ATP
- Is an **all-or -none** response
- In any neuron, it is always the same <u>shape, magnitude and duration</u>



b) Graded potential: depolarization

(c) Action potential

Fig. 48.12

What happens when the action potential reaches the end of the axon?

Information is passed to another cell by:

- **Electrical means** (not common)
  - The cells are connected by a tight junction
  - There is an actual <u>electrical continuity between the cells</u>
  - impulse travels from cell to cell without delay or loss of strength - <u>much quicker</u> *eg: flicking of crayfish tails*
- **Chemical means**
  - synaptic knob at end of axon <u>releases a chemical</u> which stimulates next cell

How Synapse Works

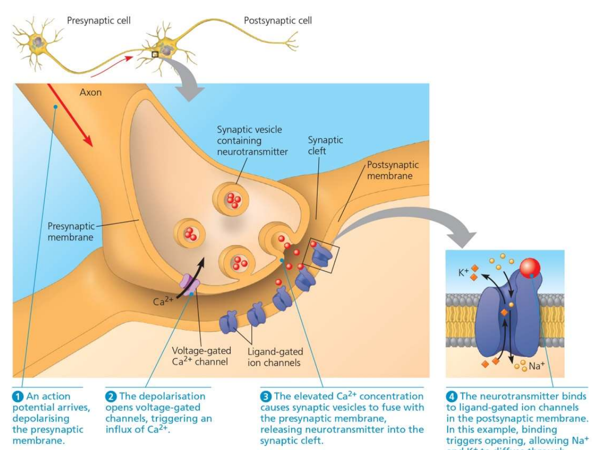
https://www.youtube.com/watch?v=Ibzfwtdtong

Chemical Synapses

1. **action potential** reaches synaptic knob

2. **depolarisation** opens gated channels that allow Ca^{2+} to enter synaptic knob

3. High Ca^{2+} concentration causes synaptic vesicles to fuse with the membrane and release of transmitter into the synaptic cleft



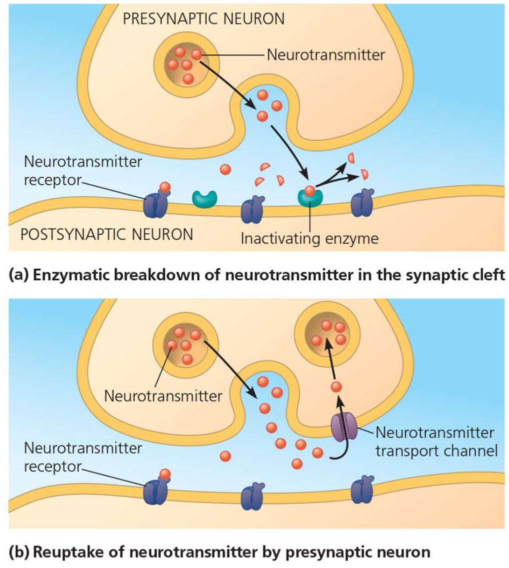
▲ **Figure 48.16 A chemical synapse.** This figure illustrates the sequence of events that transmits a signal across a chemical synapse. In response to binding of neurotransmitter, ligand-gated ion channels in the postsynaptic membrane open (as shown here) or, less commonly, close. Synaptic transmission ends when the neurotransmitter diffuses out of the synaptic cleft, is taken up by the synaptic terminal or by another cell, or is degraded by an enzyme.

WHAT IF? *If all the Ca^{2+} in the fluid surrounding a neuron were removed, how would this affect the transmission of information within and between neurons?*

4. <u>neurotransmitter moves across cleft</u> & attaches to receptors on membrane across the synapse.

5. attachment of neurotransmitter <u>opens the Na⁺ gated channels</u>, & produces an **action potential**

6. neurotransmitter is <u>broken down</u> by an enzyme



▲ **Figure 48.18** **Two mechanisms of terminating neurotransmission.**

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Neurotransmitters
(FYI, you don't need to remember these!)

- **Acetylcholine:** Memory, learning, muscles (sarin, botulinum-botox)
- **Glutamate:** CNS and PNS – long term memory
- **GABA:** inhibitory synapses in brain (Valium)
- **Endorphins:** natural analgesics (opium receptors)
- **Nitrous Oxide:** Blood vessel dilation (Viagra)

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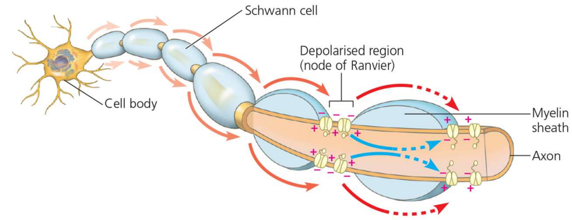
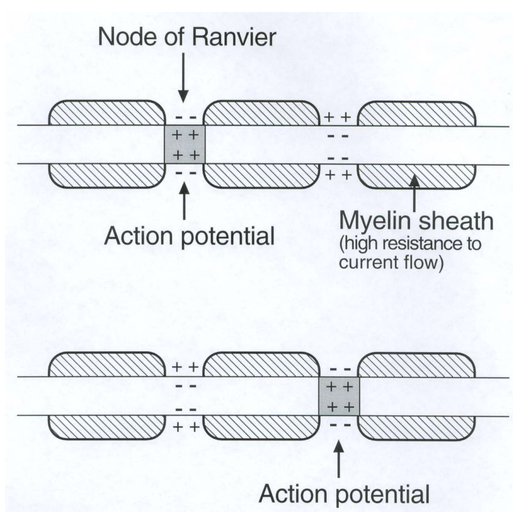
Speed of Conduction

- The larger the **diameter** of an axon, the faster the speed of conduction
  - *eg. Squid giant axon is 0.5 mm diameter (conduction 25m/sec)*
- Vertebrate axons have **myelin sheaths** to increase speed of conduction
  - Saltatory (jumping) conduction

▶ **Figure 48.14 Saltatory conduction.** In a myelinated axon, the depolarising current during an action potential at one node of Ranvier spreads along the interior of the axon to the next node (blue arrows), where voltage-gated sodium channels enable reinitiation. Thus, the action potential appears to jump from node to node as it travels along the axon (red arrows).



Saltatory conduction



Examples of conduction speeds in mammals

Speed of conduction is dependent on axon diameter and presence of myelin sheath

	Myelin Sheath	Diameter (mm)	Speed (m/s)
Motor neuron to leg	yes	0.2	120
Sensory neuron from skin	yes	.005	20
Motor neuron to heart	no	.001	2

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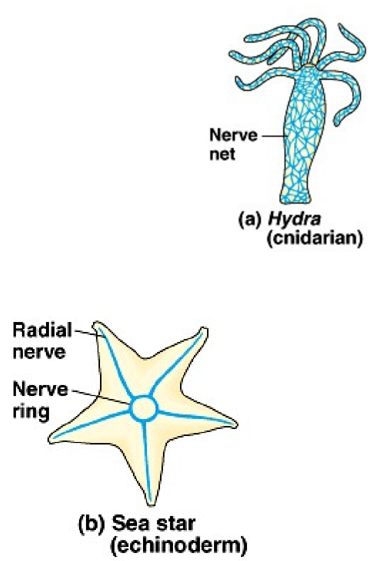
The structure of nervous systems

The function of nerves is similar in all animals, but their organisation varies

- **Hydra** - nerve net.
  Loosely organized network of neurons
  mainly with electrical synapses
  stimulus spreads like a ripple

- **Echinoderms** - nerves & nerve net
  – but no brain



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More complex animals have more complex nervous systems.
These animals show two features:

- **Centralization** = organization of the nervous system into clusters of cells (ganglia) and nerve cords
- **Cephalization** = development of anterior brain i.e. development of a Central Nervous System (CNS)

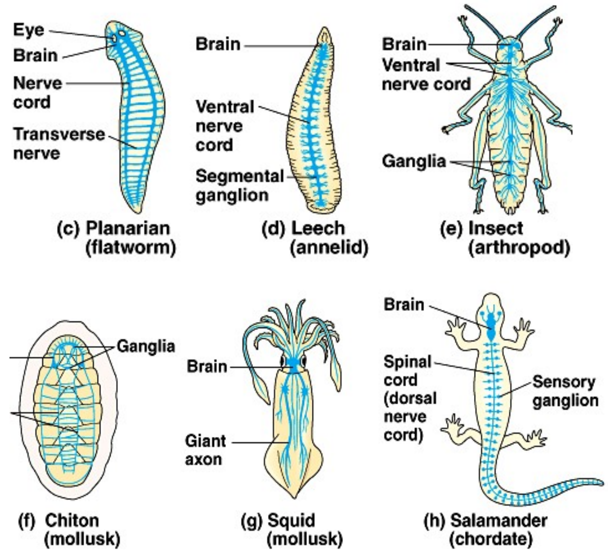

Fig. 48.15

Quick Question

1. The sodium-potassium pumps in neuron cells, pumps…….

a) Sodium and potassium into the cell
b) Sodium and potassium out of the cell
c) Sodium into the cell and potassium out of the cell
d) Sodium out of the cell and potassium into the cell

Quick Question

2. After an action potential, the resting potential is restored by

a) The opening of sodium ion gated channels
b) The opening of potassium ion gated channels and the closing of sodium ion gated channels
c) An increase in the membrane permeability to potassium and chloride ions
d) The delay in the action of the sodium potassium pump

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Quick Question

3. Saltatory conduction is a term applied to conduction of impulses

a) Across electrical synapses
b) Along the post synaptic membrane from dendrite to axon
c) In two directions at the same time
d) From one neuron to another
e) Along myelinated nerve fibres

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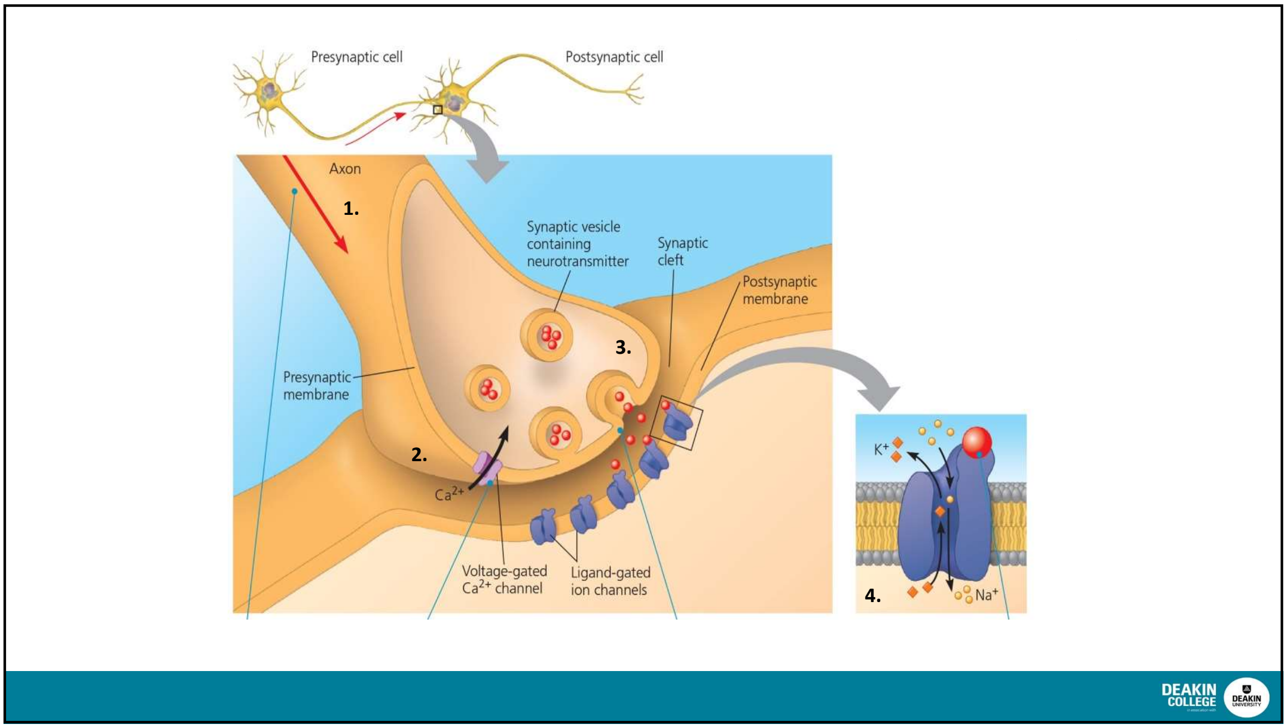
Presynaptic cell
Postsynaptic cell
Axon
1.
Synaptic vesicle containing neurotransmitter
Synaptic cleft
Postsynaptic membrane
3.
Presynaptic membrane
2.
Ca^{2+}
Voltage-gated Ca^{2+} channel
Ligand-gated ion channels
K^+
4.
Na^+
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