Neurophysiology for Allied Health Students

Book 1: The Basics

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Neurophysiology: The Basics Overview

Neurophysiology is all about how the nervous system communicates information. The nervous system is the master controller of bodily functions. The basic functional unit is the neuron and the neurons communicate within themselves and from one neuron to another to allow us to move, to think, to breathe, to read, to remember and to learn. So how do neurons and the nervous system do all of this?

This book is intended to help you understand the broad overview of how the nervous system works. Once complete you should be able to:

✤ Describe neuron and nerve structure

✤ Explain the ionic mechanism underlying membrane potential

✤ Describe how neurons use changes in membrane potential to communicate

✤ Describe the mechanism of neurotransmission at a chemical synapse

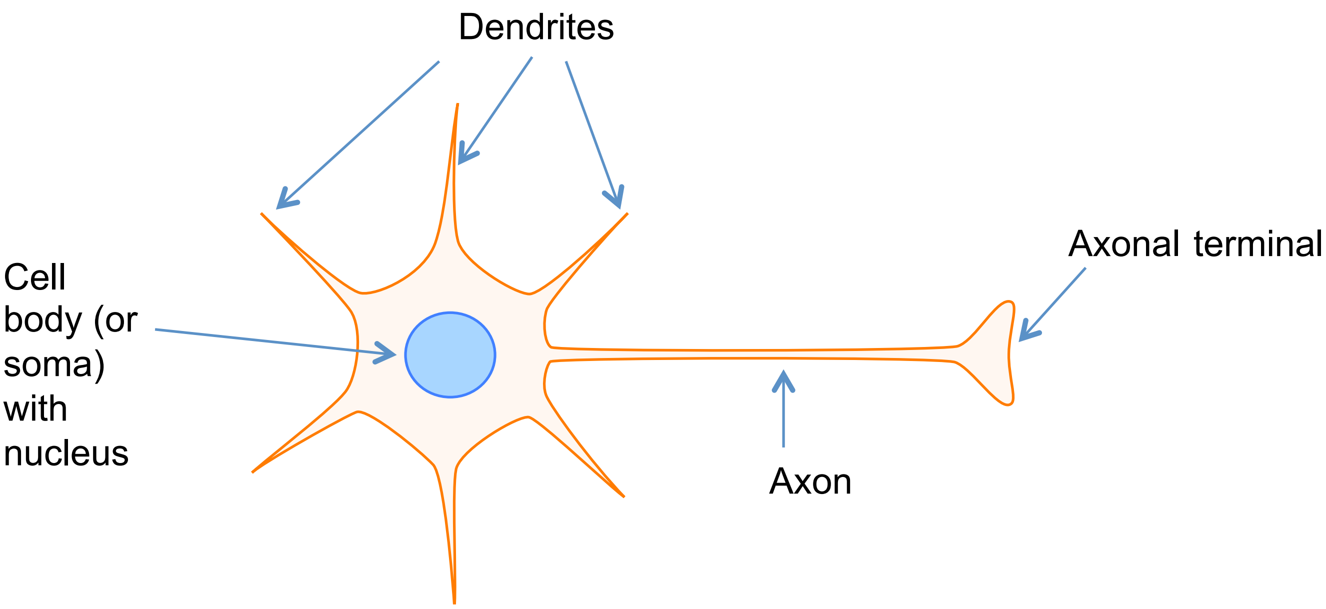
✤ Explain the importance of sodium, potassium and calcium ions to normal bodily function

Throughout the book there are animations you can click on the explain key concepts as well as a mini-quiz at the end of each section that you can use to check your understanding of the sections content

Part 1: Neuron and Nerve Structure

Neurons are specialised cells which have a cell body or soma containing the *cell nucleus.* Extending from the cell body are branch-like structures, the dendrites, and an axon (Figure 1).

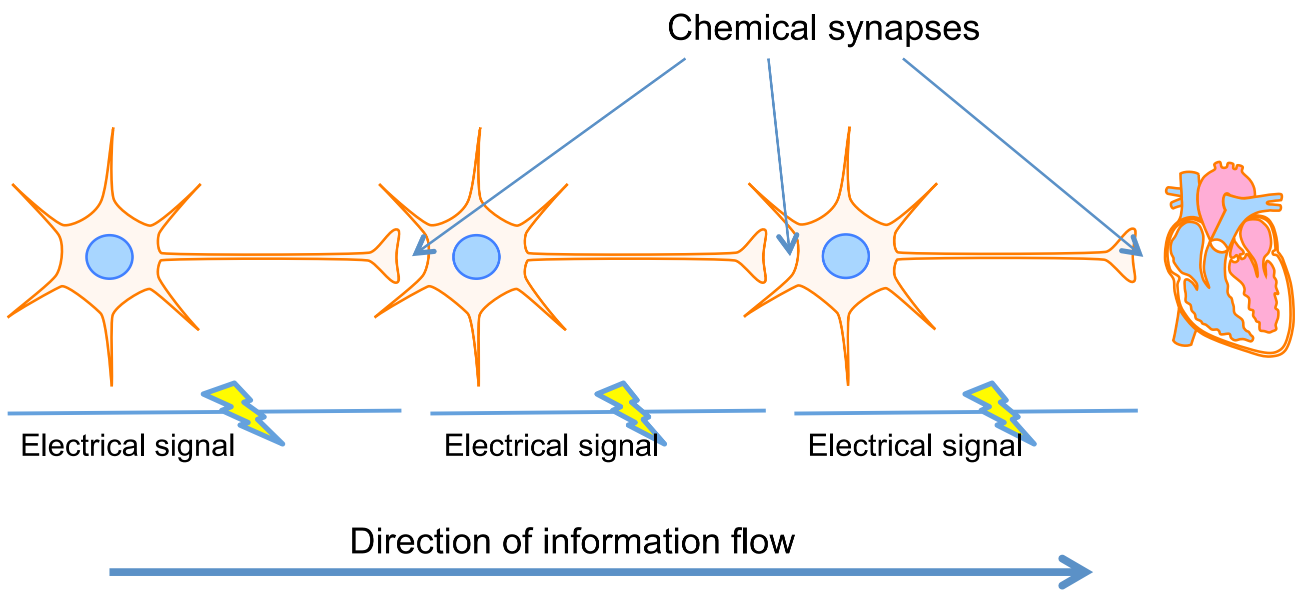
Figure 1: A Typical Neuron



This figure shows the structure of the cell body, dendrites, axon and axonal terminal of a typical motor neuron

Nerves are made up of groups of neurons which communicate with each other. Incoming information arrives at the dendrites of a neuron, is integrated in the cell body, and the output leaves the neuron via the axon. This information is in the form of an electrical current. The information is communicated from one neuron to the another neuron or cell via a chemical synapse (Figure 2)

Figure 2: Connected Neurons make a Nerve



A nerve is composed of multiple neurons joined together. The signal which travels from the cell body to the axonal terminal is electrical in nature. The signal travels from neuron to another neuron or cell via a chemical synapse.

Review 1.1 Check you understanding of part 1

Question 2 of 3

The neuronal cell body contains:

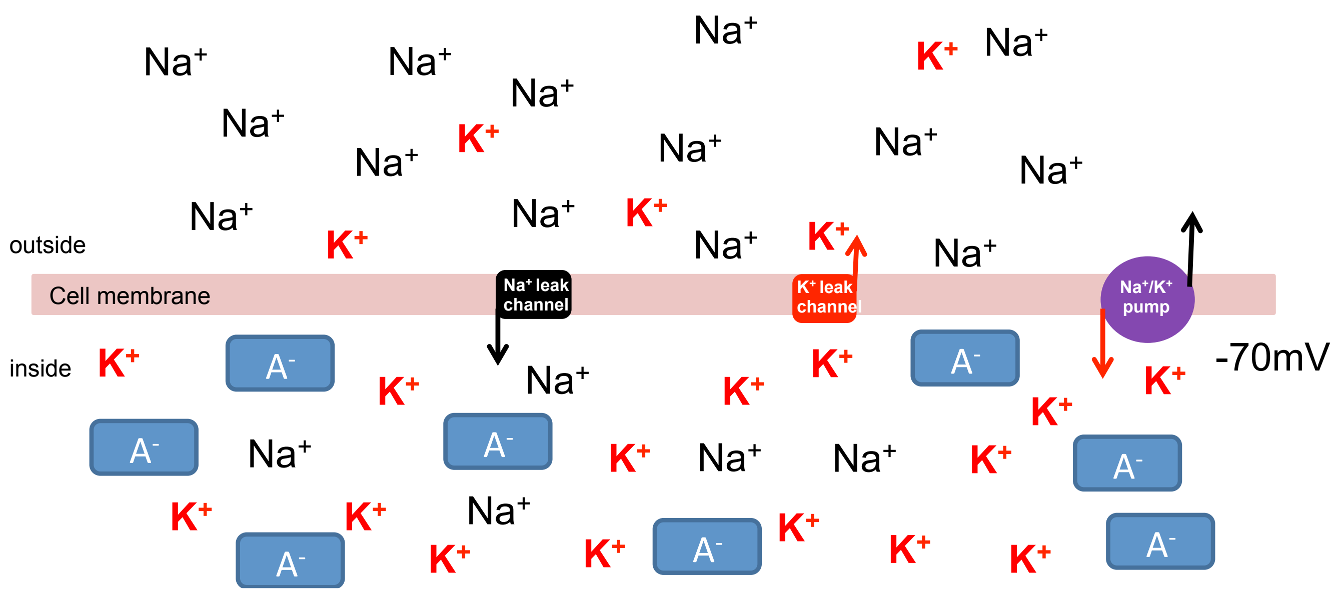
- **A.** the cell nucleus
- **B.** the roots of the dendrites
- **C.** the axon hillock
- ✓ **D.** all of the above

Check Answer

Part 2: The Electrical Current

The signal which travels from the dendrites of a neuron through the cell body, an don through the axon, is in the form of an electrical current. So where does this electrical current come from? It comes about because there is a specific distribution of ions across the *cell membrane.* The main ions involved are sodium (Na^+), potassium (K^+), and organic anions (A^-) such as proteins. The ionic concentrations across the membrane are: Na^+ high outside (150 mM) and low inside (5 mM); K^+ low outside (5 mM) and high inside (150 mM); and A^- high inside (100 mM) and negligible outside (Figure 3). This distribution means that if the membrane becomes *permeable* to a particular ion, the ion will cross the membrane *with its concentration gradient* and take its charge with it. It is this charge movement that makes up the electrical current that neurons use as signals. We can measure the voltage of this electrical current as a membrane potential.

Figure 3: Distribution of Ions Across the Membrane at Rest



The concentration of sodium (Na^+) is high outside and low inside; potassium (K^+) is low outside and high inside; and organic anions (A^-) is high inside and negligible outside. Na^+ and K^+ leak channels mean a measurable current at rest and the activity of the Na^+/K^+ pump maintains the ionic distribution. Resting membrane potential is -70 mV.

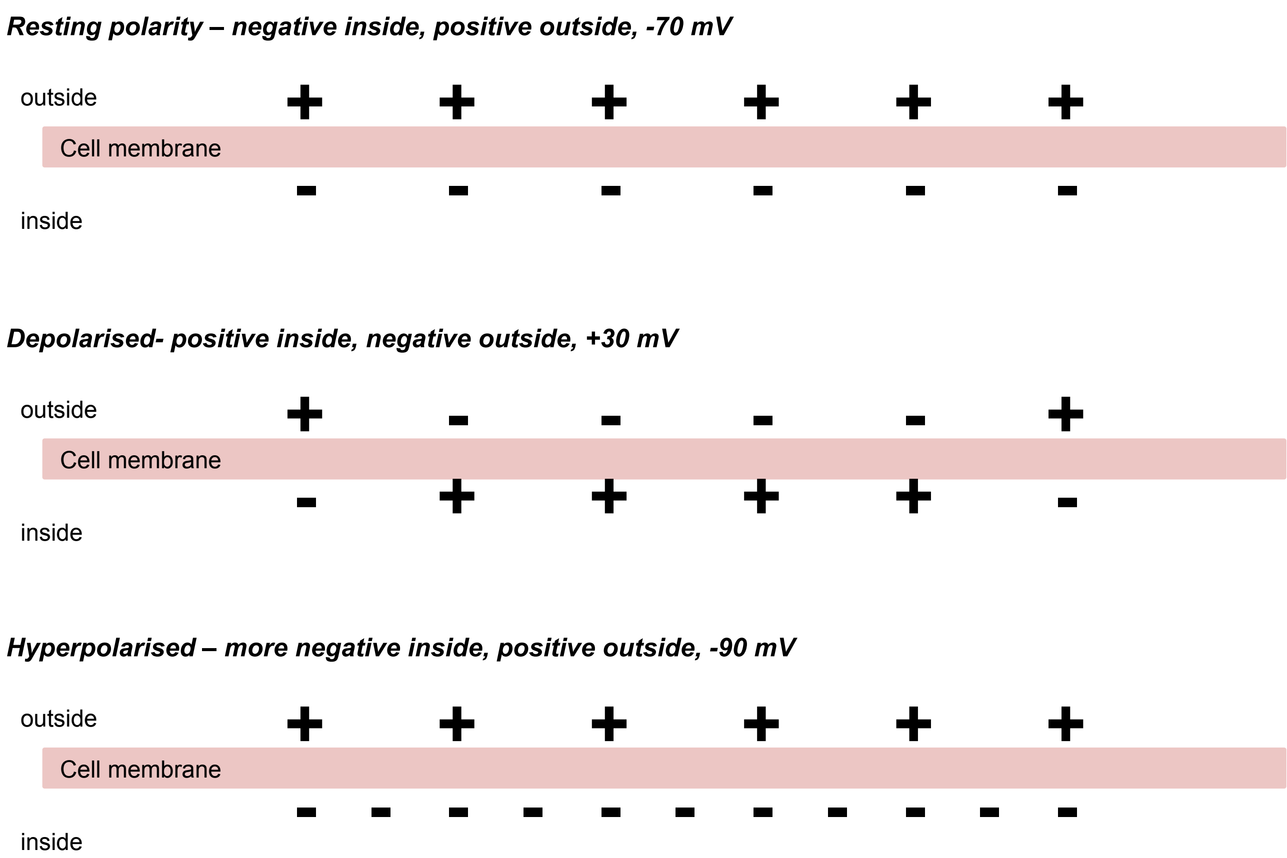
Resting Membrane potential

All cells have a resting membrane potential, which is the voltage measured across the cell membrane when it is not active. This comes about because there is a leak of Na^+ and K^+ ions across the membrane where Na^+ moves in to the cell and K^+ moves out of the cell.The activity of the Na^+/K^+ pump prevents this leak from dissipating the concentration gradient by actively pumping Na^+ and K^+ back into or out of the cell, against their concentration gradients. Resting membrane potential is measured at -70 mV for a typical neuron (Figure 3). The voltage is negative because there is a predominant negative charge inside the cell, if the voltage was positive it would mean that there was a predominant positive charge inside the cell. This means that at rest, cell membranes are *polarised* - they are negatively charged inside the membrane and positively charged outside the membrane (Figure 4).

Changes in Resting Membrane Potential

Neurons (and muscle cells) use changes in membrane potential as signals. There are two possible changes from resting potential - depolarising chnages and hyperpolarising changes (Figure 4). Depolarising changes occur when the inside of the cell becomes more positive than at rest; and are associated with cell excitation. These changes can occur if positively charged ions enter the cell or if negatively charged ions leave the cell. Depolarising changes effectively reverse the polarity of the membrane. Hyperpolarising changes occur when the inside of the cell becomes more negative than at rest; and are associated with cell inhibition. These changes can occur if positively charged ions leave the cell or if negatively charged ions enter the cell. Hyperpolarising changes effectively reinforce the polarity of the membrane.

Figure 4: Membrane Polarity



At rest, the cell membrane is polarised where it is negative inside, and positive outside, it is depolarised when it becomes positive inside and negative outside, it is hyperpolarised when it becomes more negative inside than it was at rest.

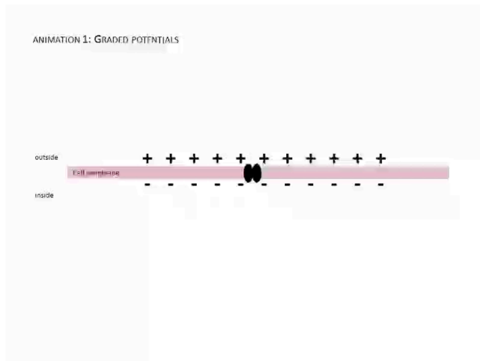
How Do Changes in Membrane Potential Happen?

Clearly, for changes in membrane potential to happen, the membrane must become permeable to ions somehow. These changes in permeability involve i*on channels*, which are specific for a particular ion and whose opening and closing can be controlled. These channel mediated changes in membrane potential can be passive or active changes, depending on the channels involved.

Passive Potentials

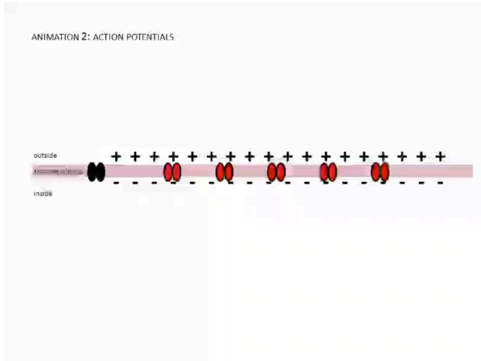
Passive, or graded, changes in membrane potential are local changes in potential which spread in all directions from the ion channel where they start, and which do not travel very far (Animation 1). The ion channels may be opened by physical *deformation* (ie from touch or pressure changes) or by a *ligand* binding to the channel. If the ion channel opened is a Na^+ channel, Na^+ will flow in to the cell with its concentration gradient and depolarise the cell membrane. If the ion channel opened is a K^+ channel, K^+ will flow out of the cell with its concentration gradient and hyperpolarise the cell membrane. Passive changes in membrane potential in their own right are not very useful as signals because they do not travel very far nor do they travel in a specific direction. However, they are very useful in the integration process where they ‘add up’ to *threshold* for generating an action potential.

Animation 1: A passive change in membrane potential



Action Potentials

Animation 2: Action potential

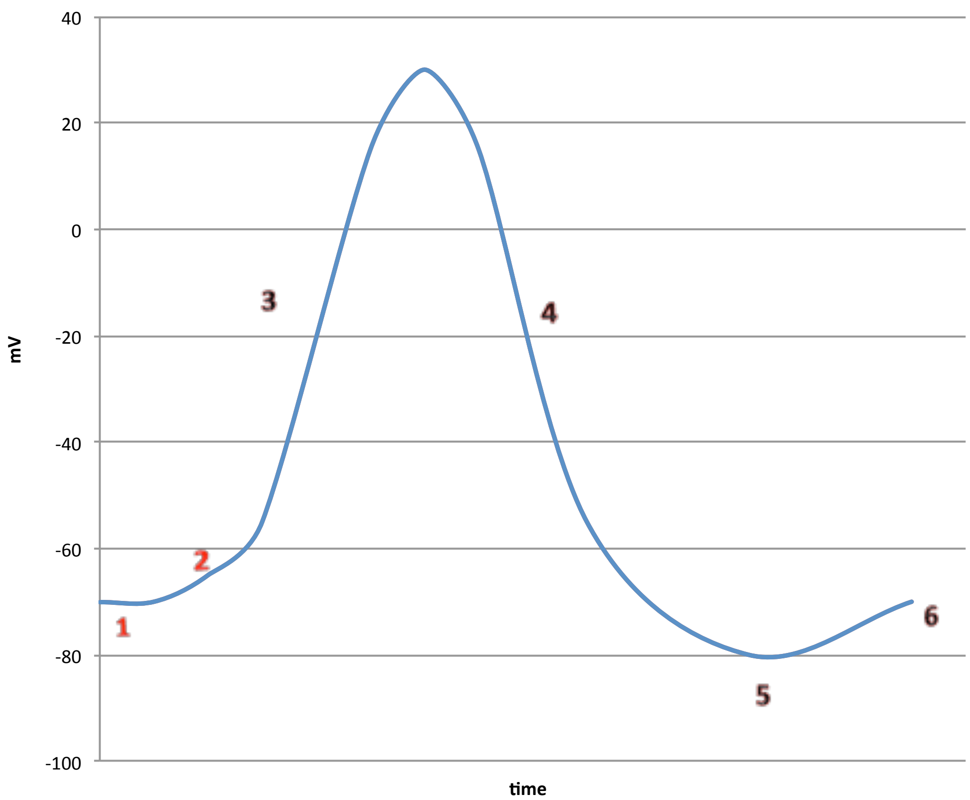


As you may have guessed, action potentials are able to travel in one direction over large distances (Animation 2). An action potential is a wave of depolarisation which travels from the *axon hillock* to the axon terminal.

The key difference between passive and action potentials is the Na^+ and K^+ ion channels involved. These ion channels are *voltage-gated*. The first voltage-gated Na^+ channel is opened once graded potentials add up to threshold. Once this channel is opened, the Na^+ flowing in depolarises the membrane to +30 mV (Figure 5), this depolarisation opens subsequent voltage-gated Na^+ channels and a wave of depolarisation flows along the membrane. This also means that action potentials are self-propagating - once one voltage-gated channel is opened, the other channels will automatically be opened as a consequence.

Voltage-gated K^+ channels open slightly later than the voltage-gated Na+ channels and the resulting K^+ influx brings the membrane back to and then beyond resting potential (to around -80 mV), before the Na^+/K^+ pumps take over to restore the concentration gradients and resting membrane potential. Action potentials only occur in the neuronal axon, because this is where the voltage-gated ion channels are located. Action potential end in the axonal terminal as there are no more voltage-gated Na^+ and K^+ channels present. The arrival of the action potential at the axonal terminal does however, initiate synaptic transmission.

Figure 5: An action potential voltage trace

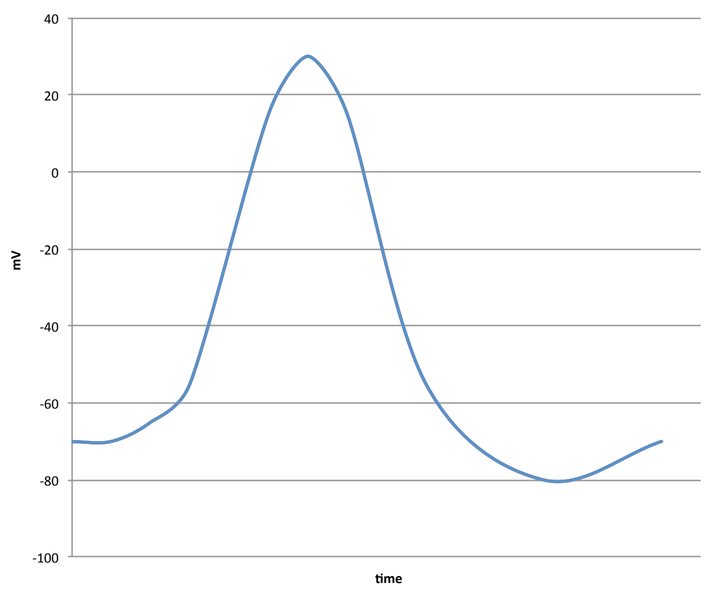


The action potential voltage trace measures the changes in potential at a point in the membrane as an action potential passes over it. It begins at -70 mV, resting potential (1), depolarises by15 mV when it reaches threshold (2), depolarises to a peak at +30 mV (3) and then repolarises (4) and beyond to hyperpolarisation (5) before restoring to resting potential (6)

Review 1.2 Check your understanding of part 2

Question 12 of 12

The depolarisation phase of the action potential trace below goes from:



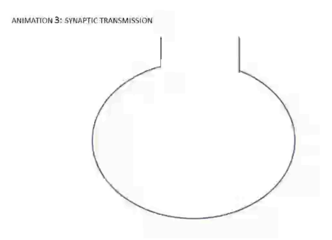
- A. -70 mV to -55 mV
- B. -55 mV to +30 mV ✓
- C. +30 mV to -70 mV
- D. -70 mV to -80 mV

Check Answer

Part 3: Synaptic Transmission

So far, we have explored the electrical signal which travels from one end of a neuron to the other. Remember though that nerves are comprised of multiple neurons joined together and for information to get from one end of the nerve to the other it needs to travel from one neuron to the next neuron (Figure 2). The information travels from one neuron to the next neuron or cell at a chemical synapse, via synaptic transmission, and the arrival of the action potential at the axon terminal signals the start of synaptic transmission.

Animation 3: Synaptic Transmission



There are some key features in the axon terminal and the synapse which facilitate synaptic transmission. These are: voltage-gated calcium (Ca^{2+}) channels, neurotransmitters packaged into vesicles, and neurotransmitter receptors on the post-synaptic membrane (Animation 3). When the action potential arrives at the axon terminal, it opens the voltage-gated Ca^{2+} channels and Ca^{2+} flows in to the cell. This increases the concentration of Ca^{2+} in the axon terminal which acts on the neurotransmitter filled vesicles, causing them to move toward and then dock with the pre-synaptic membrane. This docking causes the vesicles to release the neurotransmitter into the synaptic cleft via exocytosis. The neurotransmitter then binds with the receptors on the postsynaptic membrane . This binding of neurotransmitter to receptor causes a response in the postsynaptic cell which can be a change in membrane potential or a metabolic change, depending on the receptor. Synaptic transmission is then terminated by removal of the neurotransmitter from the cleft. Removal from the cleft can occur by enzyme breaking the neurotransmitter down or reuptake of the neurotransmitter into the presynaptic cell where is is recycled for further signaling.

Review 1.3 Check your understanding of section 3

Question 3 of 3

The response that the receiving cell makes in synaptic transmission is a property which of the following?

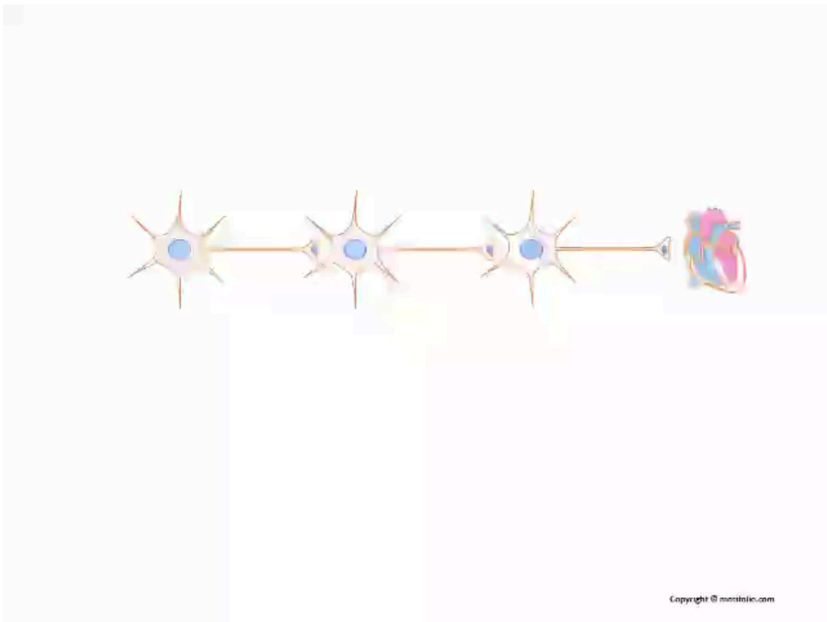
- **A.** Ca2+
- **B.** neurotransmitter
- **C.** receptor ✓
- **D.** vesicle

◀ Check Answer ▶

Summary

Animation 4 is a summary of the main points covered in this book

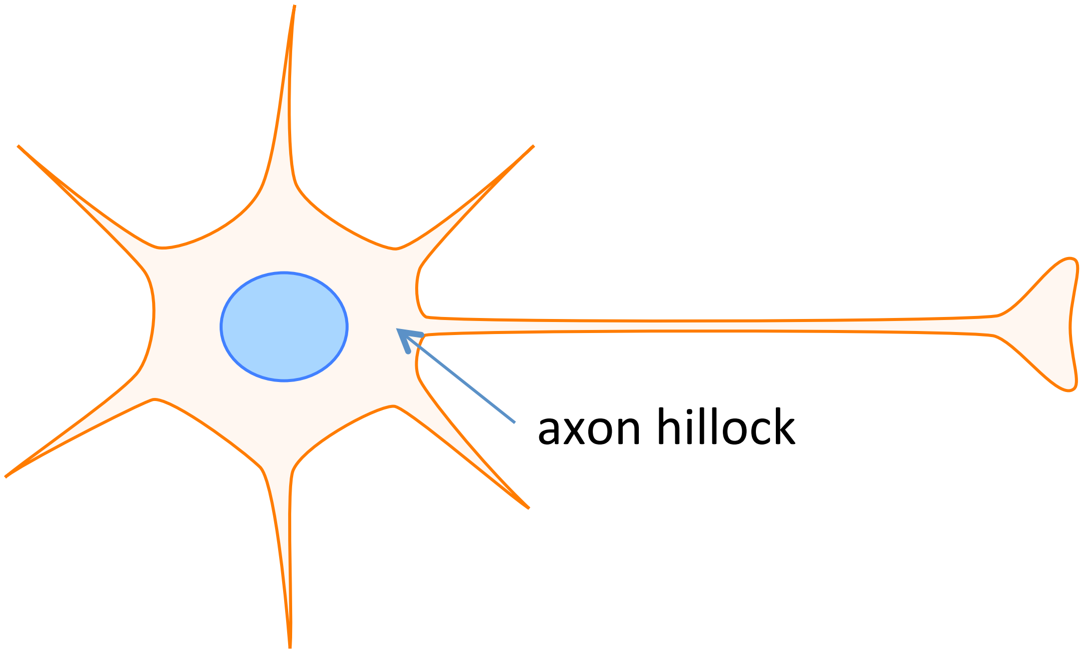
Animation 4: Summary



Clearly, Na^+, K^+ and Ca^{2+} have key roles in these processes, which means they are key for normal bodily function and levels of all of these ions are very closely regulated. This is why levels of these ions are regularly measured when people are unwell and also why they feature prominently in dietary guidelines and in sports drink additives - it all about ensuring the nerves function properly!

Axon hillock

The point in the neuronal cell body from which the axon arises. Grad
tials sum to threshold here to generate an action potential.



Related Glossary Terms

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Cell membrane

The cell membrane in composed of a phospholipid bilayer. This mem
the borders of a cell and also determines which substance can cros
via a process of selective permeability

Related Glossary Terms

Drag related terms here

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Cell nucleus

The cell nucleus is a specialised organelle which contains the cells D
termines which proteins will be produced by a cell and hence the ce

Related Glossary Terms

Drag related terms here

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Concentration gradient

A concentration gradient exists when the concentration of a substar
side and low on the other side of a barrier. In this case the barrier is
brane. If the cell membrane becomes permeable to the substance it
membrane from the area of high concentration to the area of low co
concentrations will be same on both sides of the membrane. This m
its concentration gradient'.

Related Glossary Terms

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Deformation

a change in shape

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Ion channels

an ion channel is a protein structure which forms a ‘pore’ in the cell
channels are specific for a particular ion - they let only one ion throu
ing and closing can be controlled.

Related Glossary Terms

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Ligand

a molecule which can bind to a protein

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Permeable

if a membrane is permeable to a particular substance then that subs
cross to the other side of the membrane

Related Glossary Terms

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Find Term

Polarised

when something is polarised it means that one side of it is different t
instance we are talking about a cell membrane and it is polarised be
positively and the other negatively charged.

Related Glossary Terms

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Threshold

The change in membrane potential required to open voltage gated N
and initiate an action potential. It is a 15 mV depolarising change fro

Related Glossary Terms

Drag related terms here

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Voltage-gated

Opened by a change in voltage (charge)

Related Glossary Terms

Drag related terms here

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