Bio Factsheet

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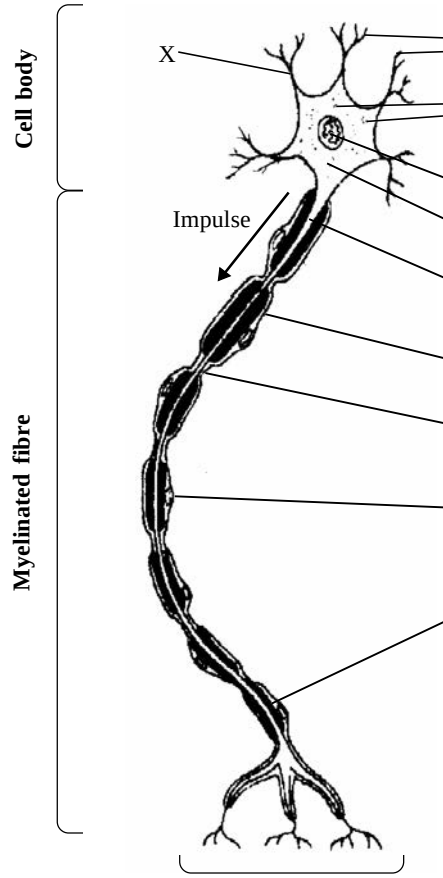
Answering exam questions on neurones and synapses

You must know the structure (histology) of a neurone, the functions of its component parts and be able to distinguish between different types of neurone.

Fig. 1. Structure of a motor neurone (light microscope detail)



Dendrites (form synapses other neurones – usually relay neurones

Nissl granules (contain mitochondria, ribosomes and short lengths of rough endoplasmic reticulum - synthesize enzymes involved in impulse transmission and tropic factors which regulate the growth and development of nervous tissue).

Nucleus

Cytoplasm

Axon (conducts impulse).

Myelin sheath (insulating lipid which speeds up impulse conduction).

Node of Ranvier (has little myelin so impulse 'jumps' from node to node).

Schwann cell sheath (forms the myelin).

Schwann cell nucleus

Motor end plate (forms synapses with skeletal muscle fibres)

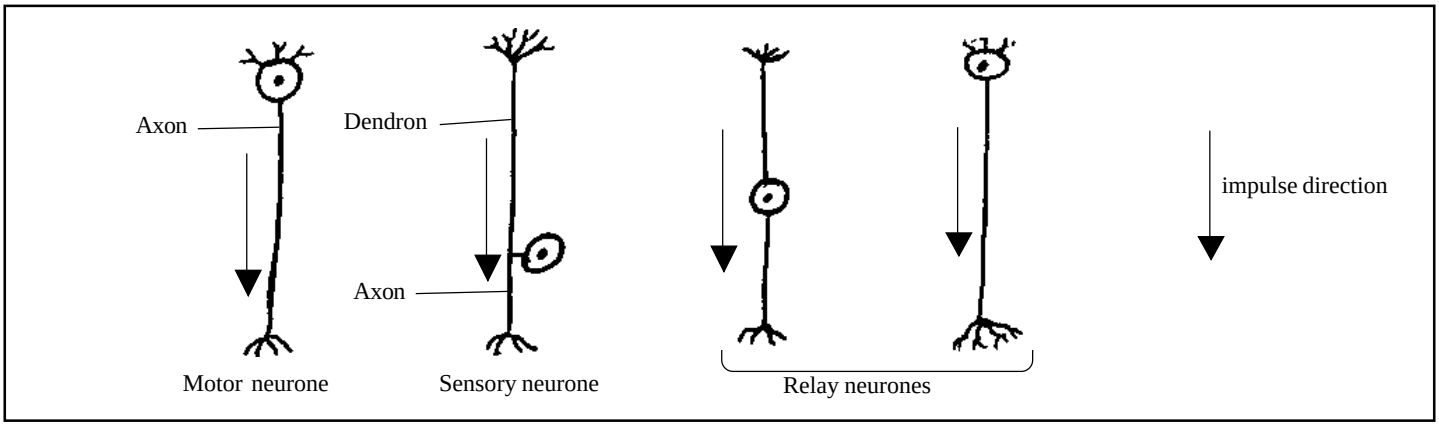
Examiners will not ask you to draw a neurone but you may have to label a neurone and to state the functions of the parts. Common errors that students make are:-

- To call dendrites, 'dendrons'. Dendrons are extensions of the cell body which branch into dendrites. On the drawing above, structure X is a dendron.
- To describe the function of the myelin sheath as 'insulation'. Although myelin is an insulator, its function is to speed up the impulse passage by making the impulse jump from node to node.
- To call the fibre a 'nerve'. A nerve is an organ, consisting of a collection of many neurones bound together by connective tissue sheaths. A fibre refers to an individual neurone fibre.

Remember that, instead of a motor neurone, you may be asked to label a sensory or relay neurone. These do not have a motor end plate synapsing with skeletal muscle. Instead:

- a sensory neurone will receive impulses from a receptor and synapse at the other end with a relay neurone or with a motor neurone,
- a relay neurone will usually synapse with a sensory neurone at the 'receiving' end and synapse with a motor neurone at the other end.

Fig. 2. Different types of neurones



From shape alone a motor neurone may be confused with a relay neurone – you must know what the neurone is synapsing with, or its position in the nervous system to decide which type of neurone it is.
Neurones may have:

- myelinated fibres –these contain much myelin and conduct impulses rapidly;
- non-myelinated fibres – these only contain a small amount of myelin and conduct impulses slowly.

A particular neurone will always conduct impulses at the same speed. Having different conduction rates in different neurones is one way in which the nervous system can organise and time events to happen in a coordinated way.

Labelling diagrams of neurones, stating functions of their parts and recognising the different types of neurones is often the basic content of exam questions used to test recall knowledge. More searching questions, looking to measure a student's understanding, may ask about how the nervous system is organised or integrated to work as a coherent system. The data given in the table below, about how different neurones interrelate and behave to form 'integrated circuits' forms an important section of the answer.

Table 1. Variety of neurones.

Neurone type	Impulse speed/m sec^{-1}	Voluntary or autonomic system	Position and function
Myelinated sensory	25 - 100	Voluntary and some autonomic	From receptors to CNS where rapid response/ transmission is needed, in voluntary control and some involuntary control e.g. iris reflex.
Non-myelinated sensory	0.5 - 5	Autonomic	From receptors to CNS where slow response/ transmission is needed in involuntary control, e.g. peristalsis.
Myelinated motor	25 - 100	Voluntary	From CNS to skeletal muscle where rapid response/transmission is needed.
Non-myelinated motor	0.5 - 5	Autonomic	From CNS to smooth muscle or glands where slow response/ transmission is needed.
Myelinated relay	25 - 100	Voluntary and autonomic	In white matter for carrying impulses quickly up or down the length of the brain and spinal cord.
Non-myelinated relay	0.5 - 5	Voluntary and autonomic	In grey matter for carrying impulses across the brain or spinal cord. Slow transmission still allows rapid responses because distances involved are short.

CNS stands for central nervous system which consists of the brain and spinal cord. Remember that the autonomic nervous system is not under voluntary control and regulates visceral functions, such as heart beat.

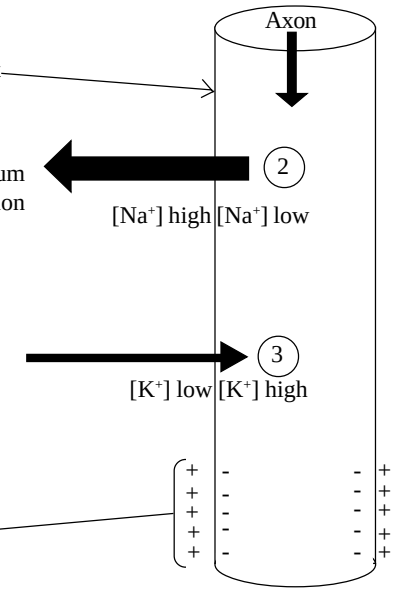
A common error made by candidates is to state that 'the autonomic system only contains non-myelinated fibres'. This is not so – some sensory fibres involved in autonomic responses are myelinated. This is because fast responses may be needed, as in the iris reflex and focussing reflexes of the eye, also in the reflexes of balance.

The physiology of nervous transmission

This is a very common area tested in examinations. Remember that, in order to conduct an impulse a neurone must already have a resting potential. Candidates are often asked to describe how the resting potential is caused:-

At rest,

1. the neurone membrane is **impermeable to the entry of sodium ions** but
2. sodium ions are **actively transported out by a sodium pump**. Thus, the resting neurone becomes deficient in positive ions with a low sodium concentration (10 mmoles dm^{-3}) inside compared with a high concentration (142 mmoles dm^{-3}) outside.
3. At the same time, the neurone membrane **is freely permeable to potassium ions and these are attracted into the neurone. to balance the deficit of positive ions within.** This results in low potassium concentrations (7 mmoles dm^{-3}) outside compared with a high concentration (135mmoles dm^{-3}) inside. However, **the influx of potassium never quite catches up with the outflow of sodium so there is always a deficit of positive ions within the neurone.**
4. Thus, **inside remains negative with respect to the outside.** This resting potential is usually in the range **-60 to -90 millivolts**.



The inflow of potassium into the resting neurone is supplemented by a potassium pump – however, it is a weak pump and its effects are minimal.

Common errors made by candidates include:-

- A failure to describe the data in a logical sequence. For example, candidates often fail to mention that the **resting** neurone membrane is impermeable to sodium ions, a fact that the whole process depends on. Learn the data in the logical sequence given above.
- A failure to realize that the potassium ions enter because they are attracted through the potassium permeable membrane by surplus negative charges inside the neurone. Candidates often attribute the re-entry of potassium ions to the potassium pump, but this is too weak to account for all the movement of potassium ions.
- Reversing the polarity of the **resting** membrane so that the outside is negative with respect to the inside. If this mistake is made it becomes impossible to explain (if needed later in the question) the nature of a nerve impulse.

Do not use the terms 'depolarisation' and 'repolarisation' when describing how resting potentials are established. These processes occur during nerve impulse generation.

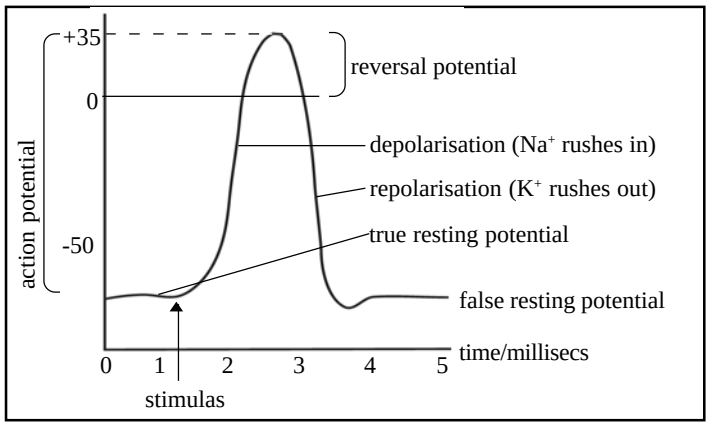
You may be asked to describe how an impulse is formed and transmitted. Candidates often forget to include the 'transmitted' information which is separate from the 'formed' information:

- the impulse is formed by the generation of an **action potential**, (not 'axon' potential),
- which is then transmitted along a neurone by **local currents**.

When describing the formation of a nerve impulse it is important to present the information in a logical sequence, remembering that the neurone is initially in the 'resting potential state'.

- First, give three pieces of information about the **stimulus**.
  1. The nature of the stimulus, for example, light, gravity, acids, blood pressure, blood pH, body temperature, electric current, synaptic transmitter substances.
  2. The stimulus must be above a minimum value (the **threshold value**) before it can cause an effect, which will be an '**all or none**' maximum effect on the neurone.
  3. The effect of the stimulus – it causes the sodium impermeable resting neurone membrane to become highly permeable to sodium ions for a few thousandths of a second. (Don't forget the time reference).
- Second, describe **depolarisation**. Due to the change in membrane permeability, sodium ions rush into the axon along the concentration gradient. This changes the polarity from the resting potential (- 60 to – 90 mV) to a reversal potential (+ 35 mV) so the membrane becomes positively charged on the inside (depolarised).
- Third, describe **repolarisation**. When depolarised the membrane becomes even more permeable to potassium ions. The surplus of positive ions inside the axon, coupled with the surplus of negative ions outside the axon cause potassium ions to flood out of the axon along the electro-chemical gradient, until the polarity returns to around the resting potential value (repolarised). (A very common error made by candidates is to say that 'repolarisation is caused by the sodium pump'. This is not so – the sodium pump would be far too slow to restore a true resting potential).
- Fourth, describe the return to the true resting potential. By the time repolarisation finishes the neurone membrane recovers its impermeability to sodium ions. The sodium pump then pumps sodium ions out of the axon, so potassium ions now pass back in to balance the charges and restore the resting potential.
- Fifth, point out that once the membrane has become repolarised, another stimulus can establish another action potential. Single impulses rarely pass along neurones – usually many successive impulses pass along the neurone so that impulses flow in groups or **volleys**. A volley of impulses is called a **signal.** The **refractory period** is the time that must elapse after an initial stimulus has set up an action potential before a second stimulus can set up a second action potential. In myelinated neurones the refractory period is around $^1/_{2500}$ of a second so that a volley frequency of around 2500 impulses per second can be achieved. In non-myelinated neurones the refractory period is around $^1/_{50}$ of a second so that a volley frequency of only 50 impulses per second can be achieved. This variation allows a wide range of responses to be controlled. (This information is relevant to questions which ask about how the nervous system is organised and integrated into a coherent system)

Fig. 3. An action potential (You may be given a diagram like this to describe or explain).

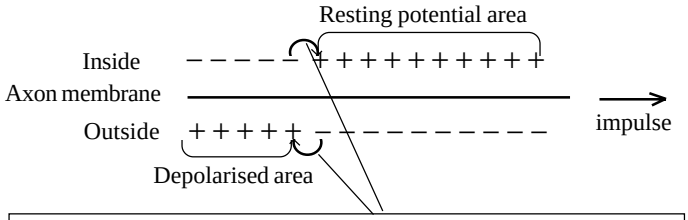


Candidates often ignore the instructions 'describe' and 'explain'. If you are asked to describe the data do so in as precise a way as possible including mathematical values if given. Do not attempt to explain the data – it won't score you any marks and may lose you some. If you are asked to explain the data then do so in a logical sequence, but do not describe it because there will be no marks available for this.

When describing the propogation of an impulse along the neurone refer to '**local currents**'. These occur at the margins of the depolarised area due to electron flow. If you are asked to describe this, it is easiest to use a simple labelled diagram.

Fig. 4. Propogation of impulse in a non-myelinated neurone

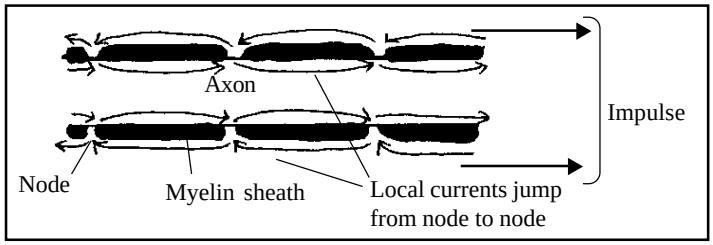
Make sure you show the electron flow from negative to positive



Local current (electron flow) makes next section of membrane permeable to Na^+ and so depolarises the next section of membrane. This continues along the membrane so the impulse passes along the membrane.

Candidates are often asked about 'saltatory conduction' and its advantages. 'Saltation' means 'jumping' and this type of conduction occurs in myelinated neurones where the local currents jump from node to node across the blocks of insulating myelin.

Fig. 5. Propogation of impulse in a myelinated neurone



The advantages of salutatory conduction are:

- it increases the speed at which impulses travel so that response times are reduced.
- it reduces ion exchange by restricting it to the nodes so that less energy is expended by the sodium (and potassium) pumps, making repolarisation quicker. (This advantage is often forgotten by candidates).

Synapses

Examiners frequently ask questions about synapses. Remember that synapses may be:-

- **Interneuronal,** i.e. junctions between neurones, for example, between sensory and relay neurones, also between relay neurones and motor neurones.
- **Neuromuscular junctions,** i.e. between motor neurones and muscle. For example, voluntary myelinated motor neurones synapse with skeletal (striated) muscle fibres. Non-myelinated autonomic motor neurones synapse with smooth muscle or cardiac muscle, (or with glands).

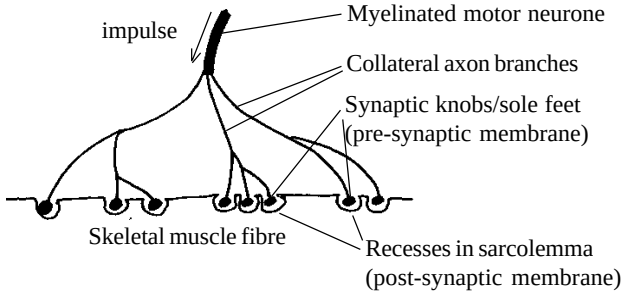
Synapses transmit signals (volleys of impulses) between neurones by means of transmitter chemicals, so that neuronal circuits can be completed. However, their role is more subtle than this – the transmitter substances may be **excitatory** or **inhibitory**, enabling processes to be switched on or off.

- Excitatory transmitters transmit signals from one neurone to the next by establishing impulses in the post-synaptic neurone. Thus the activity under the nervous control is continued.
- Inhibitory transmitters do not transmit signals but make it more difficult for excitatory transmitters to depolarise the post-synaptic neurone. Thus the activity under the nervous control is stopped.

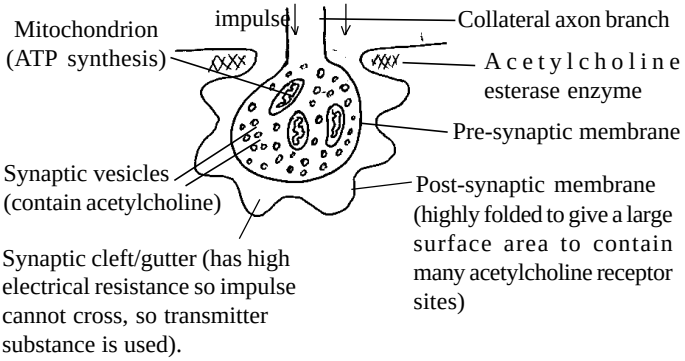
Fig. 6. Structure of synapses (You may be provided with a diagram to label)

(i) A neuromuscular junction (light microscope detail)

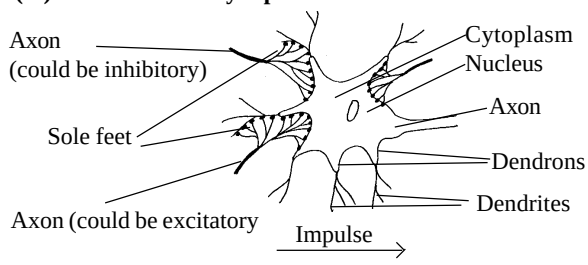
You may be given a drawing with a non-myelinated neurone. The muscle would then be smooth or cardiac muscle.



(ii) A synaptic knob/sole foot (electron –microscope detail)



(iii) Interneuronal synapses



Many pre-synaptic neurones, (some excitatory, others inhibitory), will synapse with a single post-synaptic neurone.

Acetylcholine (Ach) is the commonest transmitter substance in excitatory synapses and these synapses are referred to as **cholinergic.** They include most interneuronal synapses in the voluntary nervous system, neuromuscular junctions and many interneuronal synapses in the autonomic nervous system. Examiners often ask questions about how a cholinergic synapse works. It is very important to present the information in answers in a logical sequence:-

1. Ach is synthesised in synaptic vesicles from choline and acetate, under the influence of the enzyme choline acetylase. ATP from numerous **mitochondria** present supplies the energy for this.

2. When an impulse reaches a synaptic knob, its depolarisation causes voltage-gated calcium channels to open. Calcium ions rush into the synaptic knob and cause some vesicles to rupture (exocytosis), releasing Ach into the synaptic cleft.

3. The Ach attaches to specific receptors on the post-synaptic membrane and makes it permeable to sodium ions which flood into the neurone, causing depolarisation.

4. The enzyme **acetylcholine esterase,** present on neurone membranes and on muscle sarcolemmas, then detaches Ach from the receptors and hydrolyses it to acetate and choline.

5. Acetate and choline are then **actively** reabsorbed back into the synaptic knob using ATP from the mitochondria. Ach is then resynthesised.

6. When Ach is removed the post-synaptic membrane becomes impermeable to sodium ions again and repolarisation can occur due to potassium ion outflow.

7. Once the refractory period is over, the synapse can transmit another impulse.

Candidates often forget the second role of acetylcholine esterase – to hydrolyse the acetylcholine into acetate and choline so that they can be actively reabsorbed.

Also be careful to note whether the question asks about an interneuronal synapse or a neuromuscular junction.
If the latter, then remember that the post synaptic membrane is the sarcolemma of the muscle.

Excitatory synapses between sympathetic motor neurones and effectors are termed **adrenergic** because they release **noradrenaline** as their transmitter substance. After depolarisation the noradrenaline is destroyed by the enzyme **monoamine oxidase.**

Other excitatory transmitters, in the brain, are serotonin, dopamine and glutamic acid.

Inhibitory synapses release transmitters which act by increasing the resting potential on the post-synaptic neurone, thus making it more difficult achieve depolarisation. Examples of such transmitters are glycine and gamma-amino butyric acid.

You may be asked questions about the effects of drugs on synaptic transmission. Know the effects of the following drugs.

Nicotine lowers the threshold for activation of neurones. It does this by mimicking the action of acetylcholine on the post-synaptic membrane. **Caffeine** can have a similar effect.

Atropine blocks the action of acetylcholine in parasympathetic synapses and so inhibits parasympathetic functions and so sympathetic control would dominate.

Curare blocks the action of acetylcholine at the neuromuscular junctions and thus causes paralysis.

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