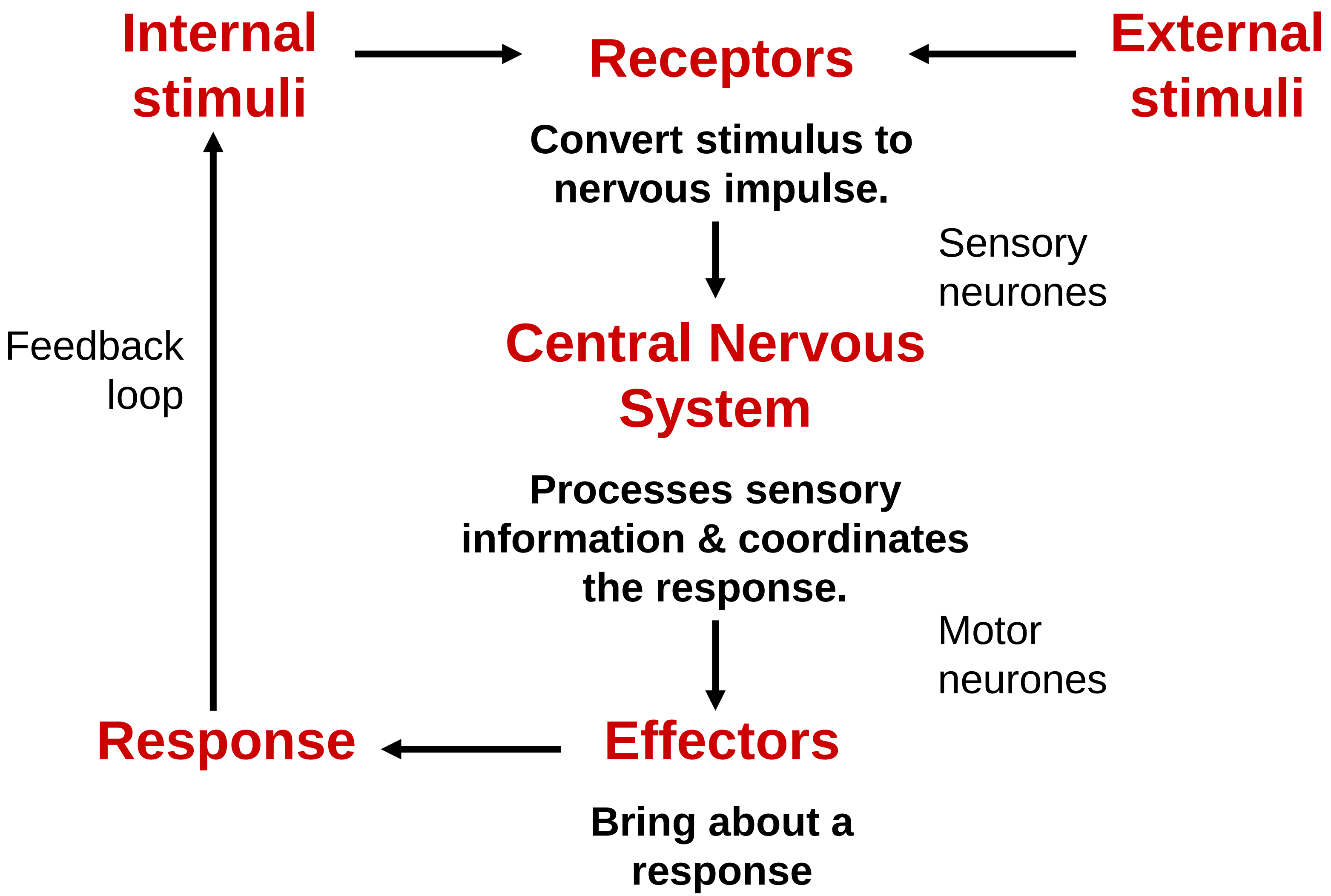
Nerves, Receptors & Potentials

- Outline the roles of sensory receptors in mammals.
- Describe the structure and functions of sensory and motor neurones.
- Describe and explain how the resting potential is established and maintained.
- Describe and explain how an action potential is generated & transmitted.
- Interpret graphs of the voltage changes taking place during the generation and transmission of an action potential.

Introduction

- The ability of an organism to respond to stimuli is crucial.
  - Natural selection favours organisms with better responses.
    - Stimuli are received by receptors.
    - Responses are carried out by effectors.
  - Communication is needed between them if an organism is to respond effectively.
    - Slow endocrine system.
    - Rapid central nervous system.

Components of the nervous system are inter-related



Sensory Receptors

- Convert the energy of the stimulus into an electrical nerve impulse.

Receptor	Where	Stimulus
Light sensitive rods & cones	Retina	Intensity & wavelength of light.
Olfactory cells	Nasal membranes	Presence of volatile chemicals
Taste buds	Tongue	Presence of soluble chemicals
Pressure receptors	Skin	Touch
Sound receptors	Cochlea	Vibrations
Muscle spindles	Skeletal muscles	Length of muscle fibres

Structure of the Neurone

- Specialised cells adapted to carry impulses.
- Mammalian neurones have:
  - A Cell Body.
    - Contains a nucleus & lots of RER grouped to form Nissl's granules.
      - These produce proteins & neurotransmitters.
  - A number of Dendrons.
    - Extensions of the cell body. Sub-branched into dendrites. Carry impulses towards the cell body.
  - An Axon.
    - Single, long fibre carrying impulses away from the cell body.

Structure of a neurone

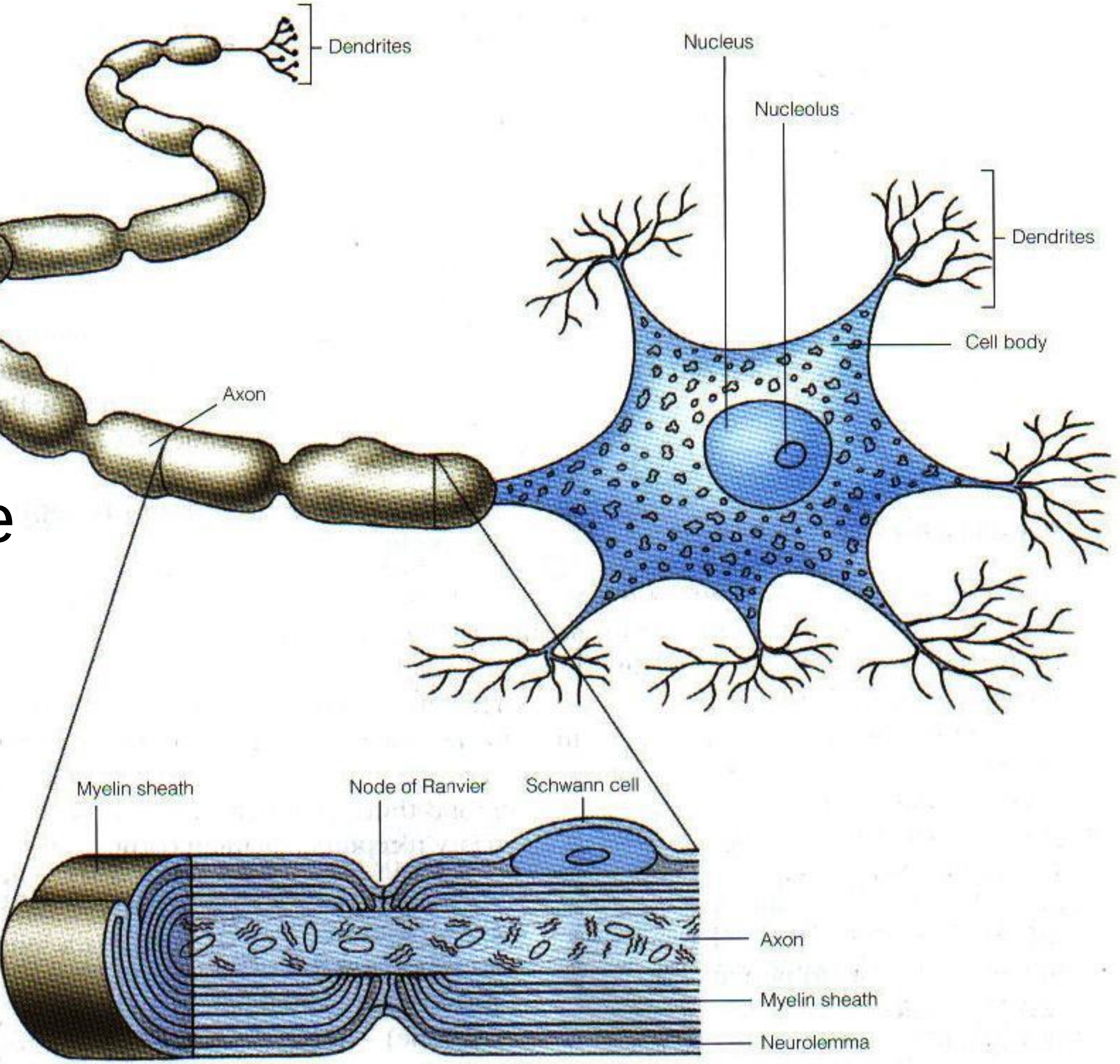


Fig 6.12 *Motor (effector) neurone*

Types of Neurone

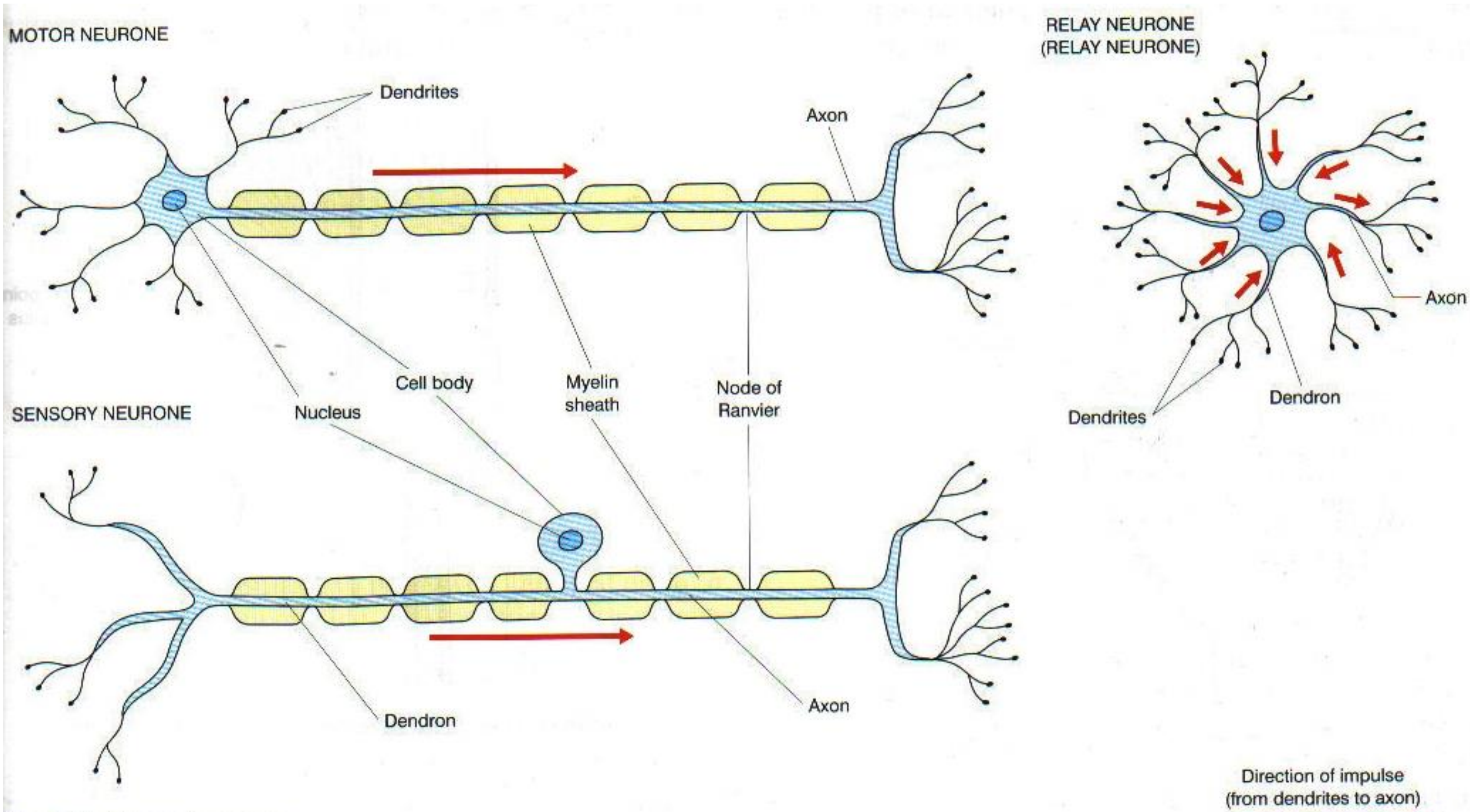
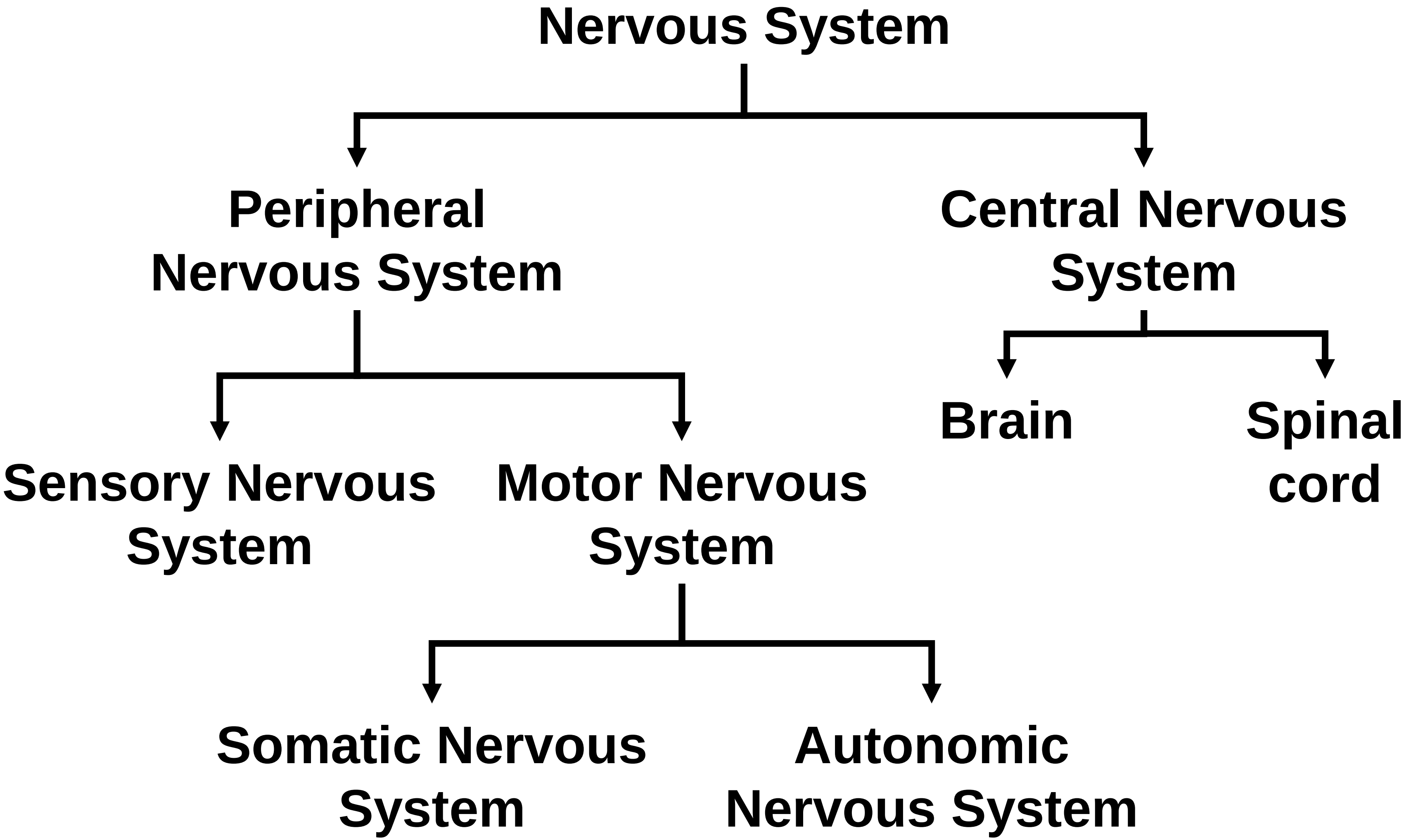


Fig 6.13 *Types of neurone*

Nerve Organisation



The nerve impulse…

- Is NOT a current flow of electricity.
- Is a temporary reversal of electrical charges either side of the cell plasma membrane.

- The reversal is between a state called the resting potential and one called the action potential.

Resting Potential

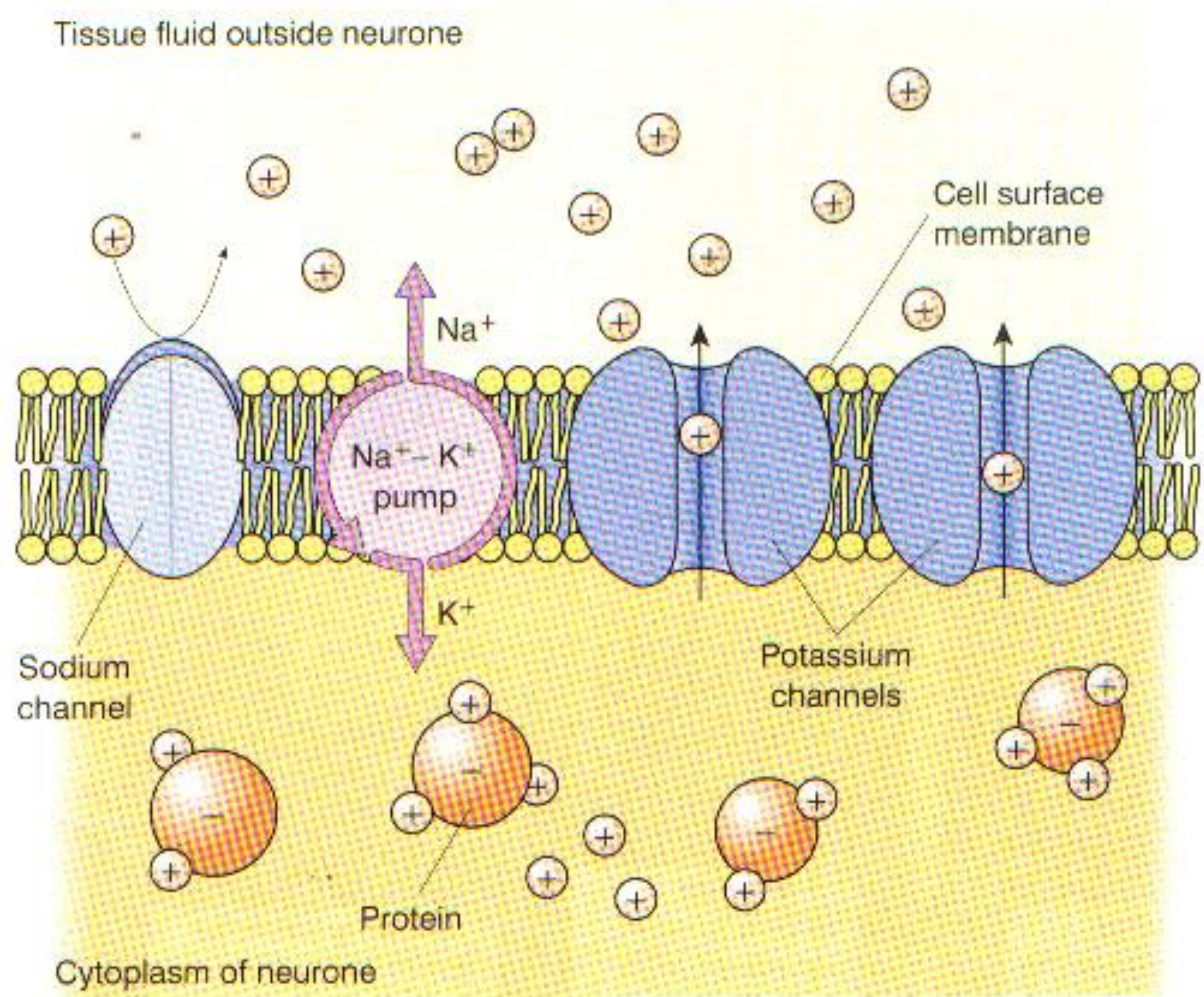


Fig 6.21 *Distribution of ions at resting potential*

Action Potential

- A stimulus at a receptor or synapse which is above a threshold can cause a reversal of the charges across the nerve cell membrane.
- -65mV inside the cells becomes +40mV.
  - The membrane is said to be depolarised.
- This occurs because ion channels in the membrane open or close depending on the voltage across the membrane.
  - They are, therefore, called voltage gates.

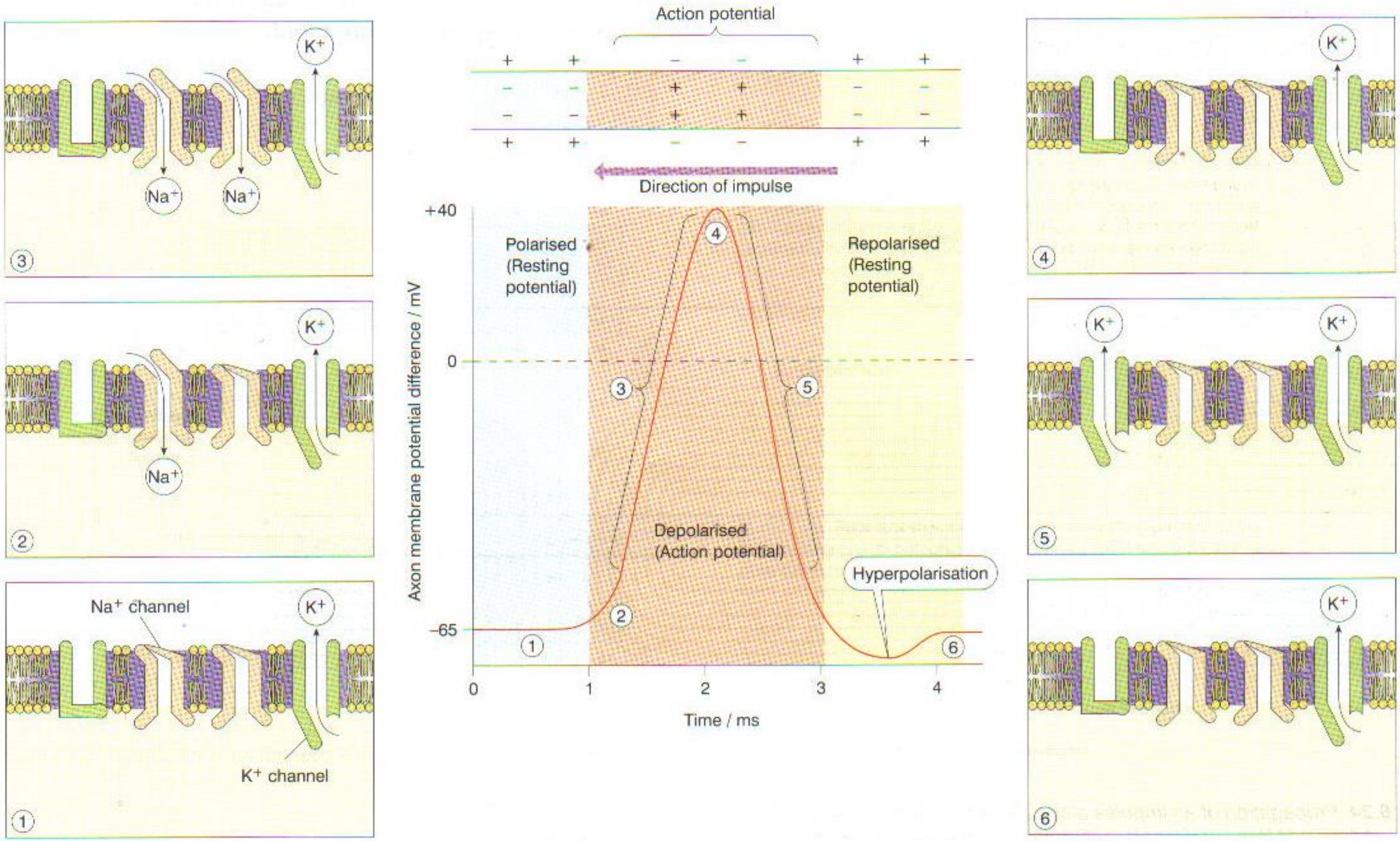


Fig 6.22 *The action potential*

This is confusing ..!~#@}??

- Movement of Na+ ions into the cell during the action potential is entirely by diffusion – a passive process.

- The resting potential is maintained by active transport – an active process.

Summary Test

A nerve impulse is the result of a temporary reversal of [1] potential difference across the neurone cell membrane. At resting potential, the potential difference is usually around [2] millivolts. In this condition the neurone is said to be [3], with the outside being [4] charged relative to the inside. During an action potential, the charges are reversed with a potential difference of about [5] millivolts. The membrane is now said to be [6].

Summary Test Answers

1. Electrical
2. -65mV
3. Polarised
4. Positively
5. +40mV
6. Depolarised

Propagation of the Impulse

- Once created, the action potential moves along the length of the neurone.
  - Nothing actually “moves” along the neurone.
  - The reversal of charge is reproduced at different points along the length.
    - Like a mexican wave around a stadium.
    - Each region that is depolarised acts as the stimulus for the next region to become depolarised, while the previous region becomes repolarised.

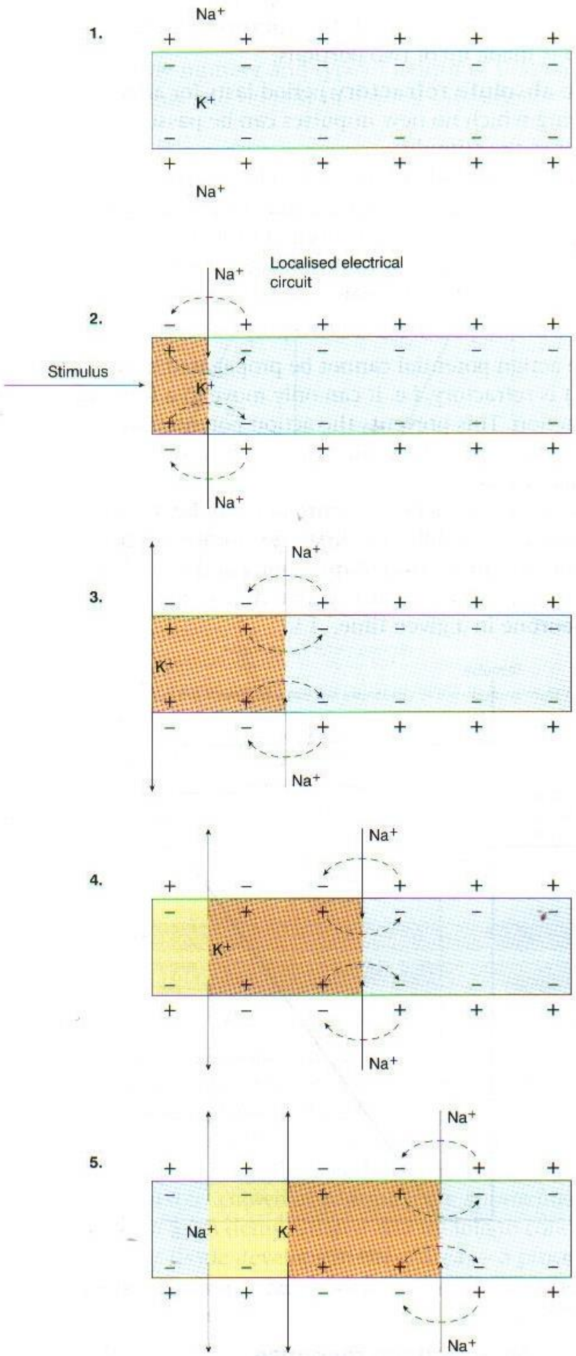


Fig 6.23 Propagation of an impulse along an unmyelinated nerve

1. At resting potential (section 6.10.1) the concentration of sodium ions outside the axon membrane is high relative to the inside, whereas that of the potassium ions is high inside the membrane relative to the outside. The overall concentration of positive ions is, however, greater on the outside, making this positive compared with the inside. The axon membrane is polarised. In our Mexican wave analogy, this is equivalent to the whole stadium being seated, i.e. at rest.

2. A stimulus causes a sudden influx of sodium ions and hence a reversal of charge on the axon membrane. This is the action potential (section 6.10.2) and the membrane is depolarised. In our analogy, a prompt leads a vertical line of people to stand and wave their arms, i.e. they are stimulated into action.

3. The localised electrical circuits established by the influx of sodium ions cause the opening of sodium voltage-gated channels (section 6.10.2) a little further along the axon. The resulting influx of sodium ions in this region causes depolarisation. Behind this new region of depolarisation, the sodium voltage-gated channels close and the potassium ones open. Potassium ions begin to leave the axon along their electrochemical gradient. The sight of the person next to them standing and waving prompts the person in the adjacent seat to stand and wave. A new vertical line of people stands and waves, while the original line of people begin to sit down again.

4. The action potential (depolarisation) is propagated in the same way further along the neurone. The outward movement of the potassium ions has continued to the extent that the axon membrane behind the action potential has returned to its original charged state (positive outside, negative inside), i.e. it has been repolarised. The second line of people standing and waving prompts the third line of people to do the same. Meanwhile, the first line have now resumed their original positions, i.e. they are re-seated.

5. Repolarisation of the neurone allows sodium ions to be actively transported out, once again returning the neurone to its resting potential in readiness for a new stimulus if it comes. The people who have just sat down settle back in their seats and readjust themselves in readiness to repeat the process should they be prompted to do so again.

What starts the action potential in the first place?

- Energy from the stimulus causes some Na^+ gates to open.
  - Allowing some Na^+ into the cell.
  - Once the negative voltage drops to a threshold of about -40mV the process continues.
    - This is called the generator potential.

How does a myelin sheath help?

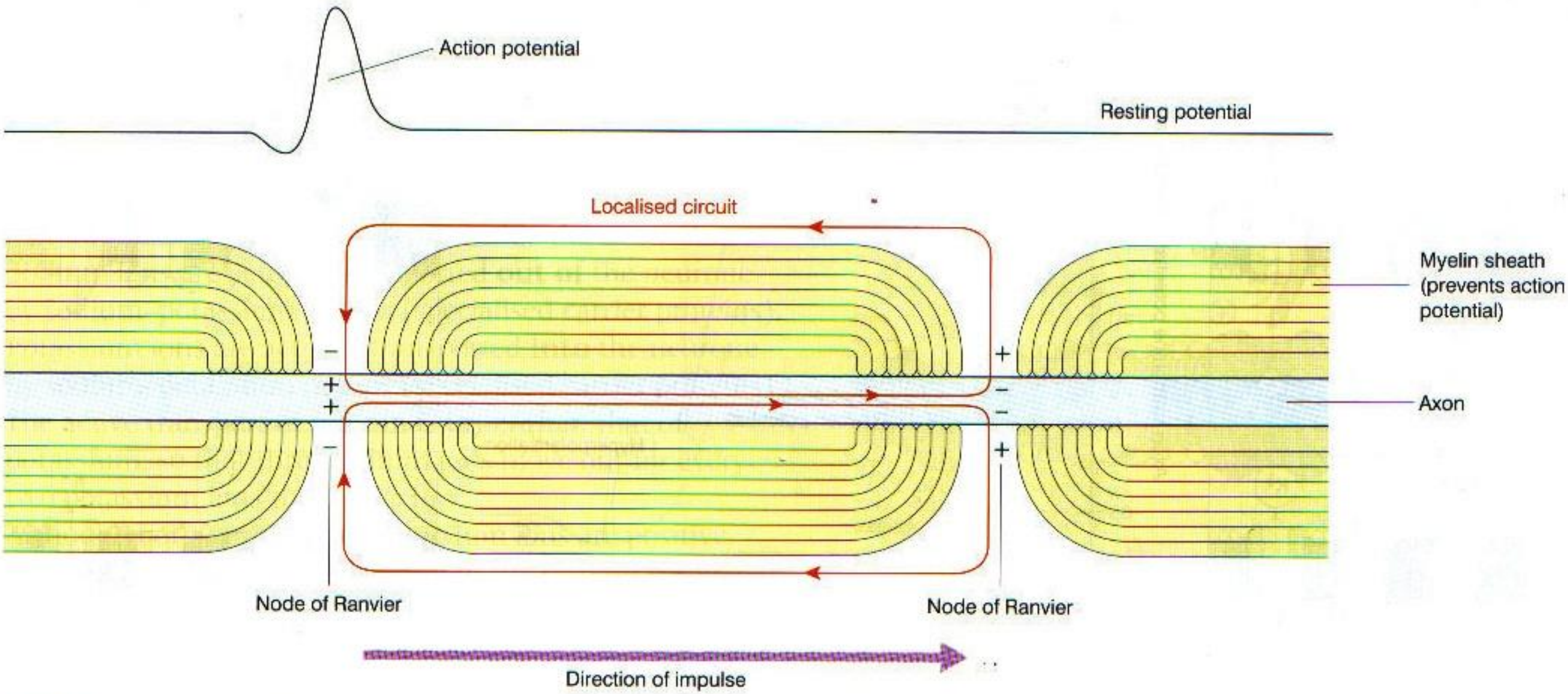
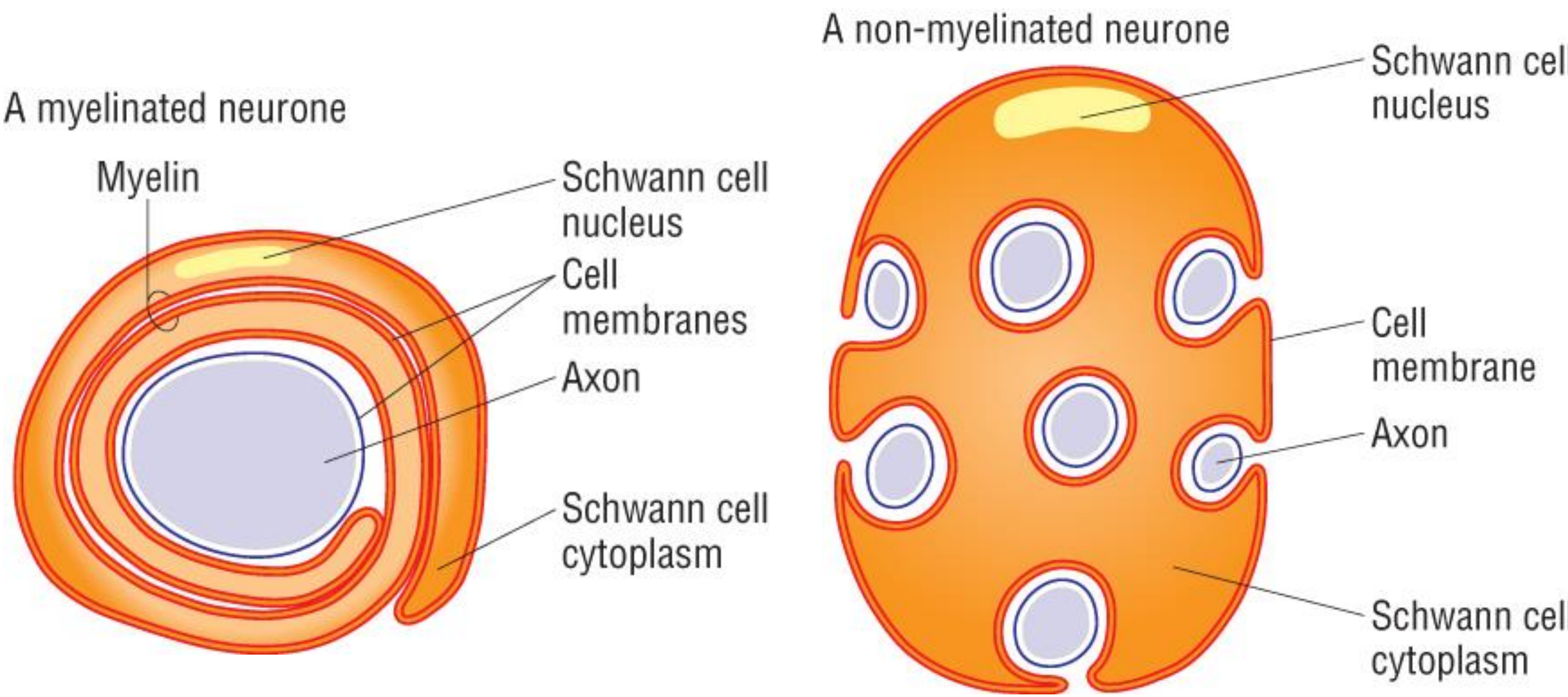


Fig 6.24 *Propagation of an impulse along a myelinated neurone. Action potentials are produced only at nodes of Ranvier. Depolarisation therefore skips from node to node – saltatory conduction*

Myelination v Non-myelination



What factors affect the propagation of action potentials?

- Myelin Sheath.
  - This allows the impulse to jump from one node of Ranvier to another, so speeds up the propagation.
- Diameter of Axon.
  - The greater the diameter the faster the impulse speed.
- Temperature.
  - Higher temperatures = higher rate of diffusion = higher impulse speed.
  - Too high & cell membrane proteins are denatured & propagation stops.
    - Temperature is particularly important in endothermic animals.
- Refractory Period.
  - What the flip is this?

The Refractory Period

- After an action potential has passed there is a period of time when a subsequent action potential is prevented.
  - Allows the cell to recover following an action potential.
  - Ensures action potentials travel in one direction only.

Nerve impulses are “All or Nothing”

- A stimulus will only trigger an action potential if it is above a certain threshold value.

- Below this value no impulse is generated.

- Above this value the action potential is the same regardless of how much the stimulus is above threshold.

So how can an impulse show the size of a stimulus?

- Done in two ways:
  - – Different neurones have different threshold values.
    - The brain can then interpret the number & type of neurones that are active & determine the intensity of the stimulus.
  - – A neurone can vary the frequency of action potentials in a given time.
    - The larger the stimulus the higher the frequency of impulses – known as Frequency Coding.

Put these impulse transmission speeds in order.

Axon	Myelin Sheath?	Axon Diameter (μm)	Transmission speed (ms^{-1})
Human motor axon to leg muscle	Yes	20	120 (First)
Giant squid axon	No	500	25 (Third)
Human motor axon to internal organ	No	1	2 (fourth)
Human sensory axon from skin pressure sensor	Yes	10	50 (Second)

Summary Test

The speed at which an action potential passes along an axon is influenced by various factors. For example, it is [1] if the diameter of the axon is smaller & it is slower if the temperature is [2], the latter being because ions [3] at a slower rate. The presence of a myelin sheath [4] the rate of transmission because the action potential jumps from one [5] to the next in a process called [6]. Once an action potential has passed the sodium [7] remain closed & prevent any inward movement of Na^+ ions. There is a period of about 1ms, called the [8], during which no new action potential can be passed.

Summary Test Answers

1. Slower
2. Lower
3. Diffuse
4. Increases
5. Node of Ranvier
6. Saltatory Conduction
7. Voltage Gates
8. Refractory Period