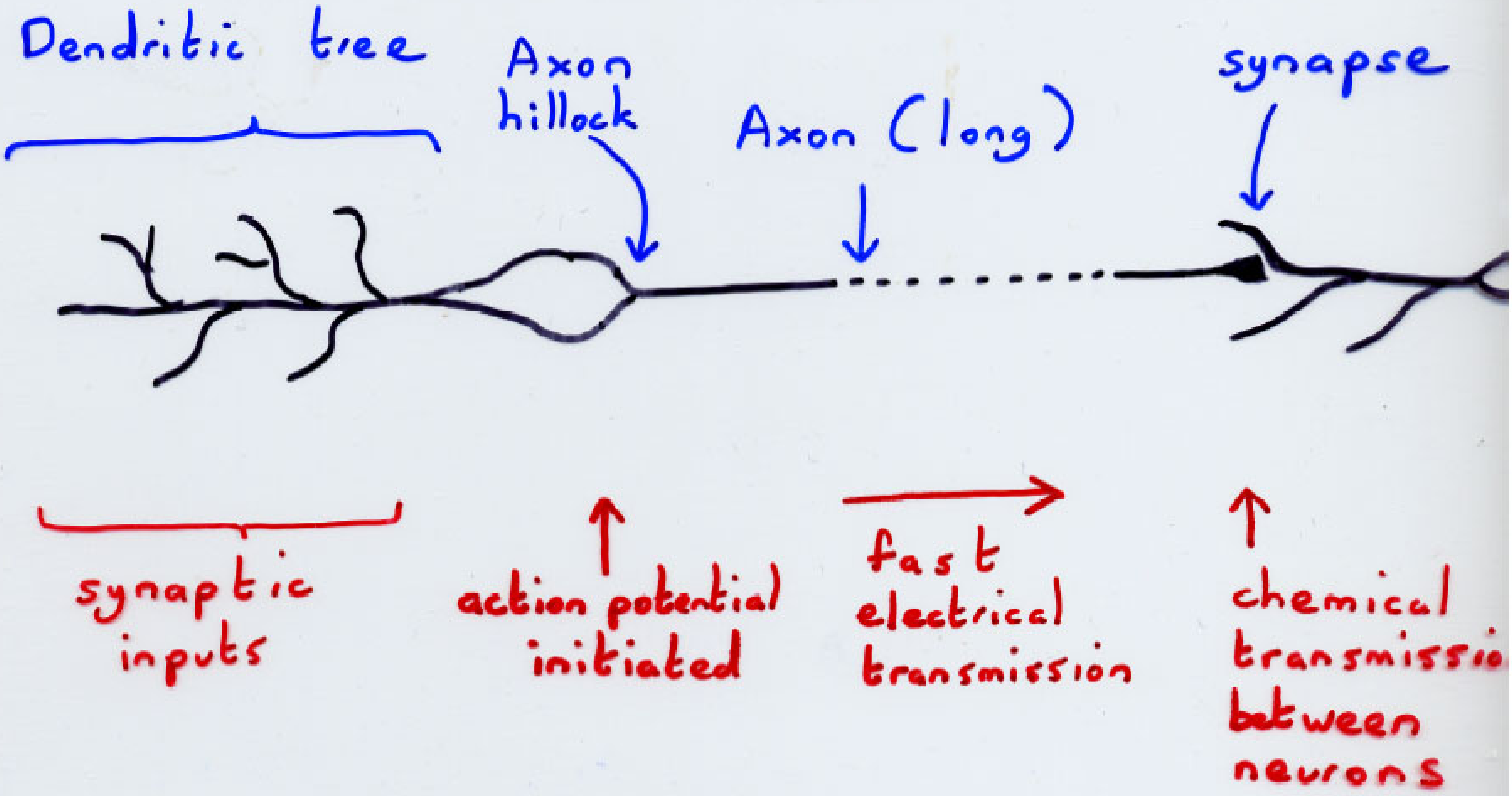
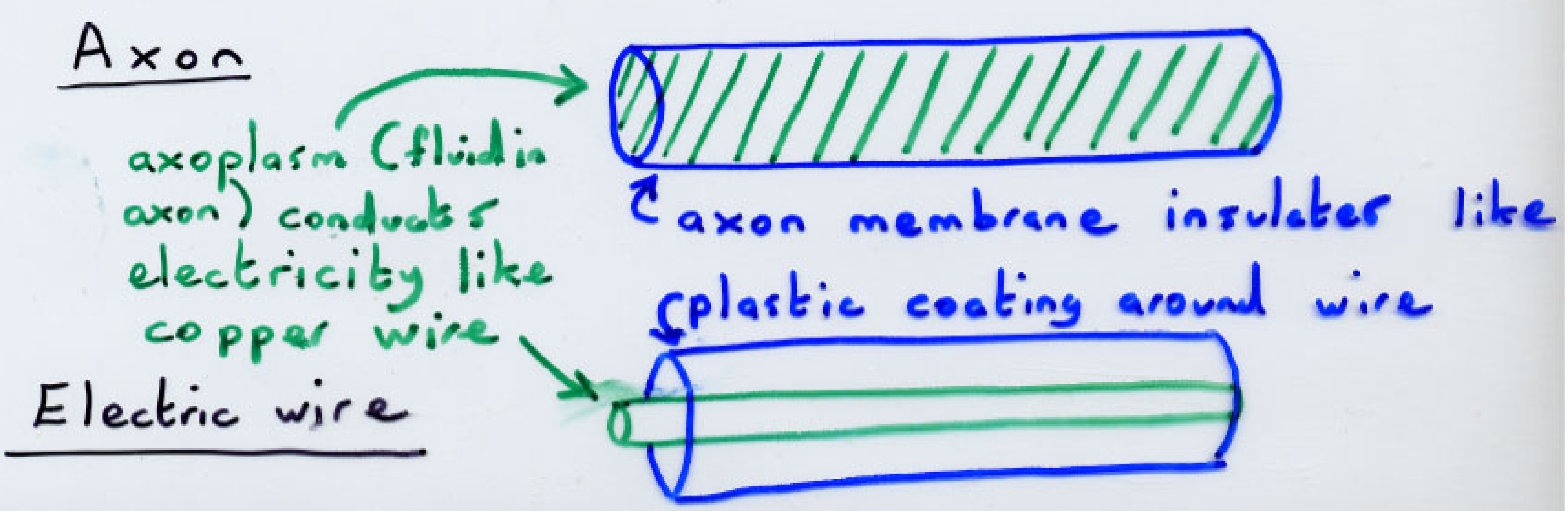
Neuronal Structure and Signaling

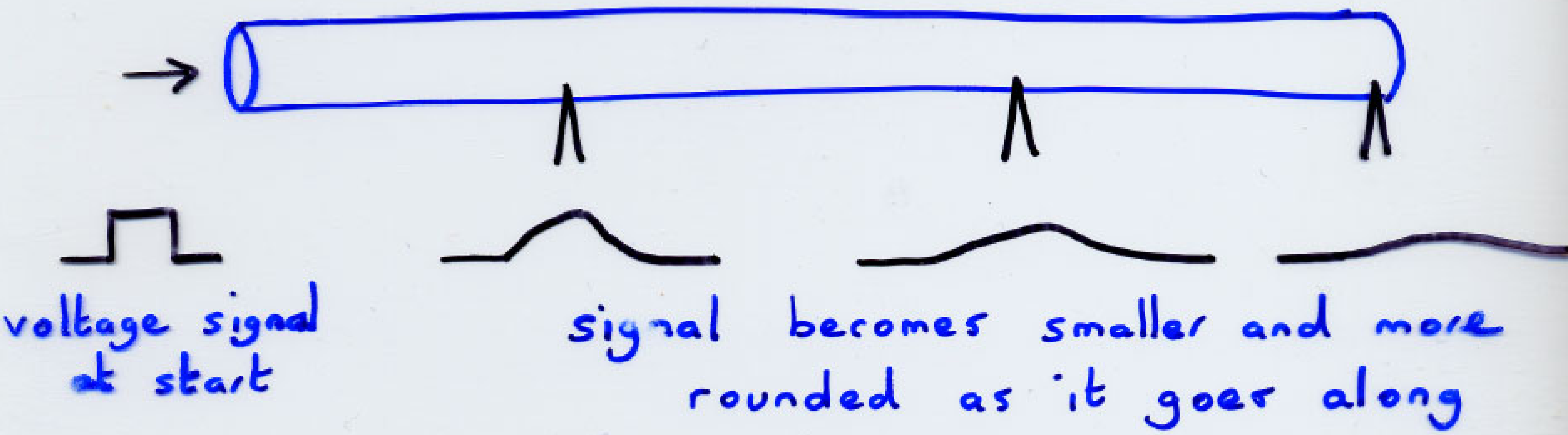


To a limited extent a nerve axon works like an electric cable



But:

Axon may be very thin (a few μm) and long (>1m), and passive electrical signals decay within a few mm.



Why?

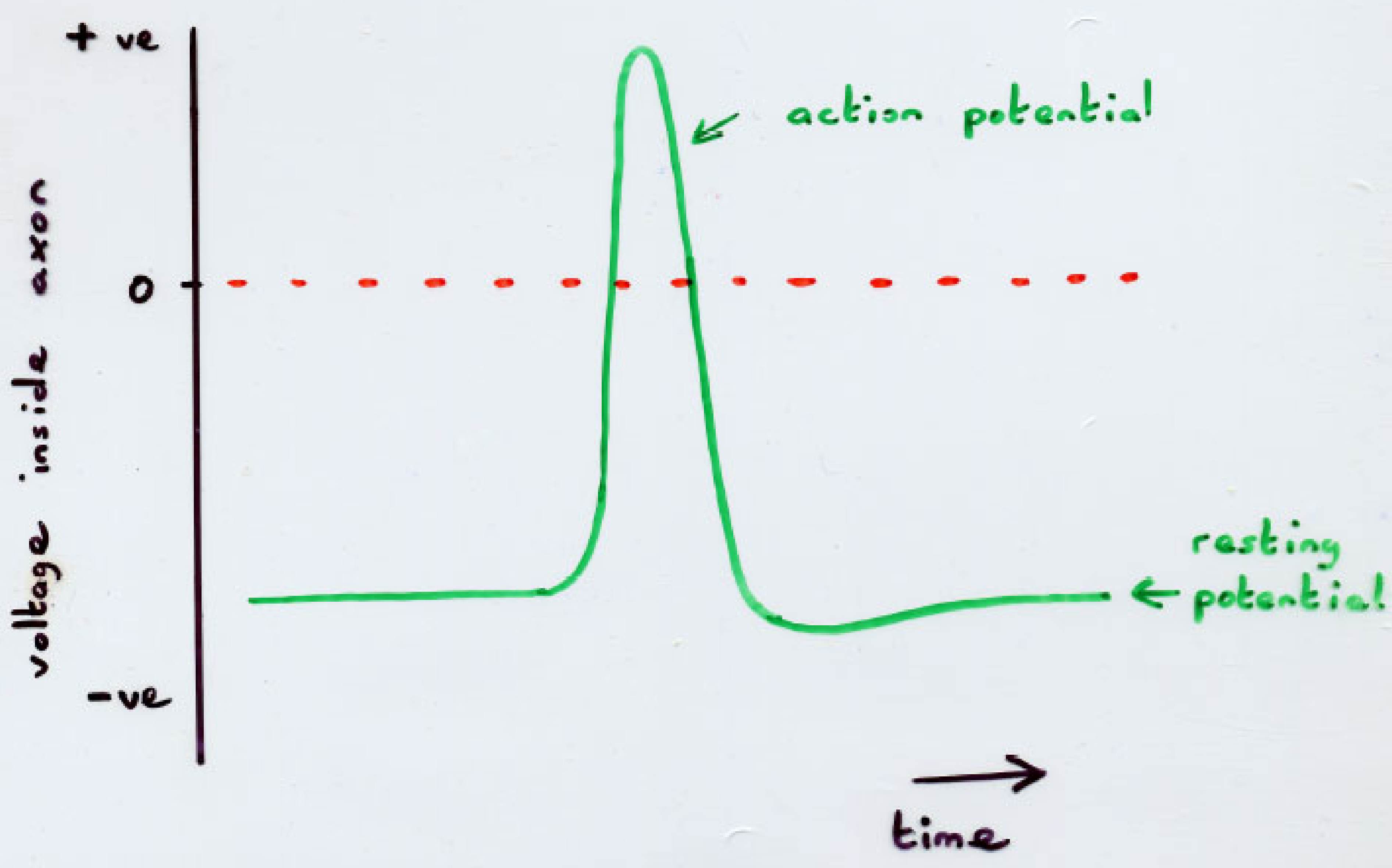
① The axoplasm (a solution of salts) is not a perfect conductor (it has electrical resistance)

② The axon membrane is not a perfect insulator

③ The axon membrane acts like an electrical capacitor (it 'stores' some electrical charge).

In practice, passive conduction of signals along axons is limited to a few mm (often much less) — not nearly enough.

Axons get around this problem by active transmission — a regenerative signal (action potential) that is actively 'boosted' as it travels along a nerve.



How ionic movements produce electrical signals

1. There are differences in concentrations of specific ions across the nerve cell membrane. These concentration gradients are established by ion pumps.

2. Ion channels in the membrane allow selective permeability to some of these ions.

Analogy —

Concentration gradient ≡ car battery

Ion pumps ≡ alternator

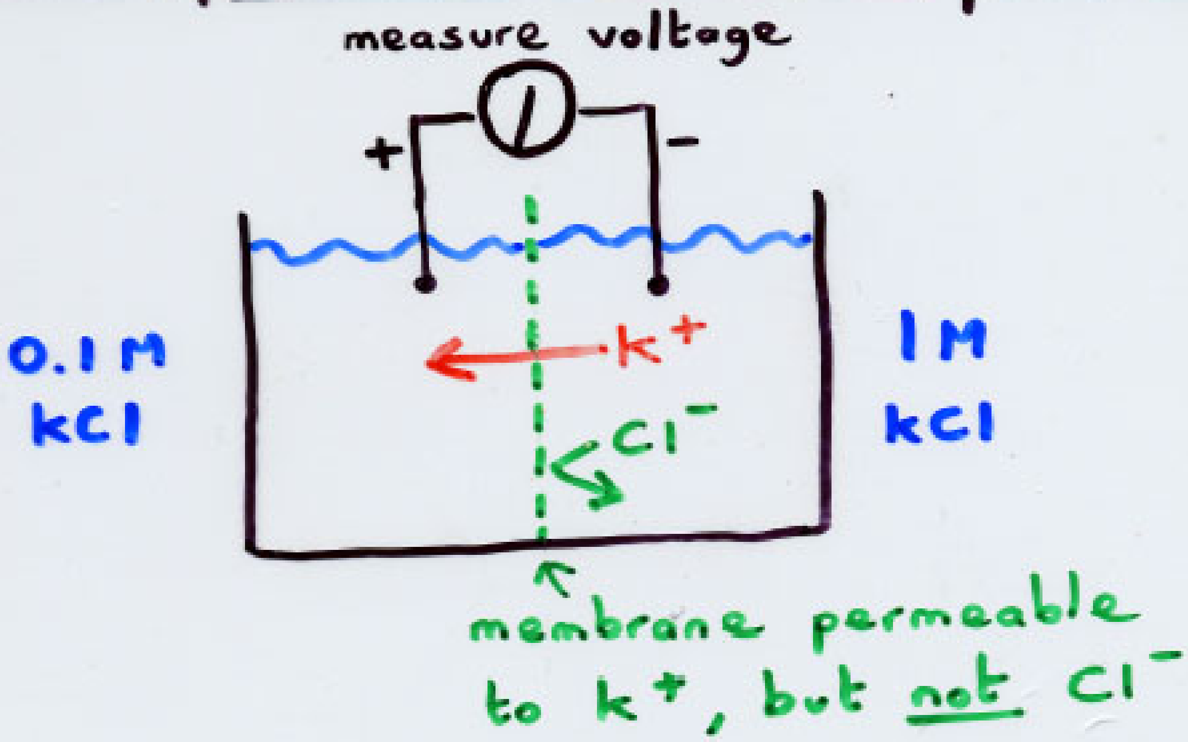
Ion channels ≡ headlight switch

Diffusion Potentials

The resting potential and the action potential both arise through diffusion potentials — a voltage generated by passive diffusion of ions down a concentration gradient

Simple example of a diffusion potential

2.4
↑ figure in textbook



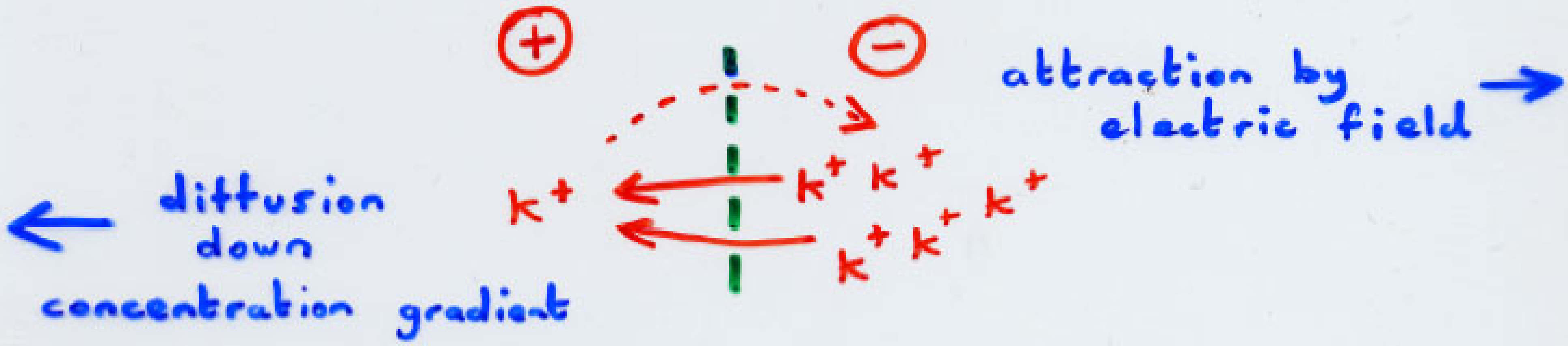
At first instant, K^+ ions will move to left down concentration gradient

Cl^- ions cannot move down gradient, since membrane is impermeable

So, movement of K^+ without corresponding movement of Cl^- will set up a potential difference — a diffusion potential

But — as this voltage is established, it exerts an opposite force, tending to stop any more K^+ ions from moving.

K^+ ions come into equilibrium where chemical driving force (diffusion down concentration gradient) = electrical driving force.



Equilibrium potential

What is the relation between concentration difference and the resulting diffusion potential?

At equilibrium, work in moving K^+ ion up concentration gradient must equal work in moving against electrical gradient.

given by **Nernst Equation**

$$E = \frac{RT}{zF} \log_e \frac{[K^+]_{right}}{[K^+]_{left}}$$

- E — equilibrium potential
- R — gas constant
- T — absolute temp.
- z — valence of ion (1 for K^+)
- F — Faradays constant

for practical purposes we can simplify this;

for a monovalent ion at room temperature

$$E = 58\,mV * \log_{10} \frac{[K^+]_{right}}{[K^+]_{left}}.$$

Note

① E varies logarithmically with ratio of concentrations.

Eg.

$[K]_{right}$	$[K]_{left}$	E
1 M	100 mM	58 mV
10 M	100 mM	116 mV
10 mM	0.1 mM	116 mV

Vanishingly few K^+ ions need to move to establish the equilibrium potential (only enough to charge the membrane capacitance).

To a good approximation there is no change in concentrations of ions on either side of the membrane and

[+ve ions] = [-ve ions] for each side.