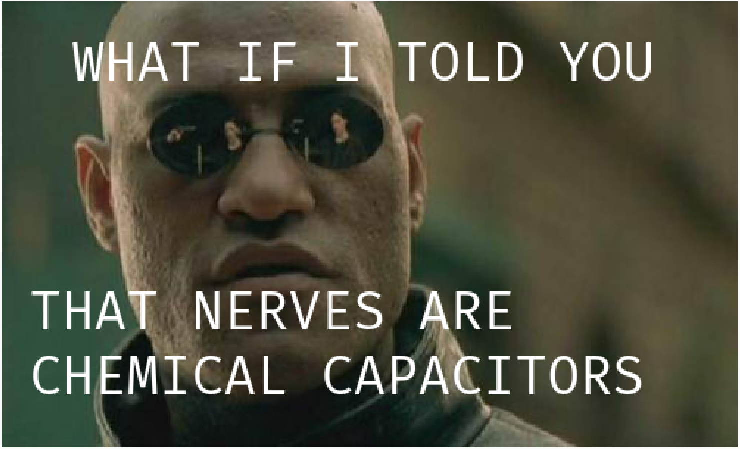
NERVE SIGNALS


WHAT IF I TOLD YOU
THAT NERVES ARE
CHEMICAL CAPACITORS

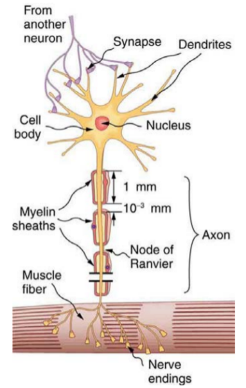


Figure 18: Structure of particular nerve cells known as *axons*, which have 1 mm long sections of *myelin* insulation, and 10^{-3} mm nodes. Nerve signals are measured to propagate at 100 m/s in some cases. No myelin means slower propagation.

Sensory fiber types

Type	Erlanger-Gasser Classification	Diameter	Myelin	Conduction velocity	Associated sensory receptors
Ia	Aα	13–20 µm	Yes	80–120 m/s[4]	Responsible for proprioception
Ib	Aα	13–20 µm	Yes	80–120 m/s	Golgi tendon organ
II	Aβ	6–12 µm	Yes	33–75 m/s	Secondary receptors of muscle spindle All cutaneous mechanoreceptors
III	Aδ	1–5 µm	Thin	3–30 m/s	Free nerve endings of touch and pressure Nociceptors of neospinothalamic tract Cold thermoreceptors
IV	C	0.2–1.5 µm	No	0.5–2.0 m/s	Nociceptors of paleospinothalamic tract Warmth receptors

Figure 19: Lack of myelin allows cross-talk, but also slows down signals by a factor of 100.

https://en.wikipedia.org/wiki/Nerve_conduction_velocity

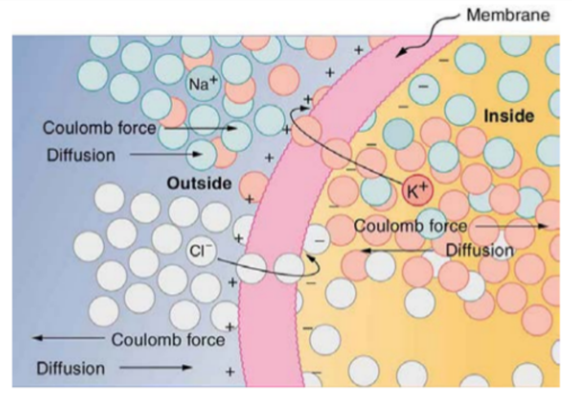


Figure 20: The sodium-potassium pump is responsible for creating an action potential that propagates along a nerve fiber. But how does this actually work?

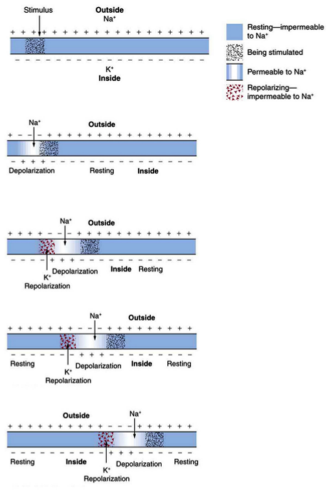


Figure 21: The depolarization-repolarization process is cascaded at a speed of ≈ 1 m/s.

We have a PhET simulation that demonstrates the mechanics of the pump.

`https://phet.colorado.edu/en/simulation/neuron`

1. Click *stimulate neuron* (the large yellow button) to cause a propagating pulse.
2. Click *potential chart* in the brown box at right to see the voltage versus time. This is called the *action potential*.

Write down the following observations in your notes:

1. What is the *peak-to-peak* voltage of the action potential?
2. What is the *pulse-width* of the action potential, measuring from depolarization to polarization?
3. Assuming the resistance R of the entire neuron surface is 100 kΩ, compute the power of the nerve signal in μW.
4. **Question:** If the cell membrane is 10 nm thick, and the voltage is 100 mV, what is the electric field across it?

Submit these answers as a table at the end of class.

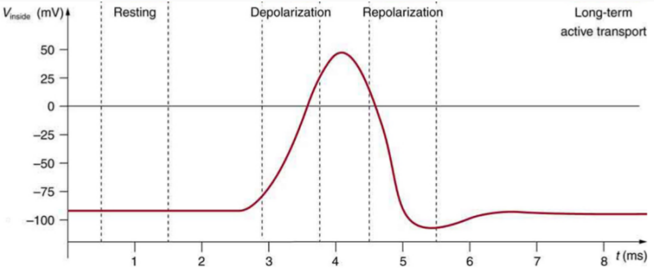


Figure 22: We understand now how our nerves create this action potential, but there is a problem: **it is not fast enough.**

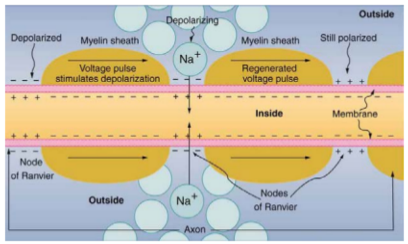


Figure 23: The *nodes of Ranvier* between *myelin sheaths* create a system which propagates the signal without losing speed.

Professor calculation: *Let the speed of a signal in myelinated region be v_m, and the speed in the node v_n. Similarly, let the length of the myelinated area be Δl_m, and that of the node be Δl_n. For a total nerve length L that propagates a signal in time T, derive an expression for the speed of the signal, given N nodes.*

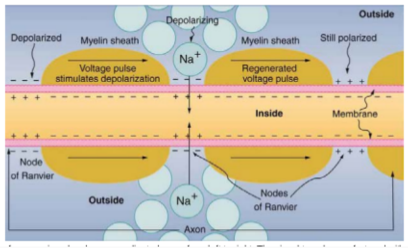


Figure 24: The *nodes of Ranvier* between *myelin sheaths* create a system which propagates the signal without losing speed.

$$L = N(\Delta l_{\mathrm{m}} + \Delta l_{\mathrm{n}}) \tag{16}$$

$$T = T(\Delta t_{\mathrm{m}} + \Delta t_{\mathrm{n}}) \tag{17}$$

$$v = \frac{L}{T} = \frac{\Delta l_{\mathrm{m}} + \Delta l_{\mathrm{n}}}{\Delta t_{\mathrm{m}} + \Delta t_{\mathrm{n}}} \tag{18}$$

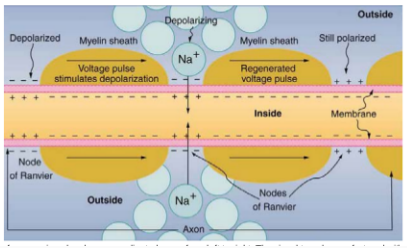


Figure 25: The nodes are small, the sheaths are large.

$$v = \frac{L}{T} = \frac{\Delta l_{\mathrm{m}} + \Delta l_{\mathrm{n}}}{\Delta t_{\mathrm{m}} + \Delta t_{\mathrm{n}}} \tag{19}$$

$$\epsilon = \frac{\Delta l_{\mathrm{n}}}{\Delta l_{\mathrm{m}}} \quad \kappa = \frac{v_{\mathrm{m}}}{v_{\mathrm{n}}} \tag{20}$$

$$v = v_{\mathrm{m}} \left(\frac{1 + \epsilon}{1 + \kappa\epsilon} \right) \tag{21}$$

Now, we know that $\epsilon \approx 10^{-3}$ and $\kappa \approx 10^2$, so $\kappa\epsilon \approx 10^{-1}$. We can approximate the final expression as

$$\boxed{v \approx v_\mathrm{m}\left(1 - \kappa\epsilon + (\kappa\epsilon)^2\right)} \tag{22}$$

Using $\kappa \approx 100$ and $\epsilon \approx 1/1000$, we get $v = 91\% v_\mathrm{m}$.

- Our nerves have evolved to have the smallest nodes possible so that we get the highest nerve speed possible
- But we need the nodes to repolarize, otherwise the *IR* drop would dissipate the signal (think of electrical grid)

`https://en.wikipedia.org/wiki/Nerve_conduction_velocity`

Suppose the distance from a boy's spinal chord to his finger tip is 0.5 m, and the nerve conduction velocity is 100 m/s. The boy touches a hot stove, sending a signal from his finger tip to his spinal chord, and the nervous system there sends a signal to jerk the hand away from the stove. The signal travels back to the finger tips. What is the total time elapsed? (In other words, what is the reaction time?)

- A: 0.1 ms
- B: 1 ms
- C: 10 ms
- D: 100 ms

What limits our reaction time? Nerve conduction velocity.

CONCLUSION

Reading: Chapters 20 and 21

1. Current, Ohm's Law, resistors and conductors
2. DC circuits I
3. Nerve signals
4. DC circuits II