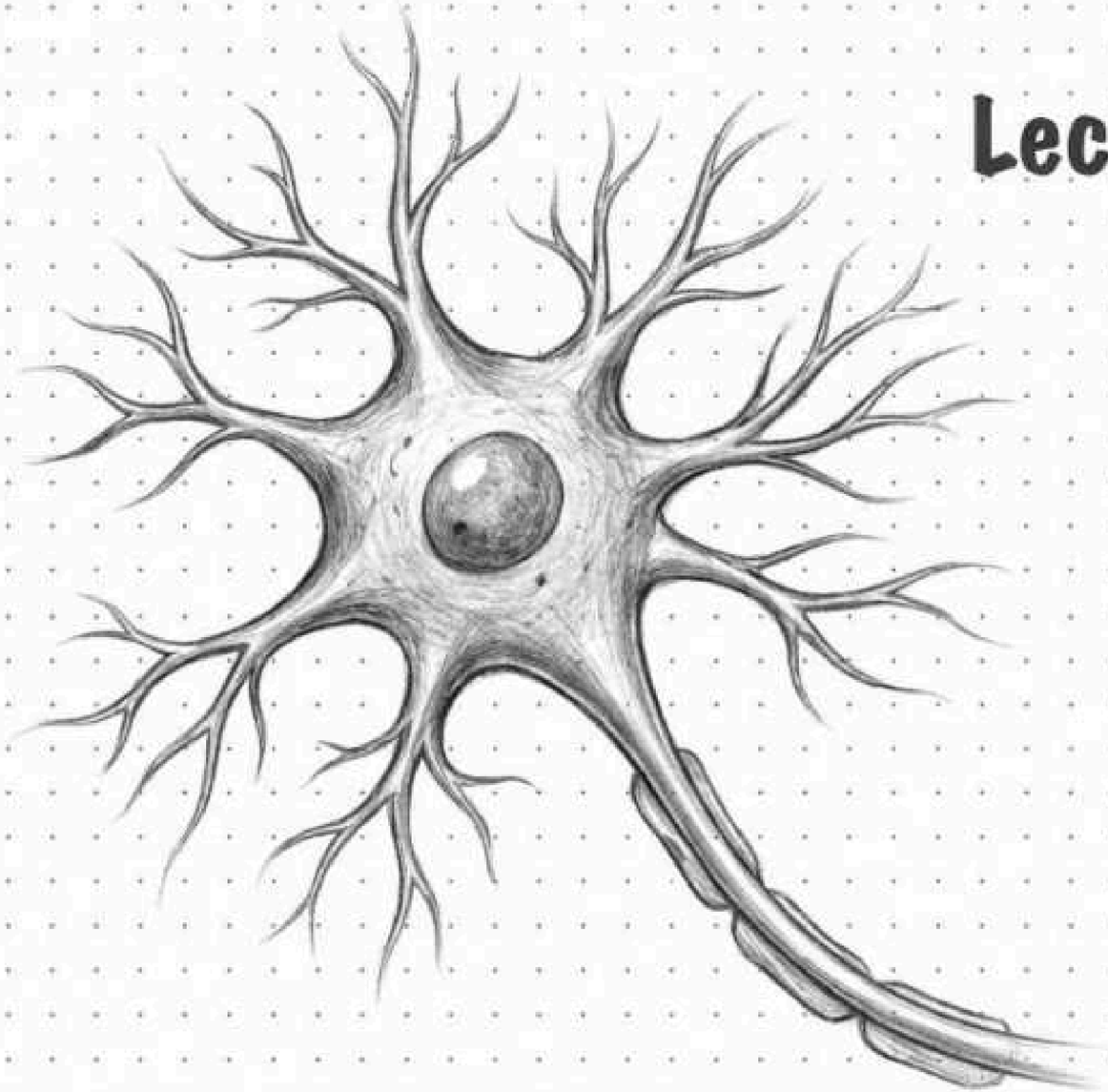


Lecture 2 - The Electrical Signal

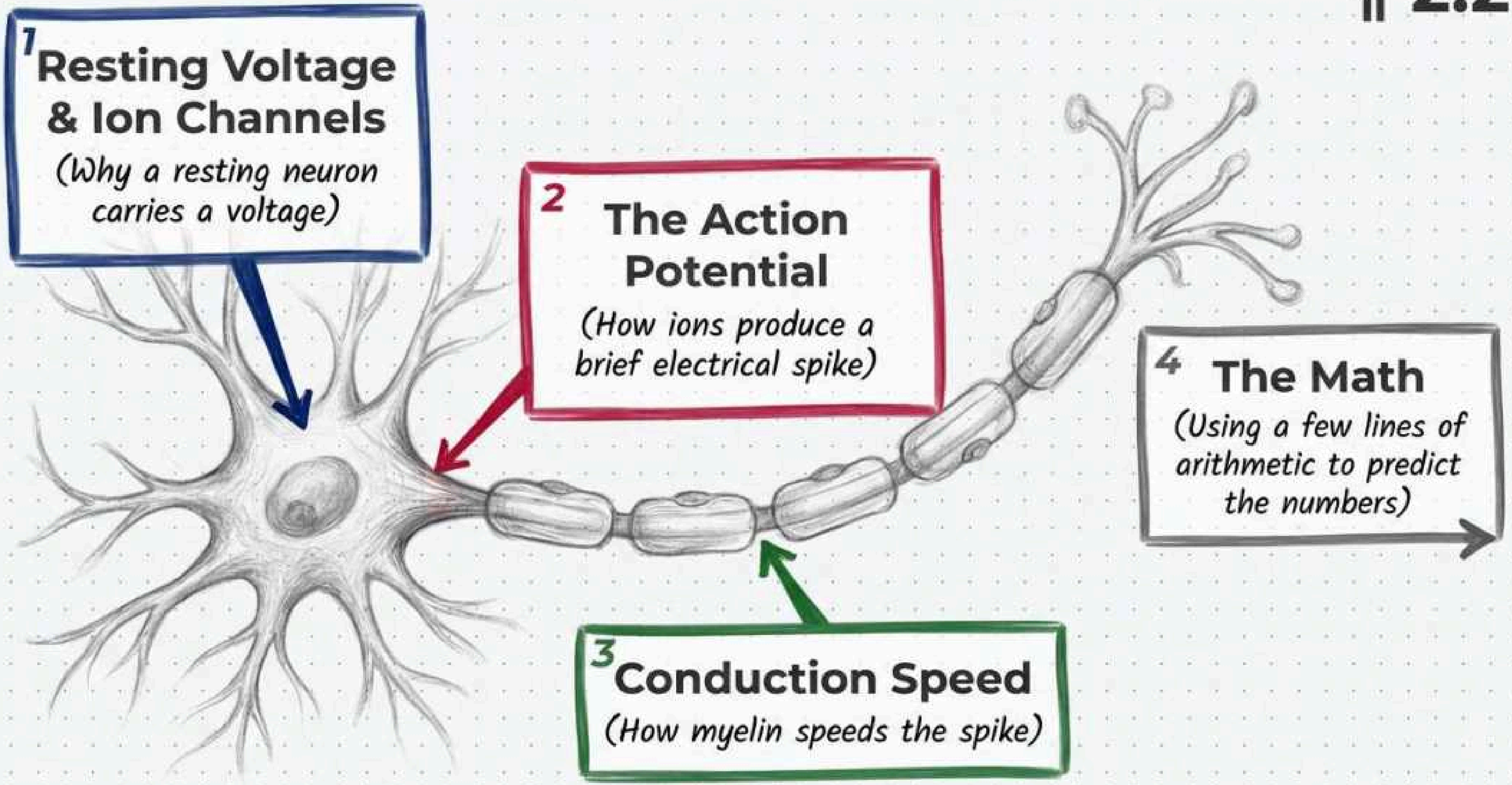
Resting Potential and the Action Potential.

At a glance:

- The resting potential
- Ion gradients
- The Nernst equation
- The action potential
- How myelin speeds conduction

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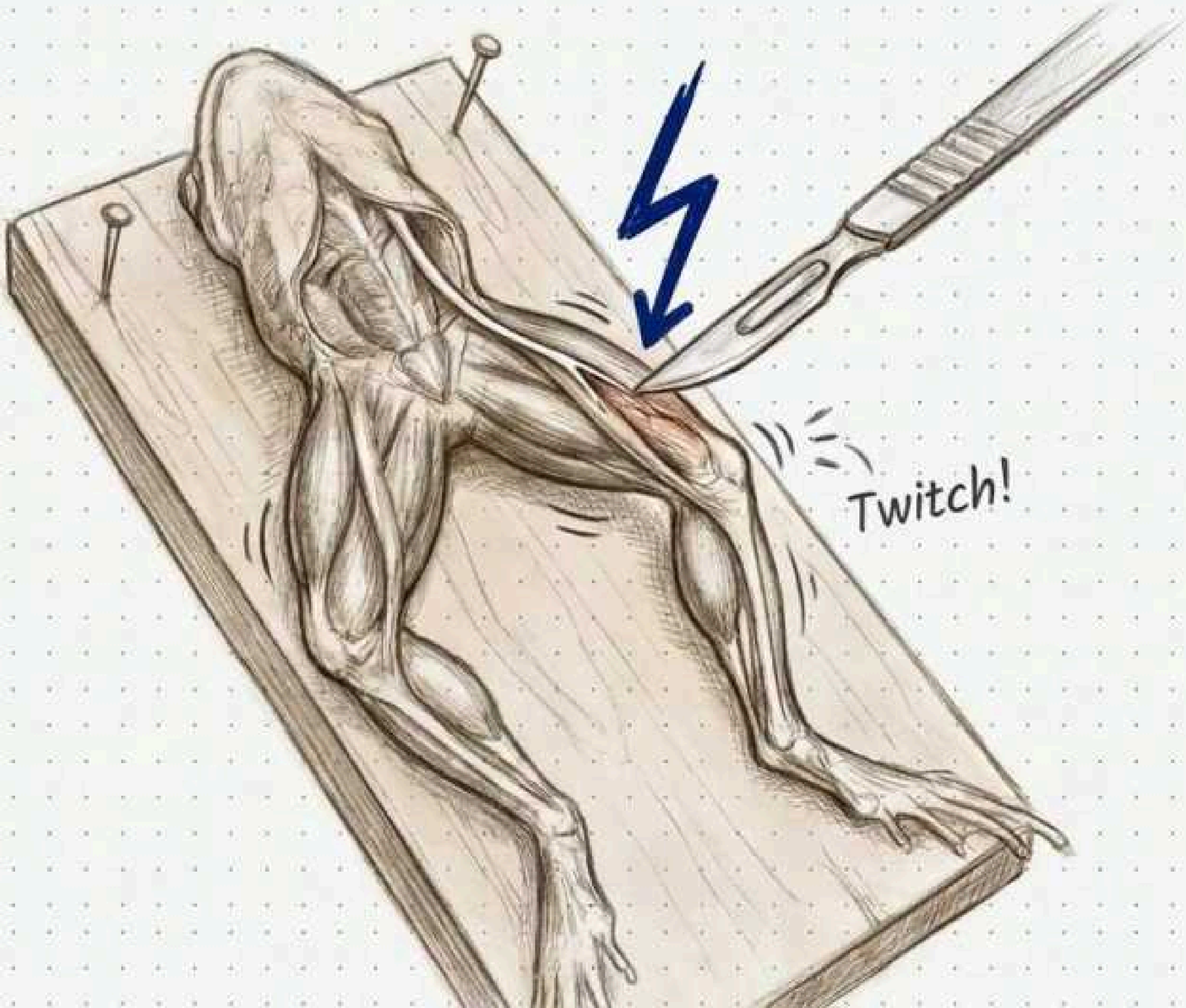
¶ 2.2



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Galvani's Twitching Frog (1780s)

¶ 2.3



Luigi Galvani's Conclusion:

Animals carry their own electricity

(Partly wrong about the specific cause)

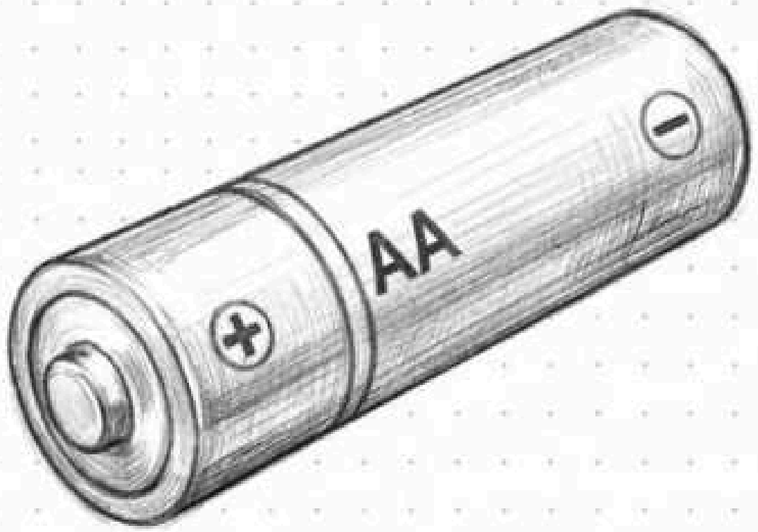
The Modern Principle:

Nerves and muscles work by electrical signals.

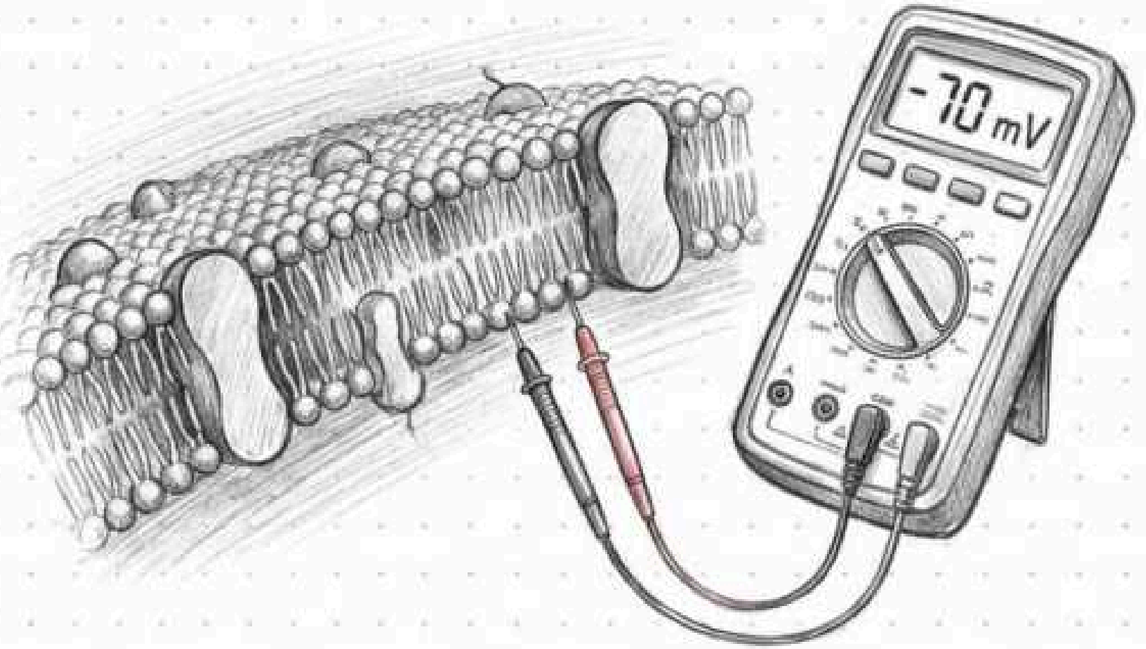
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The Scale of the Resting Potential

¶ 2.4



1500 millivolts (+)



-70 millivolts

(Inside negative compared to the outside)

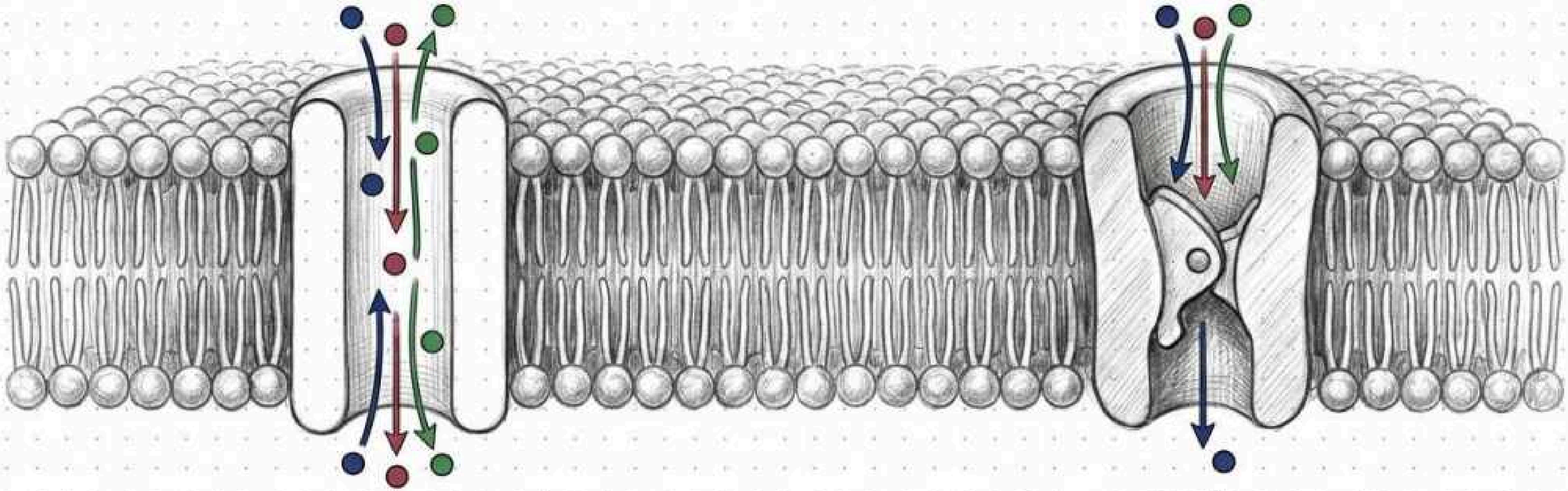
A neuron's resting voltage is tiny—a standard AA battery supplies more than 20 times as much voltage as a resting neuron.

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The Membrane & Ion Channels

¶ 2.5

Charged ions cannot cross the fatty double layer on their own; they require spanning proteins.



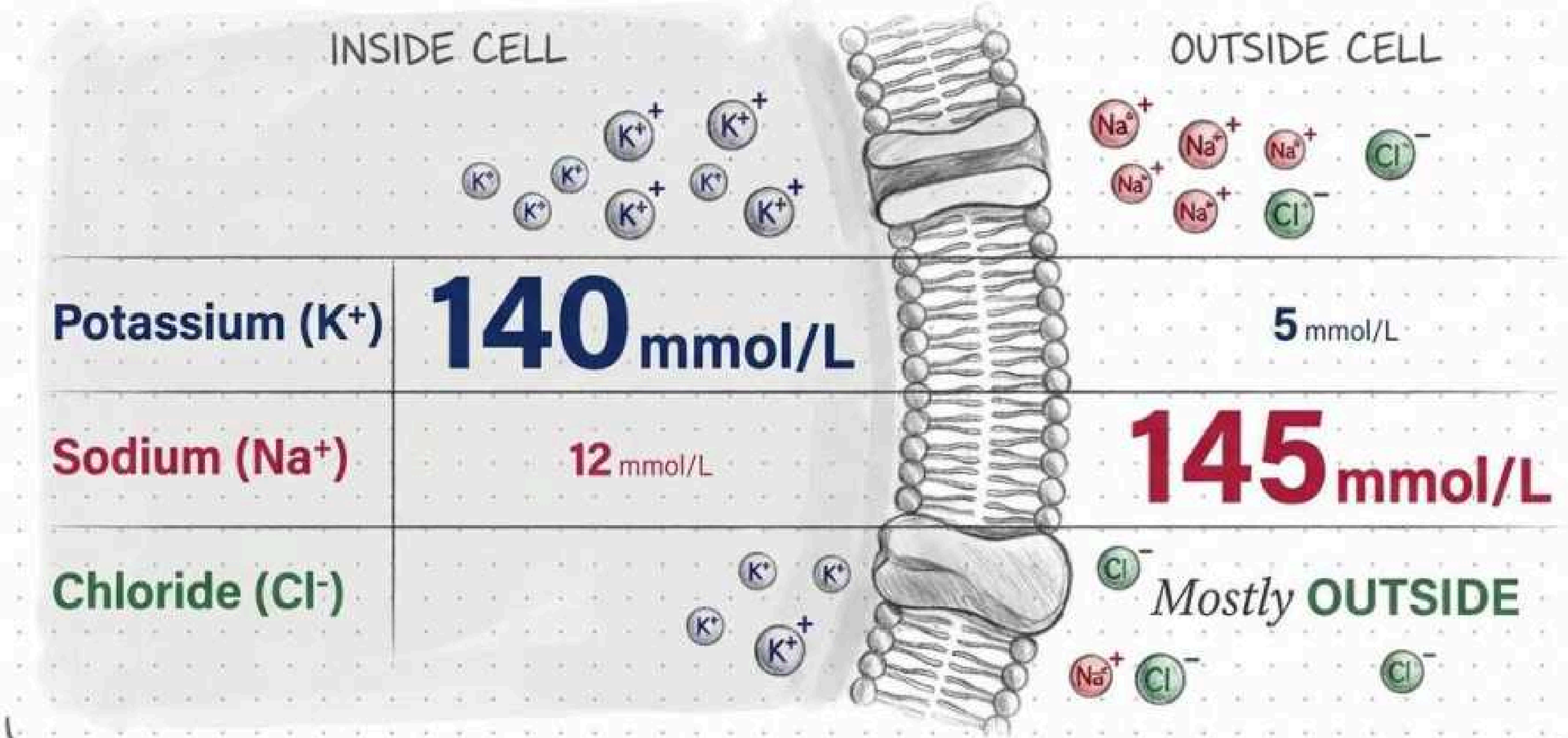
Leak Channels
(Always open)

Gated Channels
(Open or close only in response to a voltage change or chemical signal)

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The Stored Energy of the Nervous System

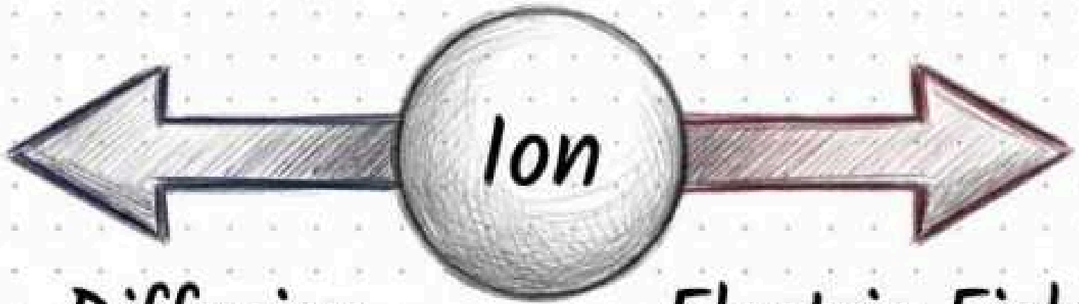
¶ 2.6



This uneven distribution acts as stored energy waiting to be released.

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Two Forces & The Equilibrium Potential



Diffusion
(Pushes from high concentration toward low)

Electric Field
(Pushes charged ions toward opposite charge)

When forces cancel, no net flow occurs (Equilibrium Potential).

The Nernst Equation

(at body temperature)

$$E = 61.5\text{mV} \times \log_{10}\left(\frac{[\text{Outside}]}{[\text{Inside}]}\right) \div \text{charge}$$

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Predicting the Numbers

Potassium (K^+)

$$\log\left(\frac{5}{140}\right) \approx -1.45$$

$$E_K \approx -89 \text{ mV}$$

Sodium (Na^+)

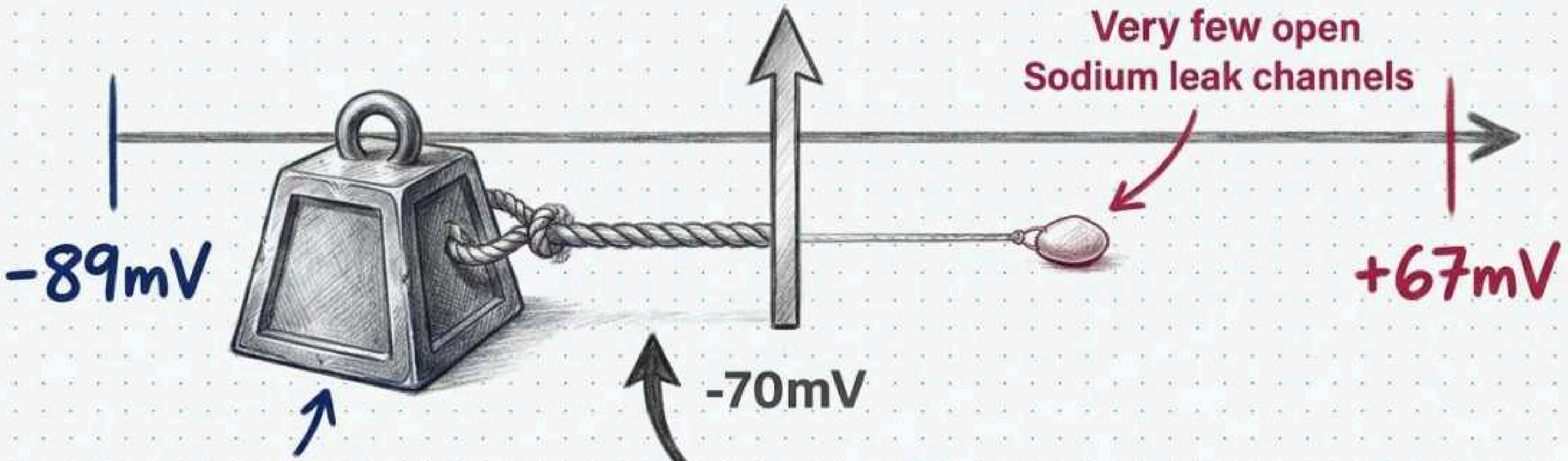
$$\log\left(\frac{145}{12}\right) \approx 1.08$$

$$E_{Na} \approx +67 \text{ mV}$$

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¶2.9

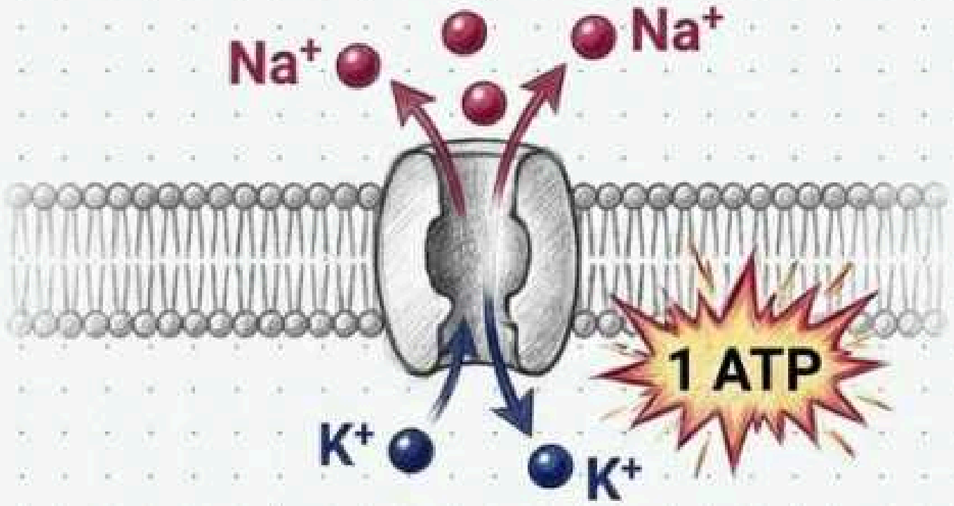
Settling at -70 Millivolts



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¶2.10

The Sodium-Potassium Pump





- Works constantly to restore gradients against the natural leaks (like bailing a leaky boat).

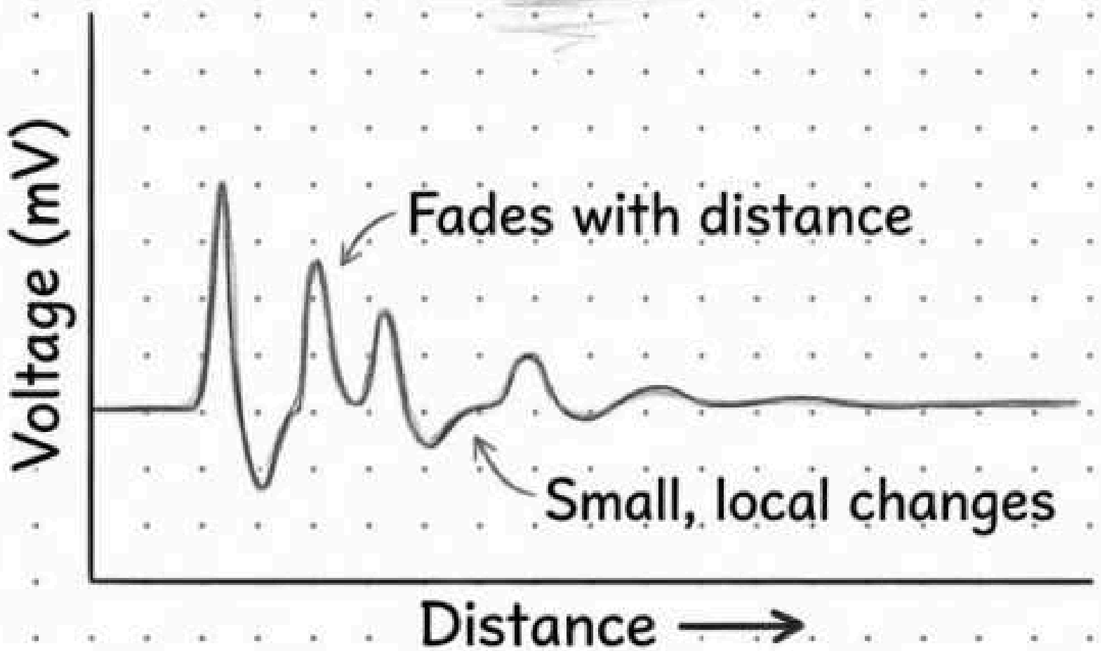
- Ejects 3 Na+ out / Takes 2 K+ in per cycle.

- Consumes a massive share of the brain's energy (ATP). Without oxygen, the brain fails within minutes as these pumps stop.

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Graded Potentials (The Fading Signal)





① Definitions:

Depolarization: A voltage change toward zero.

Hyperpolarization: A voltage change to a more negative value.

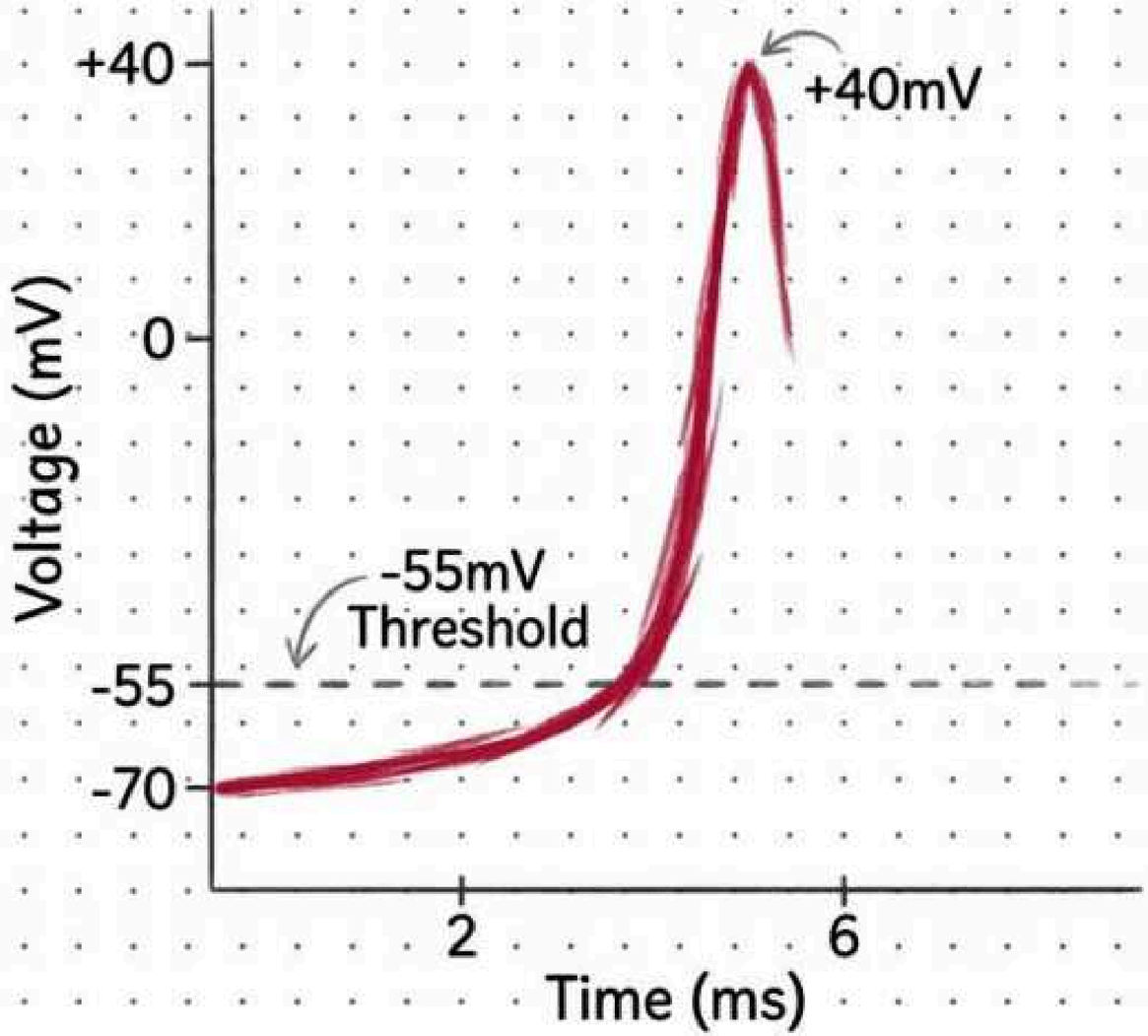
② The Problem:

Small inputs change voltage by only a few millivolts. Like ripples in a pond, they are small and fade with distance.

The neuron needs something stronger to communicate afar.

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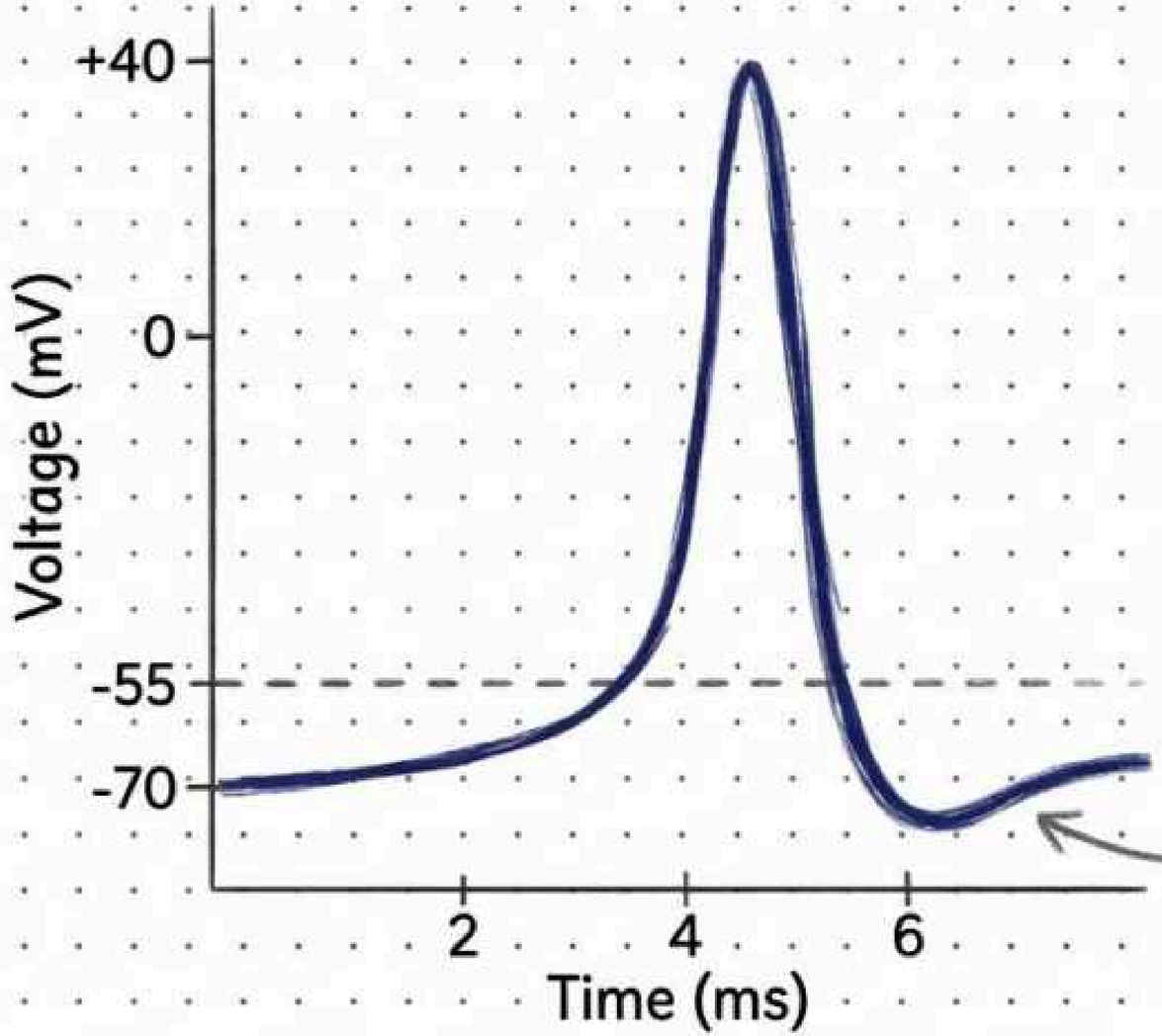
The Action Potential (Rising Phase)



1. Depolarization reaches roughly -55mV threshold.
2. Voltage-gated Sodium channels spring open.
3. Sodium rushes in, driving voltage soaring in ~1ms to roughly +40mV.
4. This depolarizes the cell further, opening even more channels.

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The Action Potential (Falling Phase)



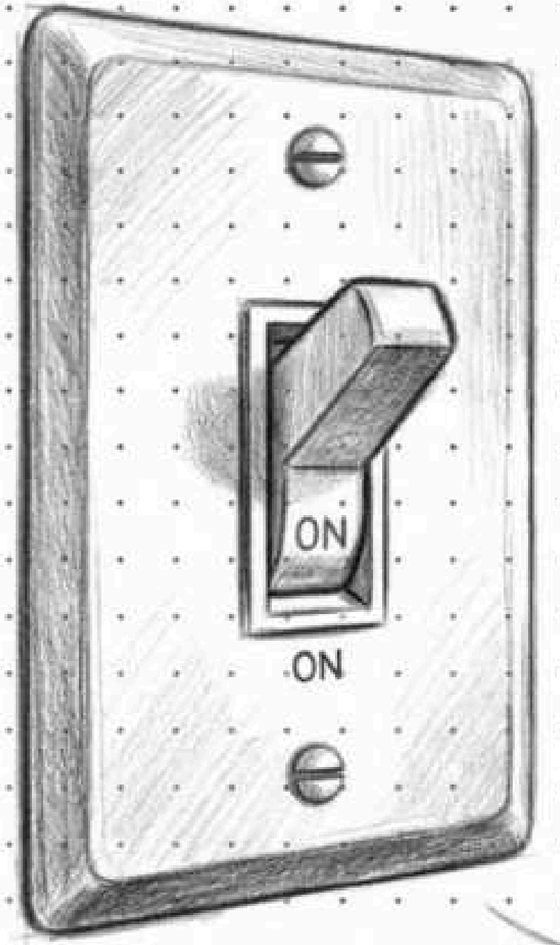
Two reasons the spike ends:

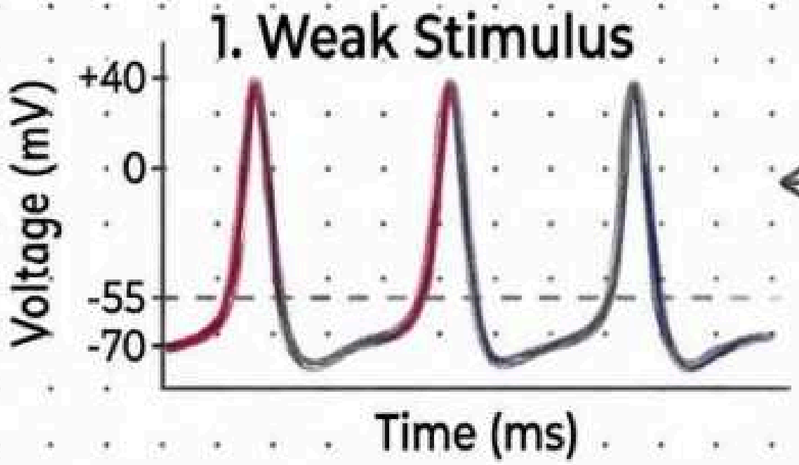
1. Sodium channels inactivate (closing themselves after a moment).
2. Voltage-gated Potassium channels open (more slowly), letting **Potassium** flow out to pull voltage down.

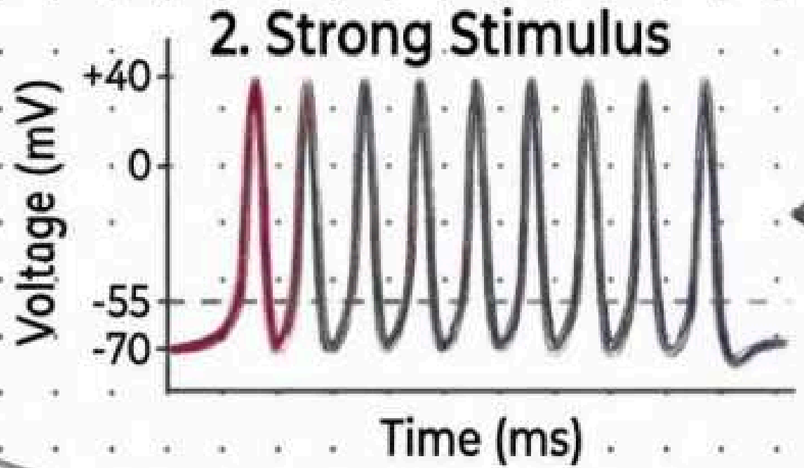
Afterhyperpolarization
(The membrane overshoots below resting level before settling)

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The All-or-None Principle





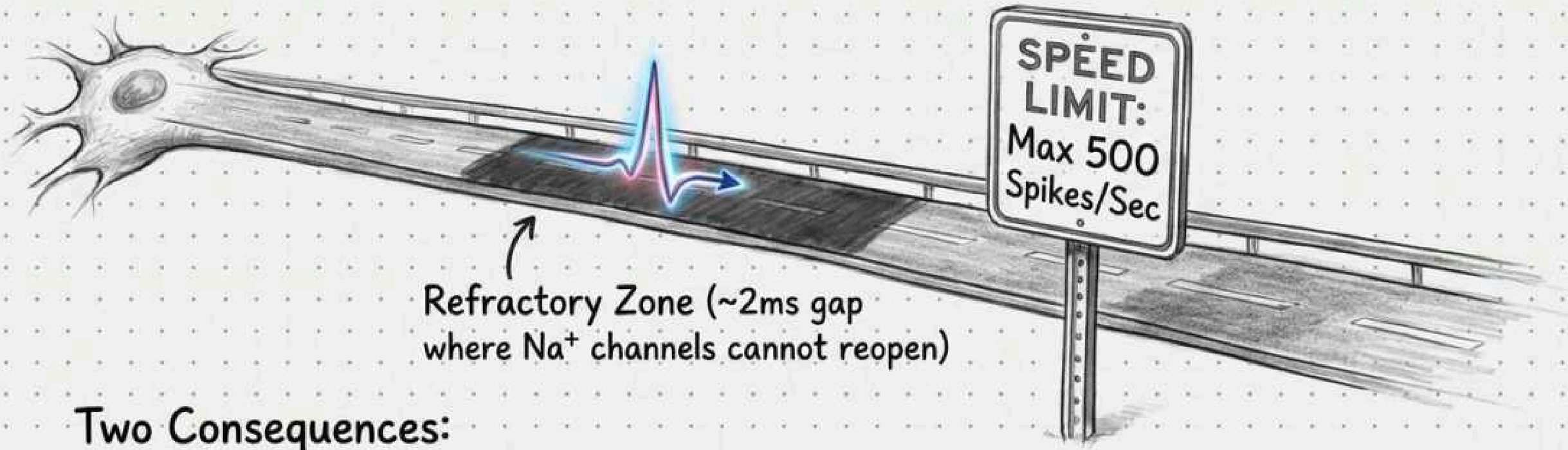


Core Rule:
Once threshold is crossed, the spike is the exact same size every time.

Insight:
A stronger stimulus does not make a bigger spike; it makes more spikes per second. Information is carried by the rate and timing impulses, not by their height. Pressing a light switch harder doesn't make it brighter.

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The Refractory Period & Unidirectional Flow

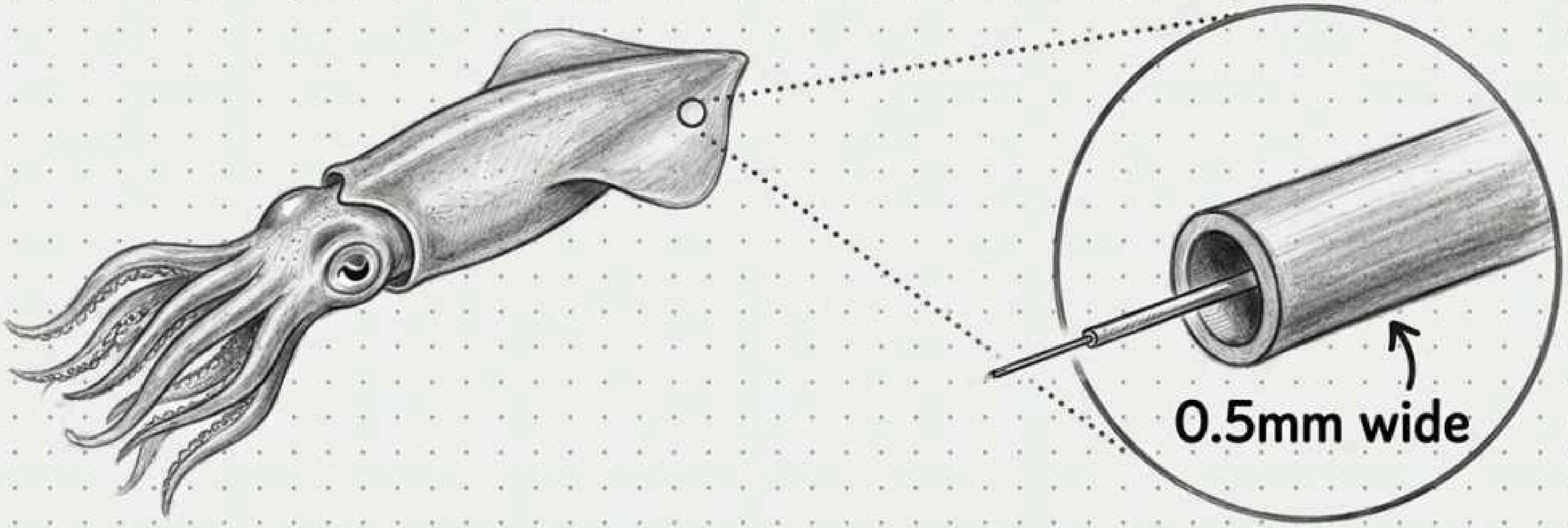


Two Consequences:

1. Sets a biological speed limit of about 500 fires per second.
2. Keeps the signal moving in one direction, as the stretch of axon just behind the spike cannot immediately fire again.

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1952: Hodgkin, Huxley, and the Squid Giant Axon

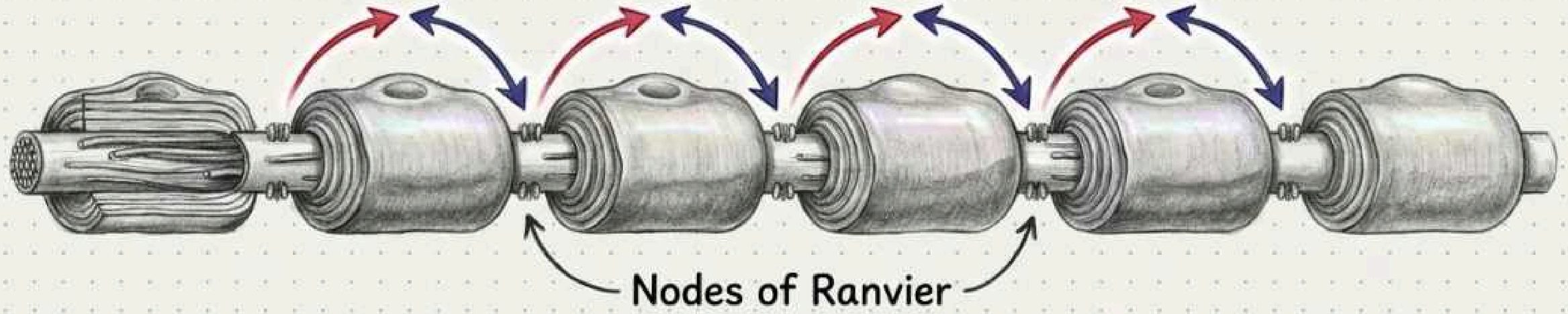


Alan Hodgkin and Andrew Huxley used a squid's giant axon (wide enough to fit a physical wire) to measure currents, fit equations, and predict the spike.

Result: Awarded the Nobel Prize in 1963.

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Saltatory Conduction & Myelin



The Problem:

In a thin, bare axon, regenerating the spike point-by-point travels only ~1 meter per second.

The Solution:

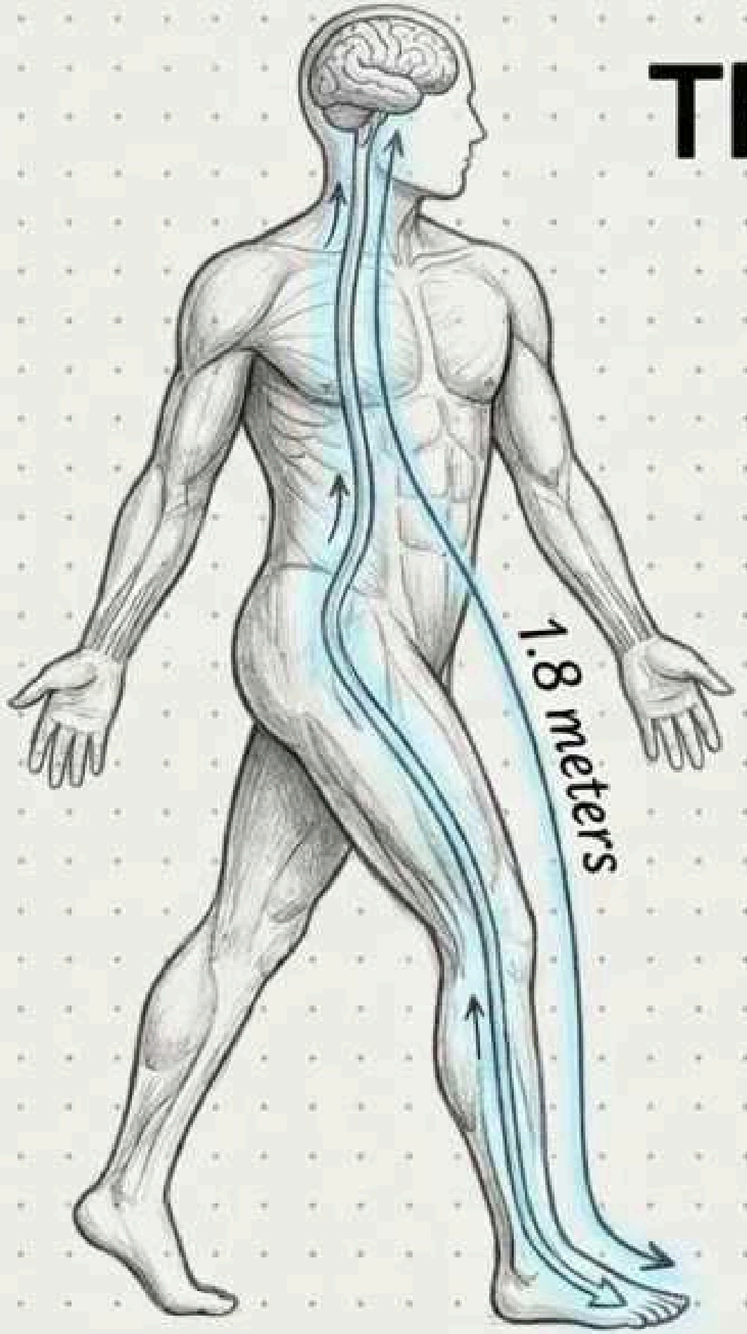
Vertebrates developed Myelin to insulate the axon. The spike jumps from node to node (Saltatory conduction, from Latin for leaping).

Benefit:

Leaping saves vast amounts of time and the energy the pump must spend afterward.

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The Speed Problem Solved



Myelinated Axon

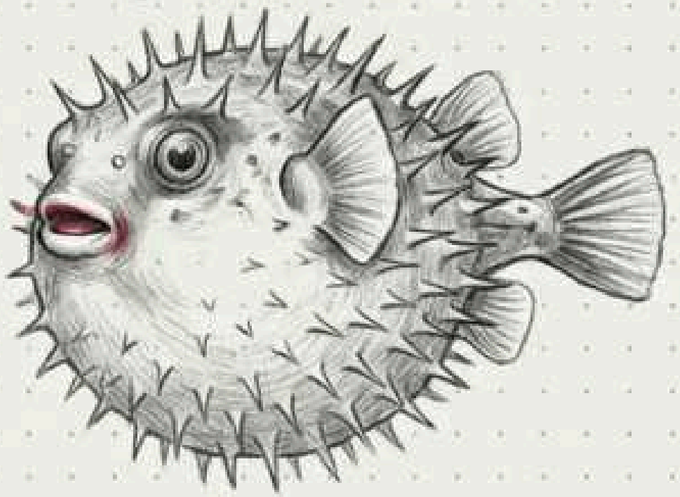
Conducts up to ~120 m/s.
(At 100 m/s, the trip takes exactly 18 milliseconds).

Bare Thin Axon

Conducts at 1 m/s.
(The same trip would take a painfully slow 1.8 seconds).

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When Mechanisms Fail (Clinical Impact)

Multiple Sclerosis	Lidocaine (Anesthetic)	Tetrodotoxin
The immune system attacks myelin, slowing or blocking conduction entirely.	Blocks voltage-gated Sodium channels locally. Pain signals can never form or cross cross the threshold.	The poison of the pufferfish blocks the exact same Sodium channels system-wide. Deadly shutdown. 

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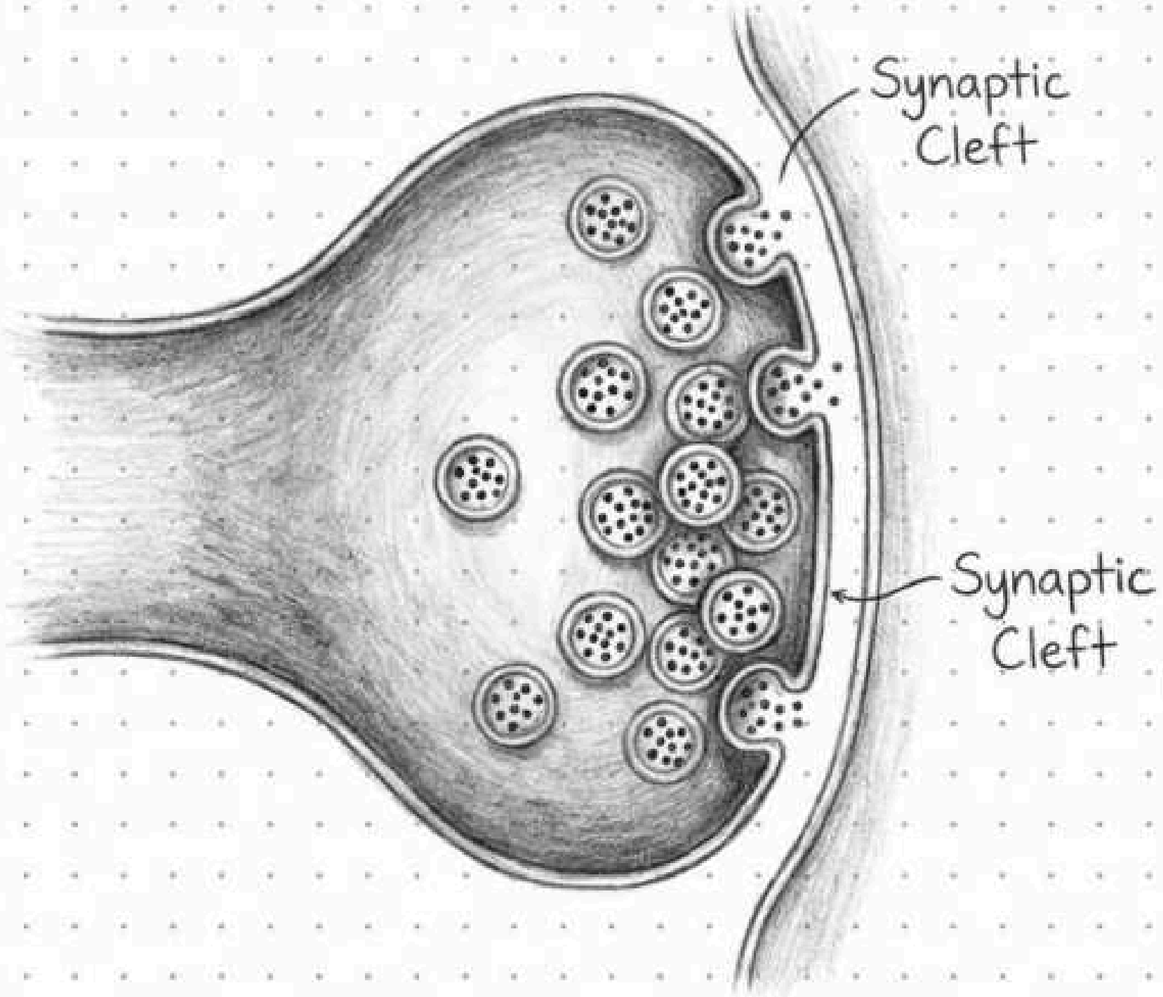
Lecture Question

A neuron's resting potential is minus seventy millivolts, and a drug opens extra potassium channels in its membrane. Predict the direction of the change in voltage, and explain whether the neuron becomes more or less likely to fire. Use the potassium equilibrium potential in your answer.

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Looking Ahead to Lecture 3

¶ 2.21



We've covered the electrical signal's journey down the axon.

Next time: What happens when the spike reaches the very end?

The Synapse and the Chemical Messengers.

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