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Measuring potentials in actual neurons

Today's Topics

- The neuron at rest
- The neuron in action

Resting potential

Resting potential arises from

- A balance of forces
 - Force of diffusion
 - Electrostatic force
- Forces cause ion flows across membrane
- Ion channels allow ion flow

Ion channels

- Openings in neural membrane
- Selective
- Vary in permeability
- Types
 - Passive/leak
 - Voltage-gated
 - Ligand-gated (chemically-gated)
 - Transporters/pumps

Ion channels

Neuron at rest permeable to K⁺

- Passive K⁺ channels open
- [K⁺] concentration inside >> outside
- K⁺ flows out

Force of diffusion

Force of diffusion

Neuron at rest permeable to K⁺

- Organic anions (A⁻) too large to move outside of cell
- A⁻ and K⁺ largely in balance == no net internal charge
- K⁺ outflow creates charge separation: K⁺ <-> A⁻
- Charge separation creates a voltage
- Outside +/inside -
- Voltage build-up stops outflow of K⁺

The resting potential

Balance of forces in the neuron at rest

- **Force of diffusion**
 - K⁺ moves from high concentration (inside) to low (outside)

Balance of forces in the neuron at rest

- **Electrostatic force**
 - Voltage build-up stops K⁺ outflow
 - Specific voltage called *equilibrium potential* for K⁺
 - K⁺ positive, so equilibrium potential negative (w/ respect to outside)
 - Equilibrium potential close to neuron resting potential

Equilibrium potential and Nernst equation

Building on intuition

Equilibrium potentials calculated under typical conditions

Ion	[inside]	[outside]	Voltage
K ⁺	~150 mM	~4 mM	~ -90 mV
Na ⁺	~10 mM	~140 mM	~ +55-60 mV
Cl ⁻	~10 mM	~110 mM	- 65-80 mV

Resting potential K⁺ equilibrium potential

- Resting potential not just due to K⁺
- Other ions flow
- Resting potential == net effects of all ion flows across membrane

Goldman-Hodgkin-Katz equation

Na⁺ role

- Na⁺ concentrated **outside** neuron
 - Membrane at rest not very permeable to Na⁺
 - Some, but not much Na⁺ flows *in*
 - Na⁺ has equilibrium potential $\sim +60$ mV
 - Equilibrium potential is positive (with respect to outside)
 - Would need positive interior to keep Na⁺ from flowing in
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Electrical circuit model

Summary of forces

Ion	Concentration gradient	Electrostatic force	Permeability
K ⁺	Inside \gg Outside	- (pulls K ⁺ in)	Higher
Na ⁺	Outside \gg Inside	- (pulls Na ⁺ in)	Lower

Party On

- Annie (A⁻) was having a party.
 - Used to date Nate (Na⁺), but now sees Karl (K⁺)
- Hired bouncers called
 - “The Channels”
 - Let Karl and friends in or out, keep Nate out
- Annie’s friends (A⁻) and Karl’s (K⁺) mostly inside
- Nate and friends (Na⁺) mostly outside
- Claudia (Cl⁻) tagging along

What happens if something changes?

- Easier for Karl [K⁺] to exit?
- Easier for Nate [Na⁺] to enter?
- Some action!

Action potential

Action potential

- Threshold of excitation
- Increase (rising phase/depolarization)
- Peak
 - at positive voltage
- Decline (falling phase/repolarization)
- Return to resting potential (refractory period)

Action potential break-down

Phase	Neuron State
Rise to threshold	+ input makes membrane potential more +
Rising phase	Voltage-gated Na ⁺ channels open, Na ⁺ enters
Peak	Voltage-gated Na ⁺ channels close and deactivate; voltage-gated K ⁺ channels open
Falling phase	K ⁺ exits
Refractory period	Na ⁺ /K ⁺ pump restores [Na ⁺], [K ⁺]; voltage-gated K ⁺ channels close

What's a Na⁺/K⁺ pump?

- Enzyme (*Na⁺/K⁺ ATP-ase*) embedded in neuron membrane
- Pumps Na⁺ and K⁺ *against* concentration gradients
- Na⁺ out; K⁺ in
- Uses ATP or chemical energy

Example in another domain

Refractory periods

- *Absolute*
 - Cannot generate action potential (AP) no matter the size of the stimulus
 - Voltage-gated Na⁺ channels inactivated, reactivate in time.
- *Relative*
 - Can generate AP with larg(er) stimulus
 - Some voltage-gated K⁺ channels still open
- Refractory periods put 'spaces' between APs

Generating APs

- *Axon hillock*
 - Portion of soma adjacent to axon
 - Integrates/sums input to soma
- *Axon initial segment*
 - Unmyelinated portion of axon adjacent to soma
 - Voltage-gated Na⁺ and K⁺ channels exposed
 - If sum of input to soma > threshold, voltage-gated Na⁺ channels open

Axon hillock, axon initial segment

Axon Hillock” by M.aljar3i - Own work. Licensed under CC BY-SA 3.0 via Commons

Next time

- How action potentials propagate
- Review for Exam 1