260-2017-02-03

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2017-02-02 14:22:21

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+ flows out

Force of diffusion

Force of diffusion

Neuron at rest permeable to K+

- K+ outflow creates charge separation: K+ <-> A-
- Organic anions (A-) to large to move outside of cell
- Charge separation creates a voltage
- Voltage prevents K+ from flowing back inside

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 intution

But, why is resting potential K+ equilibrium potential?

- K+ equilibrium potential: ~ -90 mV

Na+ role

- Na+ concentrated **outside** neuron
- Na+ has equilibrium potential ~ + 60 mV
- Membrane at rest not very permeable to Na+
- Some, but not much Na+ flows *in*
- Equilibrium potential is positive (with respect to outside)

Resting potential

- Net effects of ion flow across membrane
- Goldman-Hodgkin-Katz equation

Electrical circuit model

Summary of forces

Ion	Concentration gradient	Electrostatic force	Permeability
K+	Inside >> Outside	- (pulls K+ **in**)	Higher
Na+	Outside >> 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

Phase	Neuron State
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*
  - Umyelinated 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