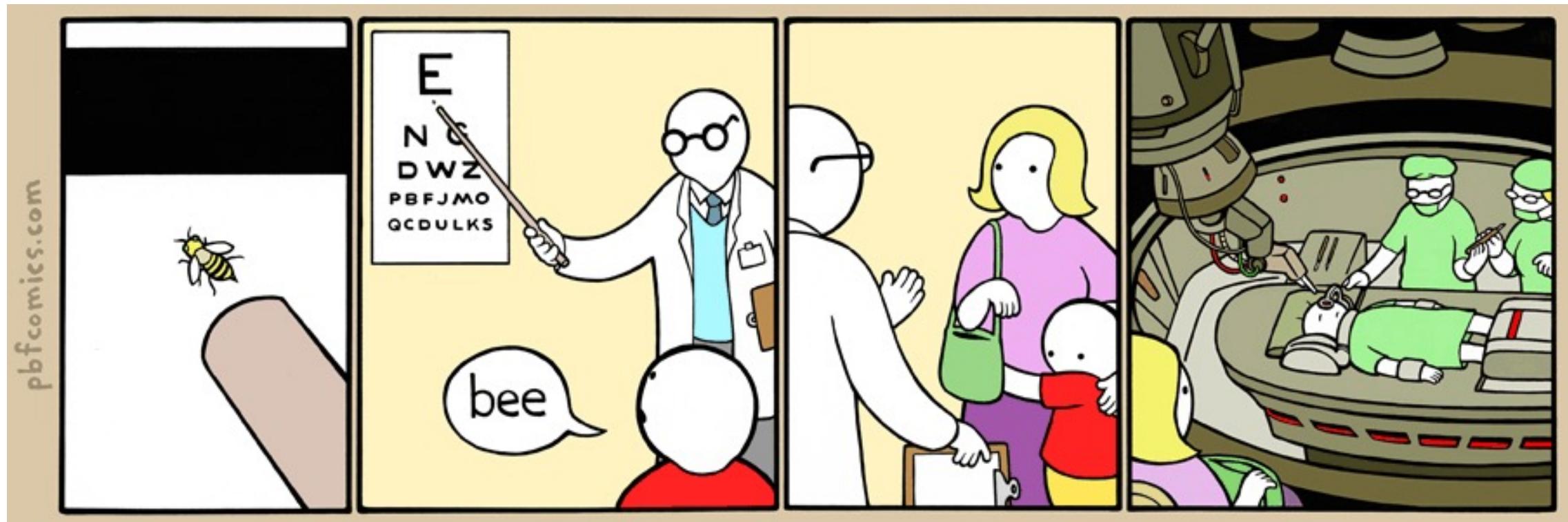


PSYC301: Neural communication

Jay Hosking, PhD



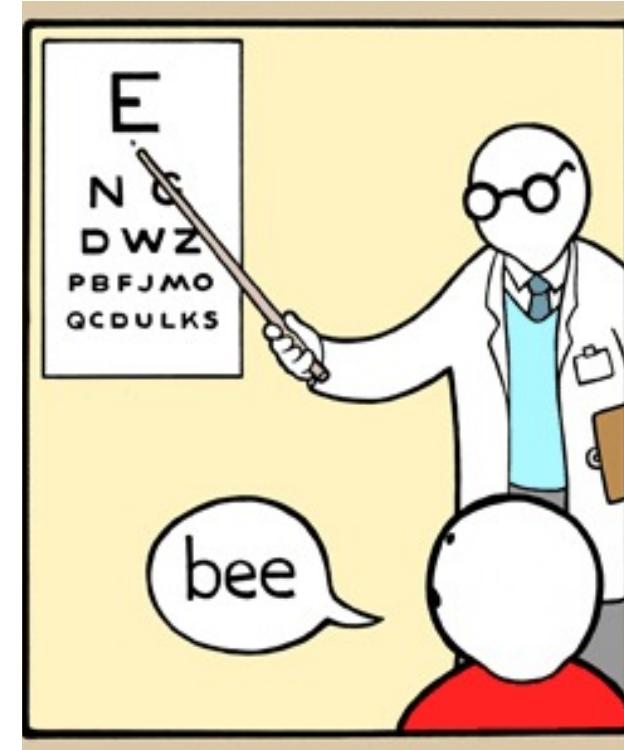
Overview

I. Within one cell

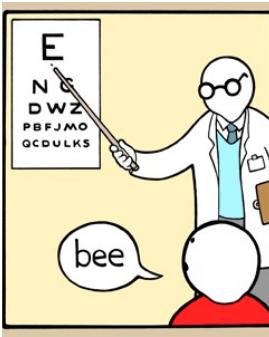
- a. The resting membrane potential
- b. Post-synaptic potentials
- c. Action potentials
- d. Action potential conduction

II. Between cells

- a. The synapse and neurotransmission
- b. Receptors



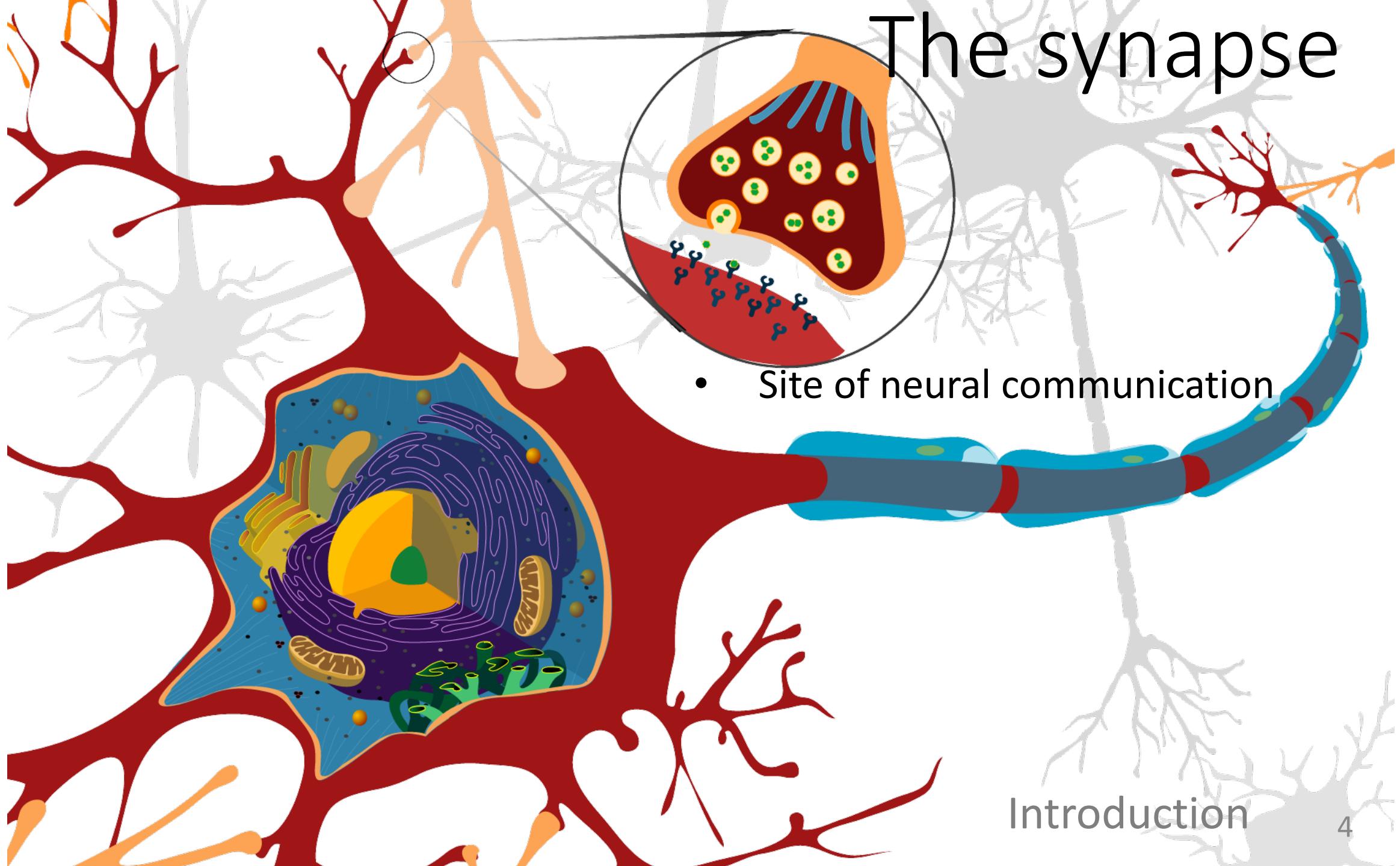
Learning objectives



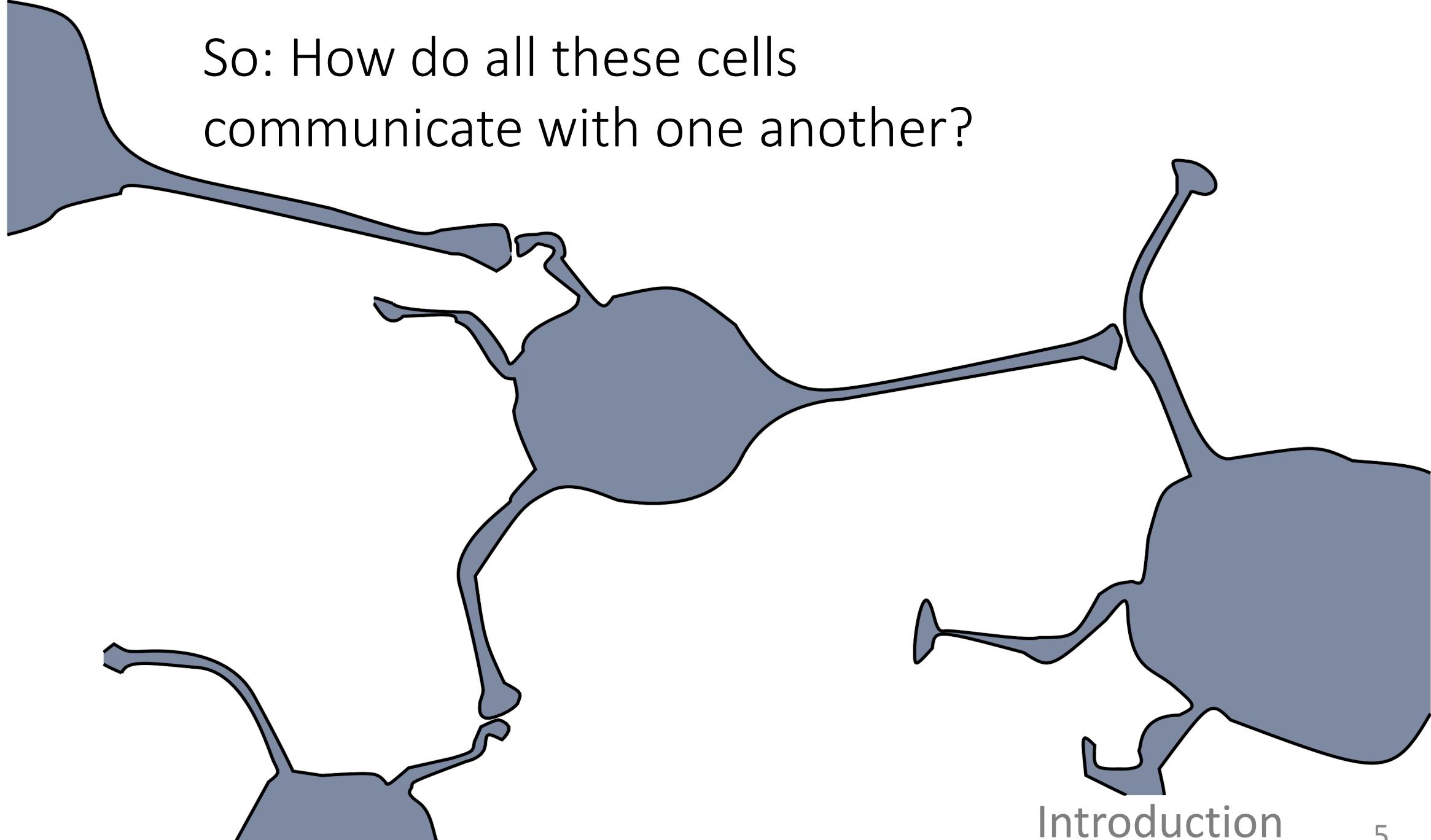
1. How is neural communication measured and recorded?
2. Identify the ions that are important for neural communication, including their electrical properties.
3. What is the resting membrane potential and why is it important? What happens if the resting membrane potential is disrupted?
4. Describe the proteins involved in maintaining the resting membrane potential.
5. What are post-synaptic potentials? Describe the two main forms they take, their effects, and what causes them.
6. What is an action potential? Where does it occur? What proteins cause it?
7. Describe conduction of the action potential, and strategies to increase speed.
8. Describe the axon terminal, and the effect of an action potential on the bouton.
9. What are receptors? Be sure you can explain effects, types, and location.
10. How is a signal between cells ended?
11. (Optional.) Read chapter 4 of Pinel & Barnes for some extra help on the material.

The synapse

- Site of neural communication

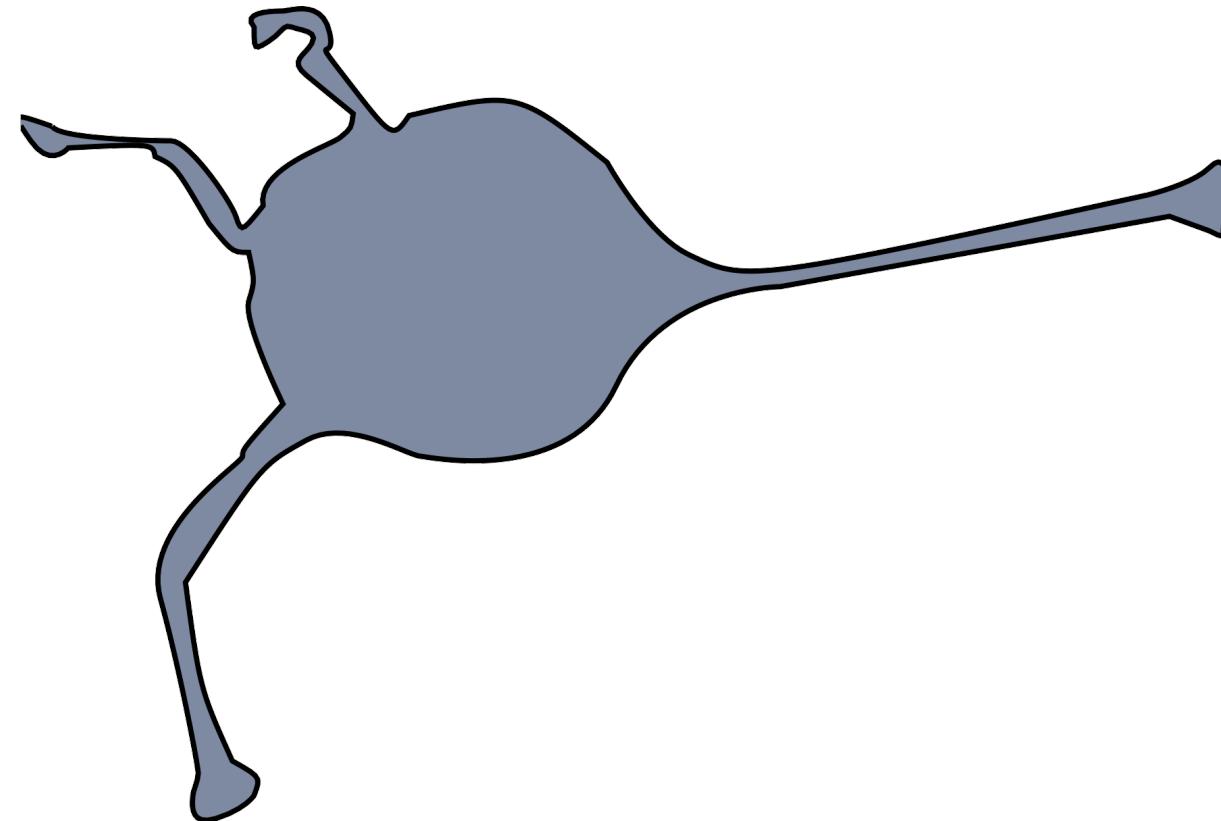


Introduction

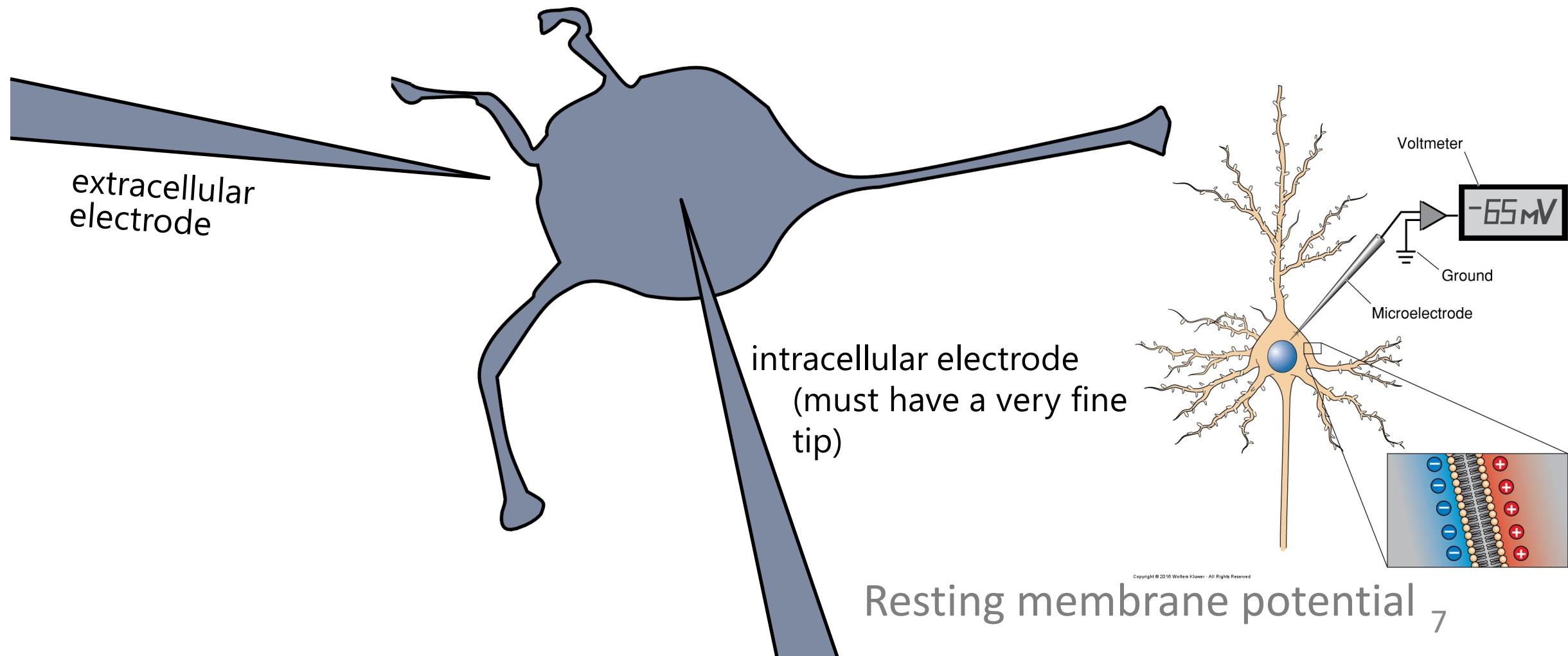


So: How do all these cells
communicate with one another?

As a first step: How does communication occur within a single neuron?



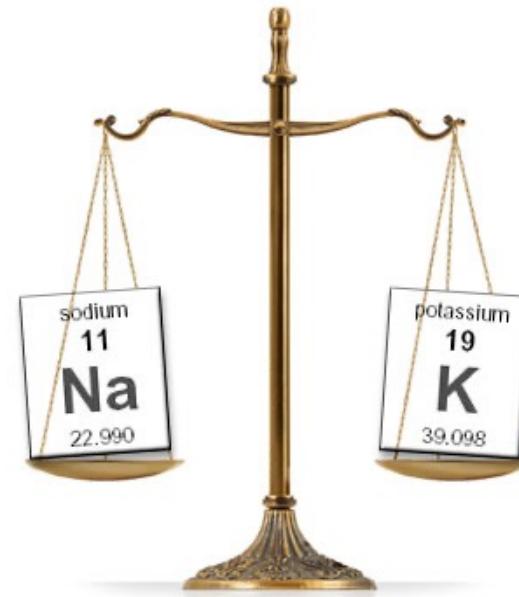
A healthy neuron has a resting membrane potential (voltage) of between -60 and -80 mV; you'll hear me say -65mV or -70mV often.



Neuronal communication is chemical

1. Primarily the result of two ions, sodium (Na^+) and potassium (K^+)
2. Ions move into or out of the cell, but not freely

Periodic Table of the Elements																																																																																																																																																																																																																																																																																																																																																																																															
Atomic Number	Symbol		Name		Atomic Mass																																																																																																																																																																																																																																																																																																																																																																																										
1	H	Hydrogen	1.008	2	Be	Boron	9.012	3	Li	Lithium	6.941	4	Mg	Magnesium	24.305	5	VB	V	6	VIIB	7B	7	VIIIB	7B	8	VIII	8A																																																																																																																																																																																																																																																																																																																																																																				
9	Na	Sodium	22.990	10	Ca	Calcium	40.078	11	K	Potassium	39.098	12	Sc	Scandium	44.956	13	Ti	Titanium	47.88	14	Cr	Chromium	51.996	15	Mn	Manganese	54.938	16	Fe	Iron	55.893	17	Co	Cobalt	58.933	18	Ni	Nickel	58.933	19	Cu	Copper	63.546	20	Zn	Zinc	65.39	21	Ga	Gallium	69.752	22	Ge	Germanium	72.61	23	As	Arsenic	74.922	24	Se	Selenium	75.00	25	Br	Bromine	79.904	26	Kr	Krypton	84.80	27	Tc	Technetium	98.907	28	Rh	Ruthenium	101.07	29	Pd	Palladium	106.42	30	Ag	Argentum	107.883	31	In	Inertium	114.818	32	Sn	Stannum	118.71	33	Te	Tellurium	121.760	34	I	Iodine	126.904	35	Xe	Xenon	131.29	36	Rb	Rubidium	84.488	37	Sr	Samarium	87.62	38	Y	Yttrium	88.905	39	Zr	Zirconium	91.224	40	Mo	Molybdenum	92.905	41	Ta	Tantalum	101.965	42	W	Tungsten	178.49	43	Tc	Technetium	198.907	44	Ru	Ruthenium	199.02	45	Rh	Ruthenium	192.22	46	Pd	Palladium	195.08	47	Ag	Argentum	196.967	48	Cd	Cadmium	197.411	49	In	Inertium	204.383	50	Sn	Stannum	207.2	51	Sb	Sbismuth	208.950	52	Te	Teledium	208.952	53	I	Iodine	209.967	54	Xe	Xenon	222.018	55	Cs	Cesium	132.905	56	Ba	Barium	137.327	57	La	Lanthanum	138.908	58	Ce	Cerium	140.115	59	Pr	Praseodymium	144.24	60	Nd	Neodymium	140.908	61	Pm	Protactinium	144.913	62	Sm	Samarium	150.36	63	Eu	Europium	151.965	64	Gd	Gadolinium	157.25	65	Tb	Terbium	158.925	66	Dy	Dysprosium	162.50	67	Ho	Holmium	164.930	68	Er	Erbium	167.26	69	Tm	Thulium	168.934	70	Yb	Ytterbium	173.04	71	Lu	Lutetium	174.967	72	Hf	Hafnium	178.49	73	Ta	Tantalum	180.948	74	W	Tungsten	183.85	75	Re	Rhenium	186.207	76	Os	Osmium	190.23	77	Ir	Iridium	192.22	78	Pt	Platinum	195.08	79	Au	Gold	196.967	80	Hg	Mercury	200.59	81	Tl	Thallium	204.383	82	Pb	Lead	207.2	83	Bi	Bismuth	208.950	84	Po	Poliomylia	208.952	85	At	Astatine	209.967	86	Rn	Radon	222.018	87	Fr	Francium	223.020	88	Ra	Radium	226.025	89-103	Rf	Rutherfordium	[261]	104	Df	Dubnium	[262]	105	Db	Seaborgium	[264]	106	Sg	Bohrium	[266]	107	Bh	Hassium	[269]	108	Hs	Methmerium	[269]	109	Mt	Darmstadtium	[272]	110	Ds	Roentgenium	[273]	111	Rg	Copernicium	[274]	112	Cn	Ununtrium	[289]	113	Uut	Ununpentium	[289]	114	F1	Flerovium	[289]	115	Uup	Ununhexium	[289]	116	Lv	Livermorium	[289]	117	Uus	Ununoctium	[289]	118	Uuo	Ununbium	[289]
Lanthanide Series																																																																																																																																																																																																																																																																																																																																																																																															
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Resting membrane potential ₈

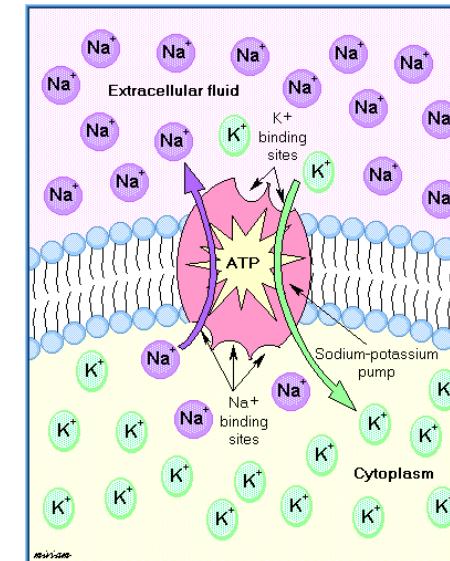
Neuronal communication is electrical

1. Ions are positively and negatively charged (Na^+ and K^+ are both positive, as per "+")
2. As they move into or out of cell, they change the *potential* (voltage) at the membrane

Note: absence of pos. is neg.!

i.e. remove a pos., leave a neg.

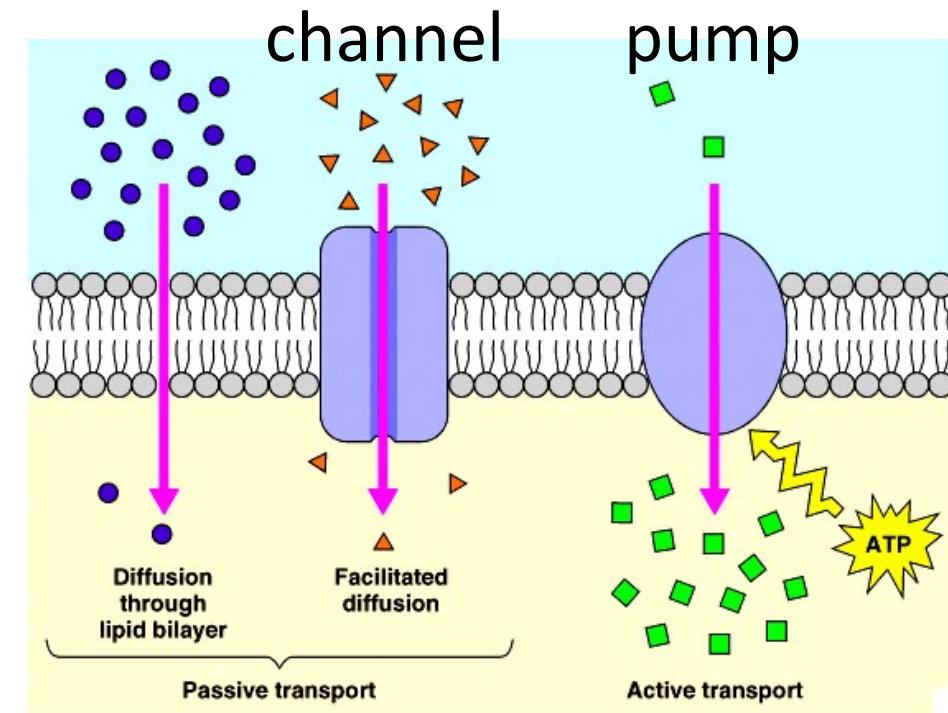
And yes, neurotransmission is also chemical,
but we'll talk about that one later!



Resting membrane potential 9

Channels and pumps

- Remember, the plasma membrane is an effective barrier!
- Only certain molecules/ions are permitted to cross membrane, via *channels* and *pumps*
 - Channels: allow *passive* diffusion (i.e. along chemical gradient)
 - Pumps: actively push ions against their chemical gradient
 - Requires energy (ATP)



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Resting membrane potential₁₀

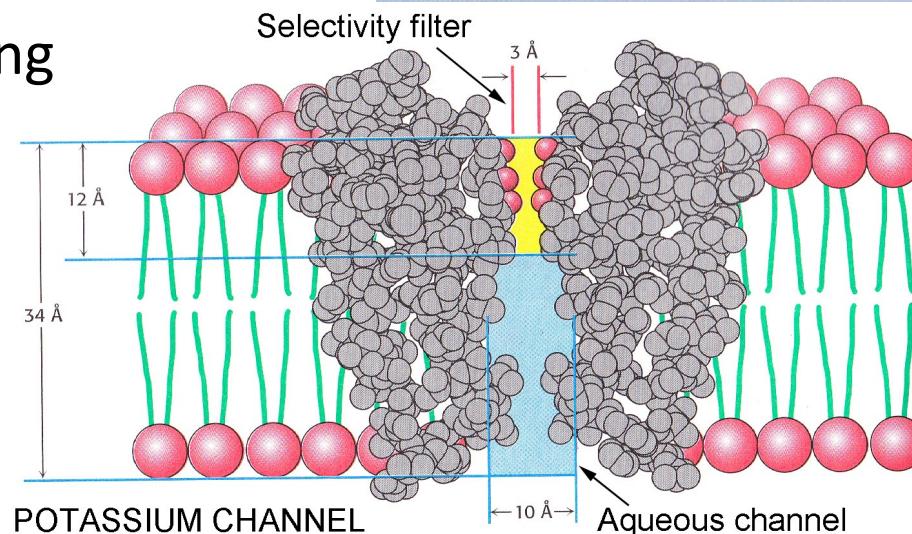
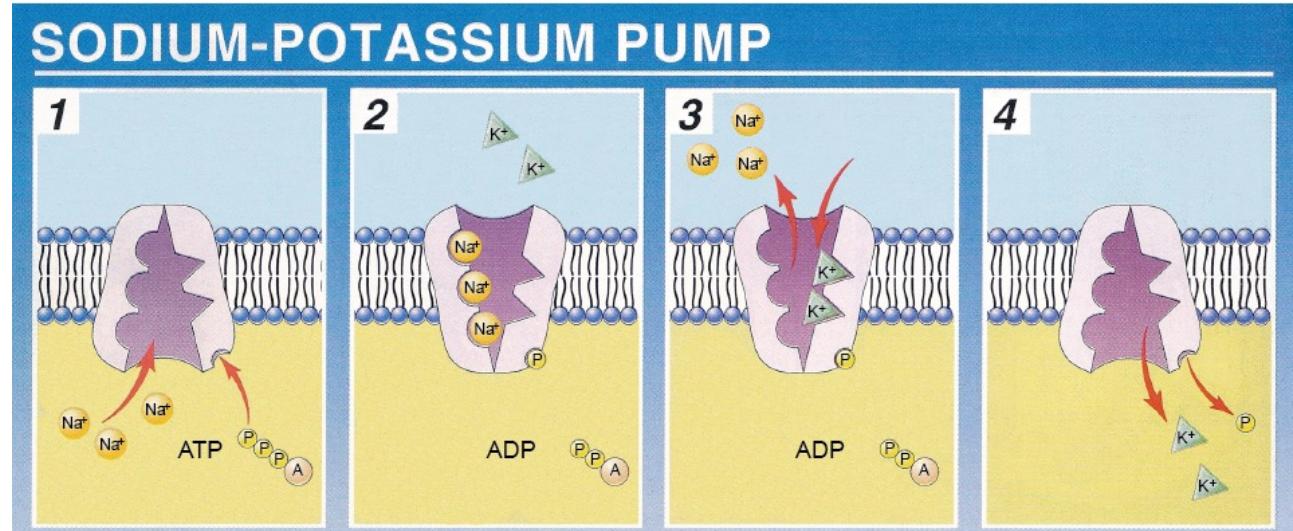
Proteins of the resting membrane potential

1. Sodium-potassium pumps

- Use 2/3rds of all brain energy (ATP)
- 3 Na⁺ out, 2 K⁺ in

2. Potassium “leak” channels

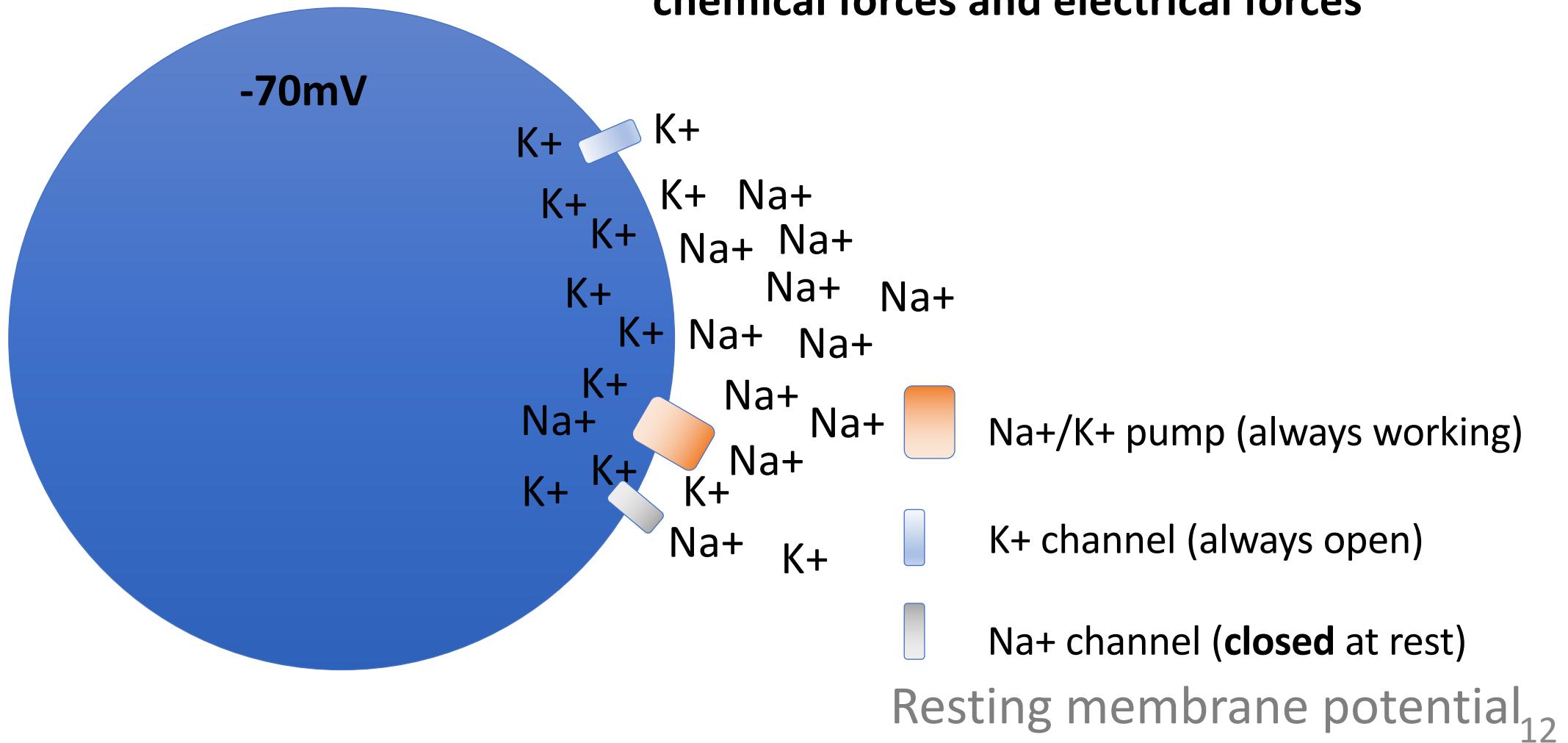
- Require no energy
- Both are embedded in membrane
- Both are constantly working



Resting membrane potential₁₁

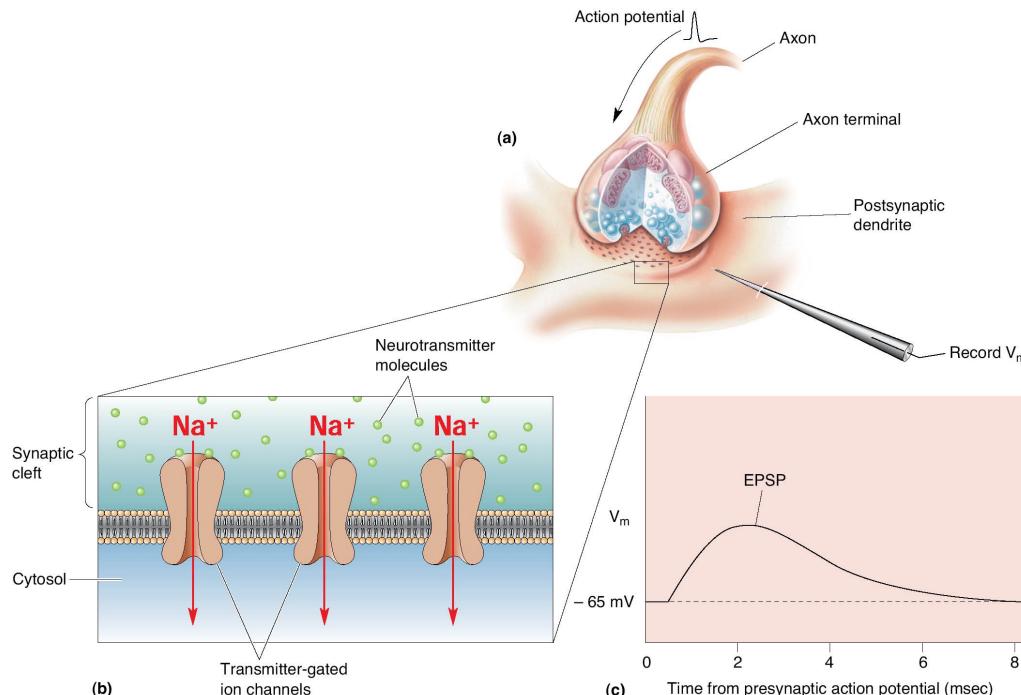
Cells are *polarized*

The RMP is an equilibrium between chemical forces and electrical forces



When a neurotransmitter binds to a receptor, it can have one of two localized effects:

- 1. Depolarize the membrane** (e.g. from -70 to -67mV) → excitatory post-synaptic potential (EPSP) → increase likelihood of an action potential (AP)
- 2. Hyperpolarize the membrane** (e.g. from -70 to -72mV) → inhibitory post-synaptic potential (IPSP) → decrease likelihood of AP



Why transmitters/receptors cause these effects will be talked about once we reach the synapse!
(But the image to the left is a hint.)

Postsynaptic potentials₁₃

When a neurotransmitter binds to a receptor, it can have one of two localized effects:

- 1. Depolarize the membrane** (e.g. from -70 to -67mV) → excitatory post-synaptic potential (EPSP) → increase likelihood of an action potential (AP)
- 2. Hyperpolarize the membrane** (e.g. from -70 to -72mV) → inhibitory post-synaptic potential (IPSP) → decrease likelihood of AP

The transmission of postsynaptic potentials (PSPs) is **graded, rapid, and decremental**: PSPs travel like an electrical signal along an uninsulated wire.

AP Generation

If the sum of the EPSPs and IPSPs that reaches the **axon initial segment** is sufficient to depolarize the membrane there above its **threshold of excitation**, then an **action potential (AP)** is generated

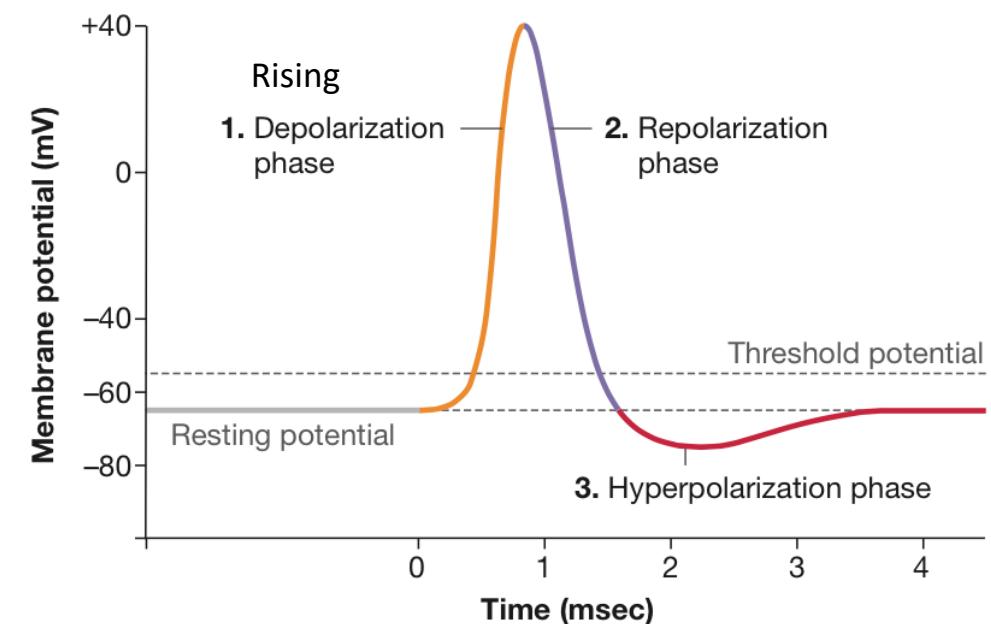
The AP is a massive, brief reversal of the membrane potential (e.g. from -70 to +55 mV)

The AP is an all-or-none phenomenon

i.e. Not graded

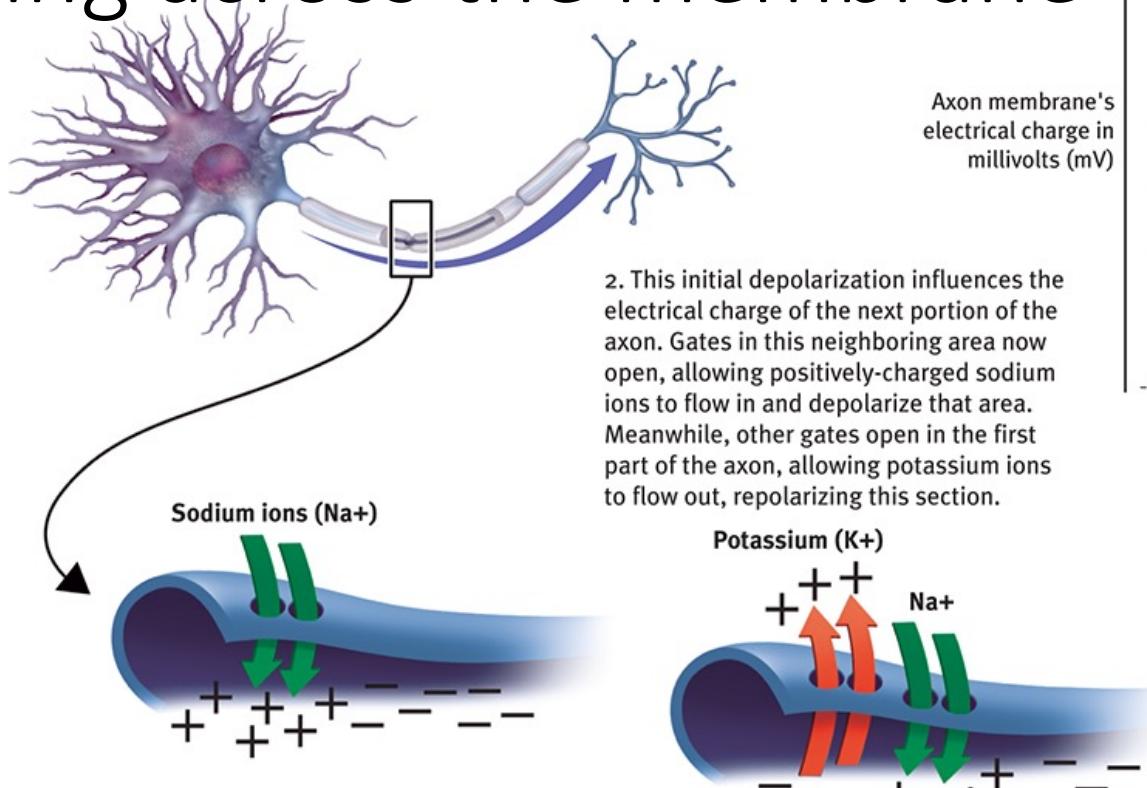
Always same size/shape

The threshold of excitation is simply where **voltage-gated Na⁺** channels open!



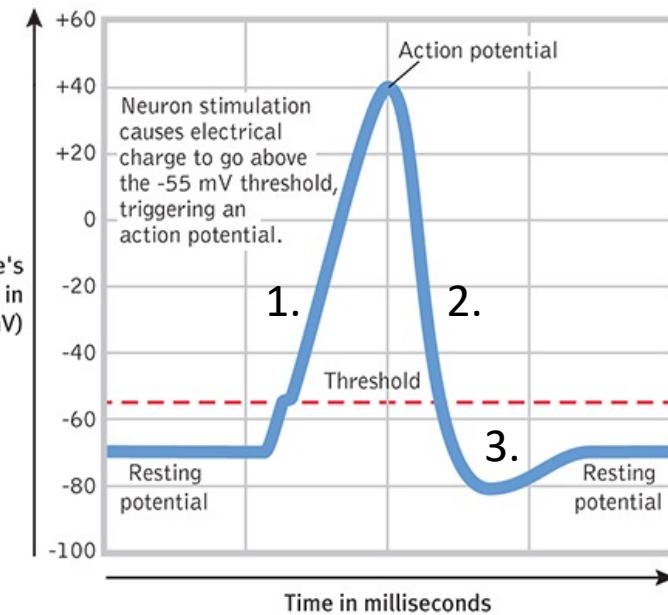
Action potentials

The action potential is just ions moving across the membrane



1. Neuron stimulation causes a brief change in electrical charge. If strong enough, this opens gates to allow positively-charged sodium ions to flood in, producing a momentary depolarization called the action potential.

Direction of action potential: toward axon terminals



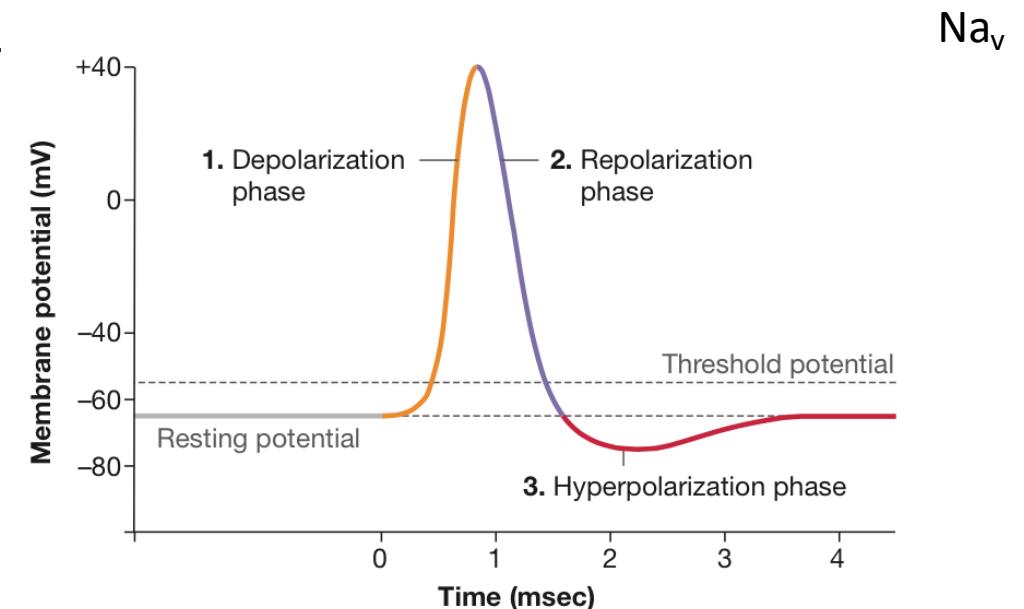
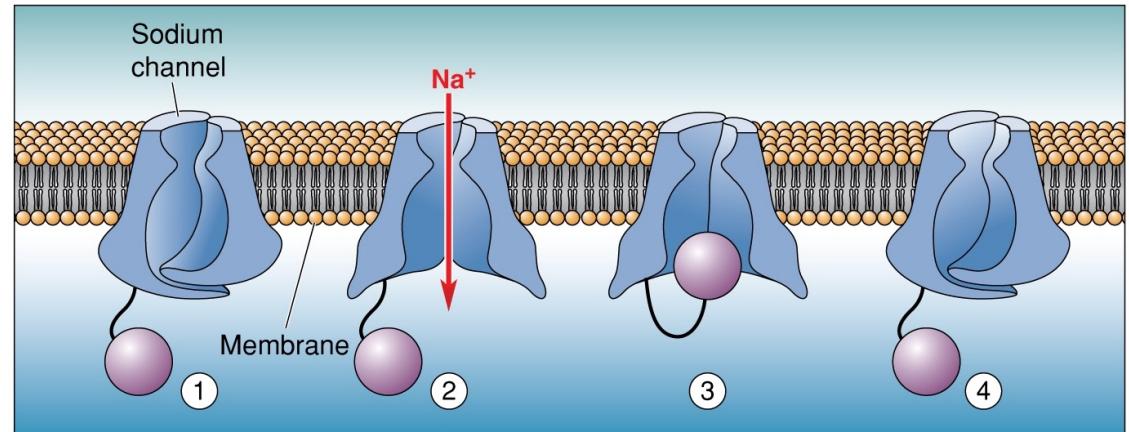
Proteins of the action potential

1. Voltage-gated sodium channels (Na_v)

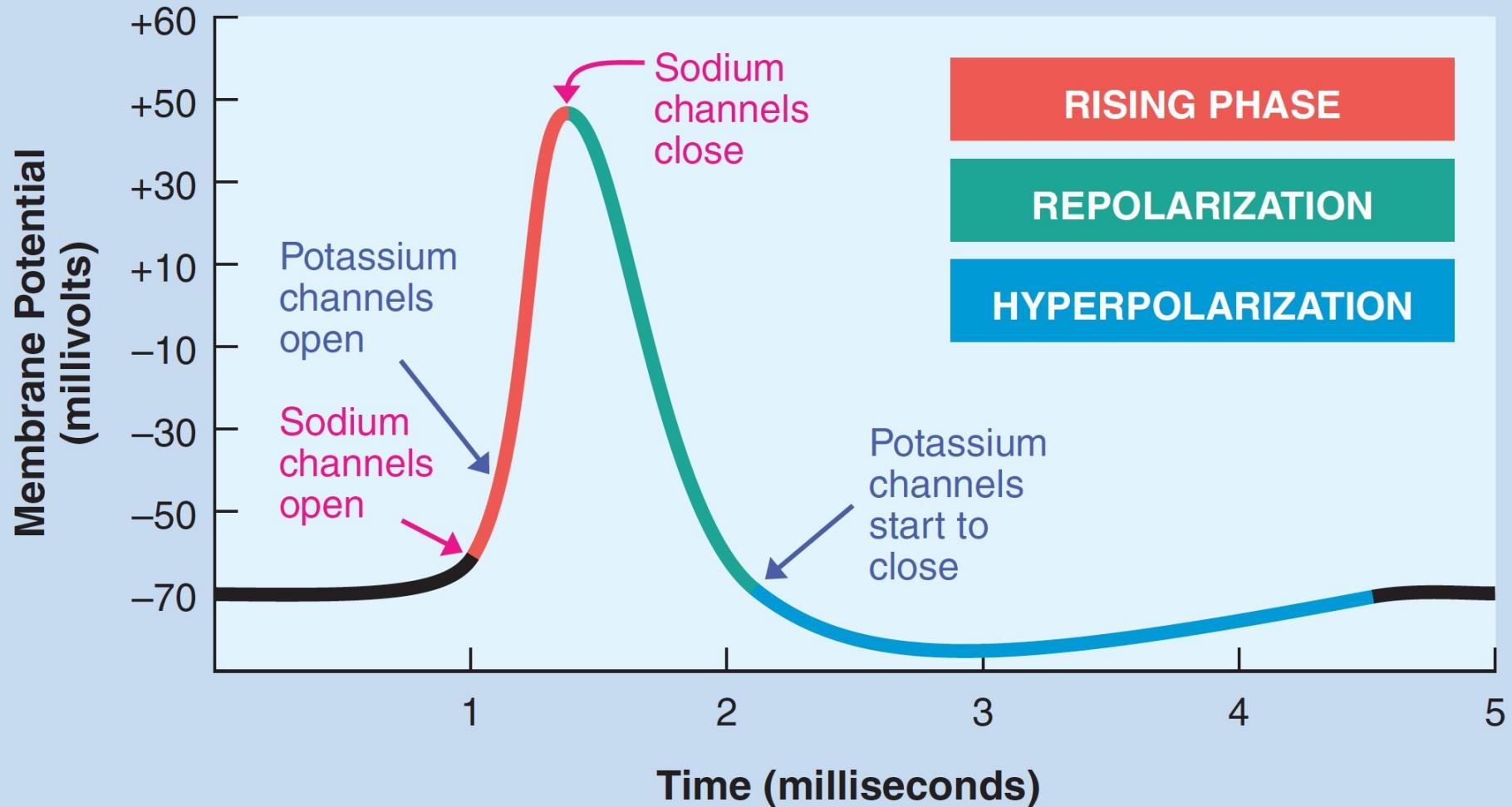
- Open at the threshold of excitation
- Have an “auto-shutoff” after about 1ms
- Responsible for rising phase of AP

2. Potassium channels (two types)

- Leak channels, same as before, always open
- Also voltage-gated channels (K_v) that start to open during the rising phase of the AP
- Responsible for repolarization & hyperpolarization
- Note that the sodium-potassium pump is too slow to play a role in the AP!

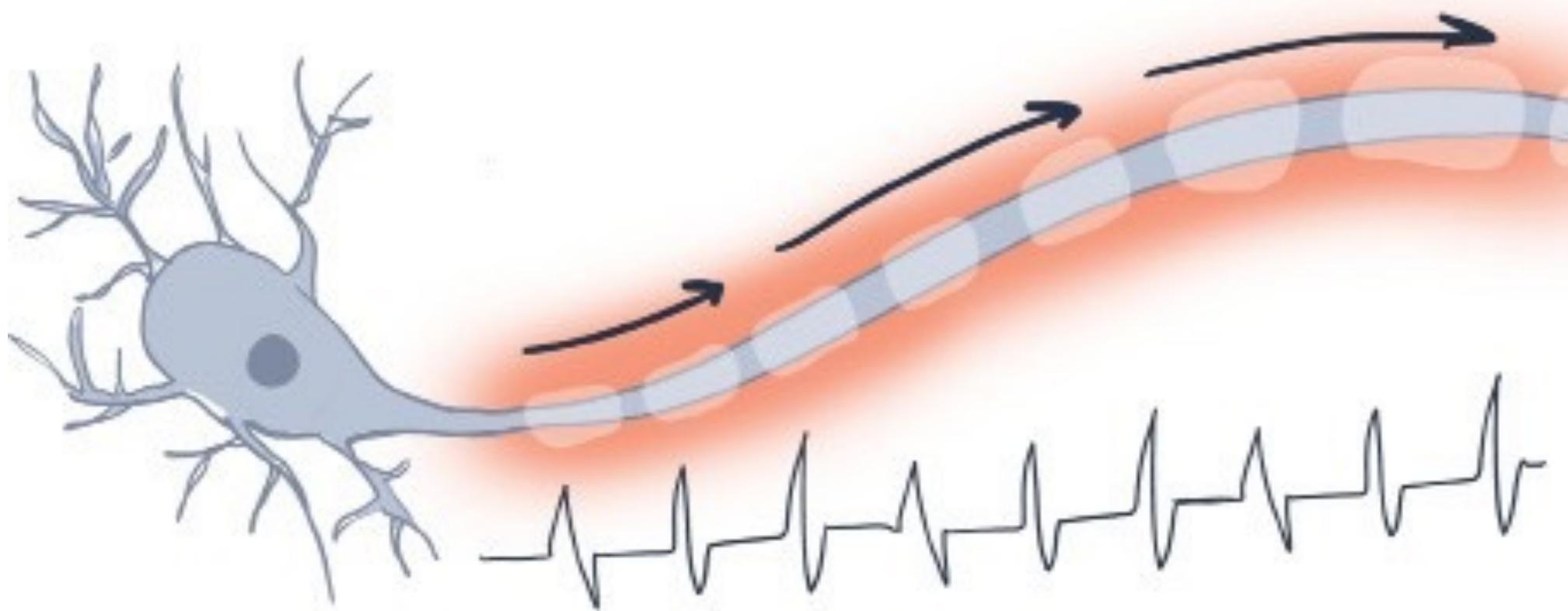


Action potentials



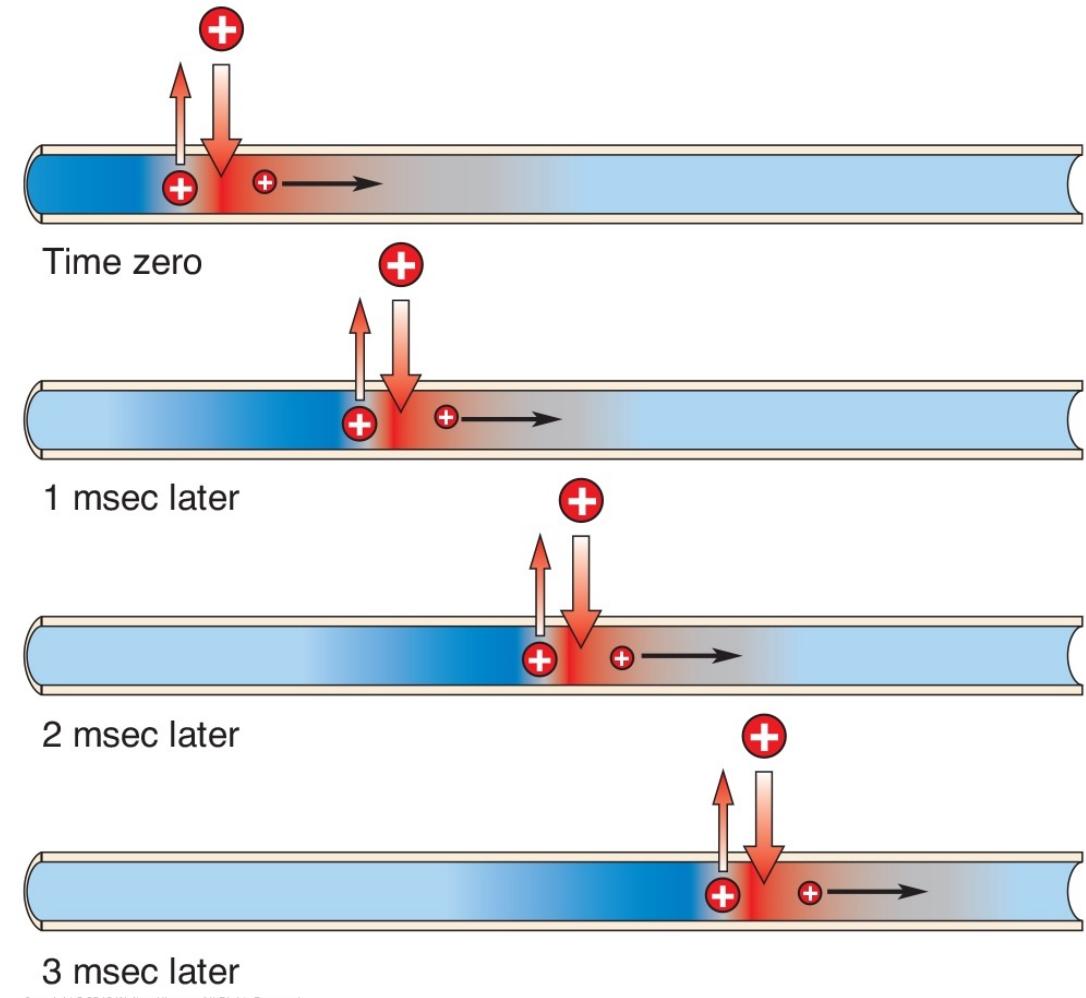
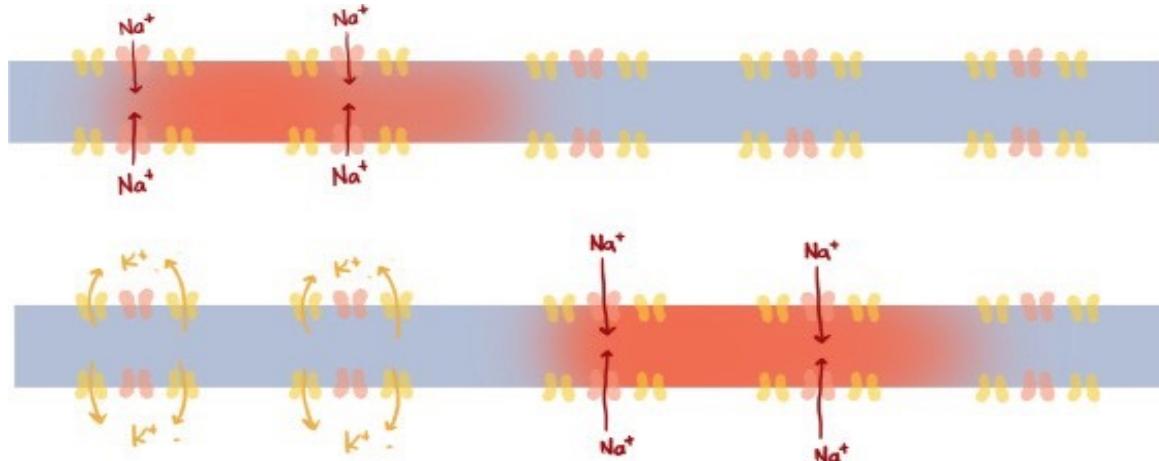
Action potentials

The AP starts at the initial segment and travels to the terminal:
conduction



AP looks the same all down axon
i.e. it does not decay (it is constantly regenerated)

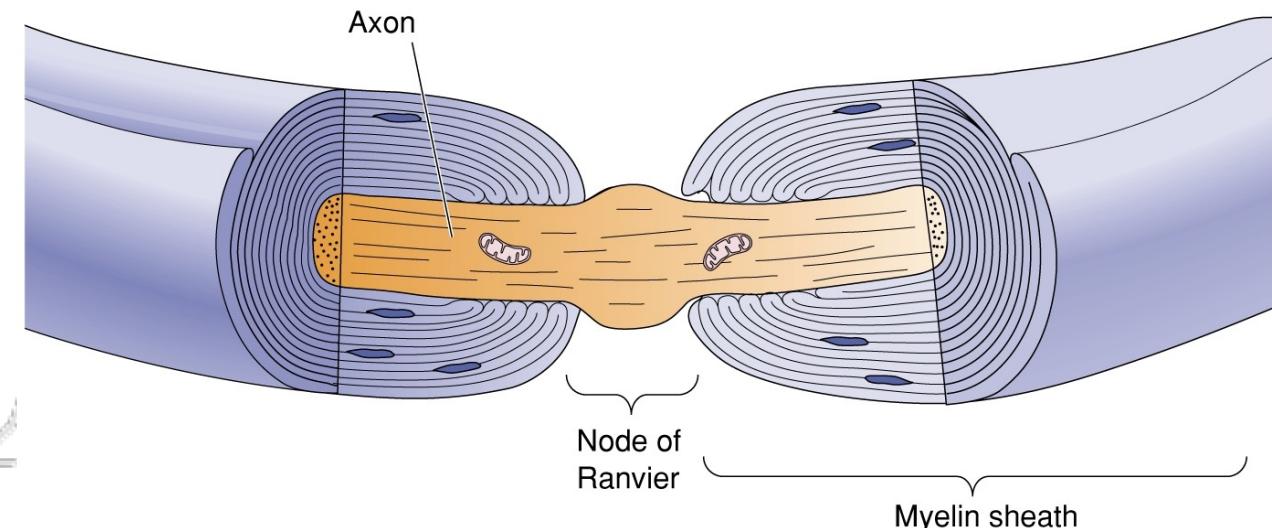
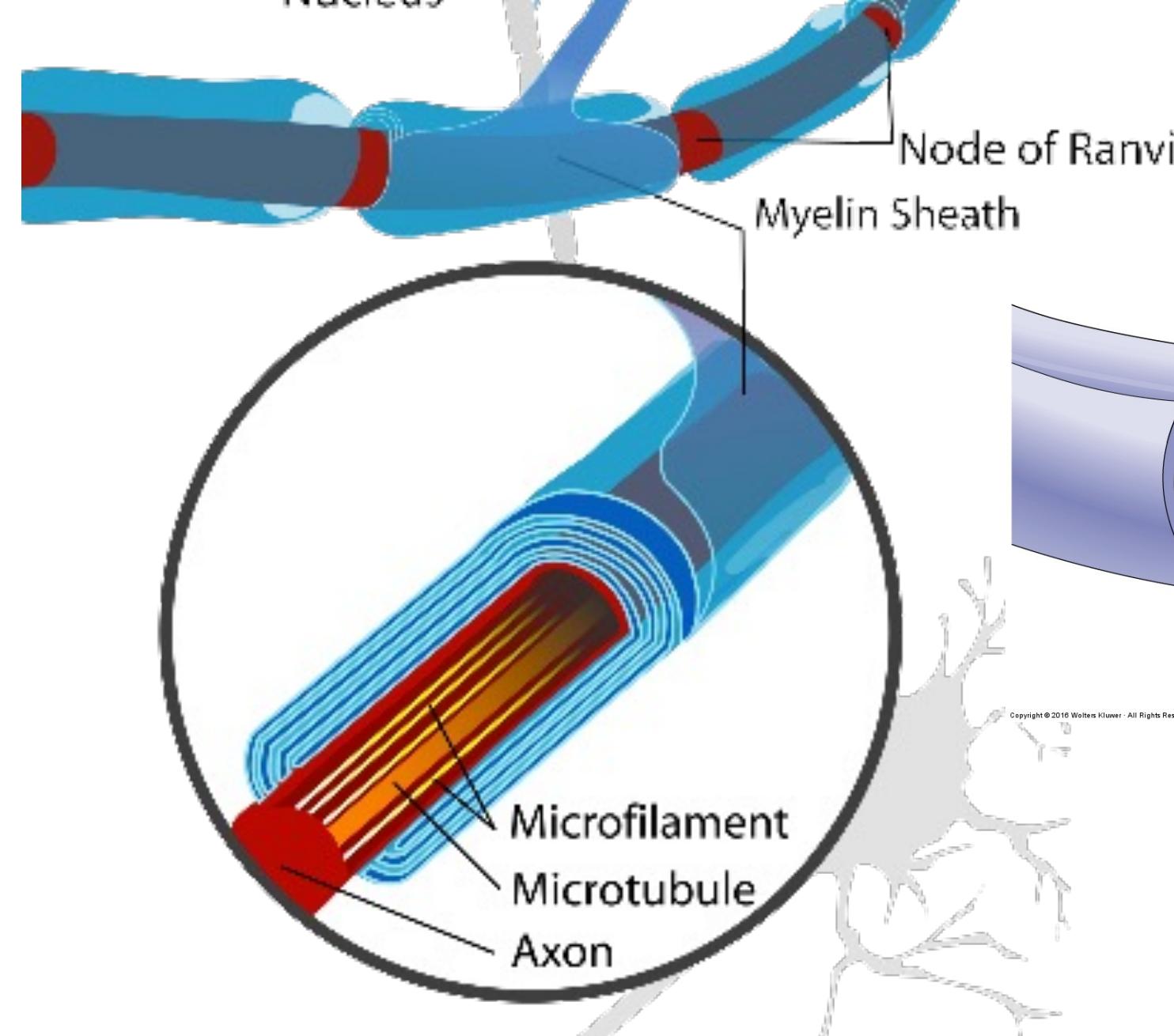
Conduction in an Unmyelinated Axon



- Na^+ channels (Na_v) are present along axon
- Unmyelinated axons: Na_v everywhere
- Conduction speed is limited by number of Na_v (like doors in a hallway)
- But if you have too few Na_v , the AP decays

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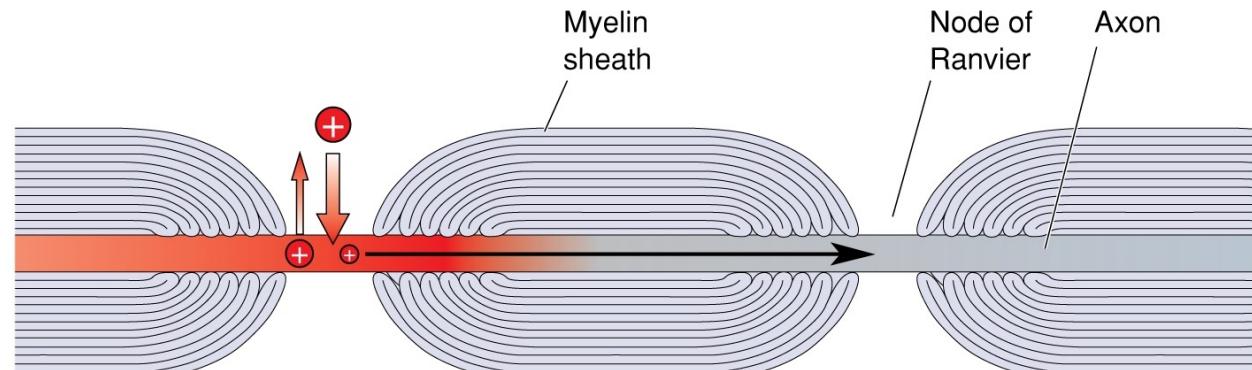
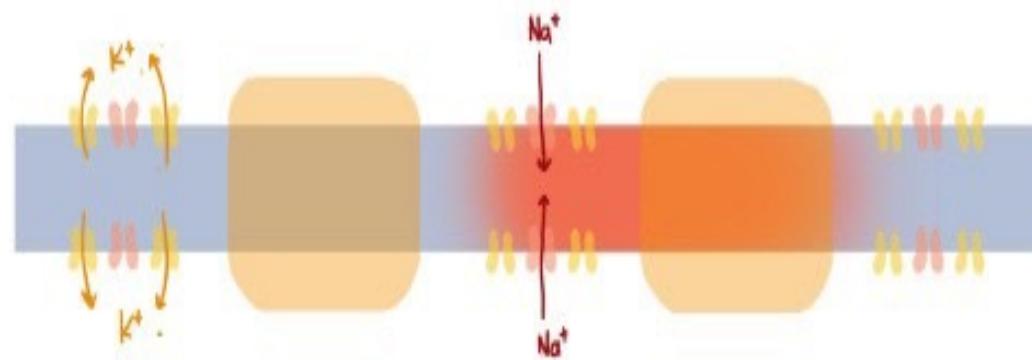
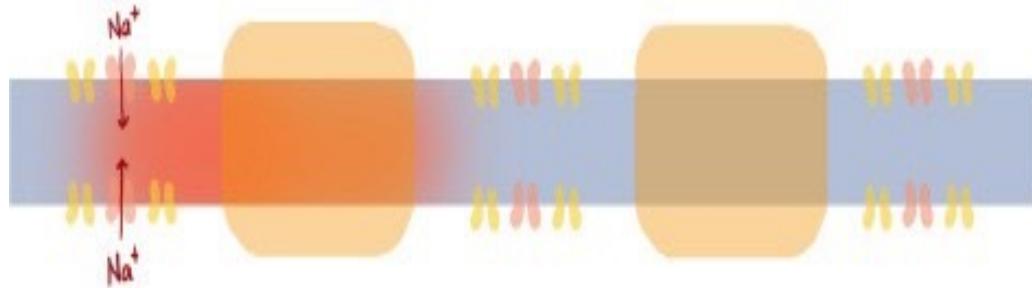
Axon Myelination



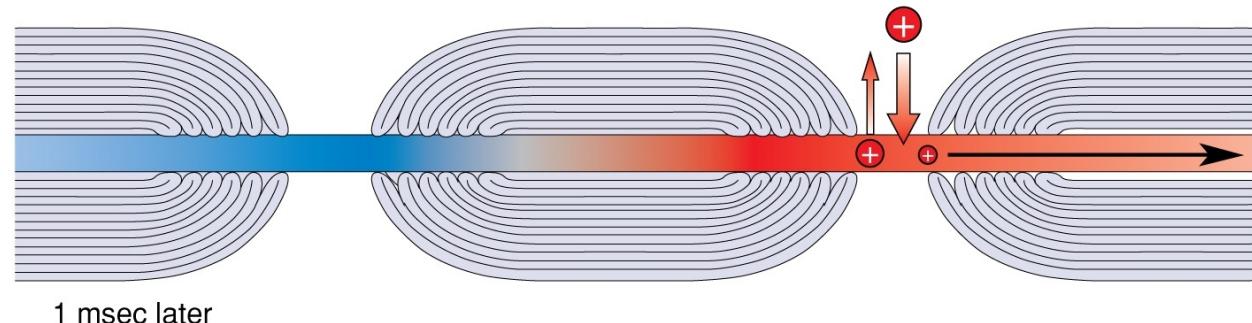
Myelin causes the AP to decay less quickly as it spreads

Conduction

Conduction in a Myelinated Axon



Time zero



1 msec later

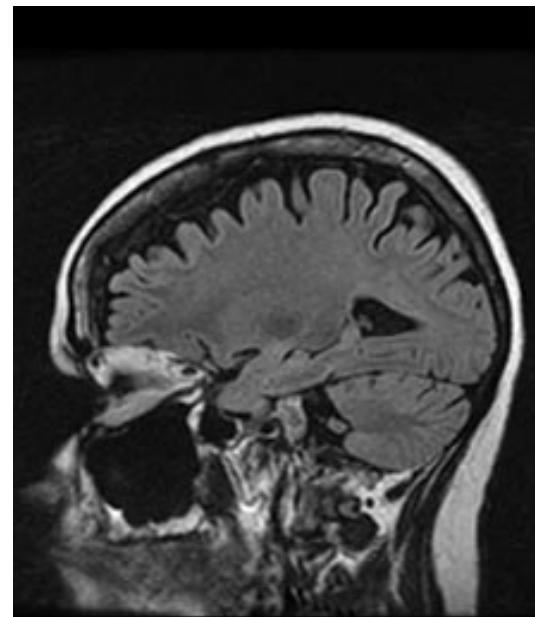
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- Na_v are present all along the axon
- Unmyelinated axons: Na_v everywhere
- Myelinated axons: Na_v only at the Nodes of Ranvier
 - Fewer "doors", faster conduction down the "hall"

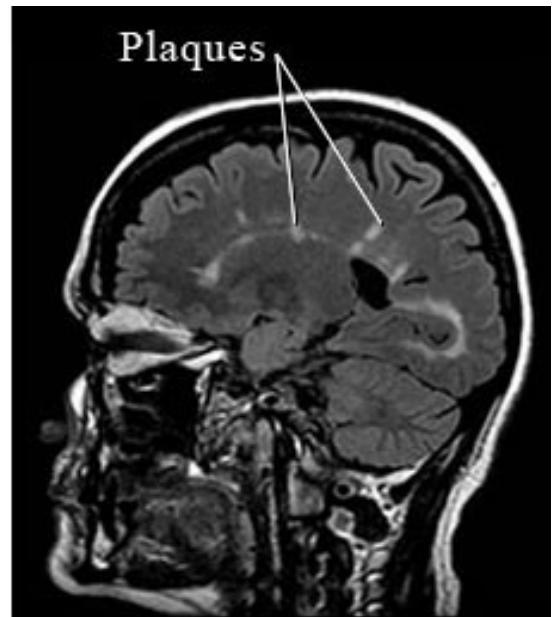
Conduction

Related to myelin: Multiple Sclerosis (MS)

- A disorder that progressively damages myelin
- 55-75K in Canada (3 new/day)
- Canadians have one of the highest rates of multiple sclerosis in the world
- Likely some connection to Epstein-Barr virus (a type of herpes virus)
- More on this later



Healthy brain

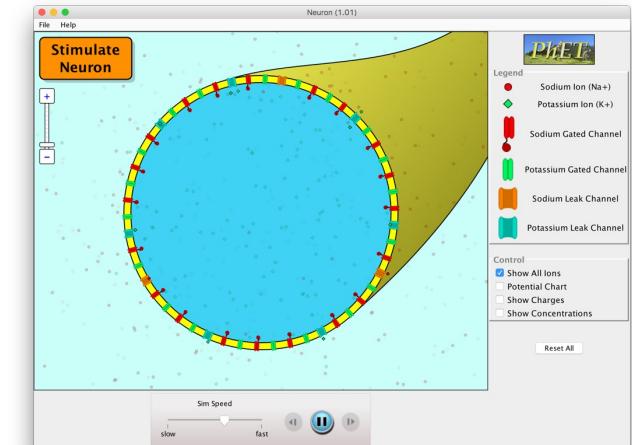


Brain with damage (lesions or plaques) caused by MS

Image from:
myhealth.alberta.ca/health/Pages/conditions.aspx?hwid=zm6056&

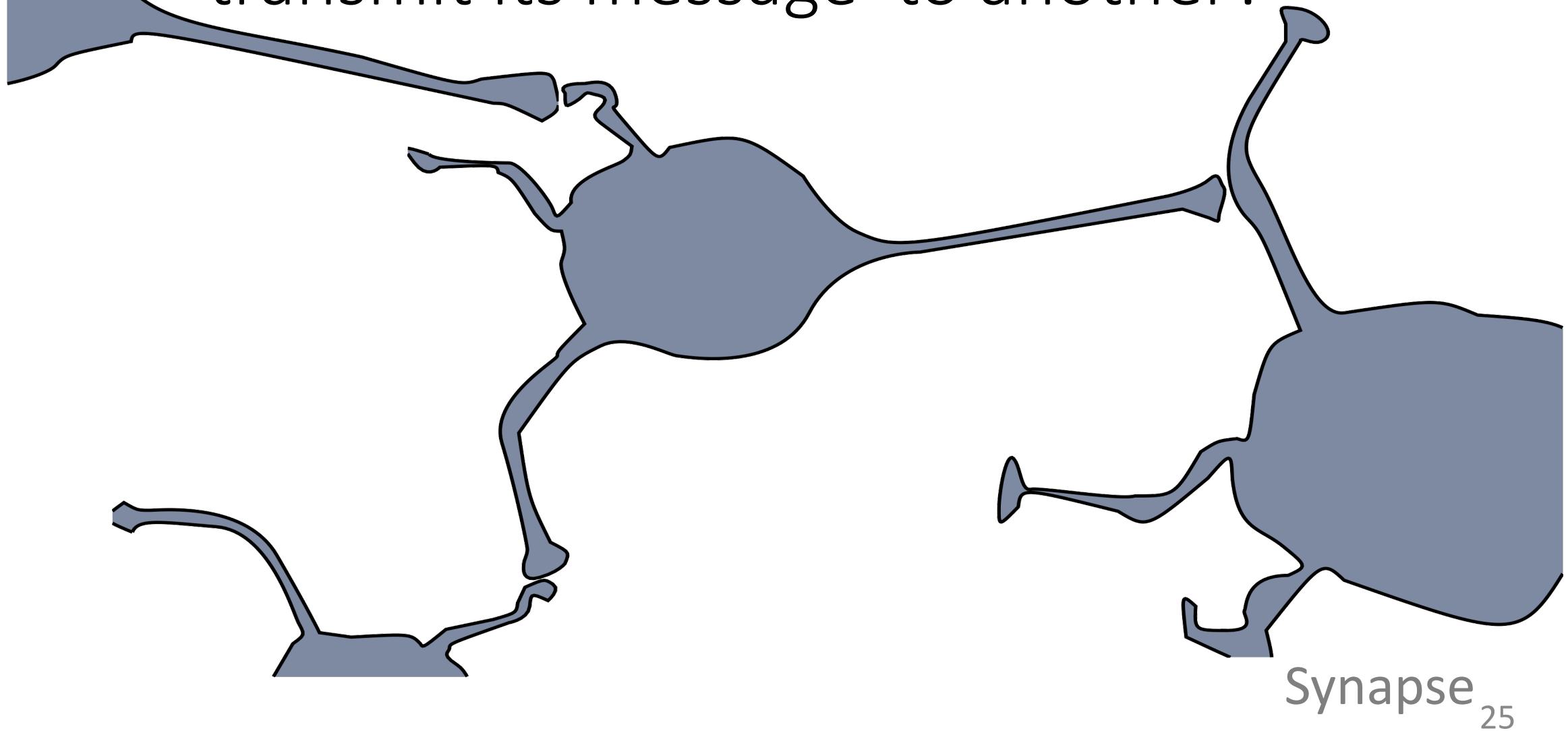
A virtual neuron

1. Go to: <https://phet.colorado.edu/en/simulation/neuron> and run the simulation
2. Identify three proteins that we discussed
3. Identify one protein we did not discuss—it is real, but not particularly physiologically relevant for our story of RMPs and APs
4. Describe what's happening at rest (i.e. during resting membrane potential), as regards ionic flow (it helps to zoom in)
5. Describe the order of events when you stimulate the neuron (it helps to slow it down)
6. Turn on the potential chart (bottom right corner). What do you see when you stimulate the neuron? Be specific about voltage changes.
7. Turn on the “Show Concentrations” option (bottom right corner). What do the concentrations tell you at rest? How do those concentrations change when you stimulate the neuron? What do those changes tell you about the effects of an action potential?

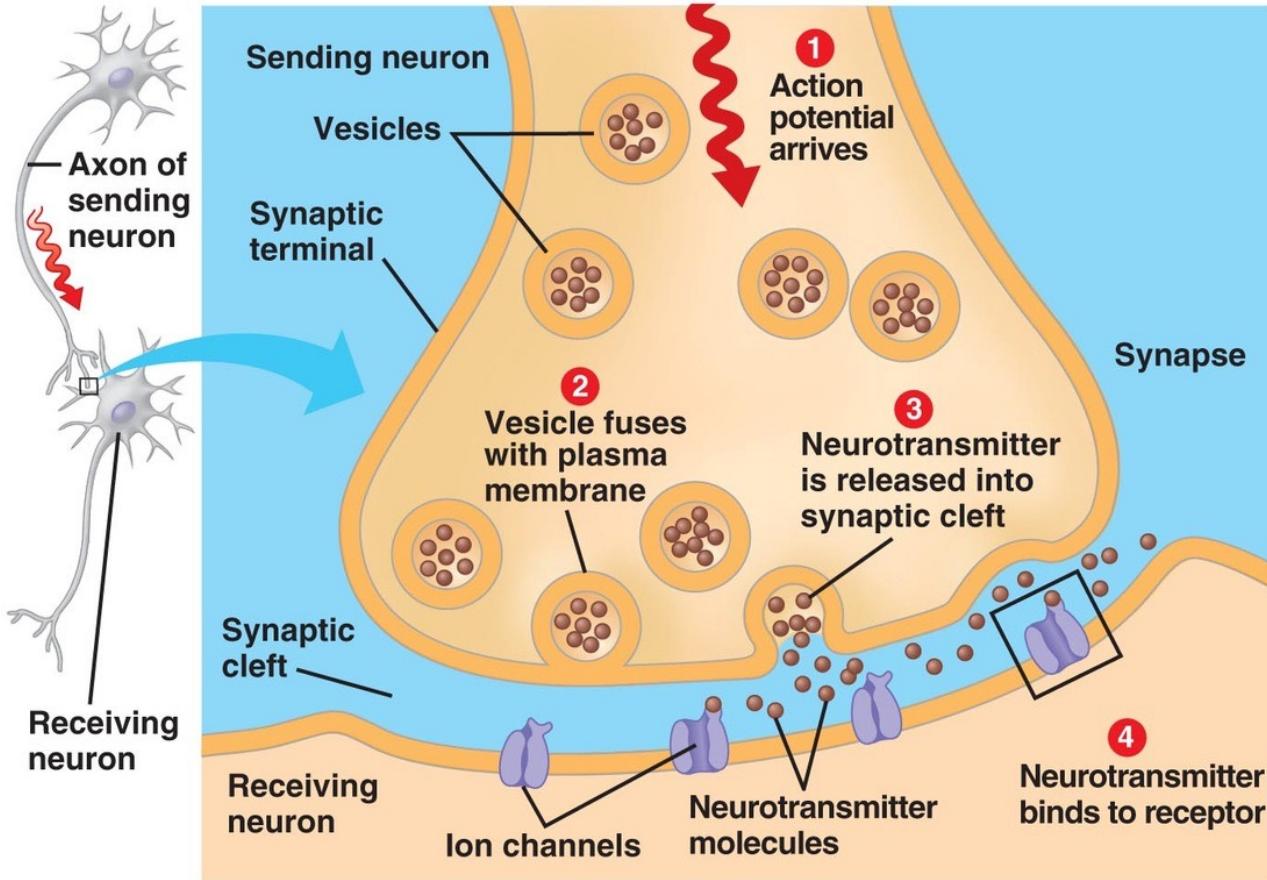


Totally optional extra learning

Next question: How does one neuron transmit its message to another?



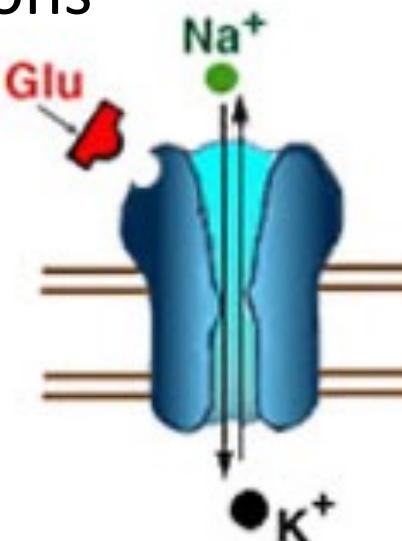
End of the line



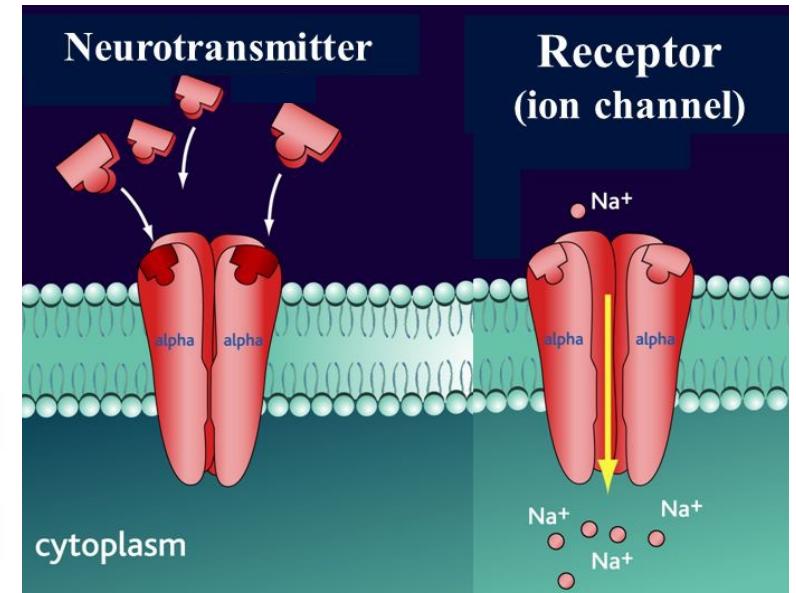
- Axon ends in terminal *boutons* (“buttons”)
- Bouton has *vesicles* (“bubbles”?) filled with *neurotransmitters*
- Action potential travels to bouton and depolarizes it
 - Causes voltage-gated Ca^{++} channels to open
 - Ca^{++} causes vesicles to fuse with membrane
 - Neurotransmitters released into synapse

Welcome to the synapse

- Dendrite membrane has special *receptors* that fit, like lock and key, with the neurotransmitters
- Receptors are often just (closed) channels that open when they bind with neurotransmitter!
 - i.e. *ligand-gated ion channels*
- i.e. EPSPs/IPSPs are just ions crossing the membrane! (Sound familiar?)

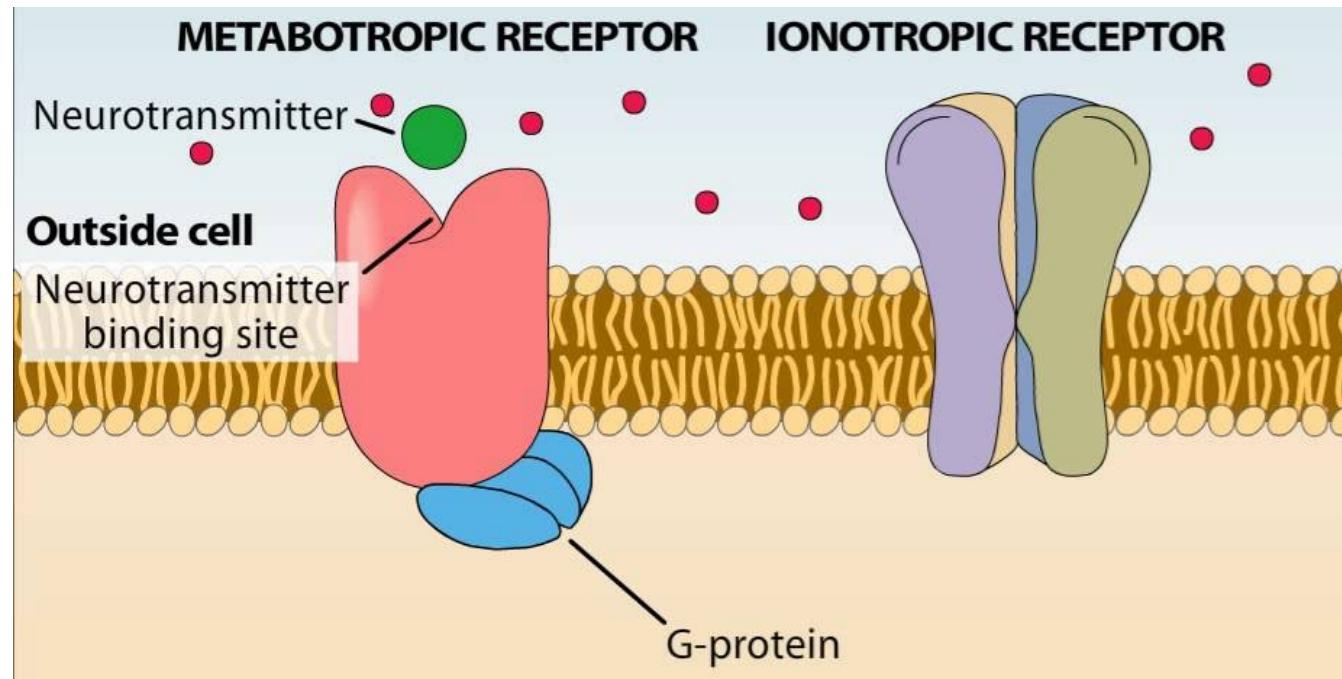


Glu: glutamate, most common excitatory neurotransmitter



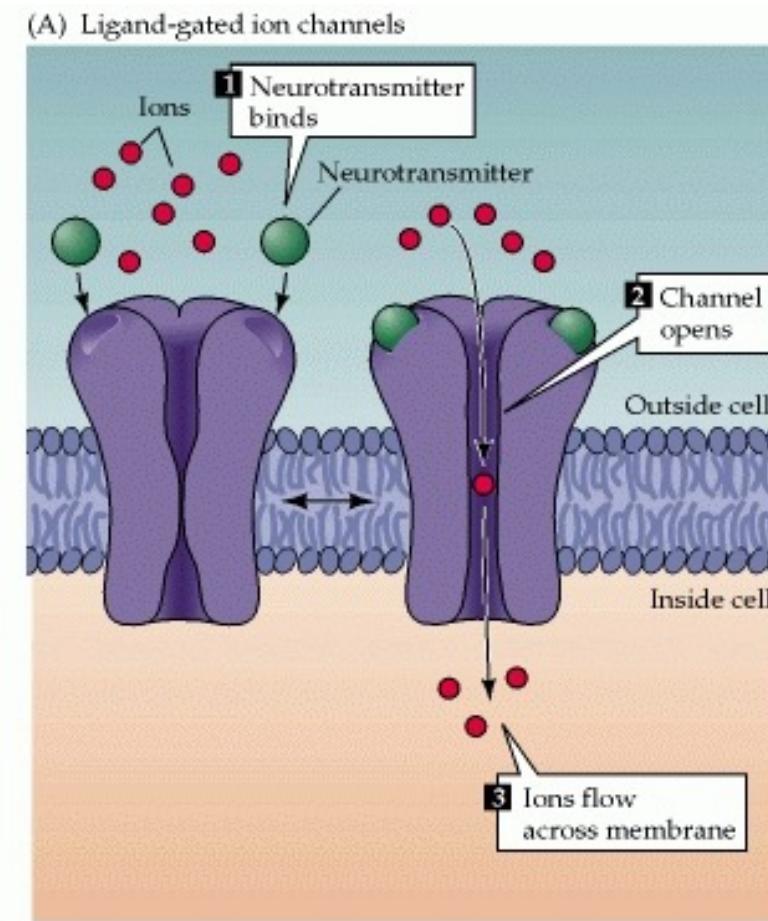
Receptor types

- Ionotropic (channels)
- Metabotropic (signalling proteins)



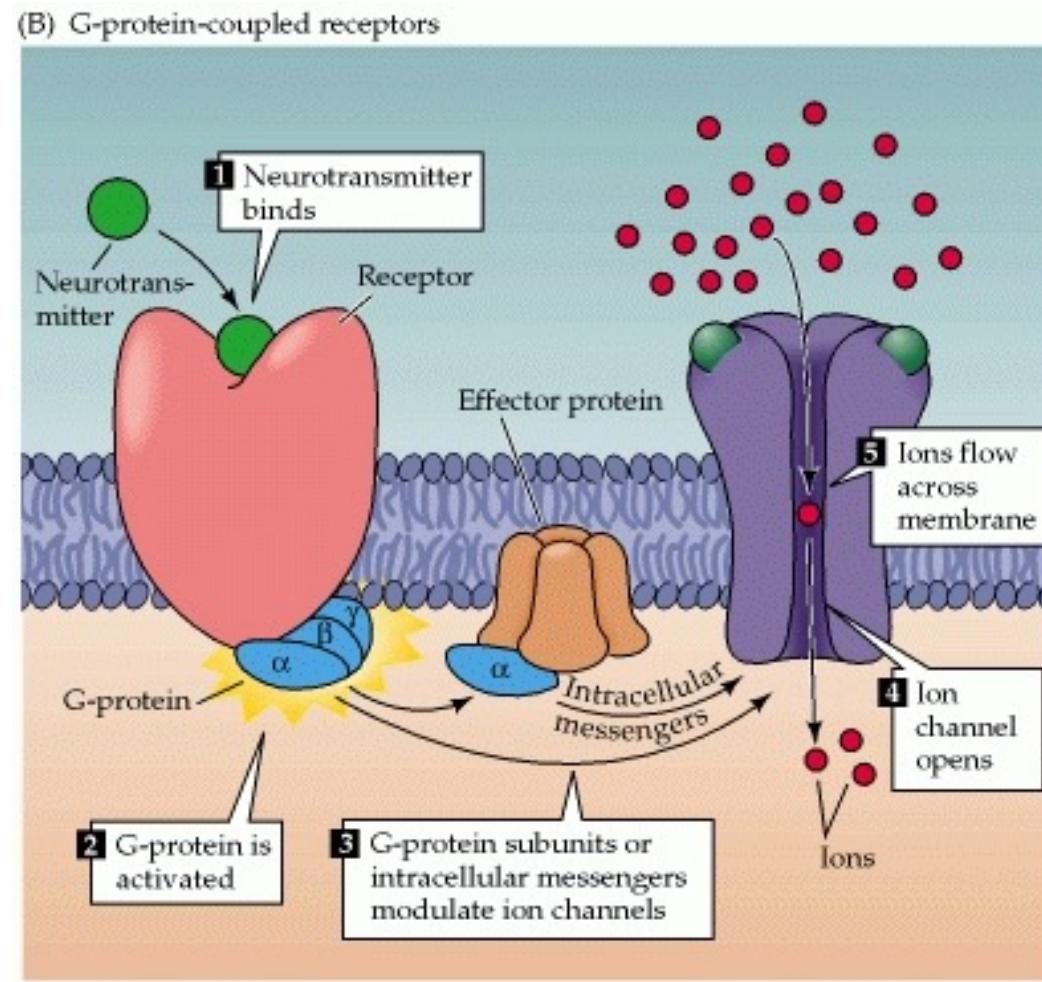
Receptor types

- Ionotropic
 - AKA ligand-gated ion channels
 - Excitatory (depolarize, EPSPs)
 - Inhibitory (hyperpolarize, IPSPs)
 - Fast, transient effect



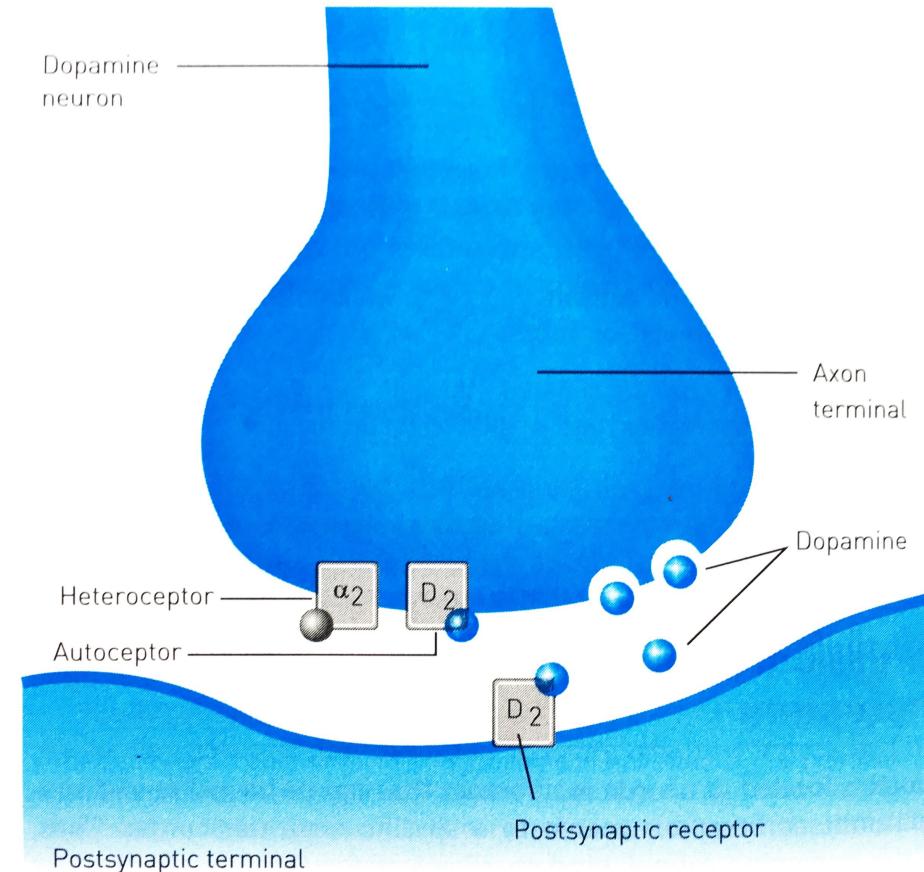
Receptor types

- Metabotropic
 - AKA G-protein-coupled receptors (GPCRs)
 - Modulate cell
 - Modulate signals
 - Slow, longer lasting effect
 - Cause *signal cascades*



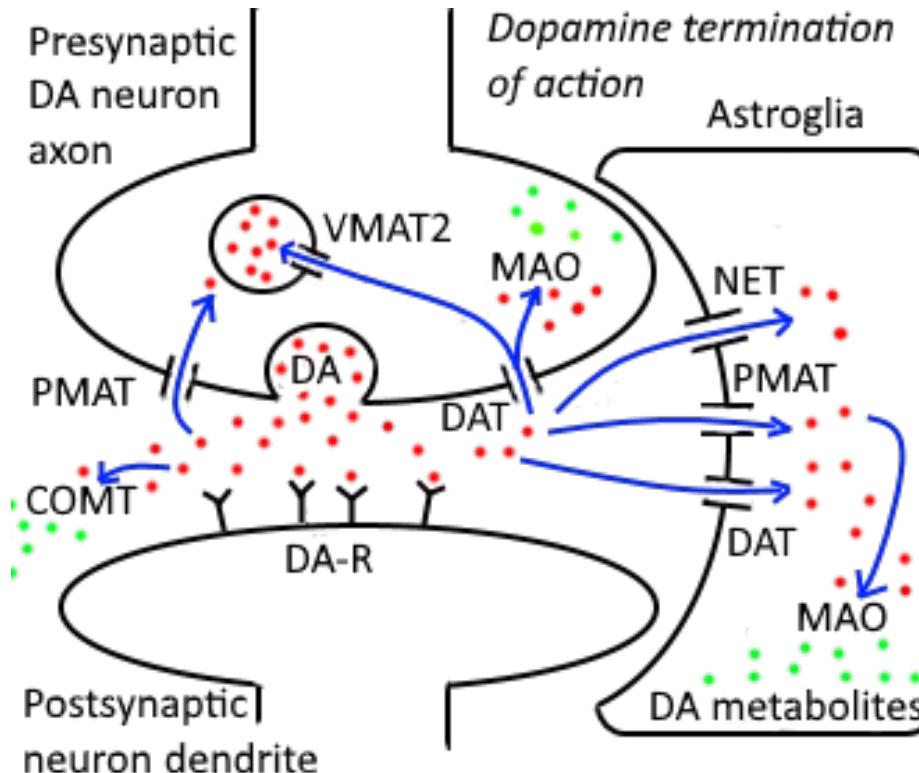
Receptor locations

- Postsynaptic
- Presynaptic
 - Autoreceptors
 - Heteroreceptors



Neurotransmitter clean-up

- Diffusion
- Enzymatic degradation
- Re-uptake
 - Pre-synaptic
 - Astrocytes



End of neurotransmission