

Electrical events in neurons

- Resting potential
- Action potentials
- Synaptic potentials

Electrical events in neurons

- Resting potential
- Action potentials
- Synaptic potentials

Fetcho lecture 1 main goal

(A first step toward understanding resting membrane potential)

- To understand how diffusion of charged particles and the electrical forces acting on them can produce a potential difference across a membrane.

Things you should know AT THE END and for Exams.

- How the concentrations of **uncharged** particles change in solution via diffusion.
- How movement of particles across a semipermeable membrane changes when they are electrically **charged**.
- The **key idea** that a potential difference across a membrane develops as a result of a diffusion force pushing charged particles in one direction that comes into balance with an electrical force pushing the particles in the opposite direction
- The **Nernst equation** that describes the potential at which the two forces are in balance across a membrane that is permeable to ONLY ONE charged particle type (ion).

Why you should care about these things.

All of brain function depends on flow of charged ions such as potassium and sodium!

302

T. Bourgeron / C. R. Biologies 339 (2016) 300–307

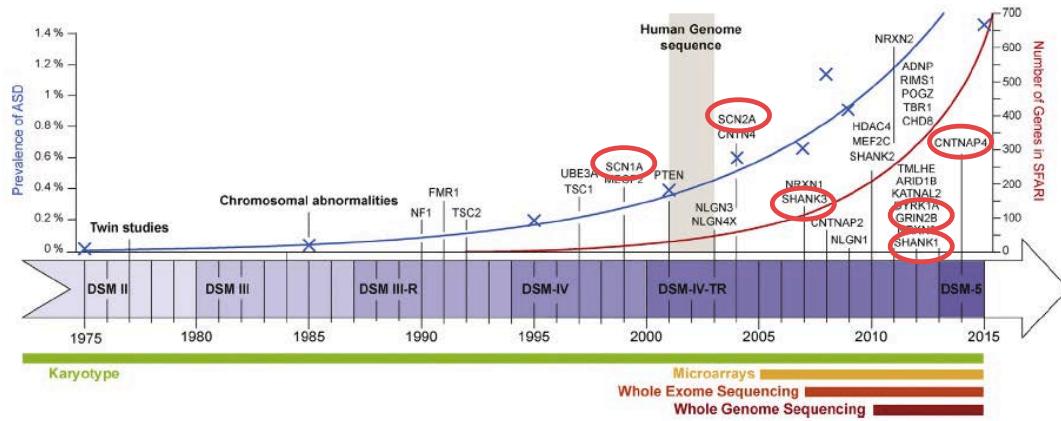


Fig. 1. The history of the genetics of autism from 1975 to 2015. The increase in the number of genes associated with ASD (SFARI, March 2015) is represented together with the prevalence of ASD (data taken from the Center for Disease Control and Prevention), the different versions of the Diagnostic Statistical Manual (from DSM II to DSM-5.0), and the advance in genetics technology.

Why you should care about these things.

All of brain function depends on flow of charged ions such as potassium and sodium!

Baby Dies In Hospital, And Parents Plan to Sue

By BRUCE LAMBERT FEB. 9, 2002



He was their first child, and Ana and Giovanni Vargas feared they might lose him even before birth. Doctors discovered a heart valve defect and called the pregnancy high-risk. But little Gianni was born full-term by Caesarean section on Jan. 30, weighing almost 8 pounds.

Then his parents worried about whether he would survive delicate corrective heart surgery last Saturday. They were thrilled when the operation was declared a success and doctors said he would go home in a week or so.

But then a seemingly tiny mistake occurred while Gianni was recuperating in the neonatal intensive care unit of Stony Brook University Hospital in Stony Brook, N.Y. A missing decimal point in a prescription resulted in a tenfold overdose of intravenous potassium chloride, the Vargas family said they were told by hospital officials, and Gianni died early Tuesday.

Only after Gianni's death did his mother and father hold him in their arms for the first time. "I am angry because I was so close to bringing him home," Mr. Vargas said yesterday at a news conference. His wife, a native of the Dominican Republic who spoke through an interpreter, said she could not explain how she felt.

Family sues nurse, healthcare company after baby's death

Katie Terhune, KTVB 1:44 PM, MST August 30, 2016



TWIN FALLS -- The parents of a baby who died after a hospital worker accidentally gave him the wrong medication have filed a lawsuit against that nurse and the healthcare company he worked for.

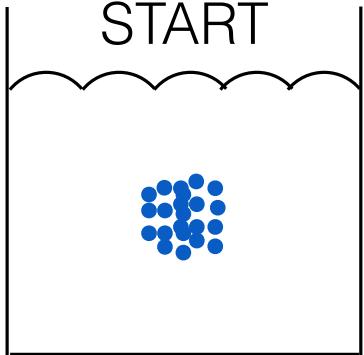
Chance and Tiffany Elliott filed the wrongful death suit earlier this month, almost one year after the death of their son.

According to a complaint, 7-month-old August Dean Elliott was brought to Saint Luke's Magic Valley Sept. 22, 2015 with supraventricular tachycardia (SVT), a condition that causes an elevated heart rate. The ailment is rarely life-threatening, and can be treated with medication.

MORE: St. Luke's Magic Valley: Child dies after receiving wrong medication

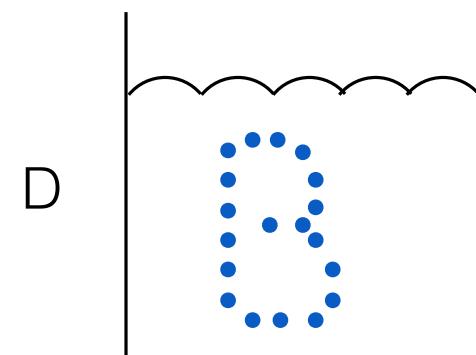
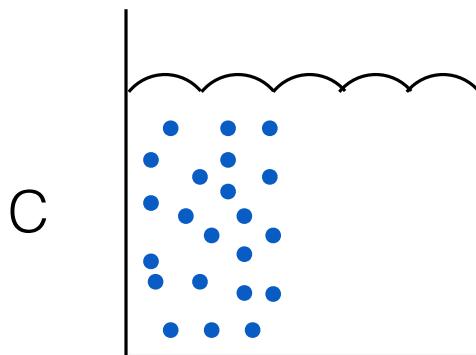
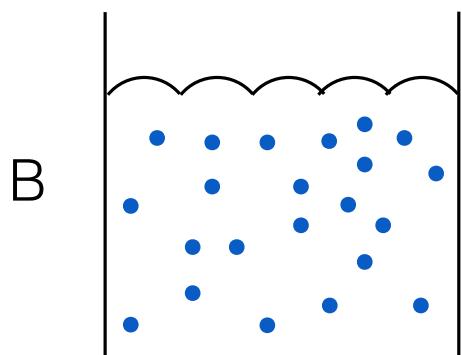
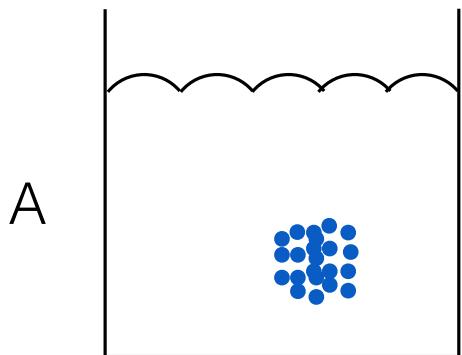
A doctor at St. Luke's ordered the baby be given heart medication and IV saline solution. But Jeffrey Smith, a traveling nurse with San Diego-based Aya Healthcare, mistakenly grabbed a pre-mixed bag of saline and an adult dose of potassium from the nurses' station that was intended for another patient.

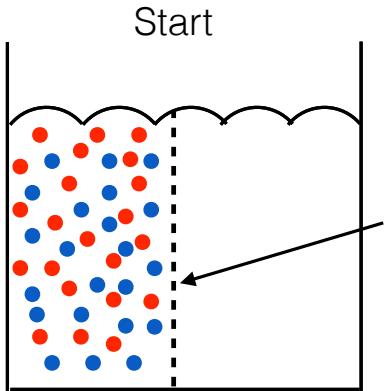
Potassium can be lethal to infants in high doses.



Key point: particles tend to move from regions of high concentration to regions of lower ones

What does it look like if we wait a long time?

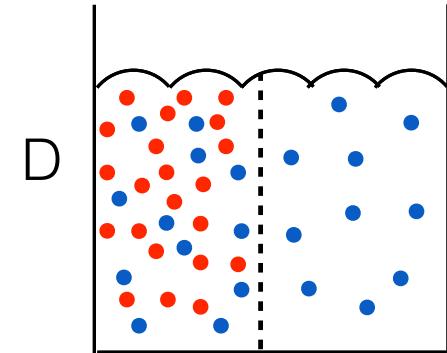
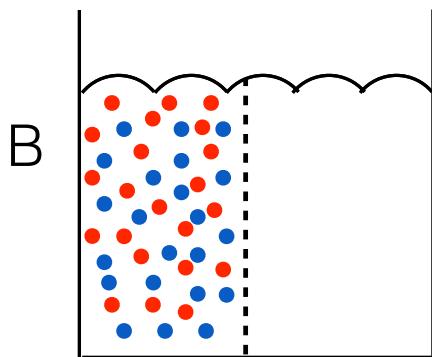
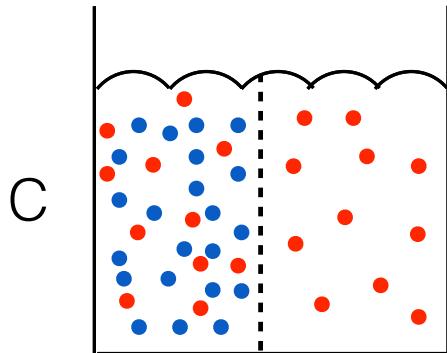
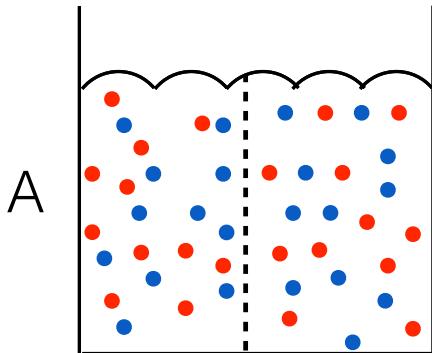


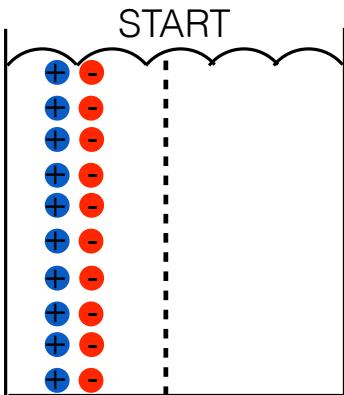


Key point: permeable *non-electrically charged* particles will tend to move to equal concentrations on two sides of a semipermeable membrane

Semi-permeable membrane: **ONLY RED PERMEABLE**

What does it look like if we wait a long time?

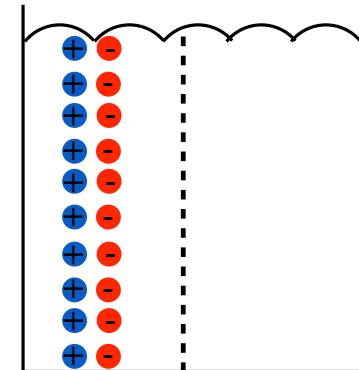
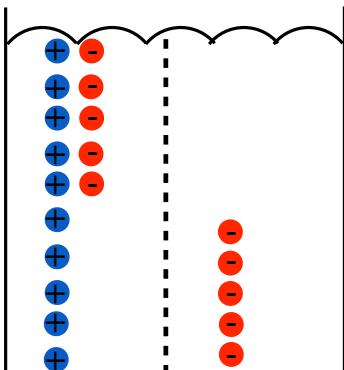




Add with equal $\textcolor{blue}{+}$ and $\textcolor{red}{-}$ on left
Diffusion force, but now also electrical one

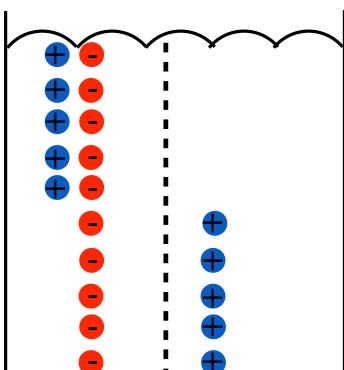
Like charges repel one another
Unlike charges attract one another

Suppose $\textcolor{blue}{+}$ is permeable? After a while...



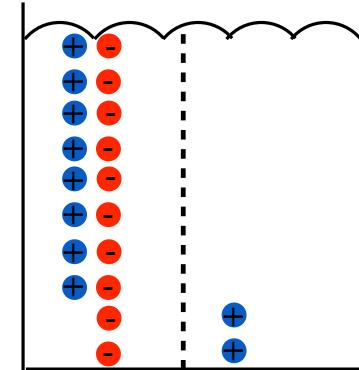
A

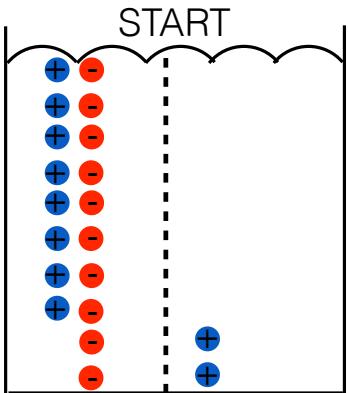
C



B

D





Is there a diffusion force on + ?
Is there a electrical force on + ?

diffusion
→

←
electrical

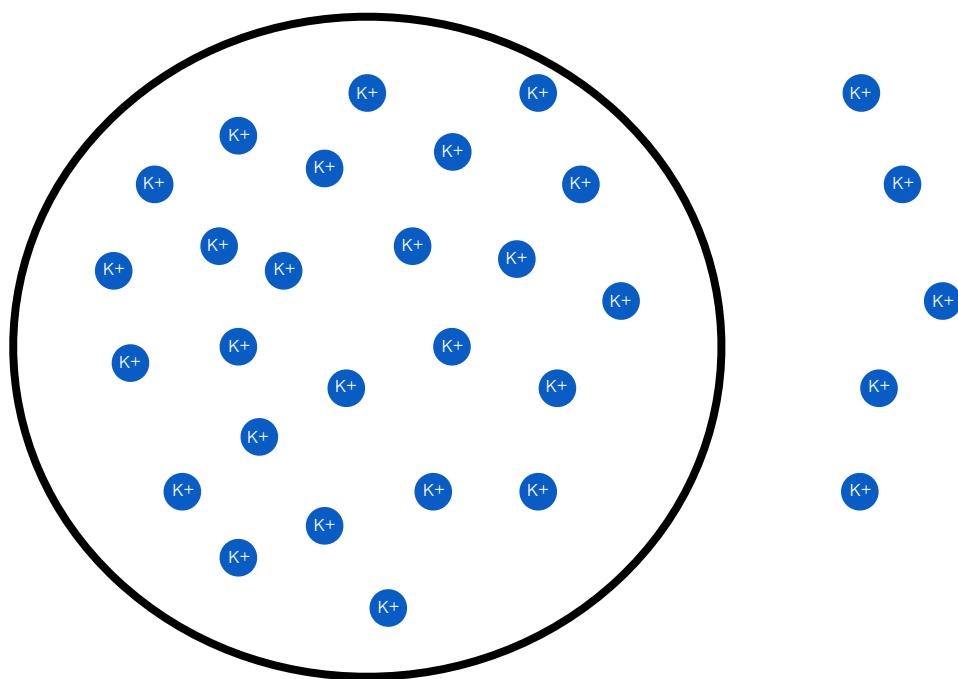
Unpaired -
on left Unpaired +
on right

Is there a potential difference (voltage) across the membrane ?

Key idea: When a single type of charged particle is permeable, **a potential difference** across the membrane can **develop as a result of a diffusion force** (from the conc. gradient) pushing charged particles in one direction that **comes into balance with an electrical force** (from the charge) pushing the particles in the opposite direction.

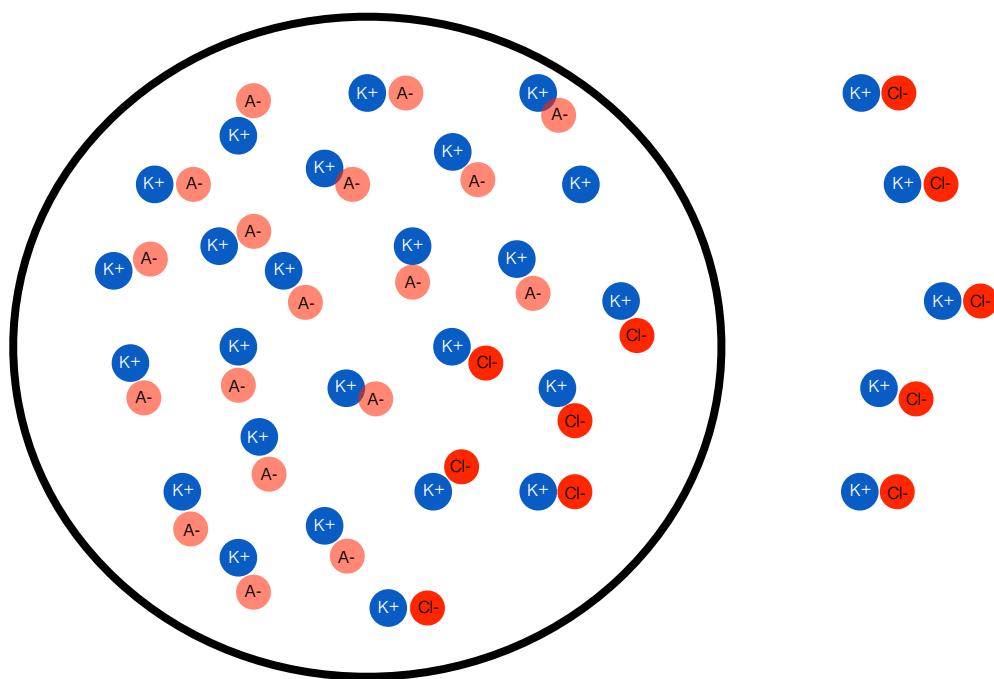
A. “typical” major contributors to chemical composition of fluids inside and outside a mammalian neuron:

	Internal (mM)	External (mM)	Permeable?
K+	Potassium(K ⁺)	125	Y
Na+	Sodium (Na ⁺)	12	sometimes
Cl-	Chloride (Cl ⁻)	5	Y
A-	Large anions(A ^{-1,2})	108	N
Also important:			
Calcium (Ca ²⁺)	.0001	1	sometimes



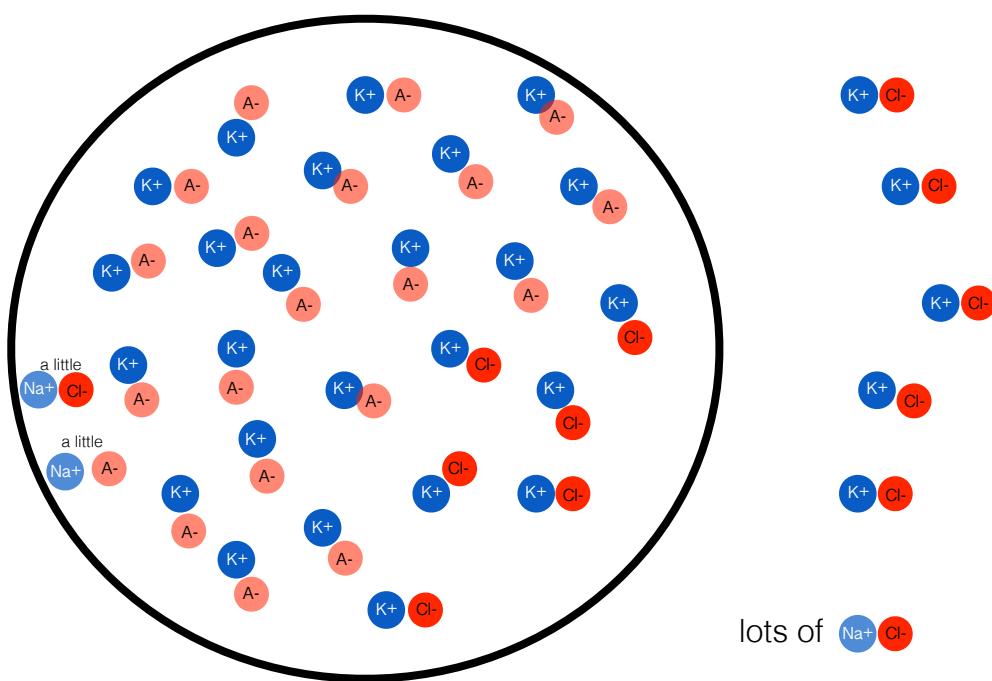
A. “typical” major contributors to chemical composition of fluids inside and outside a mammalian neuron:

	Internal (mM)	External (mM)	Permeable?	
K+	Potassium(K ⁺)	125	5	Y
Na+	Sodium (Na ⁺)	12	120	sometimes
Cl-	Chloride (Cl ⁻)	5	125	Y
A-	Large anions(A ^{-1,2})	108	0	N
	Also important: Calcium (Ca ²⁺)	.0001	1	sometimes

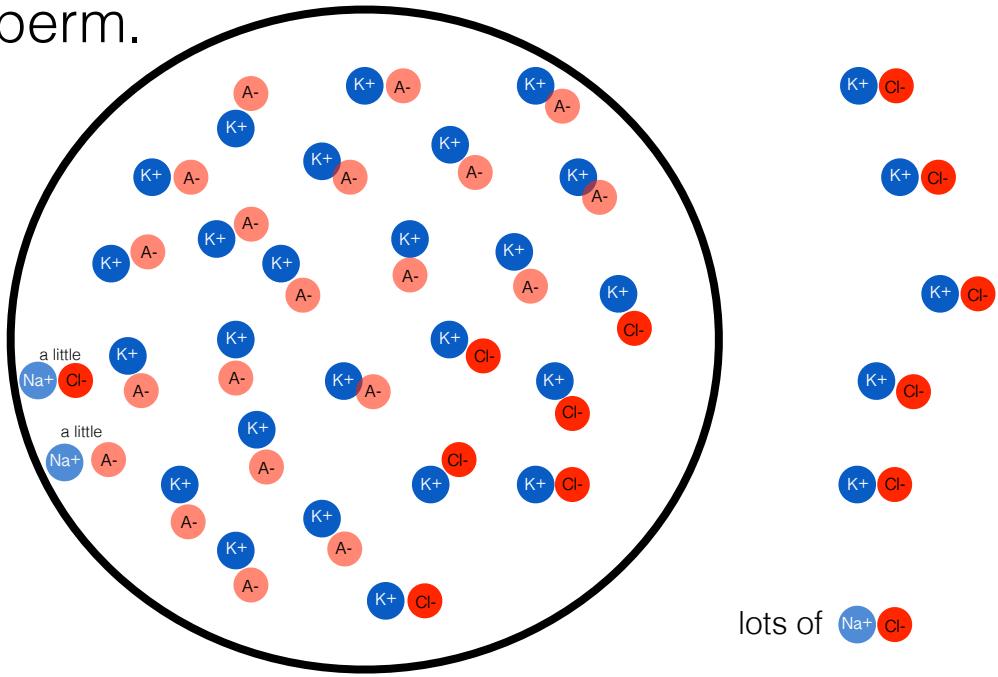


A. “typical” major contributors to chemical composition of fluids inside and outside a mammalian neuron:

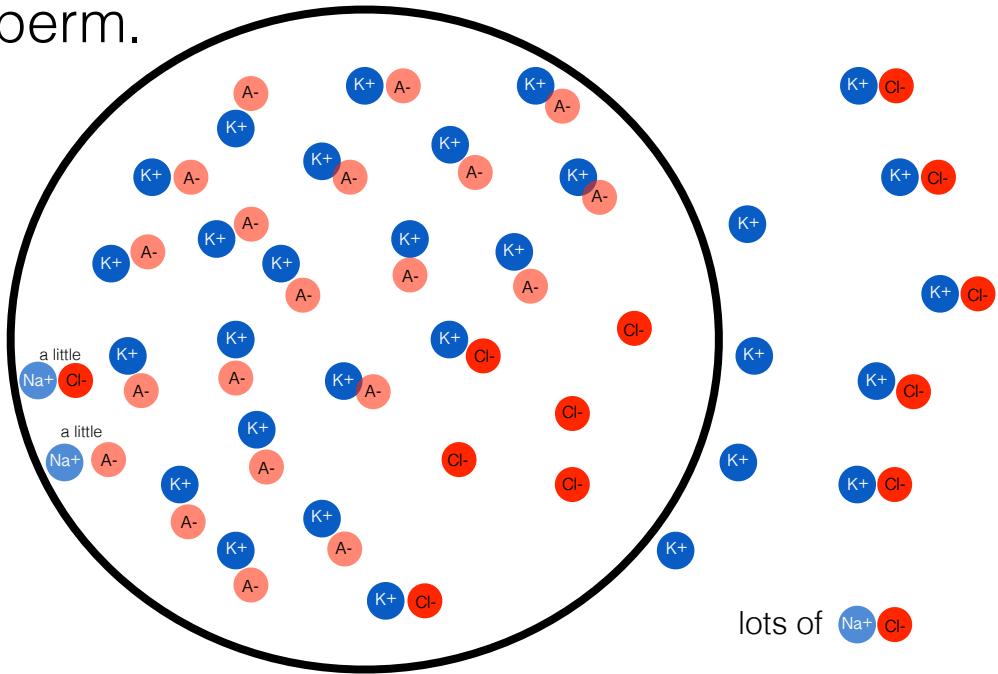
	Internal (mM)	External (mM)	Permeable?
K ⁺	Potassium(K ⁺)	125	Y
Na ⁺	Sodium (Na ⁺)	12	sometimes
Cl ⁻	Chloride (Cl ⁻)	5	Y
A ⁻	Large anions(A ^{-1,2})	108	N
	Also important: Calcium (Ca ²⁺)	.0001	1 sometimes



Only K^+ perm.



Only K^+ perm.



Potential difference?

Inside negative relative to outside.

How negative relative to outside?

NERNST equation

NERNST equation

- **Key point:** The **Nernst equation** that describes the potential at which the two forces are in balance across a membrane that is permeable to ONLY ONE charged particle type (ion).

$$E_x = \frac{RT}{zF} \ln \frac{[X_{\text{out}}]}{[X_{\text{in}}]}$$

E_x = equilibrium potential of ion x (inside relative to outside)

R = 8.314 Joules/(°K mole)

T = Temp °K

Z = Valence of the ion

At room temp (20 degrees C) and in \log_{10} :

$$E_x = \frac{58_{\text{mV}}}{Z} \log \frac{[X_{\text{out}}]}{[X_{\text{in}}]}$$

A. “typical” major contributors to chemical composition of fluids inside and outside a mammalian neuron:

	Internal (mM)	External (mM)	Permeable?
Potassium(K ⁺)	125	5	Y
Sodium (Na ⁺)	12	120	sometimes
Chloride (Cl ⁻)	5	125	Y
Large anions(A ^{-1,2})	108	0	N
Also important: Calcium (Ca ²⁺)	.0001	1	sometimes

$$E_x = \frac{58_{\text{mV}}}{Z} \log \frac{[X_{\text{out}}]}{[X_{\text{in}}]} \quad E_K = \frac{58_{\text{mV}}}{1} \ln \frac{[5]}{[125]} = -81_{\text{mV}}$$

$$E_{\text{Na}} = +58_{\text{mV}}$$

$$E_{\text{Cl}} = -81_{\text{mV}}$$

Important things about Nernst:

Applies when only one permeable ion!
True equilibrium

Fetcho lecture 2 main goals

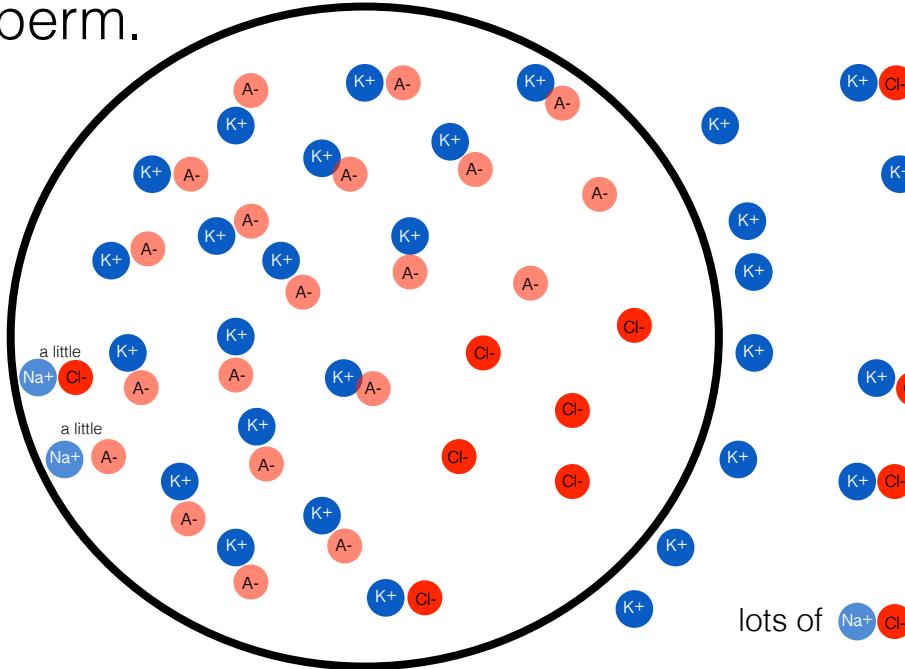
- To solidify your understanding of the Nernst situation.
- To understand how a stable membrane potential is achieved when more than one ion is permeable.
- To learn the Goldman equation used to calculate that potential.

Things you should know AT THE END.

- An intuition for what happens if MORE than one ion is permeable, including the concept of driving force and the current flows.
- The Goldman equation and its application.

Nernst Applicability

Only K^+ perm.



Higher temp

More neg. than
-81 mV

Hyperpolarized

New equilibrium

Low temp

Diffusion force (K^+)

Electrical force (K^+)

Equal and opposite in balance at -81

Higher temp

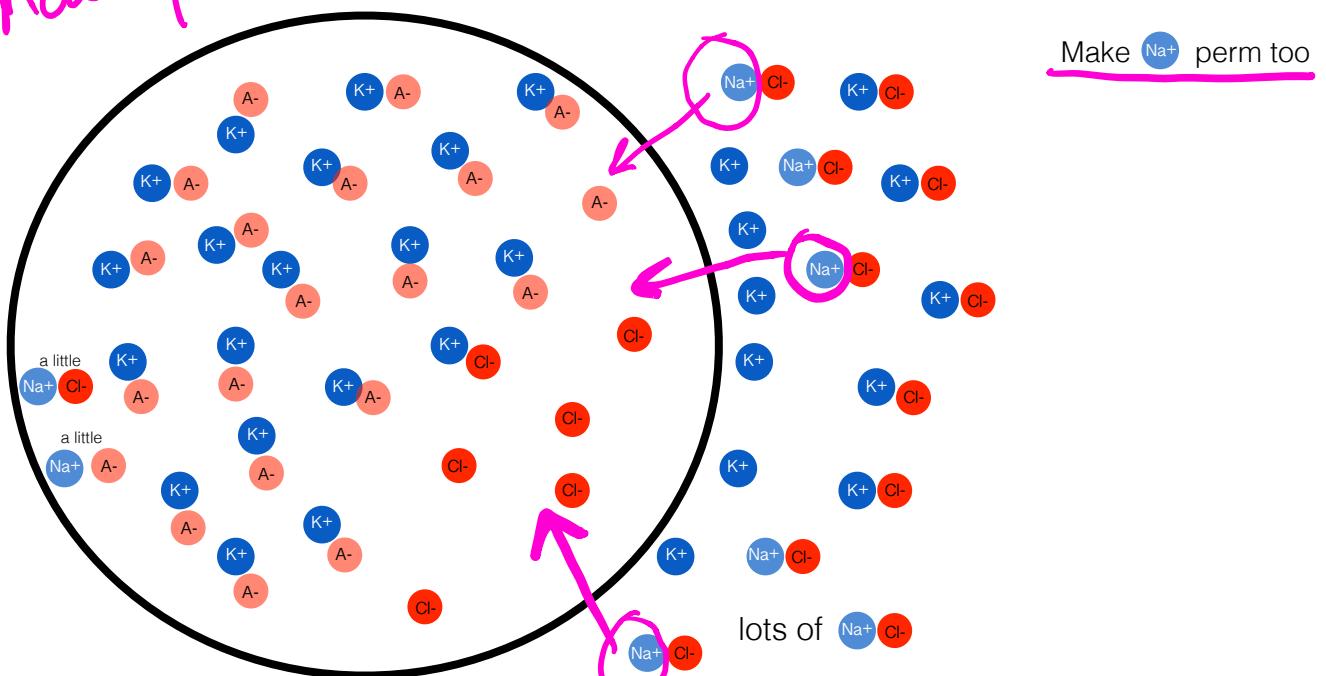
Diffusion force (K^+)

Electrical force (K^+)

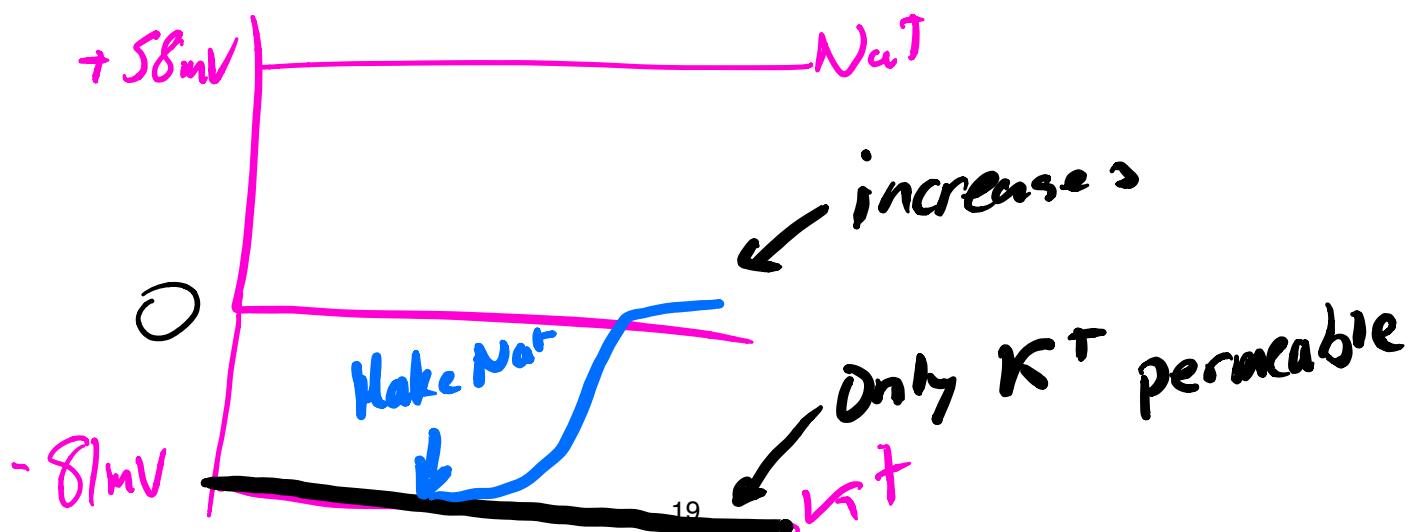
Equal and opposite in balance, but more neg.

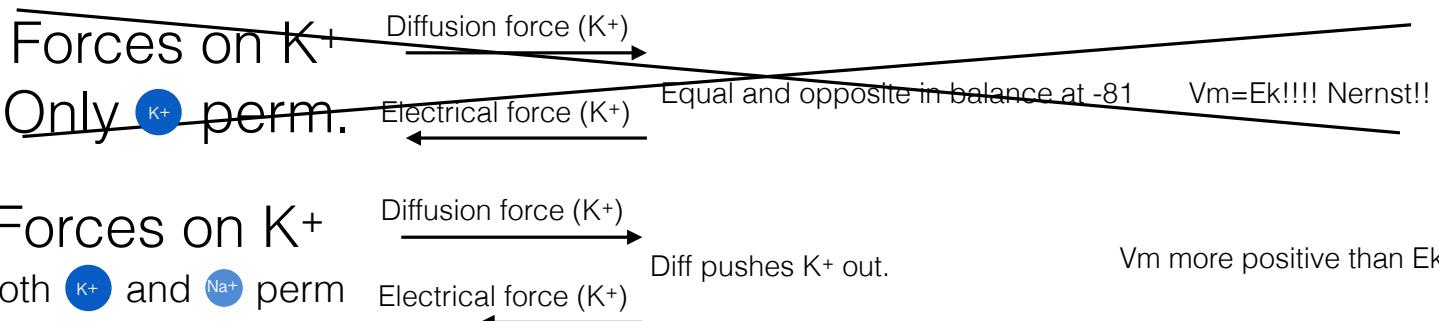
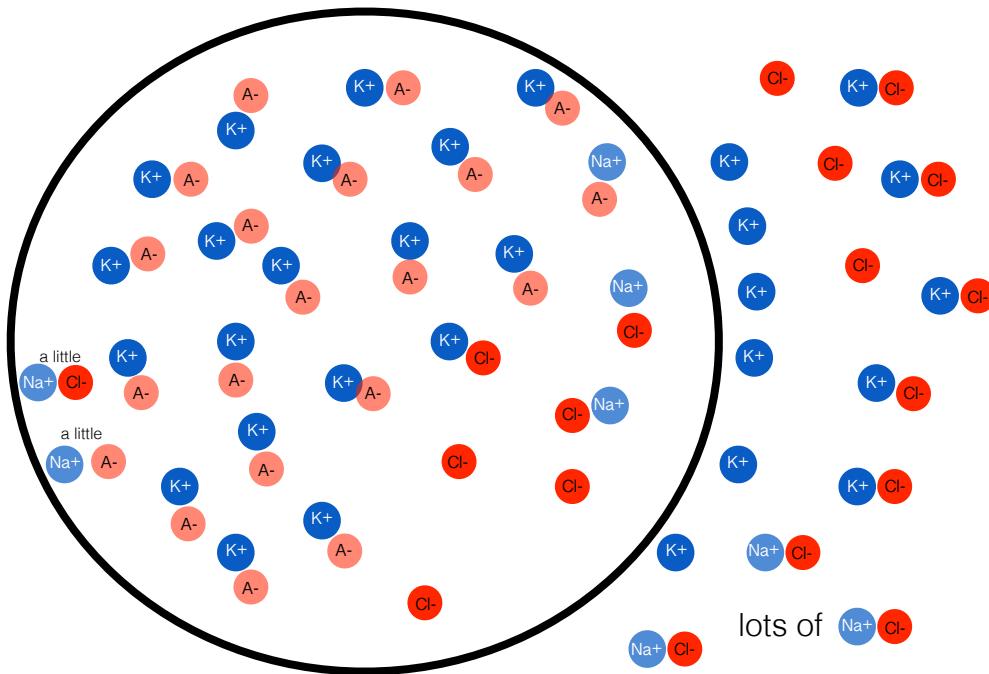
More than one permeable ion

Nat now permeable.



Equilibrium potential of sodium is **VERY positive!**





KEY: K flows out at the new potential to try to move to the K^+ Nernst. But opposed by Na flowing in to try to reach its Nernst.

K flows out and Na in and V_m reaches a stable potential at which K flow in equal Na flow out

$$\text{_____} +58 \text{ mV} = E_{Na}$$

$$\text{_____} = V_m = 0$$

$$\text{_____} -81 \text{ mV} = E_K$$

when sodium channels open
membrane potential depolarizes

What is the K+ current (I_K) flow at the new membrane potential V_m ?

$$+58 \text{ mV} = E_{Na}$$

electrical force change on K is a voltage (V) = ($V_m - E_K$) that pushes K ions

$$= V_m = 0$$

$$-81 \text{ mV} = E_K$$

We know $V = IR$ $I = V/R$ so

$$\Delta \text{Voltage} \rightarrow I_K = (V_m - E_K)/R$$

$1/R = g$ (conductance) so

$$I_K = (V_m - E_K)g_K$$

SO: K current equals conductance (g) times the so called driving force, ($V_m - E_K$)

Answer: $I_K = (V_m - E_K)g_K = (81 \text{ mV})g_K$: Positive = K⁺ flow out

What is the Na⁺ current (I_{Na}) flow at the new membrane potential V_m ?

Answer: $I_{Na} = (V_m - E_{Na})g_{Na} = (-58 \text{ mV})g_{Na}$: Negative = Na⁺ flow in

KEY Point: Stable membrane potential at zero means no net charge flow: $I_K + I_{Na} = 0$
For every K that flows out a Na flows in — so no membrane potential change even though K constantly flowing out and Na in.

Positive cells flow out of cell $\Rightarrow (+)$ current

Negative cells flow out of cell $\Rightarrow (-)$ current

The equation that describes the stable membrane potential when multiple ions are permeable is the **Goldman equation.**

At room temp and in \log_{10} :

$$V_m = 58_{\text{mV}} \log \left(\frac{p_K[K^{+}_{\text{out}}] + p_{\text{Na}}[Na^{+}_{\text{out}}] + p_{\text{Cl}}[Cl^{-}_{\text{in}}]}{p_K[K^{+}_{\text{in}}] + p_{\text{Na}}[Na^{+}_{\text{in}}] + p_{\text{Cl}}[Cl^{-}_{\text{out}}]} \right)$$

Expressed as permeability ratios

$$V_m = 58_{\text{mV}} \log \left(\frac{\frac{[K^{+}_{\text{out}}]}{[K^{+}_{\text{in}}]} + b[Na^{+}_{\text{out}}] + c[Cl^{-}_{\text{in}}]}{b[Na^{+}_{\text{in}}] + \frac{[Cl^{-}_{\text{out}}]}{[Cl^{-}_{\text{in}}]}} \right)$$

$b = p_{\text{Na}}/p_K$

$c = p_{\text{Cl}}/p_K$

Reference

More convenient

form



A. "typical" major contributors to chemical composition of fluids inside and outside a mammalian neuron:

	Internal (mM)	External (mM)	Permeable?
Potassium(K ⁺)	125	5	Y
Sodium (Na ⁺)	12	120	sometimes
Chloride (Cl ⁻)	5	125	Y
Large anions(A ^{-1,2})	108	0	N
Also important: Calcium (Ca ²⁺)	.0001	1	sometimes

assume K⁺ 50 times more perm than Na⁺

$$V_m = 58_{\text{mV}} \log \left(\frac{[K^+_{\text{out}}] + b[Na^+_{\text{out}}] + c[Cl^-_{\text{in}}]}{[K^+_{\text{in}}] + b[Na^+_{\text{in}}] + c[Cl^-_{\text{out}}]} \right) \quad b = p_{Na}/p_K \\ c = p_{Cl}/p_K$$

$$V_m = 58_{\text{mV}} \log \left(\frac{5 + (.02) 120 + 0}{125 + (.02) 12 + 0} \right)$$

$$V_m = -71 \text{ mV}$$

Resting potential!

typically dominated

by Na⁺, K⁺, permeability

Fetcho Lecture 3 main goals

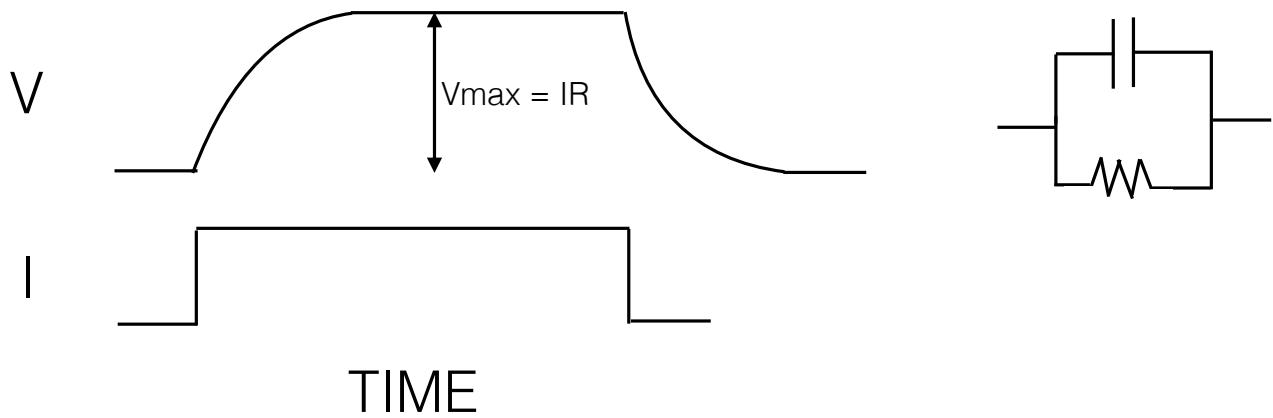
- Test of your intuition about Nernst/ Goldman situations to firm up your fluency and see if you are retaining the ideas.
- To develop your understanding of the passive properties of neurons that result from membrane resistance and capacitance.
- To develop an appreciation for how potentials rise and decay over time and distance along neurons.

Things you should know AT THE END.

- Nernst and Goldman should be getting easier.
- How potential rises after a current injection and the equation for it.
- What is time constant and temporal summation.
- How membrane potential decays with distance and the concept of the space/length constant.

**Turn to Passive properties -
building on pre-lecture
video**

Passive properties: time constant

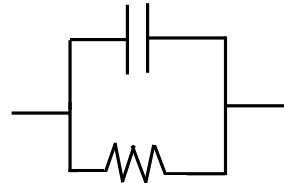


$$V(t) = V_{\max} (1 - e^{(-t/\tau)}) \quad \tau = \text{time constant}$$

$e^{(-t/\tau)} = 1/e^{(t/\tau)}$ if t is long then this goes to zero and $V(t)=V(\max)=IR$

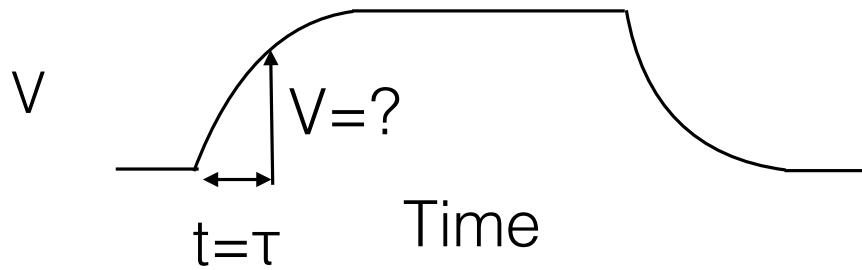
$$V(t) = V_{\max} (1 - e^{(-t/\tau)}) \quad \tau = \text{time constant}$$

$$\tau = (r_m)(C_m)$$



Keypoint: **Time constant (τ)** is an indicator of how fast or slow the membrane potential will change after a current injection.

Ask: What is the membrane potential when time has passed that is equal to τ ?



$$\begin{aligned} V(t) &= V_{\max} (1 - e^{(-t/\tau)}) \\ &= V_{\max} (1 - 1/e) \\ &= V_{\max} (1 - 1/2.72) \end{aligned}$$

$$V(t) = V_{\max} (1 - e^{(-t/\tau)})$$

$$= V_{\max} (.63)$$

Key point: **time constant (τ) is time to rise to 63% of the Maximum.**

What sorts of values of τ occur in neurons?

$$\tau = (r_m)(c_m)$$

r_m = 100's of megohms

c_c = 10's of picofarads (coulombs/volt)

Units of τ is seconds:

For unit obsessed (don't memorize):

$$(r_m)(c_m) = (V/I)(C/V)$$

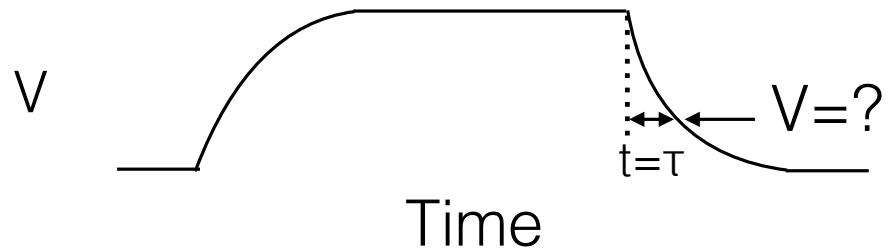
$$I=C/S$$

$$\text{so } (r_m)(c_m) = (V/(C/S))(C/V) = \text{seconds}$$

Key point: τ is on the order of several milliseconds

τ example: $(200 \times 10^6 \text{ ohms})(20 \times 10^{-12} \text{ farads}) = 0.004 \text{ secs} = 4 \text{ msec}$

τ also affects the decay of potential!



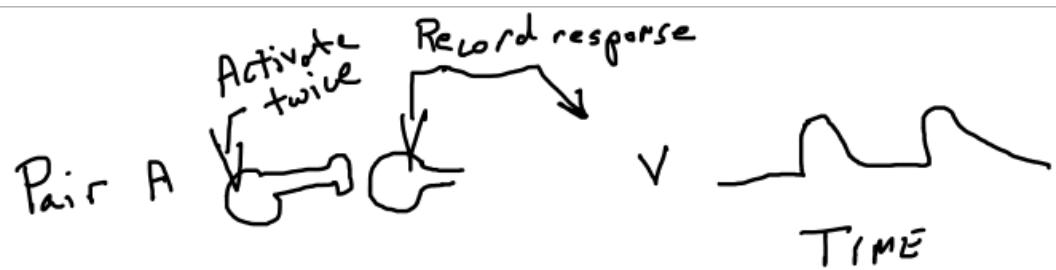
$$V(t) = V_{\max} (e^{(-t/\tau)})$$

at $t = \tau$

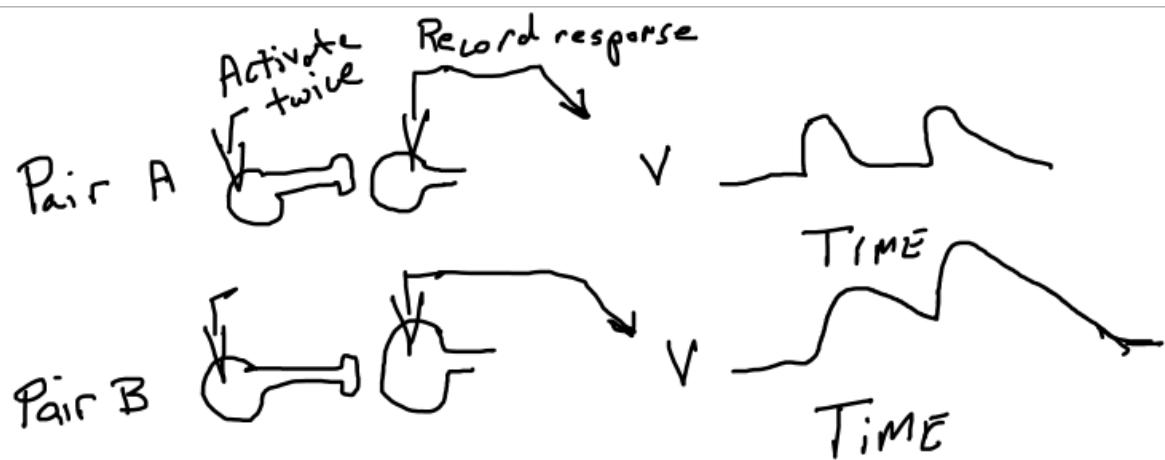
$$V(t) = V_{\max} (.37)$$

KEY: For decay, τ tells how long it will take to decay from V_{\max} to 37% of V_{\max}

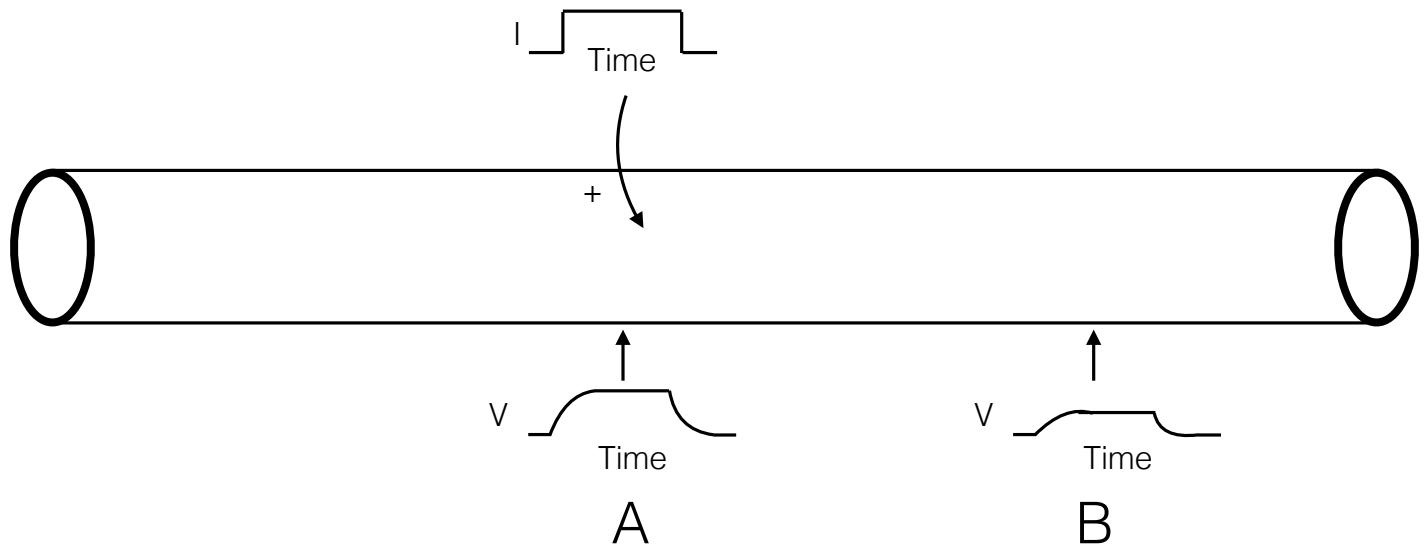
Why does the time constant τ matter?



Why does the time constant τ matter?

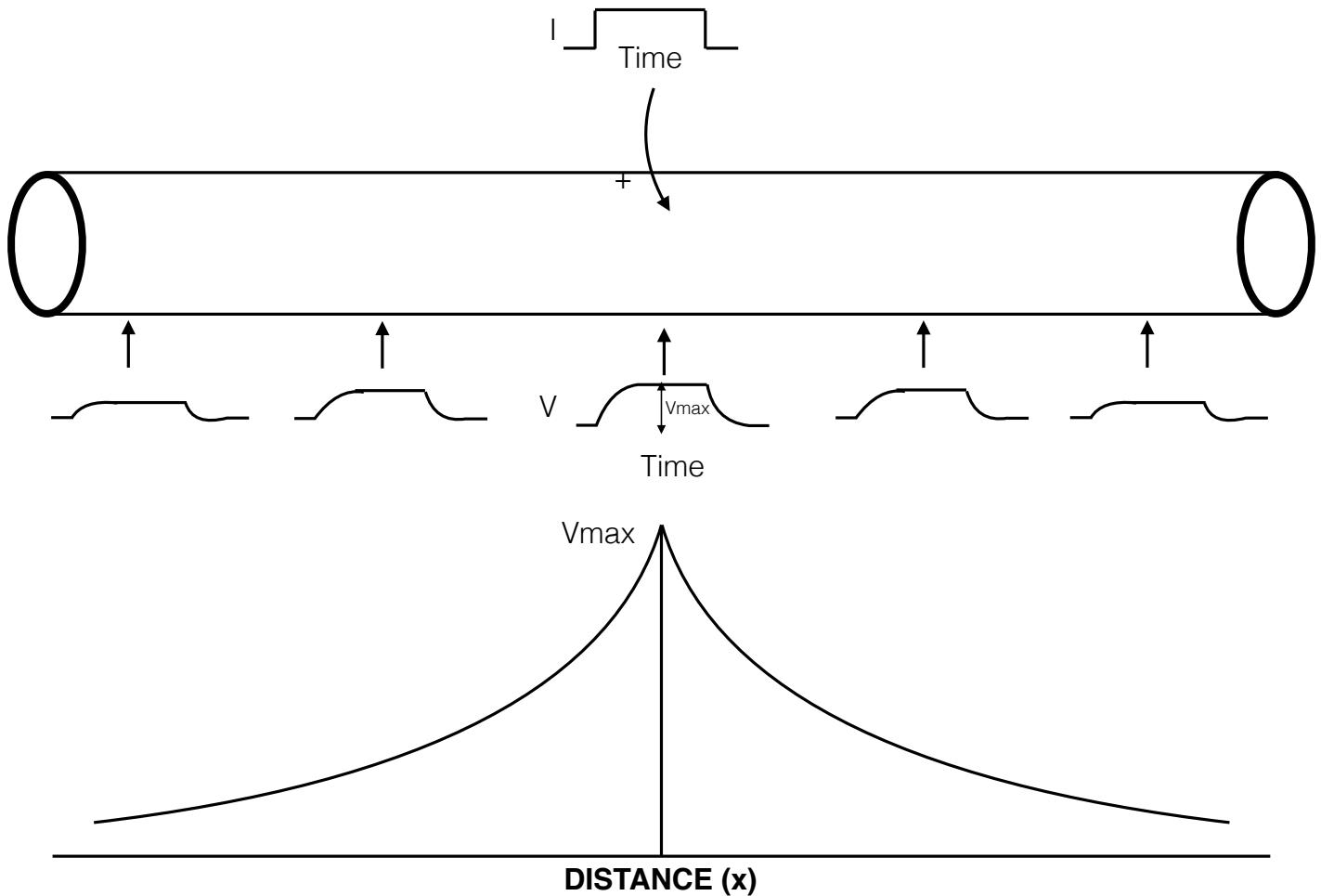


Passive properties also affect how the potential changes with distance along a neuronal process



The depolarization (V_{max}) at B will be _____ than the one at

- A. Higher
- B. Lower**
- C. The same

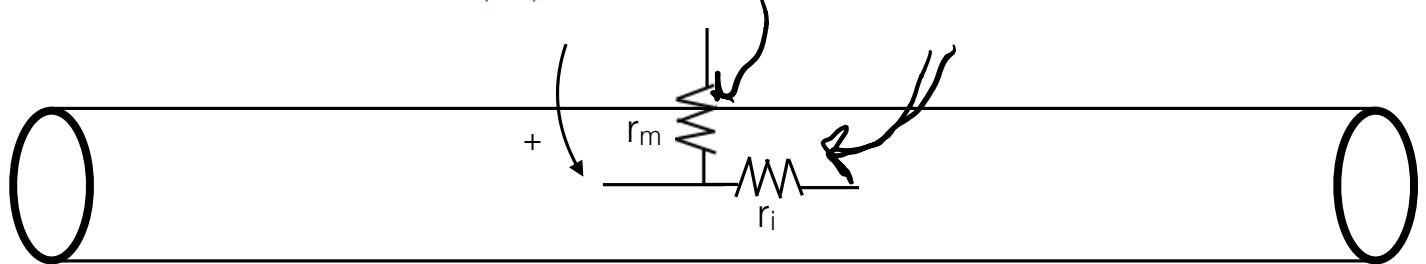


$$V(x) = V_{\max} (e^{(-x/\lambda)}) \quad \lambda = \text{length/space constant}$$

How much does the potential decay over a distance = to λ ? $V(x) = V_{\max} (e^{(-\lambda/\lambda)}) = .V_{\max} (.37) = 37\%$

Key point: λ is the **distance** over which a potential decays to 37% of what it was at the point where it started.

What properties of a neuron affect λ ?



Oh god, another
equation...but the last
from Joe.

$$\lambda = \sqrt{r_m/r_i}$$

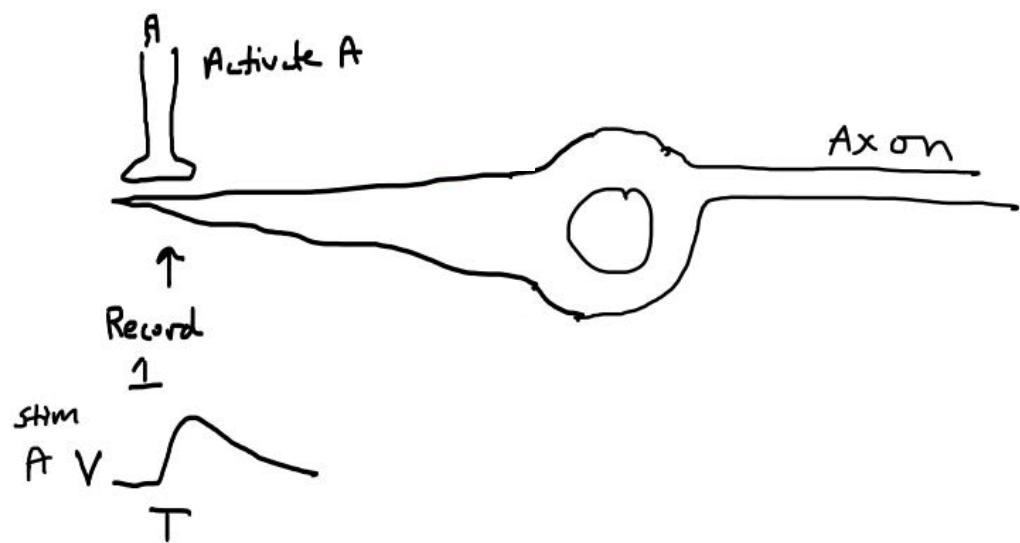


$\uparrow r_i$ bigger diameter

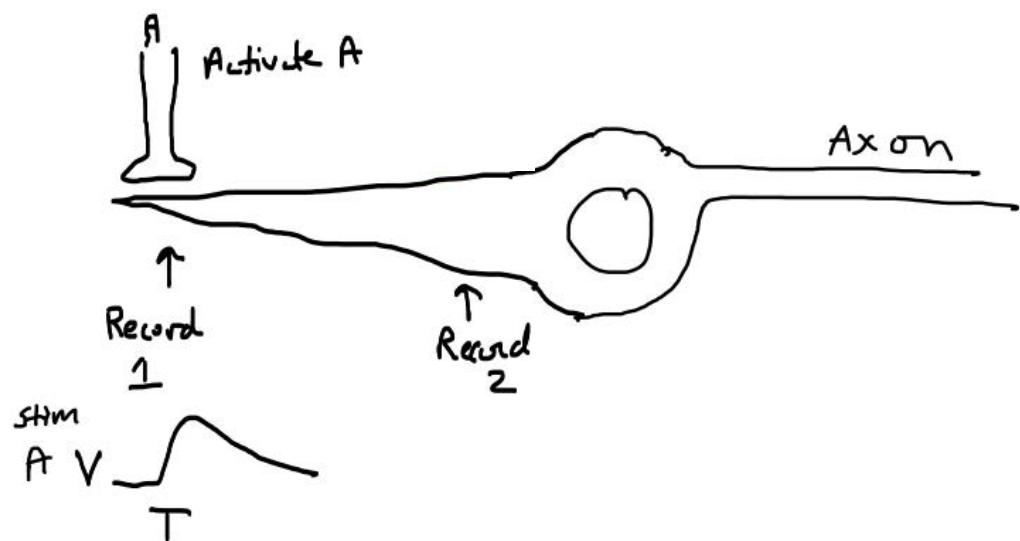
$\lambda = 0.1 \text{ mm}$ for small unmyelinated

$\lambda = 5 \text{ mm}$ for large myelinated

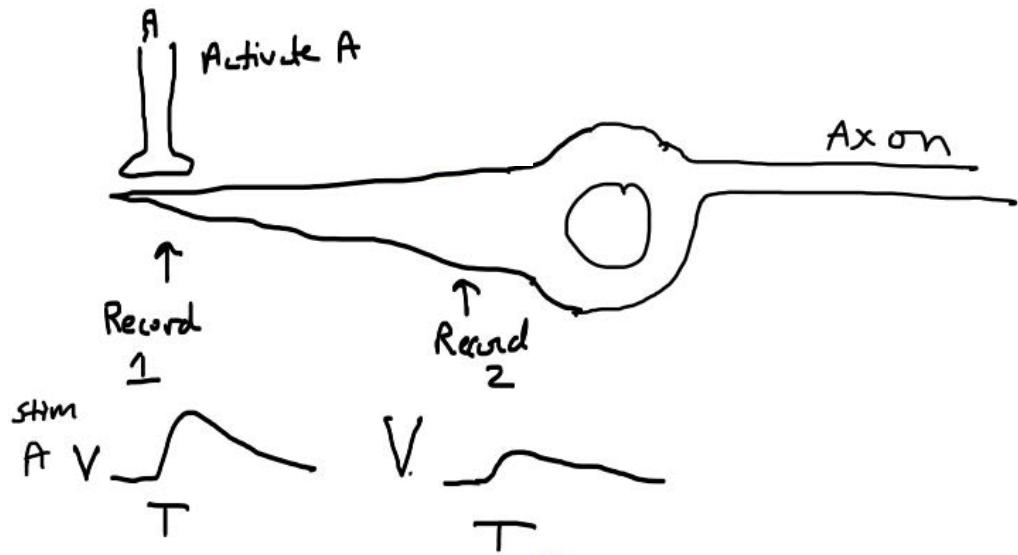
Keypoint: Importance of λ is in the ability of summation.



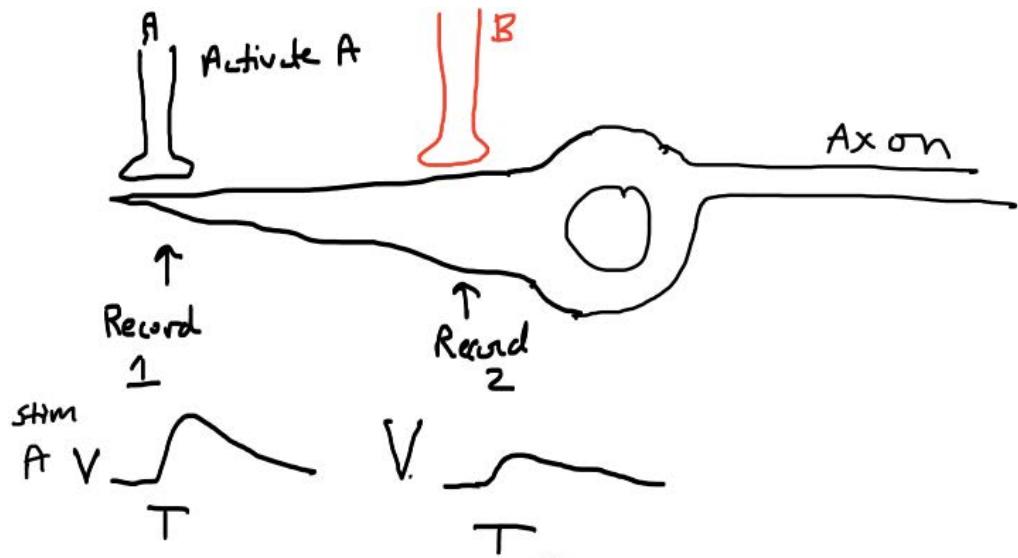
Keypoint: Importance of λ is in the ability of summation.



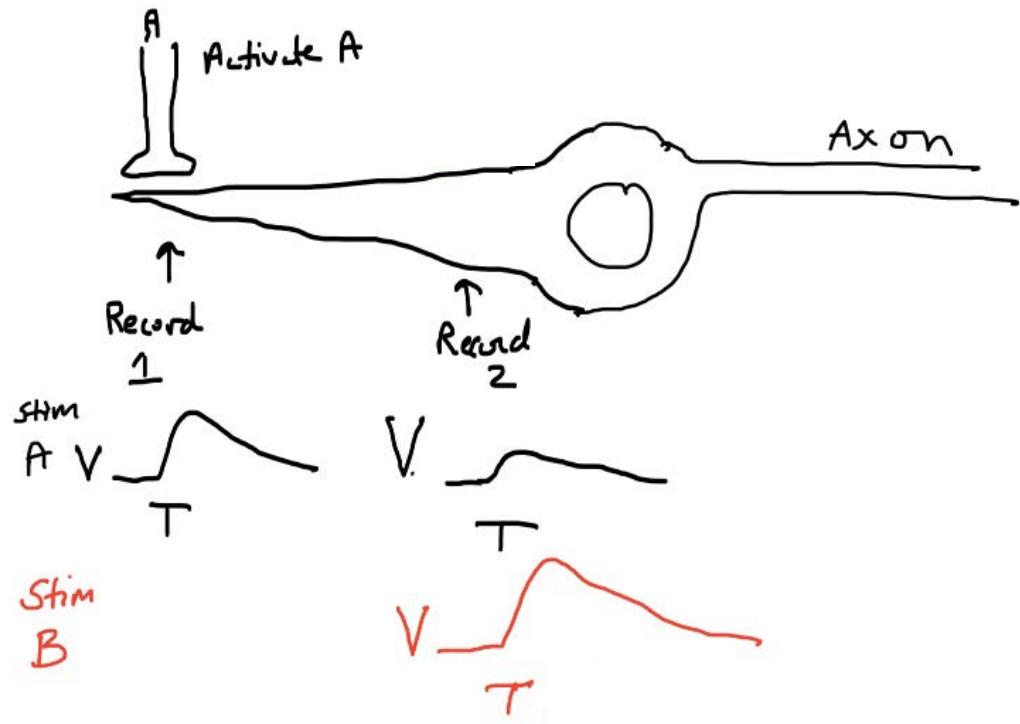
Keypoint: Importance of λ is its affect on the summation of input at different places on a neuron.



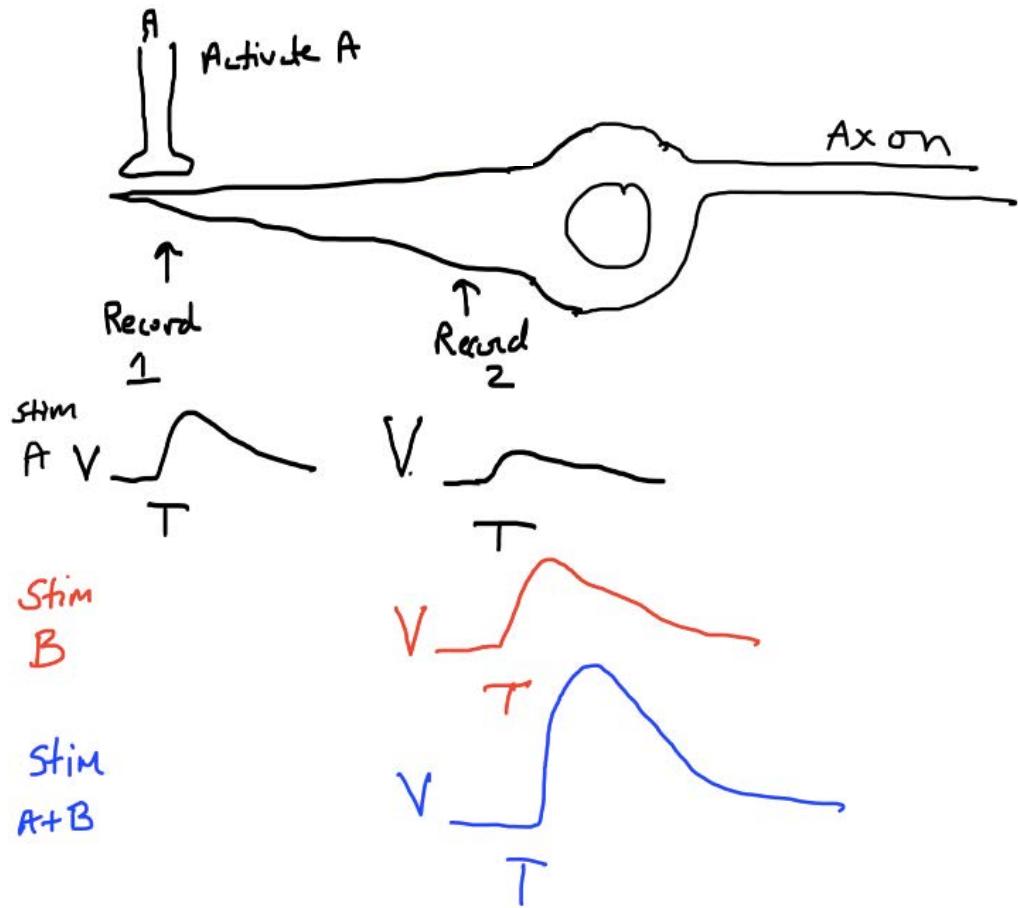
Keypoint: Importance of λ is its affect on the summation of input at different places on a neuron.



Keypoint: Importance of λ is its affect on the summation of input at different places on a neuron.



Keypoint: Importance of λ is its affect on the summation of input at different places on a neuron.



Key: A larger λ allows for easier summation of inputs at different locations: called **spatial summation**

Passive properties suck if you are big!

$\lambda = 5$ mm for large myelinated - terrible for distances in our brains and body

Solved By Action Potentials: a way of amplifying the electrical signal to allow signaling over long distances

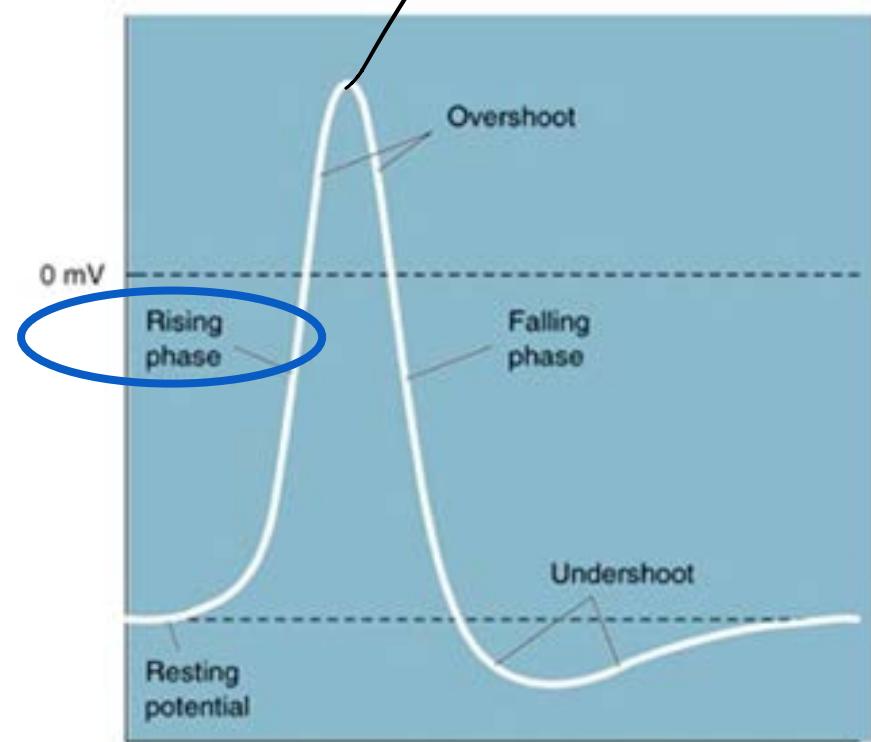
Fetcho Lecture 4 main goals

- Understand what is happening to generate the waveform of the action potential
- Consider other features of the action potential from the preclass video such as threshold, refractory period etc.

Things you should know AT THE END.

- how the voltage clamp allowed for measurements of the currents flowing during an action potential and what those currents are.
- What is responsible for other key features of the action potential

action potential is all or none



Features of AP to explain (preclass video)

- waveform
- triggered by depolarization
- threshold
- all or none
- inside positive at peak
- refractory period
- propagate without decrement

What might change in permeability to ions might lead to the rising phase?

Increase in Na permeability

Tested by lowering Na outside a neuron to see what happens to the action potential. What would you expect?

Slower rise and smaller size

So Na permeability is changing, but what are the currents flowing and how can we measure them?

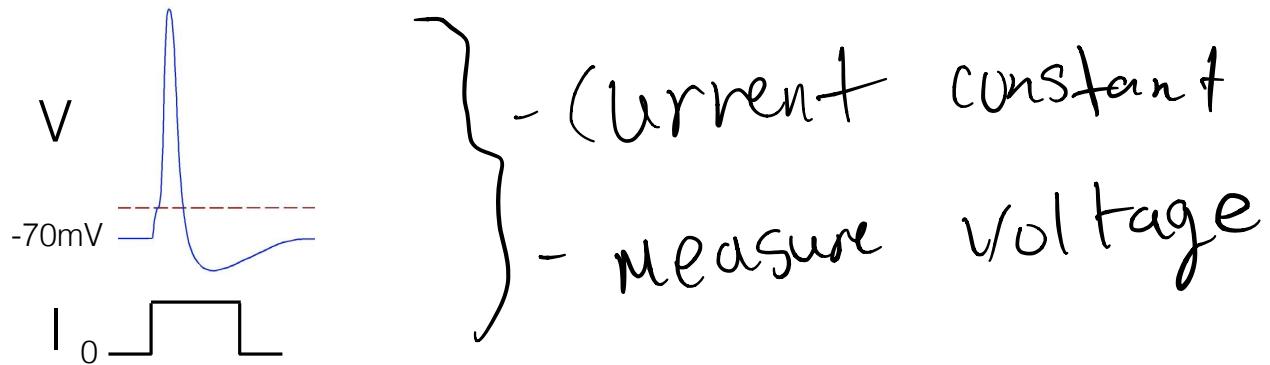
The answer was nobel prize worthy- won by Hodgkin and Huxley in 1963.

Approach: **Voltage clamp**: A device that allows for measuring currents flowing during an action potential.

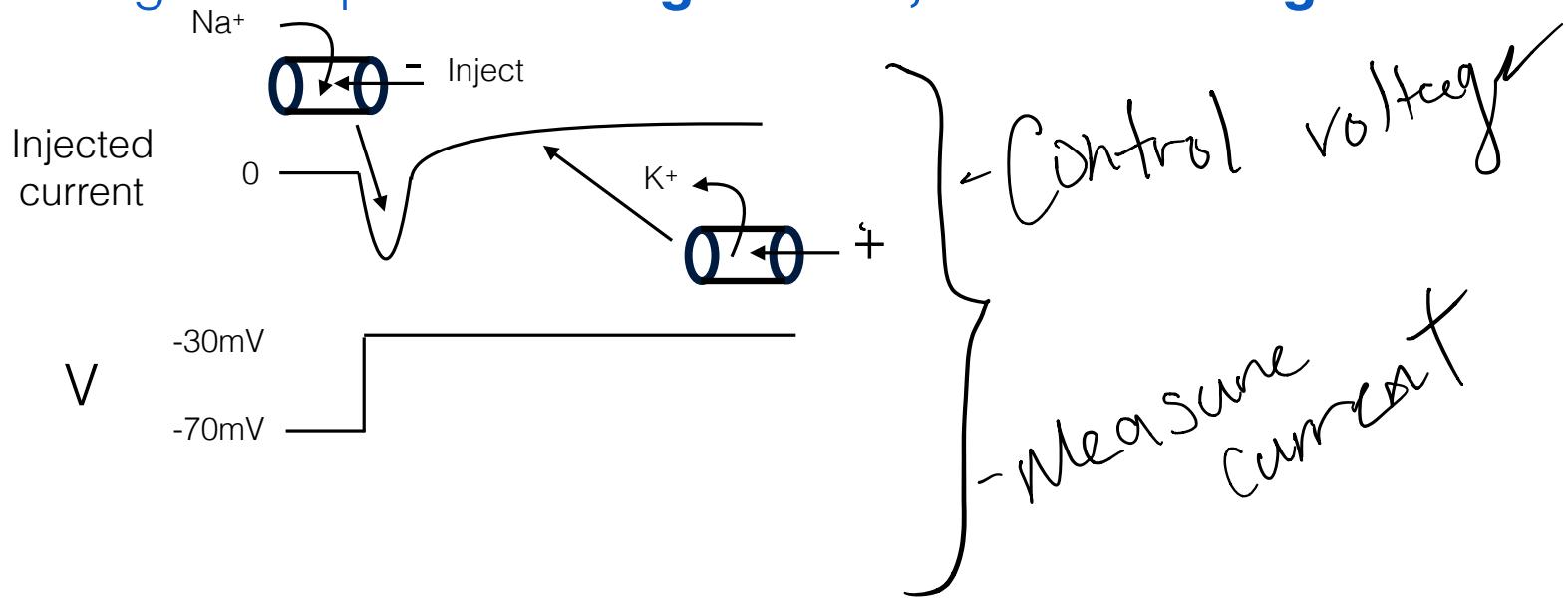
What it does : It holds the voltage across the membrane constant. To do that, it must injection a current that is opposite any currents that flow during the action potential.

Look at how voltage clamp works:

Typical recording: **measuring voltage, control current**



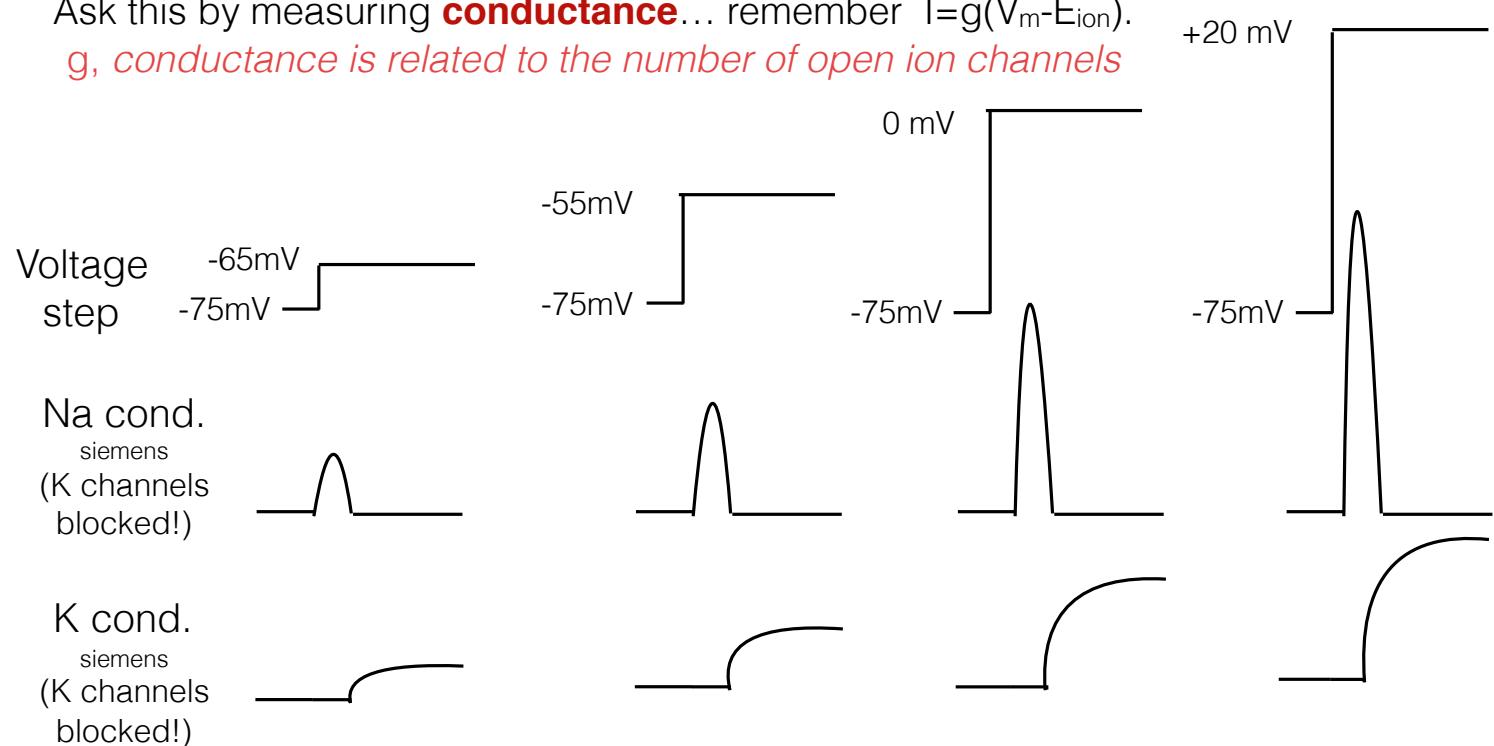
Voltage clamp: **measuring current, control voltage**



Voltage clamp shows that channels are opening with voltage, but how many open with a given amount of voltage change?

Ask this by measuring **conductance**... remember $I=g(V_m-E_{ion})$.

g, conductance is related to the number of open ion channels



Key observations:

- Bigger V steps lead to bigger Na and bigger K conductances
- Na cond. rises, but then falls, even though voltage is still depolarized
- K cond. rises later than Na and stays up during voltage increase

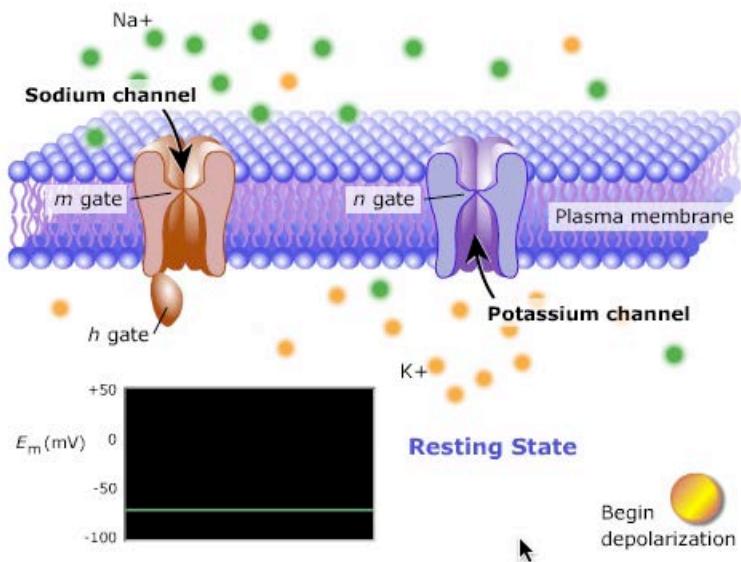
Led Hodgkin and Huxley to propose 3 processes (m,h,n), that we know correspond to gates that open and close in ion channels

NEUROBIOLOGY Molecules, Cells and Systems

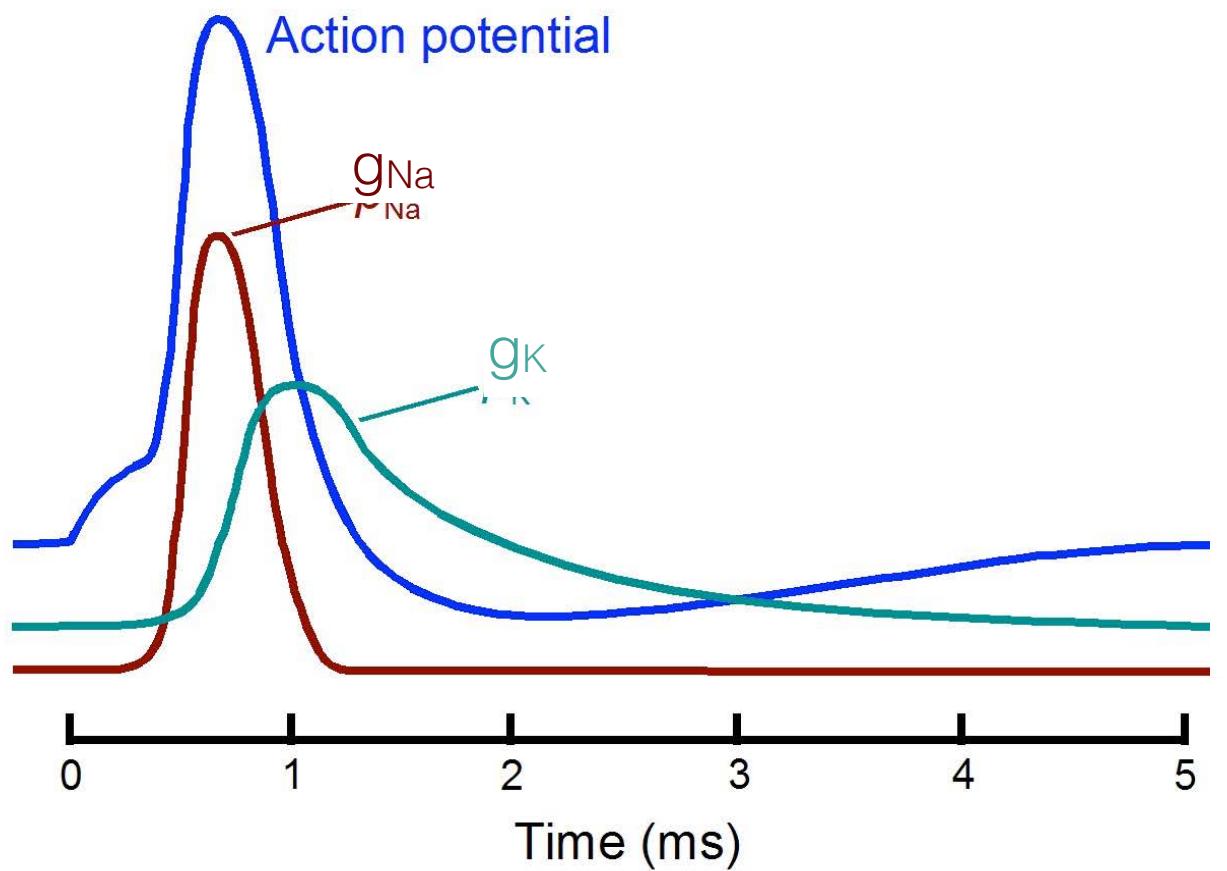
Gary G. Matthews

[Back to Neurobiology](#)

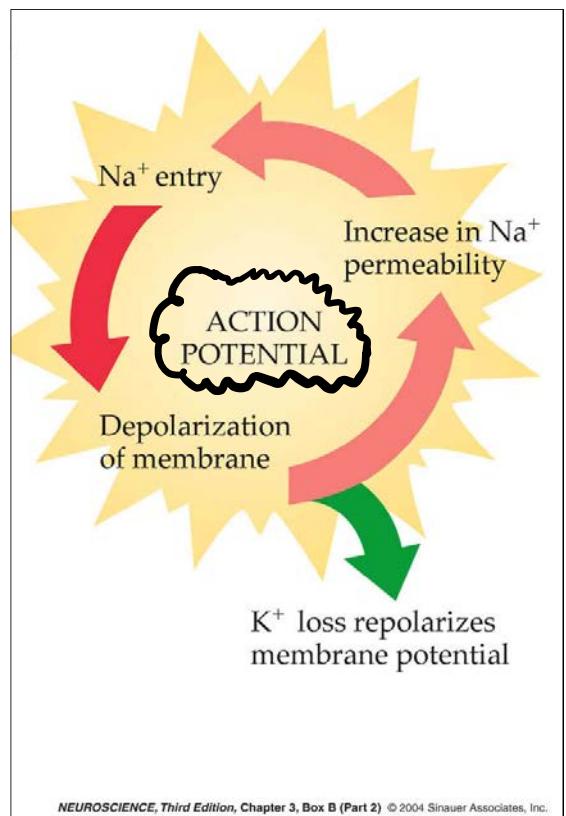
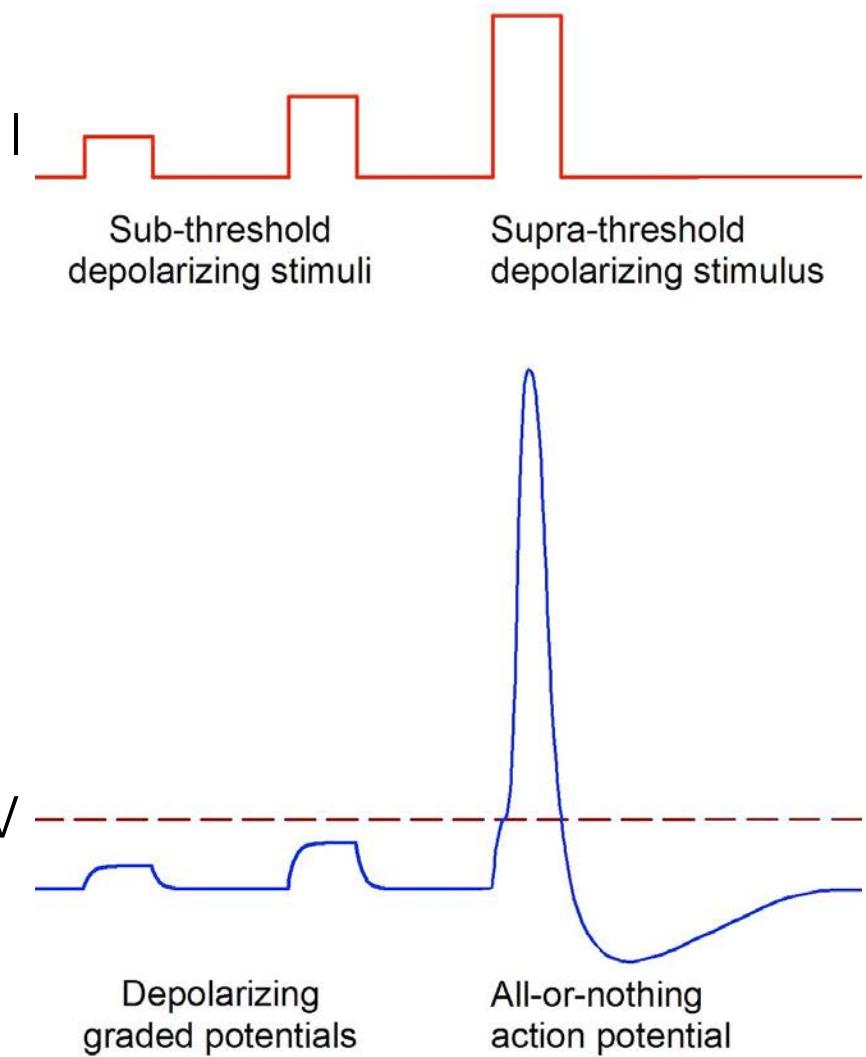
Channel Gating during an action potential



conductance changes during an action potential



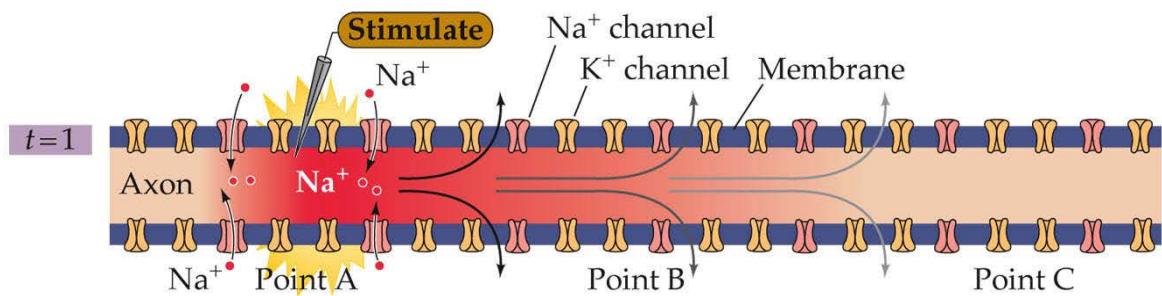
© PhysiologyWeb at www.physiologyweb.com



Key: Positive feedback on voltage dependent Na channels accounts for threshold and for overshoot of zero

ion pumps

Regeneration of action potential propagates it

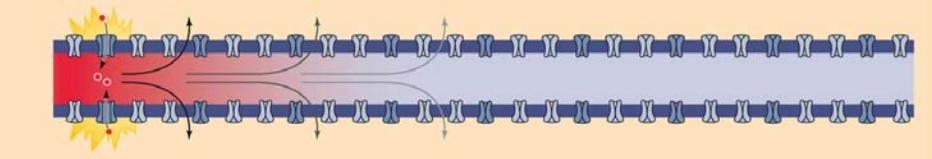


NEUROSCIENCE, Third Edition, Figure 3.12 (Part 1) © 2004 Sinauer Associates, Inc.

Unmyelinated versus myelinated axons

$t=1$

Unmyelinated axon

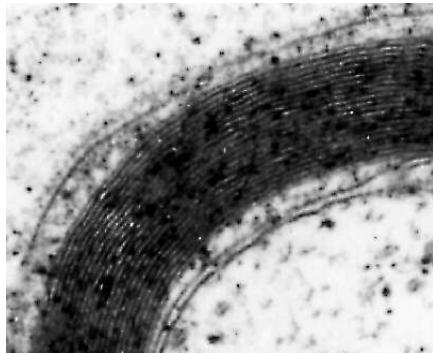
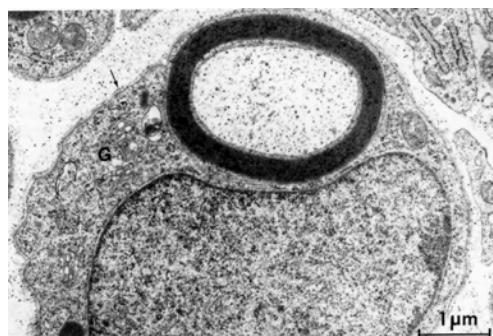


0.5-10m/sec

AP regenerates all along the membrane

10-100m/sec

AP regenerates only at breaks in Myelin - Nodes of Ranvier



Fetcho Lecture 5 main goals

- To understand the structure and function of ion channels

Things you should know AT THE END.

- Know what patch clamp recording is, the single channel data that result from it, and how those give the currents in a whole neuron.
- Know the key features of ion channels and how their structure is tied to function such as opening and closing with voltage, as well as regulating the selectivity of the ions that can pass through the channel.

Ion Channels.

What are they and how do they work?

Major contributions by:

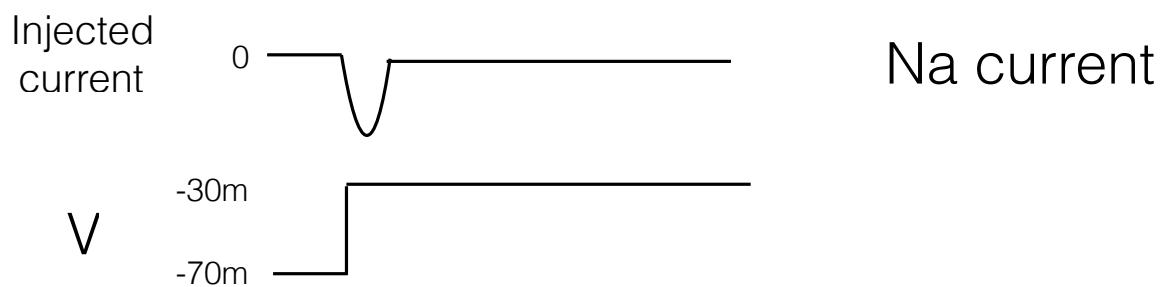
Sakmann and Neher (Nobel 1991)
and
Mackinnon (Nobel 2003)

Expected properties were known before:

1. ions go through fast (AP is 1 msec) - width
2. selective for particular ions
3. some open and closed by changes in membrane potential

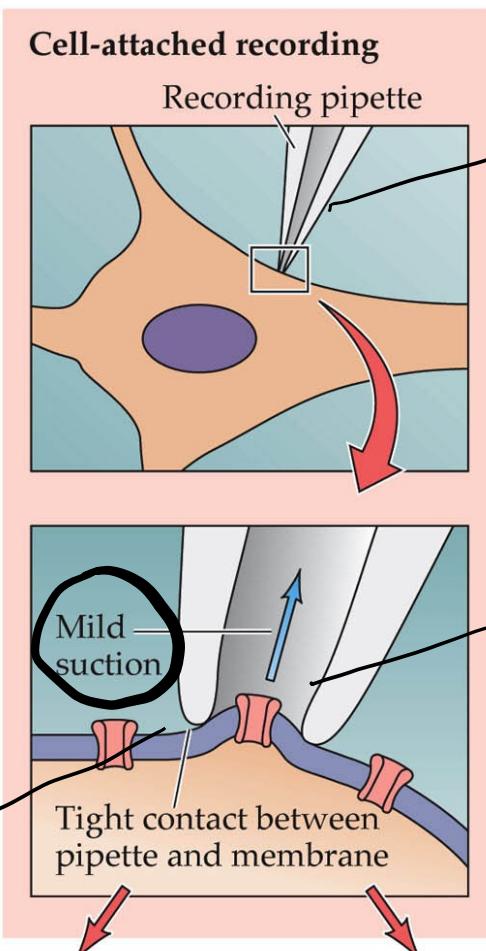
record current
through just one ion
channel
solving structure of potassium
channel

Prior to patch clamp had whole neuron voltage clamp



How do individual channels lead to this?

Patch clamp approach



have to make sure
there is no leakage

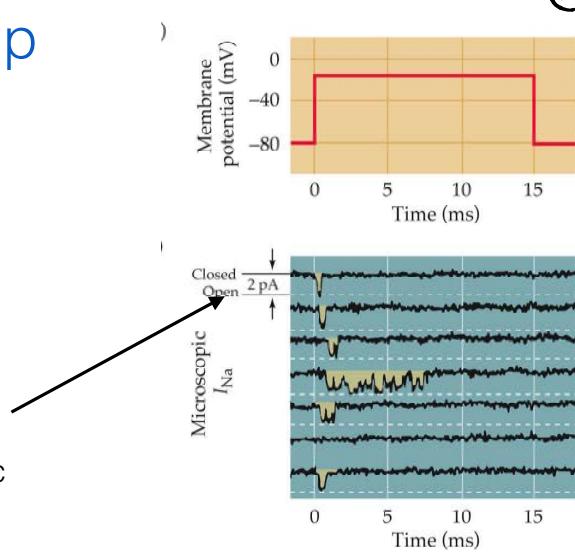
glass pipette
w/ opening filled
w/ salt solution

only one channel
in opening of
patch pipette

NEUROSCIENCE, Third Edition, Chapter 4, B

Patch clamp recording

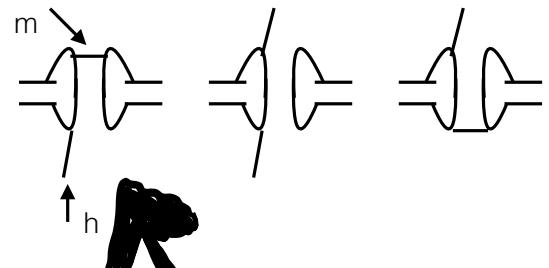
2 picoamps (-12)
 6,000 ions per msec
 6 million/sec
 pumps: 10,000/sec



Voltage step is repeated

KEY Features to explain at a molecular level:

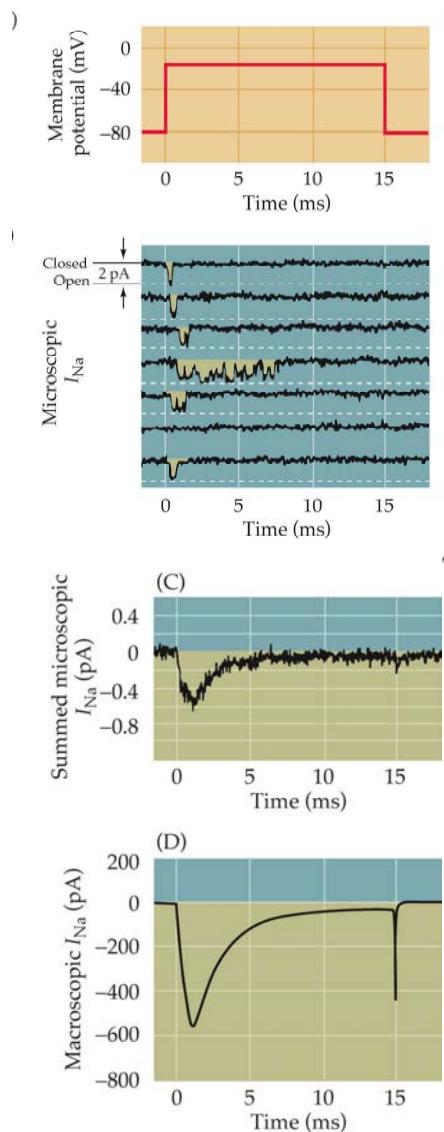
1. Open and closed states.
2. Individual channels not open the whole time.
3. More likely to be open early.



m gate effect

h gate effect

Single channels sum to give whole cell current

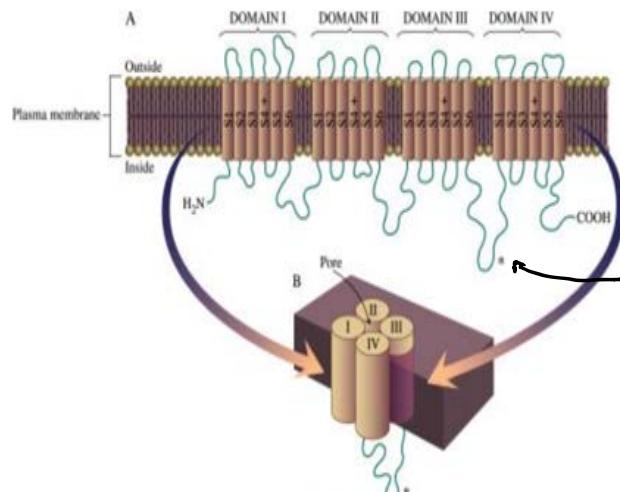


n, Figure 4.1 (Part 1) © 2004 Sinauer Associates, Inc.

P	a	b	J
R	e	m	i

What does a channel look like?

First rough idea from cloning of Na channel by Numa.

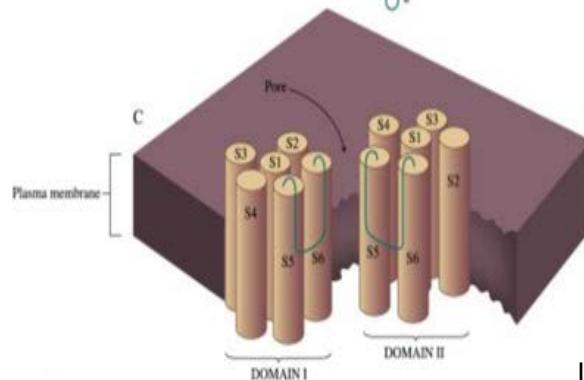


2,000 AA

one long protein

4 subregions each span mem. 6 times surround the pore

*Contains positive charge residue
→ pushed towards outside of cell
- protein too thick*

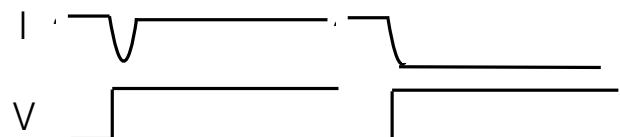
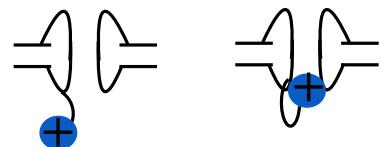


b NEUROBIOLOGY
Gary G. Matthews
Baylor College

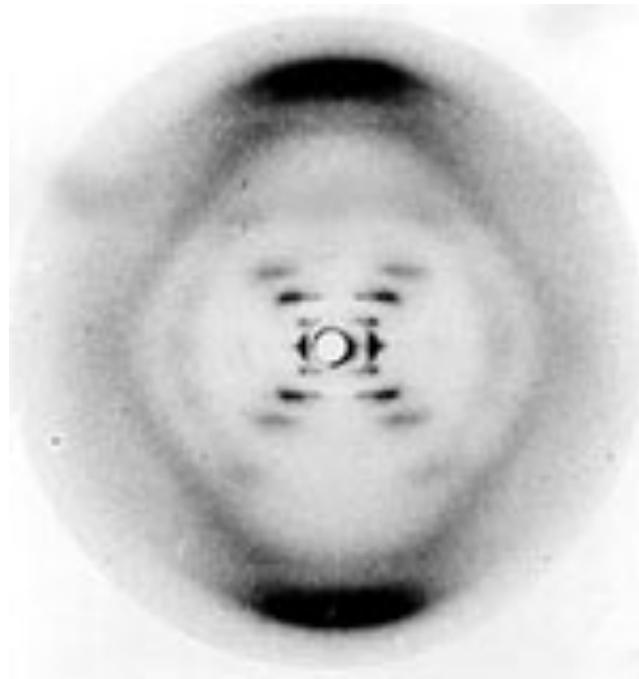
Voltage dependence?

S4 arginines and lysines... test role

Inactivation? II=IV loop



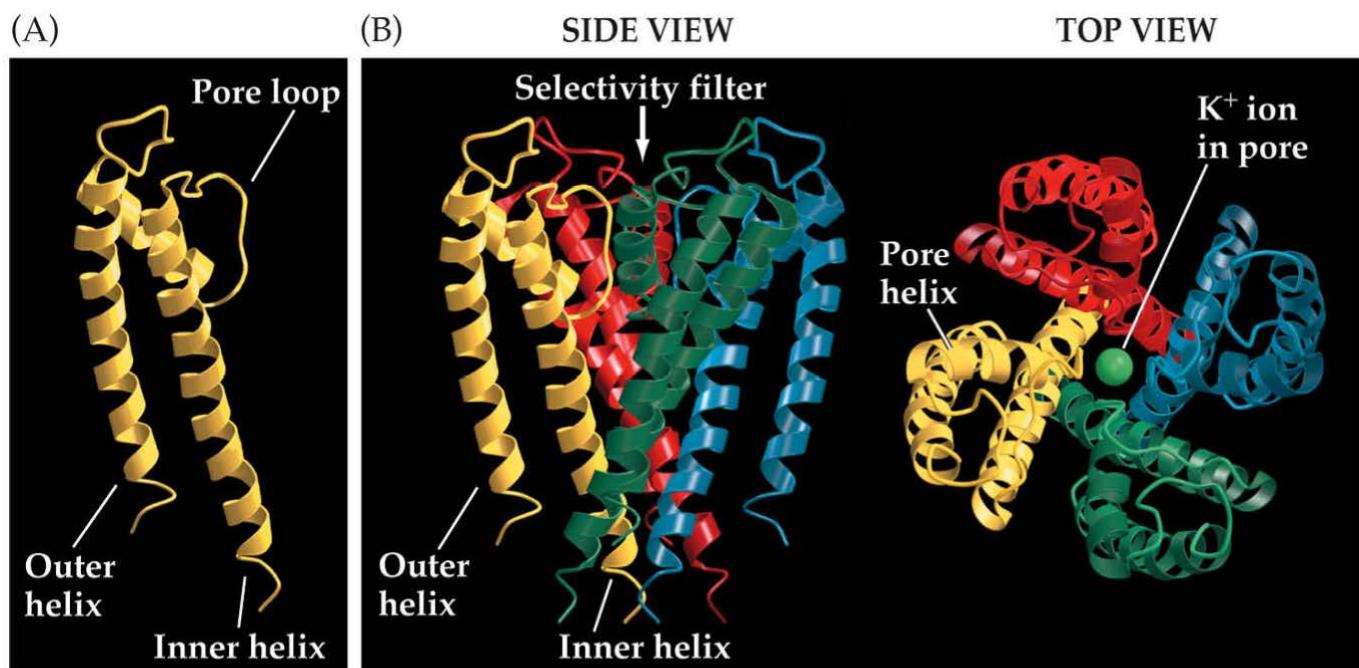
But really want to see a channel!



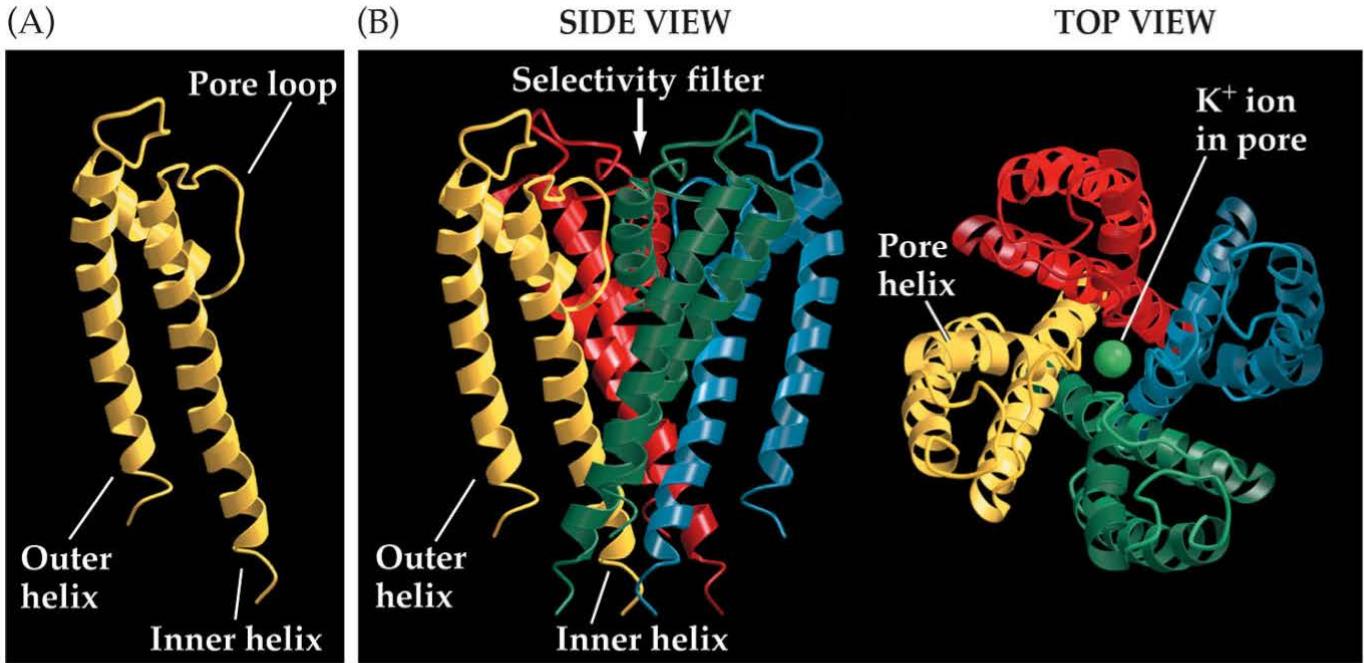
—FUCK
WATSON

AND
Cancer

Potassium channel (bacteria)



Key features: four separate subunit, each span membrane two times, surround pore

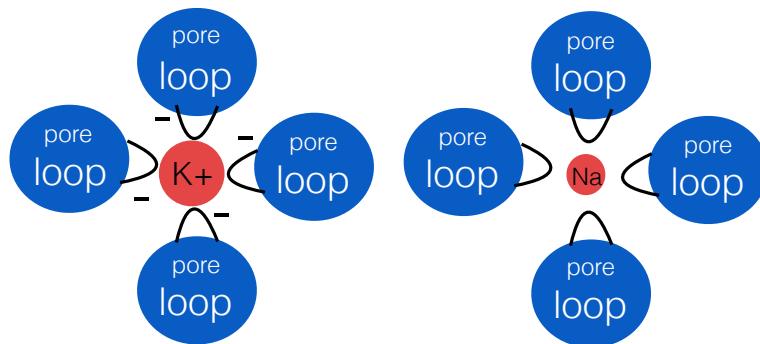
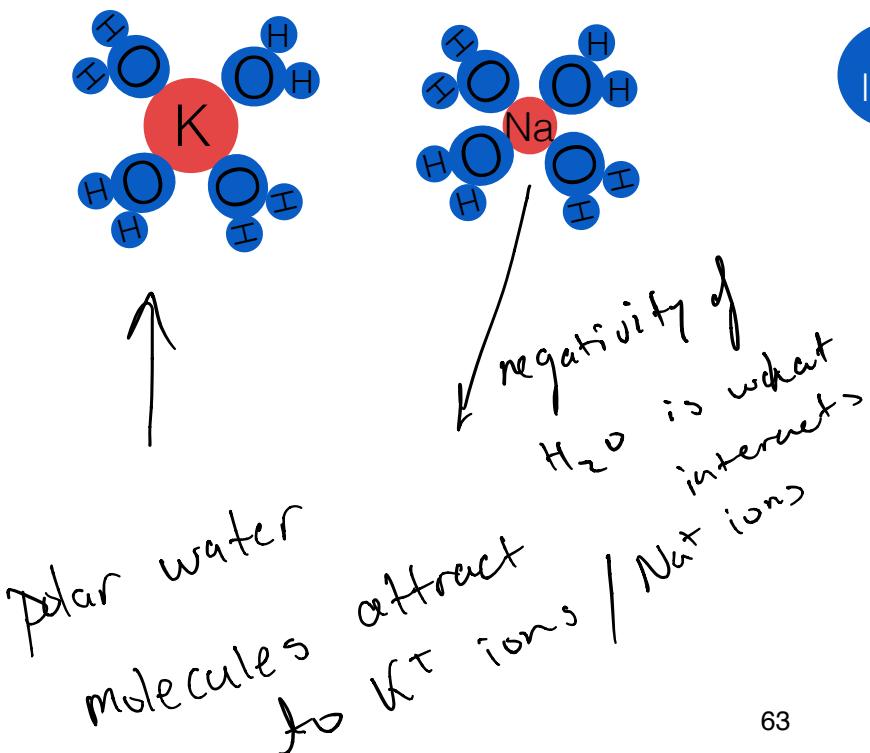


How selective? + versus - easier...charge on selectivity filter

BUT, still 10,000 times more perm to K than Na? How?

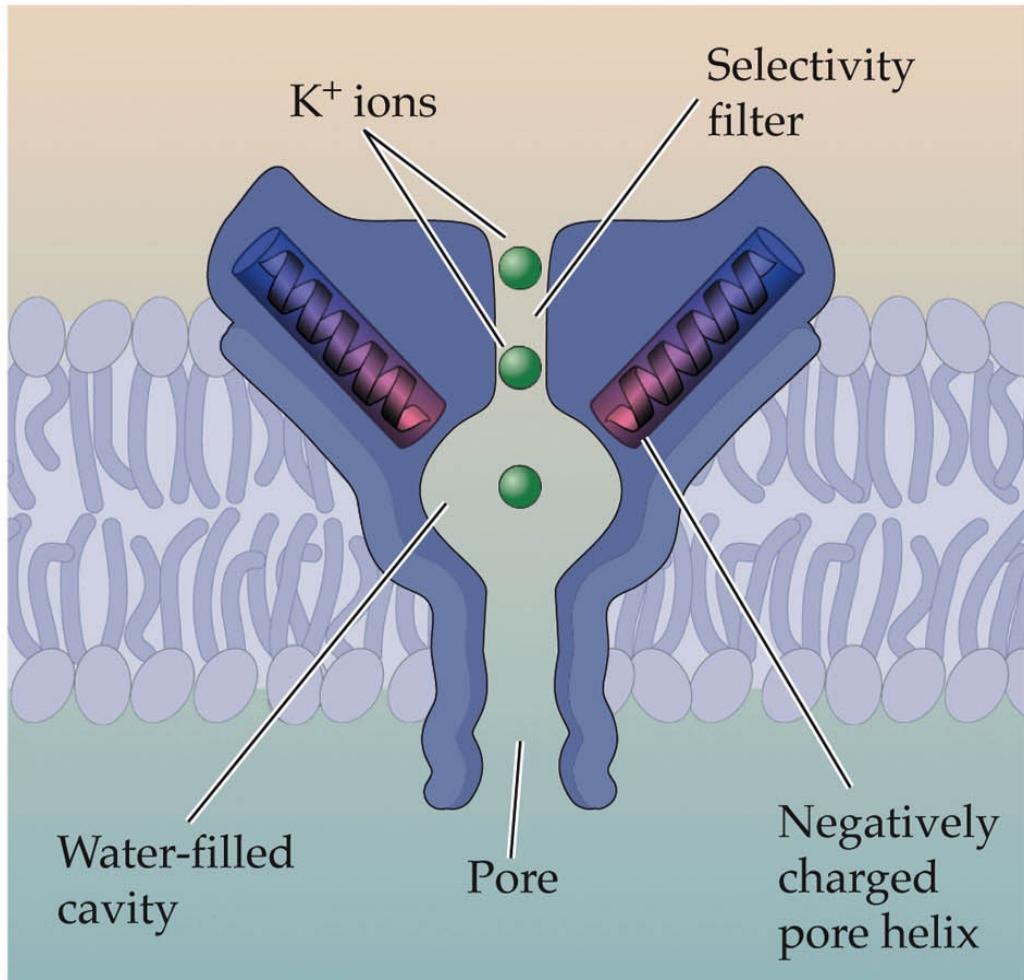
Key: pore loop substitutes for water and K fits!

K 1.33 Ang. Na is .95 Ang?



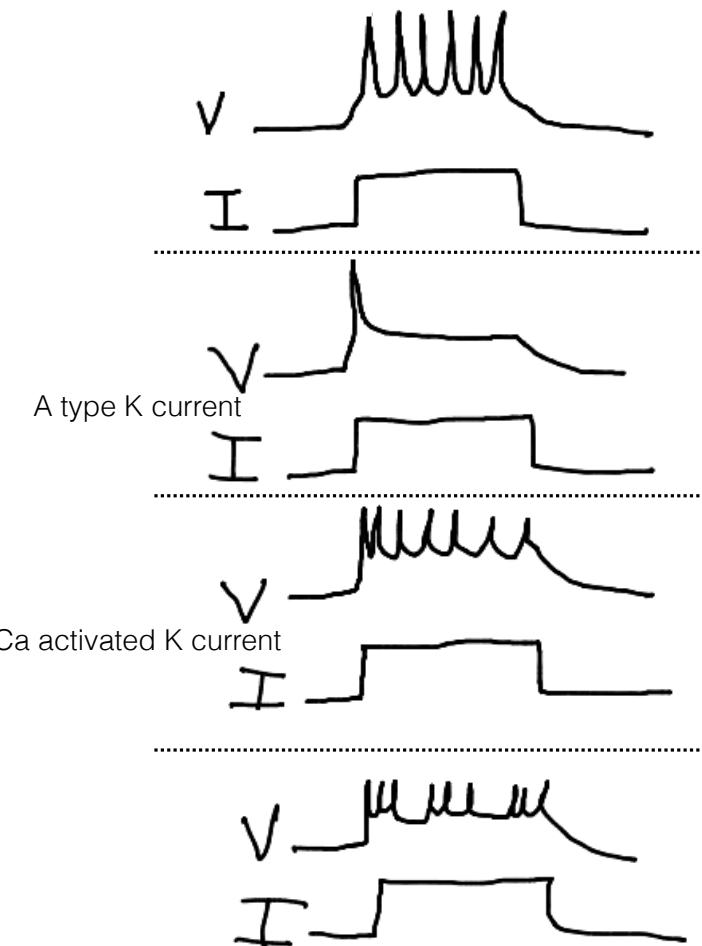
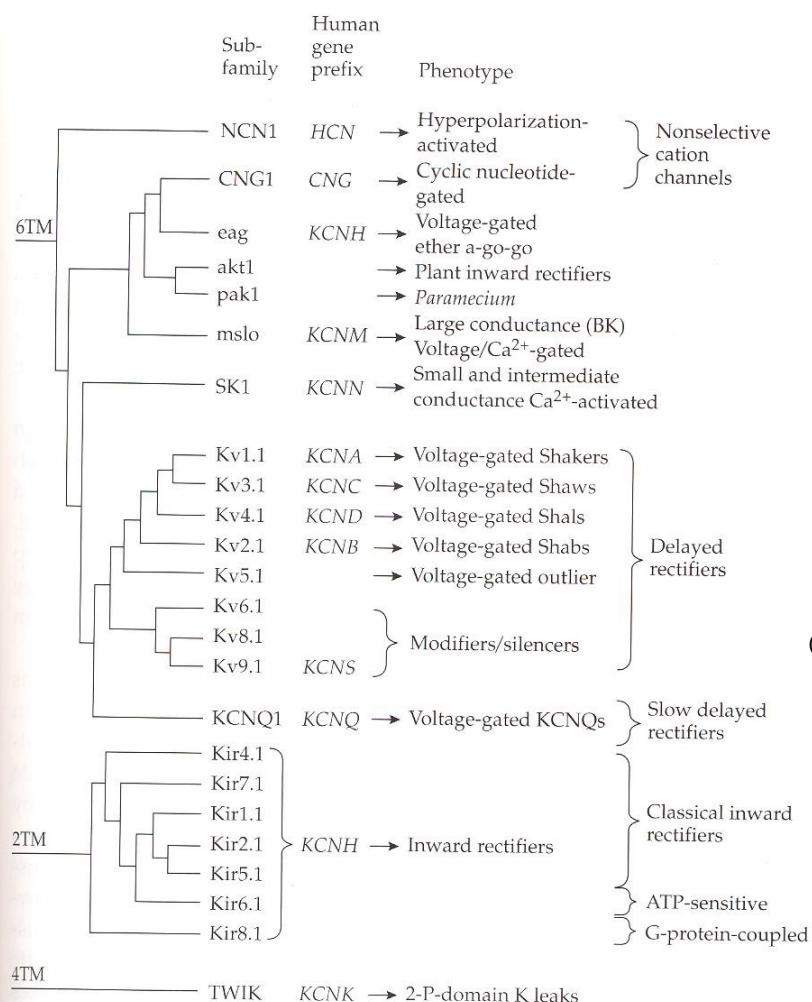
"energetic switch from
water → pore loop attachment"

How do the ions get through so fast?



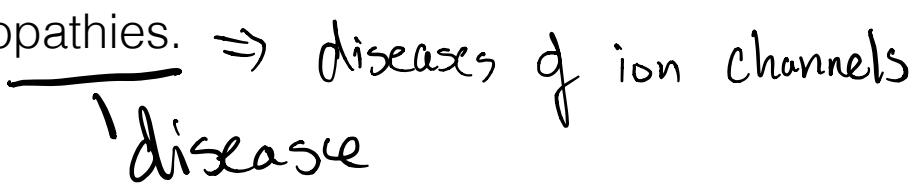
NEUROSCIENCE, Third Edition, Figure 4.8 (Part 2) © 2004 Sinauer Associates, Inc.

Large diversity of ion channels... why?



Key: Channel composition sculpts the firing pattern of neurons

Fetcho Lecture 6 main goals

- Ion channels gone wrong- diseases of ion channels called channelopathies.

diseases of ion channels

Things you should know AT THE END.

- Effects of some toxins and anesthetics on ion channels
- Defects that can lead to channelopathies
- a few examples of disease of ion channels

Toxins/anesthetics:

saxitoxin: dinoflagellates, red tide, Na channel blocker

conotoxins: cone snails, many toxins.. omega cono blocks calcium channel. pain treatment

dendrotoxin: snakes, mambas, blocks K channel, seizures

local anesthetics: tricaine,lidocaine, lipid solubility plug Na channels

Ways channels can go wrong:

Promoter defect: too many, too few

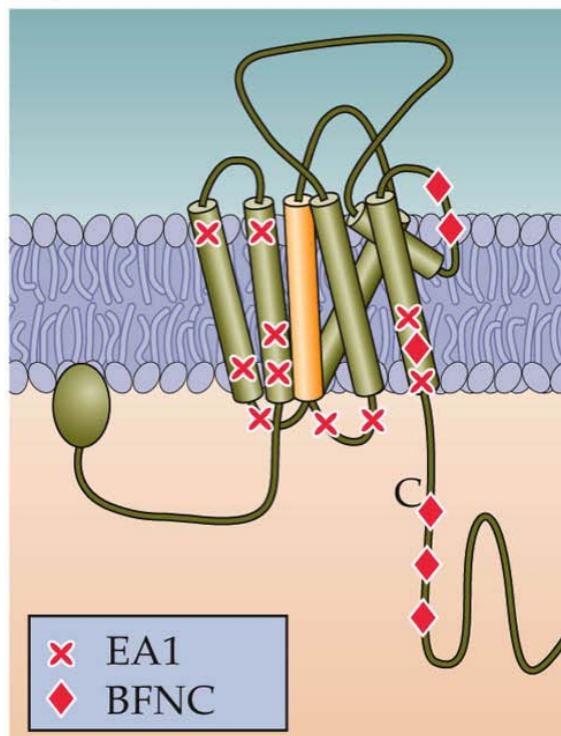
Coding mutations: altered protein

Regulation defects: phosphorylation

Auto-antibodies

Some channelopathies ... mutations in channels that cause disease

(C) K⁺ CHANNEL

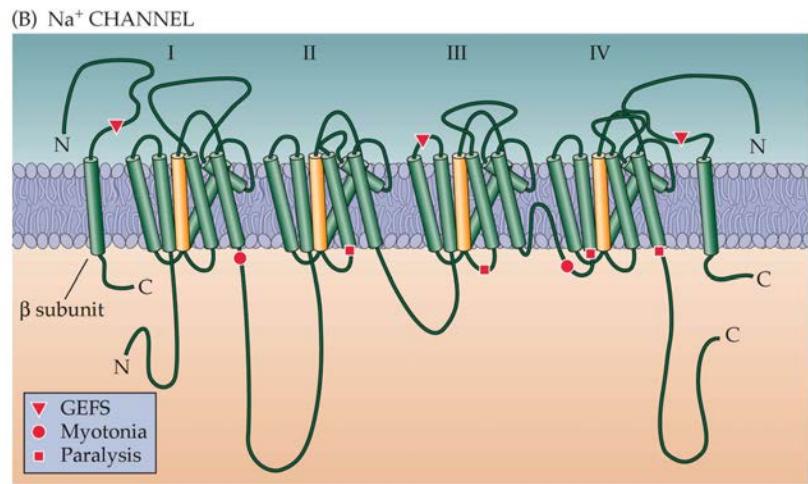


First K channel cloned was Shaker: in flies, K channel in depolarization of AP . shake in ether. prolong AP... lots of release of transmitter.

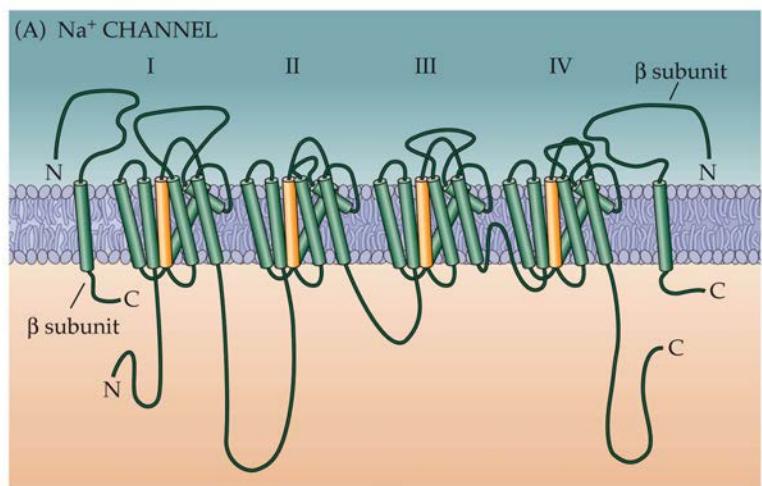
Like Human episodic ataxia (EA1): balance, coordination, spontaneous muscle contractions... autosomal dominant

elevated potassium

Equine Hyperkalemic periodic paralysis: horse, alfalfa... 1/50 quarter horses, from one called Impressive single AA in inactivation region. Triggered by high K, depolarizes opens sodium channels but Na does not inactivate right.

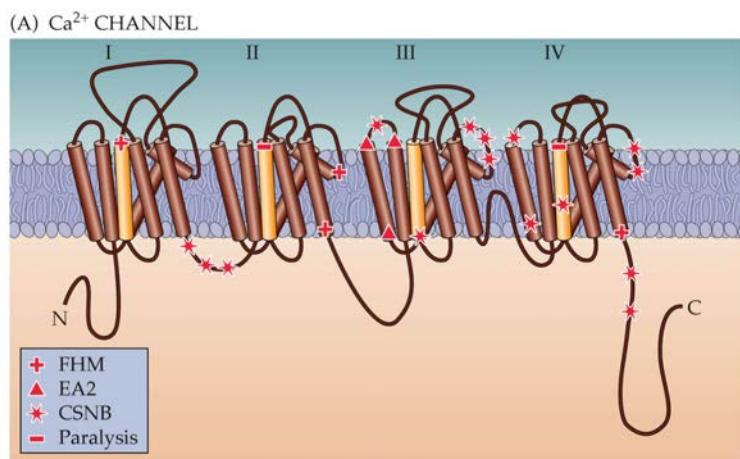


Like Human Hyperkalemic periodic paralysis: muscle stiffness, weakness, paralysis.... triggered by high K. bananas. Na channel inactivation



Febrile seizures and generalized epilepsy: beta subunit that normally speeds up Na channel inactivation. so less inactivation. Hyperexcitable.

NEUROSCIENCE, Third Edition, Figure 4.6 (Part 1) © 2004 Sinauer Associates, Inc.



Familial hemiplegic migraine (FHM): 1-3 days long migraines, with aura, vomiting, light sensitivity... in pore and other places of Ca^{++} channel