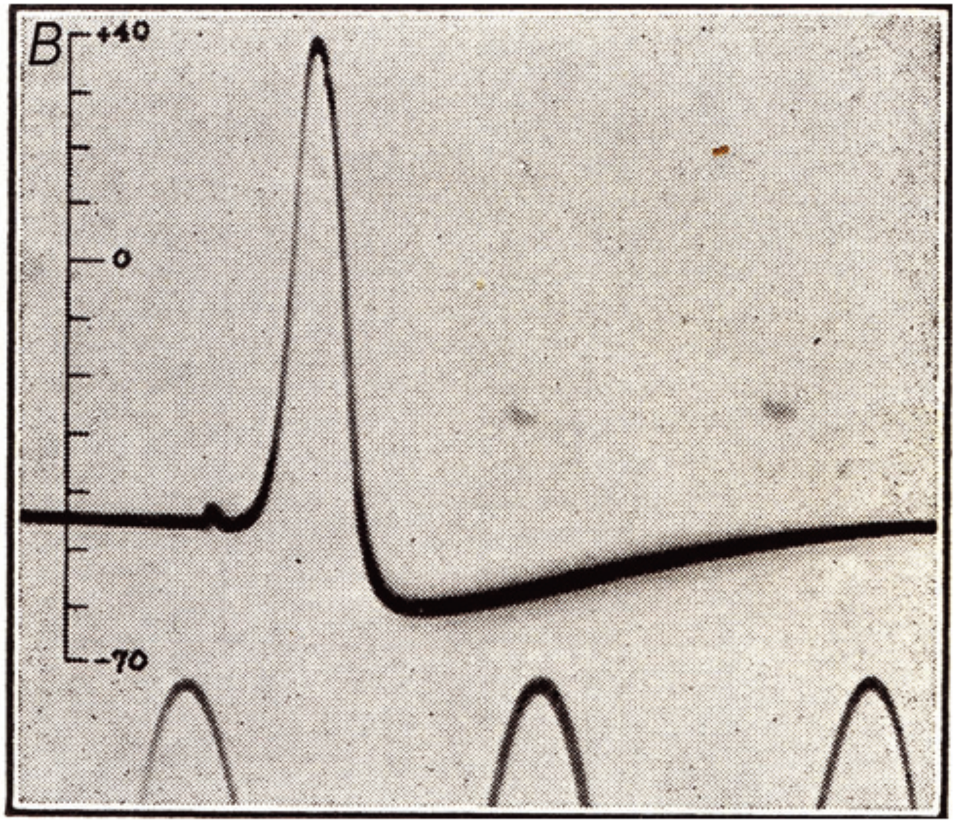
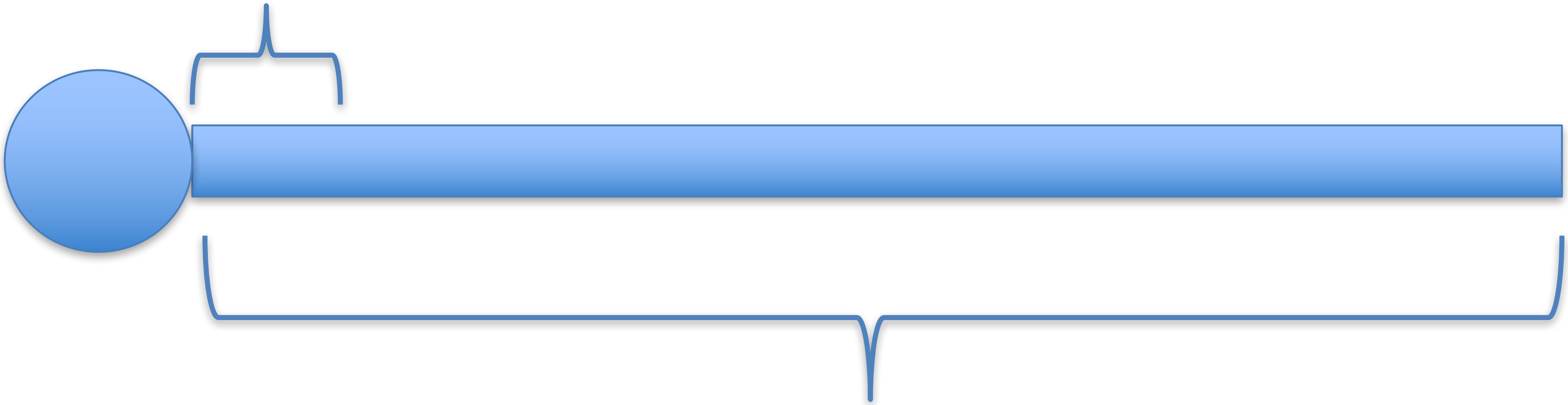
The Hodgkin-Huxley Model

The Action Potential is the Fundamental Unit of Neuronal Information



First recording of a neuronal action potential. From Hodgkin & Huxley (1945)

Why Use Action Potential Instead of Passive Electrodiffusion of Ions?



$\lambda = 5$ mm = length of battery terminal

Squid
giant
axon

50 mm = length of 9 volt battery

Depolarization of the soma due to synaptic input at dendrites will extend about one length constant λ, never reaching the end of the axon.

The Pioneers of Modern Neuroscience

Andrew Huxley
(1917-2012)

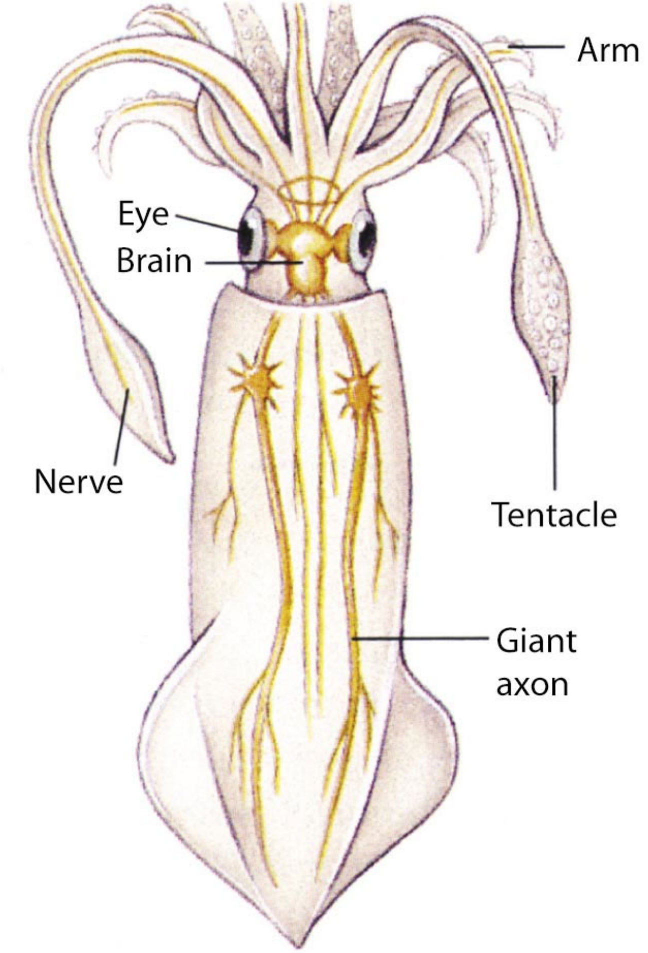
NERVE-CELL ENIGMA SOLVED

The British scientists, A. L. Hodgkin and A. F. Huxley, experimenting with the nerve fibers of squids and lobsters.

Alan Hodgkin
(1914-1998)

The cover of the 1963 Nobel Prize program

Squid Giant Axon



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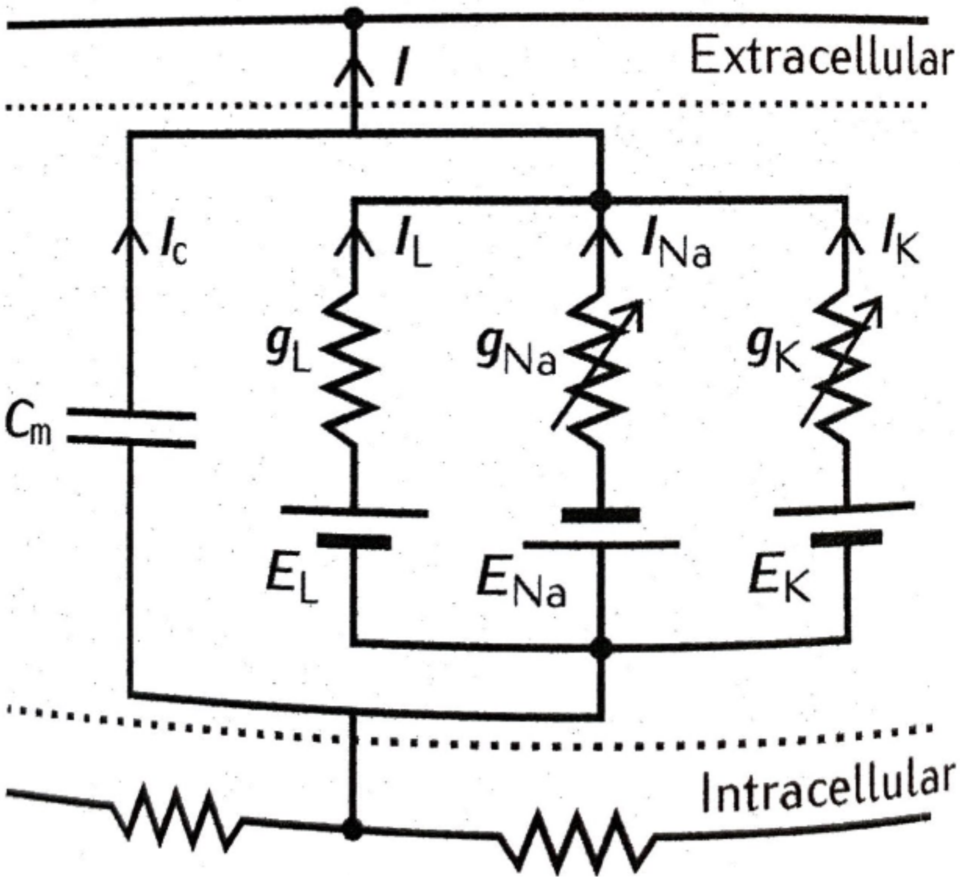
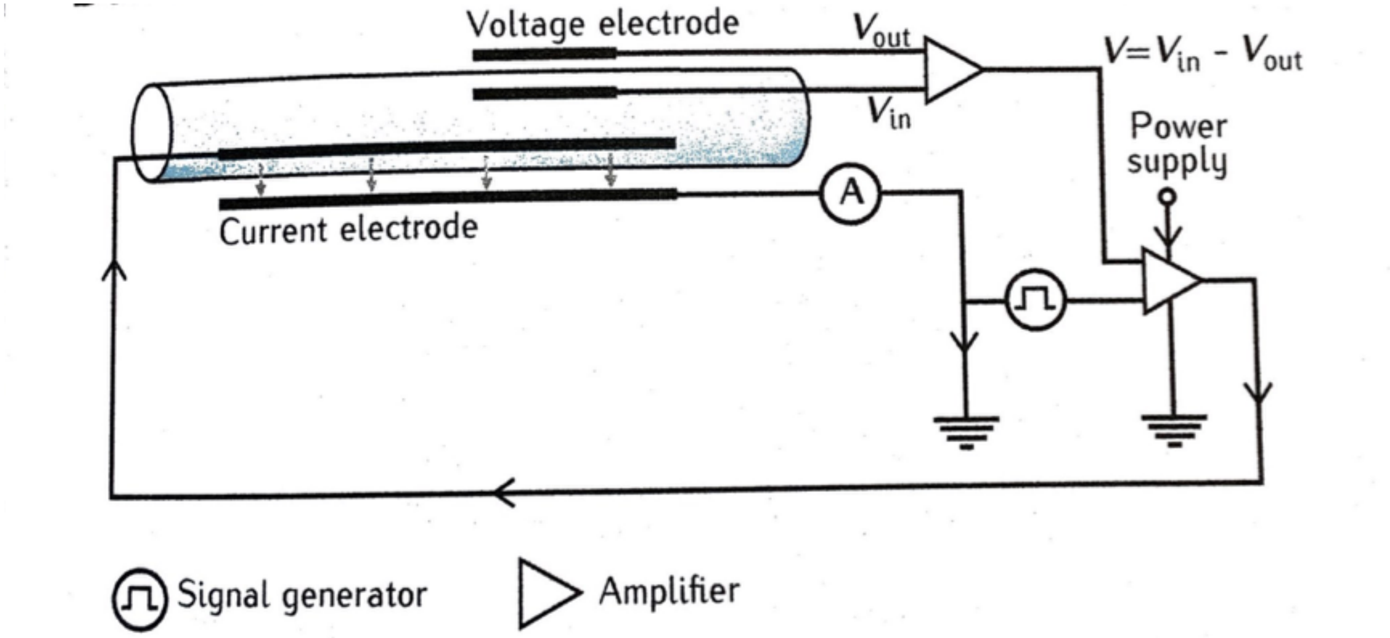
The Giant Squid Axon Has Only 3 Ionic Currents



The Na^+ and K^+ conductances are rectifying; they vary with the membrane potential

HH Used Voltage Clamp and Space Clamp to Investigate the Ionic Currents

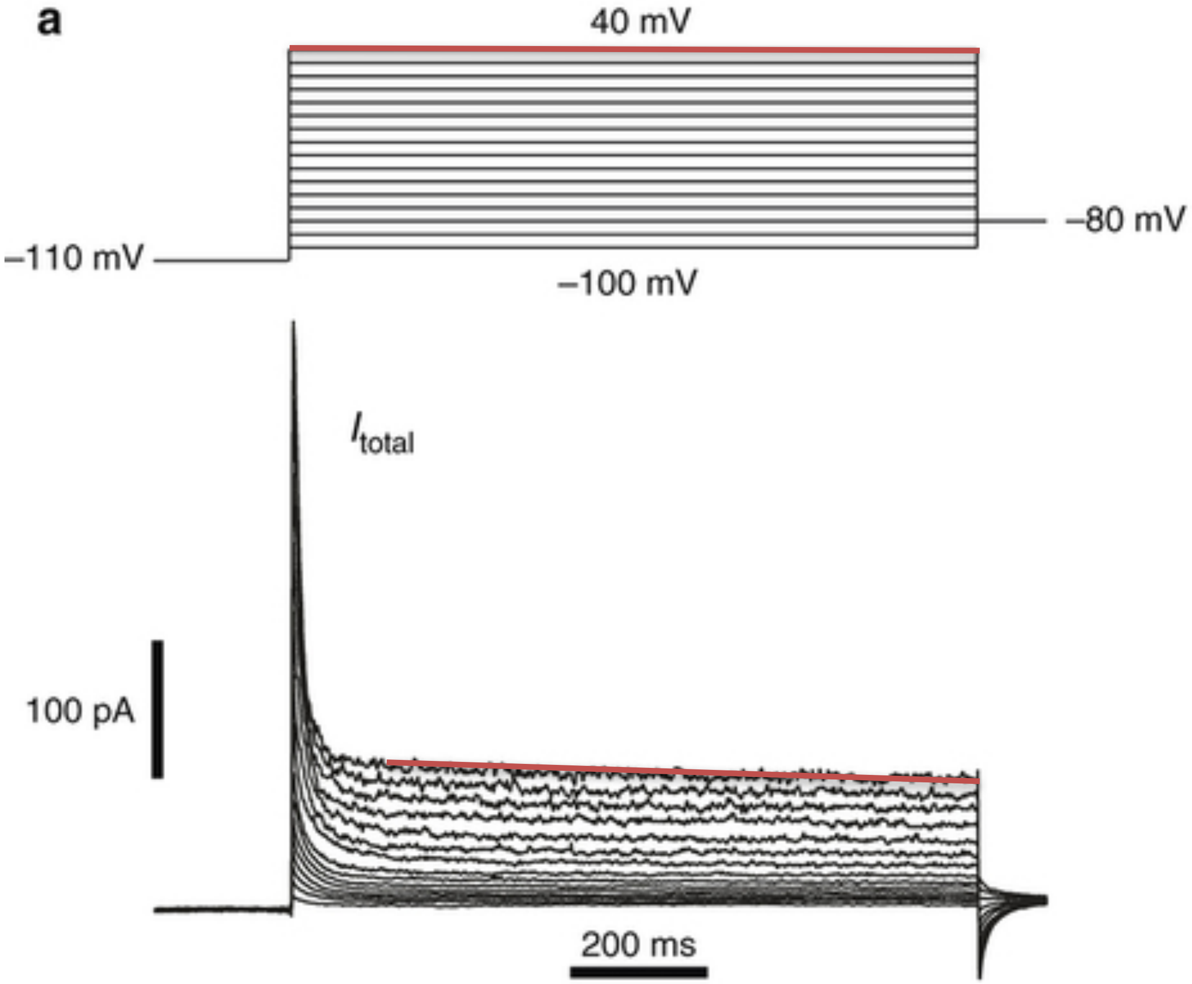


Current clamp: Apply current and measure the change in voltage.
Voltage clamp: Keep the membrane potential constant, so there is no capacitive current. Only the ionic current remains, and this is what you measure.
Space clamp: Maintains a uniform voltage throughout the axon segment. There is no net electrodiffusion of charge through the axon.

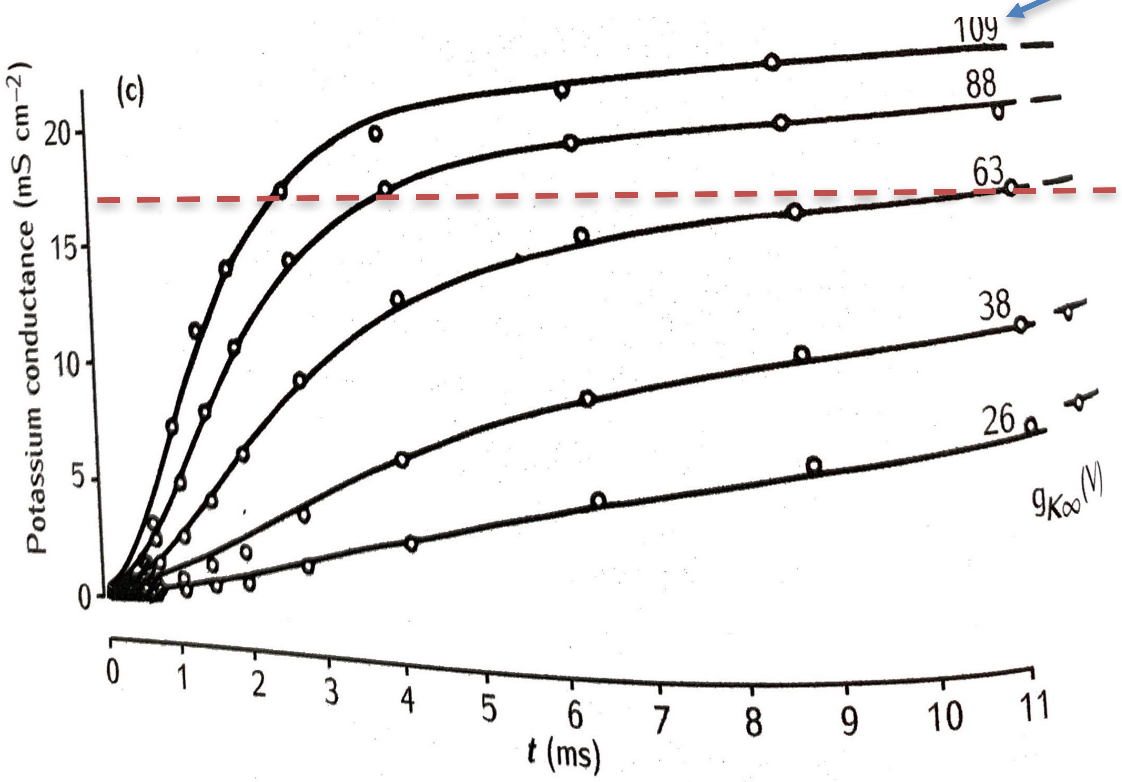
An Example of Voltage Clamp Recordings

Apply voltage pulses

Measure current



K$^+$ Channel Conductance from Voltage Clamp Recordings



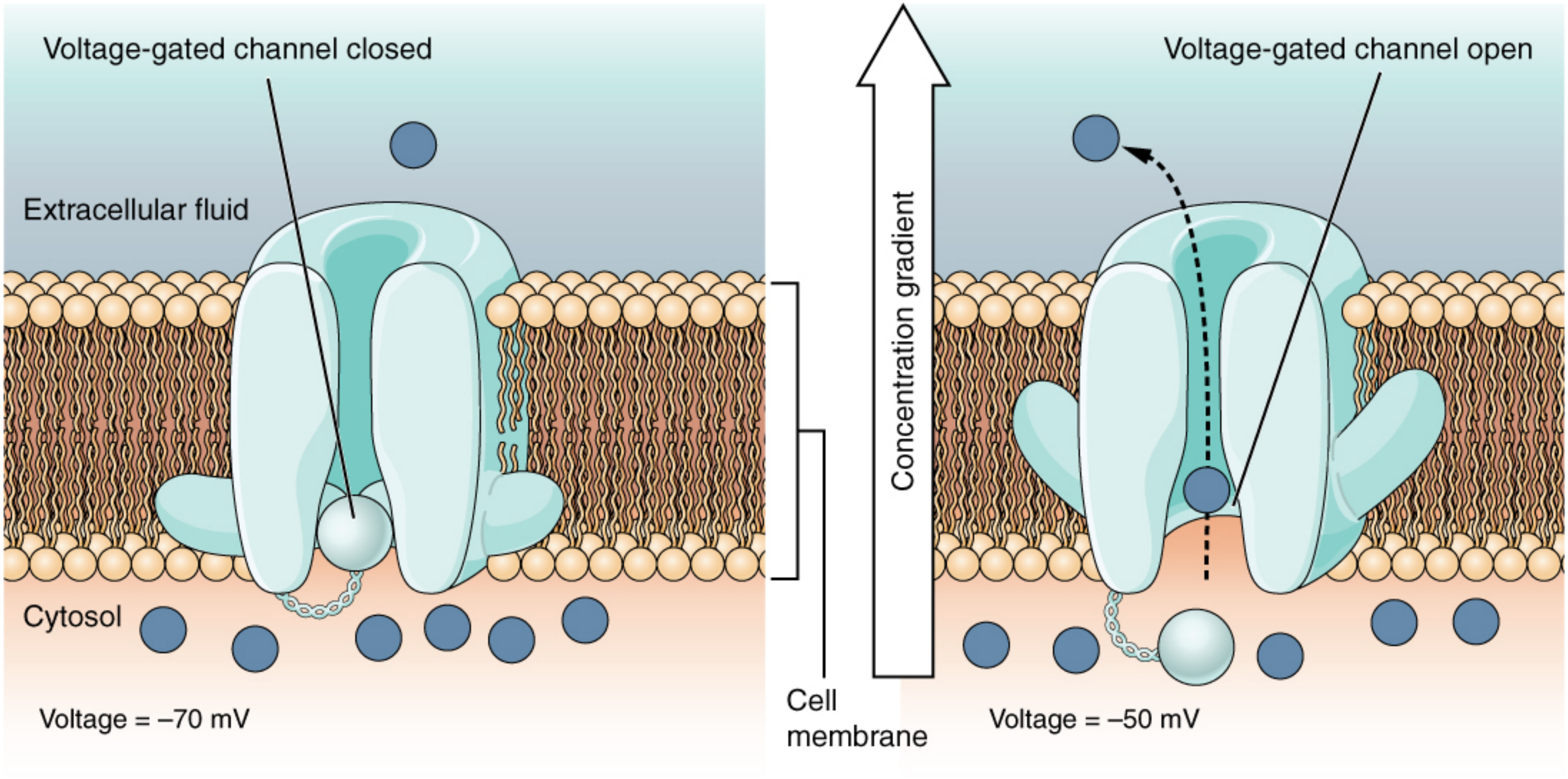
Test potential

Max conductance
when V=63 mV
above resting potential

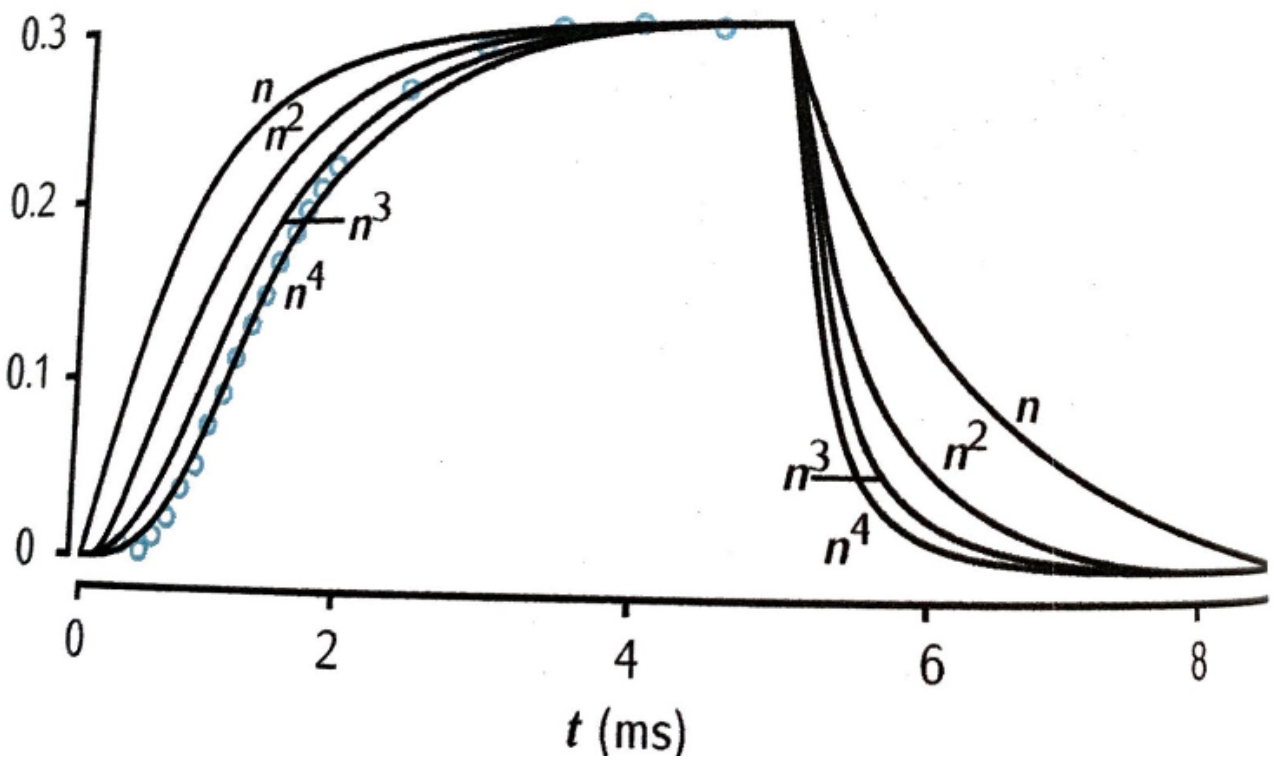
Sodium ions have been replaced by choline, which does not flow through ion channels. Conductance of K$^+$ measured by dividing current by driving force.

Both the equilibrium conductance and the rate of approach depend on the test potential.

Illustration of Voltage-Dependent Channel Opening

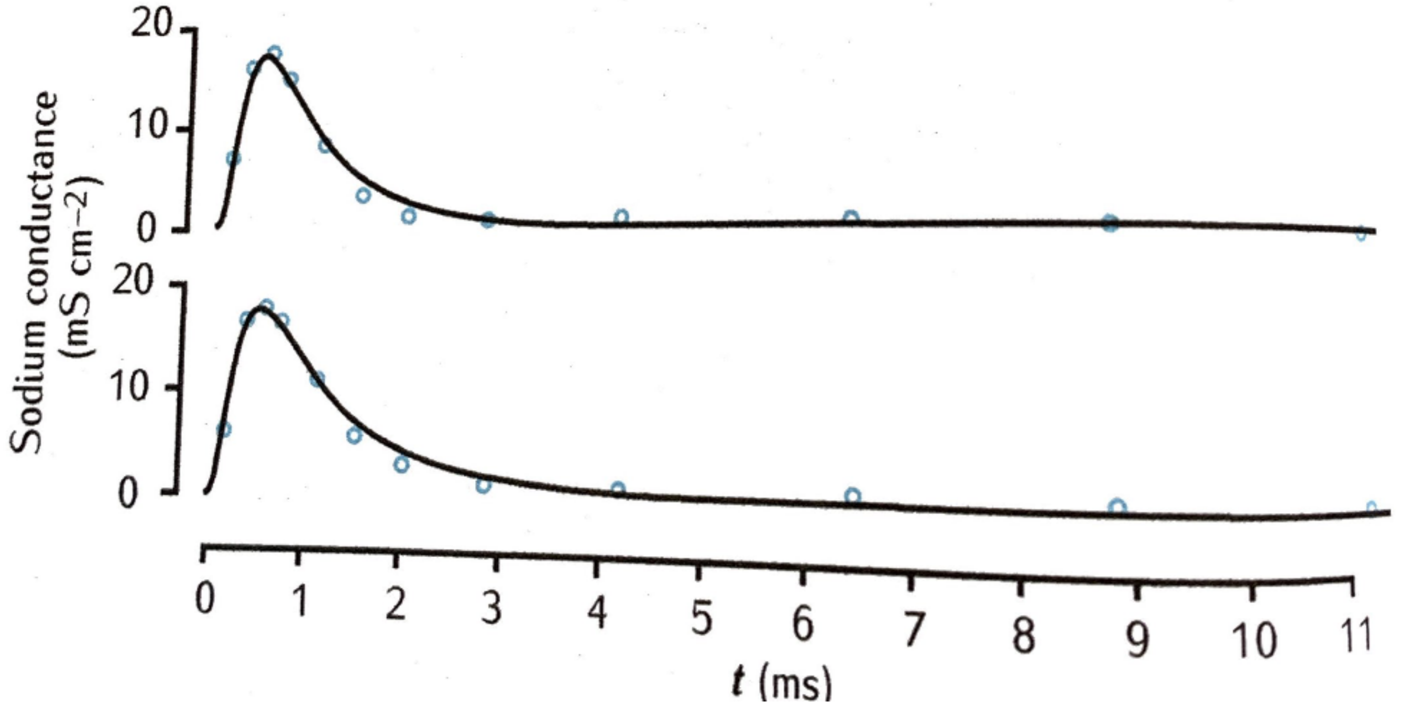


Fitting the Activation Data



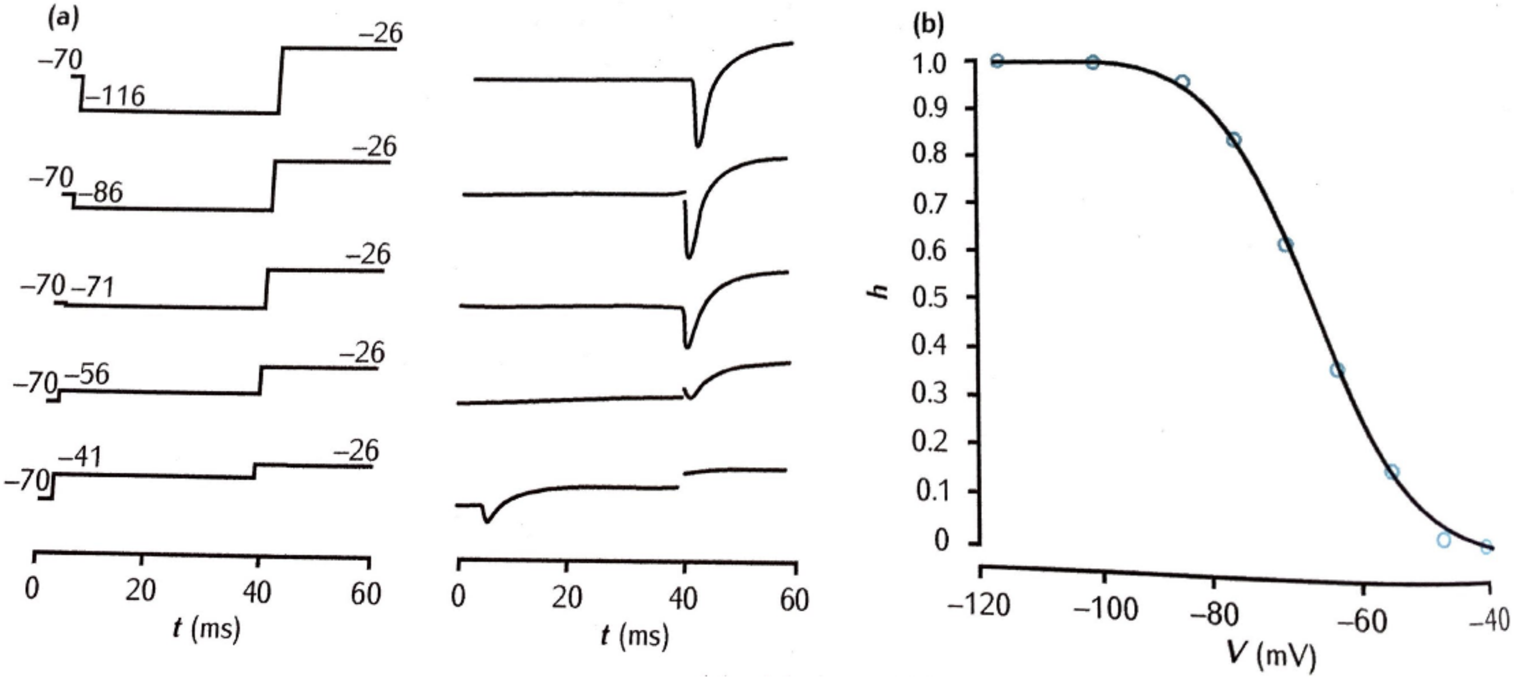
The variable *n* raised to a power exhibits inflection near t=0, matching the data (circles).

Na^{2+} Conductance Exhibits Inactivation



Response to a step change in voltage from rest to 76 mV (top) and 88 mV (bottom) above resting potential. Data (circles) are fit with curves (solid).

Two-Pulse Protocol for Determining Steady-State Inactivation Curve



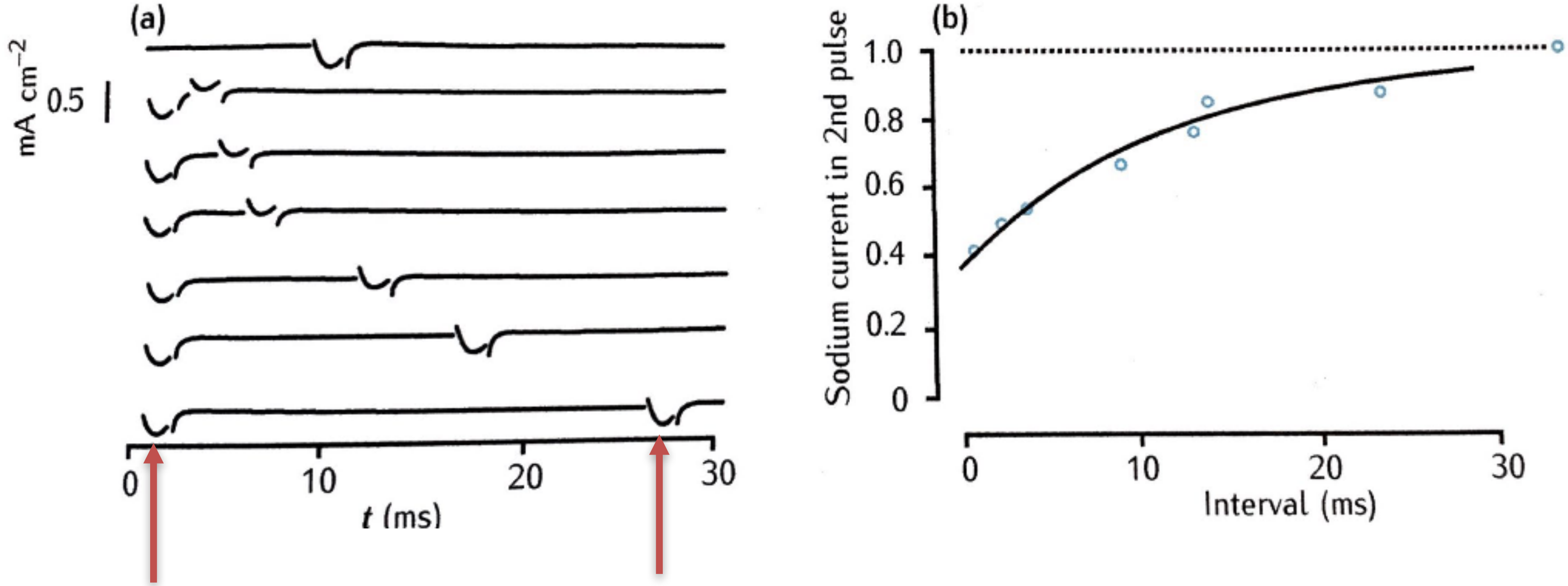
Voltage clamp

Na$^+$ current

Steady-state inactivation

h = fraction of Na$^+$ channels that are not inactivated. Can also be thought of as probability that a Na$^+$ channel is not inactivated.

Two-Pulse Protocol for Determining Inactivation Time Constant

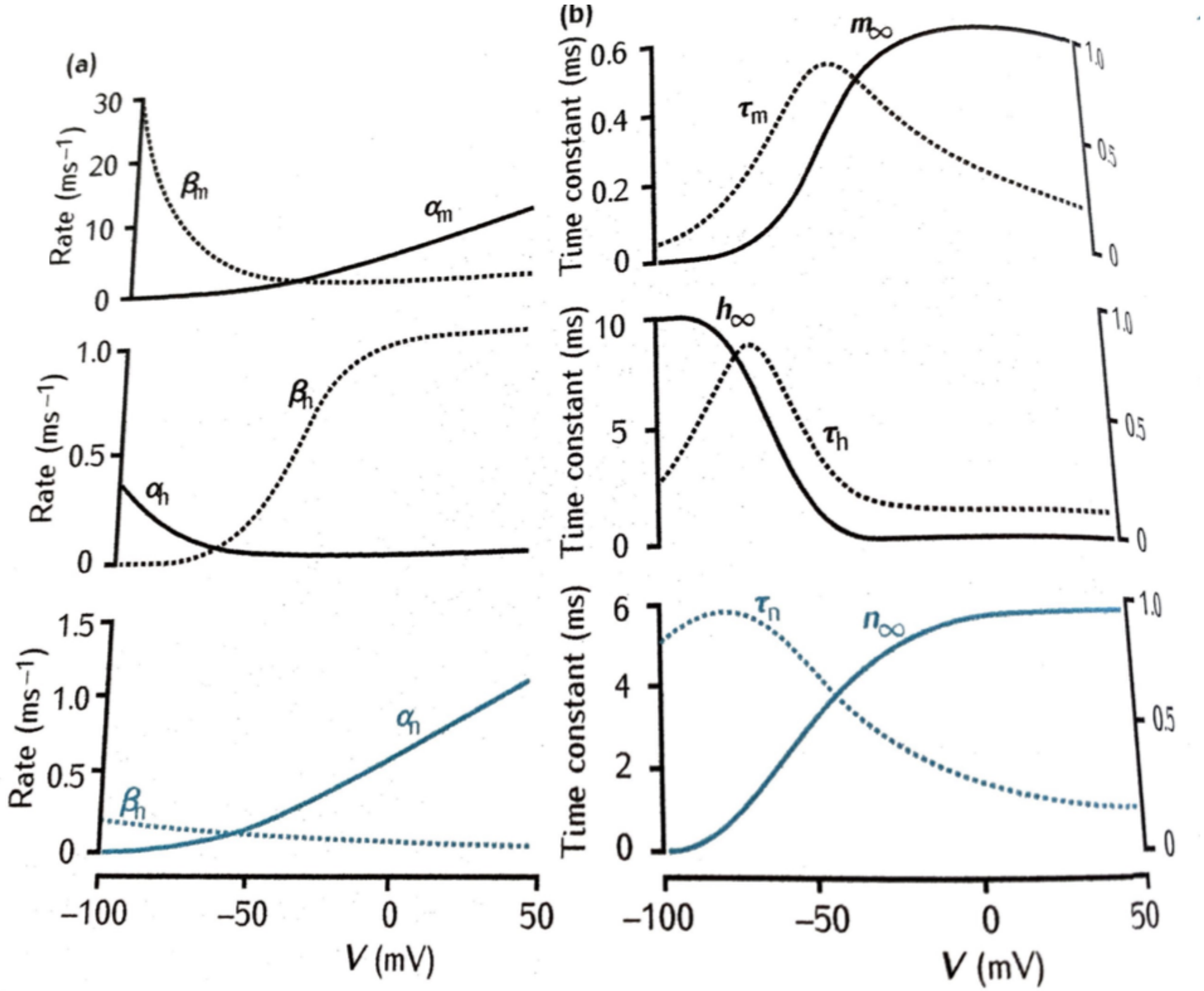


Two depolarizing V pulses are given. The response to the second is typically smaller due to inactivation. (Right panel) Ratio of the amplitude of second response to the first.

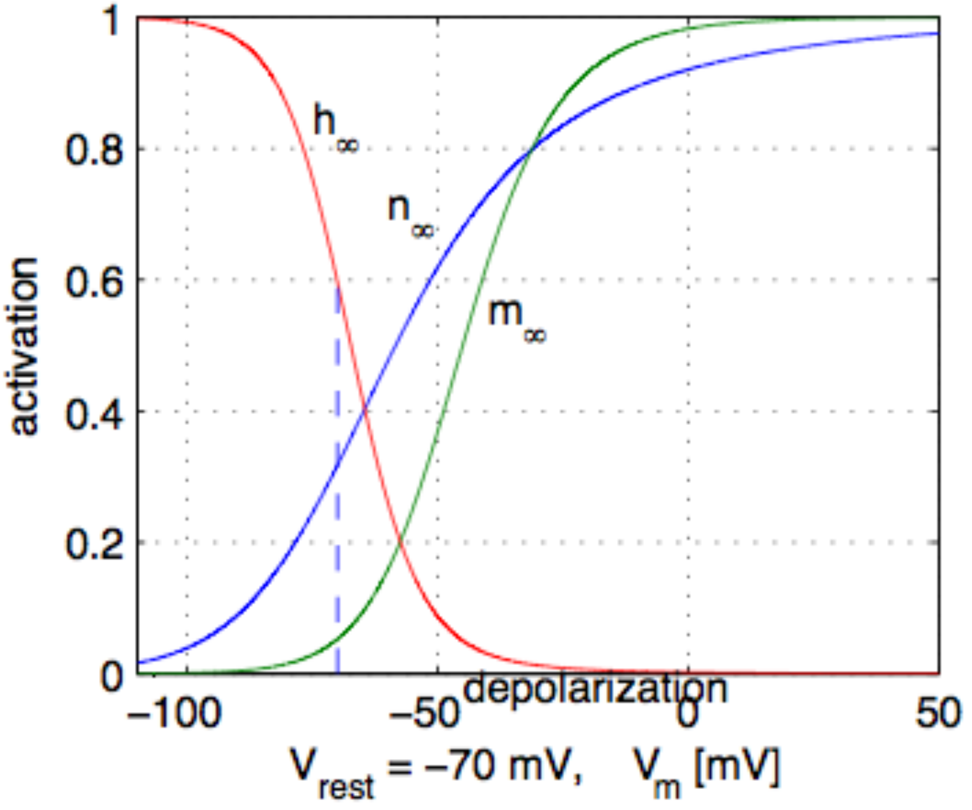
Summary of Rate Coefficients, Activation Functions, and Time Constants

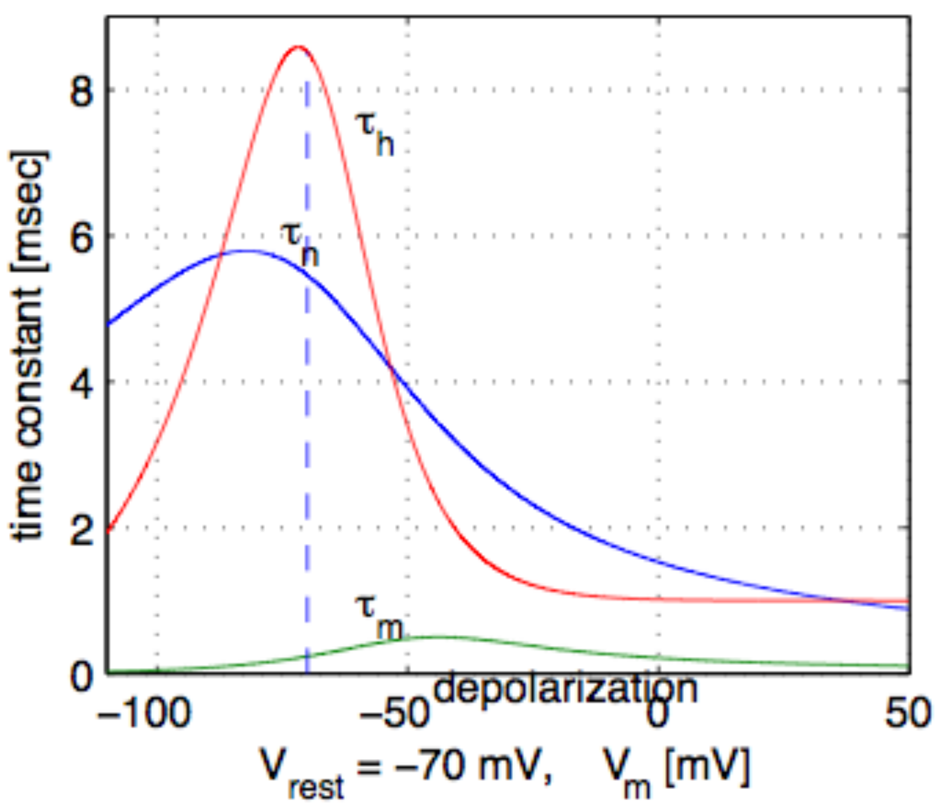
Na^+ channels

K^+ channels



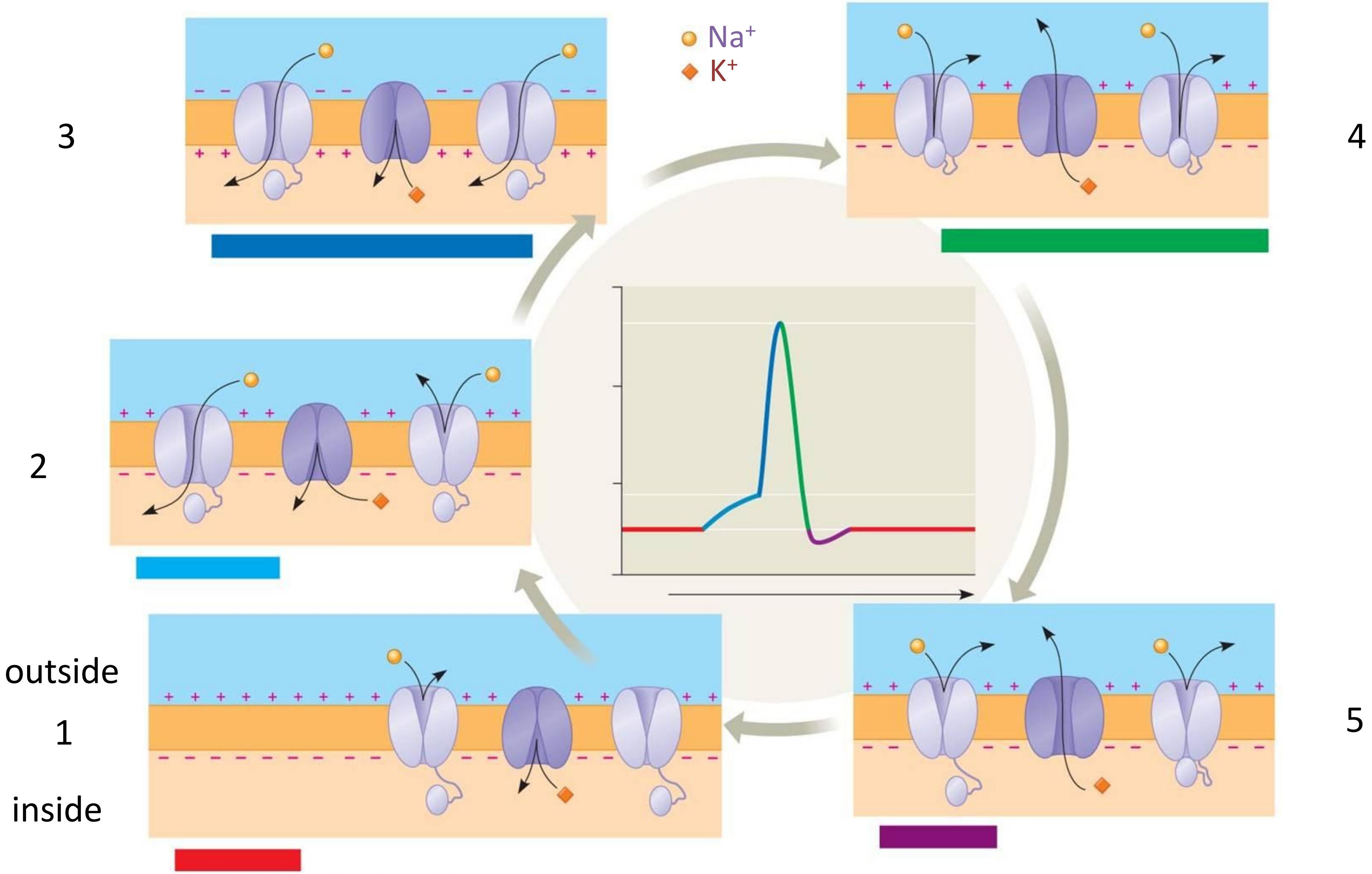
Infinity Function and Time Constant Comparisons





n: K^+ activation
m: Na^+ activation
h: Na^+ inactivation

Sequential Opening and Closing of Different Ion Channels Drives the Impulse



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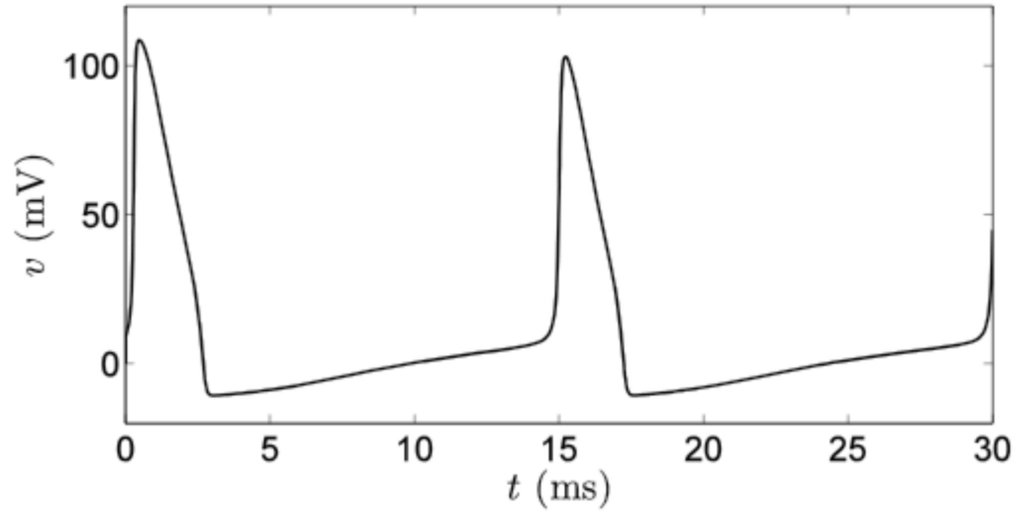
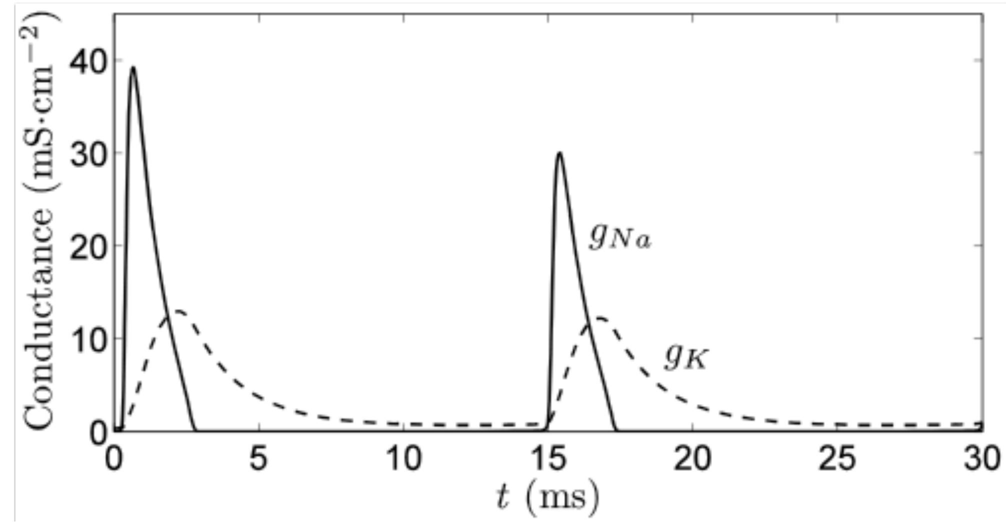
Electrical Impulses From Hodgkin-Huxley Model

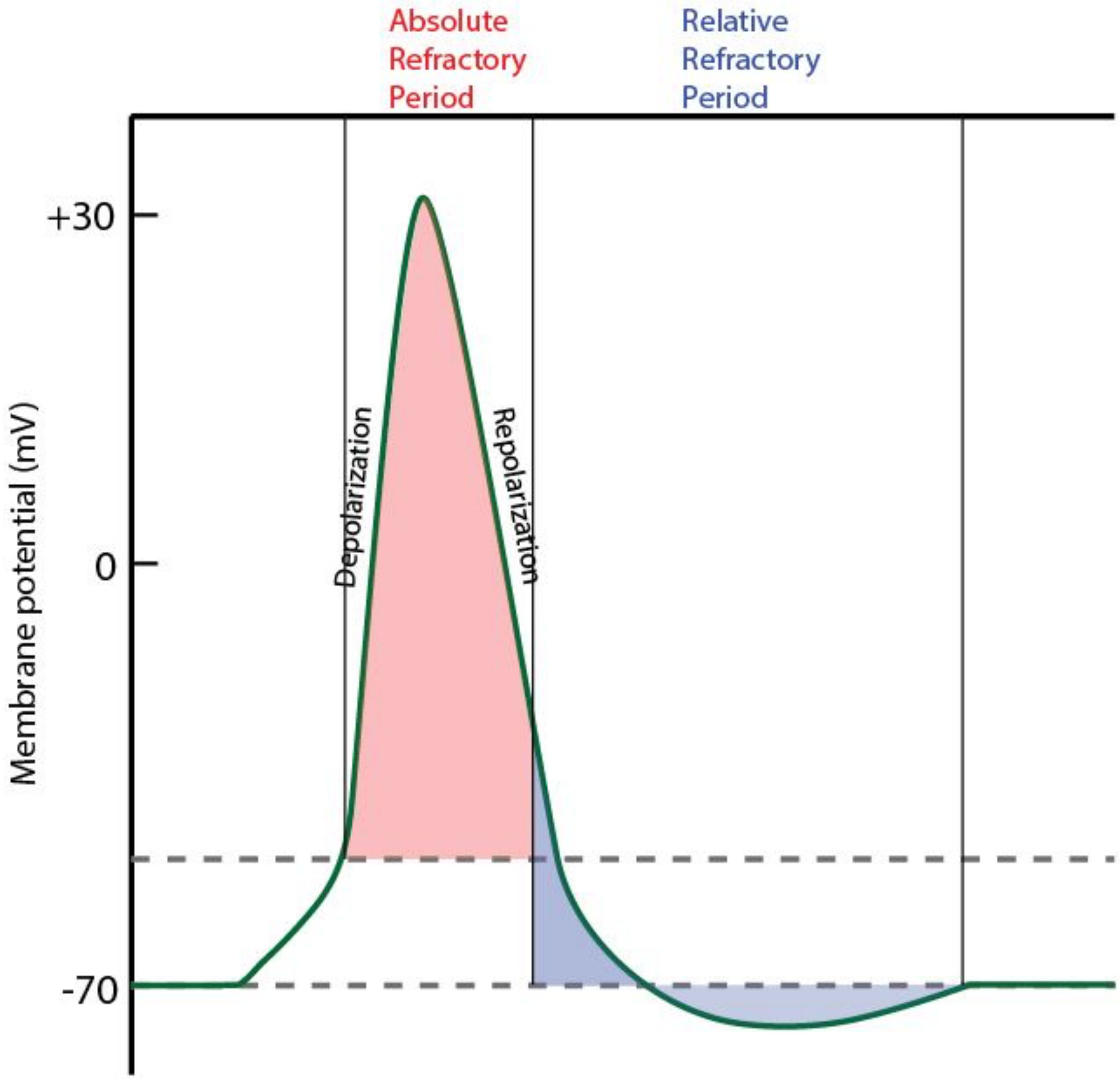
v=0 is the resting potential



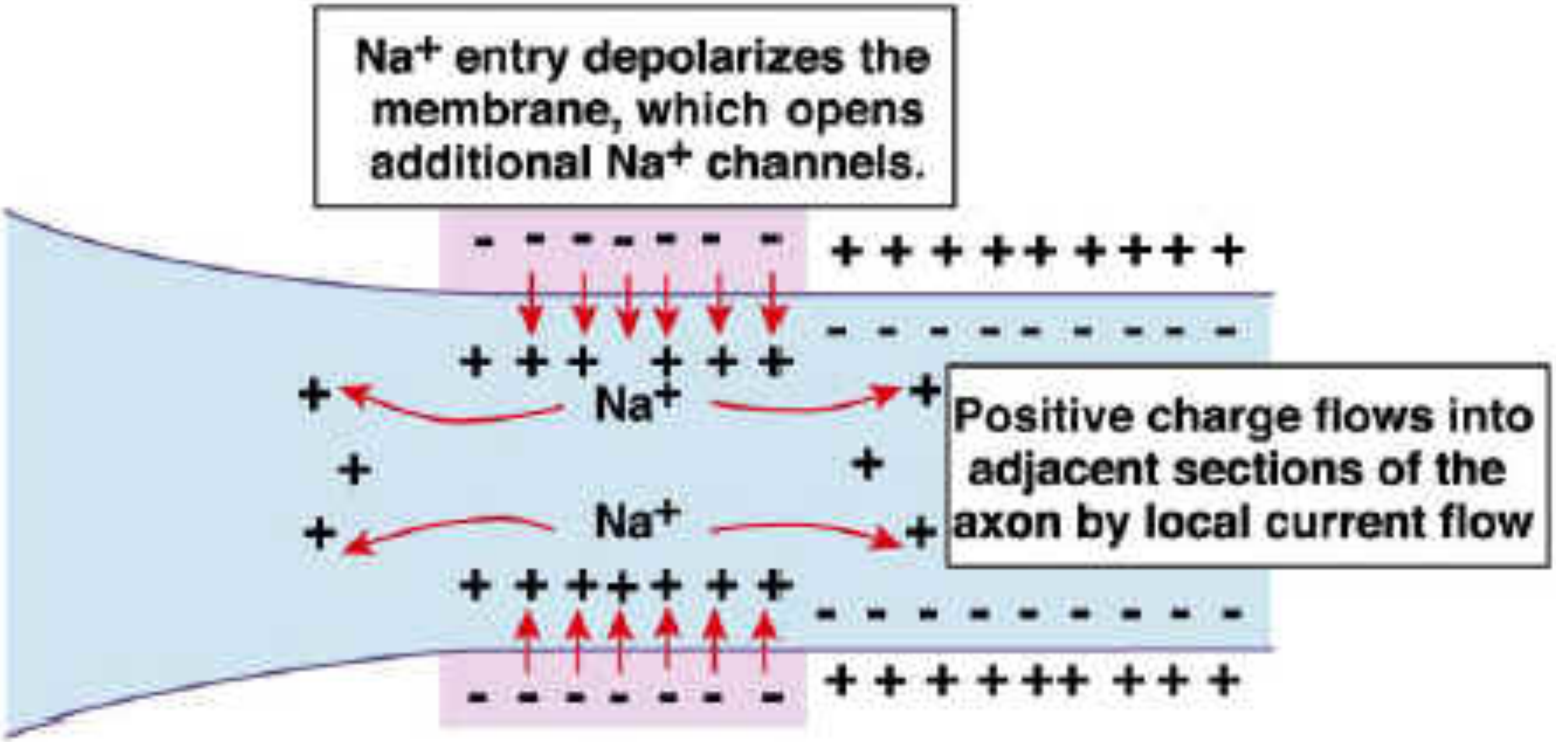


Increase in Na$^+$ conductance causes AP upstroke; decline in Na$^+$ conductance and increase in K$^+$ conductance causes AP downstroke.

Absolute and Relative Refractory Periods



Impulses Travel Into Adjacent Portions of the Cell


Na^+ entry depolarizes the membrane, which opens additional Na^+ channels.

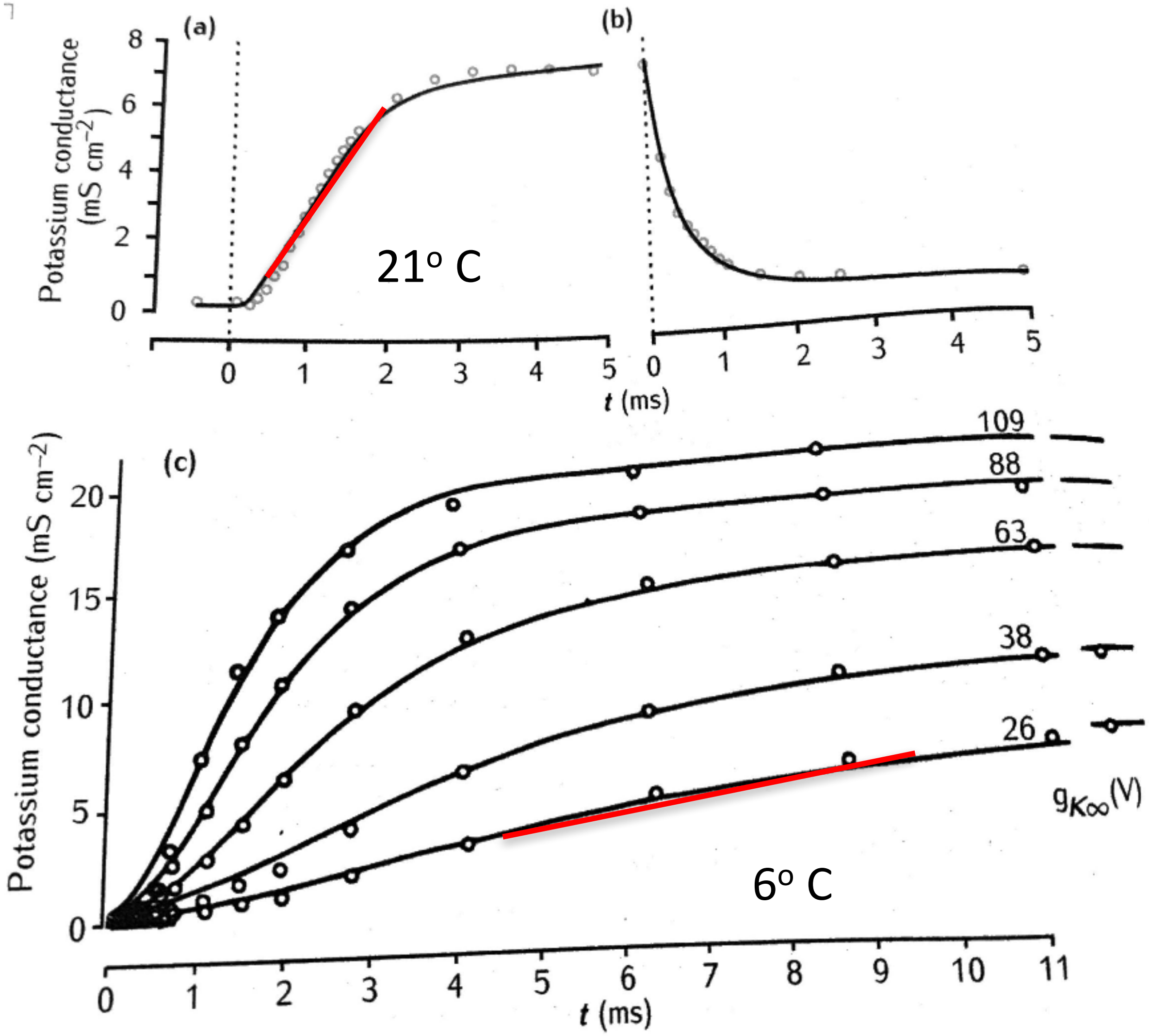
Positive charge flows into adjacent sections of the axon by local current flow

The positive charge flow is modeled by the diffusion term in the Hodgkin-Huxley cable equation

Action Potential Propagation Video

https://youtu.be/Sa1wM750Rvs

Temperature Affects Speed of Channel Activation



Voltage clamp recordings from the squid giant axon at two different temperatures