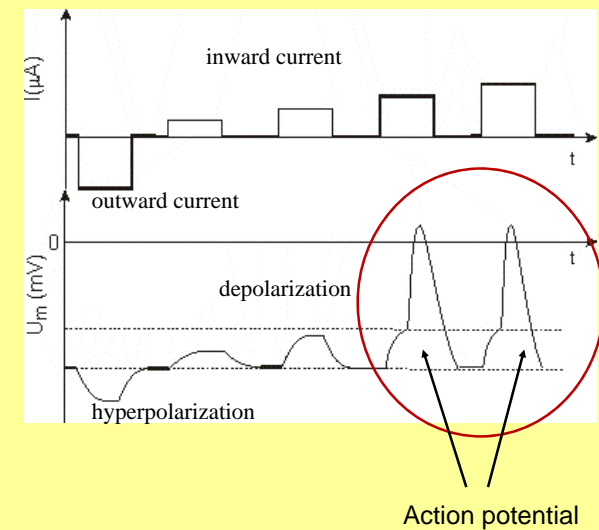


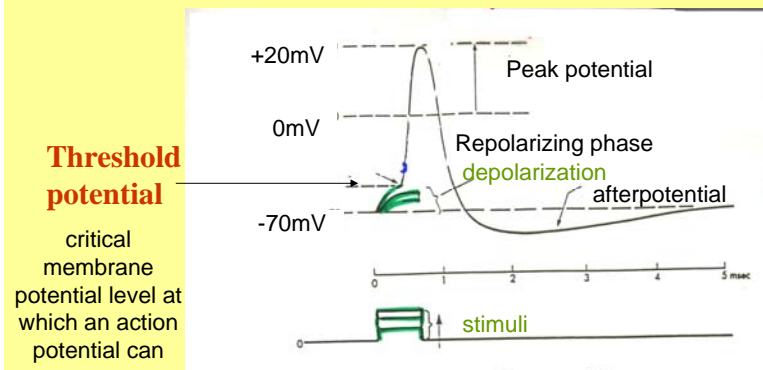
Alteration of resting membrane potential

2. “active” electric properties of the membrane in excited state

Observation



Phases and landmark of the action potential



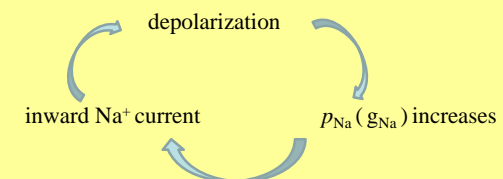
Threshold potential
critical membrane potential level at which an action potential can occur

facultative
“All-or-none” amplitude
conducted with constant amplitude

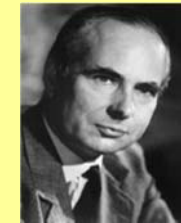
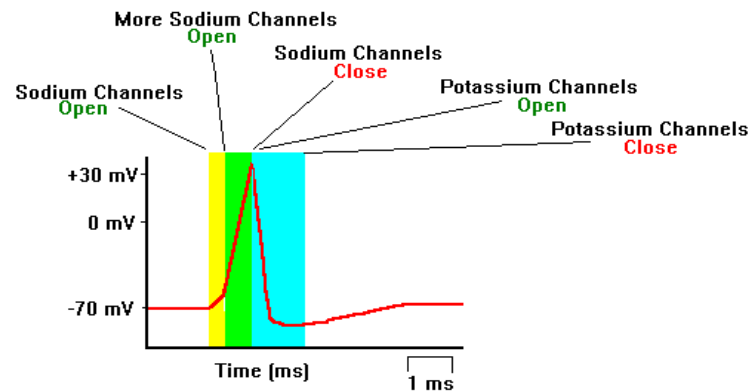
Hodgkin-Katz hypothesis of action potential generation

Voltage-gated, potential sensitive ion channels

$$\varphi_e - \varphi_i = -\frac{RT}{F} \ln \frac{\sum p_k^+ c_{ke}^+ + \sum p_k^- c_{ki}^-}{\sum p_k^+ c_{ki}^+ + \sum p_k^- c_{ke}^-}$$



Hodgkin-Katz hypothesis of action potential sequence



Andrew Fielding Huxley
(1917-)

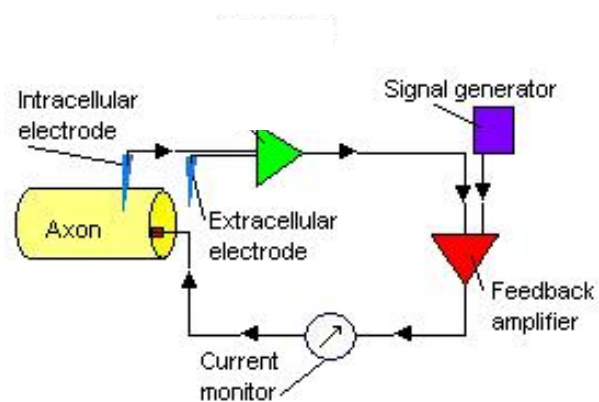


Alan Lloyd Hodgkin
(1914-1998)

The Nobel Prize in Physiology or Medicine
1963

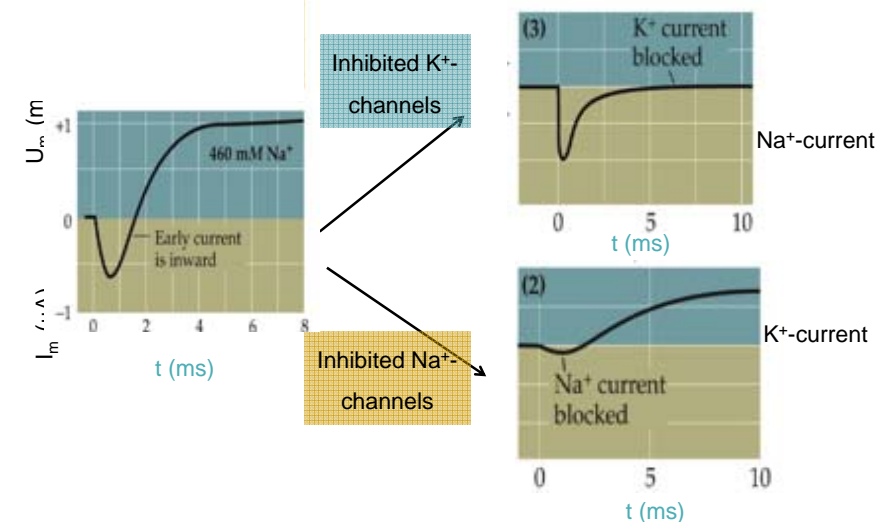
“for their discoveries concerning the ionic mechanisms involved in excitation and inhibition in the peripheral and central portions of the nerve cell membrane”

Voltage Clamp



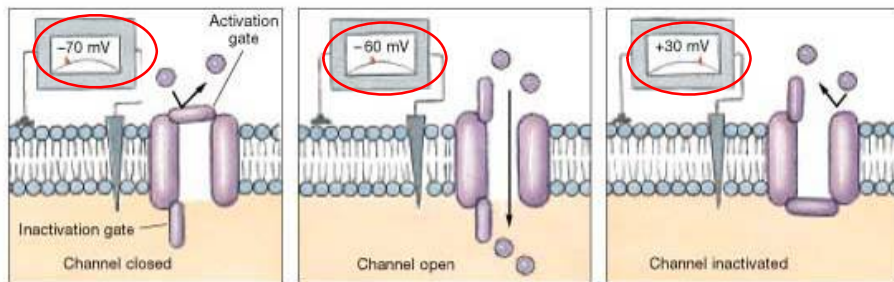
- Membrane potential is stabilized
- Ionic current is measured

Measurement of separated ionic currents



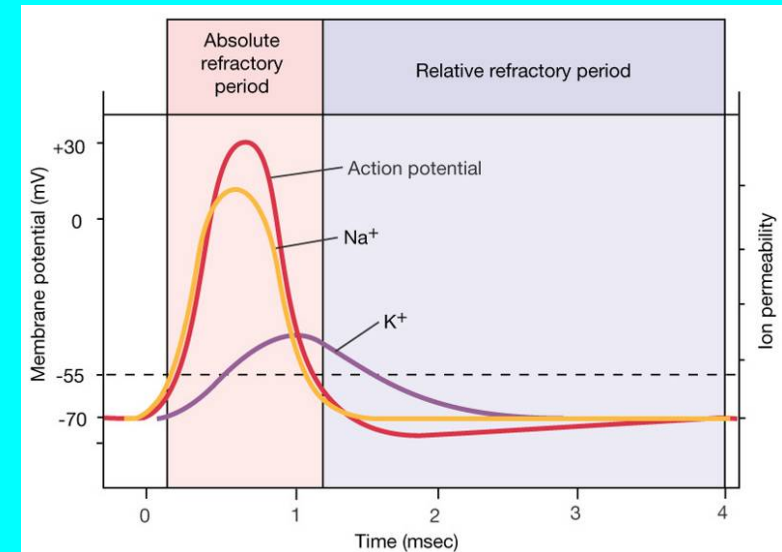
Voltage-Gated Na^+ and K^+ Channels

States of voltage-gated sodium channels



(c)
↑
at depolarization threshold

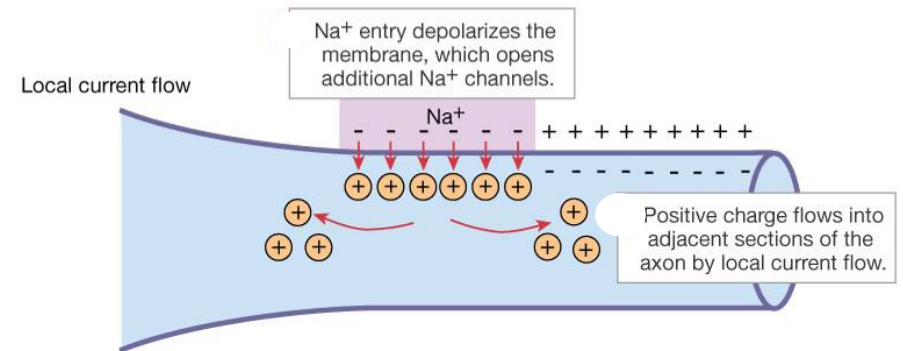
Conductivities during action potential



Factors Influencing Conduction Direction and Velocity

The evolutionary need for the fast and efficient transduction of electrical signals

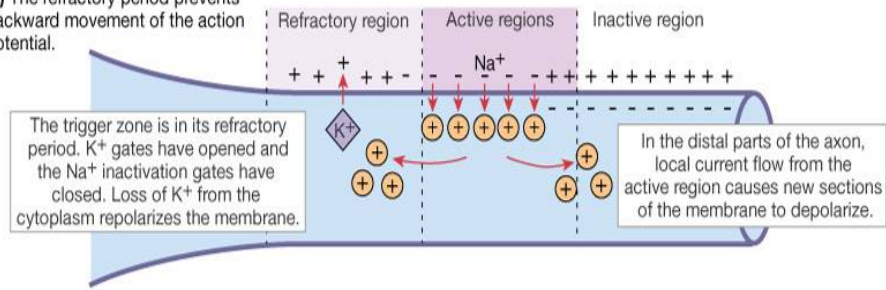
Propagation of action potential (1)



based on local current flow and depolarization of adjacent membrane area

Propagation of action potential (2)

(c) The refractory period prevents backward movement of the action potential.

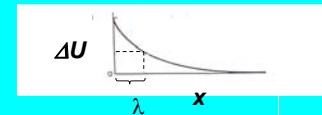


Speed and distance of propagation?

How are the **time constant** and the **space constant** related to propagation velocity of action potentials

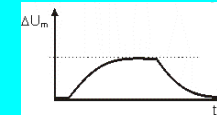
Generation of the next peak potential

Where?



The greater the space constant, the more rapidly distant regions will be brought to threshold and the more rapid will be the propagation velocity

When?



The smaller the time constant, the more rapidly a depolarization will affect the adjacent region.

Velocity is the function of passive properties – τ and λ – of membranes

Effect of axon diameter:

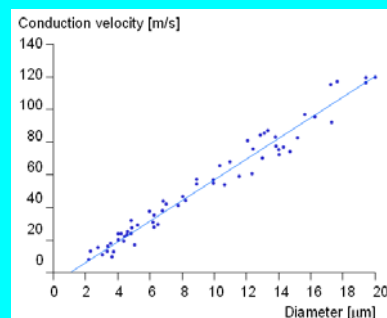
$$r \uparrow \Rightarrow \begin{matrix} R_i \downarrow (\sim 1/r^2) \\ R_m \downarrow (\sim 1/r) \end{matrix} \Rightarrow \begin{matrix} \tau \downarrow \\ \lambda \uparrow \end{matrix}$$

$$\tau = C_m R_m$$

$$\lambda \sim \sqrt{\frac{R_m}{R_i}}$$

Squid giant axon $r=250\mu\text{m}$
 $v=25\text{m/s}$

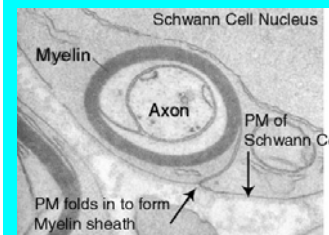
human nerve cell $r=10\mu\text{m}$
 $v \approx 0.5\text{m/s}$?



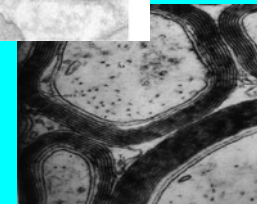
Myelination!

R_m – very high \Rightarrow big space constant

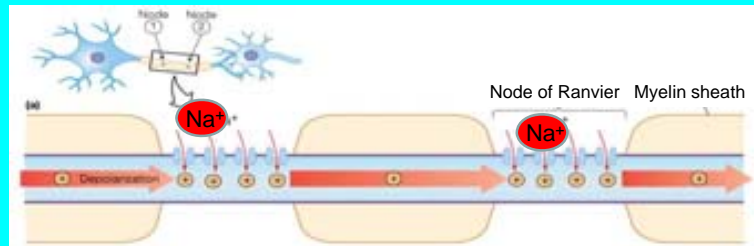
C_m – very small \Rightarrow small time constant



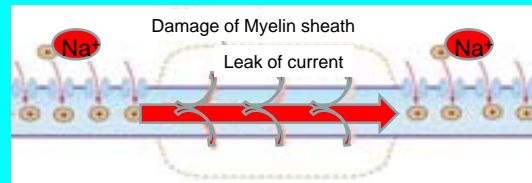
human nerve cell $r=10\mu\text{m}$
 $v \sim 100\text{m/s}$



Saltatory conduction - quick, energy saving



Myelin prevents ions from entering or leaving the axon along myelinated segments.



Effect of axon diameter and Myelination

The diameter of frog axons and the presence or absence of myelination control the conduction velocity.

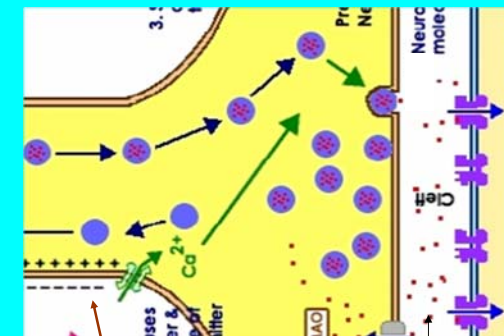
Fiber type	Average axon diameter (μm)	Conduction velocity ($\text{m} \cdot \text{s}^{-1}$)
Myelinated fibers		
A α	18.5	42
A β	14.0	25
A γ	11.0	17
B	Approximately 3.0	4.2
Unmyelinated fibers		
C	2.5	0.4–0.5

Effect of passive electric properties on signal transduction in synapses

Signal transmission in synapses

presynaptic terminal

postsynaptic terminal

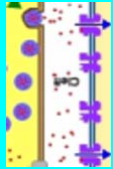


Action potential

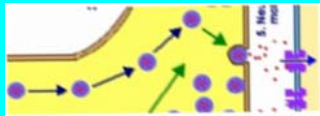
neurotransmitter

How can neurons transmit information from presynaptic to postsynaptic cells **if most synaptic effects are subthreshold?**

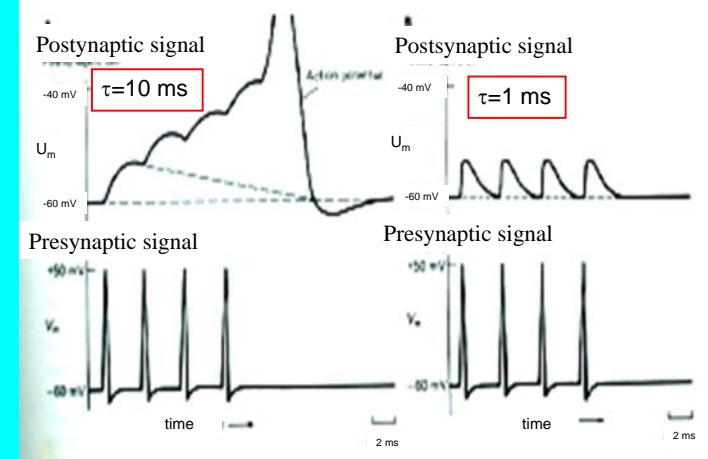
Spatial Summation : combined influences at the same cell at a particular moment in time



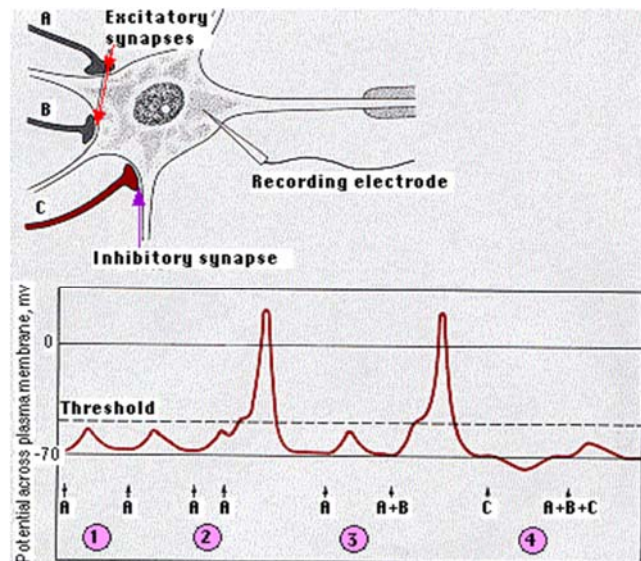
Temporal Summation : combined effects of neurotransmitter release from the same sites over time



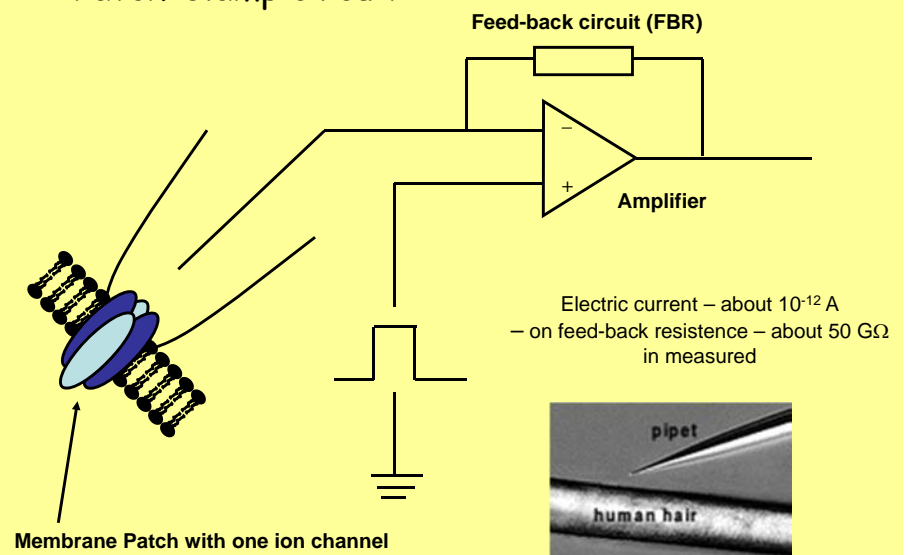
Temporal Summation : combined effects of neurotransmitter release from the same sites over time



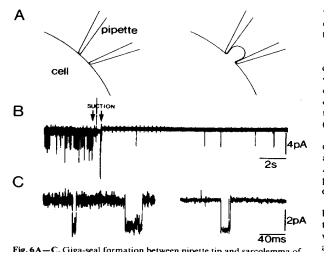
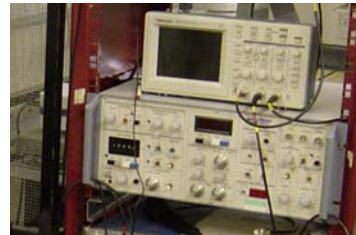
Temporal and spatial summation



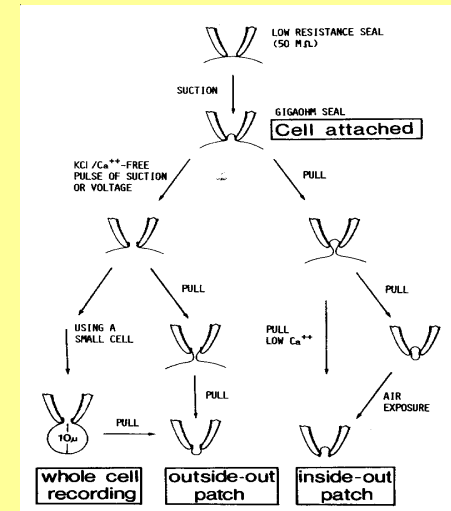
Patch-Clamp circuit



Patch-Clamp technique

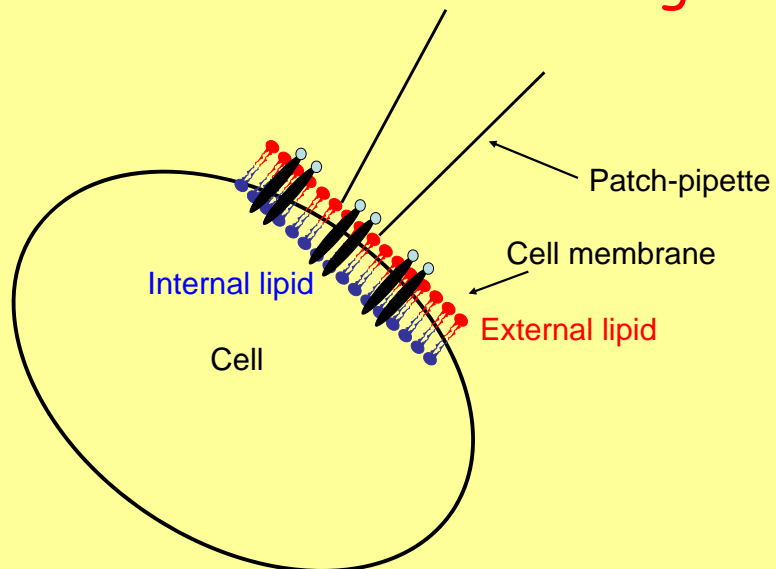


Patch-Clamp variations

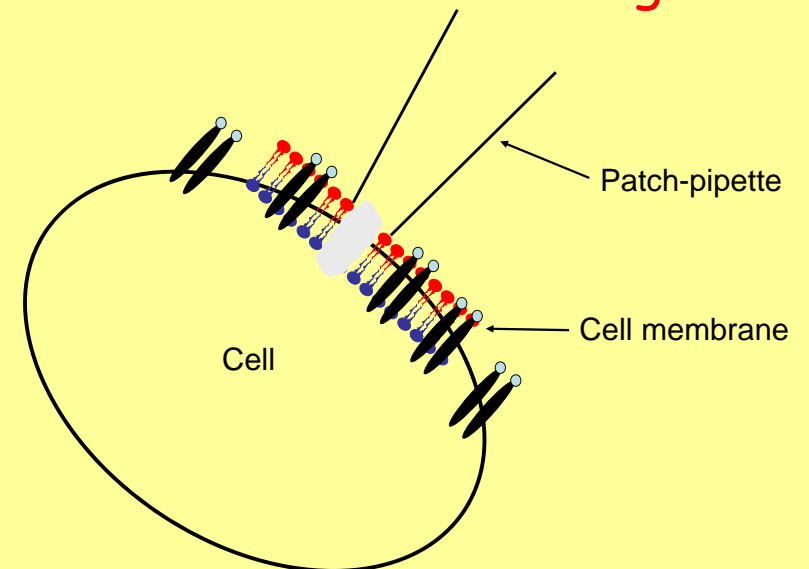


From Hamill *et al* 1981

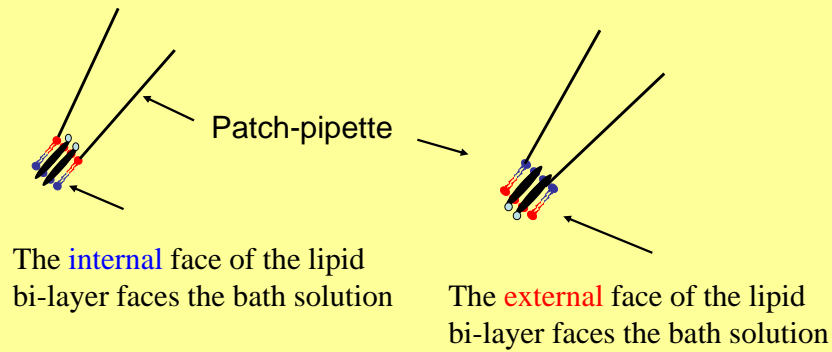
Cell-attached recording



Whole-cell recording

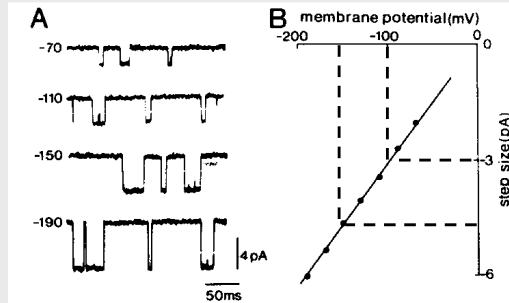


Inside-out recording



Outside-out recording

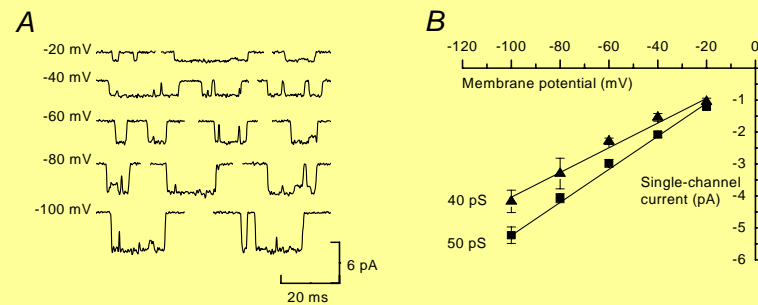
Single-channel I/V plots are used to determine the conductance of an ion channel



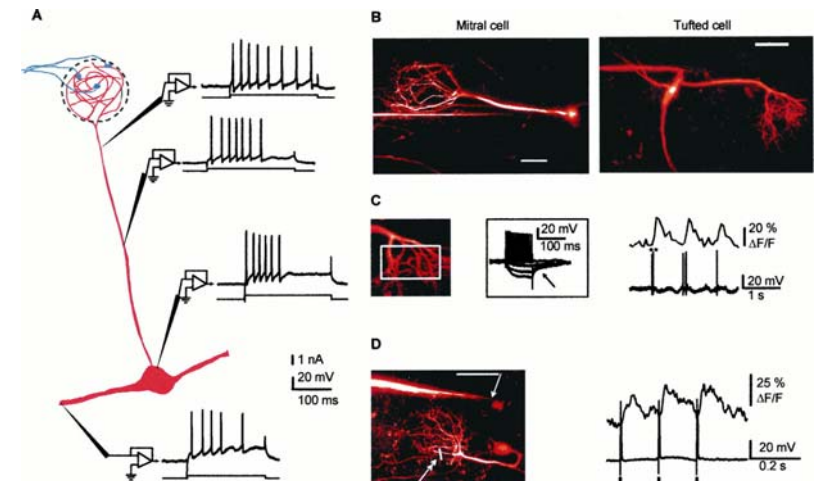
$$\begin{aligned}
 g_{\text{channel}} &= \Delta I \div \Delta V \\
 &= 1.6 \times 10^{-12} \text{ A} \div 50 \times 10^{-3} \text{ V} \\
 &= 32 \times 10^{-12} \text{ S} \\
 &= 32 \text{ pS}
 \end{aligned}$$

From Hamill *et al* 1981

Single channel with multiple states



Sodium action potentials synchronize $[Ca^{2+}]$ transients in all dendritic compartments of mitral cells in the olfactory bulb of anesthetized rats.



Charpak S *et al*. PNAS 2001;98:1230-1234