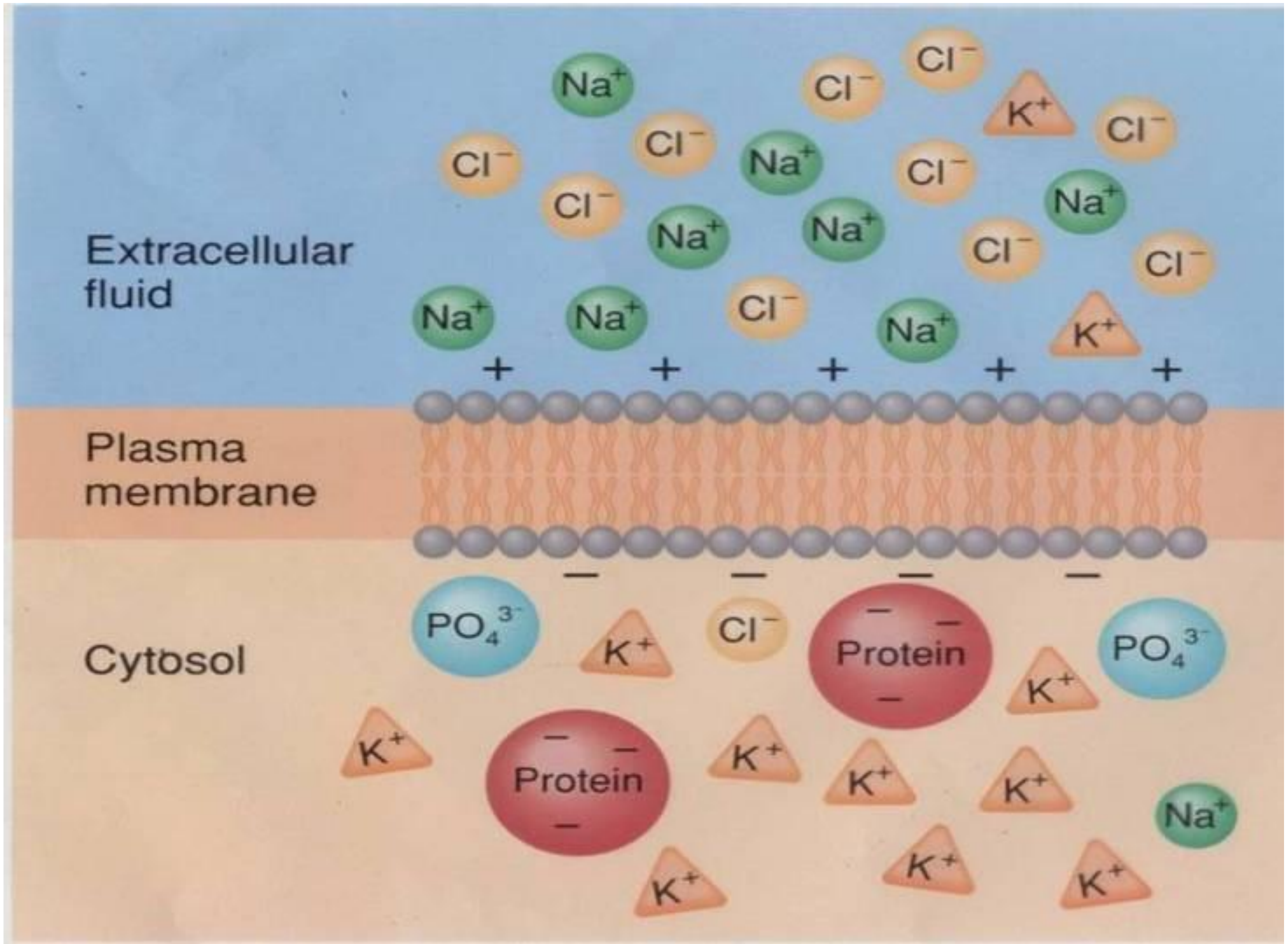
Transport of ions across plasma membranes

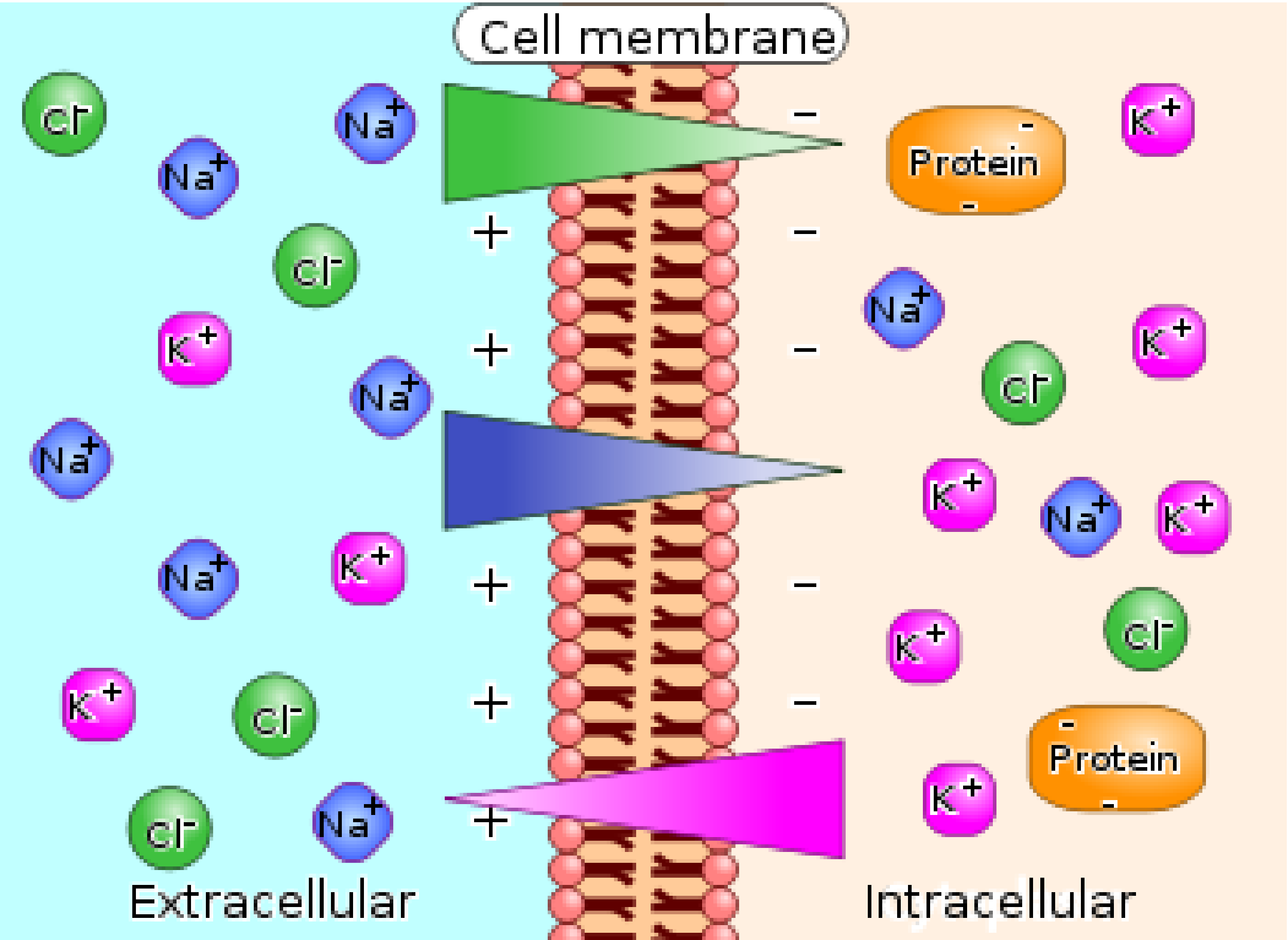
Plasma Membranes of Excitable tissues

Ref: Guyton, 14th ed: 63-76. 13th ed: pp: 61-71. 12th ed: pp: 57-69,



Extracellular fluid
Plasma membrane
Cytosol
Na+
Cl−
K+
PO4 3−
Protein

Membrane permeability

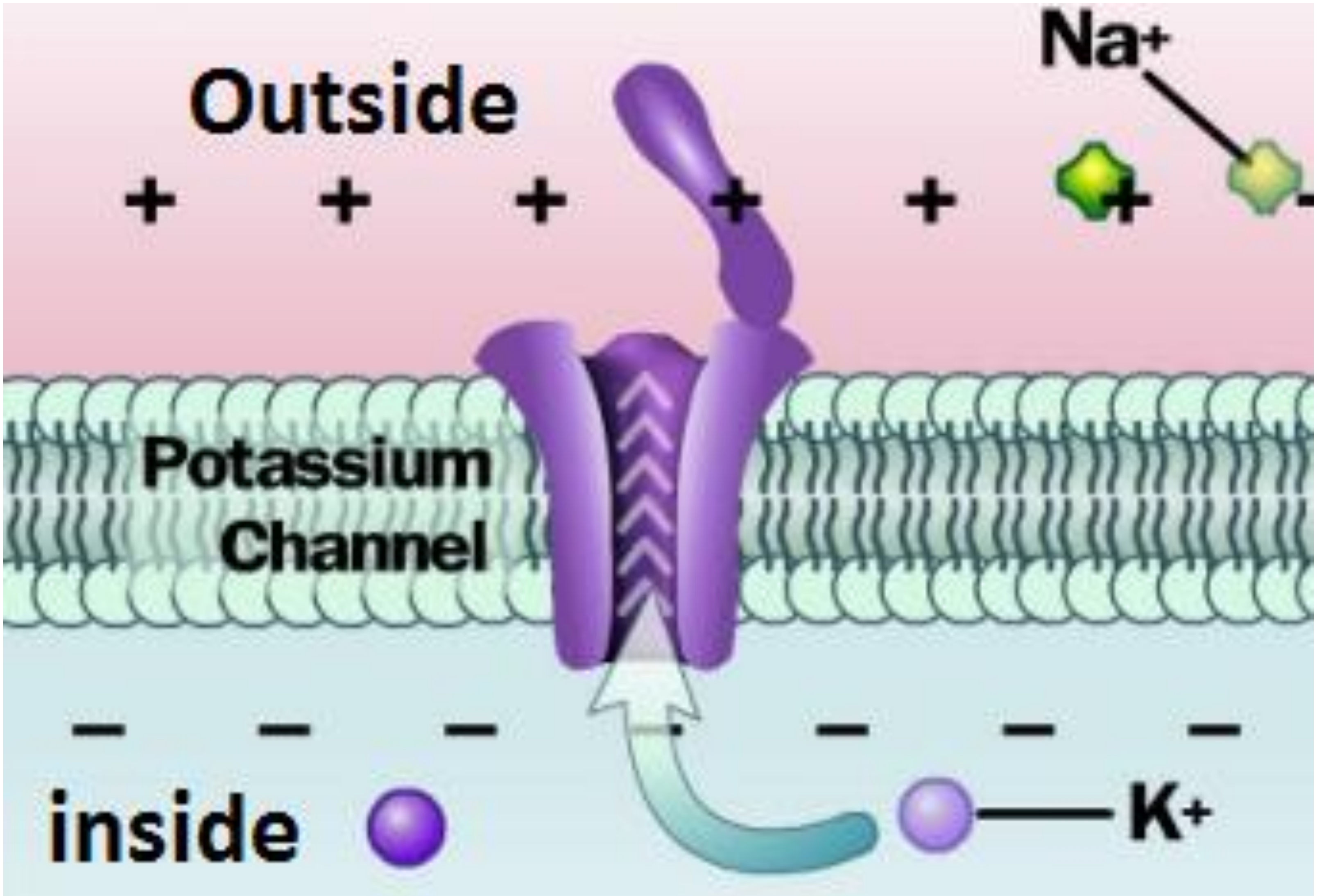


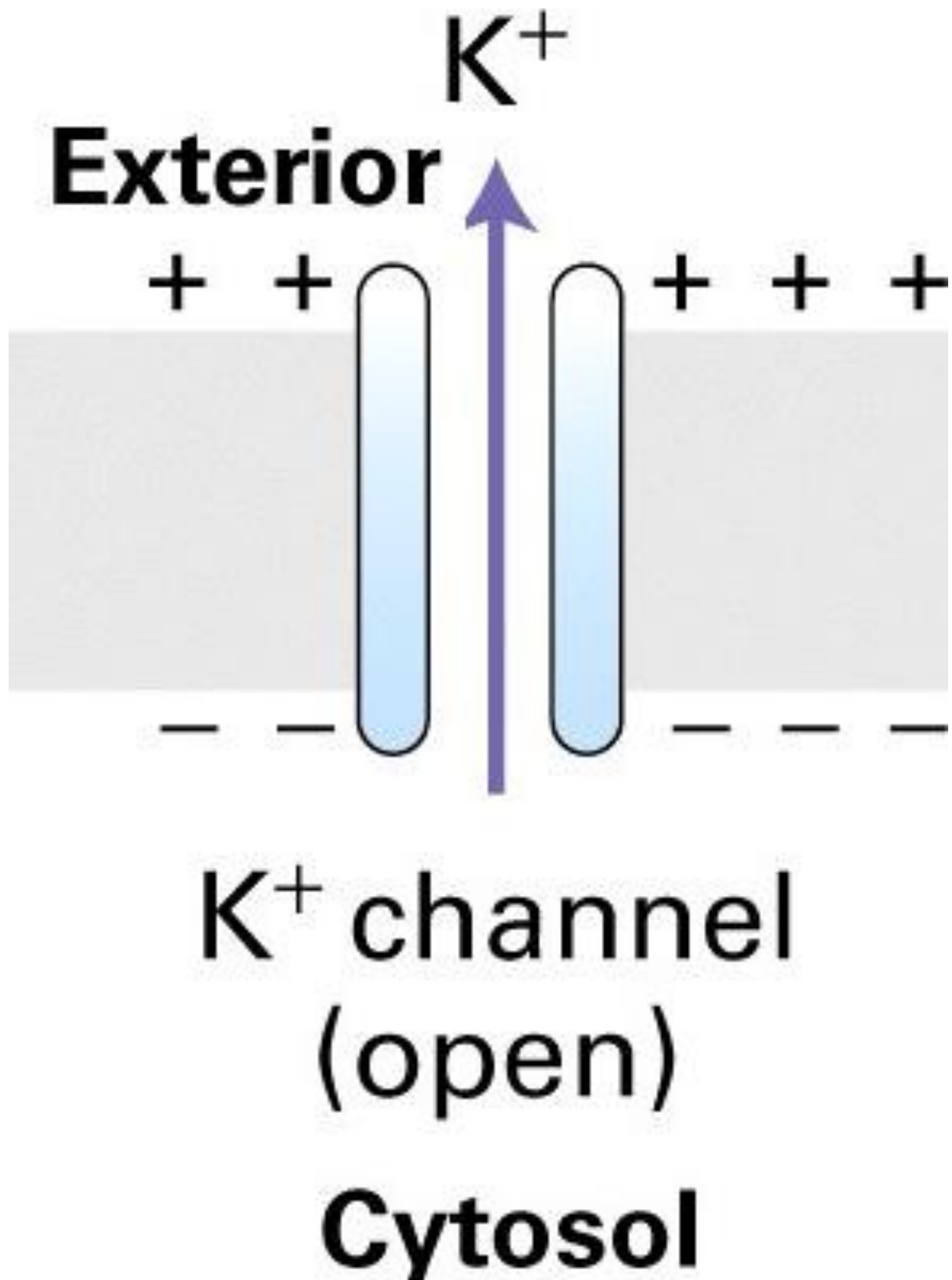
Question

- Are you getting diffusion of these ions until getting chemical EQUILIBRIUM?

First assumption:

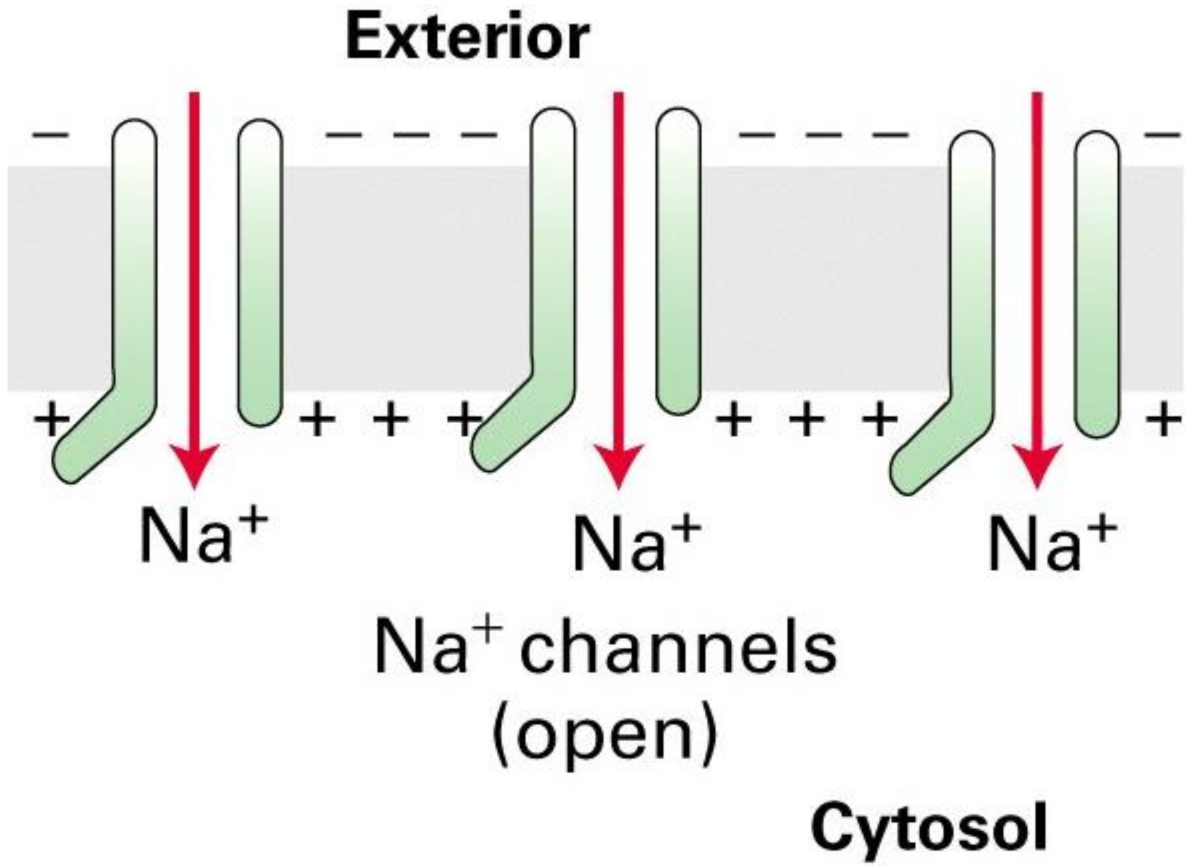
- ACTIVE K+ Channels





K+
Exterior
+ +
+ + +
− −
− − −
K+ channel
(open)
Cytosol

Second assumption:
-Active Na+ channels



Ions are moving according to:
- Electro chemical Potential
- Permeability

Electro-chemical Equilibrium

$$\Delta G_{conc} + \Delta G_{volt} = 0$$

$$zFV - RT \ln \frac{C_o}{C_i} = 0$$

$$V = \frac{RT}{zF} \ln \frac{C_o}{C_i} = 2.3 \frac{RT}{zF} \log_{10} \frac{C_o}{C_i}$$

Nernest equation

$$E = \frac{RT}{ZF} \ln \frac{[C]out}{[C]in}$$

R (Gas Constant) = 8.314472 (J/K·mol)

T (Absolute Temperature) = t °C + 273.15 (°K)

Z (Valence)

F (Faraday's Constant) = 9.6485309×10^4 (C/mol)

[C]out (Outside Concentration, mM)

[C]in (Inside Concentration, mM)

Follow the link:

https://www.youtube.com/watch?v=rJSJWosBJg0&t=377s

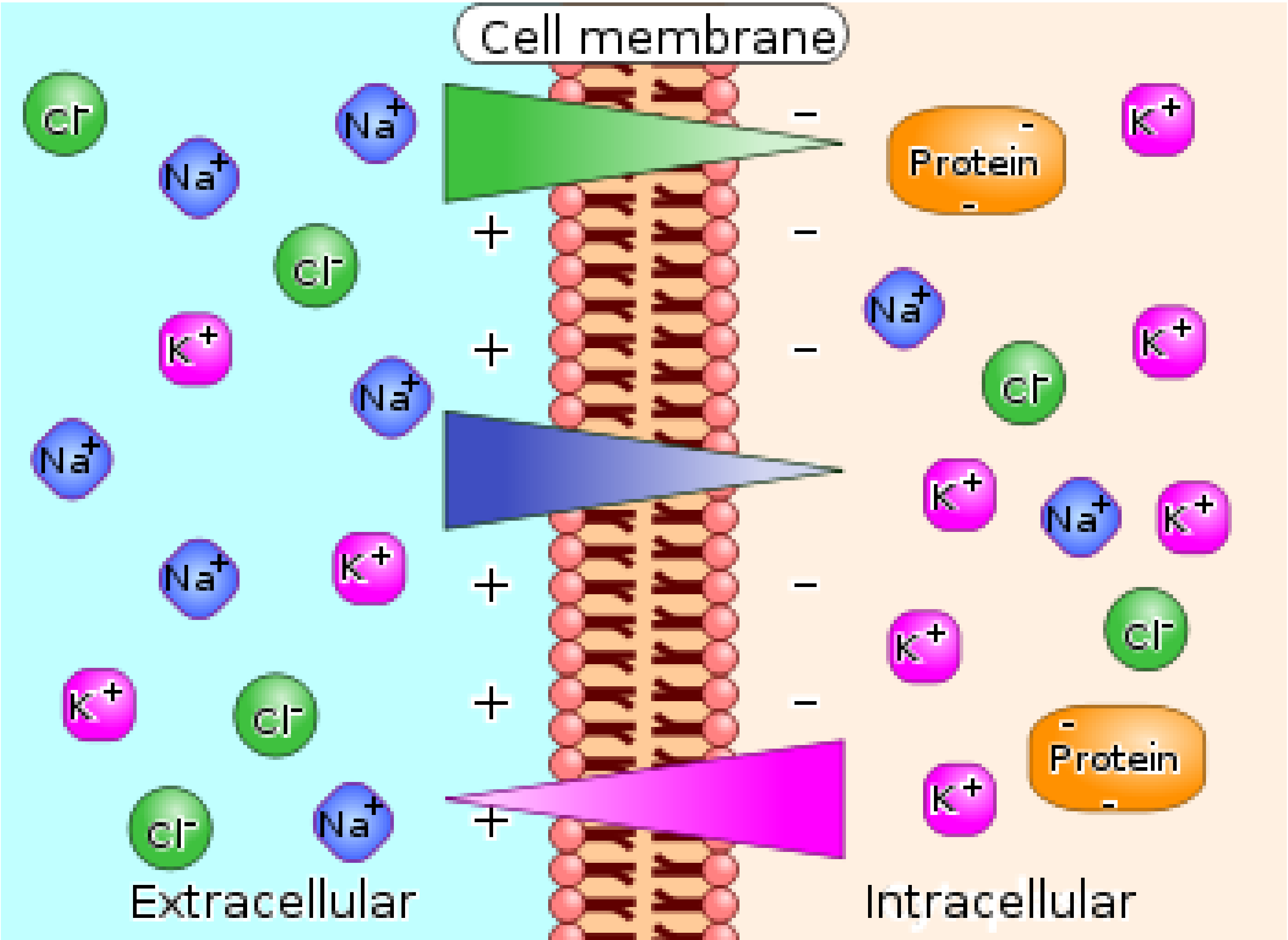
E_{k+}

$$E_{eq,K^+} = 61.54mV \log \frac{[K^+]_o}{[K^+]_i},$$

Concentration of Ions

Ion	Extracellular (mM)	Intracellular (mM)	Nernst Potential (mV)
Na^+	145	15	60
Cl^-	100	5	−80
K^+	4.5	160	−95
Ca^{2+}	1.8	10^{-4}	130

Membrane permeability



Question

- Are we having the same permeability for all these IONS?

Question

- What Happens when the membrane is permeable to many ions?
- How the Membrane potential is developed when the membrane is permeable to many ions?

Goldman Hodgkin Katz equation

$$E_m = \frac{RT}{F} \ln \left(\frac{P_{Na^+}[Na^+]_o + P_{K^+}[K^+]_o + P_{Cl^-}[Cl^-]_i}{P_{Na^+}[Na^+]_i + P_{K^+}[K^+]_i + P_{Cl^-}[Cl^-]_o} \right)$$

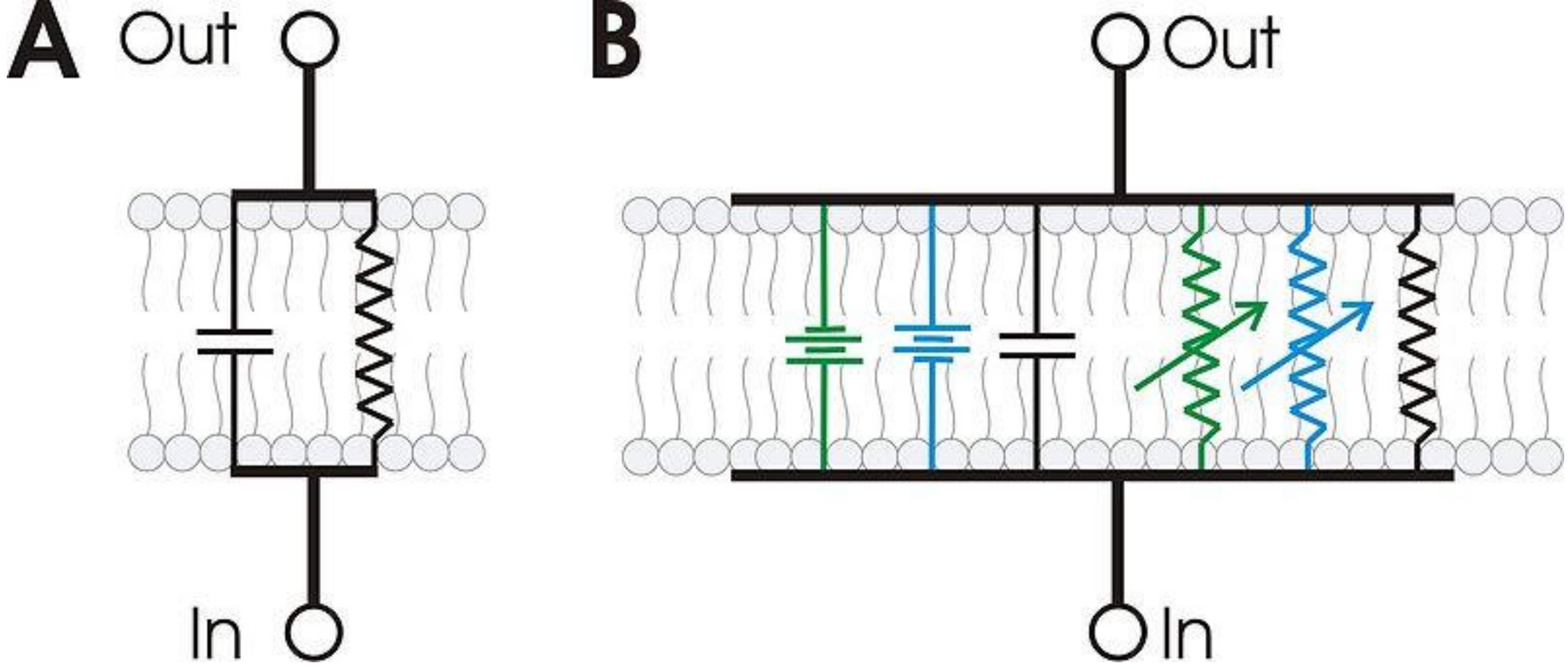
https://www.youtube.com/watch?v=YOFXkZu-r8M

Electrical properties of plasma membranes

Summary

Resting potential is set by:

- Activity K+ channels
- Activity of Na+ channels
- Na+/K+ pumps



- **Part A:** A basic en:RC circuit, superimposed on an image of a membrane bilayer to show the relationship between the two. **Part B:** A more elaborate en:RC circuit, superimposed on an image of a membrane bilayer. This RC circuit represents the electrical characteristics of a minimal patch of membrane containing at least one Na and two K channels. Elements shown are the transmembrane voltages produced by concentration gradients in potassium (green) and sodium (blue), The voltage-dependent ion channels that cross the membrane (variable resistors;K=green, Na=blue), the non-voltage-dependent K channel (black), and the membrane capacitance.

Conductance of plasma membrane (Ohm’s Law)

- $I = \Delta V/R$
- G (conductance)= $1/R$
- $I = G.\ \Delta V$

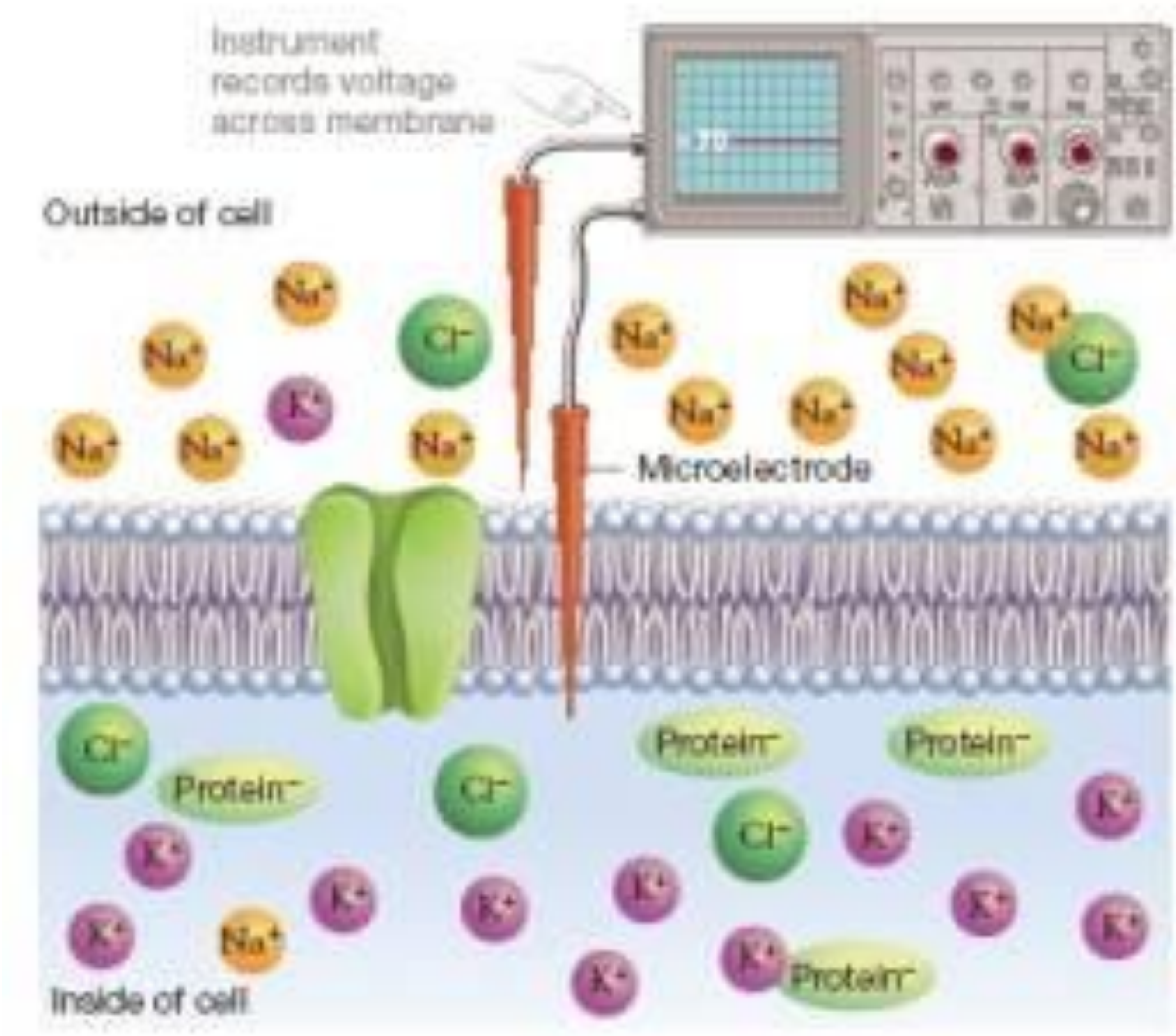
The cord Conductance equation describes the contributions of permeant ions to the resting membrane potential

$$V_m = \frac{g_K}{g_{tot}} E_K + \frac{g_{Na}}{g_{tot}} E_{Na} + \frac{g_{Cl}}{g_{tot}} E_{Cl}$$

https://www.youtube.com/watch?v=LdumhvDBpzQ

Measuring Currents at specific membrane potential

Measurement of Resting potential



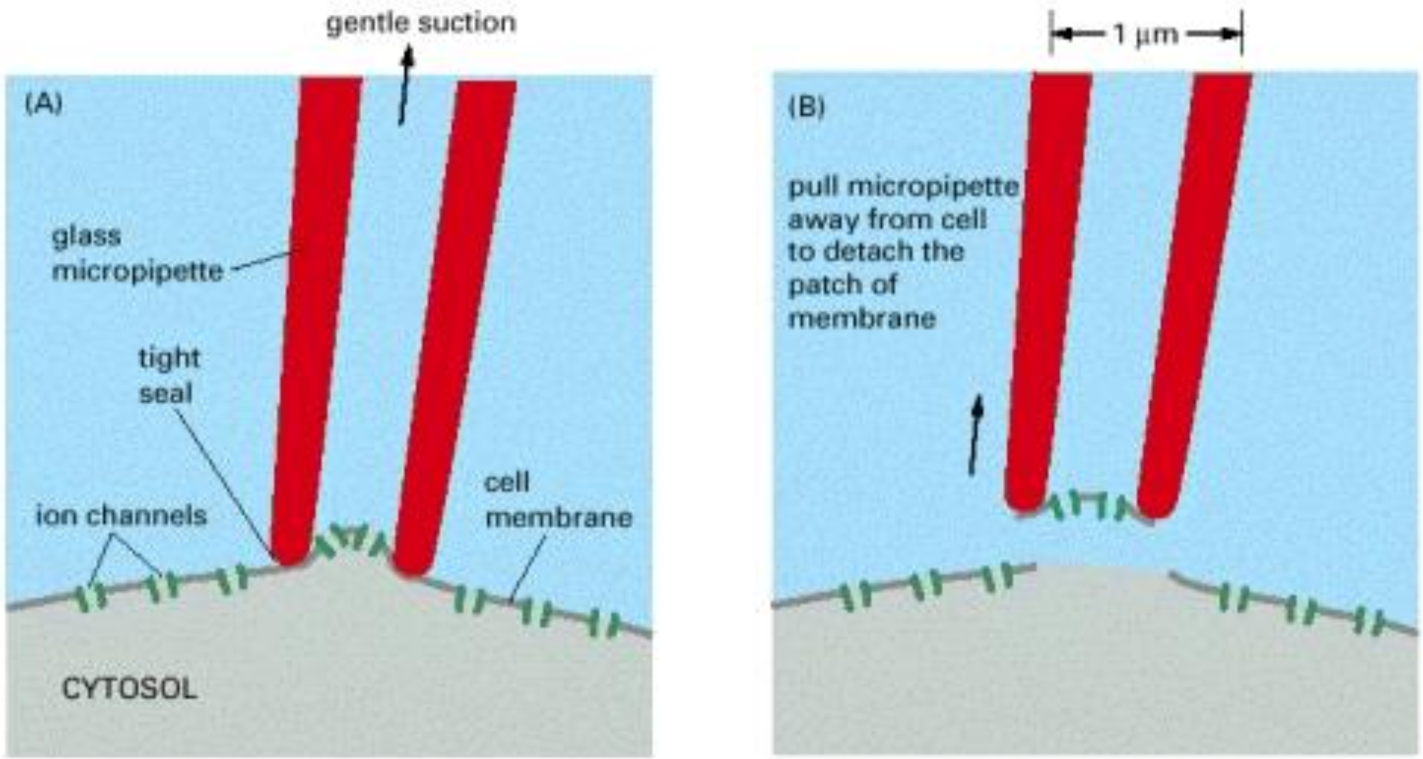
Measuring Currents at specific membrane potential

Oms Law:

$I=\Delta V/R$

Patch Clamp

- Patch still attached to the rest of the cell, as in (A), or detached, as in (B).



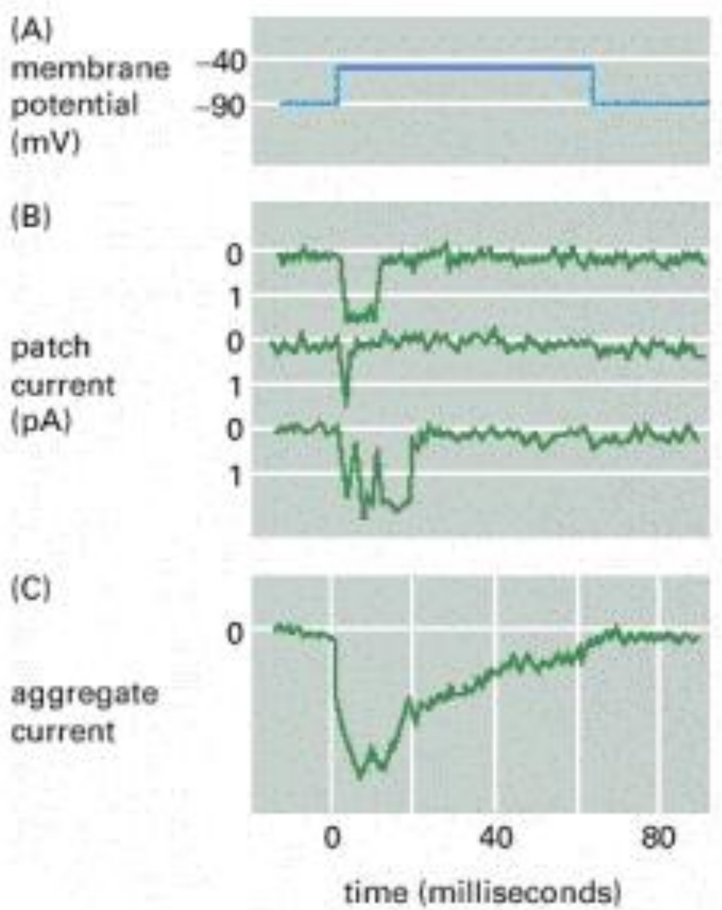
Patch Clamp

- electronic device is employed to maintain, or "clamp," the membrane potential at a set value
- recording the ionic current through individual channels

Follow the link for more information about the technique:

https://www.youtube.com/watch?v=mVbkSD5FHOw

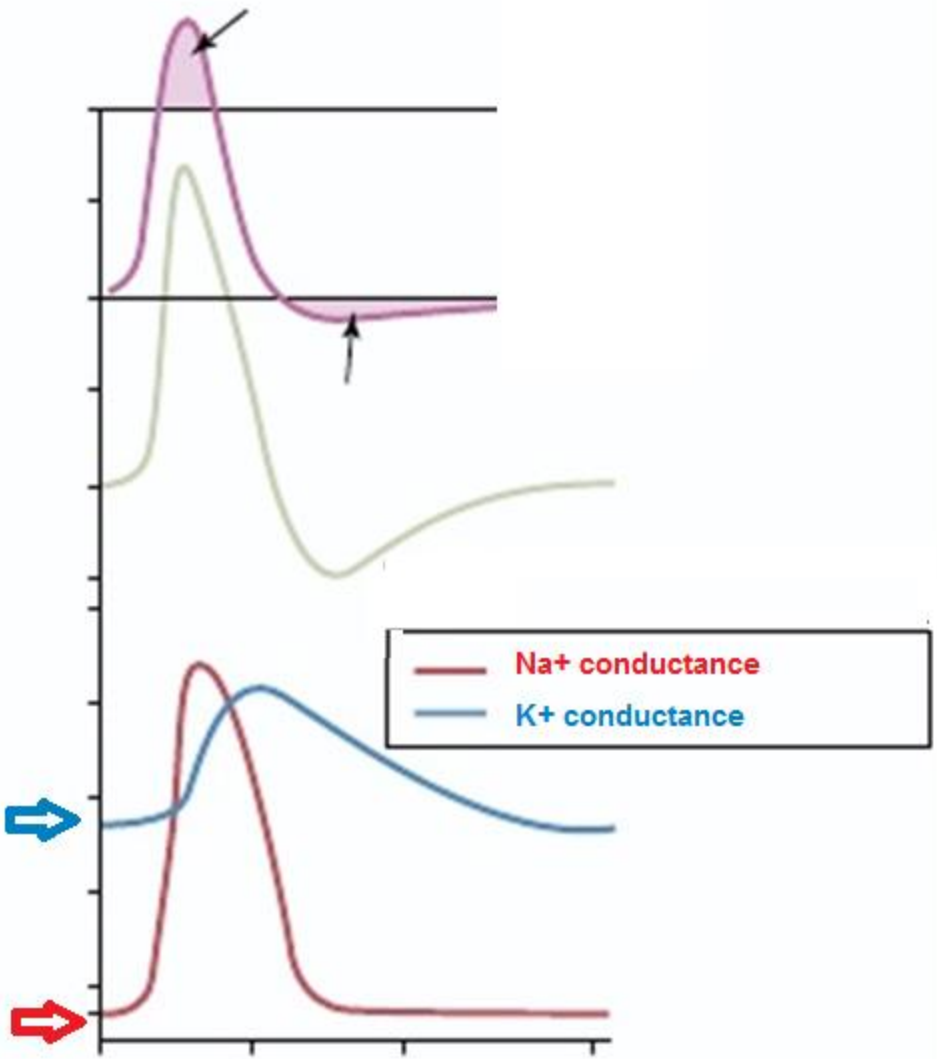
Recording of currents in Patch Clamp



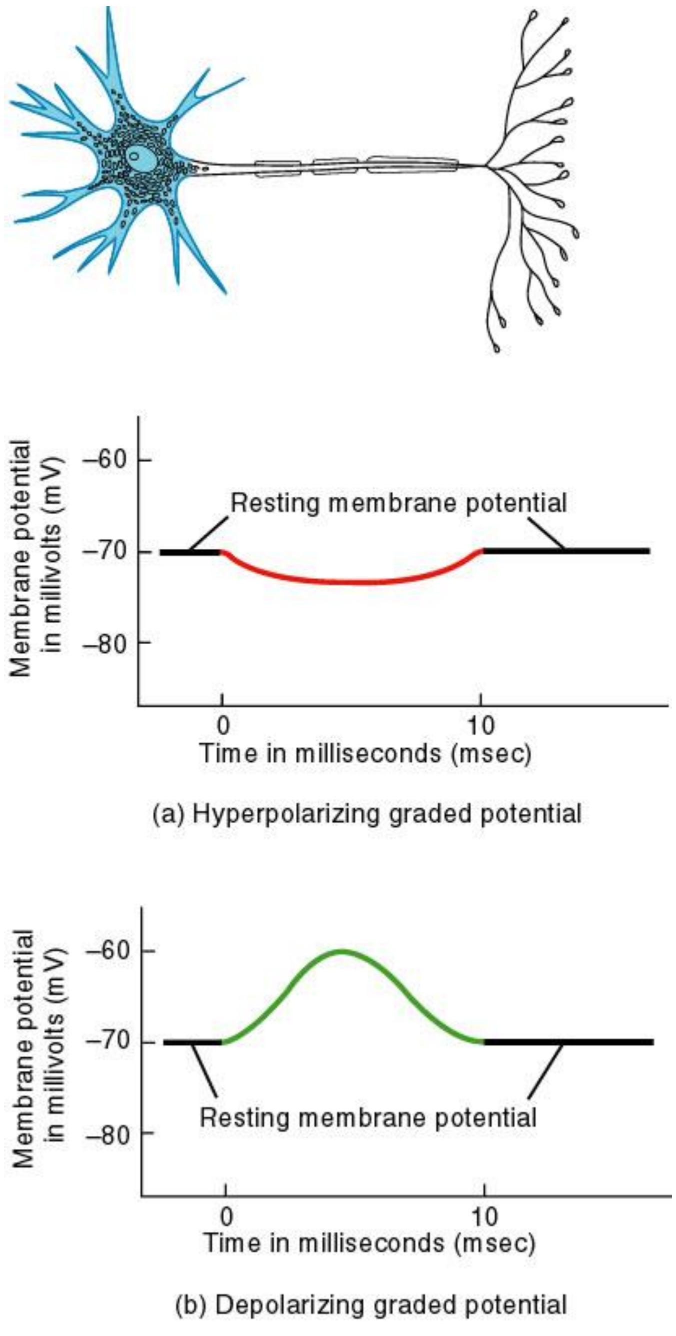
Voltage gated Channels

- The technique is important to study behaviors of channels at specific membrane potential and characterize the voltage gated channels.

- Na+ and K+ conductance at resting potential



- Changes in Resting membrane potential



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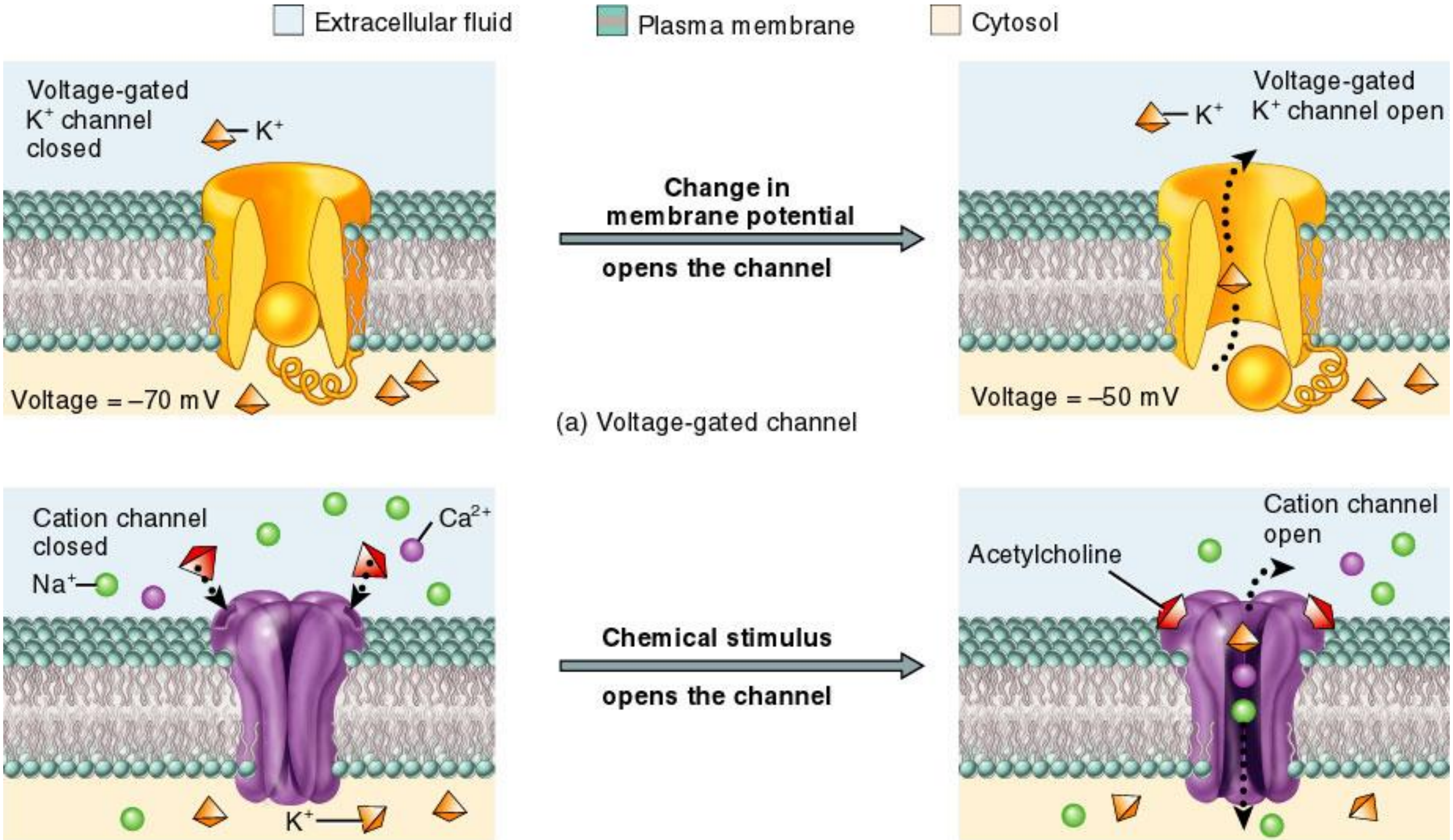
What Happens to the Resistance across membrane by activation of Channels??

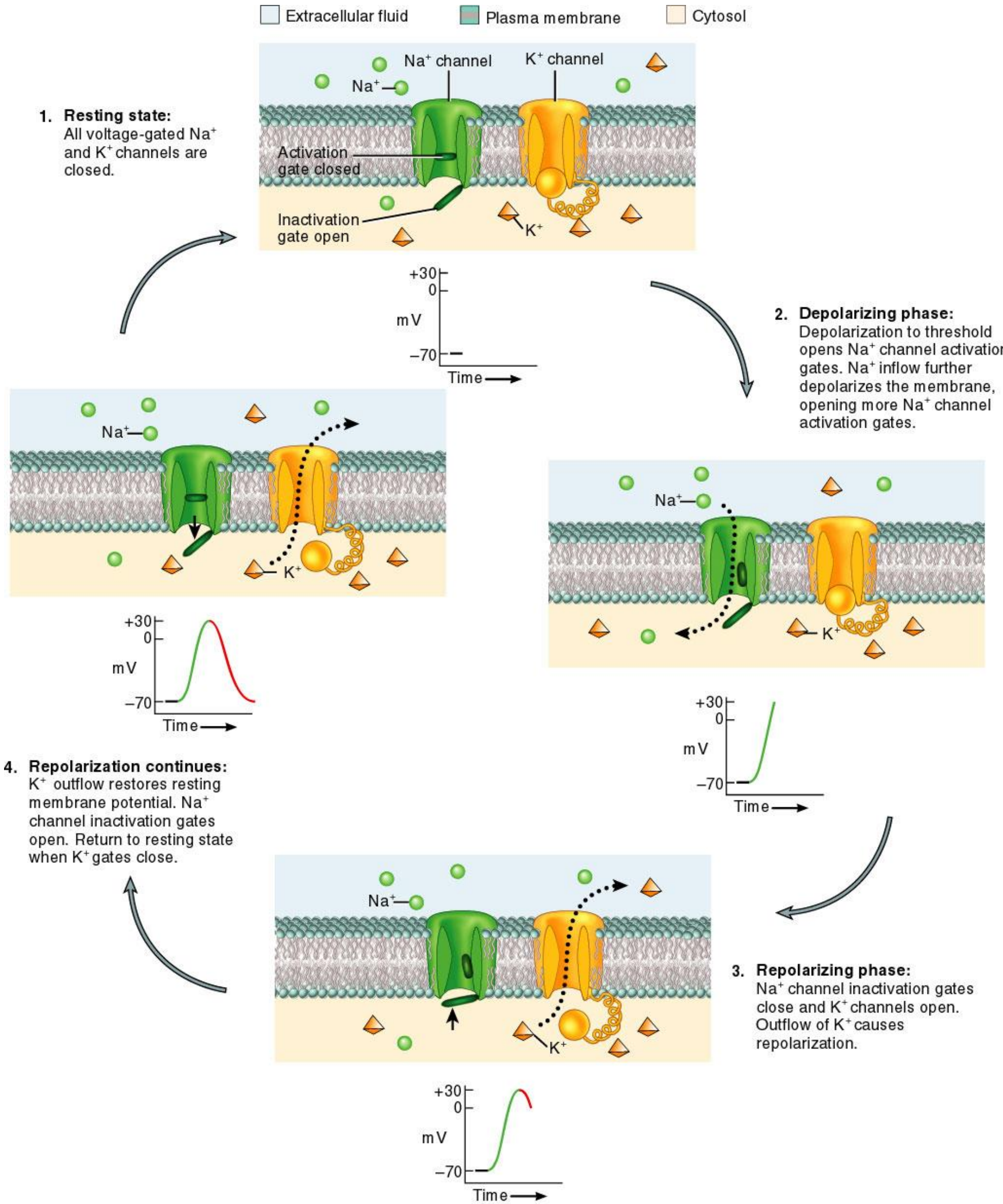


(a) Voltage-gated channel

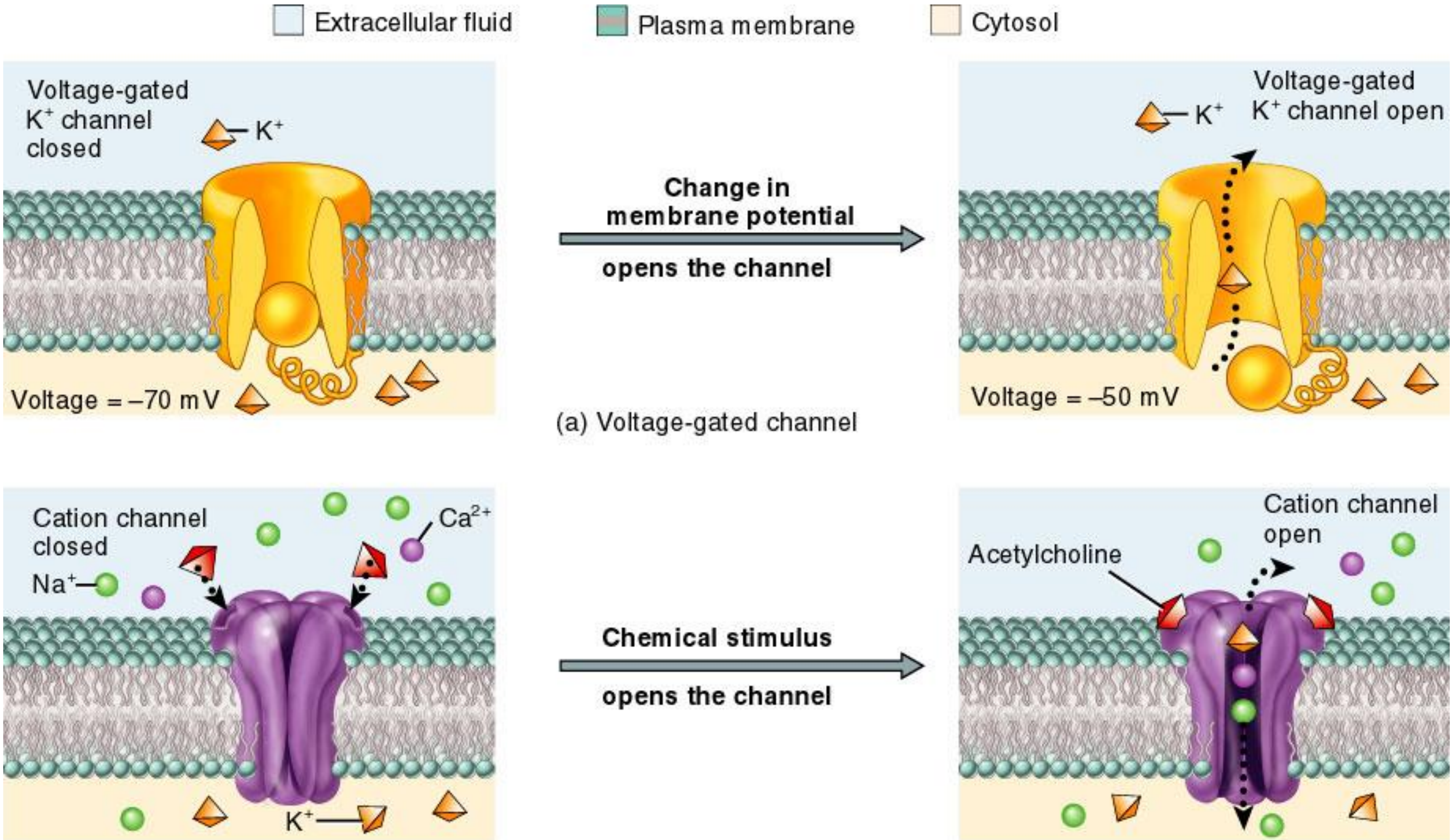
(b) Ligand-gated channel

12.08

- Changes in Channels activity results in action potential



12.12

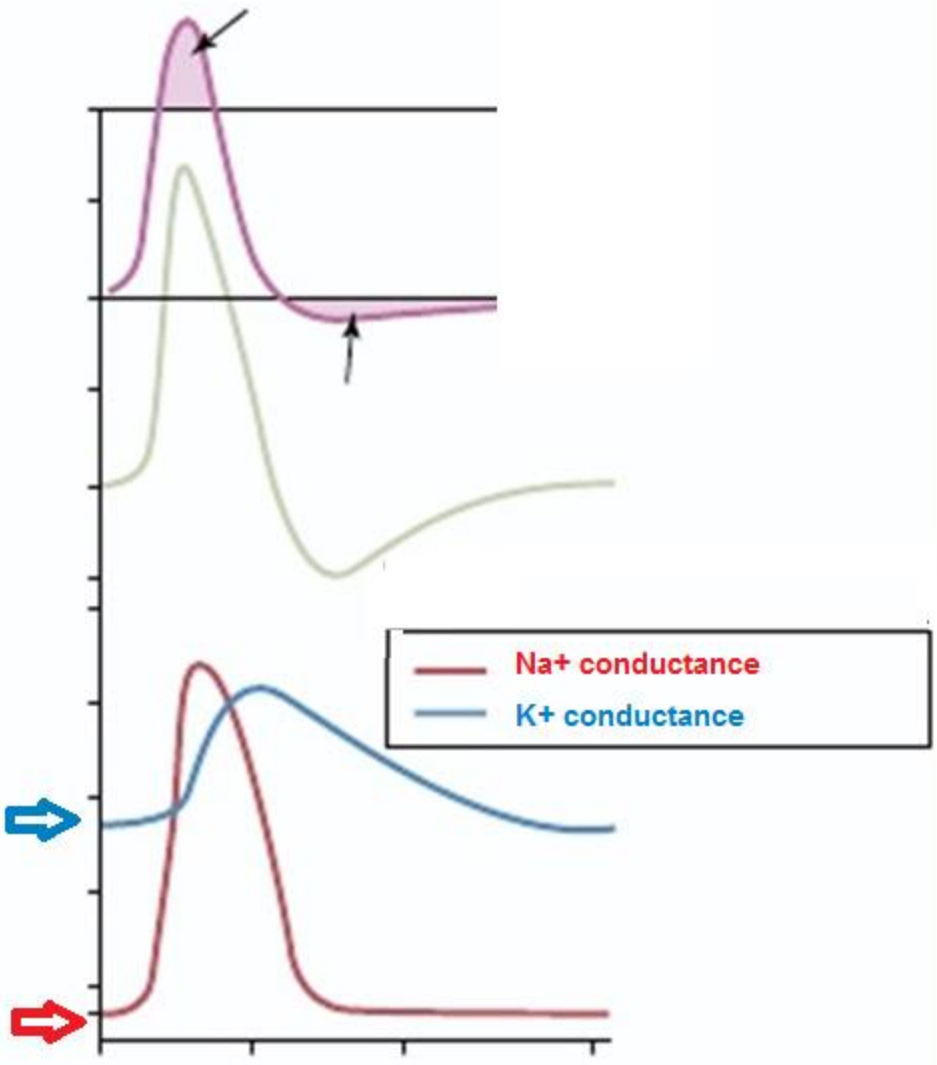


(a) Voltage-gated channel

(b) Ligand-gated channel

12.08

- Na+ and K+ conductance when the Membrane potential is changing



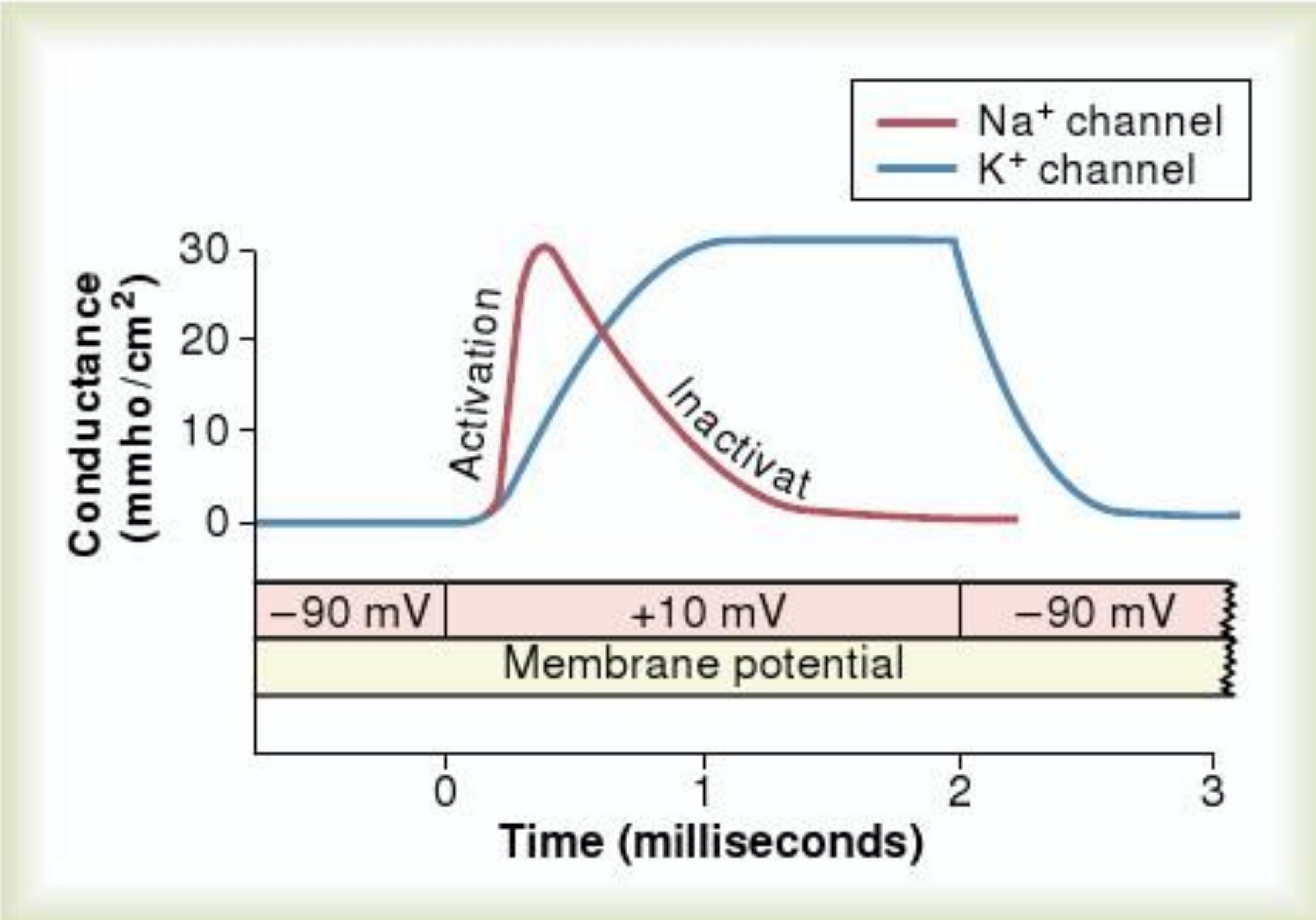

Na+ channel
K+ channel
Conductance (mmho/cm2)
30
20
10
0
Activation
Inactivat
−90 mV
+10 mV
−90 mV
Membrane potential
0
1
2
3
Time (milliseconds)

Figure 5–9

Ionic currents can cause depolarization