Plasma Membranes of Excitable tissues

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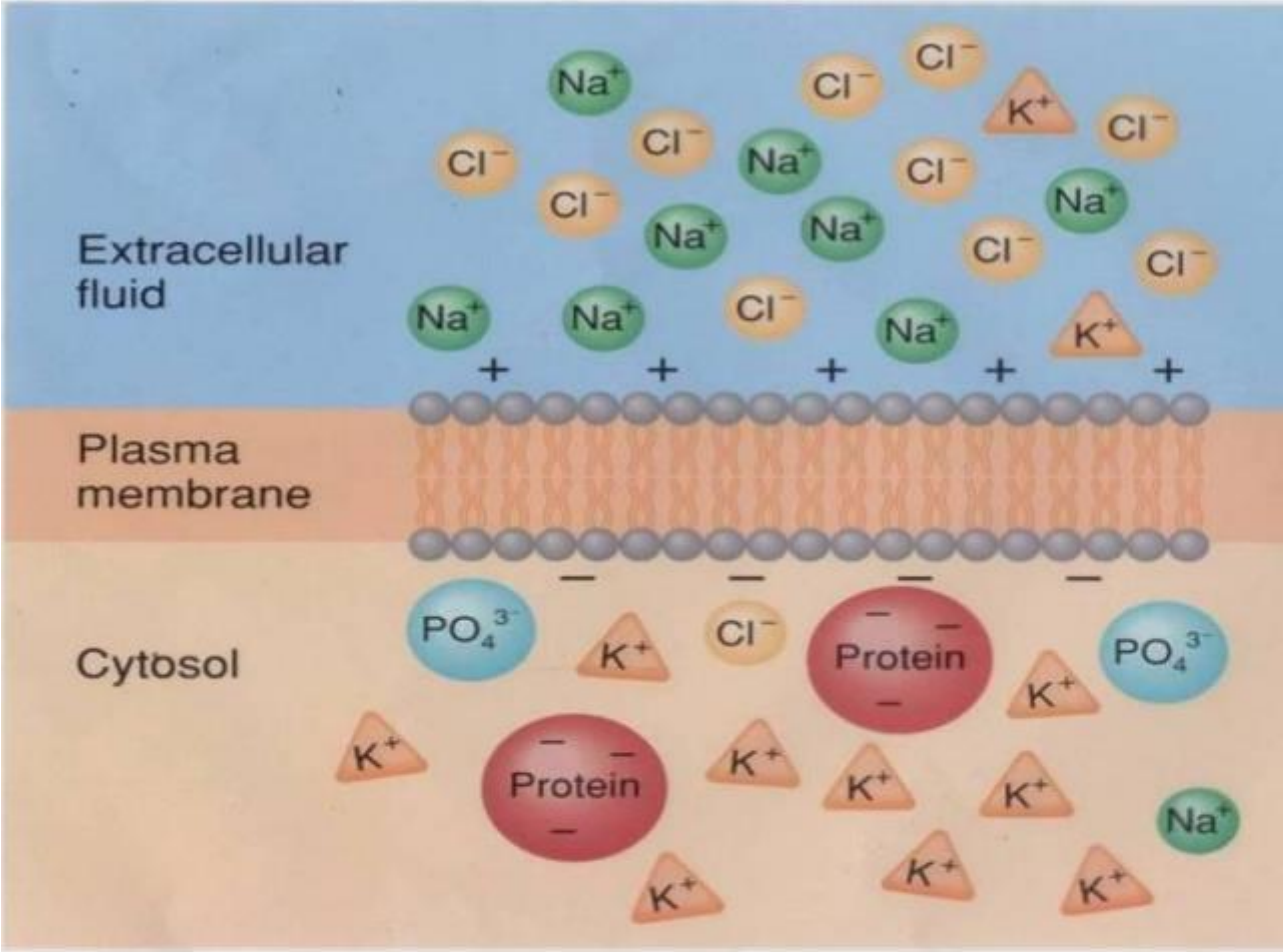
Topic of this

- 1- General overview of the membrane
- 2- Assume that the lipid membrane is a circuit
- 3- Nestren equation
- 4- Factors that determine the permeability
- 5- Goldman Hodgkin katz equation
- 6- Calculating membrane potential using electrodes
- 7- Critical thinking
- 8- Conductance



Extracellular fluid
Plasma membrane
Cytosol
Na+
Cl−
K+
PO_4^{3-}
Protein

1- General overview of the membrane

- plasma membrane separates outer and inner compartments that have different compositions
- Concentration of sodium ion outside is more than inside (O/I = 140/14 mEq), and chloride ion as well
- Concentration of potassium ion inside is more than outside (I/O = 140/5 mEq), this means that there is high tendency for K+ to move from inside to outside of the cell
- Ok, let us assume that the plasma membrane is permeable for only one ion (K+ for example), the ion will move according to its concentration gradient across the plasma membrane, this movement will create electrical potential difference across the plasma membrane that we call membrane potential, were negative charge will result inside and positive charge outside, this will resist more more movement of K+ ions until they reach a state of electro-chemical equilibrium.
- Note: Membrane potential is the difference in electric potential between the interior and the exterior of a biological cell, membrane potential for a specific ion is called nestren potential, we can calculate it by nestren equation or by replacing 2 electrode outside and inside the membrane
- So there are two factors that affect the movement of ions:
  1) Concentration gradient
  2) Membrane potential: electrical energy pushes ion in the opposite direction due to charge repulsion
- Note: membrane (electrical) potential is just across the plasma membrane not deep inside the cells and the extra cellular fluid

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

17- Assuming that we have a membrane that is NOT permeable to Cl^-, K^+ and Na^+, and permeability for Ca^{++} is the highest . Which of the following potentials is expected to develop at that membrane?

A. More positive than +160 mV.

B. Between +100 and +130 mV.

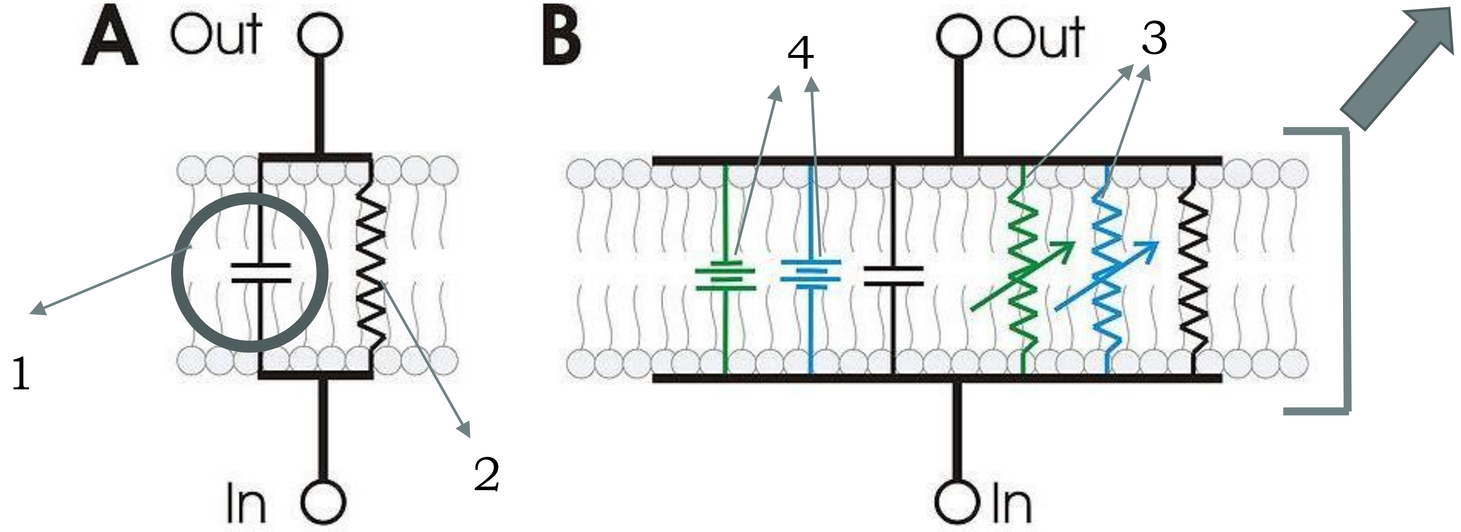
C. Between 0 and + 60 mV.

D. More negative than -30mV.

E. Between -30 and 0 mv.

2- Assume that the lipid membrane is a circuit

- 1) Circuits contain capacitors that separate charges between outside & inside = lipid bilayer
- 2) Circuits contain resistors that passes charges in a specific amount = channels that passes ionic currents
- 3) Circuits contain variable resistors that passes charges in a specific amount depending on certain criteria = The voltage-dependent ion channels K=green, Na=blue
- 4) Batteries = transmembrane voltages produced by concentration gradients in potassium (green) and sodium (blue)



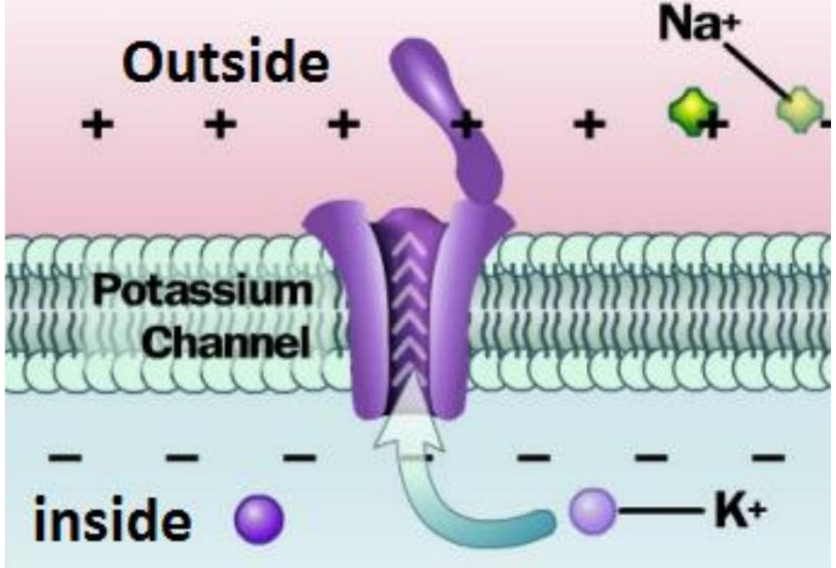
This RC circuit represents the electrical characteristics of a minimal patch of membrane containing at least one Na and two K channels

3- Nestren equation

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

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

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



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)

تعريف

إذا كانت س> ٠ ، أ > ٠ ، أ≠١، فإن: ص = $\text{لـــو}_{\text{أ}}$ س إذا وفقط إذا كان س= $\text{أ}^{\text{ص}}$ ، ويسمى الاقتران المعرف بالقاعدة ق(س) = $\text{لـــو}_{\text{أ}}$ س بالاقتران اللوغاريتمي. حيث أ: أساس اللوغاريتم.

قانون(١)

إذا كانت أ ، س ، ص أعدادًا حقيقية موجبة وكانت أ ≠ ١ فإنّ:

$\text{لـــو}_{\text{أ}}$ س ص = $\text{لـــو}_{\text{أ}}$ س + $\text{لـــو}_{\text{أ}}$ ص

قانون(٢)

إذا كانت أ ، س ، ص أعدادًا حقيقية موجبة وكانت أ ≠ ١ فإنّ:

$\text{لـــو}_{\text{أ}} \frac{\text{س}}{\text{ص}}$ = $\text{لـــو}_{\text{أ}}$ س − $\text{لـــو}_{\text{أ}}$ ص

قانون(٣)

إذا كانت أ ، س عددين حقيقيّين موجبين فإن:

$\text{لـــو}_{\text{أ}}$ $\text{س}^{\text{ن}}$ = ن × $\text{لـــو}_{\text{أ}}$ س

قانون(٤)

إذا كانت أ ، ب ، جـ أعداداً حقيقية موجبة ، وكان أ ≠ ١ ، ب ≠ ١ فإنّ:

$\text{لـــو}_{\text{أ}}$ جـ × $\text{لـــو}_{\text{ب}}$ أ = $\text{لـــو}_{\text{ب}}$ جـ

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)

→ the value z (valence) differs from ion to another in concern of charge (+,-) and number (1 or 2).

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

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

E (mV) = - 61.log (Ci/Co)

E = Equilibrium potential for a univalent ion

Ci = conc. inside the cell.

Co = conc. outside the cell.

at electro-chemical equilibrium:

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

*ΔG_{volt}: electric energy

*ΔG_{conc}: chemical energy

$$zFV - RT \ln \frac{Co}{Ci} = 0$$

*subtraction because the energies are opposite in directions.

we multiplied by this constant to convert from ln to $\log_{10}$

$$V = \frac{RT}{zF} \ln \frac{Co}{Ci} = \underbrace{2.3 \frac{RT}{zF}} \log_{10} \frac{Co}{Ci}$$

**final equation

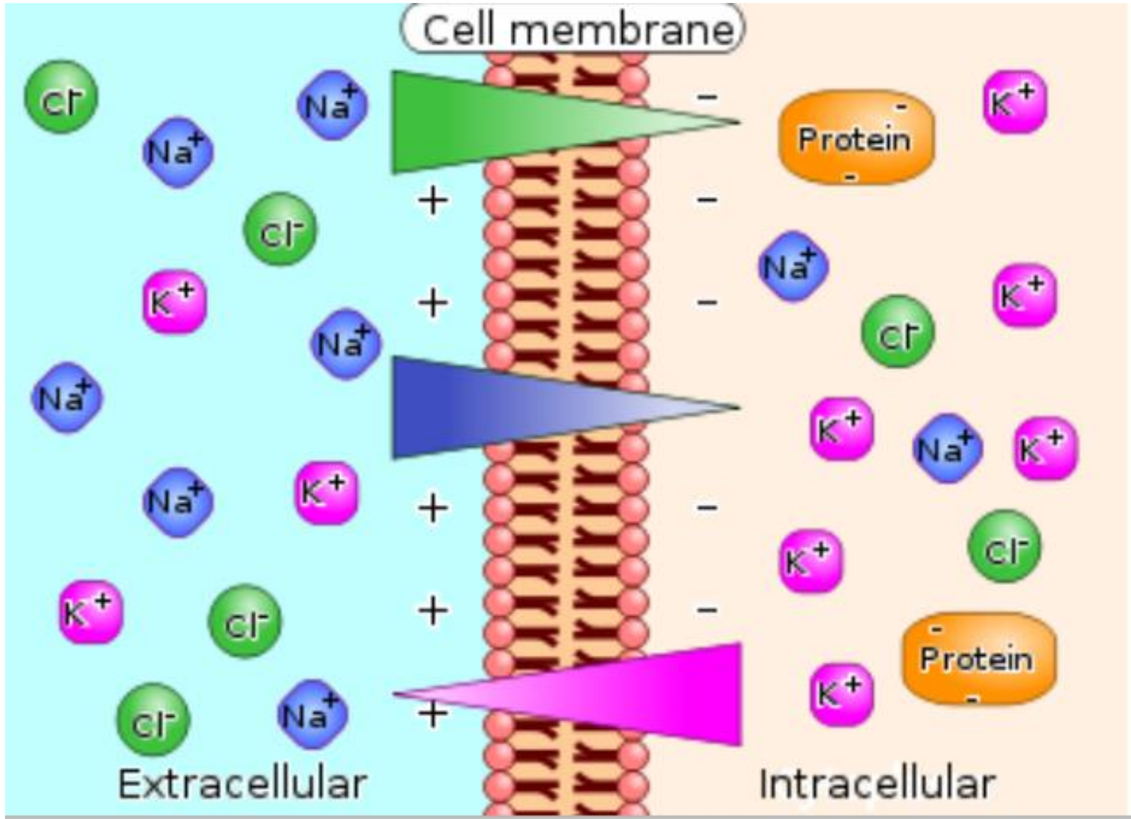
$$E_{ion} = 61.54\ mV \log_{10} \frac{[Co]}{[Ci]}$$

OR

E (mV) = - 61.log (Ci/Co)

4- Factors that determine the permeability

- Do we have a membrane permeable for only one ion? No
- Do we have a membrane which has the same permeability for all ions? No
- The membrane have a high permeability for potassium and very low permeability of chloride and sodium (P of K+ > 200 x P of Na+) , so we are creating a potential which will be very close to the equilibrium potential for potassium.
- So as a rule: If we have a membrane which is permeable for more than one ion but it is more permeable for a certain ion, the Instrument records the voltage across the membrane potential will be closer to the equilibrium potential for that ion.
- Not all membranes have the same resting potential
- excitable cells have more negative resting membrane potential
- Most cells a have net membrane potential of -90mV (called Resting Membrane Potential)



4- Factors that determine the permeability

- Factors that determine the resting membrane potential:
  1) Activity K+ channels: (Most influential) the k+ ions move from the inside to the outside and cause a negative potential for the membrane.
  → the calculated EK+ is about (-94mV), Which is not far from the recorded membrane potential but not exactly.
  2) Activity of Na+ channels: The membrane has less permeability for Na+ , so the rest potential will be away to the equilibrium potential of Na+ , both sodium and potassium channels produce -86 mV
  3) Na+/K+ pumps: It produces -4 mV

Goldman Hodgkin Katz equation

Why we have the concentration of chloride ion inside the cell above the one outside?
Because the valance of chloride = -1

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

i = Conc. inside

O = Conc. outside

P = permeability of the membrane to that ion.

5- Goldman Hodgkin katz equation

- The same equation again ☺

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

36- At the resting membrane potential of an excitable cell, the electrical driving force for Cl^-, Na^+ and K^+ ions is:

A. Equal for all mentioned ions.

B. High for Cl^-.

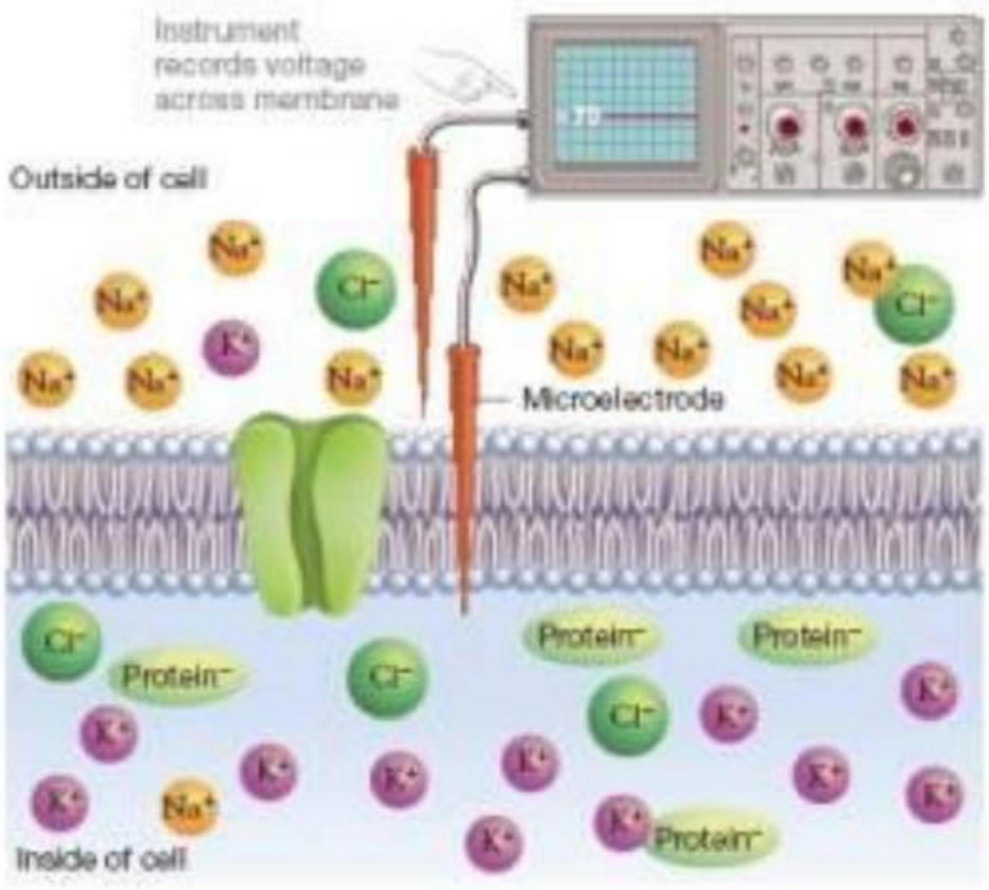
C. Low for K^+ and high for Na^+.

D. Low for Na^+.

E. High for K^+ and low for Cl^-.

6- Calculating membrane potential using electrodes

We can easily measure the membrane potential by placing one electrode just inside the cell closely to the surface and not deeply in the cell and placing another electrode just out the cell and not far away from the surface.



7- Critical thinking

- If you have -95 resting membrane potential, what is the direction of the movement of potassium ions?
  It won't move (the activation of more K+ channels will not affect the potential because this potential is equal to the equilibrium potential of k+)
- If you have a membrane with -80, the activation of Cl channels will not affect the membrane potential because it has the same value of the equilibrium potential of Cl ions even if you unlimited number of these channels.
- If you have a membrane with -90, the activation of Cl channels will induce Cl- to move <u>**from inside to outside**</u> because the membrane potential is higher than the equilibrium potential of Cl ions
- So, we can say:
  → Movement of sodium from outside to inside is established by electrical difference and concentration gradient, while the Movement of potassium from inside to outside is established by concentration gradient mainly, because the resting potential is almost the same of the equilibrium potential of potassium.

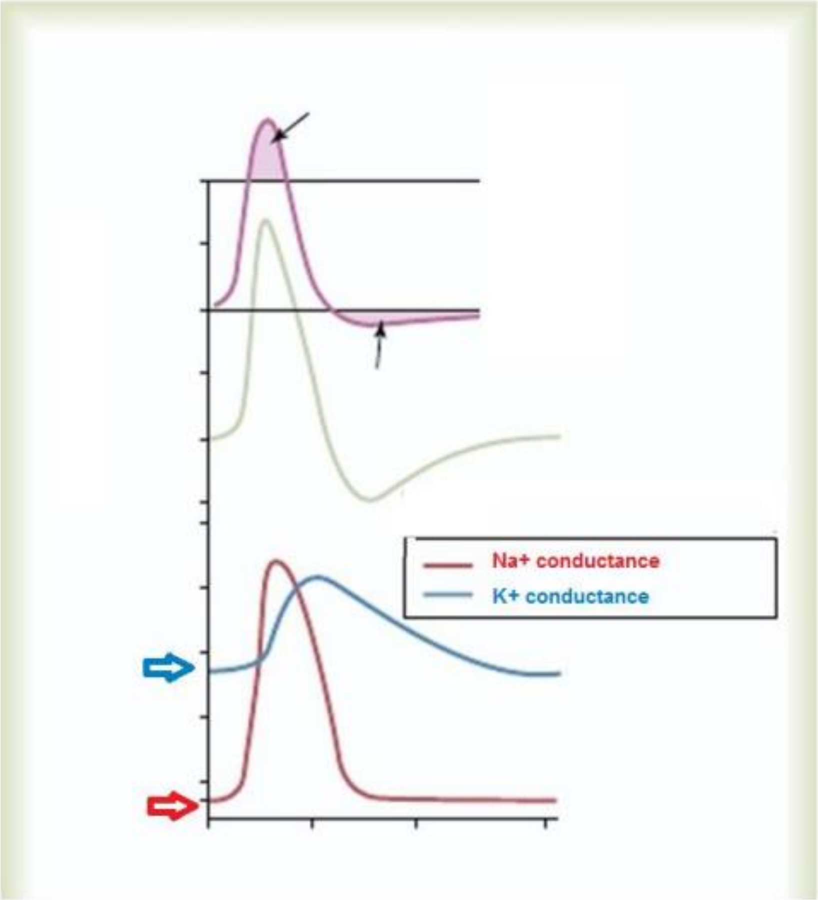
8- Conductance

- In excitable cells the membrane potential is not constant. When the cell is stimulated, the membrane potential changes. These changes in membrane potential are due to changes in permeability of plasma membrane to different ions because of voltage gated channels.
- For example, when neuron is stimulated, this will result in increased permeability to Na+. This will bring the membrane potential closely to E Na+, then the membrane potential will get close to the E K+ as there is increasing in permeability to K+
- The recorded membrane potential for a cell under resting conditions when no stimulus is involved is known as resting membrane potential. For neurons the recorded resting membrane potential is about (– 90 mV). This represents a potential difference between the inside to the outside when neuron is not active.

8- Conductance

- Conductance: the degree to which an object conducts electricity, calculated as the ratio of the current which flows to the potential difference present.

- Na+ and K+ conductance at resting potentials



Conductance of plasma membrane (Ohm's Law)

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

I = current

we can measure the potential of membrane by using the conductance.

Vm: Voltage of the membrane (potential)

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

V = Membrane potential

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

Calculations

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

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

The single ion potential

Nernest Equation

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

The membrane potential caused by all ions

Goldman Hodgkin Katz equation

Current $I = \Delta V/R$

G (conductance) $= 1/R$

$I = G. \Delta V$

(Ohm's Law)

contributions of permeant ions to the resting membrane potential

The cord Conductance equation