Physiology Team 432

Third Lecture: Excitable Tissue & Resting Membrane Potential

Done by:

Saad Al-Dosari - Naif Al-Ajji - Alaa Al-Zulfi

Reviewed by:

Khulood Al-Raddadi & Mohammad Jameel

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Excitable Tissues' Resting Membrane Potential

*Definition: They are nerve and muscle and they call potential because they have large membrane potential (MP) and can produce measurable electrical responses when stimulated.

Q: what property do excitable tissues have that makes them different from other body tissues ?

Their membrane acts as an electric capacitor مكثف , storing opposite charges on the opposite sides of the membrane this creates:

-Resting membrane potential

Resting membrane potential (RMP) of high value

(-70 to -90 mV)

compared to other body cells

(in RBC , for example MP= -5 mV)

This high RMP makes the nerve or muscle membrane function as a capacitor , that can "discharge" يفرغ , producing large voltage changes (action potentials).

Neuron:-

Unit of function of the central nervous system, mostly anterior horn cell in the spinal cord supply skeletal muscle.

Parts of motor neuron & function of each part:

1- **Soma (cell body).**

2- **Dendrites carry nerve impulses from surroundings to the soma.**

3- **Axon hillock at which nerve impulses begin &pass in one direction from soma to the axon(nerve fiber) then to axon terminal.**

4- **Axon and axon terminal end on skeletal muscle.**

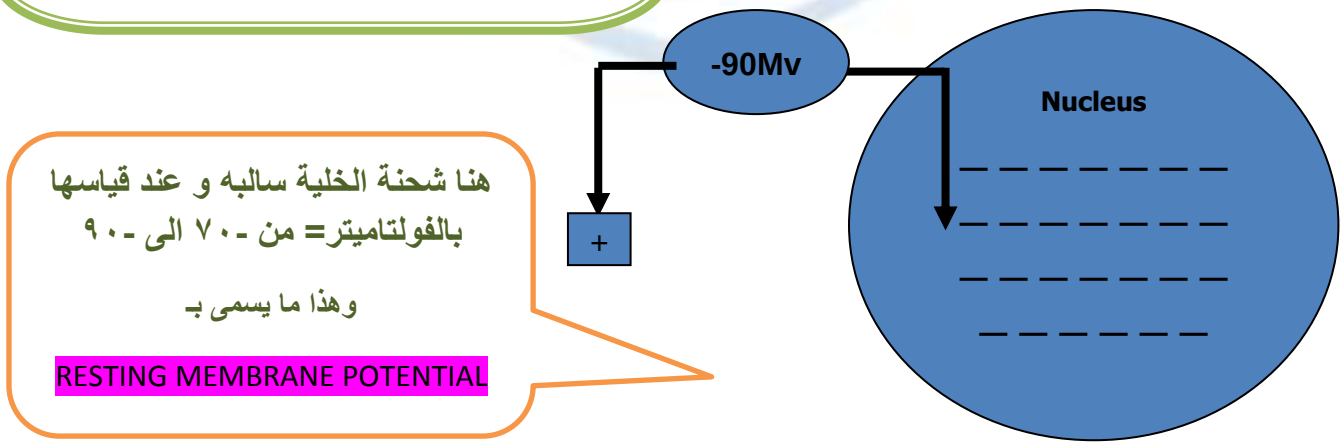
The impulses reach the muscle from nerve as **electrical** impulses

Q : What are the states of MP ?

(1) Resting Membrane Potential (RMP) :
Value of MP in a “resting ”state) unstimulated excitable nerve membrane(. It ranges between -70 and -90 mV in different excitable tissue cells.

في حالة عدم وجود Stimulate للنيرف

in large myelinatednerves = -90



هنا شحنة الخلية سالبه و عند قياسها بالفولتاميتر= من -٧٠ الى -٩٠

وهذا ما يسمى بـ

RESTING MEMBRANE POTENTIAL

(2) Graded Potential (Local Response) :

MP in a stimulated cell (nerve) that is producing a local , non-propagated potential غير منتشر (an electrical change which is measurable only in the immediate vicinity مجاوره منطقة of the cell but not far from it) .

اول ماتجي للنيرف Stimulation يسوي اثر لكن في منطقه مجاورة و قريبة لمكان الـ stimulation

(3) Action potential (AP) :

MP in case of a nerve that is generating a propagated منتشر electrical potential after stimulation by effective stimulus (an electrical potential which can be measured even at long distances far from the cell-body of the nerve)

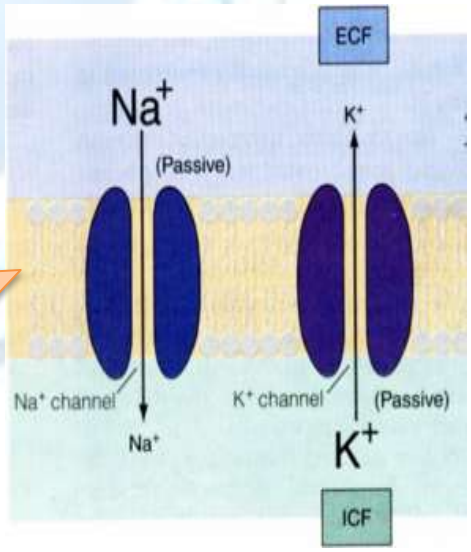
اول ماتجي للنيرف Stimulation يسوي اثر لكن في منطقه بعيدة عن مكان الـ stimulation

The Basis of the Resting Membrane Potential

* Types of membrane ionic channels:

(1) Leak (Diffusion, Passive) channels:

هي عباره عن ثقوب في غشاء الخلية مفتوحه طوال الوقت تسمح بعبور الأيونات من خلالها عن طريق منحدر التركيز (CONCENTATION GREDIANT) .

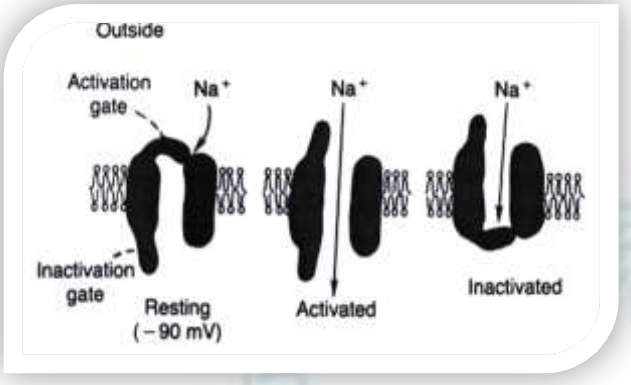


تذكر ان تركيز الصوديوم خارج الخلية اعلى من داخلها لذلك فأن اتجاه حركة الصوديوم الى الداخل INWARD

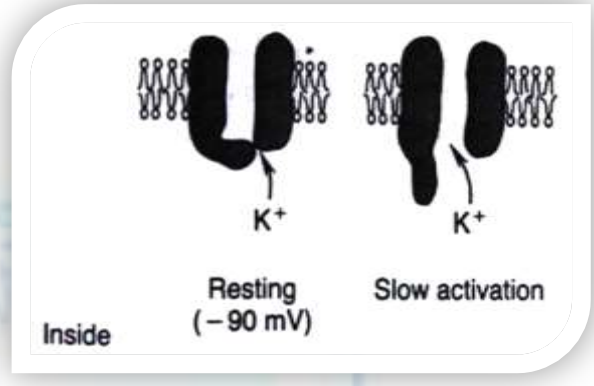
وفي المقابل فأن تركيز البوتاسيوم داخل الخلية اعلى من خارجها لذلك فأن اتجاه حركة البوتاسيوم الى الخارج OUTWARD

(2) Voltage-Gated channels: open when the cell-membrane is electrically activated.

Voltage-Gated Sodium Channel



Voltage-Gated Potassium Channel



In The Resting Cell, Potassium leak channels are 50 times leakier than sodium leak channels → therefore the RMP is closer to the Potassium Equilibrium Potential

بأختصار فأن معدل خروج البوتاسيوم اكثر ب٥٠ مره من معدل دخول الصوديوم في وضع RESTING CELL

In An Active Cell, during the AP, voltage-gated sodium channels opens. The membrane becomes much leakier to sodium than potassium. →Therefore at the peak of AP we find the value of membrane potential closer to the Sodium Equilibrium Potential.

في AP معدل عبور الصوديوم اكبر من خروج البوتاسيوم في وضع

ACTIVE CELL

-Nerve has semipermeable membrane separating the ECF from the ICF.

1-K is high inside the nerve membrane & low outside.
-therefore potassium continuously diffuses through the K+ leak channels from inside the cell to outside → Buildup of electropositivity outside & electronegativity inside.

2-Na is high outside membrane & very low inside membranes the direction of the Na+chemical gradient (Concentration gradient) is inward and sodium continuously diffuses through the Na+leak channels from outside (the extracellular fluid, ECF) to inside the cell (the intracellular fluid, ICF) → buildup of electronegativity outside & electropositivity inside.

What is Equilibrium Potential of Na or K ?

Nerst calculate the level of concentration potential of ions across the membrane that prevent net diffusion of ions to inside or outside

To understand it we should know Nernst hypothesis.

Nernst said:

(1) The ECF and ICF contained ONLY one type of ion (sodium or potassium) , &

(2) The membrane is freely permeable (100% permeable) to that ion

Then he applied this hypothesis to sodium& to potassium, in turn →

THE SODIUM NERNST (EQUILIBRIUM) POTENTIAL:

Nernst made a hypothesis which said that if we suppose that:-

(1) The ECF and ICF contained ONLY sodium ions.
(2) The nerve-membrane was freely permeable to Na+.

- سوف يعبر الصوديوم الى داخل الخلية بواسطة منحدر التركير حاملا معه شحنته الموجبه وبالتالي سوف يحدث تناقص للشحنه السالبة داخل الخلية ومع تزايد دخول الصوديوم تزداد الشحنه الموجبه داخل الخلية ينشأ جهد كهربي يمنع الصوديوم الموجب من دخول الخليه.
- وعند تساوي قوة الجهد الكهربي داخل الخليه مع منحدر التركيز (الذي يقوم بدفع الصوديوم داخل الخلية) فأن ذلك يؤدي الى توقف دخول الصوديوم الى الخليه.

The MP in that case is called Nernst Potential for Na+ (or Na+ Equilibrium or Diffusion Potential) = +61 mV .

THE POTASSIUM NERNST (EQUILIBRIUM) POTENTIAL

Nernst made a hypothesis which said that if we suppose that:

(1) The ECF and ICF contained ONLY potassium ion.
(2) The cell-membrane was freely permeable to K.

- **و بالمثل فأن البوتاسيوم يخرج من الخلية حاملا معه شحنته الموجبه للخارج وبالتالي سوف يحدث تزايد للشحنه السالبه داخل الخليه ومع تزايد خروج البوتاسيوم تزداد الشحنه السالبه دخل الخليه.**
- **وعند تساوي قوة جذب الشحنه السالبة داخل الخلية مع منحدر التركيز(الذي يقوم بدفع البوتاسيوم للخارج) فأن ذلك يؤدي الى توقف خروج البوتاسيوم. وتحاول تحافظ عليها بالداخل**

The MP in that case is called Nernst Potential for K+ (or K+ Equilibrium or Diffusion Potential) = -94 mV .

Q: What determines the value of the Equilibrium (Nernst) Potential of a given ion (sodium or potassium ion) ?

A: It is the ratio of its concentration (conc) outside the cell divided by its concentration inside the cell .

-The greater the ratio(it means ion conc inside is higher than outside) the greater the force for ions to diffuse in one direction (from inside to outside)

((it is –ve for K & + ve for Na (K diffuses out so ↓ the ratio & Na diffuses inside so ↑ the ratio))

K = -94 mv & for Na = + 61 mv

Q : How can we determine the value of Equilibrium Potentials of Sodium and Potassium ?

Answer : by one of 2 ways

A/ by calculation using Nernst Equatio

Which is → 61 log conc in ECF /conc in ICF of that ion

e.g., in case of potassium → $= 61 \log \frac{[K^+]_o}{[K^+]_i} = 61 \log \frac{5 \text{ mM/l}}{150 \text{ mM/l}} = -90 \text{ mV}$

And in case of sodium → $= 61 \log 150/15 = +61 \text{ mV}$

B/ The other method for determining the Equilibrium Potential is by direct measurement in laboratory using electrodes.

Q: Why in the Resting Cell the value of the MP is closer to the Potassium equilibrium potential and in the active cell (at the peak of the action potential) it is closer to the Sodium equilibrium potential ?

*في الـ RESTING CELL يكون غشاء الخلية ذا نفاذيه اكبر للبوتاسيوم لذا تكون قيمة ال MP =- 90 (البوتاسيوم = -٩٤)

*في الـ ACTIVE CELL يكون غشاء الخلية ذا نفاذية اكبر للصوديوم لذا تكون قيمة ال MP=+35 (الصوديوم=+٦١)

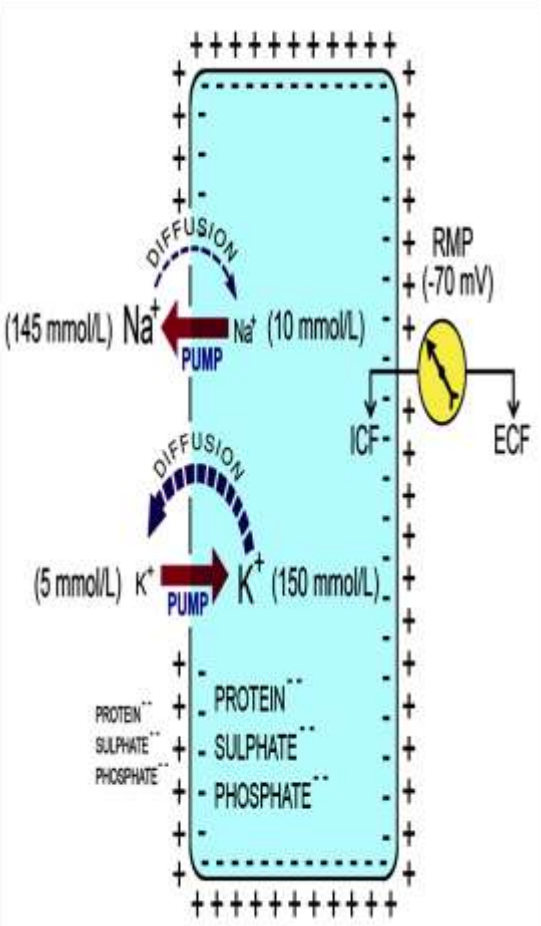
Q1: What are the 3 factors that make the inside of the cell negative?
Q2: and give the RMP the value of -70 to -90 Mv?

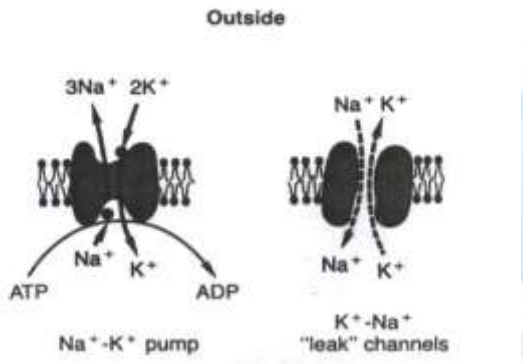
ANSWER:

1- **Contribution of K & Na diffusion potential through Na & K leak channels of nerve membrane.**
في الـ **REST** تكون قنوات البوتاسيوم ذات فعالية اكبر من قنوات الصوديوم لذلك تكون محصلة خروج البوتاسيوم اكبر من محصلة دخول الصوديوم.

2- **Negative ions inside membrane as phosphate sulphate & proteins.**
وجود بروتينات كبيرة داخل الخلية ذات شحنة سالبة.

3- **Active transport of Na & K ions (Na/K pump).**
في الـ **Active Transport** يتم ضخ ٣ ذرات صوديوم مقابل ادخال ذرتين بوتاسيوم.





لذلك تكون محصلة فقدان الشحنة الموجبة اعلى من كسبها داخل الخلية مما يجعلها سالبة

The resting membrane potential of nerves

It is potential difference across nerve membrane during rest (without stimulation)

The membrane is polarized

1-Contribution of K diffusion potential:-

(1)At rest:

K inside is 35 times higher than outside
K+ leak channels →more K+ diffuses to outside than Na+ to inside , because K leak channels are far more permeable to K than Na about 50-100 time due to small size of K molecules) →more potassium lost than sodium gained →net loss of +ve ions from inside the cell →more negative inside
(net K outflow to outside causing –ve inside)

K diffusion contributes far more to membrane potential than Na diffusion.

Applying Nernst Equation:-

-K inside is 35 times higher than outside (35/1)
-Nernst potential= -61mv x log 35/1 (1.54) = -94 mv,
(If K is the only ion act on membrane →RMP = -94 mv with negativity inside the nerve).

2-Contribution of Na diffusion potential:-

Na leak channels:-have Slight permeability to Na ions from outside to inside. لانو حجمه كبير اكبر من البوتاسيوم
Nernst potential for Na inside membrane = + 61mv.

Goldman equation

To calculate diffusion potential when membrane permeable for several ions

Net value of the internal membrane potential of about-86 mv

Almost all of this determined by K diffusion

3-contribution of Na/K PUMP:-

Pumps 3Na to outside & 2 K to inside, causing net loss of +ve ions ,loss of + ve charge from inside , create negativity about -4mv inside.

So net membrane potential will be : (-86 mv) + (-4mv) = -90 mv

يعني الملخص بشكل عام انو يبغانا نفهم كيف حصلنا على القيمة **membrane potential** = -90
فيقولك ان القيم اللي حصلنا عليها من معادلة نيرنست عن البوتاسيوم و الصوديوم استخدمنها في معادلة قولدمان و حصلنا على القيمة (-86 mv)
وأيضا يقول ان Na/K PUMP تعطينا قيمه معينه فعندما نقوم بجمع القيمتين نحصل على القيمه (-90 mv)
وايضاًعندنا بعض الايونات السالبه ولكن ليس لها تأثير يذكر مثل :

4- Effect of Large intracellular anions(negative ions)(proteins , sulphates & phosphates) very low effect

Measuring membrane potential

" VOLTMETER "

A small filled pipette containing electrolyte solution put inside the nerve fiber & another electrode is placed in the outside & membrane potential difference between inside & outside measured

GOOD LUCK