BIOELECTRIC POTENTIALS-2

Membrane Potentials

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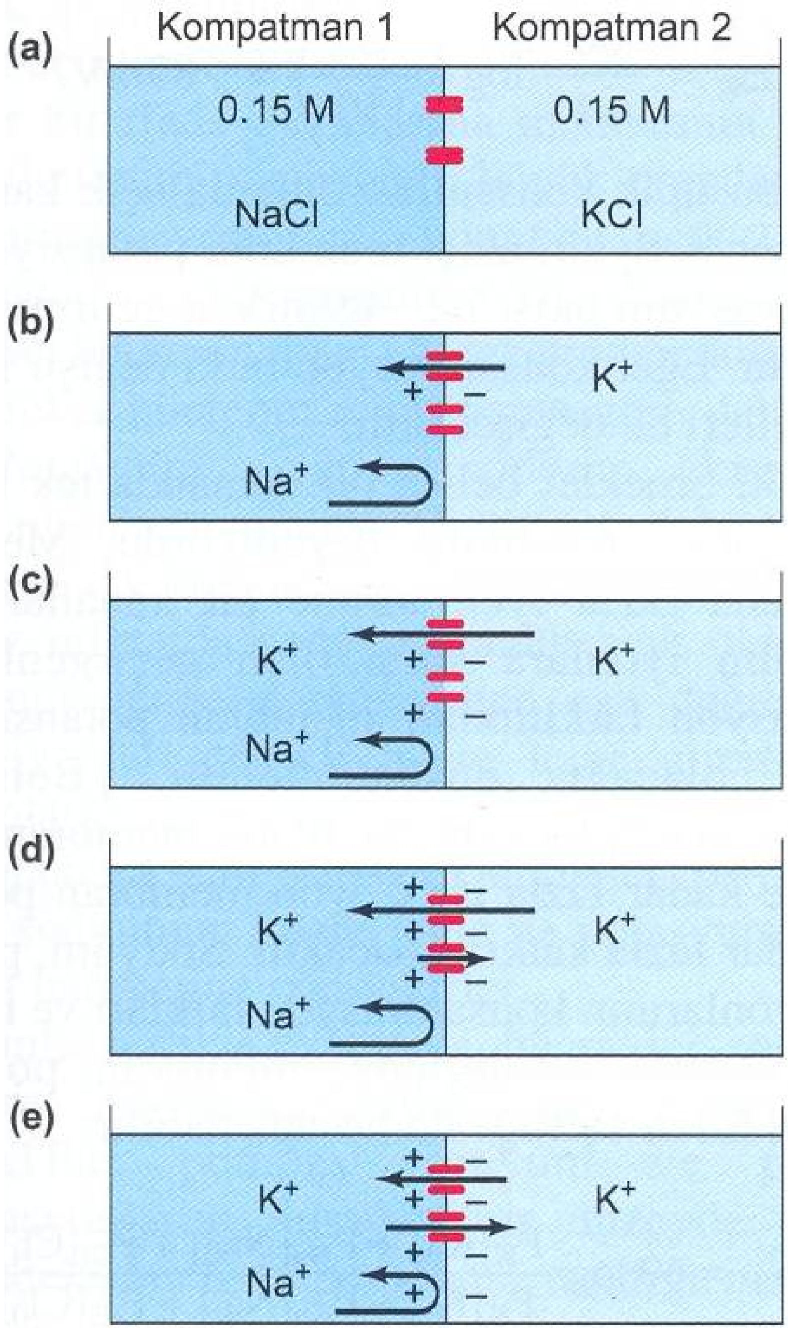


potassium (K +) permeable membrane

- **Chemical Force**

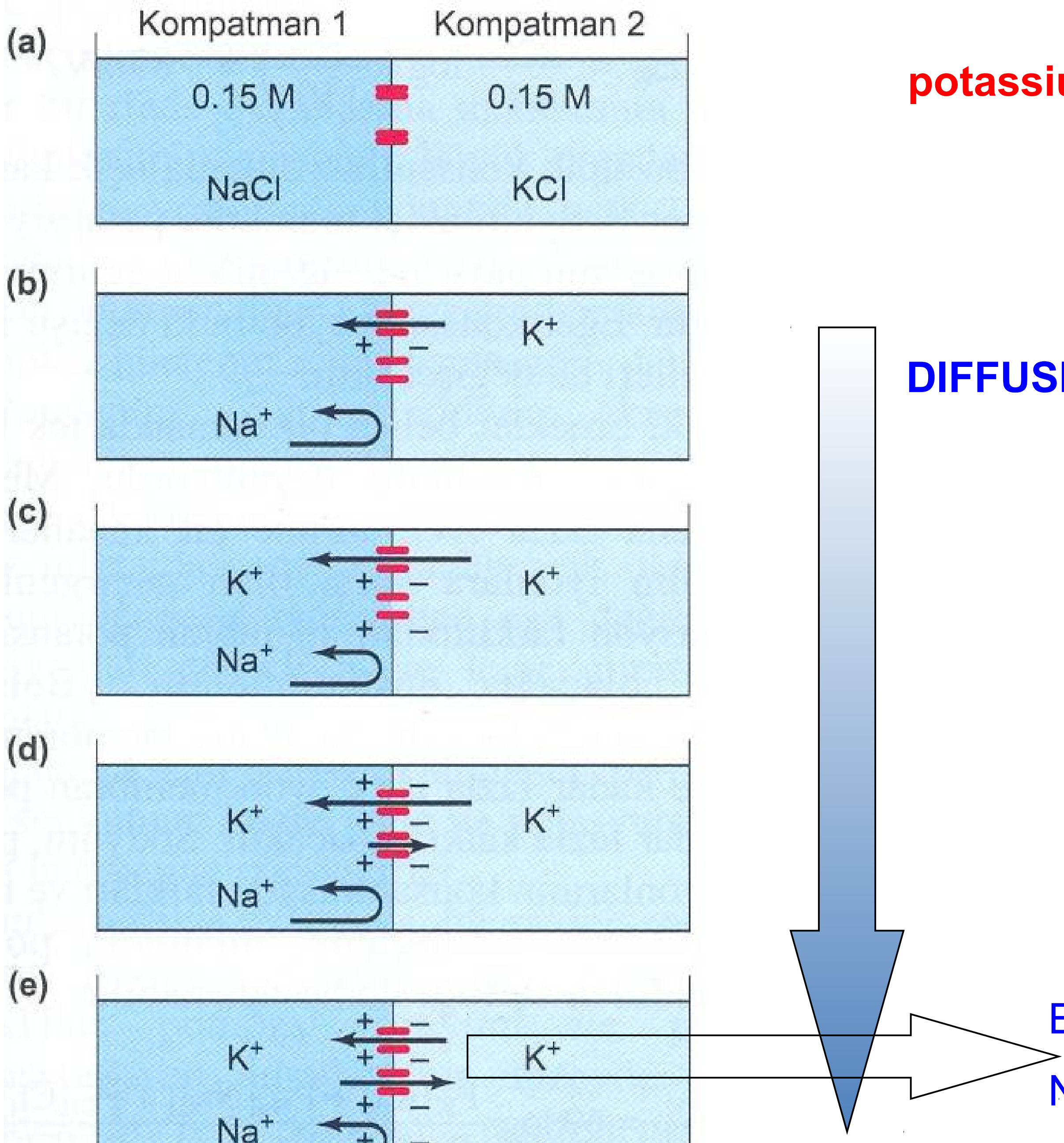
  (Concentration gradient)

- **Electrical Force**

  (Potential Difference)

- **Electrochemical equilibrium**

  (Net flux = 0)



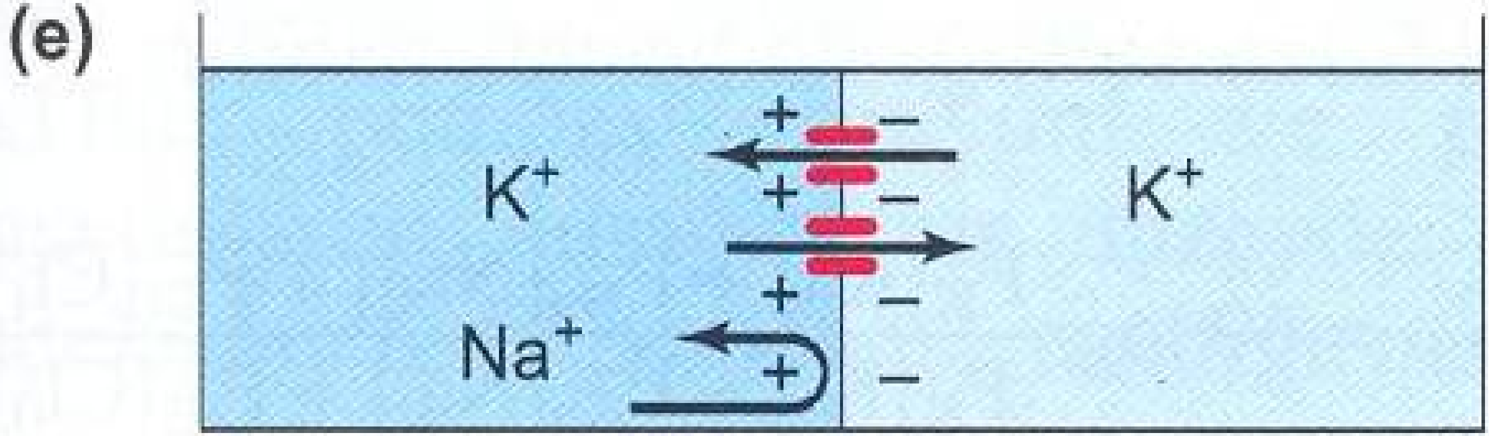
potassium (K +) permeable membrane

DIFFUSION POTENTIAL

Electrochemical Equilibrium

Net Flux = 0

EQULIBRIUM POTENTIAL



Electrical Work ⇄ Chemical Work (osmotic work) (Concentration gradient)

Electrical Work = Chemical Work

$$W_{el} = zFE \qquad W_{os} = RT\ \ln C_1/C_2$$

$$E_k = \frac{RT}{zF}\ln\left(\frac{K_o}{K_i}\right)$$

$$E_k = \frac{RT}{zF}2.303\log\left(\frac{K_o}{K_i}\right)$$

Nernst Potential

(Reversal Potential, Equlibrium Potential)

$$E_k = \frac{RT}{zF}\ln\left(\frac{K_o}{K_i}\right)$$

$$E_k = \frac{RT}{zF}2.303\log\left(\frac{K_o}{K_i}\right)$$

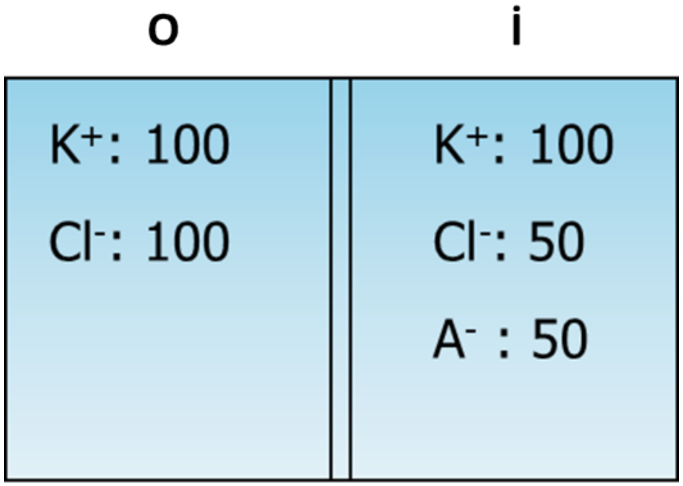
z = charge of ion (for K^+ ; z=+1)
F = Faraday constant (For 1mol ion: F= 96500 C/mol)
R = universal gas constant (8,31 J/mol.K)
T = Absolute temperature (Kelvin)

ln y = 2,303 log y

Nernst Potential

- The diffusion potential level across a membrane that exactly opposes the net diffusion of a particular ion through the membrane is called the *Nernst potential* for that ion.
- The magnitude of Nernst potential is determined by the *ratio* of the concentrations of that specific ion on the two sides of the membrane.
- The greater this ratio, the greater the tendency for the ion to diffuse in one direction, and therefore the greater the Nernst potential required to prevent additional net diffusion.

Nernst Equation for K^+ ions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K^+: 100

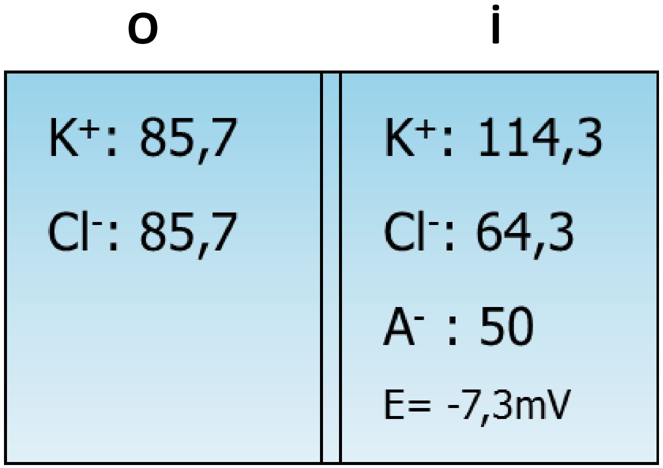
Cl^-: 100

K^+: 100

Cl^-: 50

A^- : 50

In Equilibrium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K^+: 85,7

Cl^-: 85,7

K^+: 114,3

Cl^-: 64,3

A^- : 50

E= -7,3mV

$E_k = (RT/zF)\ 2{,}303 \log(K_o/K_i)$

$E_k = ((8{,}31 \times 293)/(1 \times 96500)) \times$
$2{,}303 \times \log(85{,}7/114{,}3)$
$= 58{,}1 \times \log(0{,}75)$
$= -7{,}3$ mV

At room temperature $(RT/zF) = 25{,}2$ mV for +1 charged ions.

Nernst Equation for Cl^- ions

o	i
K^+: 100	K^+: 100
Cl^-: 100	Cl^-: 50
	A^- : 50

(z=-1)

$$E_k=-(RT/zF)\ 2{,}303\ \log(Cl_o/Cl_i)$$

$$E_k=-((8{,}31x293)/(1x96500))x\ 2{,}303x\ \log(85{,}7/114{,}3)$$

In Equilibrium

o	i
K^+: 85,7	K^+: 114,3
Cl^-: 85,7	Cl^-: 64,3
	A^- : 50
	E= -7,3mV

$$=-58{,}1 \text{ x } \log(1{,}333)$$

$$=-7{,}3 \text{ mV}$$

Calculation of the Diffusion Potential When the Membrane Is Permeable to Several Different Ions

- When a membrane is permeable to several different ions, the diffusion potential that develops depends on three factors:

(1) the polarity of the electrical charge of each ion,

(2) the permeability of the membrane to each ion, and

(3) the concentrations of the respective ions on the inside and outside of the membrane.

GOLDMAN – HODGKIN – KATZ EQUATION

$$V_m = 58 \log \frac{K_o + (p_{Na}/p_K)\,Na_o + (p_{Cl}/p_K)\,Cl_i}{K_i + (p_{Na}/p_K)\,Na_i + (p_{Cl}/p_K)\,Cl_o}$$

- P: the permeability of the membrane to each ion
- K_o,Na_o, Cl_o : are the concentrations of ions outside the membrane
- K_i,Na_i, Cl_i : are the concentrations of ions inside the membrane

$$V_m = 58 \log \frac{K_o + (p_{Na}/p_K)\,Na_o + (p_{Cl}/p_K)\,Cl_i}{K_i + (p_{Na}/p_K)\,Na_i + (p_{Cl}/p_K)\,Cl_o}$$

Sodium, potassium, and **chloride** ions are the most important ions involved in the development of **membrane potentials** in nerve and muscle fibers, as well as in the neuronal cells in the nervous system.

The concentration gradient of each of these ions across the membrane helps determine the voltage of the membrane potential.

The degree of importance of each of the ions in determining the voltage is proportional to the **membrane permeability** for that particular ion.

That is, if the membrane has zero permeability to both potassium and chloride ions, the membrane potential becomes entirely dominated by the concentration gradient of sodium ions alone, and the resulting potential will be equal to the **Nernst potential** for sodium.

Axon of Squid (-70 mV)

Ion	Intracellular Concentration	Extracellular Concentration
Na^+	460	50
K^+	10	400
Cl^-	540	40

Concentrations are in mM/l

p_K: 1.0, p_{Na}: 0.03, p_{Cl}: 0.1

$$V_m = 58 \log \frac{K_o + (p_{Na}/p_K)\,Na_o + (p_{Cl}/p_K)\,Cl_i}{K_i + (p_{Na}/p_K)\,Na_i + (p_{Cl}/p_K)\,Cl_o}$$

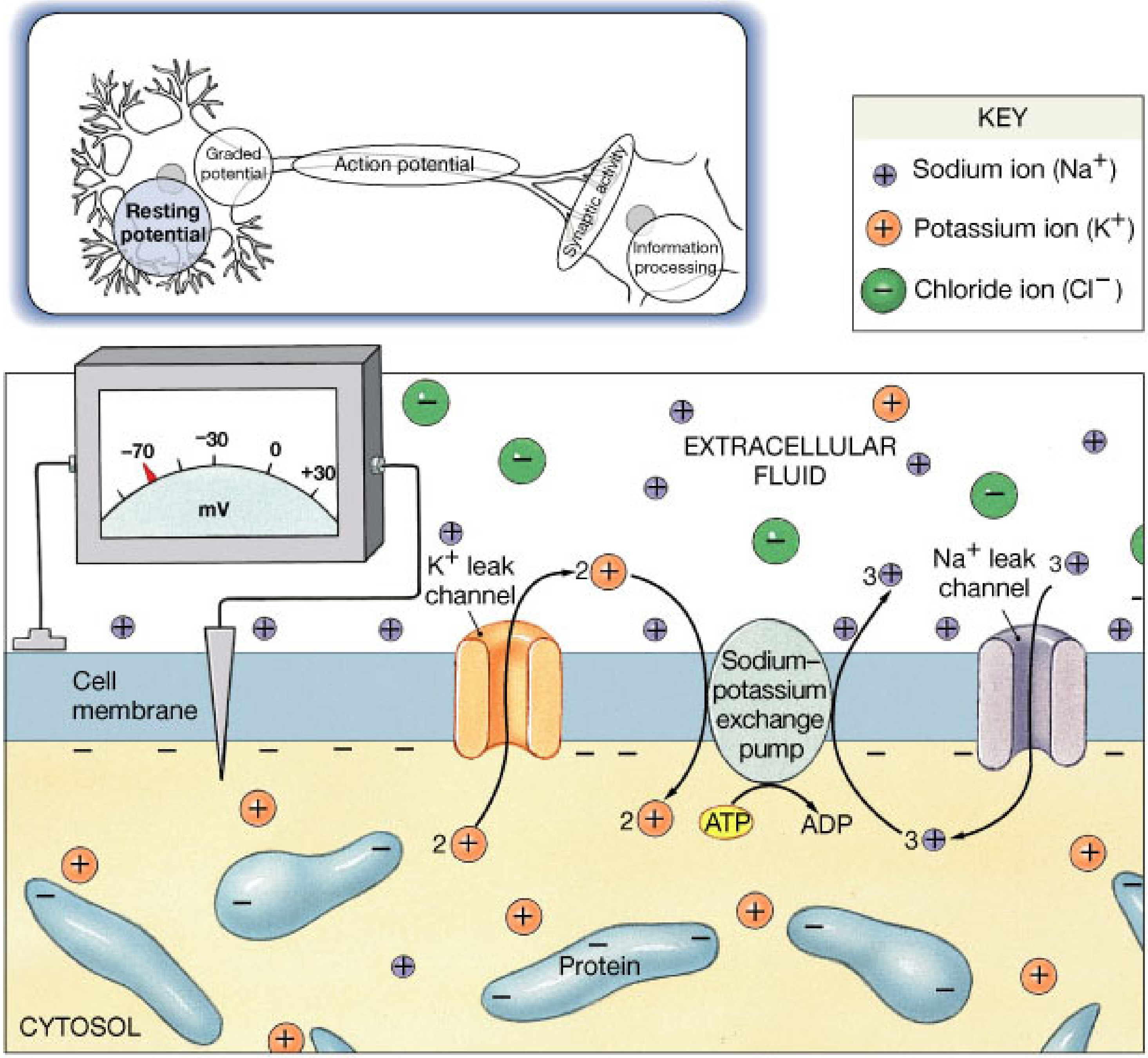
$$= 58 \log \frac{10 + (0.03)460 + (0.1)40}{400 + (0.03)50 + (0.1)540} = 58 \log \frac{10 + 13.8 + 4}{400 + 1.5 + 54} = -70 mV$$

As a result,

- Equilibrium potential for each ion that can pass through the membrane
- nondiffusible negative anions
- electrogenic effect of Na^{+} - K^{-} Pump

are important factors in the establishment of

Resting Membrane Potential.


Graded potential
Action potential
Resting potential
Synaptic activity
Information processing
KEY
Sodium ion (Na^+)
Potassium ion (K^+)
Chloride ion (Cl^-)
−70
−30
0
+30
mV
EXTRACELLULAR FLUID
K^+ leak channel
2
2
2
2
3
3
3
3
Na^+ leak channel
Sodium–potassium exchange pump
ATP
ADP
Cell membrane
Protein
CYTOSOL