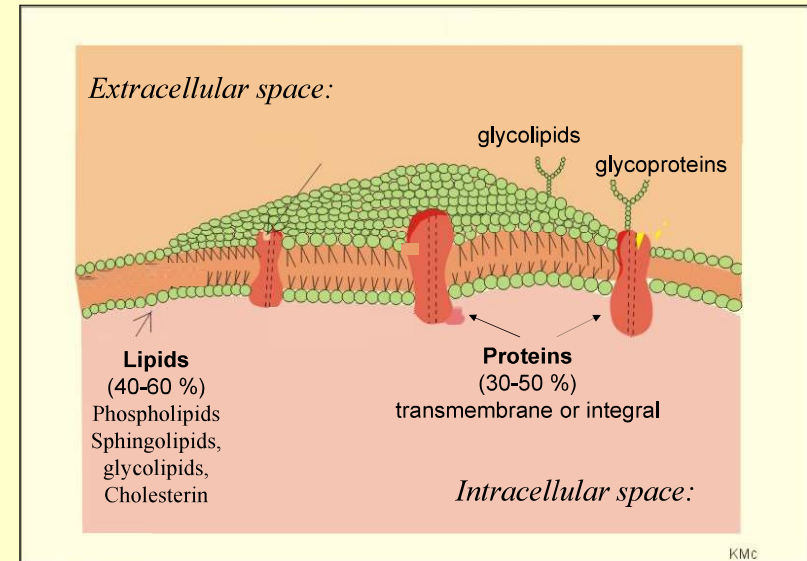


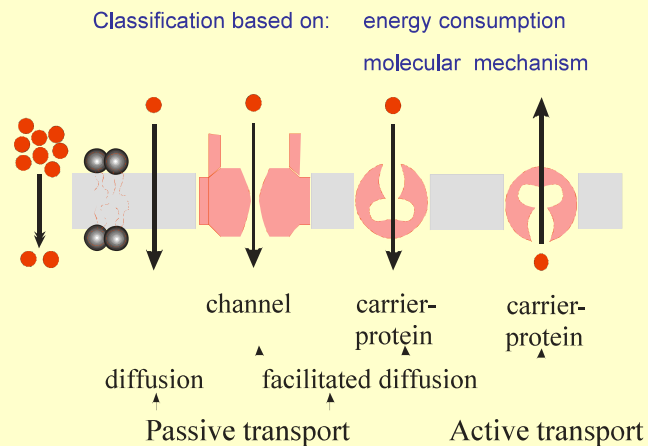
Transport across biological membranes

Transport in Resting Cell

Membrane structure



Transport types across the membranes



Diffusion of neutral particles

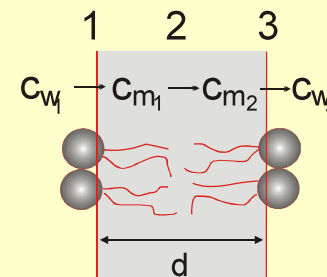
Diffusion across the lipid bilayer

Fick I.

$$J_m = -D \frac{\Delta c}{\Delta x}$$

$$D_m \ll D$$

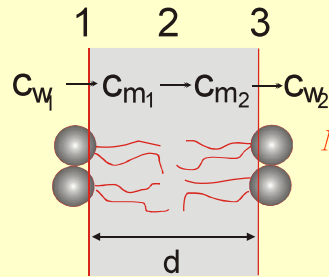
$$J_m = -D_m \frac{c_{m2} - c_{m1}}{d}$$



Assume that concentration changes linearly

Diffusion of neutral particles

Diffusion across the lipid bilayer



$$J_m = -D_m \frac{C_{m2} - C_{m1}}{d}$$

$$J_m = -p_m(C_{m2} - C_{m1})$$

Membrane permeability constant [ms^{-1}]



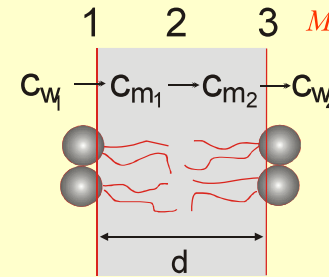
Cannot be measured

$$\frac{C_{m1}}{C_{v1}} = \frac{C_{m2}}{C_{v2}} = K$$

$$C_{m1} = KC_{v1}$$

Diffusion of neutral particles

Diffusion across the lipid bilayer



$$J_m = -p_m(C_{m2} - C_{m1})$$

Membrane permeability constant [ms^{-1}]



Cannot be measured

$$\frac{C_{m1}}{C_{v1}} = \frac{C_{m2}}{C_{v2}} = K$$

$$C_{m1} = KC_{v1}$$

$$J_m = -p_m K (C_{v2} - C_{v1})$$

$$J_m = -p(C_{v2} - C_{v1})$$

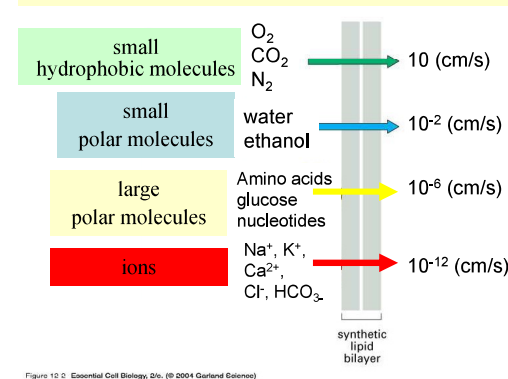
$$J_m = -p(C_{v2} - C_{v1})$$

Permeability constant [ms^{-1}]

It is influenced by:

- diffusion coefficient within the membrane
- thickness of the membrane
- partition coefficient

Permeability vs hydrophobicity



Lipid solubility v permeability

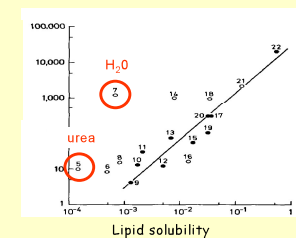


Figure 12-2 Essential Cell Biology, 2/e, (© 2004 Garland Science)

Diffusion of ions

$$\text{Fick I. } J_m = -D \frac{\Delta c}{\Delta x}$$

chemical potential
and
electric potential
together

$$J_k = L_k X_k = -L_k \frac{\Delta \mu_{ek}}{\Delta x}$$

flux of k -th ion

Diffusion of ions

$$J_k = L_k X_k = -L_k \frac{\Delta \mu_{ek}}{\Delta x}$$

$$\frac{\Delta \mu_{ek}}{\Delta x} = \frac{\Delta \mu_k}{\Delta x} + z_k F \frac{\Delta \phi}{\Delta x} \quad \text{és} \quad L_k = c_k \frac{D_k}{RT}$$

$$J_k = -D_k \left(\frac{\Delta c_k}{\Delta x} + c_k \frac{z_k F}{RT} \frac{\Delta \phi}{\Delta x} \right)$$

$$D = ukT$$

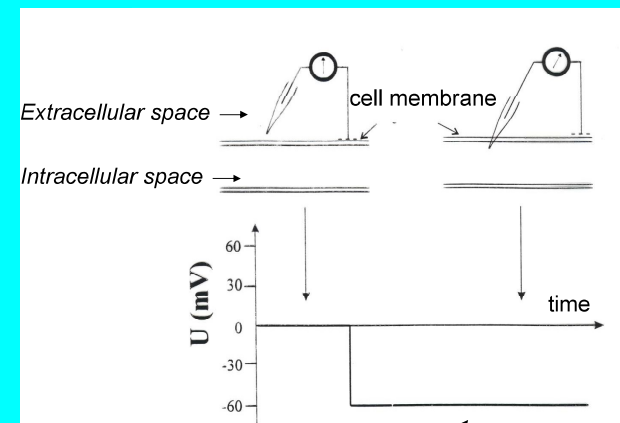
$$J_k = -u_k kT \left(\frac{\Delta c_k}{\Delta x} + c_k \frac{z_k F}{RT} \frac{\Delta \phi}{\Delta x} \right)$$

flux of k -th ion

Basic principles of electrophysiology

Interpretation by transport phenomena

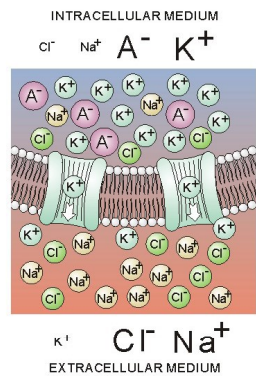
Observation 1: There is an electric potential difference between extra- and intracellular space



The intracellular side is negative with respect to the extracellular side

resting potential $\sim 60 - 90$ mV

Observation 2: Inhomogeneous ion distribution



Cell type	$C_{\text{Intracellular}}$ (mmol/l)			$C_{\text{Extracellular}}$ (mmol/l)		
	$[\text{Na}^+]_i$	$[\text{K}^+]_i$	$[\text{Cl}^-]_i$	$[\text{Na}^+]_e$	$[\text{K}^+]_e$	$[\text{Cl}^-]_e$
Squid axon	72	345	61	455	10	540
Frog muscle	20	139	3,8	120	2,5	120
Rat muscle	12	180	3,8	150	4,5	110

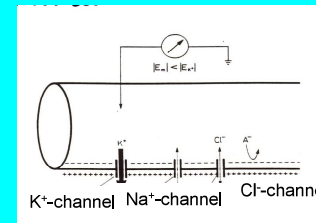
Interpretation of the membrane potential

1. Assume that the system is *not in equilibrium*

that is

transport is forced across the membrane

2. Take into consideration the real permeability of the membrane



the membrane is represented
by specific ion-permeabilities

Electrodiffusion model - transport across the membrane

$$\sum J_k = 0$$

k : Na, K, Cl,

$$\sum J = J_{\text{K}^+} + J_{\text{Na}^+} + J_{\text{Cl}^-} = 0$$

$$J_k = -D_k \left(\frac{\Delta c_k}{\Delta x} + c_k \frac{z_k F}{RT} \frac{\Delta \varphi}{\Delta x} \right)$$

$$D_k = dp_k$$

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

Electrodiffusion model

Goldman – Hodgkin – Katz formula

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

c_k : ion-concentration
 p_k : permeability constant
 e : extracellular
 i : intracellular

Electrodifusion model

Goldman – Hodgkin – Katz formula

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

potential (mV)	Squid axon	Rat muscle
U_{measured}	-62	-92
U_{GHK}	-61,3	-89,2

Good agreement with experimental results



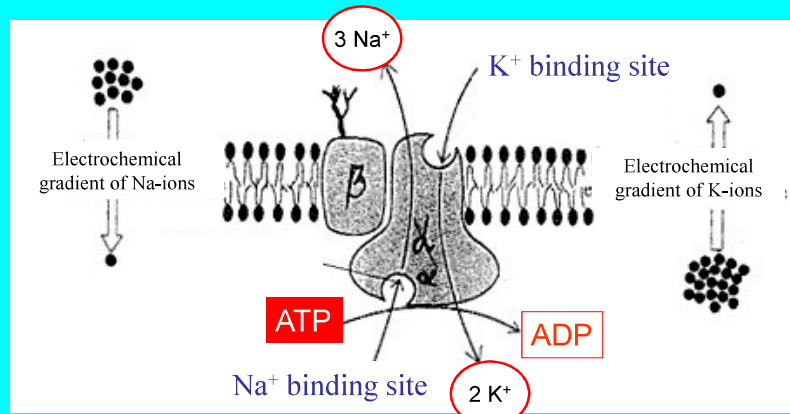
Electrodifusion model

- Resting U_m depends on the concentration gradients and on the relative permeabilities to Na, K and Cl.
- The GHK equation describes a steady-state condition, not electrochemical equilibrium.
- There is net flux of individual ions, but no net charge movement.
- The cell must supply energy to maintain its ionic gradients.

Na - K pump

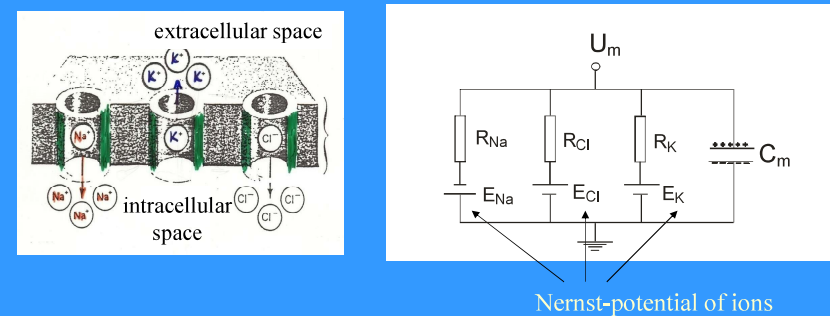
antiporter

The condition for stationary flow is maintained by the active transport



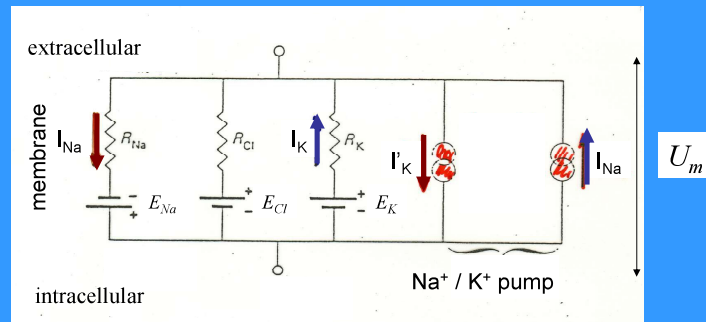
Interpretation of the membrane potential 2

Equivalent circuit model



Ionselective channels modeled by electromotive force and conductivity

Na^+/K^+ pump restores the ion distribution



Ohm's law:

$$I_k = 1/R_k(U_m - E_k)$$