Water and Solute Metabolism
Ionic and Osmotic Regulation

In order to understand how organisms maintain salt and water balance,

we must understand how:

- **water moves**
- **solutes (ions) move**

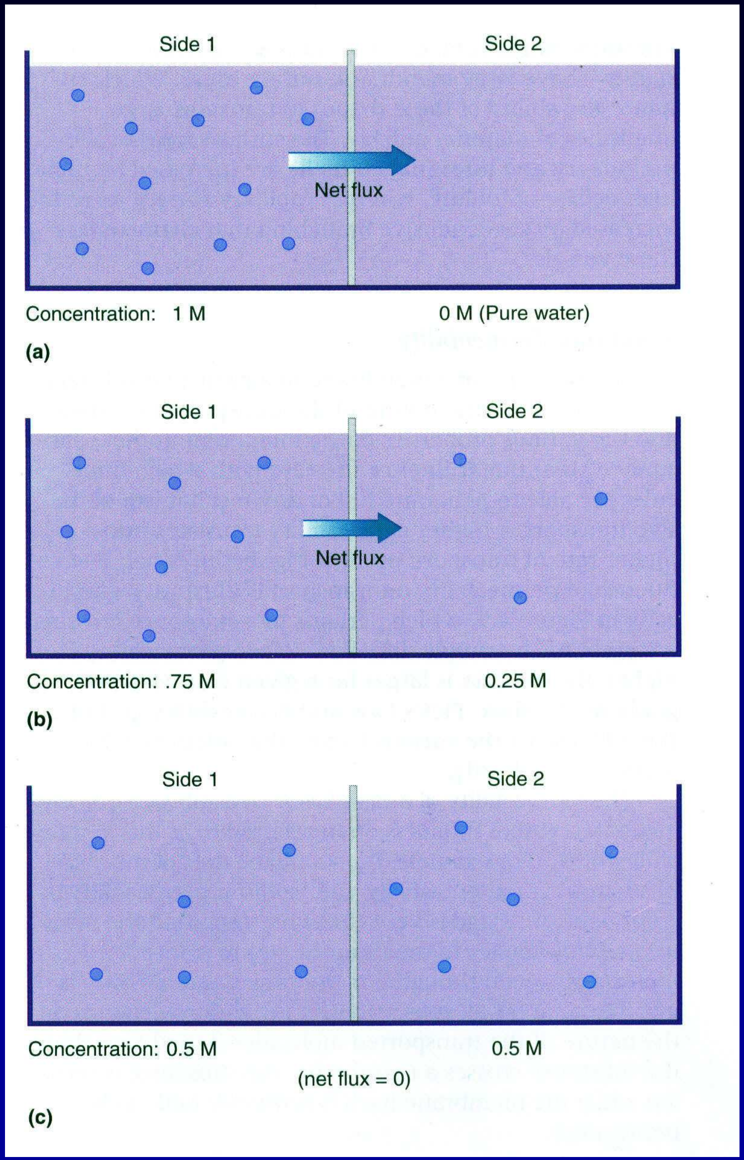
Water movement:

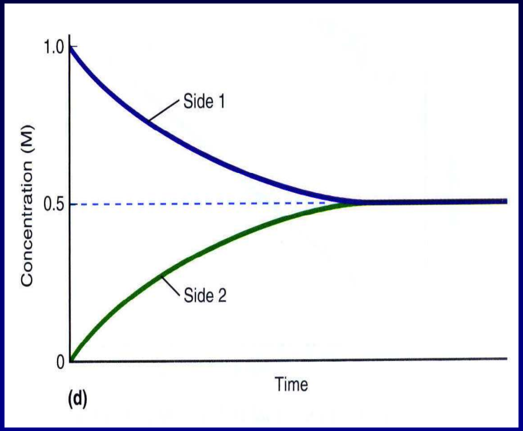
- Bulk transport (flow)
- Filtration
- Osmosis

Solute & Ion Movement

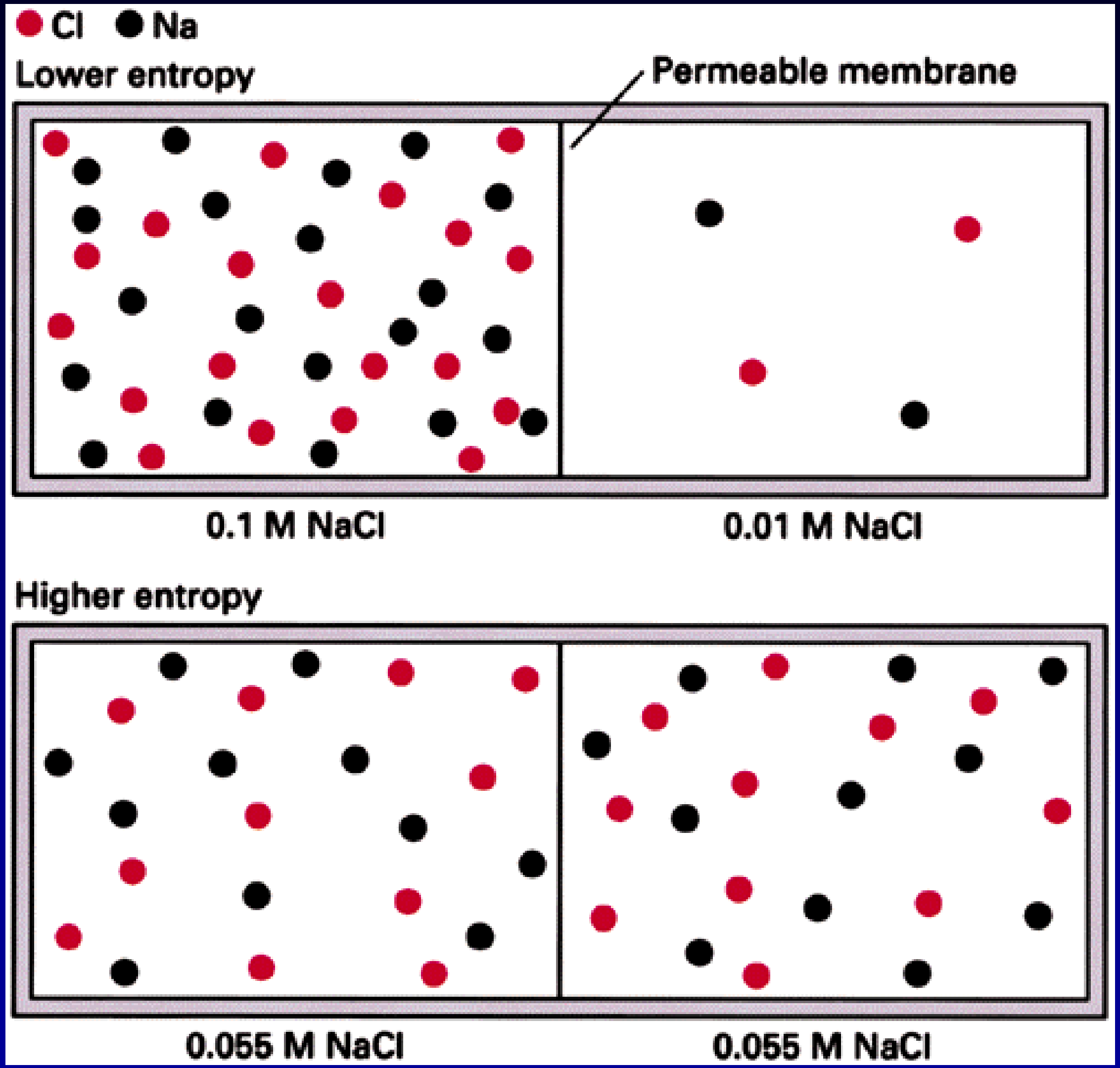
- Diffusion
- Active Transport

Simple diffusion

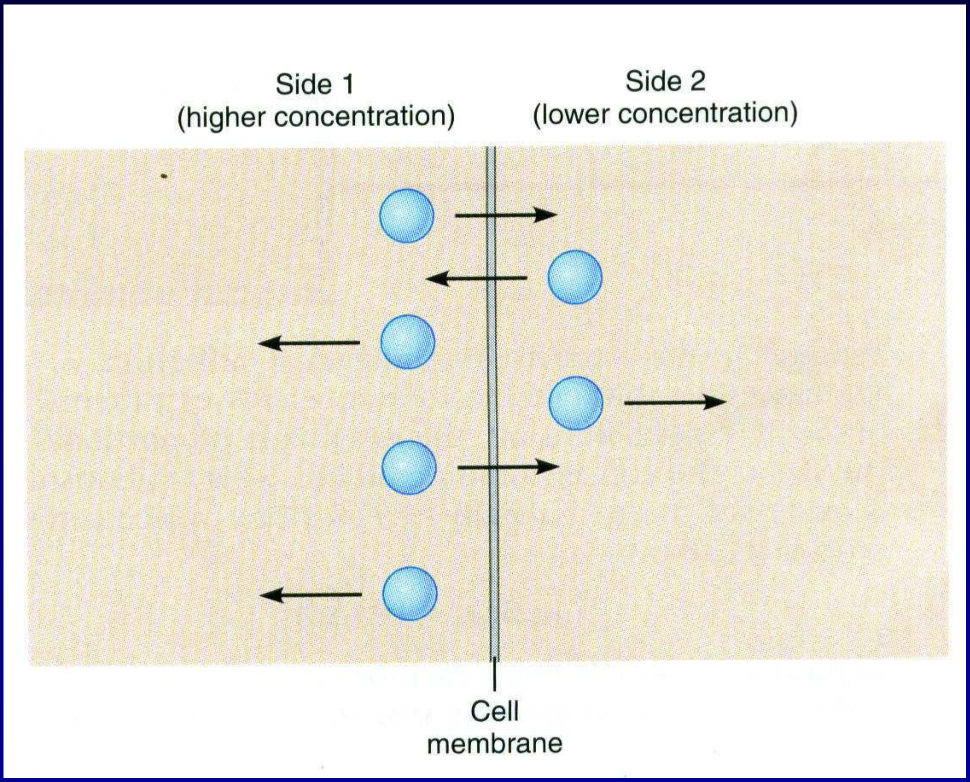




Particles move by diffusion



If thermal motion is random, why is movement down a concentration gradient?



Features of Simple Diffusion

- A passive process
- Movement from area of higher to lower concentration
- Net movement continues until equilibrium is reached
- More rapid over short distances
- Directly related to temperature
- Inversely related to molecular size
- Can take place in open site or across membrane

Some Definitions

mole = gmwt of element or compd (= 6.023 x 10^{23} molecules**)**

concentration = moles/liter or mmol/liter (e.g., 0.5 mol/l = 500 mmol/l)

1 **molar** solution = 1 mol/l = 1 gmtw/l

osmotic conc = **osmolarity** = # of particles in solution

1 mol of particles = 1 osmol

1 osmol • l^{-1} = 1 Osm (1osmolar)

1 Osm = 1000 mOsm

Non-electrolyte (e.g., sugar, urea):

osmolarity = molar concentration

(**e.g., 1 molar glucose = 1 Osm**)

Electrolyte (NaCl) = dissociates in solution

(e.g .1M NaCl = 100 mmol NaCl)

100 mmol • l^{-1} Na^+ **100 mmol • l^{-1} Cl^-**

= 200 mosmol • l^{-1} = 200 mOsm or

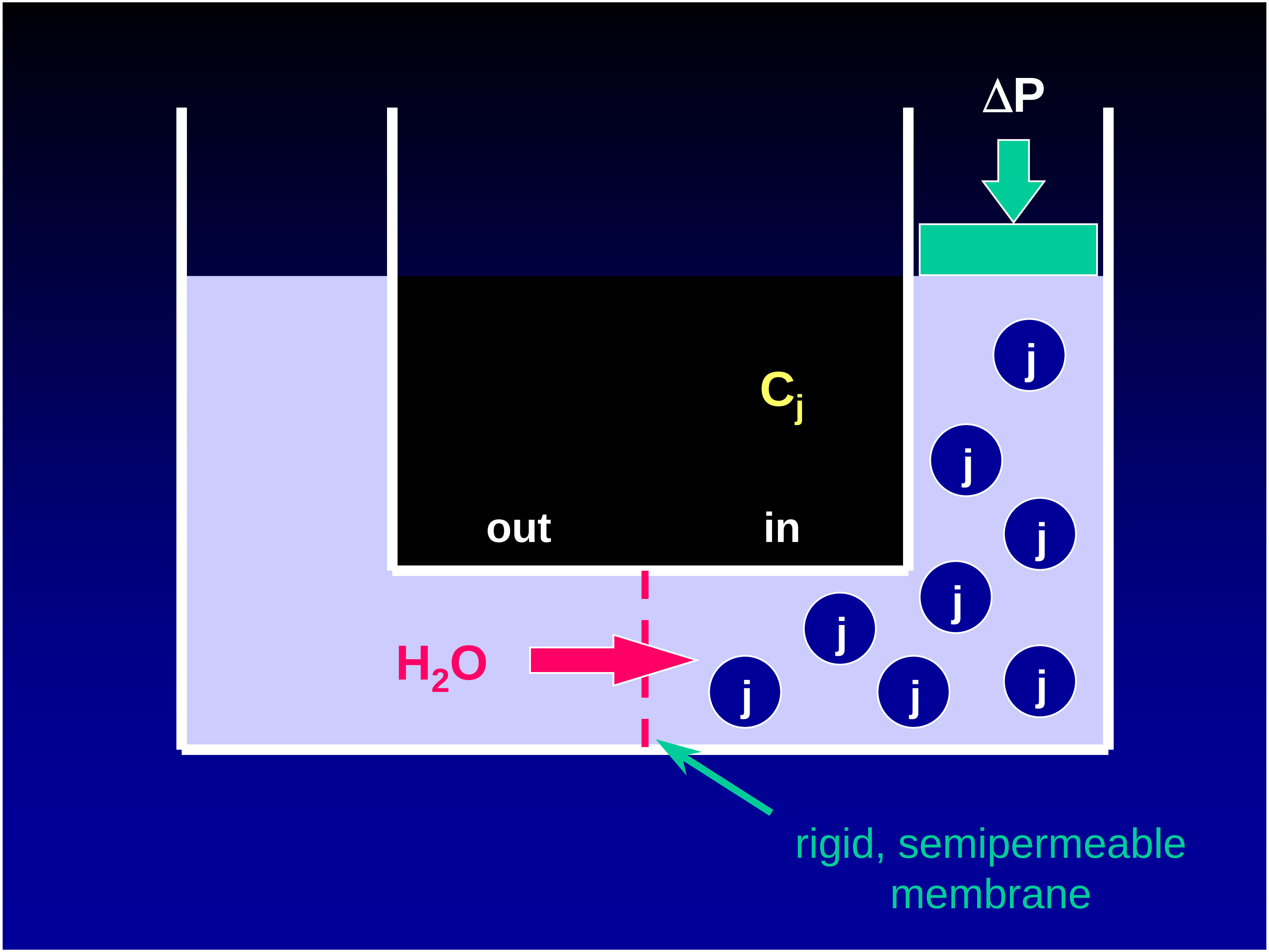
.2 Osm NaCl

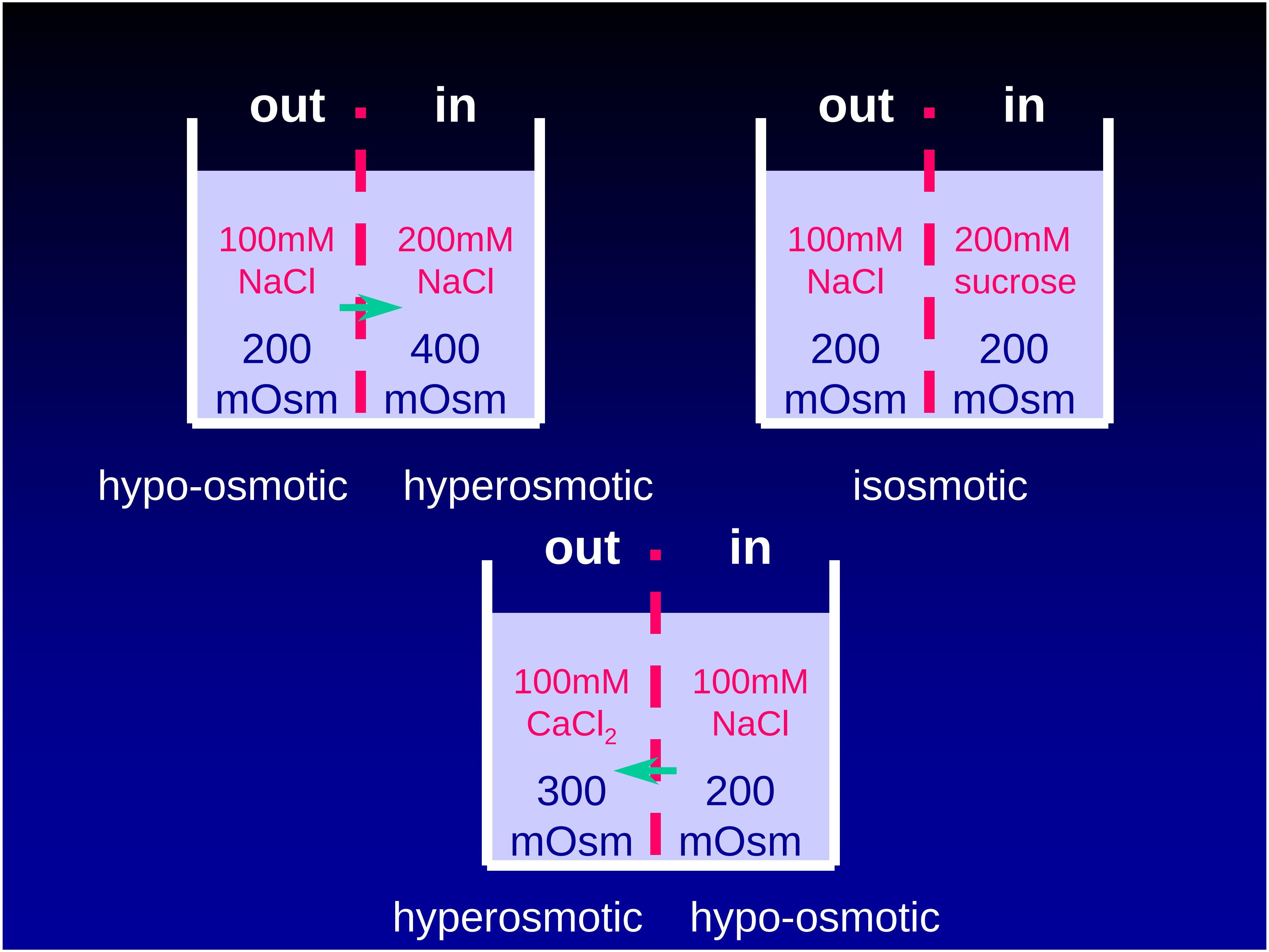
Osmosis

- Movement of water across semi-permeable membrane in response to a concentration gradient

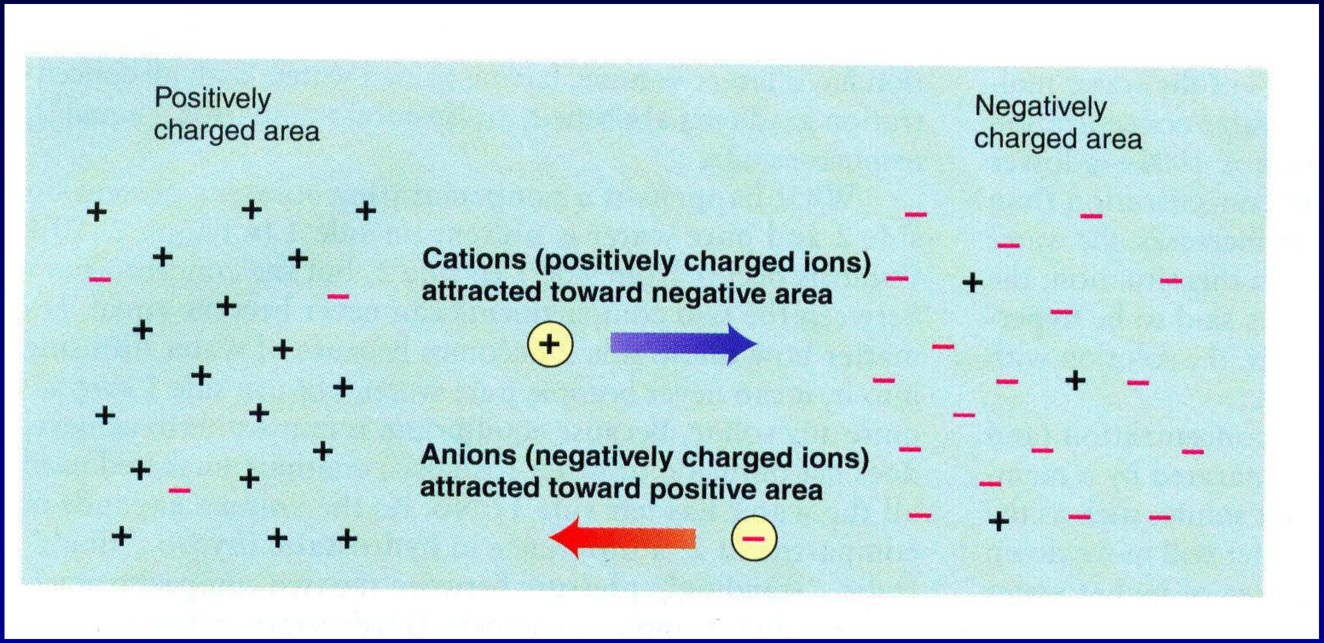
Water moves from area of high water concentration to area of lower water concentration

Water moves from an area of less concentrated solute to an area of more concentrated solute

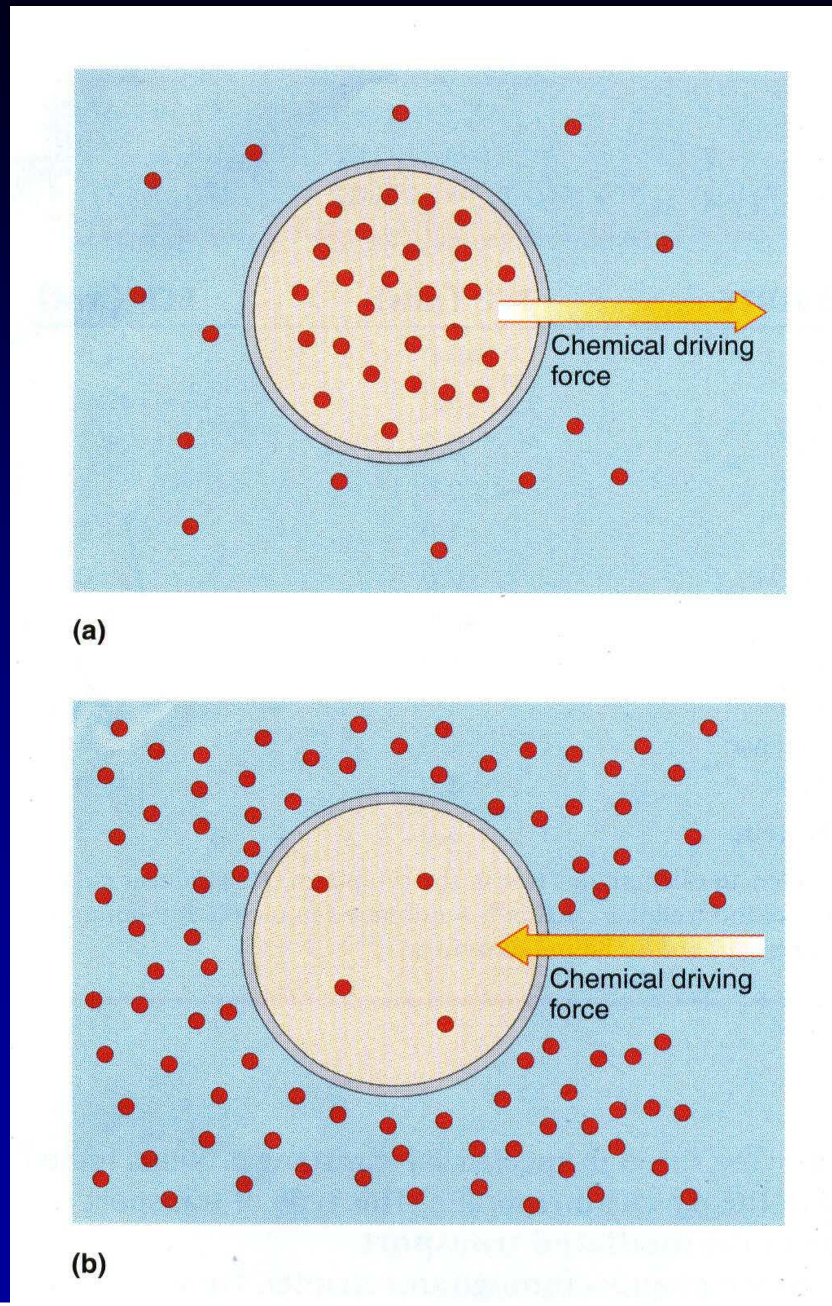

ΔP
c_j
out
in
H_2O
j
rigid, semipermeable membrane


out
in
100mM NaCl
200mM NaCl
200 mOsm
400 mOsm
hypo-osmotic
hyperosmotic
out
in
100mM NaCl
200mM sucrose
200 mOsm
200 mOsm
isosmotic
out
in
100mM $CaCl_2$
100mM NaCl
300 mOsm
200 mOsm
hyperosmotic
hypo-osmotic

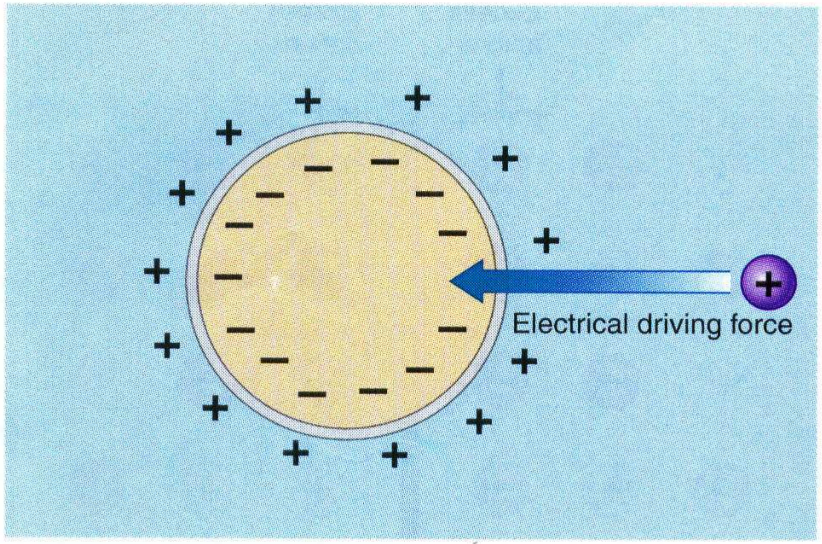
Diffusion of Charged Particles



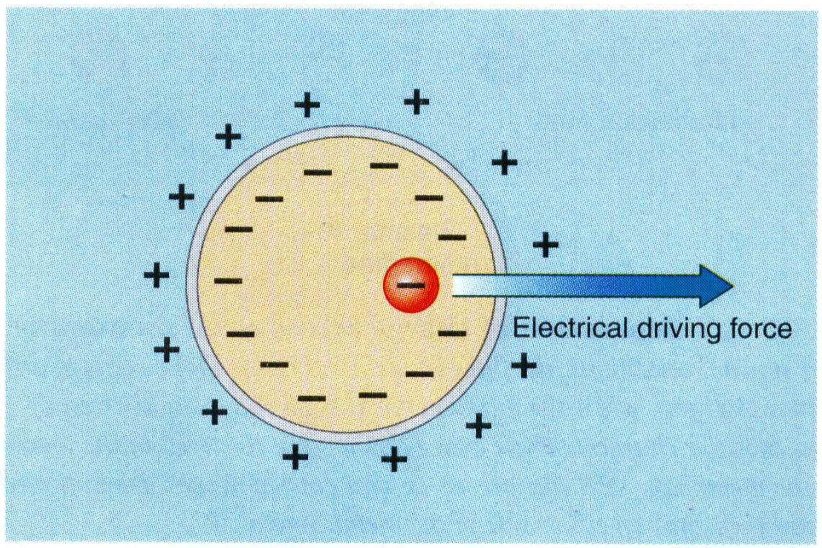
Chemical Driving Forces



Electrical Driving Forces

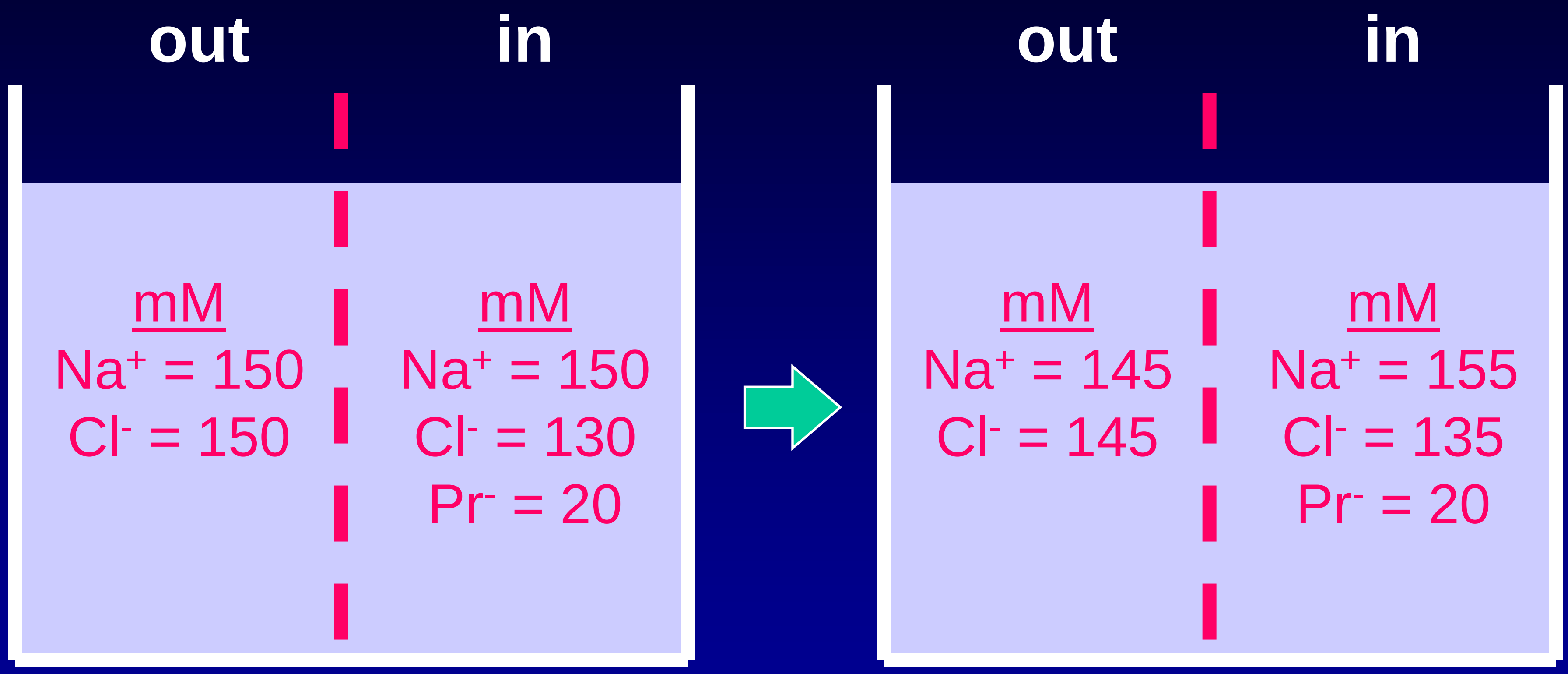


(a)



(b)

Gibbs-Donnan Equilibrium



electroneutrality - same # of + and - charges in a compartment.

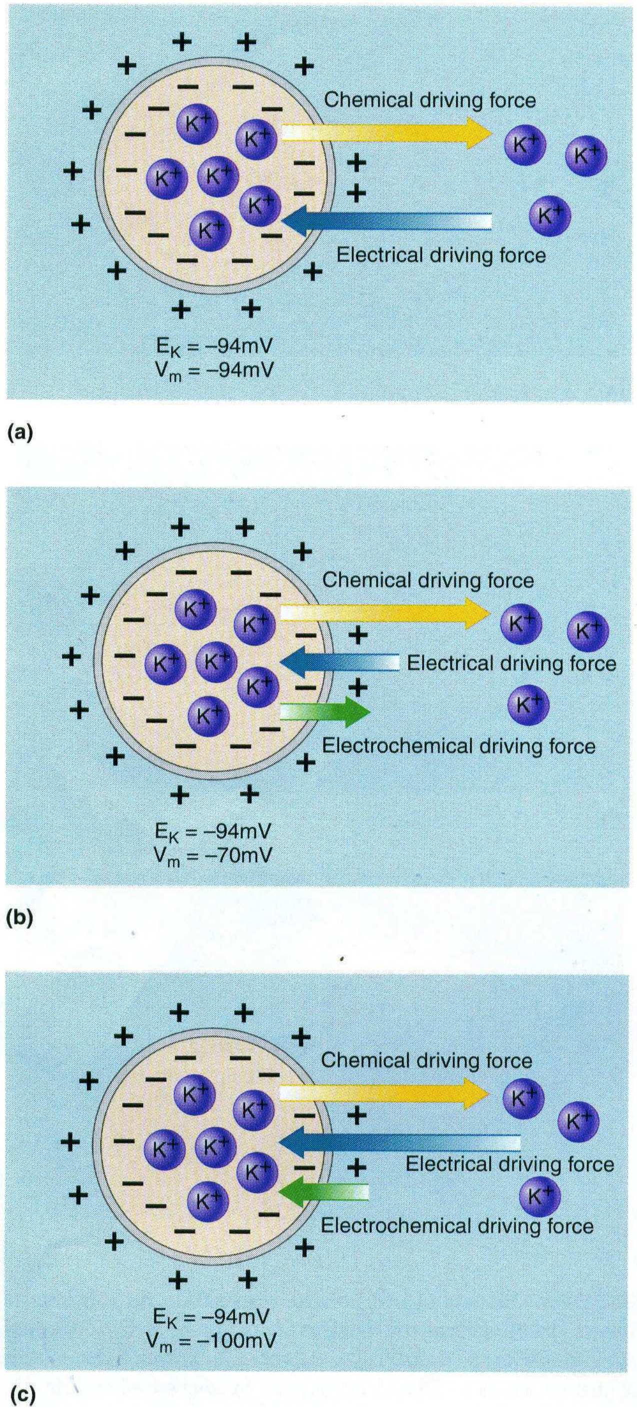
Equilibrium potential

Calculate using the Nernst equation

$$E_{Na} = \frac{+25mV}{z_{Na}} \ln \frac{C_{Na}^{o}}{C_{Na}^{i}}$$

$$E_{Na} = \frac{+25mV}{+1} \ln \frac{145}{155}$$

$$= -1.7 \text{ mV}$$



Equilibrium potential for K^+ = E_K =

-94 mv

C_K on outside = 3 mM

C_K on inside = 130 mM

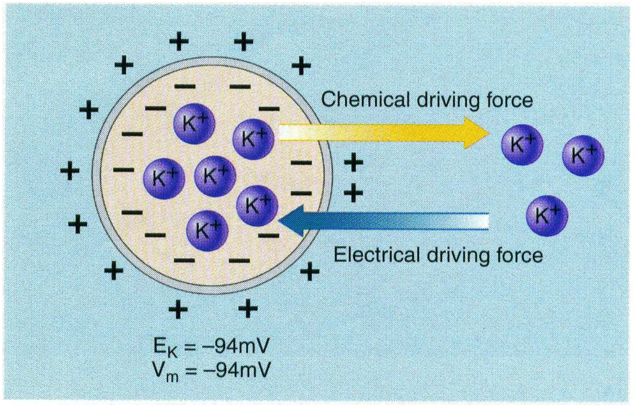
Membrane potential (V_M) assumed to be negative

Equilibrium Potential of K^+

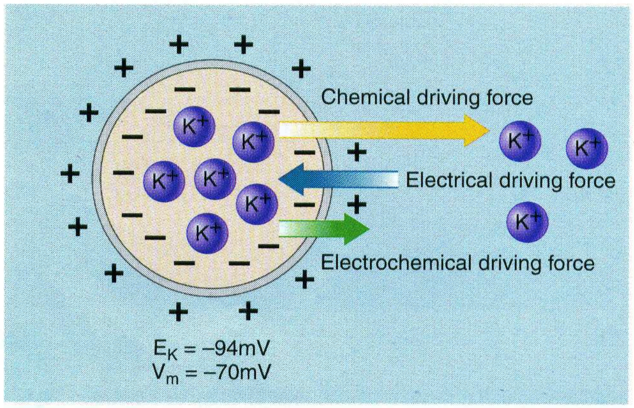
$$E_K = \frac{+25mV}{z_K} \ln \frac{C_K^o}{C_K^i}$$

$$E_K = \frac{+25mV}{+1} \ln \frac{3}{130}$$

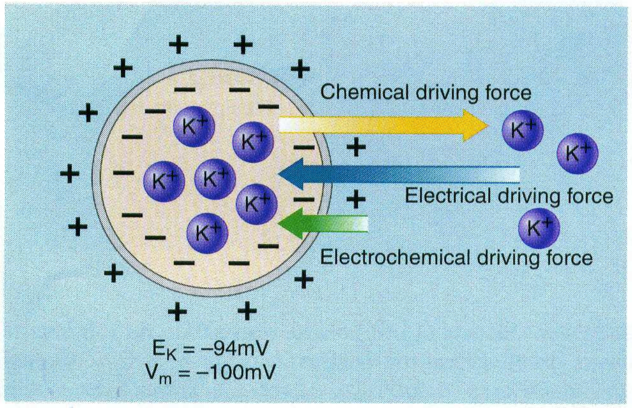
$$E_K = -94 \text{ mV}$$



(a)



(b)



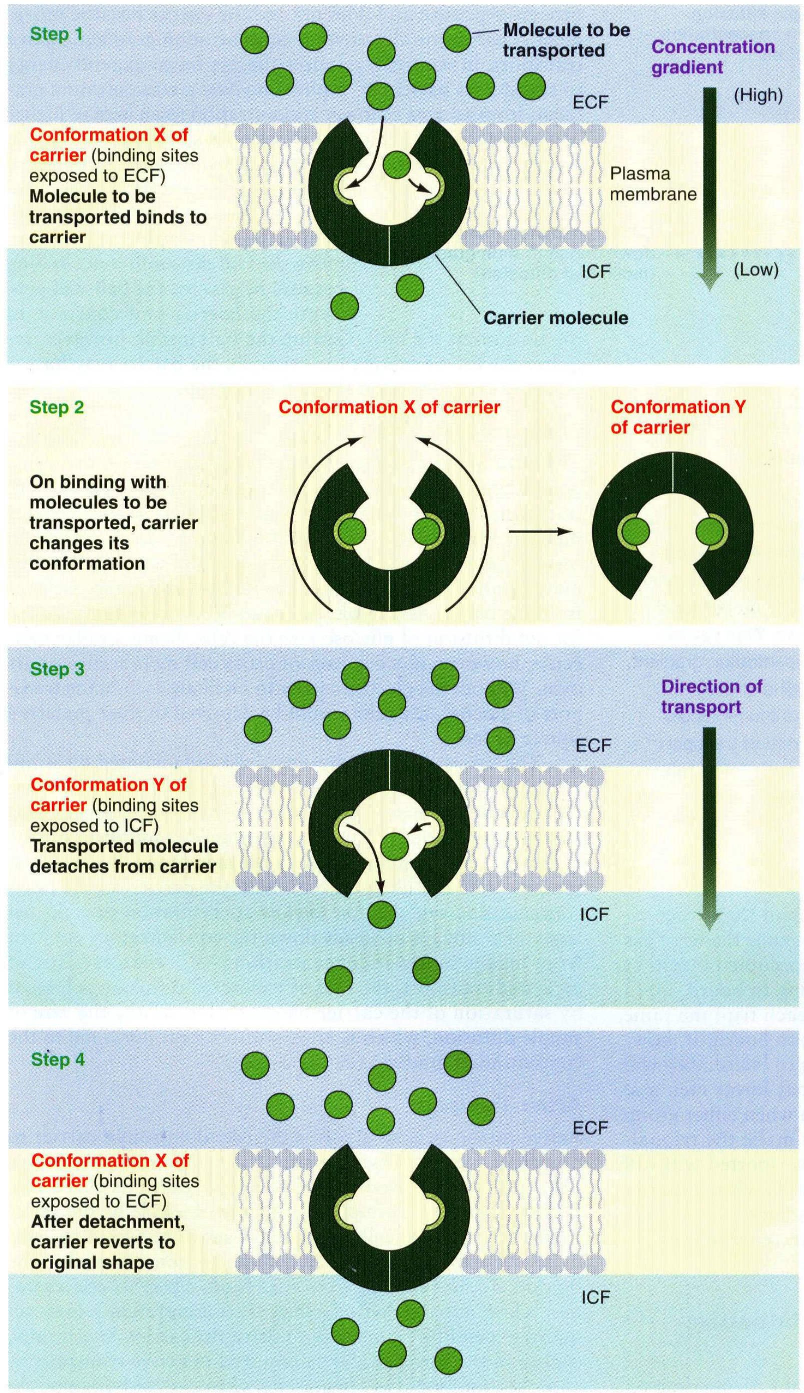
(c)

Equilibrium potential for K^+ = E_K = -94 mv

Membrane potential (V_M) assumed to be negative

Facilitated Diffusion

- Means by which many “polar organic compds” move across cell membranes
- Still obey favorable concentration gradients
- Hydrophilic—cannot dissolve in lipid interior
- Rely on proteins embedded in membrane
- Non-covalent, reversible bonding

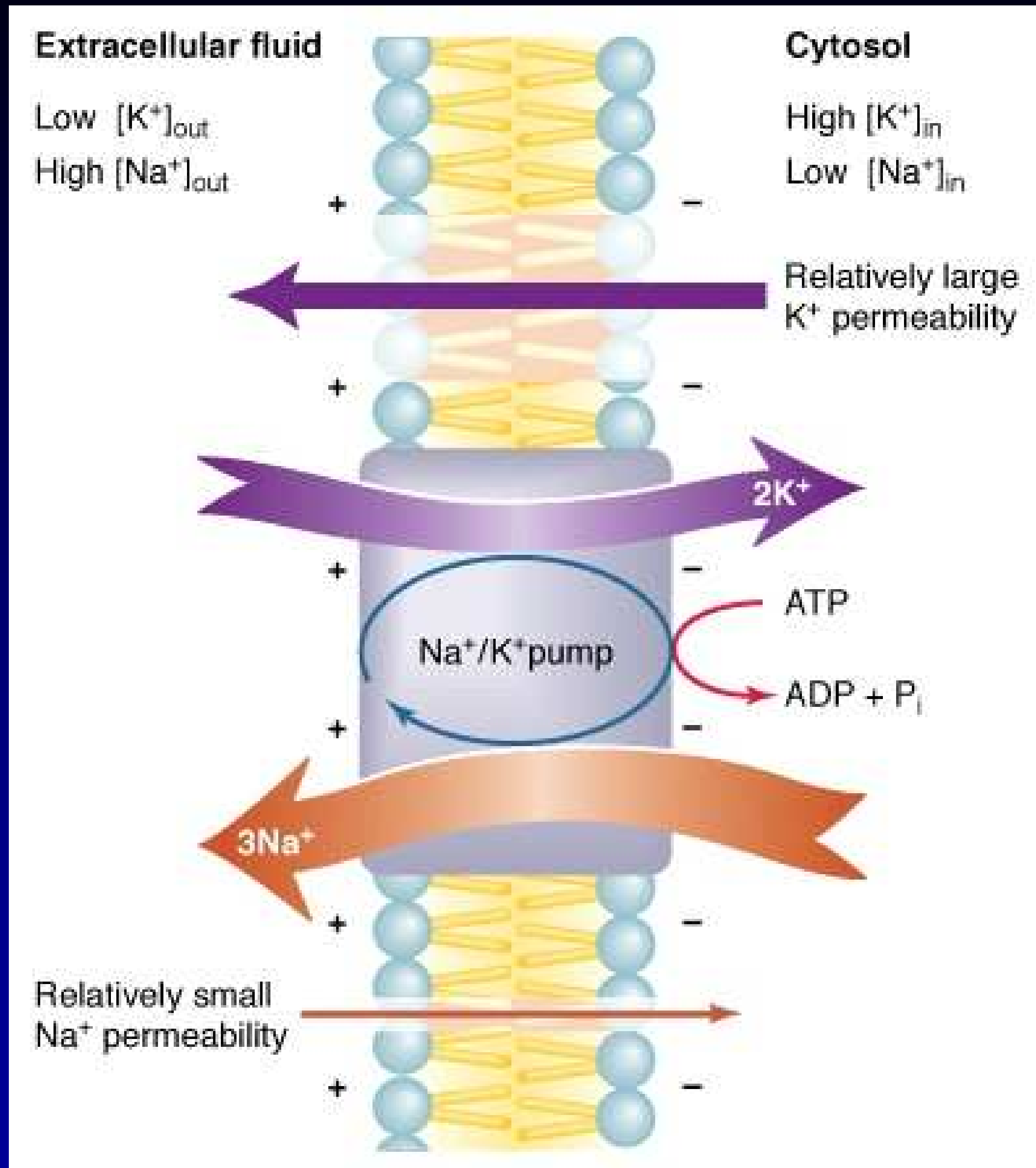

Step 1
Molecule to be transported
Concentration gradient
(High)
ECF
Conformation X of carrier (binding sites exposed to ECF)
Molecule to be transported binds to carrier
Plasma membrane
ICF
(Low)
Carrier molecule
Step 2
Conformation X of carrier
Conformation Y of carrier
On binding with molecules to be transported, carrier changes its conformation
Step 3
Direction of transport
ECF
Conformation Y of carrier (binding sites exposed to ICF)
Transported molecule detaches from carrier
ICF
Step 4
ECF
Conformation X of carrier (binding sites exposed to ECF)
After detachment, carrier reverts to original shape
ICF

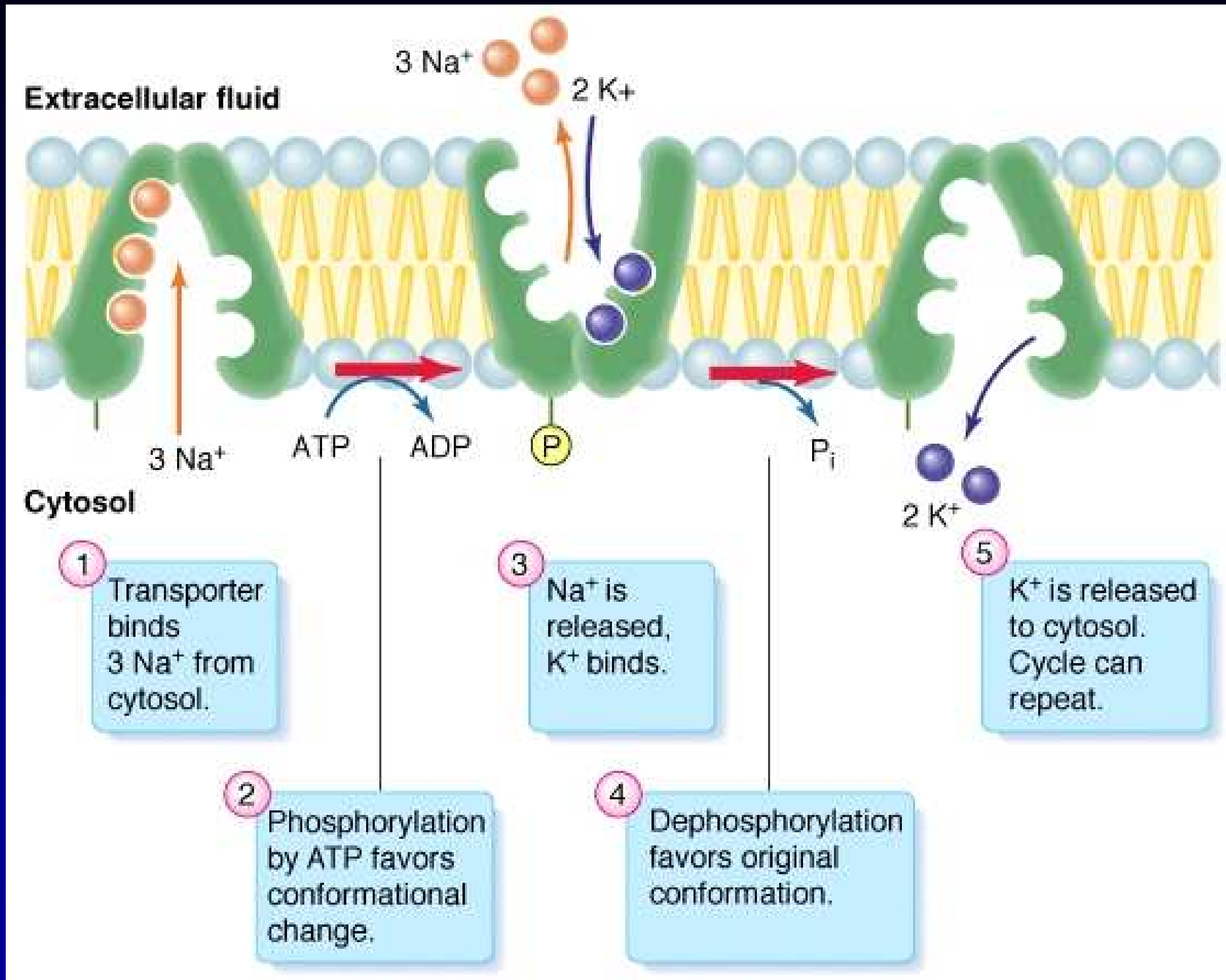
Active Transport

The net movement of a substance against
an electrochemical gradient
that is directly linked to metabolic energy.

Characteristics:

- Requires source of chemical energy
- Sensitive to metabolic poisons (e.g. CN)
- Sensitive to specific inhibitors (e.g., ouabain)


Extracellular fluid
Low $[K^+]_{out}$
High $[Na^+]_{out}$
Cytosol
High $[K^+]_{in}$
Low $[Na^+]_{in}$
Relatively large K^+ permeability
$2K^+$
ATP
Na^+/K^+pump
ADP + P_i
$3Na^+$
Relatively small Na^+ permeability


Extracellular fluid
3 Na+
2 K+
3 Na+
ATP
ADP
P
Pi
2 K+
Cytosol
1 Transporter binds 3 Na+ from cytosol.
2 Phosphorylation by ATP favors conformational change.
3 Na+ is released, K+ binds.
4 Dephosphorylation favors original conformation.
5 K+ is released to cytosol. Cycle can repeat.