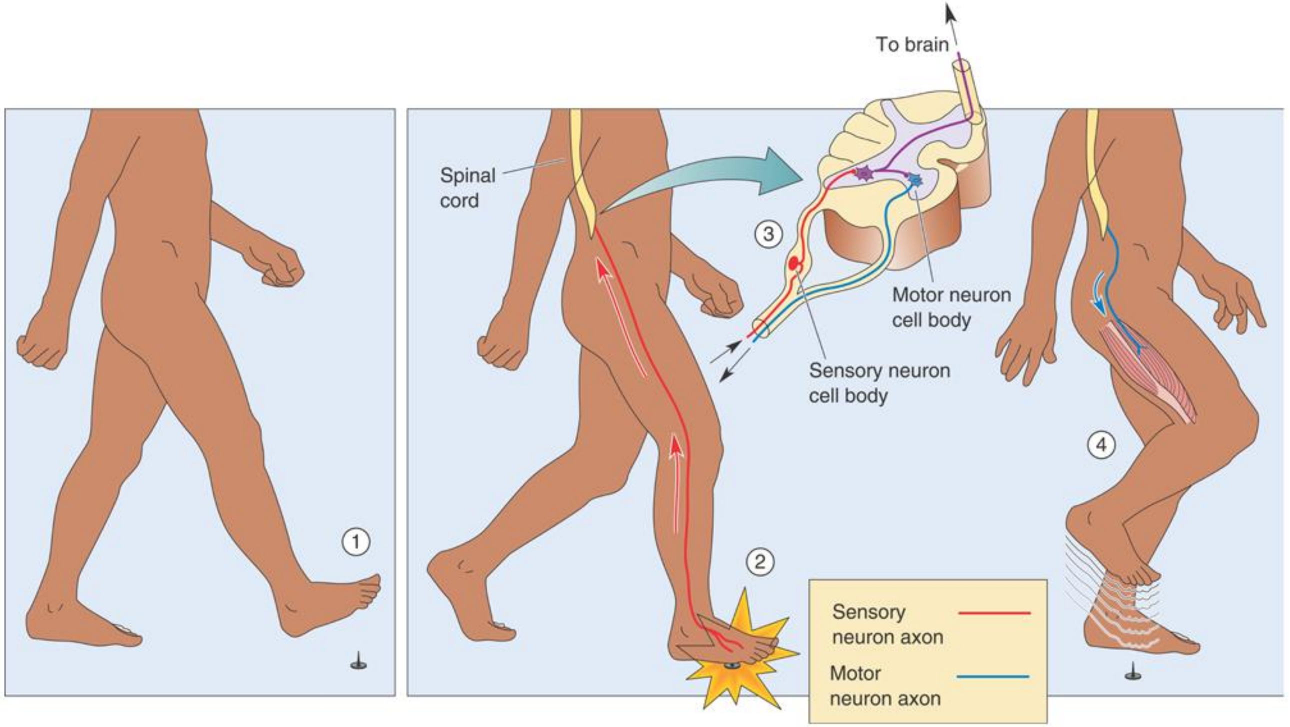
Neuroscience: Exploring the Brain

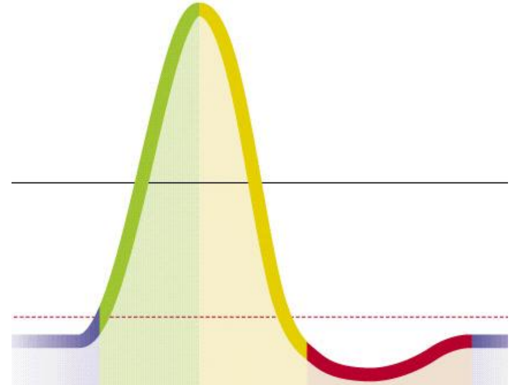
Chapter 3: The Neuronal Membrane at Rest

Introduction

- Action potential in the nervous system
  - Action potential vs. resting potential



Not at rest
action potentials

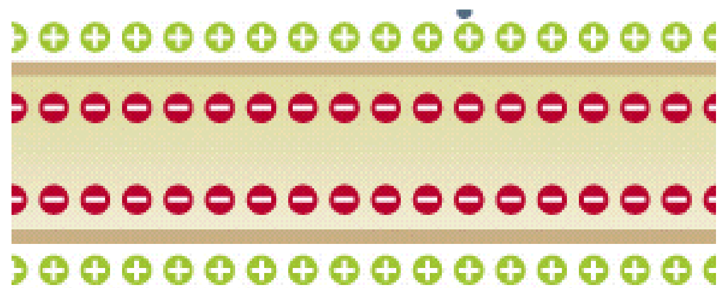


Starring:

water and its polar covalent bonds

ions and distribution of + or – charges

membranes



also starring

proteins and enzymes

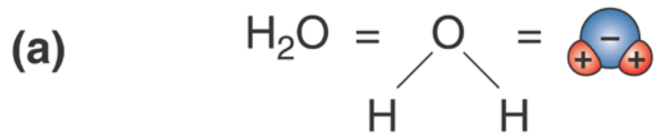
diffusion, including concentration gradients

electrical potential (VOLTAGE)

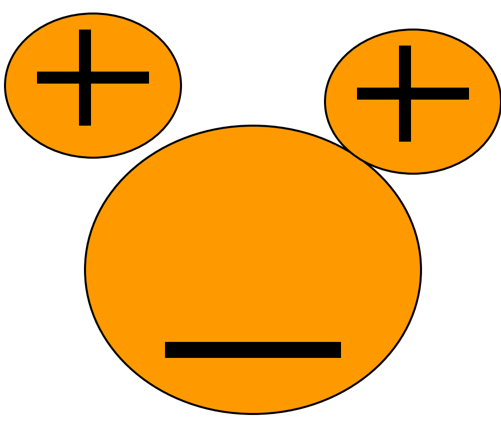
electrical conductance

The Cast of Chemicals

- Cytosolic and Extracellular Fluid

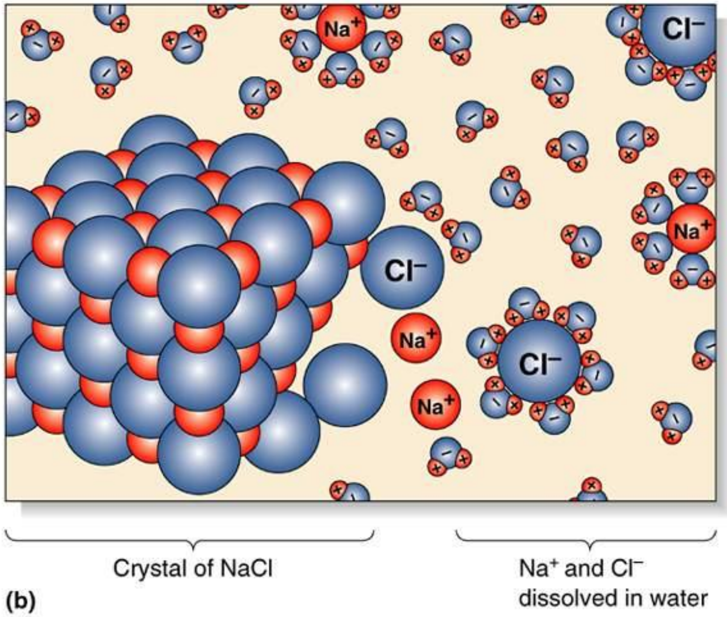


  - Water
    - Key ingredient in intracellular and extracellular fluid
    - Key feature – uneven charge



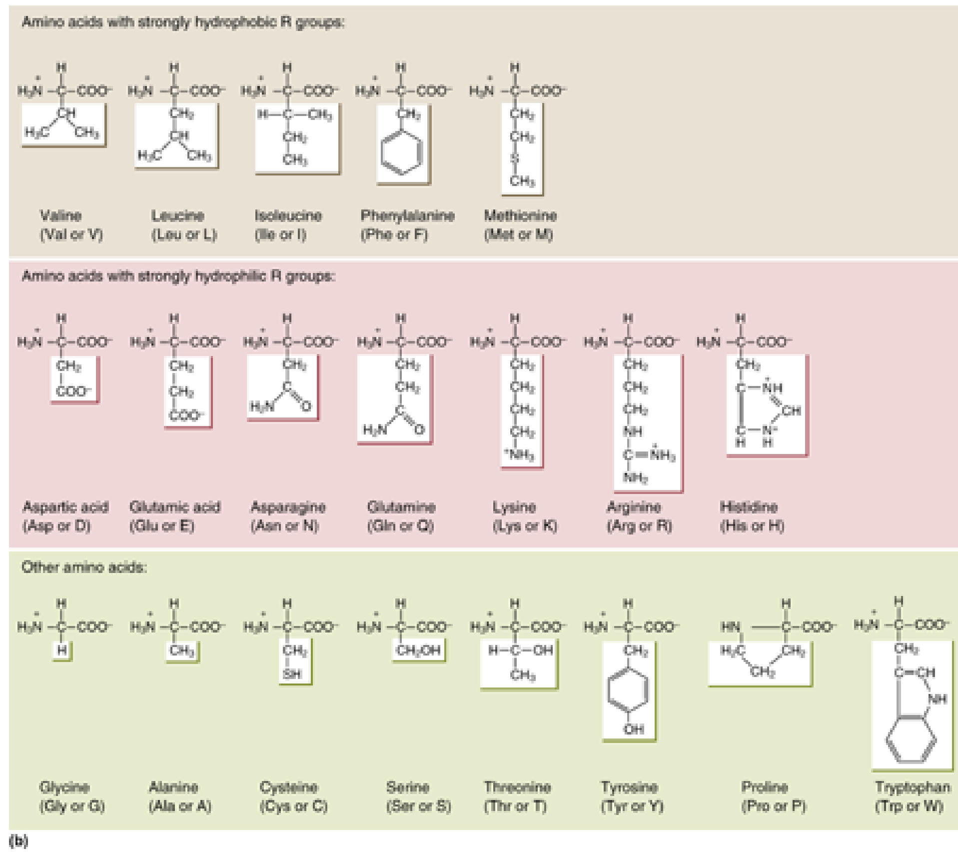
The Cast of Chemicals

- Cytosolic and Extracellular Fluid (Cont'd)
  - Ions: Atoms or molecules with a net electrical charge
  - Cations
  - Anions
    - Spheres of hydration



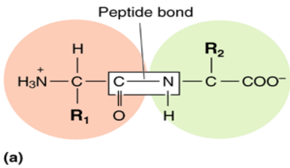
The Cast of Chemicals

- Protein – enzymes, receptors, cytoskeleton
  - 20 amino acids
  - R group variable
    - Hydrophobic
    - Hydrophillic
    - other



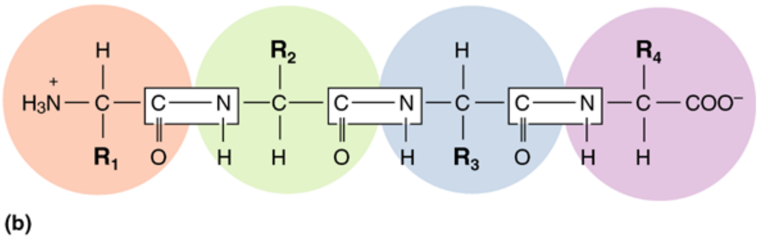
The Cast of Chemicals

- Protein
  - Structure (Cont'd)
    - Peptide bonds



Neuroscience: Exploring the Brai

- polypeptides (amino to carboxyl)



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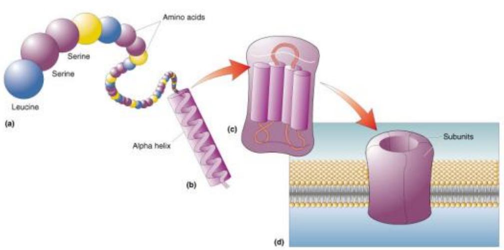
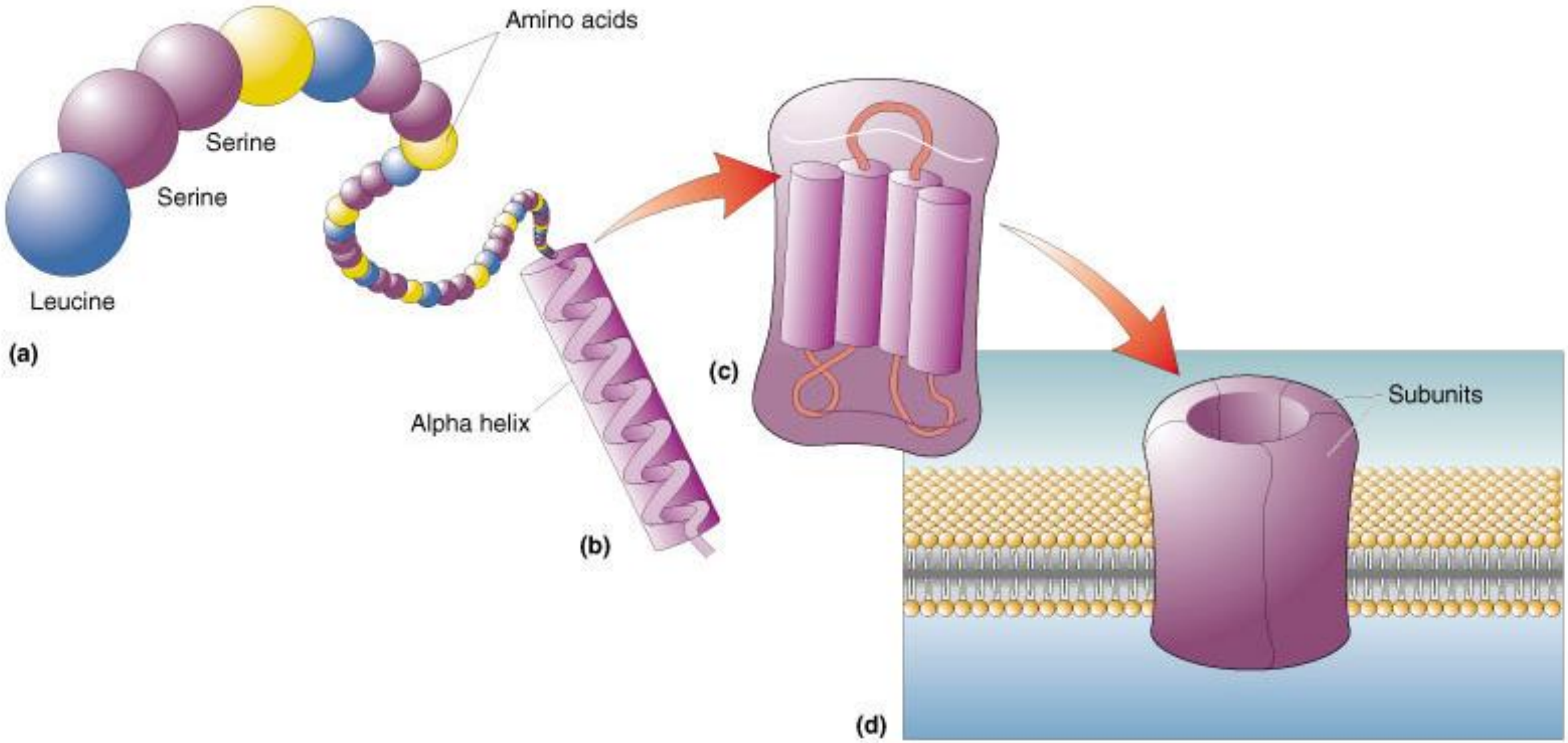
- Four levels of protein structure

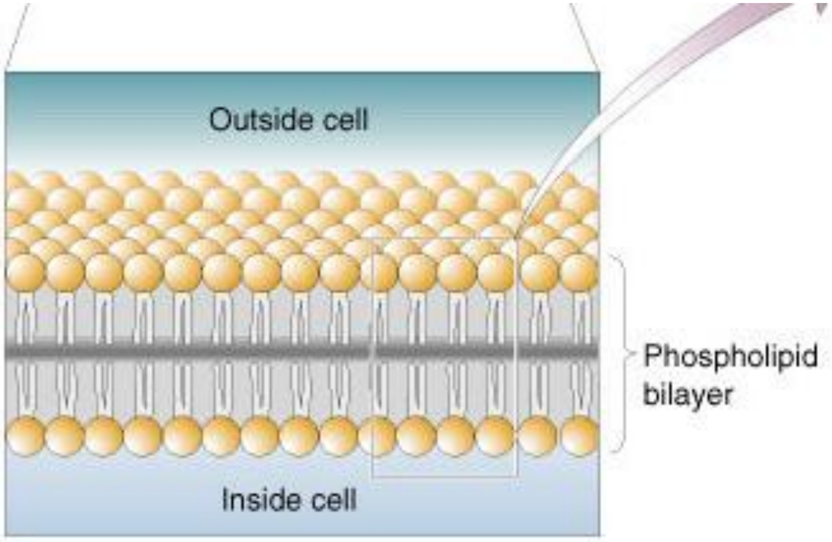
Figure 3.6
Protein structure. (a) Primary structure: the sequence of amino acids in the polypeptide. (b) Secondary structure: coiling of a polypeptide into an alpha helix. (c) Tertiary structure: three-dimensional folding of a polypeptide. (d) Quaternary structures various polypeptides bonded together to form a larger protein.




Amino acids
Serine
Serine
Leucine
(a)
Alpha helix
(b)
(c)
Subunits
(d)

The Cast of Chemicals

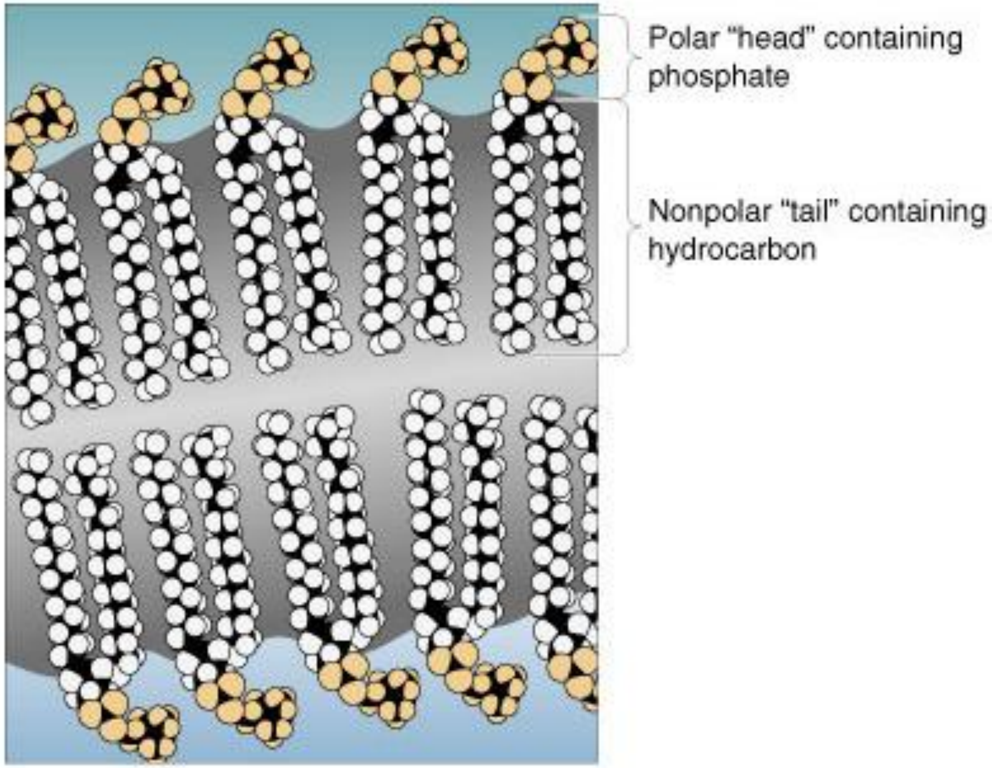
- The Phospholipid Membrane
  - Hydrophilic
    - Dissolve in water due to uneven electrical charge (e.g,, salt)
  - Hydrophobic
    - Does not dissolve in water due to even electrical charge (e.g., oil)
  - Lipids are hydrophobic
    - Contribute to resting and action potentials



< 5 nm

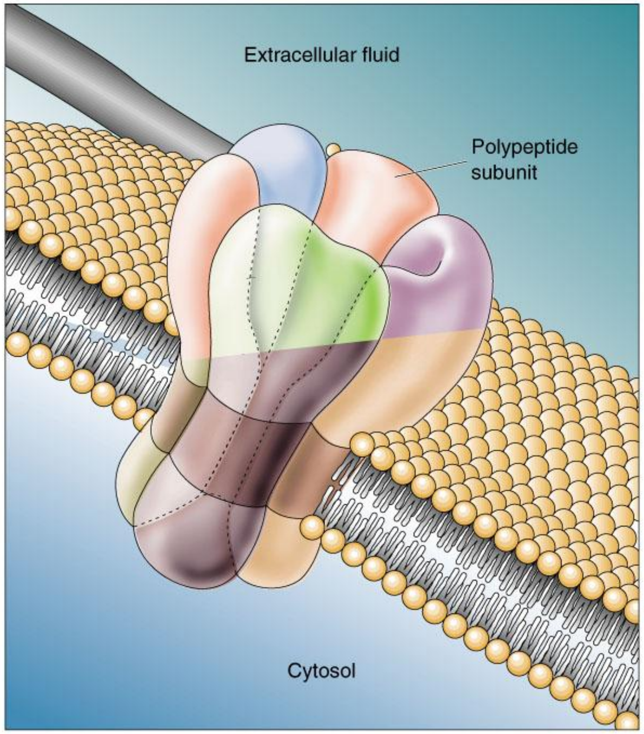
H_20 = <1 nanometer

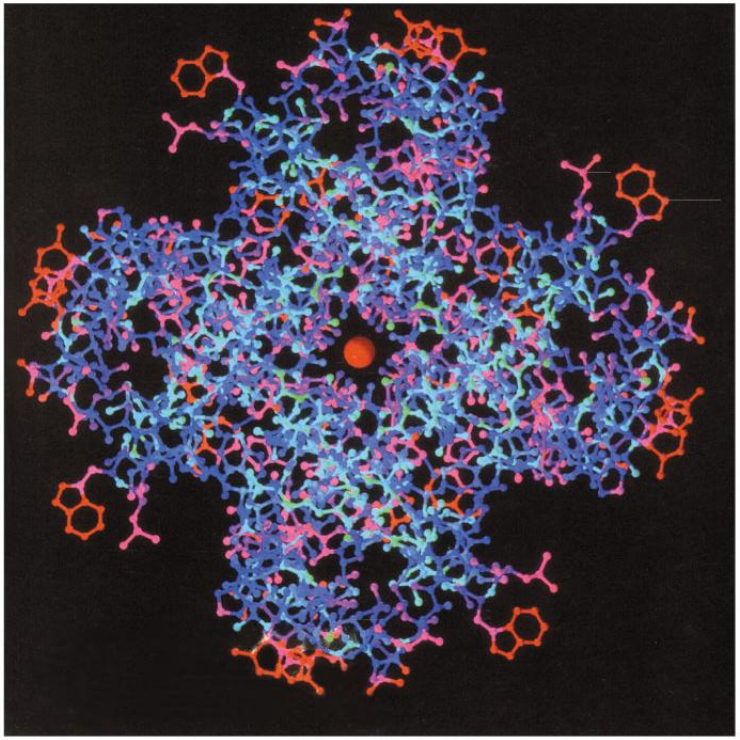
One billionth of meter



cott Williams & Wilkins

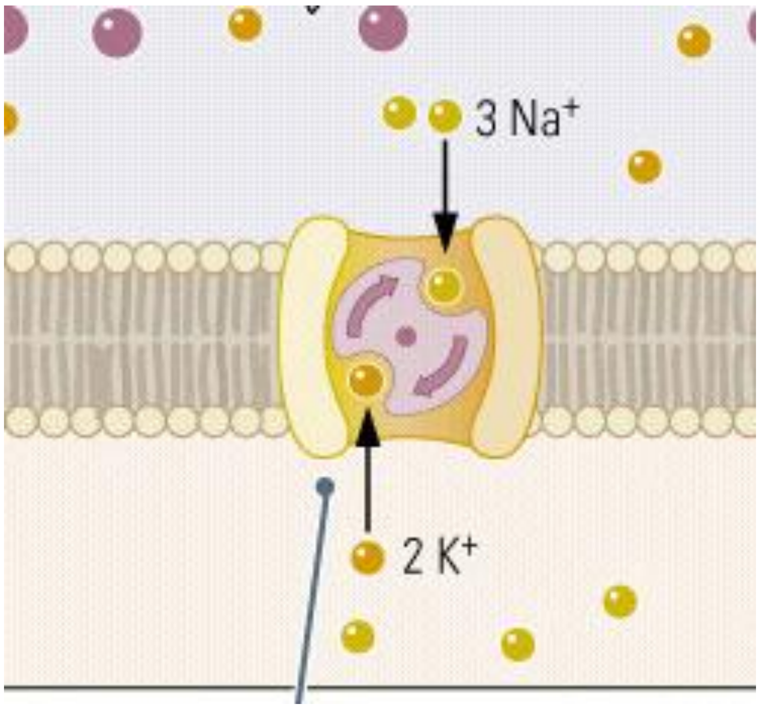
channels





can be open
or gated by environment

pumps - enzymes



sodium potassium pump

breaks down ATP in presence of internal Na+

Ion movement results from:

DIFFUSION

*Concentration gradient (movement from high to low - relative difference in concentration between 2 locations)

CHARGE

*Voltage gradient (same but volts)

Equilibrium occurs when CG balances VG

note this can be disproportionate

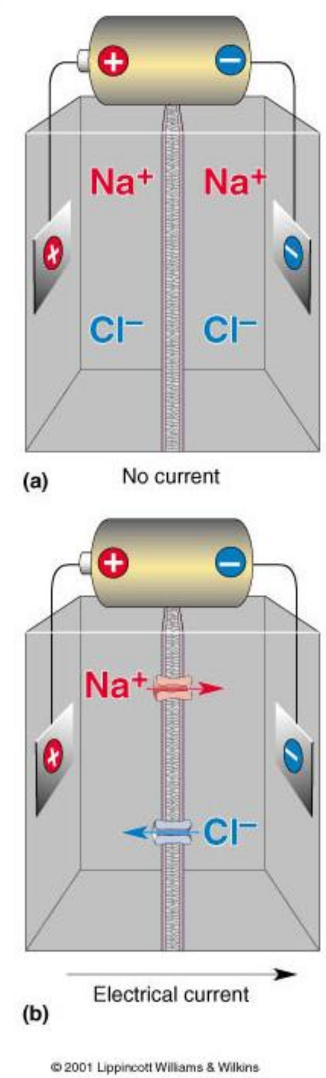
CURRENT – movement of electrical charge

I

amps

positive – movement of + charge
negative– movement of - charge

(positive in direction)

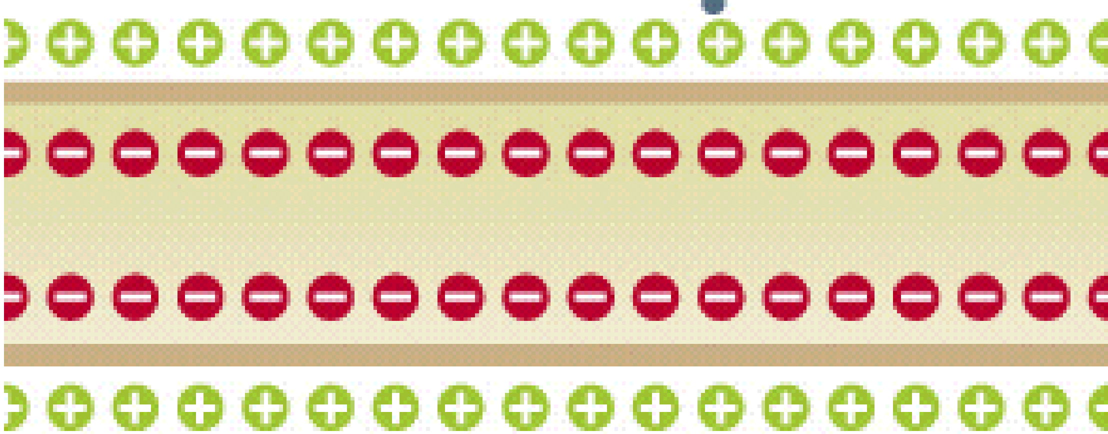


HOW MUCH CURRENT WILL FLOW?

1) ELECTRICAL POTENTIAL (voltage)

2) ELECTRICAL CONDUCTANCE

potential



membrane potential

resting membrane potential

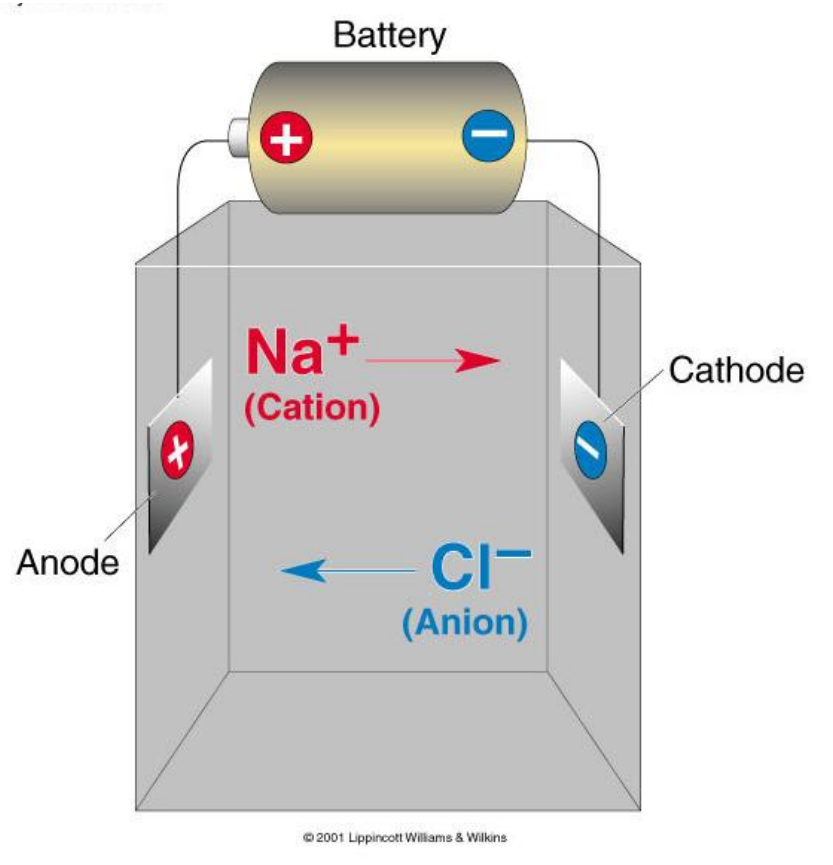
equilibrium potential

action potential – next chapter

potential = voltage V

force exerted –

difference between
(-) terminal (cathode)
(+) terminal (anode)



FLOW IS CURRENT
VOLTAGE IS DIFFERENCE (12V BATTERY)

CONDUCTANCE - ABILITY TO TRAVEL

g

measured in siemens

metal is a good conductor

it offers little resistance

Resistance - inverse of conductance

HOW MUCH CURRENT WILL FLOW??

Ohm's law

$$I = gV$$

CURRENT = CONDUCTANCE * VOLTS

I = current

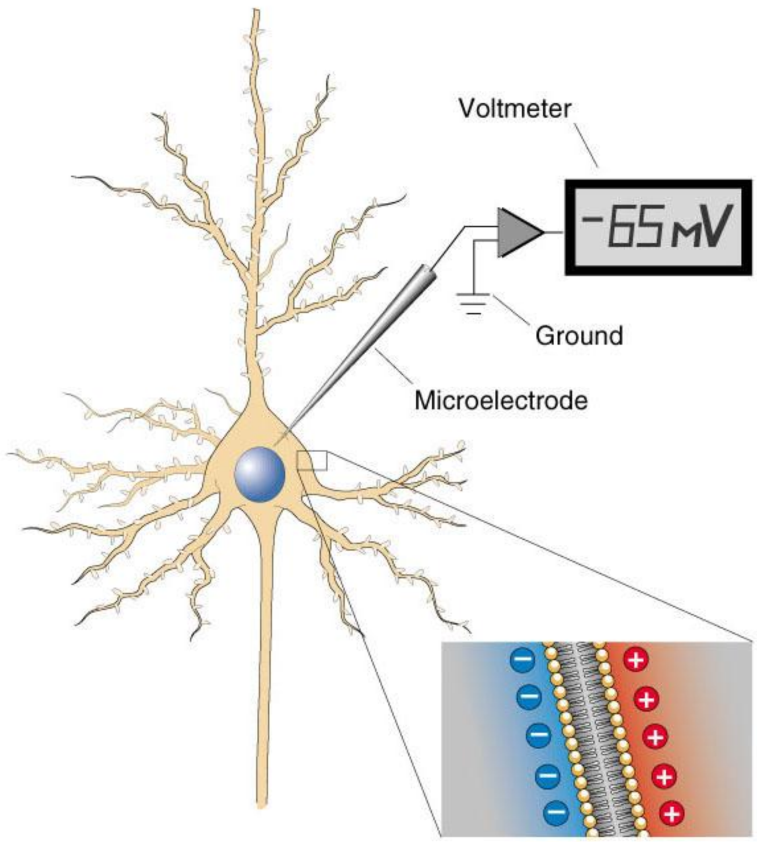
g = conductance

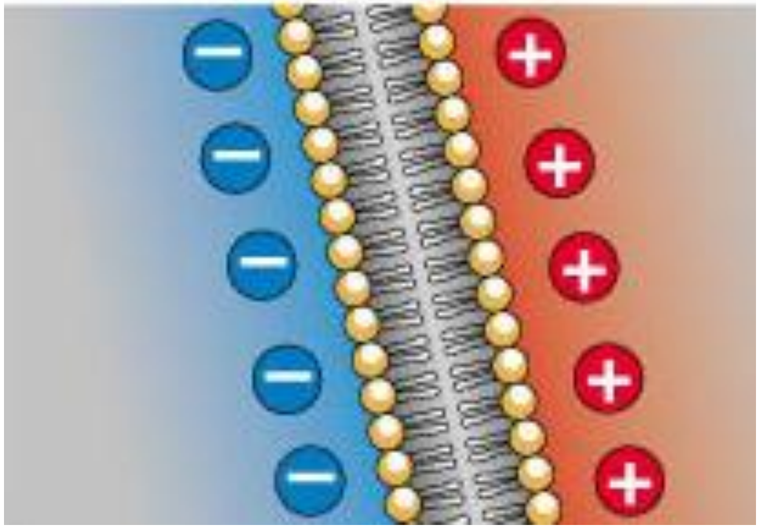
V = volts or potential difference

membrane potential

VOLTAGE ACROSS MEMBRANE

at any given moment





membrane is thin

it “stores” charge

it has “capacitance”

RESTING POTENTIAL

•GREATER NEGATIVE CHARGE INTRACELLULARLY

OUTSIDE **Na^+** and **Cl^-** (also CA++)

1) at rest, most sodium channels closed, chloride open

2) sodium potassium pump is always pumping out Na+

INSIDE **K^+** and protein anions **A^-**

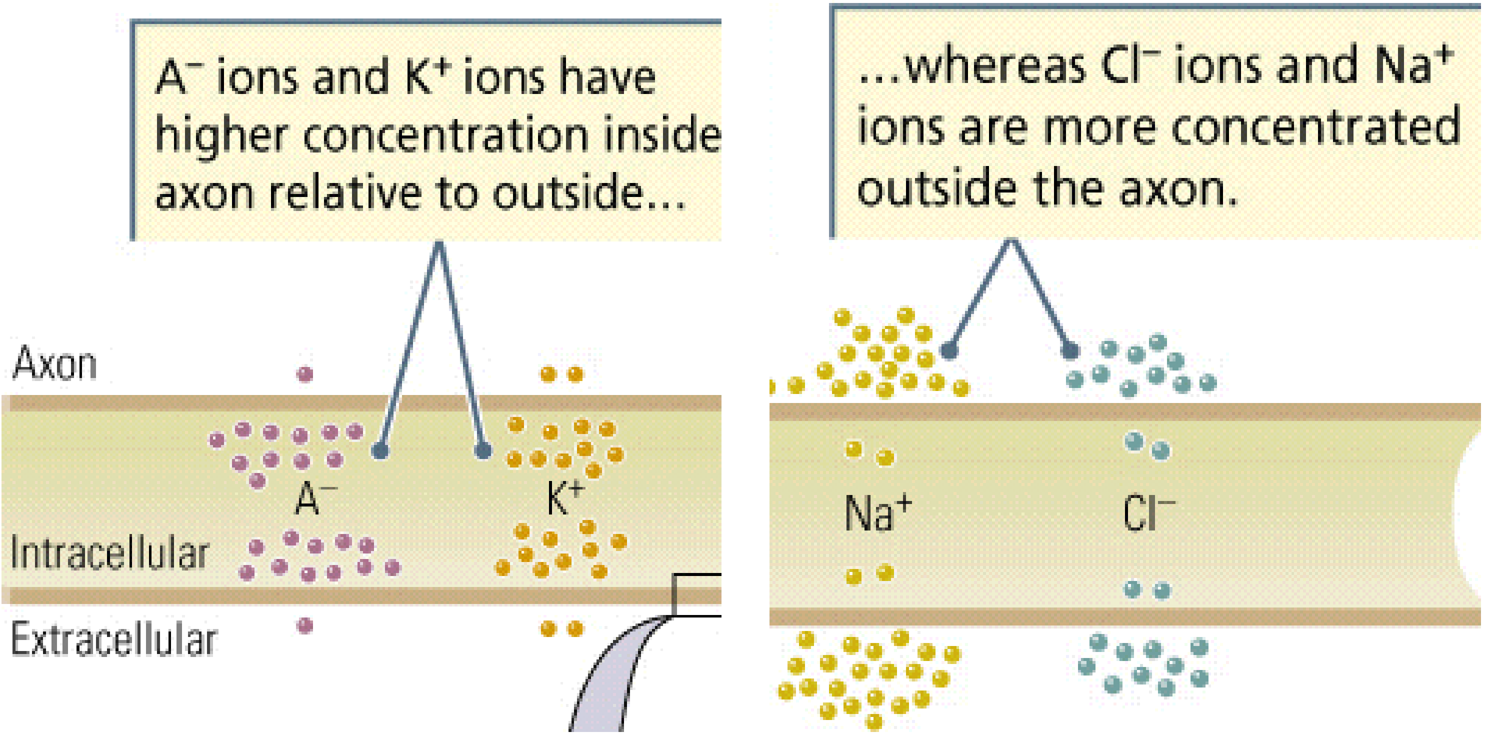
1) K+ channels always open

2) A- are too big to leave

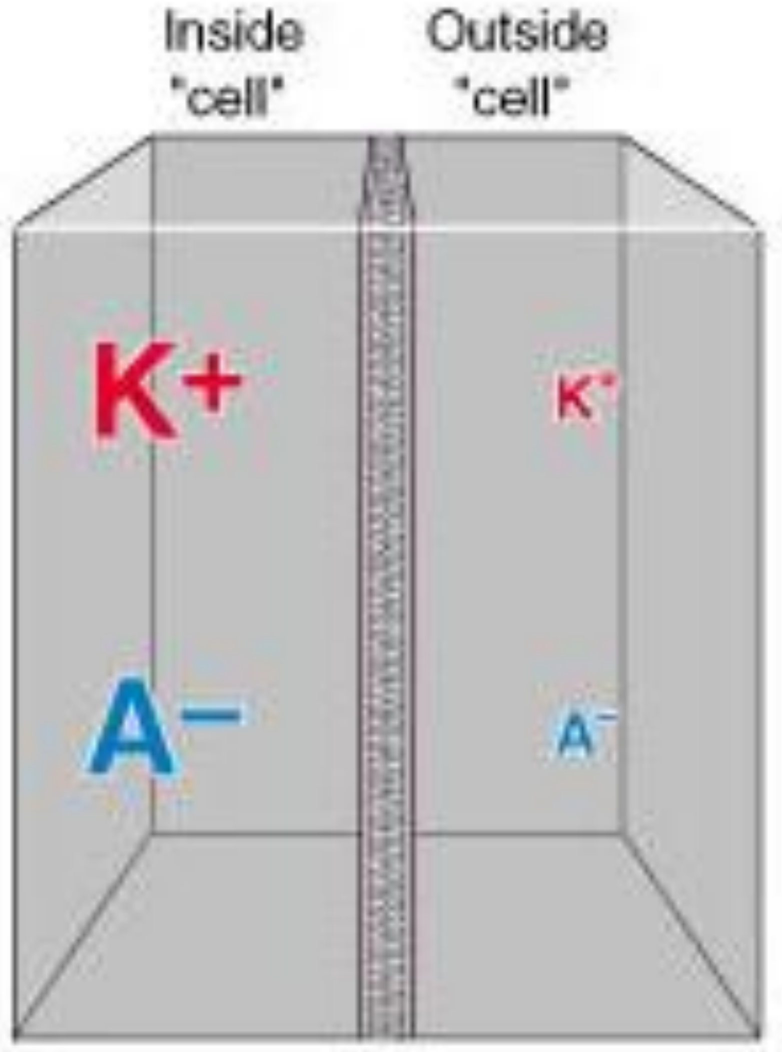
-65 mV (by convention)

Equilibrium potential

- no NET movement



concentrated

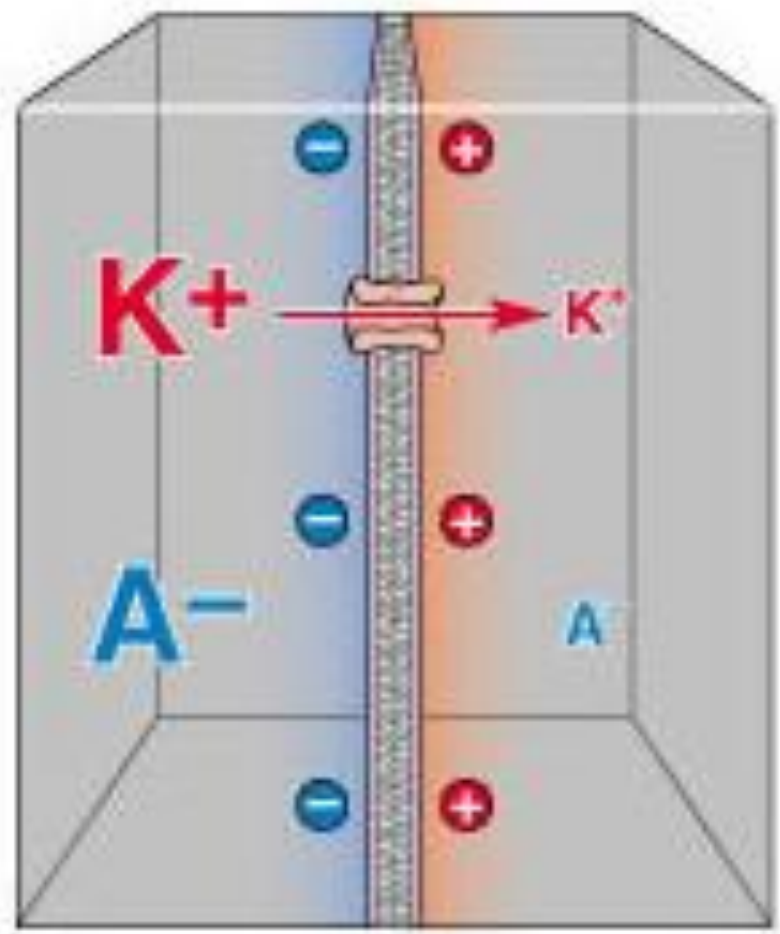


dilute

no channels, no potential - no Vm

diffusion rules! (for a while)

inside



outside

movement along concentration gradient

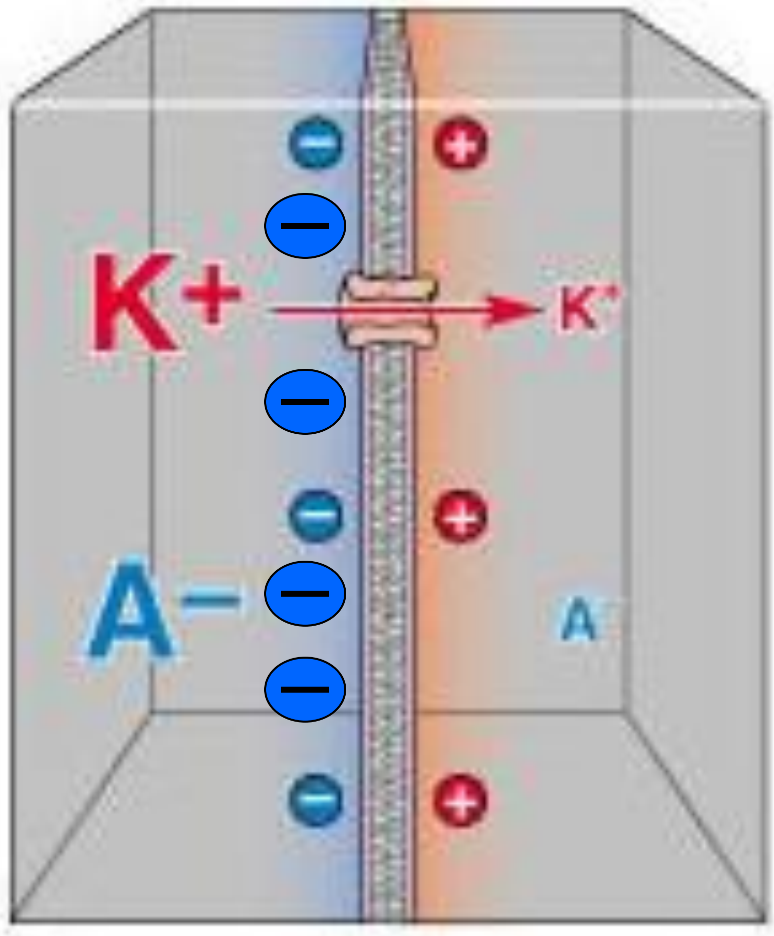
BUT REMEMBER
Ion movement results from:

DIFFUSION
*Concentration gradient (movement from high to low - relative difference in concentration between 2 locations)

AND

CHARGE
*Voltage gradient (same but volts)

inside



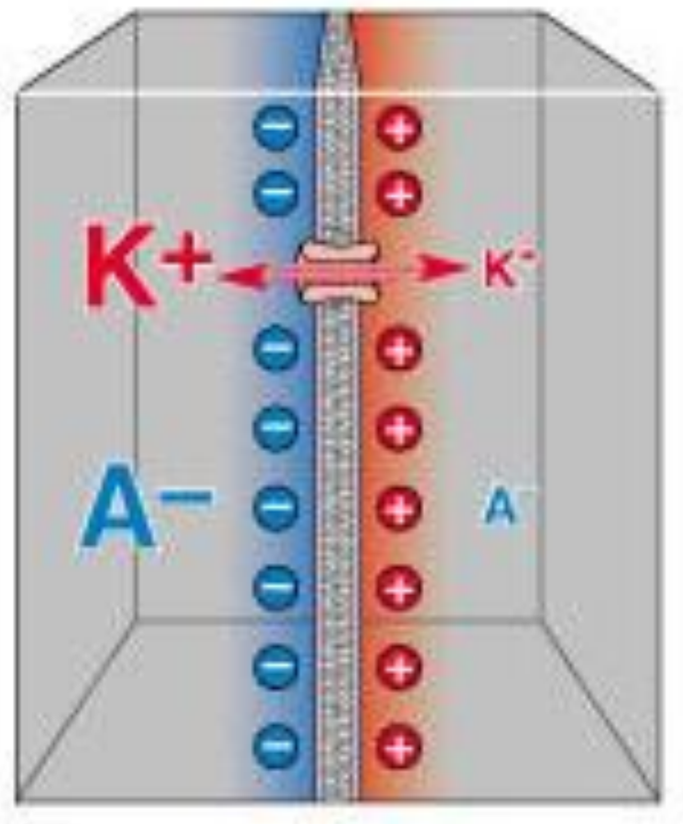
outside

A- left, so INSIDE becomes more –
and K+ will be pulled back in

Equilibrium occurs when CG <u>BALANCES</u> VG

REMEMBER

this can be disproportionate



NO <u>NET</u> MOVEMENT

Nernst Equation

Calculates equilibrium potential of ion

$$E = E^{\theta} - \frac{RT \ln\left(\frac{a_P{}^p \, a_Q{}^q}{a_A{}^a \, a_B{}^b}\right)}{nF}$$

- E=potential (volts)
- c=concentration (moles)
- z=charge or valence of the transported substance
- R=gas constant (8.3143 Joules/mole/degree)
- T=temperature (298 degrees kelvin)
- F=Faraday constant (charge of 1 mole electrons or 96490 Joules/mole/volt)

Nernst Equation
equilibrium
balance of diffusion and electricity

E_K -82 mV

E_{Na} +62mV

ionic driving force

- difference between membrane potential (whatever) and equilibrium potential

- V_m - E_{ion}

Goldman equation
resting potential

- takes all ionic PERMEABILITY into account

Mostly K+ and Na+ and CL-

- \- 65 mV

(Nernst -equilibrium potential single ion)

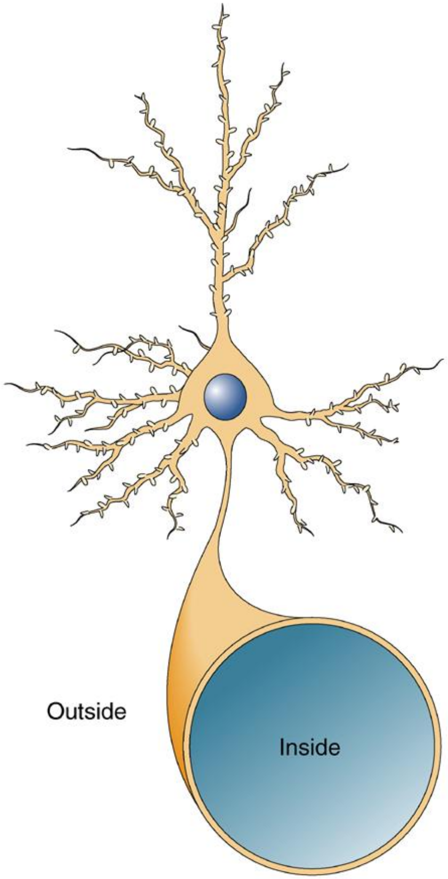
The Ionic Basis of The Resting Membrane Potential

- Equilibrium Potentials (Cont'd)
  - Four important points
    - Large changes in V_m
      - Minuscule changes in ionic concentrations
    - Net difference in electrical charge
      - Inside and outside membrane surface
    - Rate of movement of ions across membrane
      - Proportional $V_m - E_{ion}$
    - Concentration difference known: Equilibrium potential can be calculated

The Ionic Basis of The Resting Membrane Potential

- The Distribution of Ions Across The Membrane

Ion	Concentration outside (in mM)	Concentration inside (in mM)	Ratio Out : In	E_{ion} (at 37°C)
K^+	5	100	1 : 20	−80 mV
Na^+	150	15	10 : 1	62 mV
Ca^{2+}	2	0.0002	10,000 : 1	123 mV
Cl^-	150	13	11.5 : 1	−65 mV

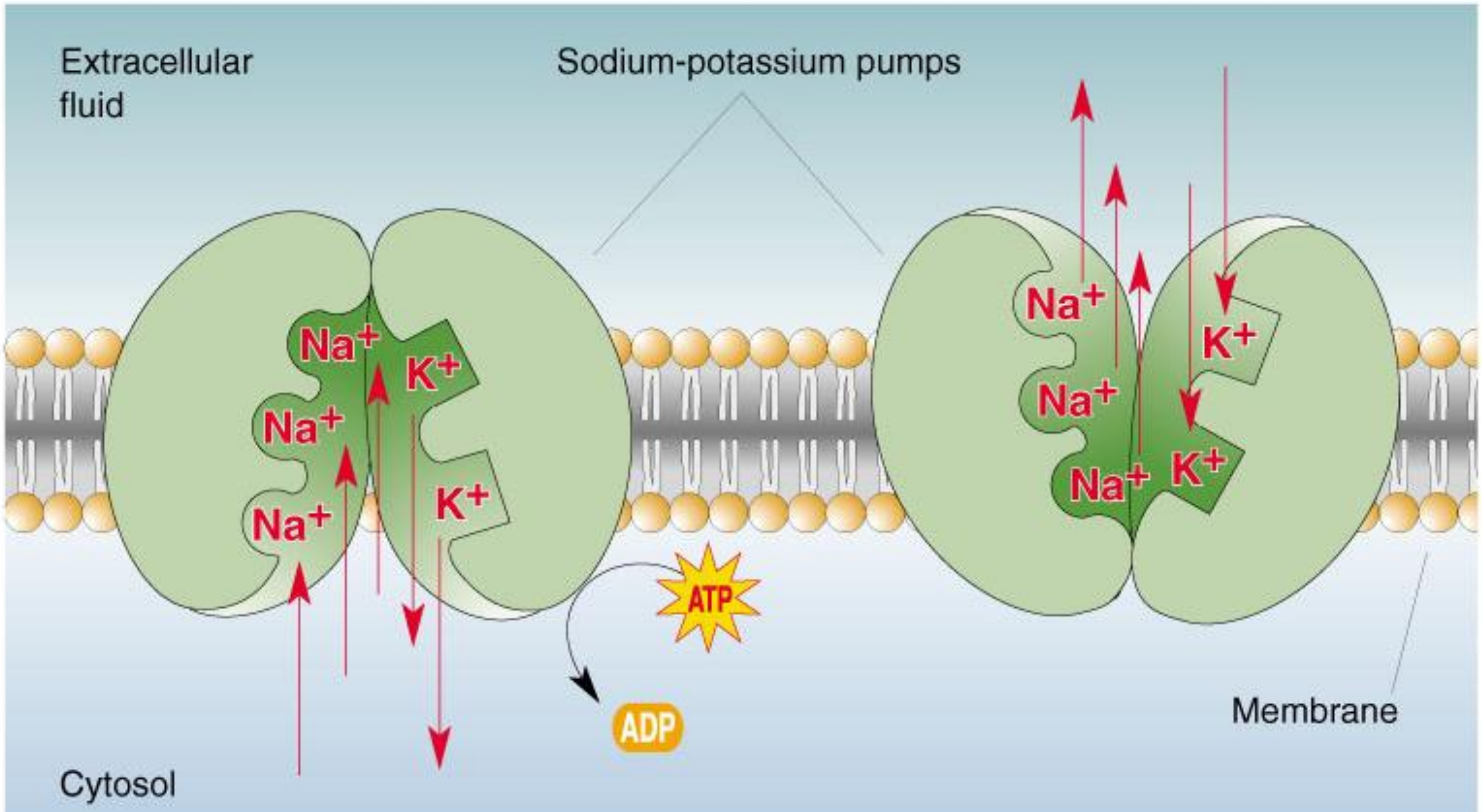


Notice CA++ small

sodium potassium pump

70% of brain ATP

breaks down ATP in presence of internal Na+



AGAINST concentration gradients K+ INSIDE NA+ OUTSIDE

Ouabain – poison arrow

also Ca++ pumps

why do you have to know this?

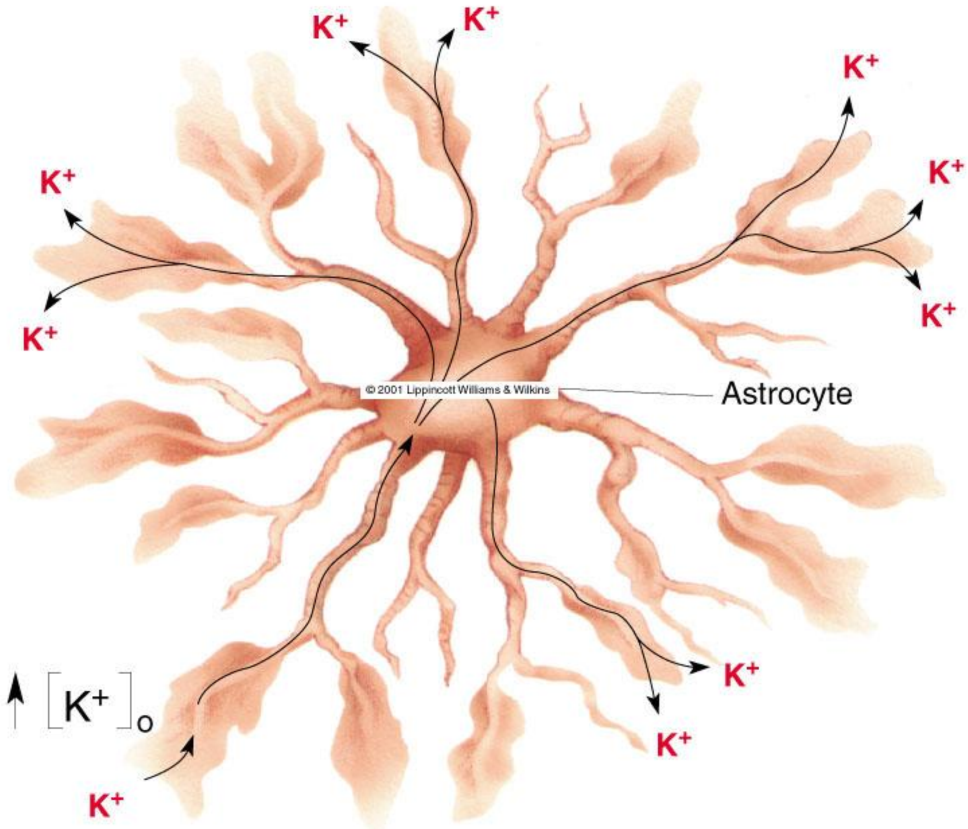
- IT is THE DIFFERENCE BETWEEN

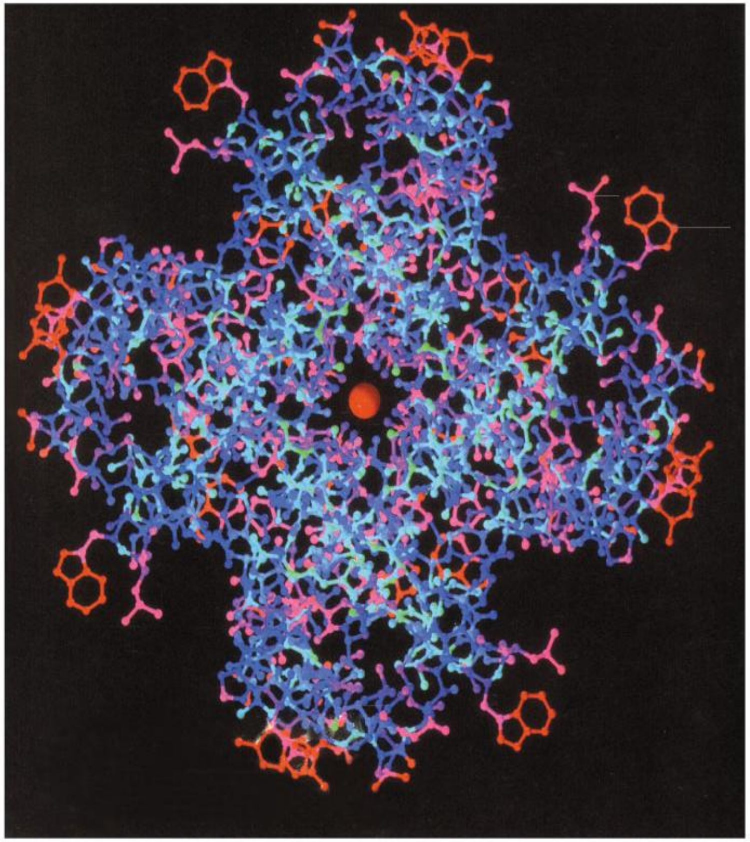
  LIFE AND DEATH

K+ tightly regulated

- BBB
  - –CNS
- astrocytes

Figure 3.20
Potassium spatial buffering by astrocytes. When brain [K1]o increases as a result of local neural activity, K1 enters astrocytes via membrane channels. The extensive network of astrocytic processes helps dissipate the K1 over a large area.





K+ channels deformed

let in NA+

epilepsy

Potassium, euthanasia, capital punishment