

Ions cannot cross membranes

- Membranes are lipid bilayers

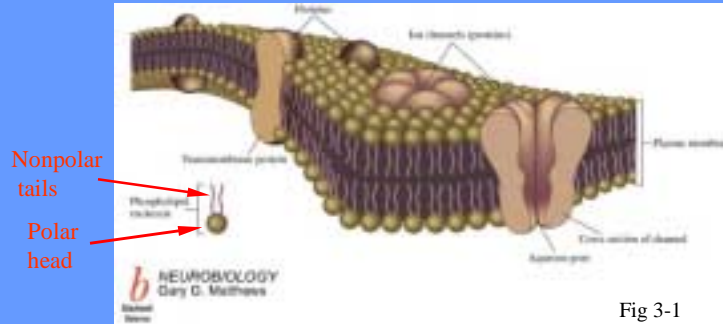


Fig 3-1

Because of the charged nature of ions, they cannot cross a lipid bilayer. The ion and its cloud of polarized water molecules can interact with the polar head of the phospholipid, but not with the hydrophobic tails of the phospholipids.

Ions move through pores

- Ions must have a protein pathway

Ions can only cross the membrane using integral membrane proteins called ion channels, or through pump proteins. This figure shows ions moving in an ion channel. Ion channels can only allow ions to move passively, without the addition of energy. They are essentially water-filled pores, and ions pass through the interior of the pore.



How ions move across membranes

Two things are required in order for an ion to move through an ion channel:

1. The forces acting on the ion must allow this movement energetically;
2. There must be a pathway, that is, an open channel.

What are ion channels?

- Example – ligand-gated AChR

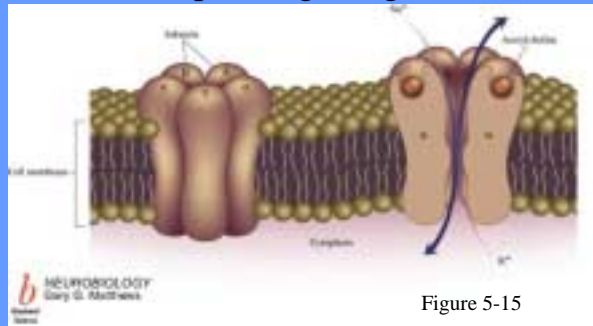
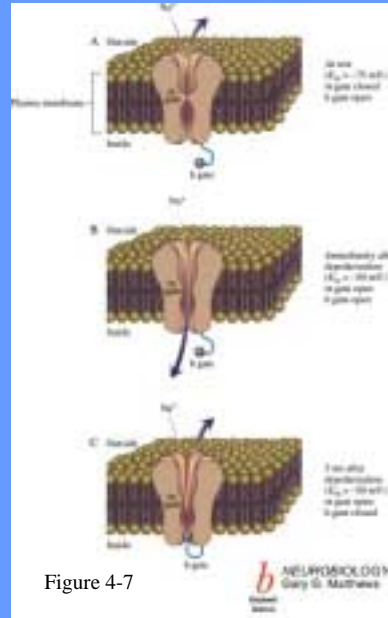


Figure 5-15

Channels may be composed of different or identical protein subunits, which are embedded in the membrane, surrounding a pore region. There are often accessory subunits as well, which modulate kinetics or other factors.

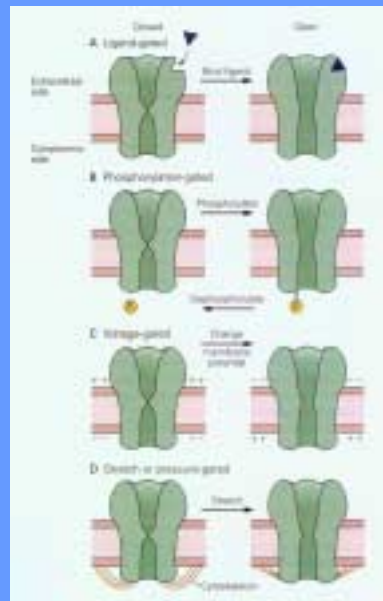
How are ion channels opened (gated)?

- Example – Na channel
- Ion channels open and close (gate) because of changes in the protein arrangement, which can be modified to open or occlude the pore.



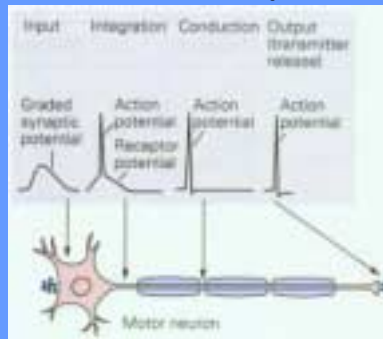
How are ion channels opened?

- A. Ligand - gated (ACh channel)
- B. Modified by cytoplasmic phosphorylation
- C. Voltage - gated (Na channel)
- D. Gated by mechanical stimulation



Neurons signal electrically

• Information in neurons is encoded by electrical signals. These signals are transient perturbations from the established resting potential of the cell.



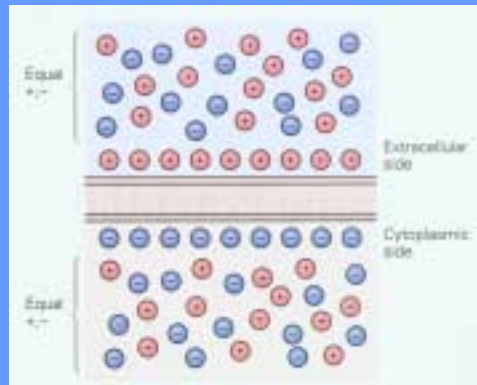
Types of signals

Receptor potentials	0.1-10 mV	5-100 ms	hyper/depol
Synaptic potentials	0.1-10 mV	5 ms-20 min	hyper/depol
Action potentials	70-100 mV	1-10 ms	depol

What is the resting potential?

- The resting potential is a standing voltage

The resting potential is a separation of charge across the cell membrane (which itself cannot move charge across it). The outside of the cell is defined as zero voltage, and at rest, the inside of the cell is negative relative to the outside.



Why do cells have a resting potential?

- Cells contain a huge number of fixed molecules that are needed for energy and synthesis, such as amino acids, proteins and sugars that are dissolved in the cytoplasm and increase the osmolarity in the cell.
- Different cells have devised different ways to get rid of the water that flows into the cell across the membrane because of the osmoles inside the cell.

Why do cells have a resting potential?

- Plants contain vacuoles to store the water

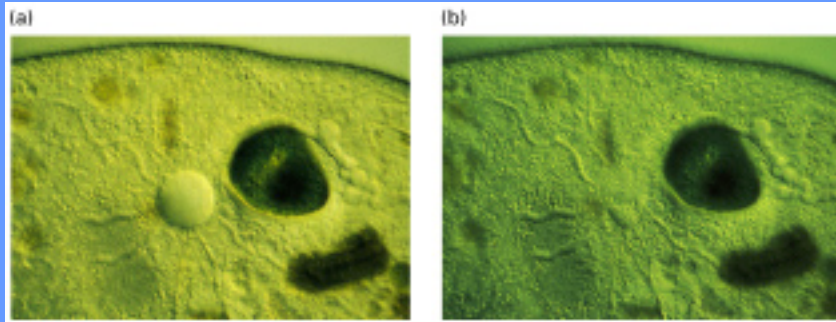
Plant cells collect the water inside of membrane-bound structures, and use the vacuoles to create turgor pressure. This allows the entire plant and the leaves to remain stiff. If there is too much water around, the plant simply doesn't take up any more via the roots.



Why do cells have a resting potential?

- Protozoa such as *Paramecium* also have vacuoles

The vacuole collects the water through radiating canals, then undergoes a contractile event that expels it to the outside.



Why do cells have a resting potential?

- Animal cells take a completely different strategy

Animal cells pump out osmoles using the Na^+/K^+ ATPase. All animal cells express a protein pump in the plasma membrane that extrudes 3 Na^+ from inside the cell, and imports 2 K^+ . This pump requires energy, since as we shall see, both ions are moving against their concentration gradients.

Why do cells have a resting potential?

- There are major consequences of this pump action
- The distribution of ions across the membrane is different on the two sides:
 - K^+ is concentrated inside the cell;
 - Na^+ is maintained at low levels in the cell;
- Osmoles are pumped out (since 3 osmoles move out while only 2 move back in). This keeps water from flowing into the cell.

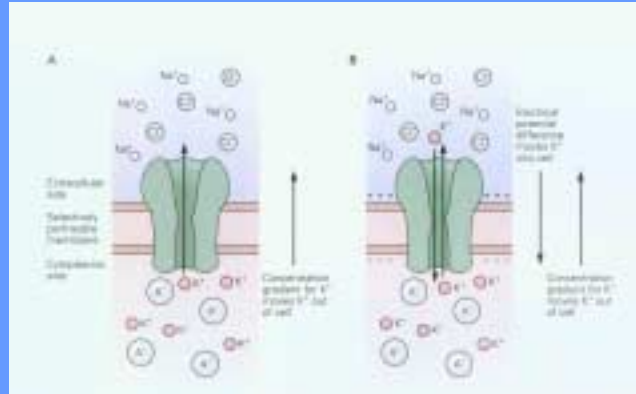
What is the resting potential?

- Ions between the inside (cytoplasm) and the outside of cells are not uniformly distributed. The distribution of ions across a terrestrial animal cell plasma membrane is shown:

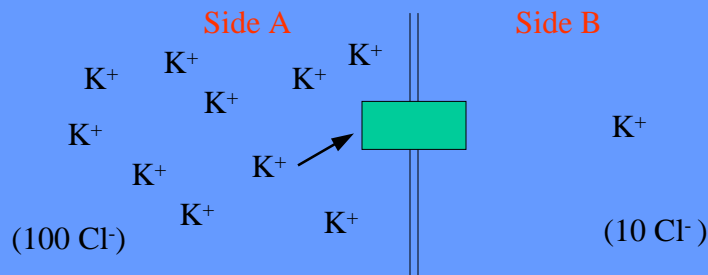
ION (mM)	CYTO	OUT
K^+	130	5
Na^+	12	140
Cl^-	10	110
Ca^{2+}	0.0001	2.5
A^- (inorg)	high	low

What is the resting potential?

- The resting potential across almost every animal cell (most cells have a resting potential) is determined largely by “leak” K^+ channels.

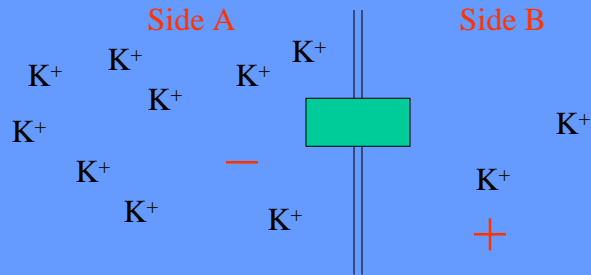


What is the resting potential?



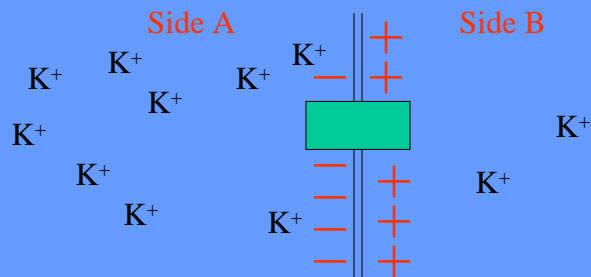
Imagine a membrane with 100 mM KCl on one side (side A), and 10 mM KCl on the other (side B). (Don't worry about osmoles, we can use something to balance those). If there is a channel that allows K^+ to move through the membrane, K^+ will start to flow down the gradient, across the membrane.

What is the resting potential?



Every time a K^+ moves, there is a voltage generated across the membrane. When will the K^+ stop moving across the membrane? What forces will make the K^+ no longer move?

What is the resting potential?



Eventually, that voltage will tend to not allow the K^+ to leave side A, and the two sides will be in equilibrium. The channel may stay open, and for every K^+ that flows one way, there will be a K^+ that flows the other way.

Nernst equation

$$V_{\text{ion}} = -59/z (\log ([\text{ion}]_{\text{in}}/[\text{ion}]_{\text{out}}))$$

- The point at which the voltage and the concentration gradient of an ion balance each other is called the equilibrium potential (V_{ion}). The balancing of these forces is formalized in the Nernst equation, which relates the two types of energy. A 10X difference in concentration of a monovalent ion contains the same energy as 59 mV of voltage. {z is the ion valence}

What are the forces on the K ions?

The concentration gradient across the membrane tends to drive K⁺ out of the cell.

The voltage across the membrane tends to drive K⁺ back into the cell.

