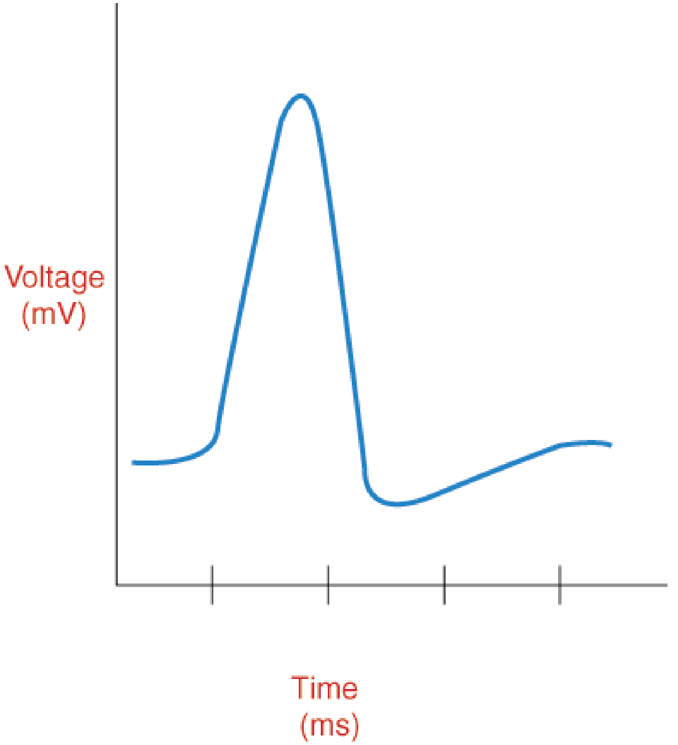
Medical Devices

Lecture 4 - The Action Potential

The Action Potential

- Membrane Potential
- What is the Action Potential
- Cell Excitability
- Conduction



Membrane Potential

- There is a difference of potential present between inside and outside of the cells. This is called the “membrane potential”.
- This potential is caused by the specialized properties of the cell membrane, which selectively separates products inside from outside.
- The cell membrane is made of a phospholipid bilayer which is electrically inert for the most part.
- The membrane acts much like a battery.
- The membrane potential is caused by the difference in the concentration of ions inside and outside the cell.
- The magnitude of the membrane potential (difference between potential inside and outside) at rest is about 50-70 millivolts.

What is the Action Potential?

- Neurons and the muscle cells have the ability to respond to a stimuli. The stimuli can be due to external effects, internal forces, thoughts, etc.
- If the stimulus has adequate strength, the permeability of the membrane to sodium ions (Na+) is significantly increased at the point of stimulation.
- As a result of this stimulation, the sodium channels open, permitting an influx of sodium ions (by diffusion).
- As there are more sodium ions entering the cell than leaving, the electrical potential of the membrane changes.
- In summary, in the resting (polarized) membrane state, the outside is positively charged and the inside of the membrane is negative. When a stimulus occurs, the inside soon becomes positive (depolarized) and the outside becomes negative. This is referred to as the reversal of polarized state.
- Once depolarized, the sodium channels close again and the potential returns to its resting state. This is what is called an Action Potential.

The Action Potential

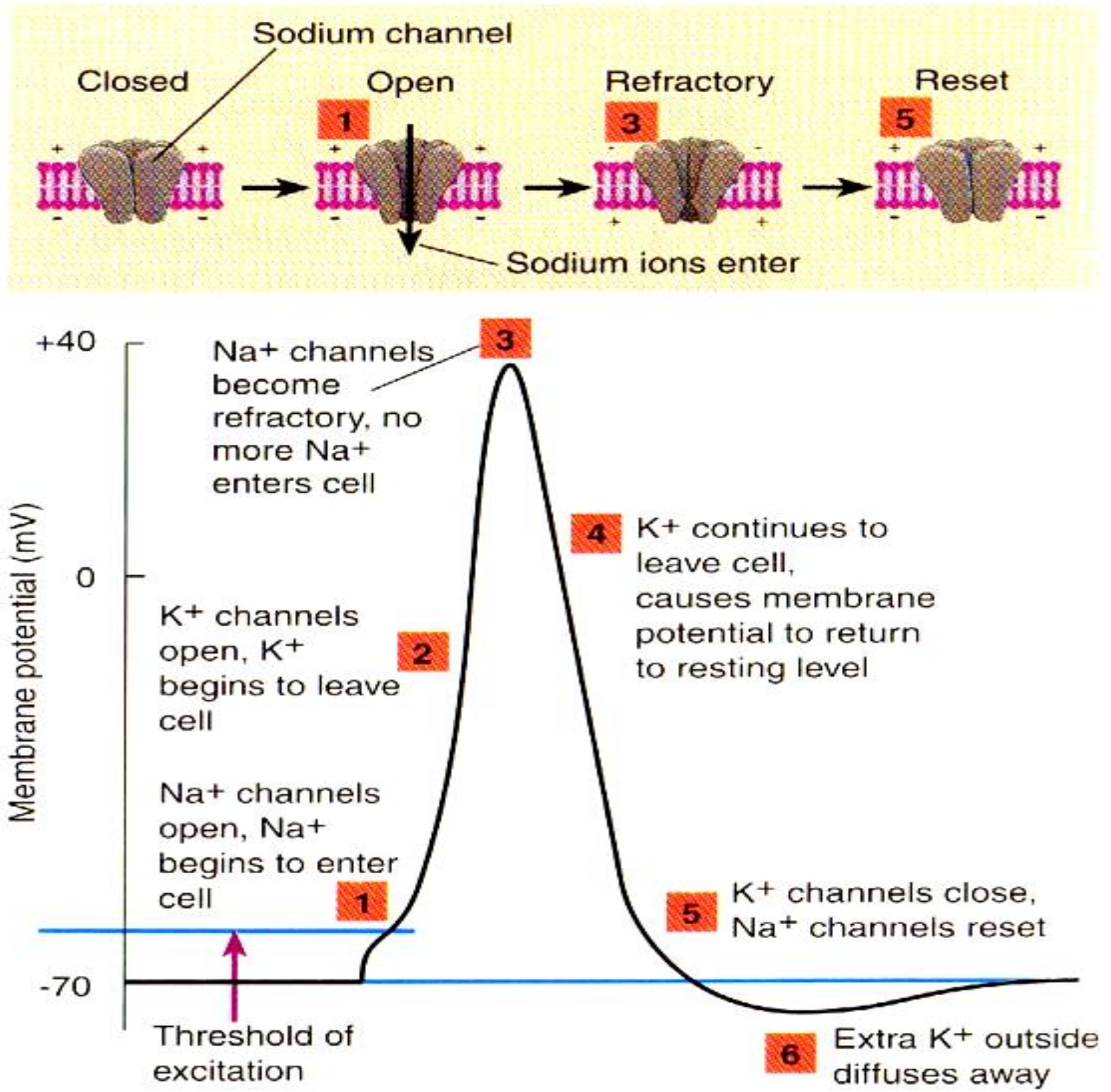
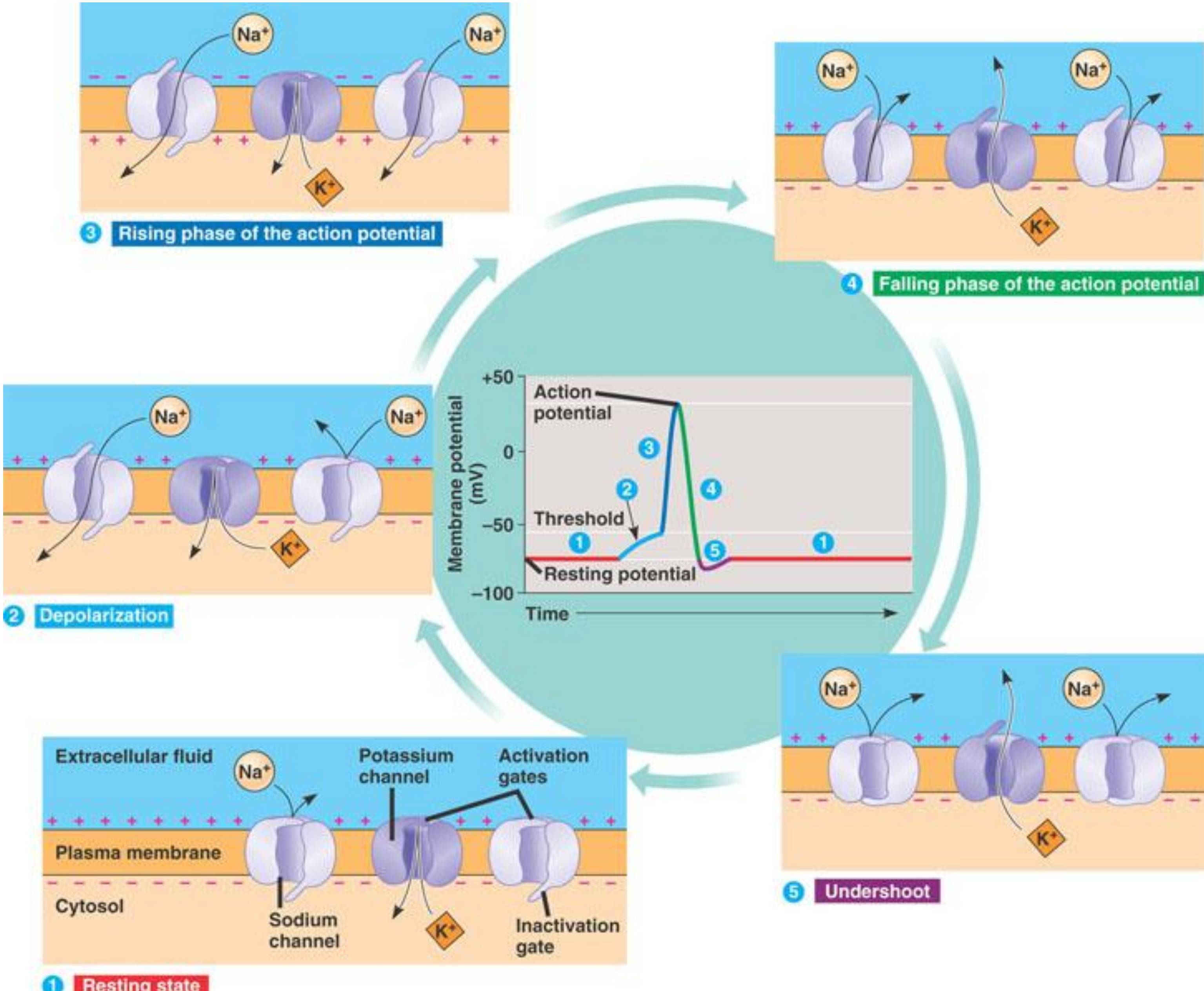
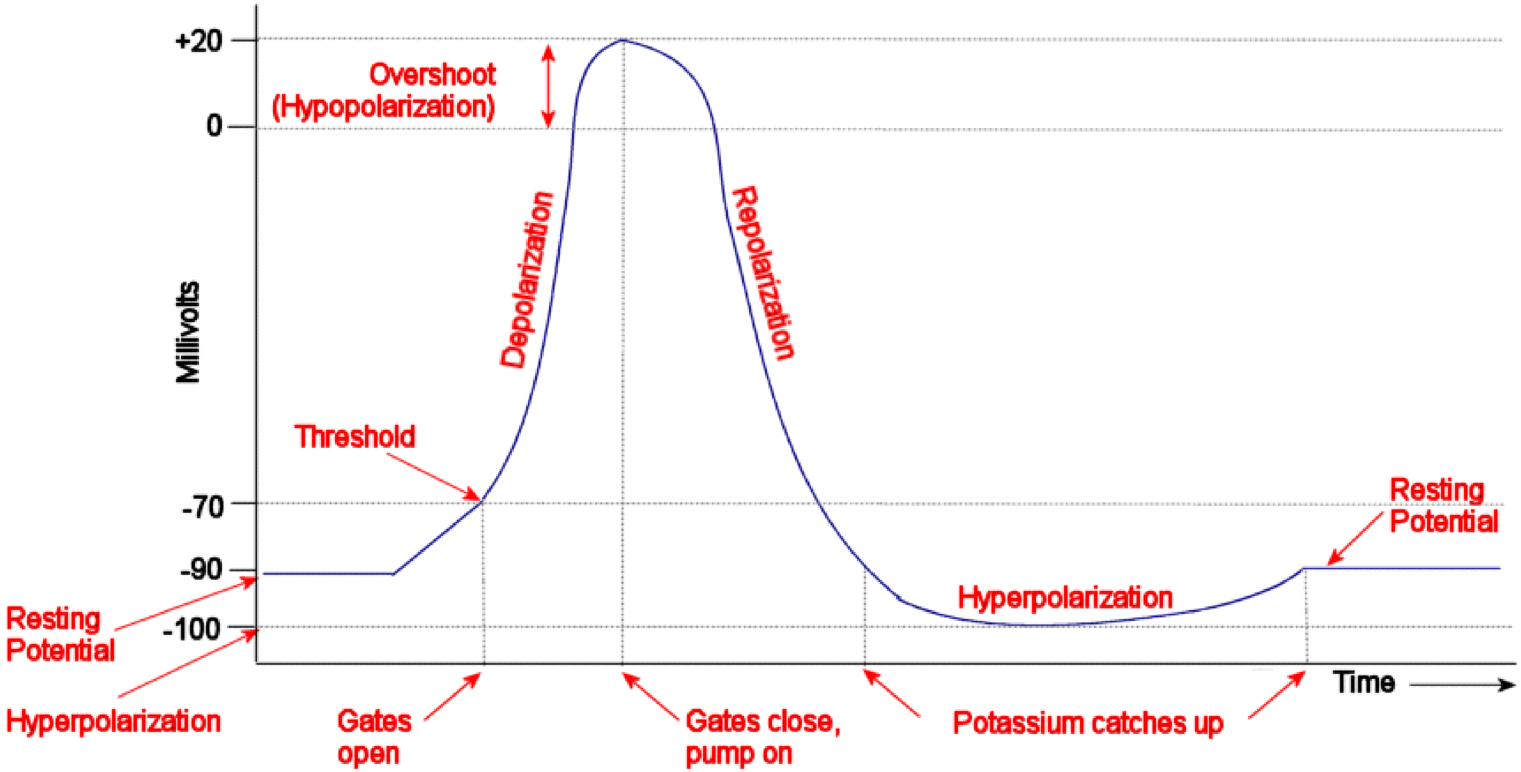


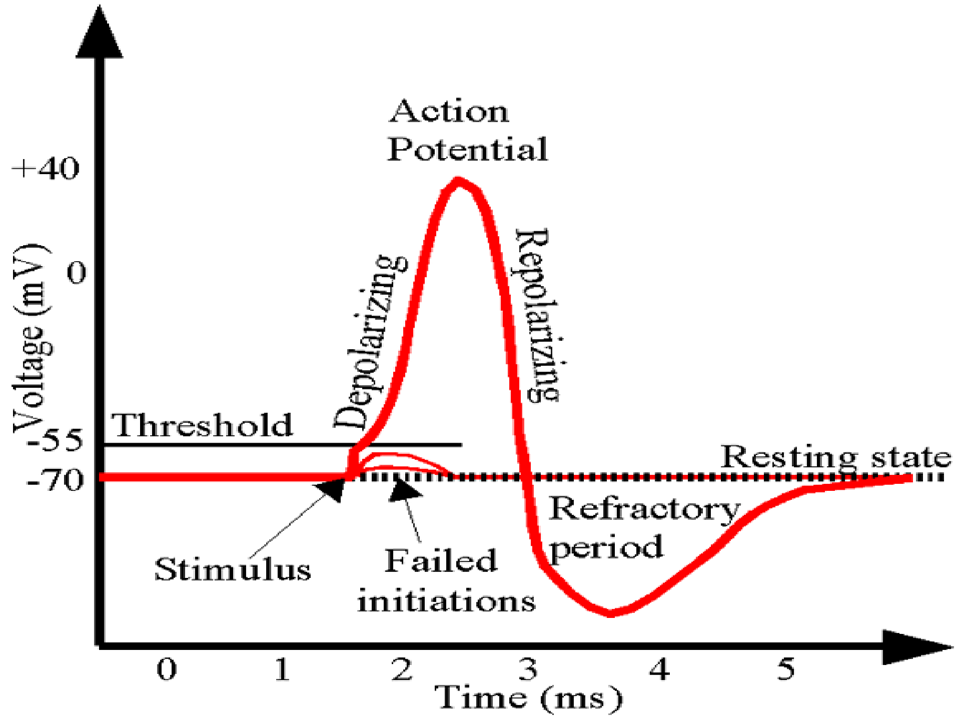
Image from: http://www.gregalo.com/neuralnets.html


Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
2 Depolarization
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
5 Undershoot
Extracellular fluid
Potassium channel
Activation gates
Plasma membrane
Cytosol
Sodium channel
Inactivation gate
1 Resting state


+20
0
-70
-90
-100
Millivolts
Overshoot
(Hypopolarization)
Depolarization
Repolarization
Threshold
Resting
Potential
Hyperpolarization
Resting
Potential
Hyperpolarization
Gates
open
Gates close,
pump on
Potassium catches up
Time

The Action Potential

- Depolarization begins at the threshold level (of about -70 mV).
- During depolarization, the potential inside the membrane changes from -70 mV and goes to 0 mV and beyond.
- The sodium ions continue to rush inside and thus depolarization continues until the membrane potential is reversed (inside membrane becomes positive and the outside becomes negative).
- At 0 mV membrane potential, the membrane is said to be depolarized (no longer polarized).



- Practical experimental measurements indicate that the inside of the neuron is about +30 mV at this stage with respect to the outside. In other words, the inside of the potential inside the membrane changed from -70 mV (at polarized state) and went to +30 mV.
- When depolarization occurs as described above, it is followed by a repolarization, and this is referred to as a pulse or an "action potential".

The Resting Potential

- Nerve cells and muscle cells have considerable differences in concentration of ions inside and outside the cells.
- The cell (e.g. neuron) is resting when it is not conducting an impulse (not sending a message).
- In the case of a muscle cell, this is when the muscle cell is not contracting. This is called “rest”.

Understanding the Membrane Potential

- The membrane potential at rest is caused by:
  - More potassium (K^+) ions within the cell than outside the cell.
  - More sodium ions (Na^+) outside of the cell than inside of the cell.
  - More chloride ions (Cl^-) outside of the cell than inside.
  - More HCO_3^- outside of the cell than inside the cell.
  - There are more negatively charged ions, such as proteins, inside of the cell than outside the cell.
- The mechanism that transports sodium ions and potassium ions actively and simultaneously across the membrane is called the sodium-potassium pump. See Figure 2.
- The difference in charges across the membrane at rest is called the membrane resting potential. It is the combined effect of the charge differences due to each of the above types of ions.
- This resting membrane potential causes the inside and outside of the cell to be polarized.

Maintaining the Membrane Potential

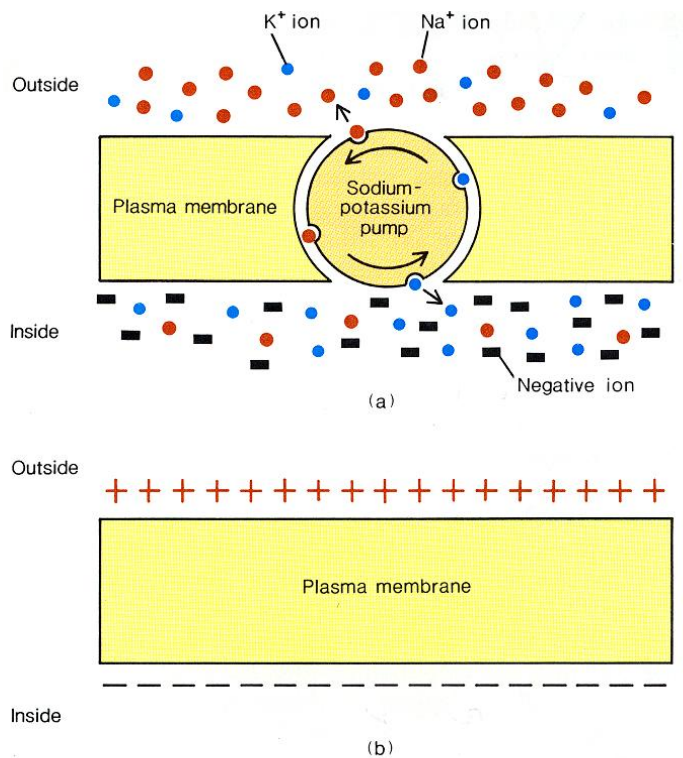
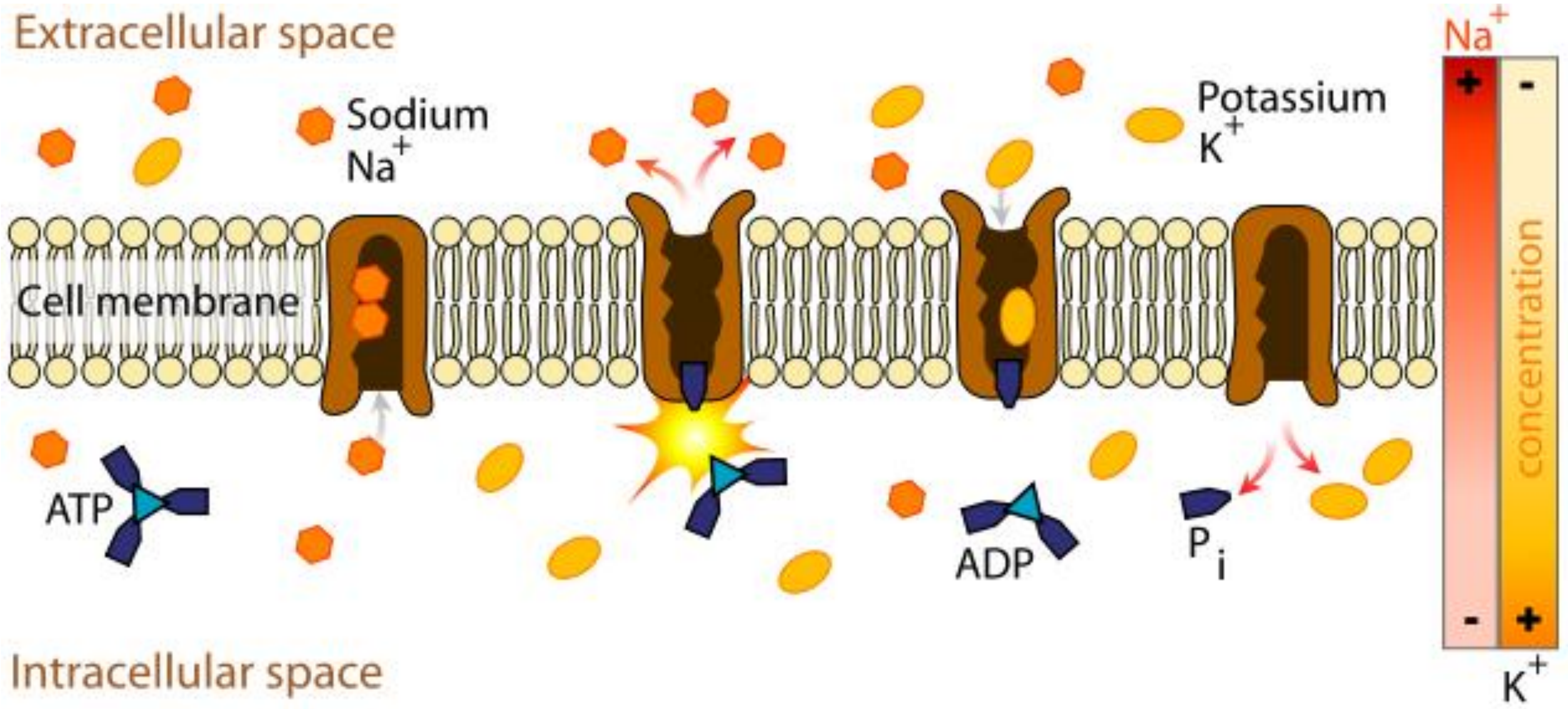


Figure 2. Development of the membrane (resting) potential. (a) Schematic representation of the sodium-potassium pump and distribution of ions. Note that the large number of Na+ ions outside the membrane results in an external positive charge. Although there are more K+ ions inside the cell membrane than outside, there are many more negative ions inside the membrane. This results in a net internal negative charge. (b) Simplified representation of a polarized membrane.

Na^+- K^+ Pump



Extracellular space
Sodium
Na+
Potassium
K+
Na+
Cell membrane
concentration
ATP
ADP
Pi
K+
Intracellular space

Membrane Current

Total membrane current is calculated as follows:

$I_m = I_c + I_{ions}$

Where: I_m = Membrane current

I_c = Charging or discharging of membrane capacitance, which can be calculated by $I_c = C_m \Delta V_m / \Delta t$, where:

C_m = Membrane capacitance per unit area

V_m = Transmembrane voltage

t = Time

I_{ions} = Current through membrane carried by ions such as Sodium, Potassium and Calcium and which can be calculated by $I_{ions} = I_K + I_{Na} + I_{ca}$

For each of I_K, I_{Na} and I_{Ca}, the current can be calculated as:

$I_{ion} = G_{ion} (V_m - E_{ion})$

Where: I_{ion} = Current of a specific ion, such as I_K, I_{Na}, or I_{Ca}

G_{ion} = Conductivity of membrane for that specific ion, i.e. G_K, G_{Na}, or G_{Ca}

V_m = Transmembrane voltage

E_{ion} = Equilibrium ion for the specific ion, which is a function of the specific ion concentration and conductivity of the specific ion (G_{ion})

Conduction of an Action Potential

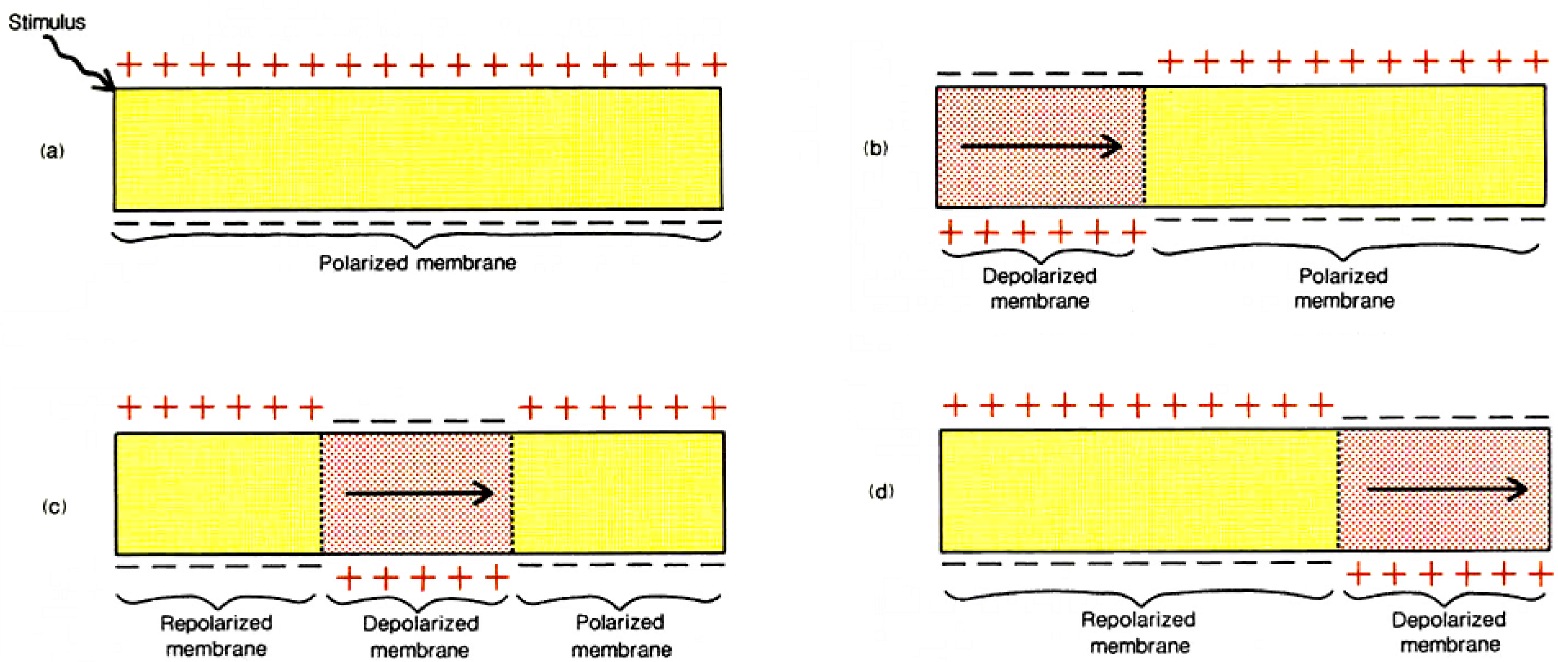
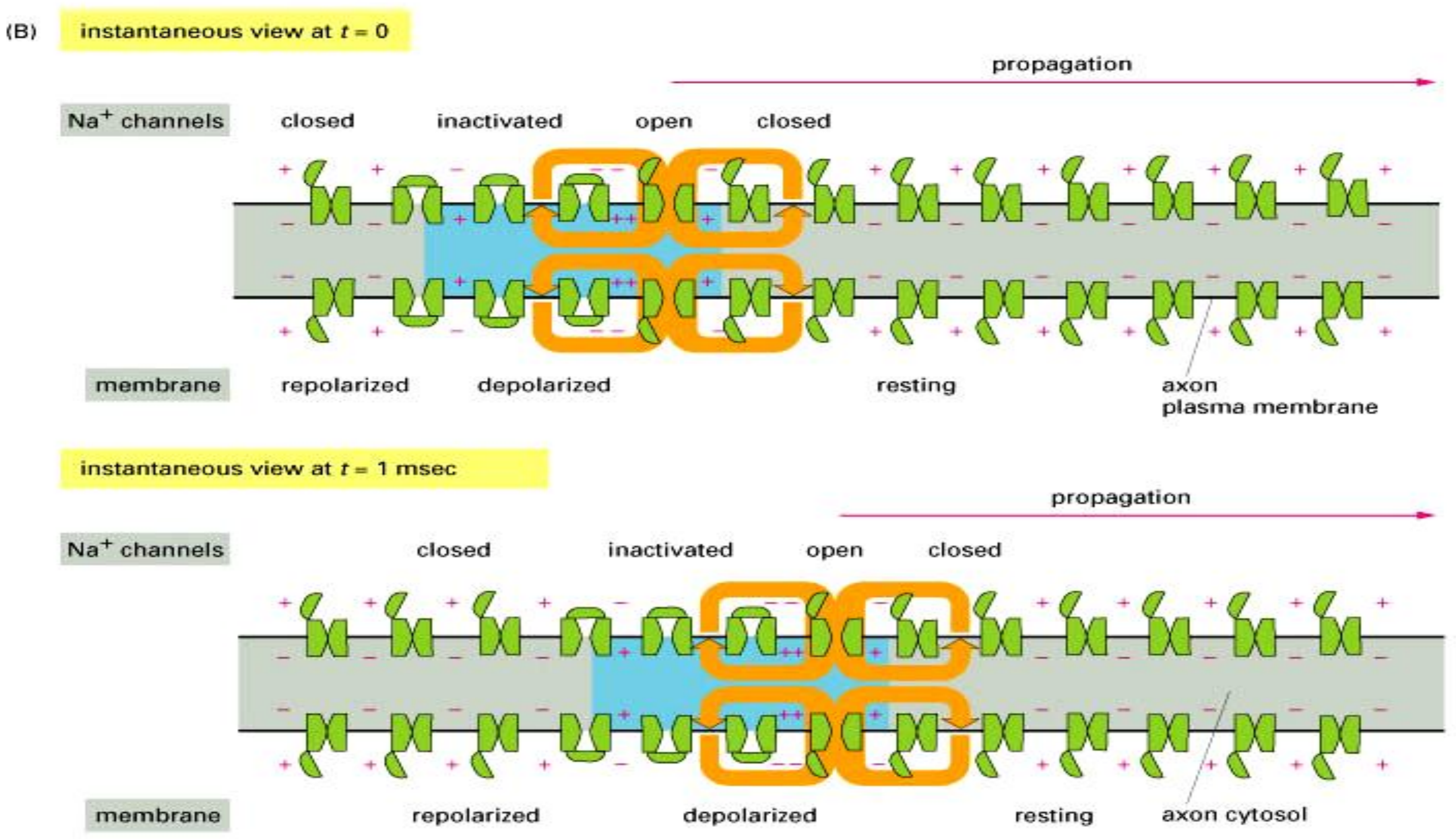


Figure 3. Initiation and conduction of a nerve impulse: (a), (b), (c) and (d). The stippled area indicates the region of the membrane that has an initiated and is conducting the nerve impulse.

Propagation of the Action Potential



Video

- http://www.psych.ualberta.ca/~ITL/ap/ap.swf

Summary

- The action potential is an efficient means of information communication within the body.
- The action potential is an all-or-nothing response at each point on the membrane surface.
- Action potentials propagate along the membrane surfaces of excitable cells (nerves and muscles).