The Sodium (Na^+) – Potassium (K^+) Pump

BIG IDEAS:

- Uses energy supplied by the cell in the form of ATP to transport Na^+ out of the cell and K^+ into the cell
- Both Na^+ and K^+ are moved **against** the concentration gradient (from **low** to **high**)
- Creates an electrical gradient across the membrane (outside of the cell is + while the inside off the cell is -)
- This difference in charge across the cell membrane is important for the conduction of nerve impulses.

SUMMARY: The sodium-potassium pump is a form of active transport in that it uses ATP to "pump" 3 sodium ions (3 Na^+) out of the cell (against the flow of diffusion) and 2 potassium ions (2 K^+)into the cell (also against the flow of diffusion). The sodium-potassium pump is important in the movement of ions across cell membranes of muscle cells (to help muscle contraction) and also for creating charge imbalances across the cell membranes of nerve cells (for generating electrical impulses).

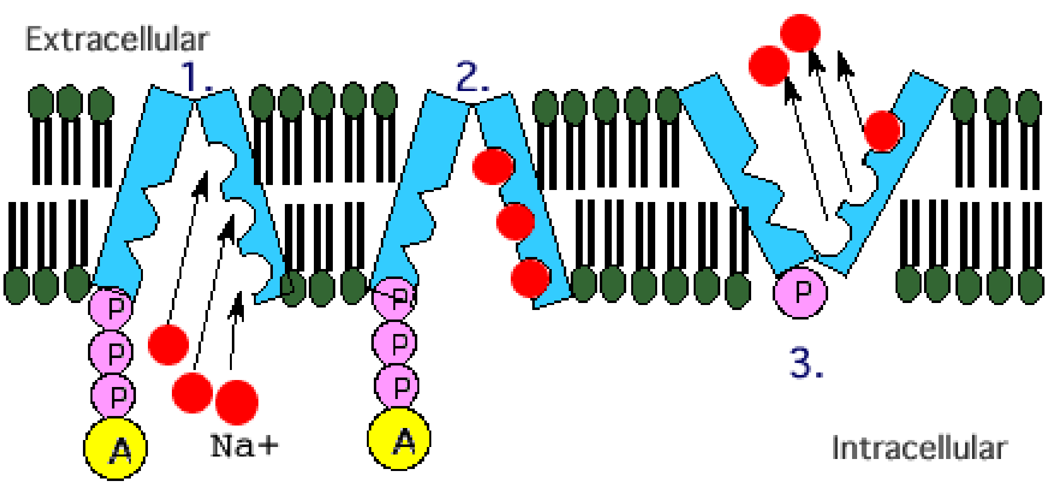
Steps involved in the Sodium-Potassium Pump (Na^+-K^+ pump):

SUMMARY:

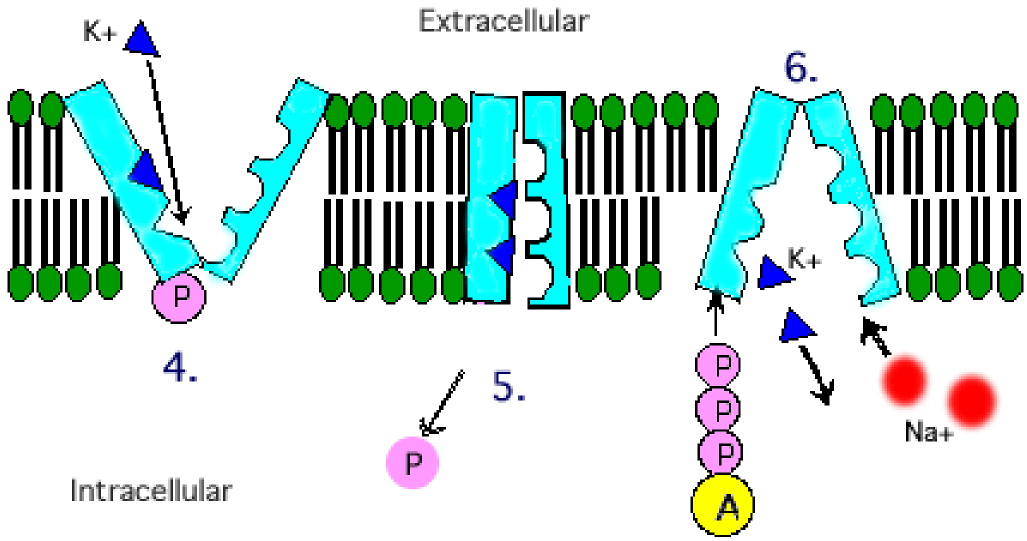
1. 3 Na^+ ions from inside the cell bind to the Na^+-K^+ pump
2. The pump changes shape, transporting the 3 Na^+ ions across the cell membrane and releases them on the outside of the cell membrane.
3. The pump is now exposed to the outside surface of the cell. 2 K^+ ions from outside the cell bind to the pump and the pump changes shape again.
4. K^+ ions are transported across the cell membrane and are released inside the cell

- During this process, ATP is split into ADP and inorganic phosphate. The breaking of this bond releases energy to power the pump.
- Overall, because 3 positively charged ions LEFT the cell and ONLY 2 positively charged ions ENTERED the cell, a charge gradient develops across the cell membrane such that the outside of the cell has more positive charge and the inside of the cell has more negative charge.

STEP-BY-STEP DETAILS:



1. A molecule of adenosine triphosphate (ATP, a source of chemical energy) binds to a site on the intracellular side of the Na^+-K^+ pump protein.
2. Three sodium ions (3 Na^+, shown as red balls) from the cytoplasm bind to "lock and key" sites on the Na^+-K^+ pump.
3. The bound ATP is then split into ADP and inorganic phosphate (the ADP is released back into the cytoplasm, while the inorganic phosphate, P, remains bound to the pump). The breaking of this bond releases energy that powers a change in the shape of the Na^+-K^+ pump protein , releasing the three sodium ions (3 Na^+) outside the cell.



4. Two potassium ions (2 K^+, shown as blue triangles) from outside the cell bind to "lock and key sites" on the protein of the Na^+-K^+ pump.
5. The protein of the Na^+-K^+ pump changes shape again as the remaining inorganic phosphate group leaves the protein's active site.
6. The two potassium ions (2 K^+) are released into the cytoplasm, as another ATP molecule binds to the active site on the Na^+-K^+ pump protein and the process starts over.
When this process repeats many times, an imbalance of charge forms across the membrane. There will be more positive charged ions outside the membrane than inside. This creates a chemical potential energy which can be used by the cell to later generate lots more ATP, for generating electrical impulses, or for muscle contractions.

Neurons communicate with one another when this charge difference is used to generate an "**action potential**" along the axon of a neuron.

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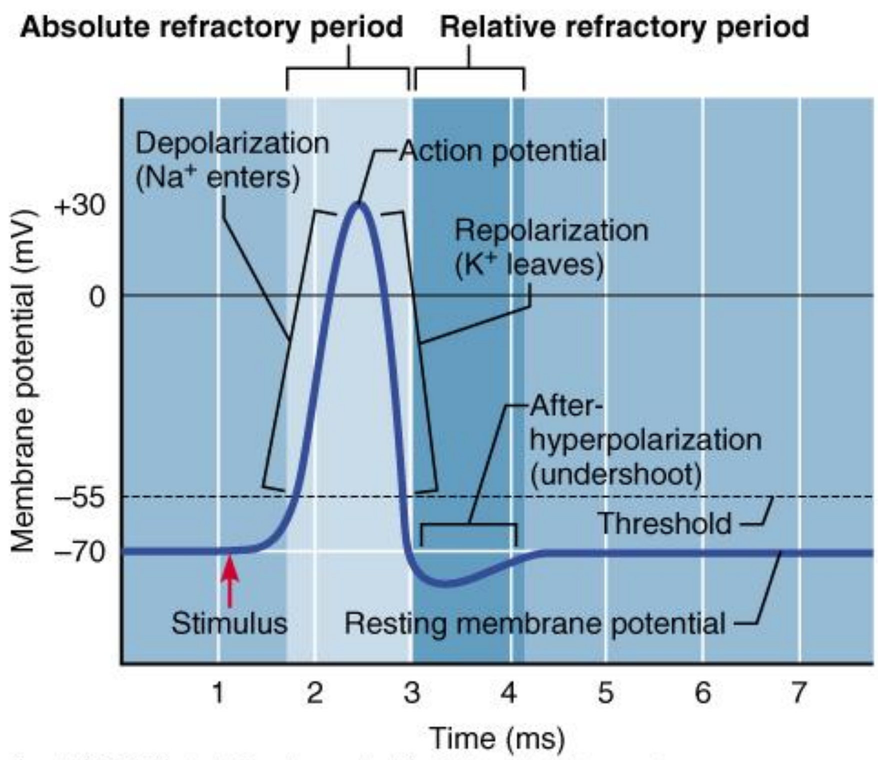
<u>**Action Potential**</u>

As derived from http://legacy.owensboro.kctcs.edu/gcaplan/anat/notes/api%20notes%20j%20action%20potential.htm
See also the animation found at http://www.psych.ualberta.ca/~ITL/ap/ap.swf

A. What is an Action Potential?

An action potential is a temporary reversal of the polarity across the membrane of a muscle cell or nerve fiber.



B. Useful Terms

1. Resting membrane potential (resting potential)
2. Depolarization
3. Threshold
4. Action potential
5. Propagation
6. Repolarization
7. Refractory period

C. Polarity of cell membrane.

- Active transport by the Na^+-K^+ pump creates a concentration gradient
- Na^+ is moved from the inside of the cell (low concentration) to the outside of the cell (high concentration)
- K^+ is moved from the outside of the cell (low concentration) to the inside of the cell (high concentration)
- There are more Na^+ ions outside the cell than there are K+ ions inside of the cell.
- As a result there is a net electrical charge across the cell membrane

Positive outside / Negative inside!!!

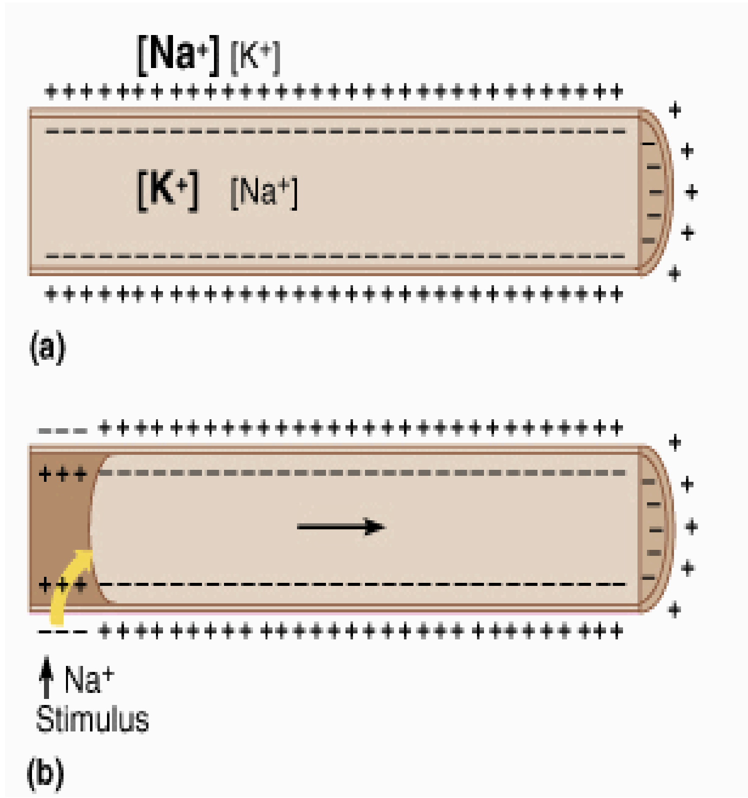
D. Action Potential Stages

(a) The Resting State – known as the Polarized State:

- The **outside** of the cell membrane is **positive** and contains a high concentration Na^+ ions (and a low concentration of K^+ ions)
- The **inside** of the cell membrane is **negative** and contains a high concentration of K^+ ions (and a low concentration of Na^+ ions)
- Neither ion type (Na^+ ions or K^+ ions) is passing through the cell membrane.
- The net electrical energy (usually measured in millivolts) generated by this charge difference is called the **resting (membrane) potential** of the neuron.

(b) Depolarization:

- A stimulus occurs (such as release of a chemical neurotransmitter or the depolarization of a neighboring section of the cell membrane)
- As a result, sodium (Na^+) channels in the cell membrane open and **Na^+ ions rush** across the membrane **into the cell** via facilitated diffusion.
- There is a decrease in the **resting (membrane) potential** as the membrane is **depolarized** and the interior of the cell **becomes positive.**



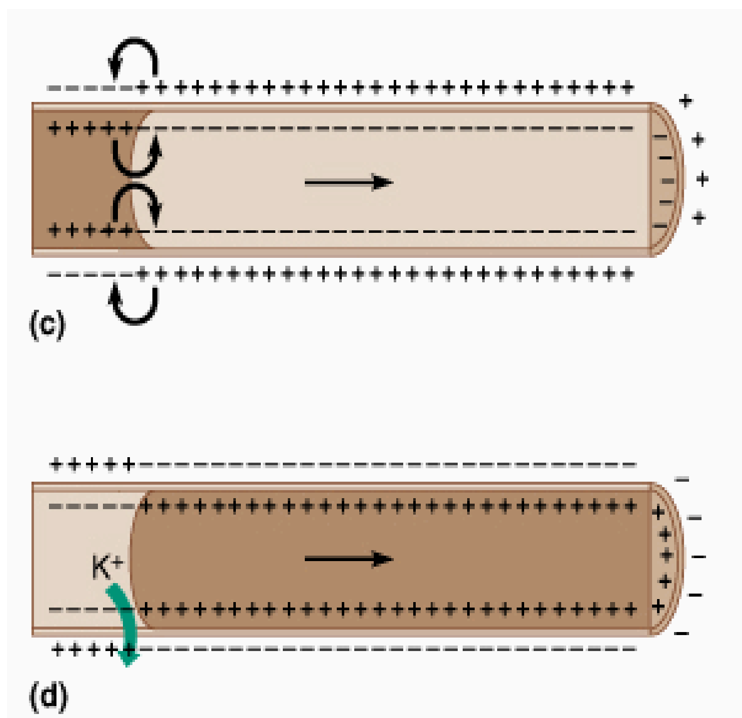
- If the stimulus is strong enough and reaches the depolarization **threshold**, an **action potential** is initiated.

(c) Propagation of the Action Potential:

- The positive patch in the membrane acts as a stimulus to the adjacent patch of the membrane.
- As a result, sodium (Na^+) channels in the cell membrane open and **Na^+ ions rush** across the membrane **into the cell** via facilitated diffusion.
- Thus the **resting potential** in this area of the cell membrane also decreases and depolarization spreads.
- The action potential thus travels rapidly along the axon of a neuron.

(d) Repolarization :

- Immediately after the action potential passes the membrane permeability changes again
- Na^+ ion channels close and K^+ ion channels open.
- **K^+ ions rush** across the membrane and **out of the cell** via facilitated diffusion
- This ion movement restores the resting state **electrical conditions** (but not the resting concentration gradient of ions).
- Thereafter the **Na^+-K^+ pump** restores the ion concentration gradient by pumping Na^+ out and K^+ in.



- Until repolarization is complete, the neuron will be in a **refractory period**, meaning it cannot be stimulated again (until repolarization is complete).