VANCOUVER COMMUNITY COLLEGE

Nerve Signal Transmission

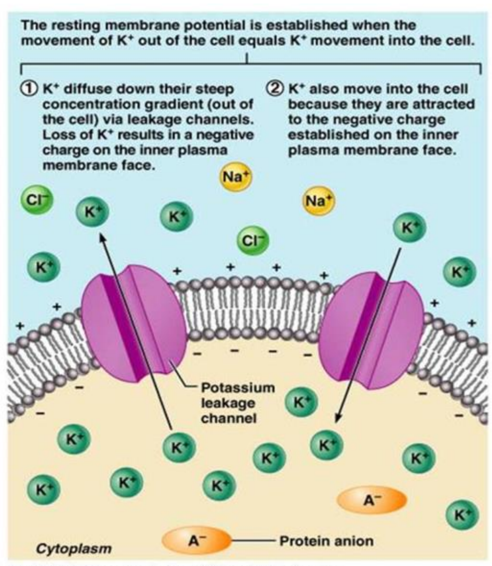
Nerves transmit information by using electrical signals that travel down the cell membrane. These signals are called **action potentials**. A nerve impulse is an "all or nothing" response: it is either "on" or "off" (like a light switch). A very weak stimulus will not trigger an impulse at all, but a stronger stimulus will trigger the same size of impulse, no matter how intense the stimulus.

A **stimulus** is an event that causes a response. For example, holding a flame to your hand will trigger a pain signal; the heat is the stimulus.

The cell membrane is the outer wall of a cell, made out of a phospholipid bilayer. It is hard for ions to enter or leave the cell without help from ion channels or ion pumps.

As long as the cell membrane reaches a certain threshold (the **threshold potential**), an action potential will be triggered. The strength of the stimulus is transmitted by changing the frequency of the impulse. Therefore, weak stimuli will trigger the impulse slowly, but strong stimuli will cause the impulse to trigger rapidly. (Think of flipping a light switch on and off again slowly versus quickly: the slow on…off would signal a weak stimulus, but a rapid on-off-on-off-on-off-on-off would signal an intense stimulus).

THE MEMBRANE POTENTIAL



Ions exist in the bloodstream and in and around all your cells. Three ions in particular are important for transmitting nerve signals: potassium (K^+), sodium (Na^+), and chloride ($C\ell^-$). When the cell is resting, special proteins in the cell membrane (**sodium-potassium Na+/K+ pumps**) use the energy stored in ATP to move K+ into the cell and Na+ out of the cell (**active transport**). One molecule of ATP is used to move 3 Na+ ions out of the cell and 2 K^+ ions into the cell. The K+ in the cell is then free to diffuse out of the cell through special K+ ion channels in the cell membrane. Na+ channels exist as well, but they are closed, meaning that only a tiny amount of the Na+ is able to move back into the cell. The result of K+ diffusion is that there are more positive ions (Na+ and K+) outside the cell, and fewer positive ions inside. Overall, this creates a negative potential inside the cell (and a positive potential outside the cell), called the **resting potential**.

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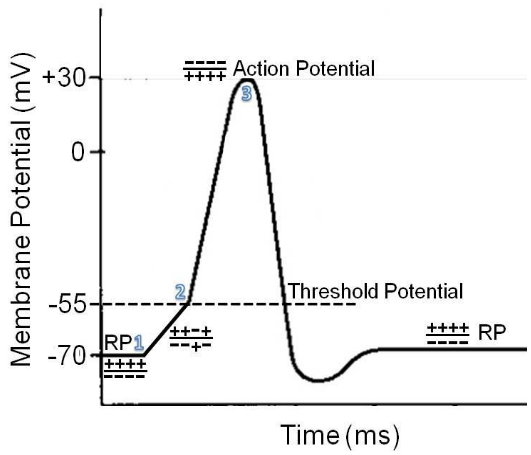
When a cell receives a stimulus (either from another nerve cell or from a sensor), the message is transmitted by altering the resting potential to create an action potential. The whole process takes less than a millisecond:



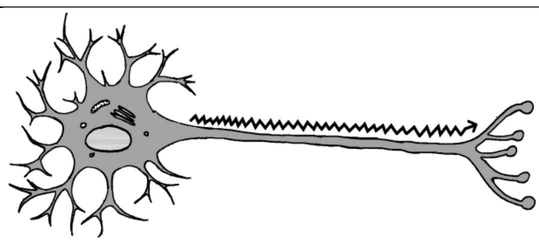
This graph shows how the cell potential changes at the resting potential (RP) and each of the 3 stages of nerve signal transmission in the list to the right. The +/− images at each of the 3 stages show how the ions are arranged at the cell membrane with the charge below the

1. The stimulus opens some ion channels in the cell, allowing the sodium ions to rush back into the cell. The movement of positive ions increases the resting potential from −70mV to −55mV, causing *depolarization*.

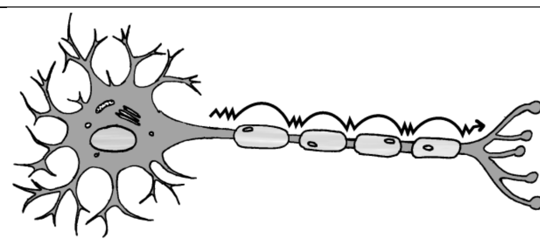
2. Once the cell is depolarized to a specific point (−55mV; the **threshold potential**), it triggers the rest of the Na+ ion channels to open, causing the cell potential to quickly change to a positive value inside the cell.

3. Reaching the peak voltage causes the Na+ channels to close and K+ channels to open. K+ ions can now exit the cell, allowing the cell to return to the resting potential, *repolarization*. A slight hyperpolarization can be seen because the K+ channels are slow to close. Then the Na+/K+ pump resumes maintenance of the resting potential, *refractory period*.

An action potential in one part of the cell membrane will cause the nearby parts of the cell membrane to depolarize as well, creating a travelling wave of depolarization along the cell membrane (like a stack of dominoes being knocked over). This travelling wave is the **nerve impulse**.



With no myelin, the action potential must travel down the length of the axon, like a string of dominoes being knocked over.



With myelin, the action potential can ‘leapfrog’ between the nodes of Ranvier, travelling much faster, since it only has to move along the membrane for short distances.

In cells with a myelin sheath, the insulating myelin prevents the covered sections of the nerve from depolarizing. However, the action potential will "jump" across the covered areas from one node of Ranvier to another. Since the cell does not have to depolarize the whole membrane, nerve impulses travel much faster on myelinated cells. This is called **saltatory conduction**.

QUESTIONS

1. What is the purpose of the Na+/K+ pump?

2. If you measured the concentration of sodium ion (Na^+) at a neuron, you would expect to see:
(a) more Na^+ inside the cell (b) more Na^+ outside the cell
(c) the Na^+ concentration would be the same inside and outside the cell

3. A mad scientist conducted an experiment where he took two wires connected to a battery and touched them to a nerve in a subject's arm. The patient's arm twitched and slapped the scientist in the face. Why did this happen?

4. What effect would a totally sodium-free diet have on the nervous system?

5. Why are axons not completely wrapped in myelin?

6. Why are the Na+ and K+ ion channels sometimes called *voltage-gated channels*?

7. Some painkillers work by modifying the resting potential.
(a) Valium (diazepam) causes relaxation by allowing more chloride ions to enter a patient's neurons, which makes the resting potential of the cell more negative. How would this affect the ability of the neuron to carry an action potential?

(b) How would the action of Valium compare to Novocain (procain), which acts by preventing Na+ from crossing the cell membrane?

8. Multiple Sclerosis (MS) is a disease that causes the destruction of the myelin sheath, leaving scarred areas on the nerve cell membrane that interfere with the formation of an action potential. How does this explain one of the common symptoms of MS, tremors (uncontrollable shaking of parts of the body)?

SOLUTIONS

1. The Na+/K+ pump maintains the neuron's resting potential by using energy from ATP to exchange sodium from inside the cell with potassium from outside the cell.

2. b. more Na^+ outside the cell

3. Nerve impulses are electrical potentials, like the voltage from a battery. Connecting the battery to a neuron would simulate an action potential and cause an impulse to be sent down the nerve. He must have found a motor neuron, since the impulse started by the battery caused the muscles in the patient's arm to contract.

4. If there was no Na+ in your body, the Na+/K+ pumps would be unable to maintain a resting potential, and it would be impossible to form an action potential. Therefore, no impulses would be able to be sent, and your nervous system would shut down. There would be other effects on the body long before you had too little Na+ for your nerves, but those are not part of this worksheet.

5. If there were no nodes of Ranvier, the action potential would be stopped from transmitting, since the potential cannot 'jump' far enough to reach the end of such a long myelin sheath. The nodes are important for allowing the nerve impulses to be transmitted for this reason.

6. They are called voltage-gated channels since their opening and closing is controlled by the cell potential. For example, most of the Na+ channels open at the threshold potential and close after the peak voltage is reached.

7. (a) It would be more difficult for the cell to achieve an action potential since many more Na+ ions would have to move into the cell in order to reach the threshold potential. (Examine the graph showing resting and action potentials in the text of the worksheet. Lowering the resting potential (e.g. to −85 mV) makes the "hill" of the action potential that much taller, meaning that only very strong stimuli will trigger a nerve impulse.).

   (b) With Novocain, the resting potential of the cell is unchanged. But since the cell relies on being able to transport Na+ in order to reach the threshold and action potentials, it will be much more difficult to achieve with the Novocain limiting Na+ transport.

8. Destruction of the myelin sheath would affect the ability of that neuron to carry an impulse properly. Therefore, the action potential would travel down the axon at a slower rate, or the action potential would only be transmitted occasionally. This would result in shaking instead of controlled movements.