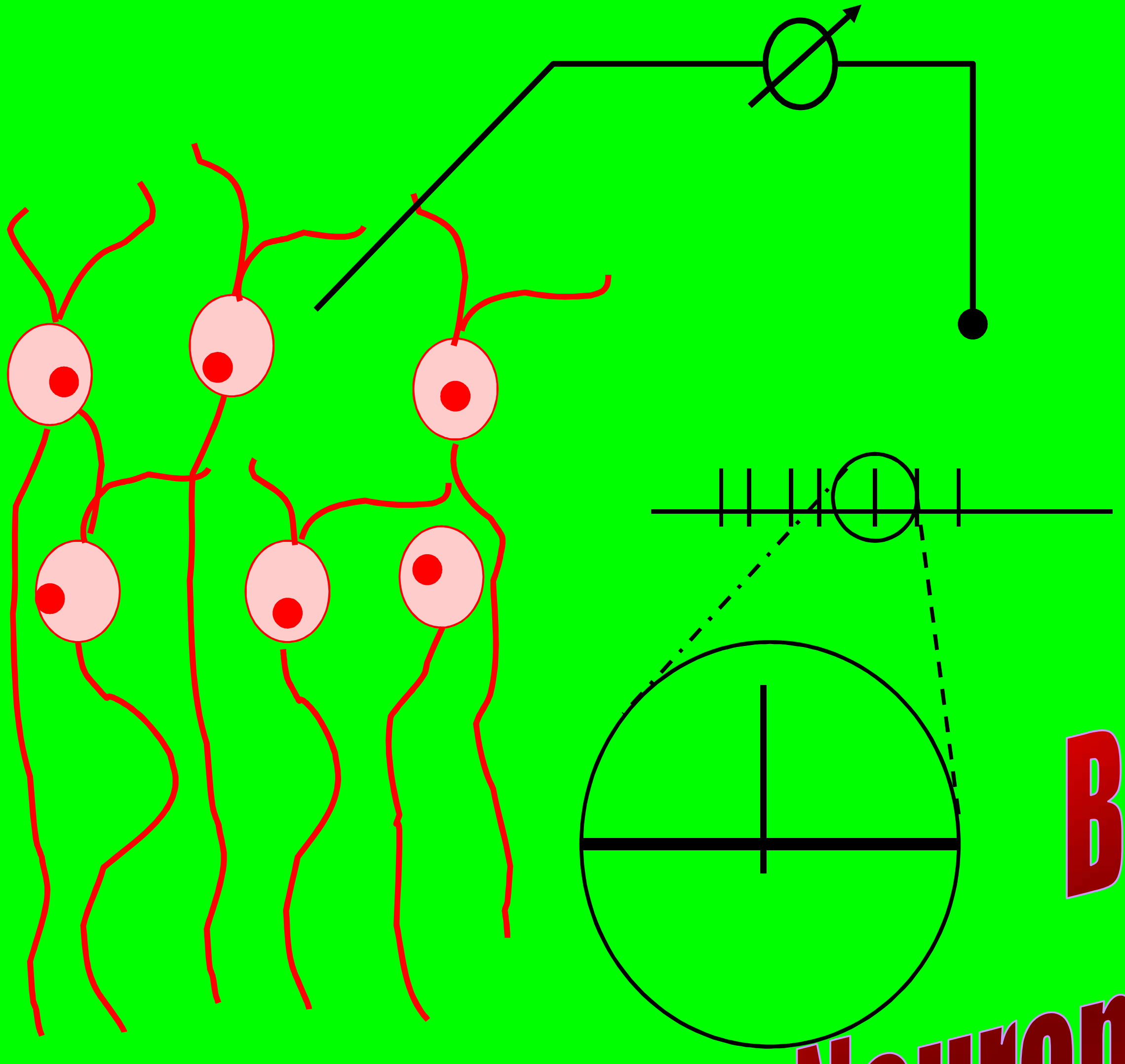


Basic Neurophysiology

Ch. 5. Membrane Potentials
and Action Potentials

Basic Physics of Membrane Potentials

- Nerve and muscle cells: Excitable
- Capable of generating rapidly changing electrochemical impulses at their membranes

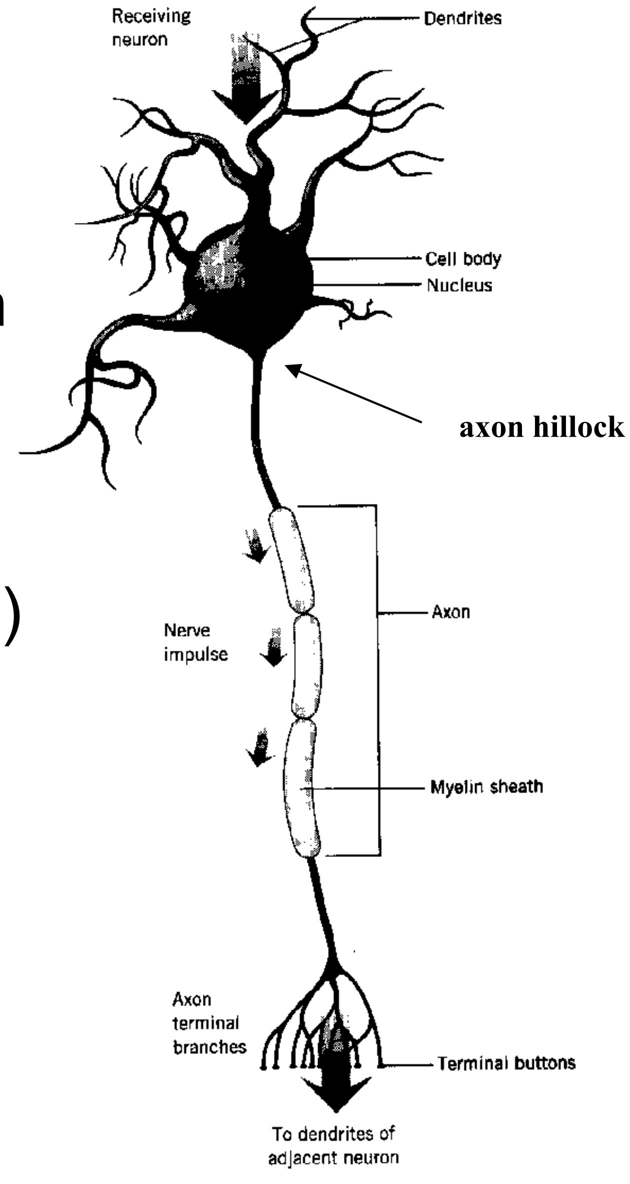
Although there are a great many neuron shapes...

...we discuss them as though they were functionally alike.

Most have: dendrites
cell body (soma)
axon hillock
axon
axon terminals

Some have myelin wrapping around the axon.

Muscles (see Fig. 6-1)



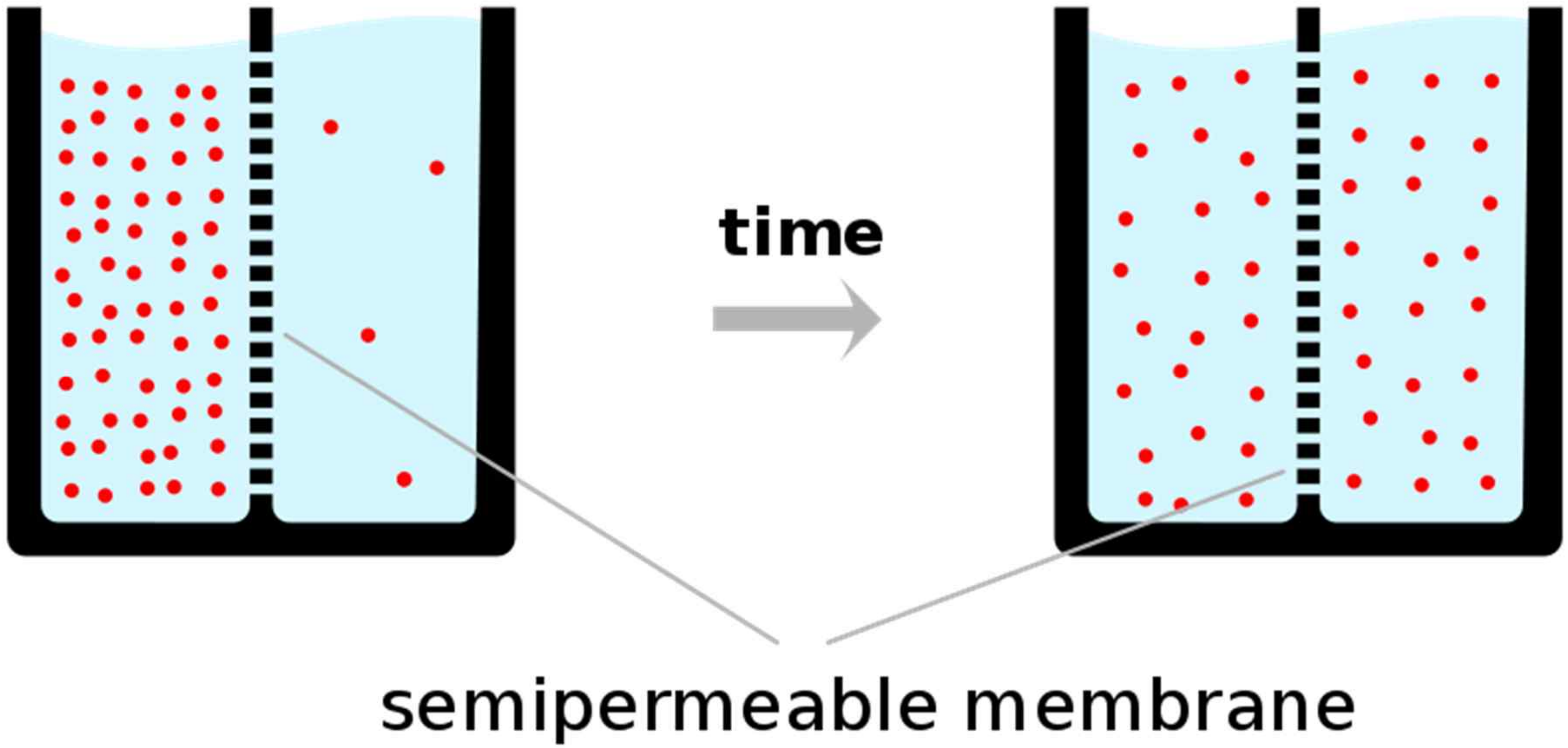
The signal of biological systems is partly based on the kind of electrical forces which are carried by wires, but there are some important differences.

To begin, we need to explain the concept of a

resting membrane potential

Check out membrane potentials caused by diffusion first

Diffusion

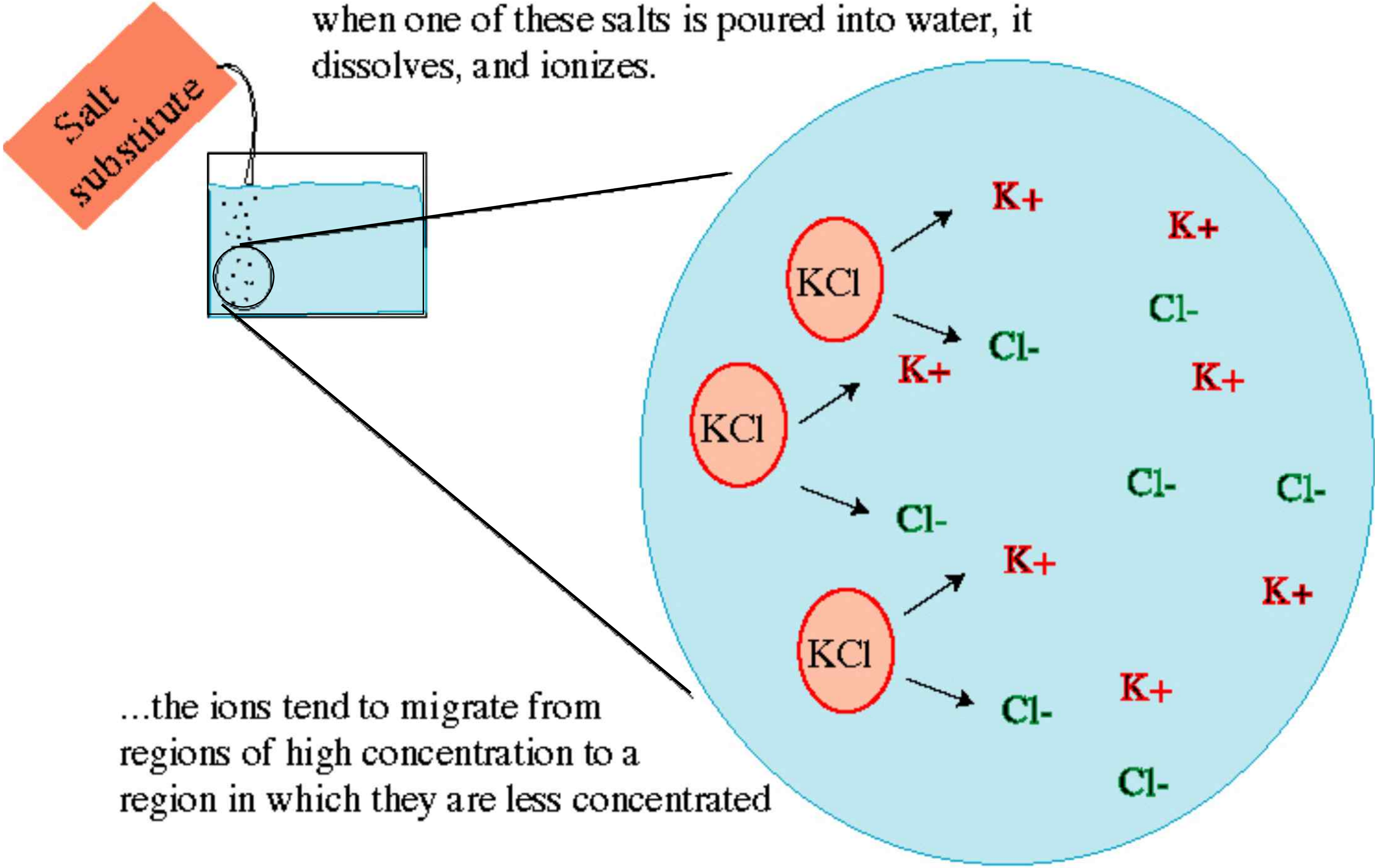


Ions (pink circles) will flow across a membrane from the higher concentration to the lower concentration (down a concentration gradient), causing a current. However, this creates a voltage across the membrane that opposes the ions' motion. When this voltage reaches the equilibrium value, the two balance and the flow of ions stops.

...the explanation begins with the salts which are dissolved into the fluids of the body, especially NaCl and KCl.

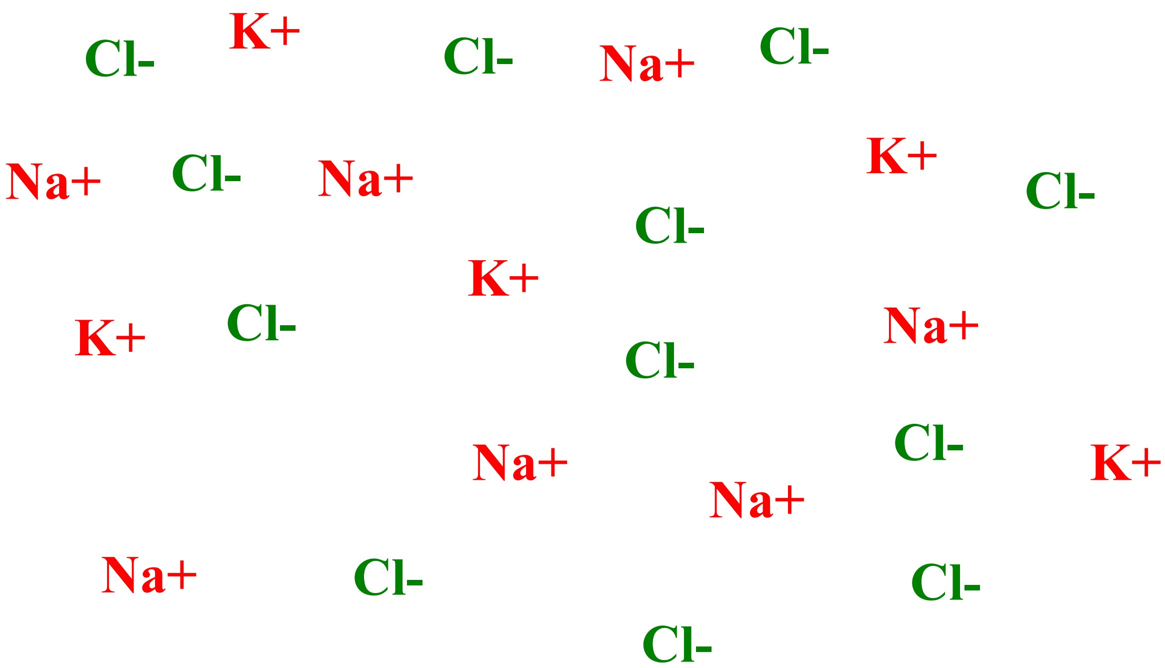
NaCl -- sodium chloride (table salt)

KCl -- potassium chloride (salt substitute) when one of these salts is poured into water, it dissolves, and ionizes.

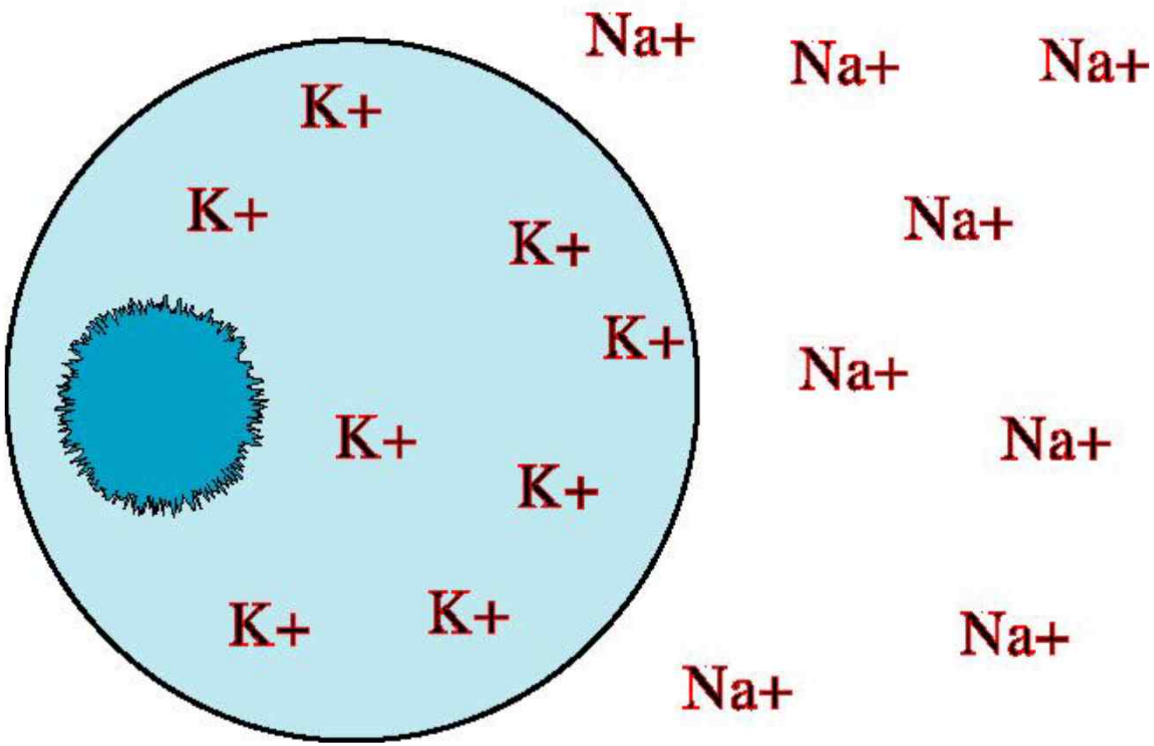


...the ions tend to migrate from regions of high concentration to a region in which they are less concentrated

--- this is know as moving down their concentration gradients.



Here is a mixture of sodium chloride and potassium chloride, wherein the molecules have ionized. All the sodium and potassium atoms carry a slight positive charge, and all the chloride atoms carry a slight negative charge.



The role of the chloride ions can be ignored!

Every cell in the body has enzymes in the membrane which pump Na+ out of the cell, and pump K+ into the cell.

The Na/K pump thus produces concentration gradients for these ions!

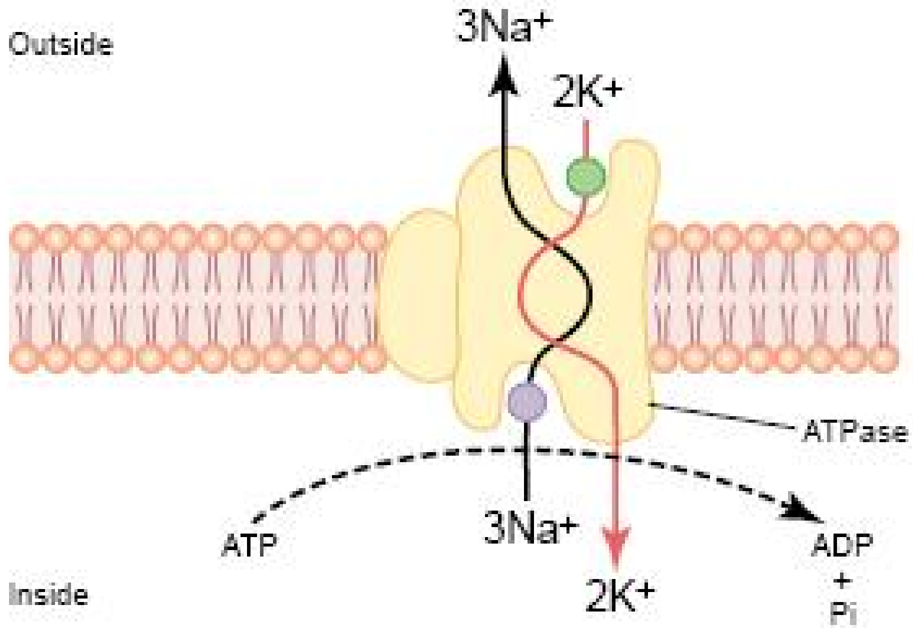
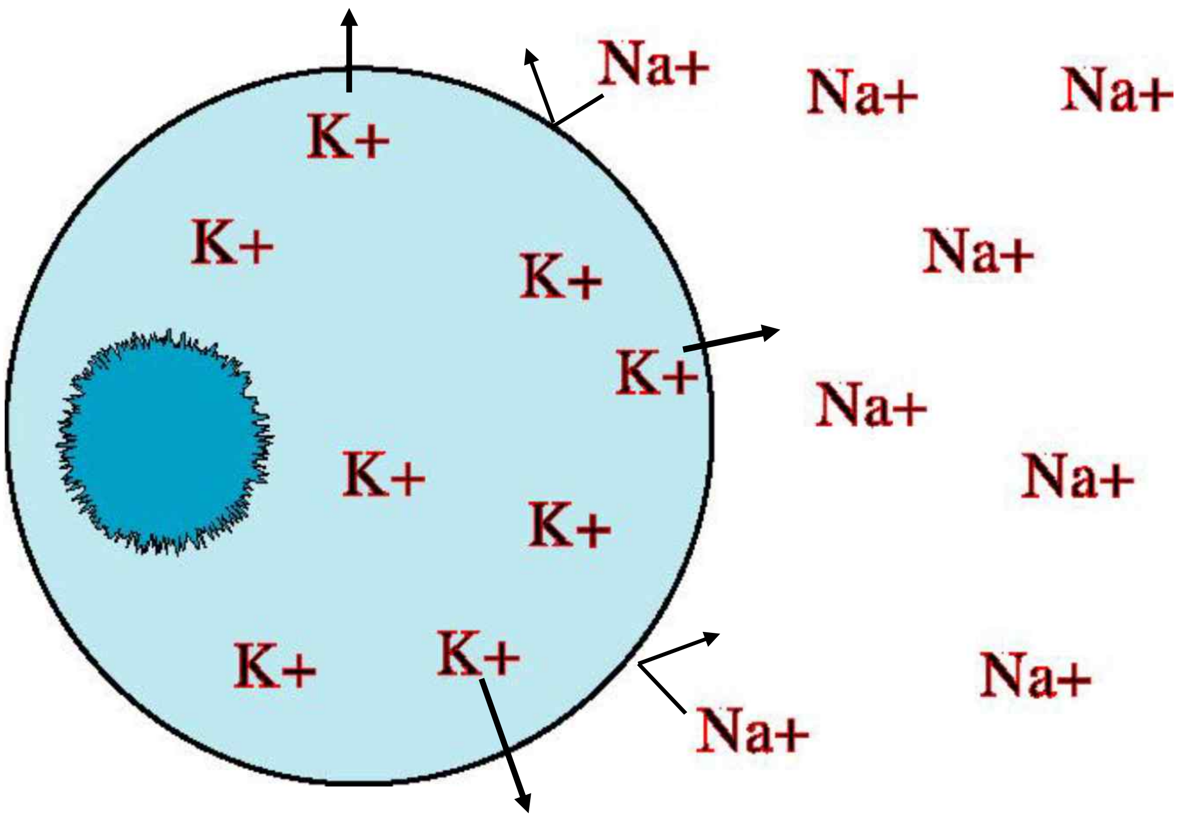


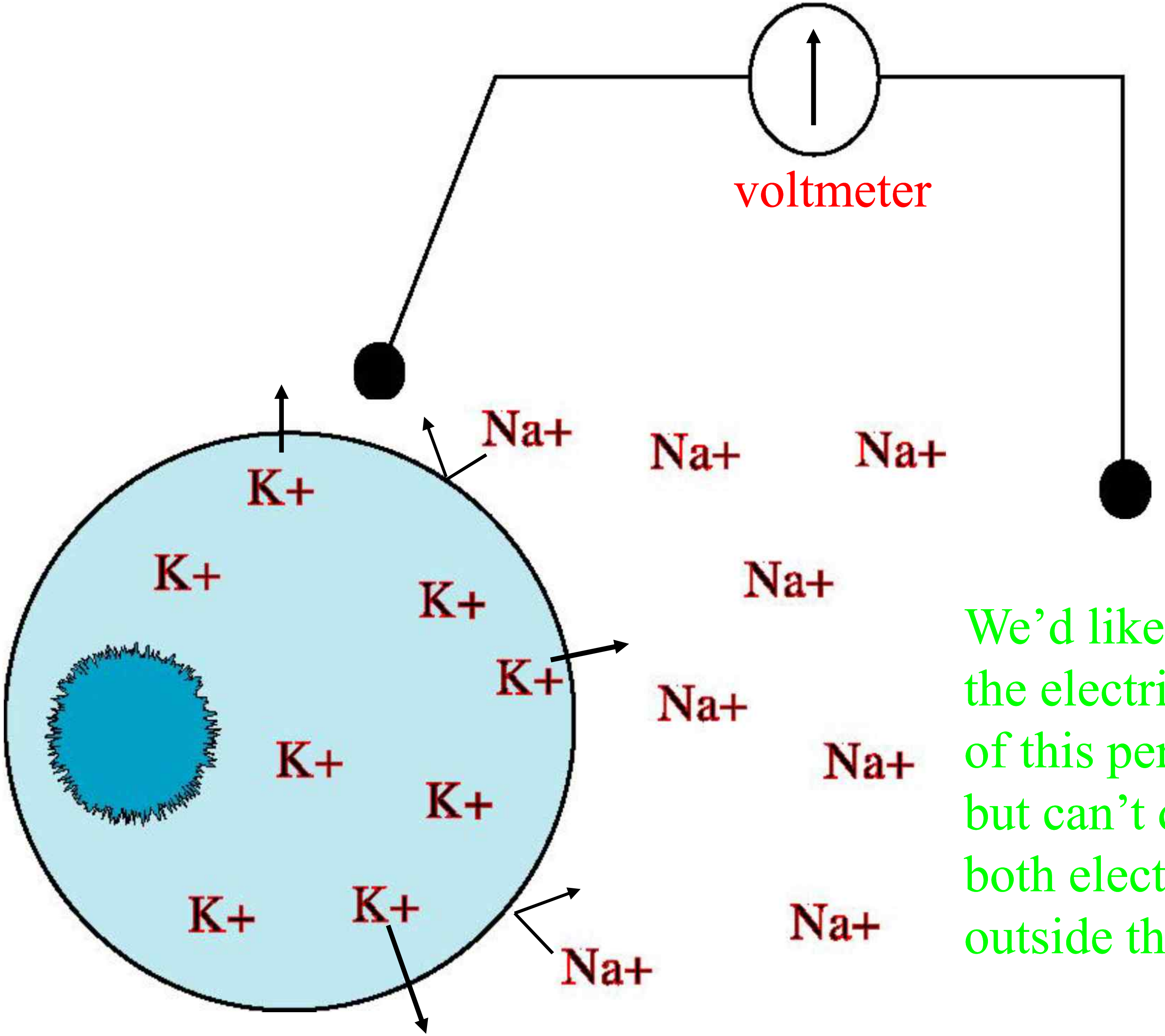
Figure 4–11

Postulated mechanism of the sodium-potassium pump. ADP, adenosine diphosphate; ATP, adenosine triphosphate; Pi, phosphate ion.

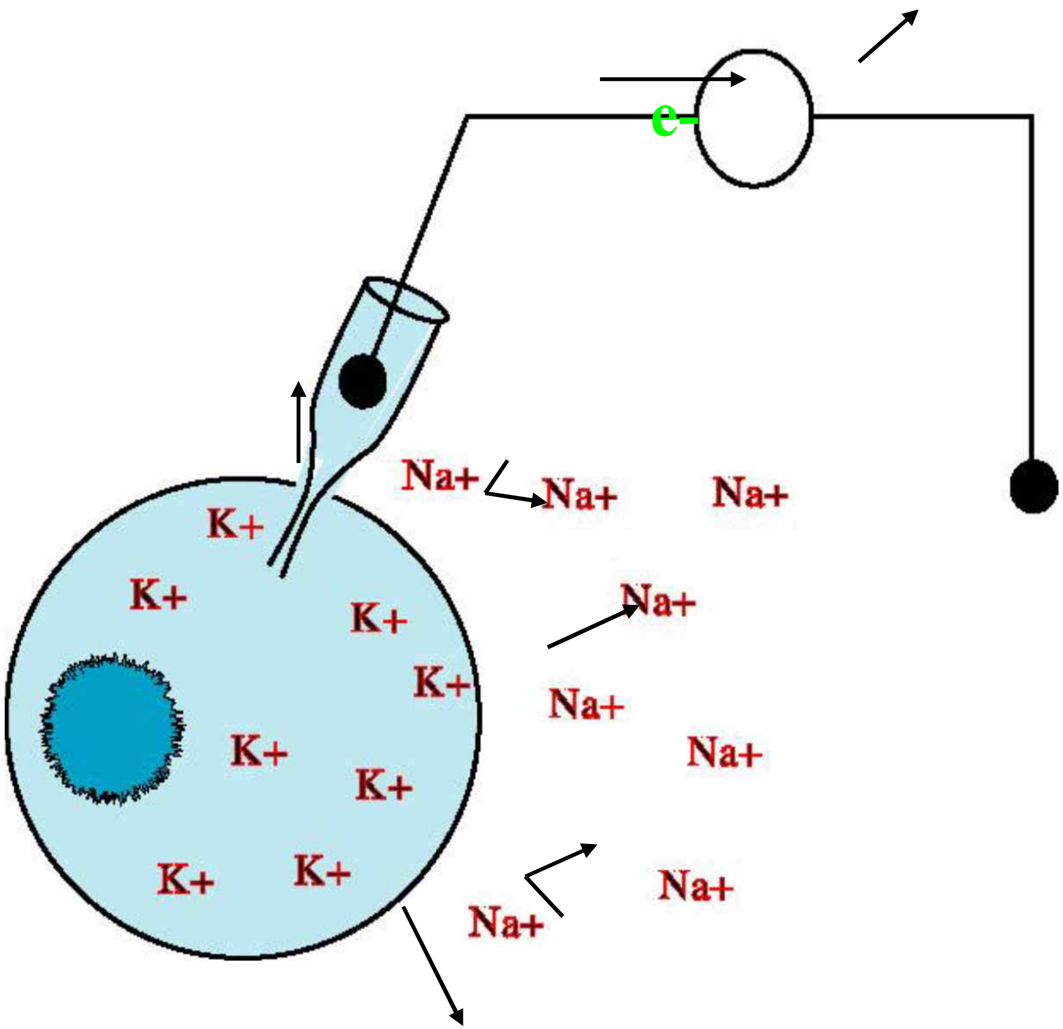
Additionally, the cell membrane is semipermeable to K+, but generally not to Na+.



So for most cells -- and for neurons at rest -- only the K+ is able to run down its concentration gradient!



We'd like to measure the electrical effects of this permeability, but can't do so if both electrodes are outside the cell.



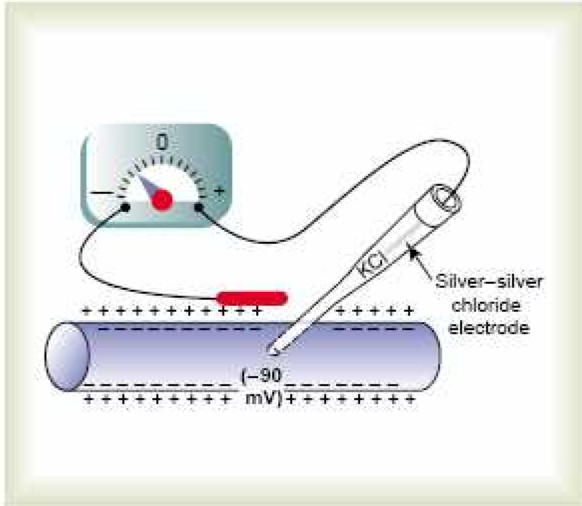


Figure 5–2

Measurement of the membrane potential of the nerve fiber using a microelectrode.

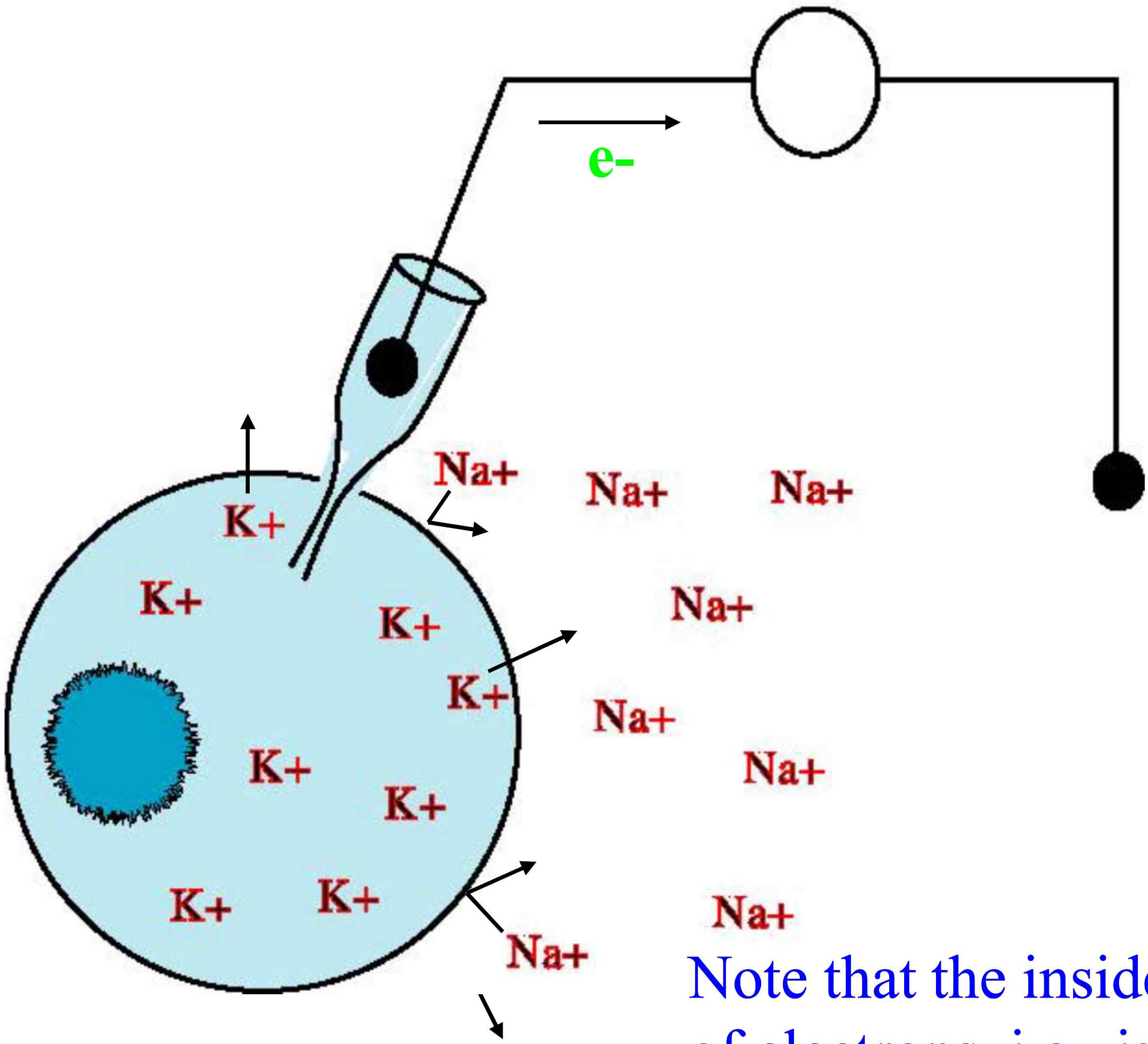
But we can see the resting membrane potential if we can get an electrode inside!!!

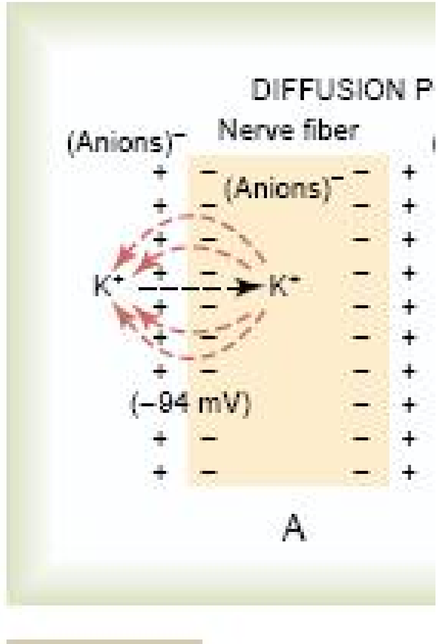
So the selective permeability of a potassium produces what is called a

resting membrane potential

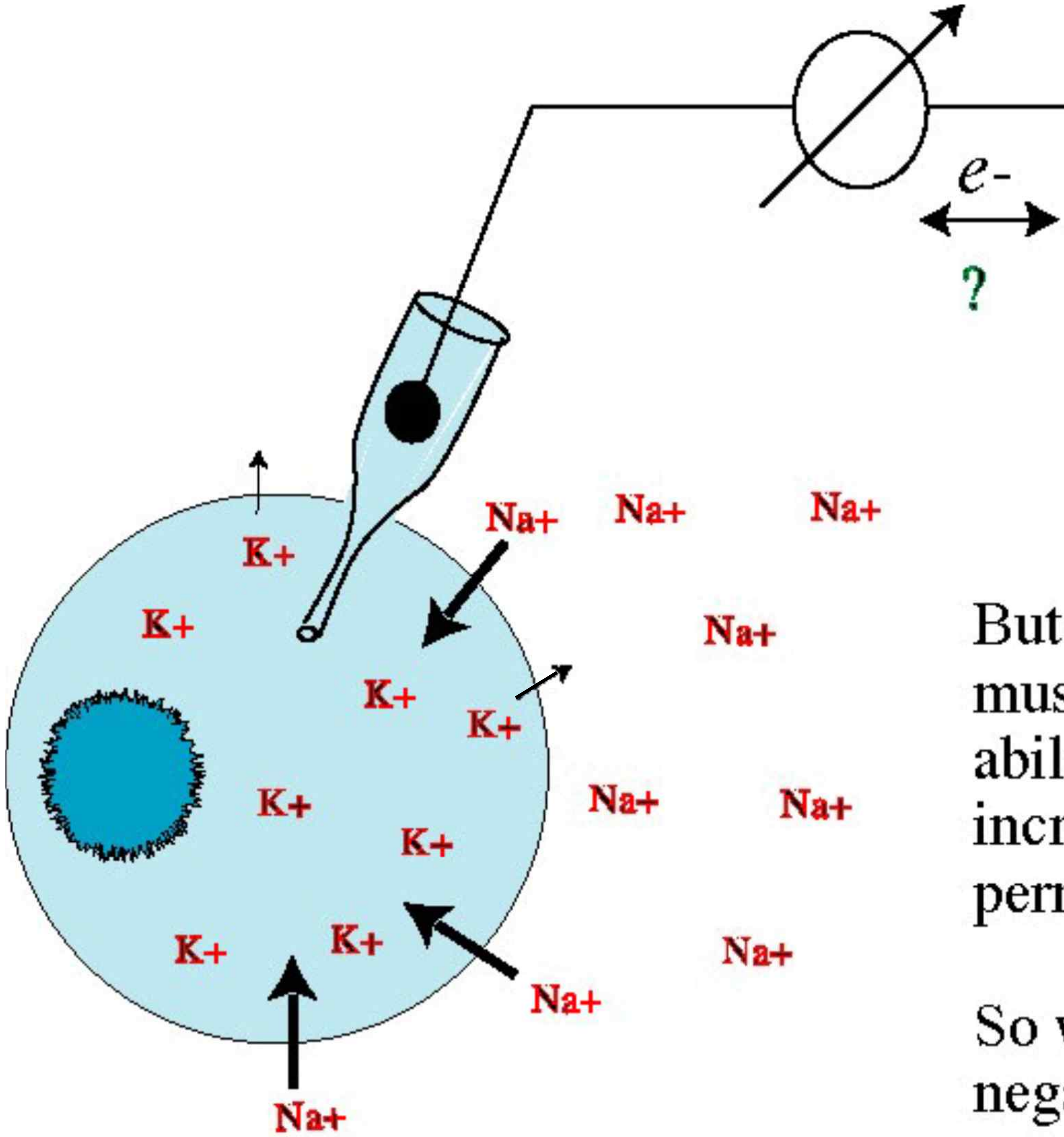
in that the flow of ions across the membrane will be registered by an electrode circuit.

The resting membrane potential of nerve fibers when they are not transmitting nerve signals is about -90mV.



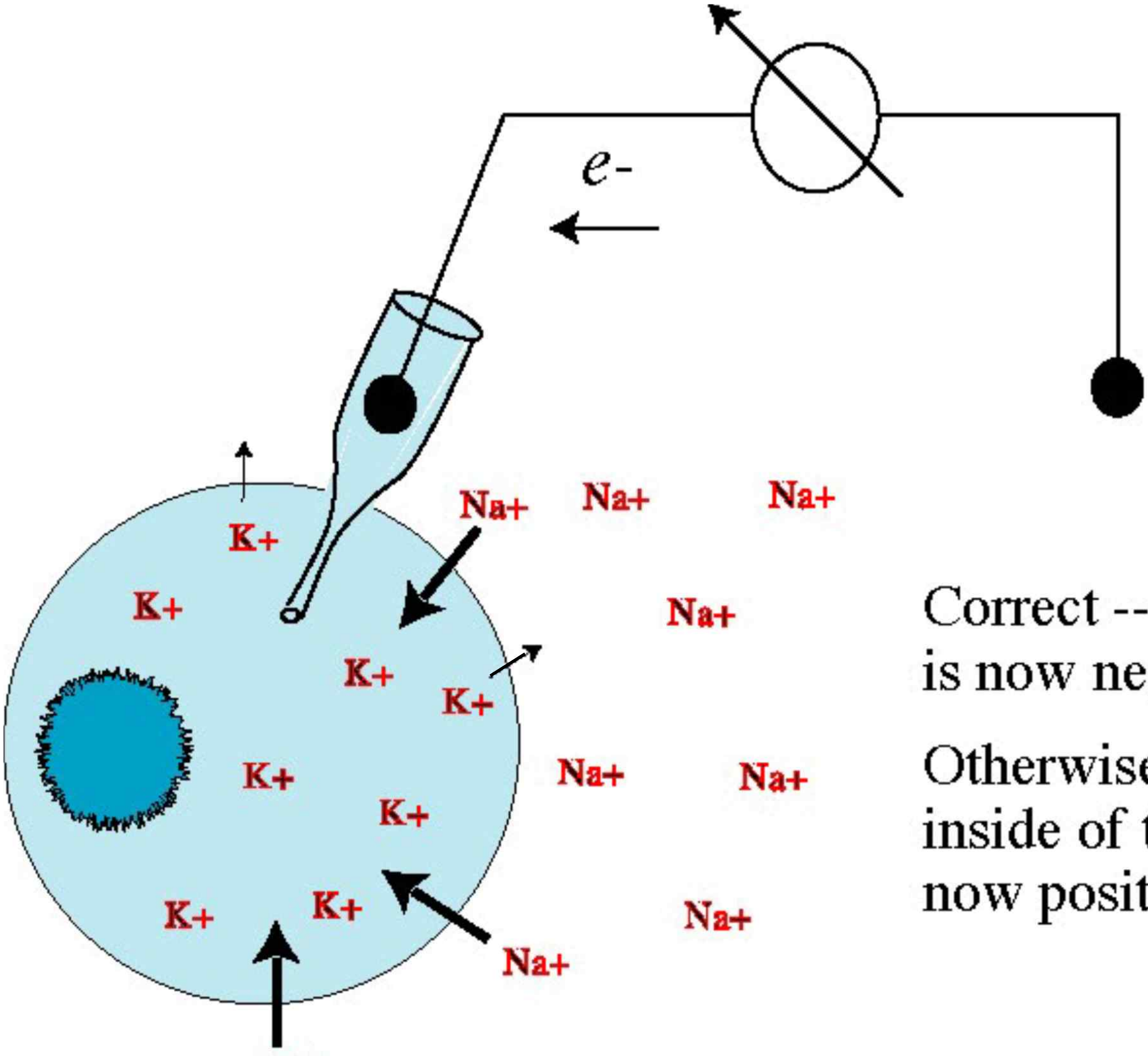


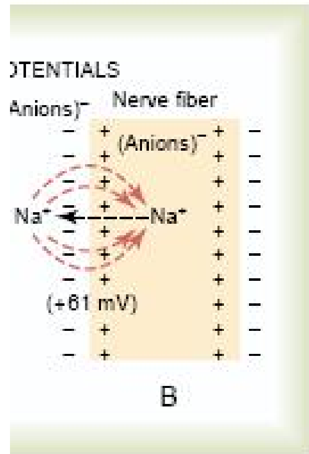
Note that the inside electrode is the source of electrons, i.e., is the negative electrode. But neurophysiologists like to say that the "inside of the cell" is negative.



But neurons and muscles have the ability to dramatically increase the permeability of Na+.

So which side is negative now?





Correct -- the outside is now negative.

Otherwise stated, the inside of the cell is now positive.

The result of increased sodium permeability
is called

depolarization-

When sodium channels are temporarily opened, the external electrode is the source of electrons, and thus
is the negative electrode. Thus the electrode inside the
cell is positive.
(See Fig. 5-6)

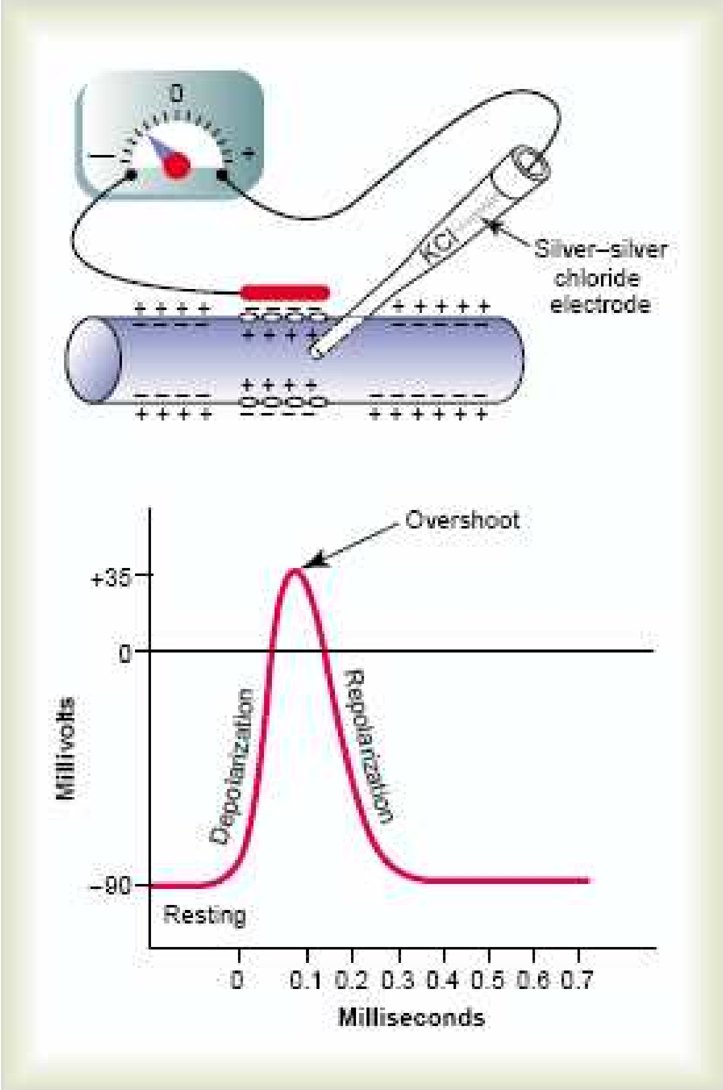
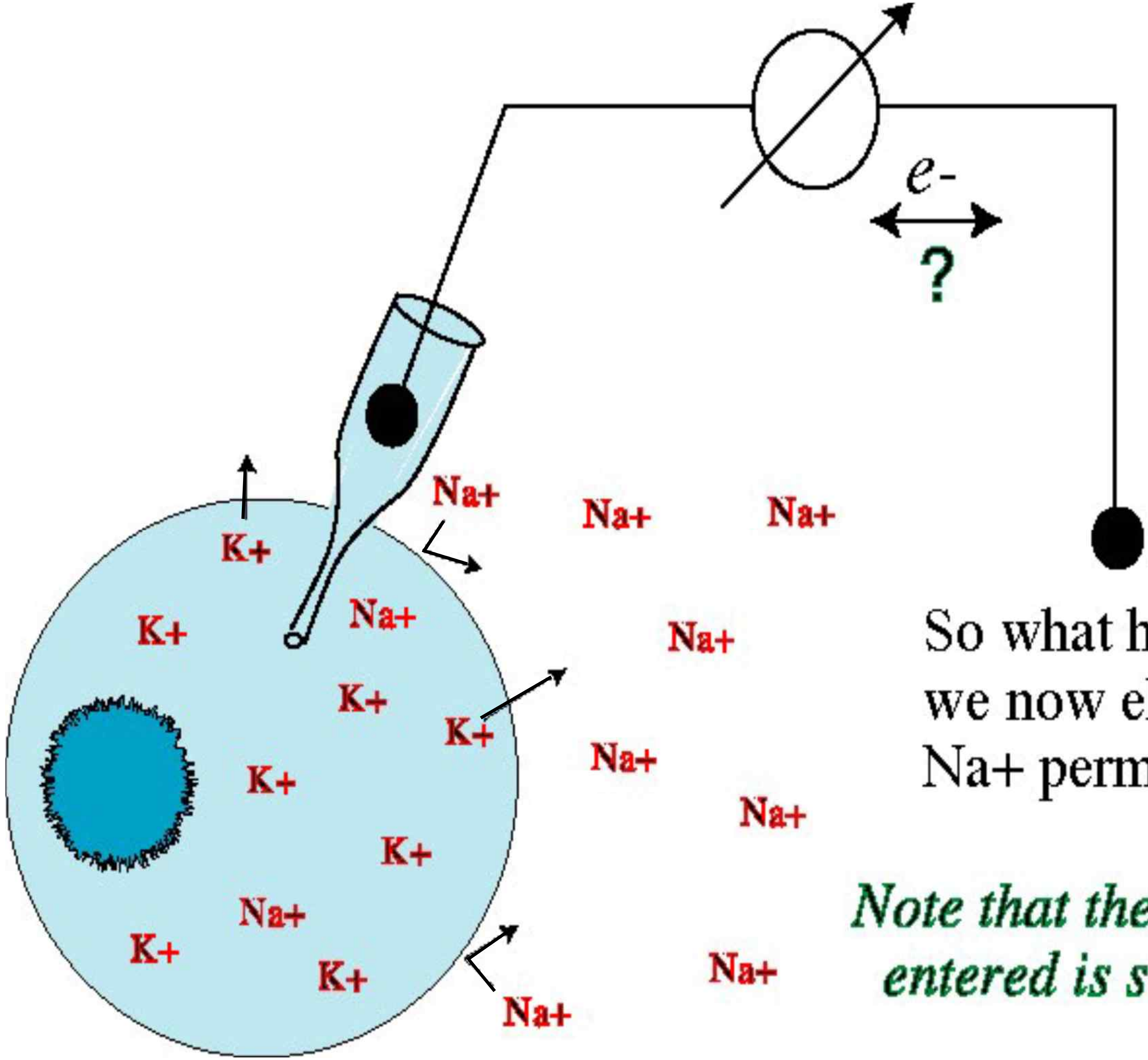


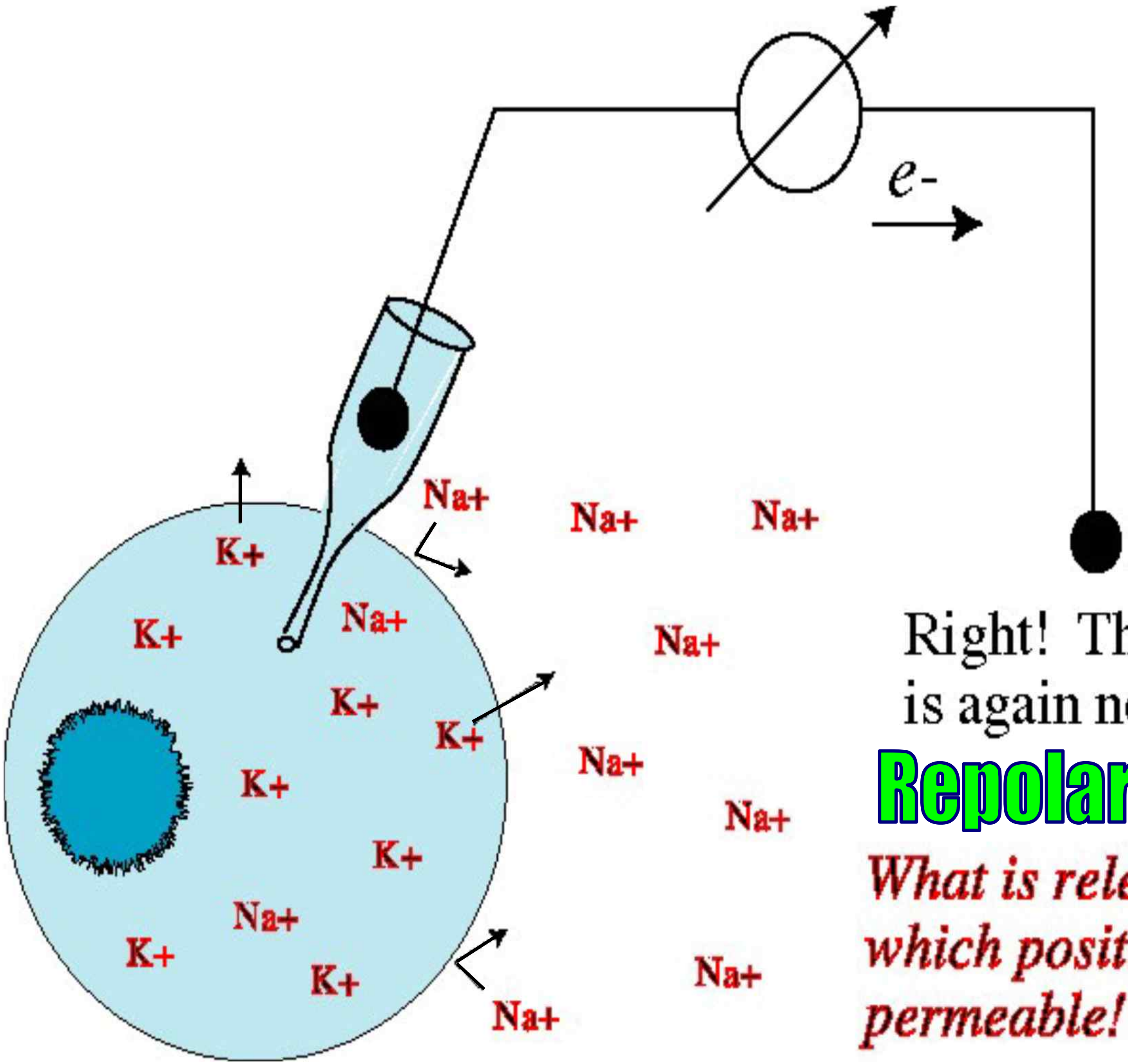
Figure 5–6

Typical action potential recorded by the method shown in the upper panel of the figure.



So what happens if we now eliminate Na+ permeability?

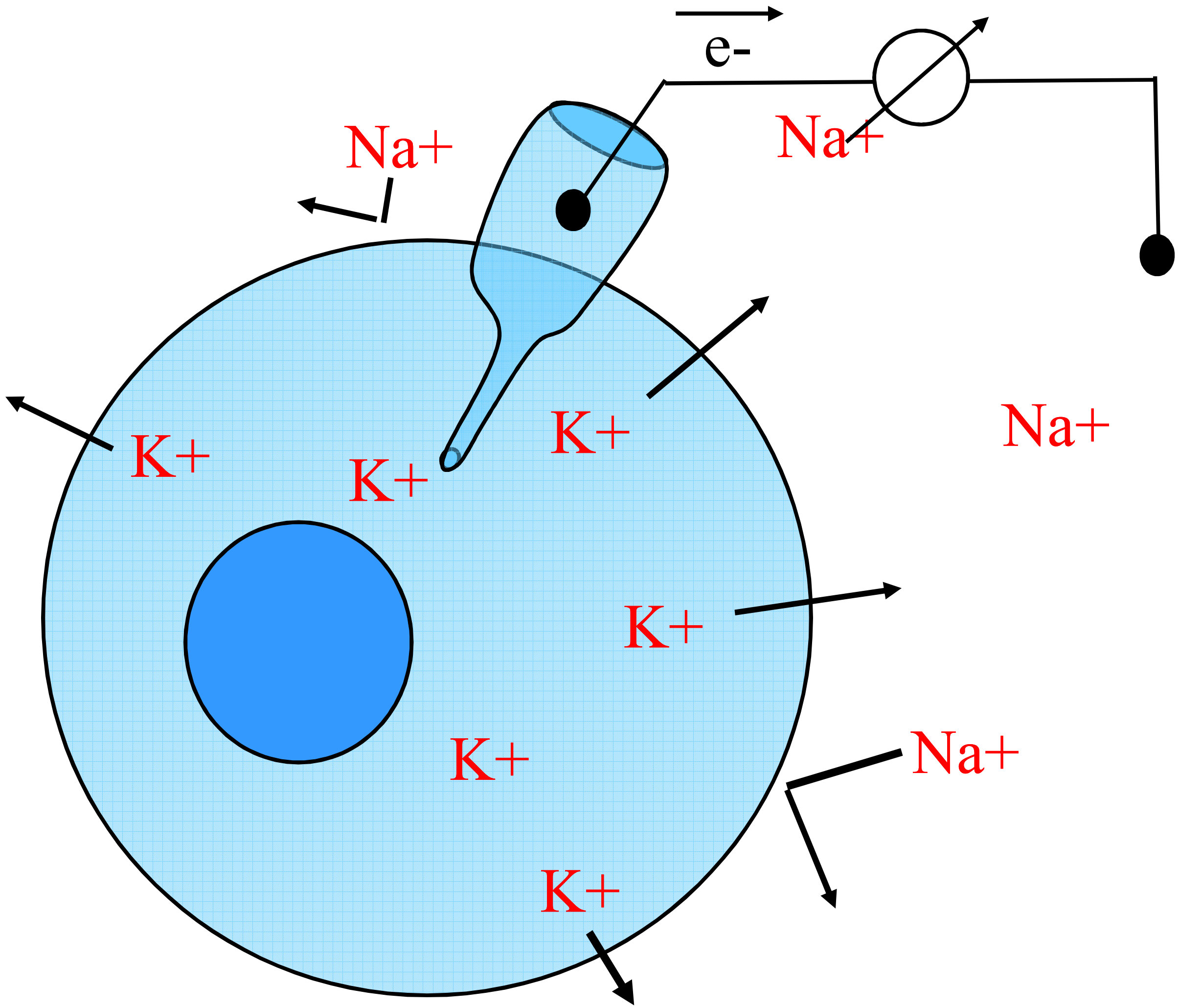
Note that the Na+ which entered is still inside!



Right! The inside is again negative.

Repolarization

What is relevant is which positive ions are permeable!



It is possible, also for additional potassium channels to open. This results in the inside of the cell becoming more negative than at it is at rest, which is called **hyperpolarization**

We have been describing the electrical influence from flow of positive ions through the membrane.

Physiologists prefer the term

electrotonic influences

The term “electrotonic” serves as a reminder that the electrical influences are being conducted by ions in a water medium -- and not by free electrons as would be the case in a metal wire.

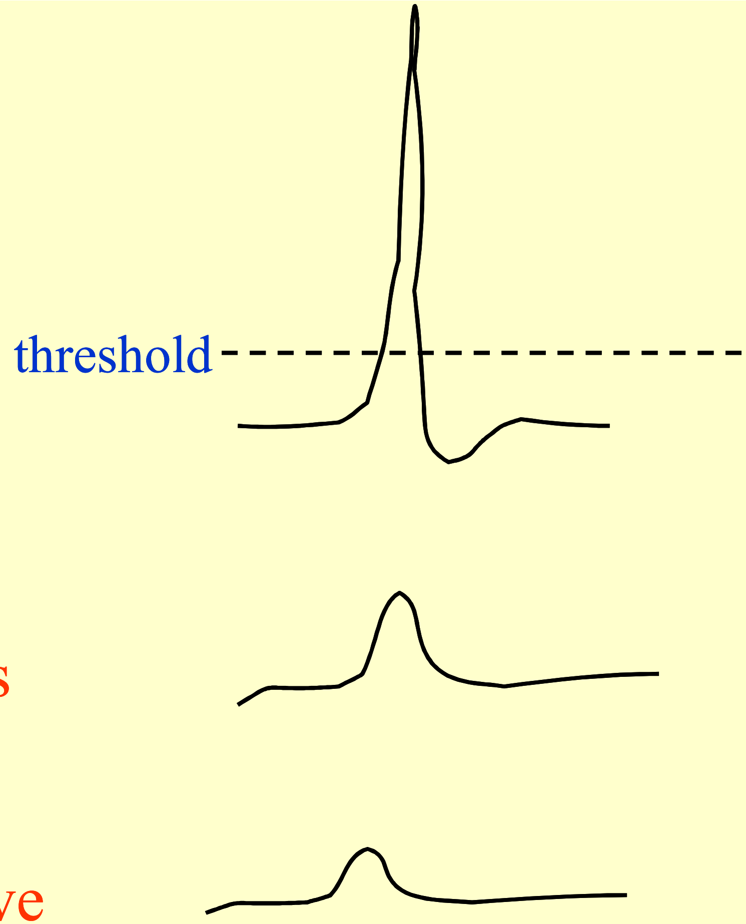
Nonetheless, electrotonic influences are conducted through the medium almost instantaneously, so the pressure on electrodes reflects the relative permeability of the membrane at each moment in time.

The changes in permeability themselves, however, are much slower, as we will see in the following slides.

slightly stronger yet

slightly stronger stimulus

very mild stimulus to a nerve



When a neuron is stimulated, the increase in Na+ permeability produces depolarization.

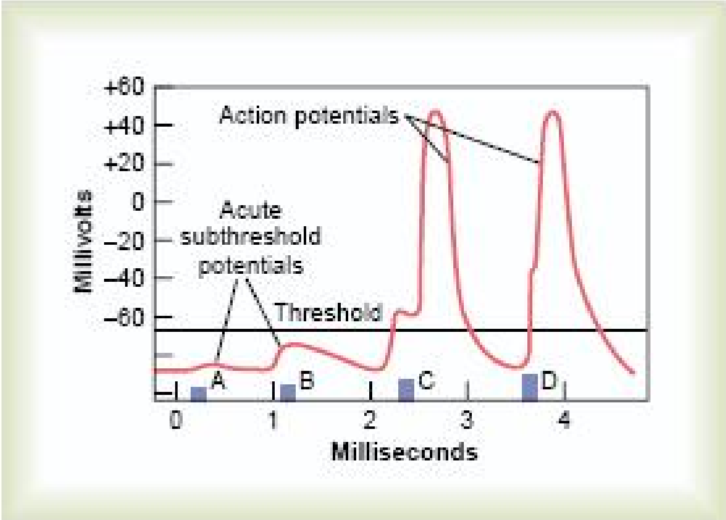
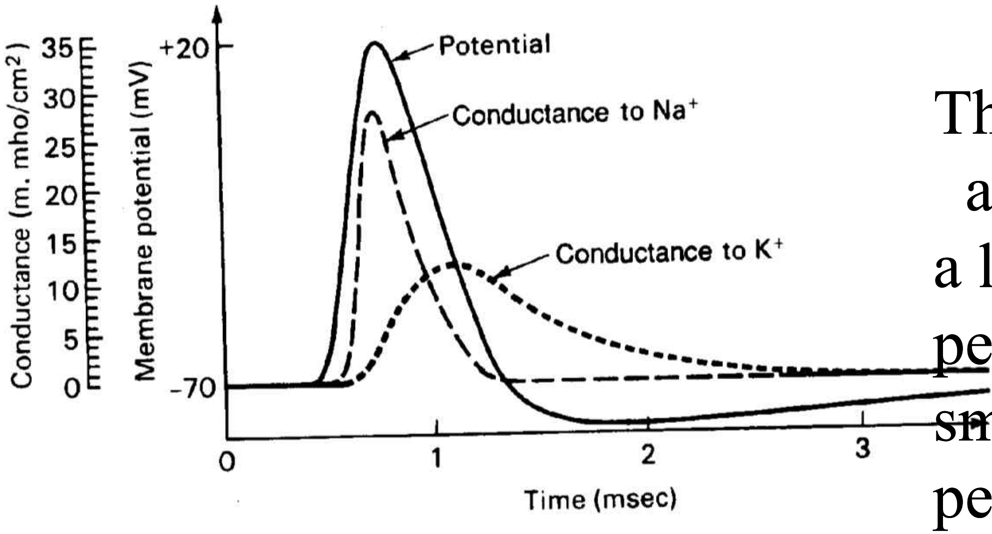


Figure 5–18

Effect of stimuli of increasing voltages to elicit an action potential. Note development of "acute subthreshold potentials" when the stimuli are below the threshold value required for eliciting an action potential.

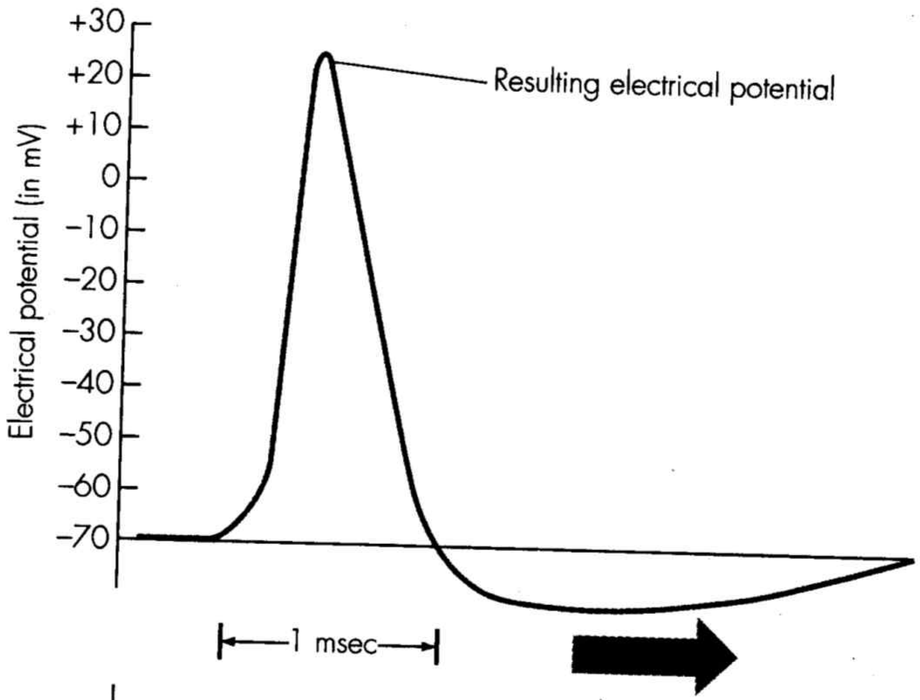
So nerve cells (and muscles) have an explosive change in their permeability to Na+ when the stimulated depolarization exceeds a threshold.

This is known as all or none responsiveness, which is to say, that if one exceeds threshold, there will be a depolarization of the same magnitude irrespective of the intensity of the stimulus which is applied.

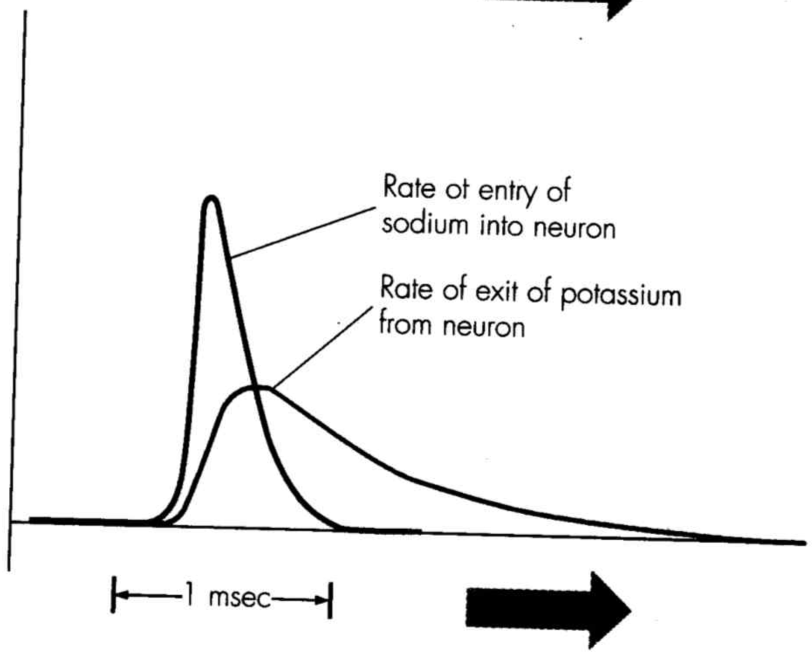


The action potential --
aka spike -- is produced by a large increase in Na+ permeability followed by a smaller increase in K+ permeability.

The rising phase is called depolarization, and the afterpotential (below the resting potential) is called hyperpolerization.

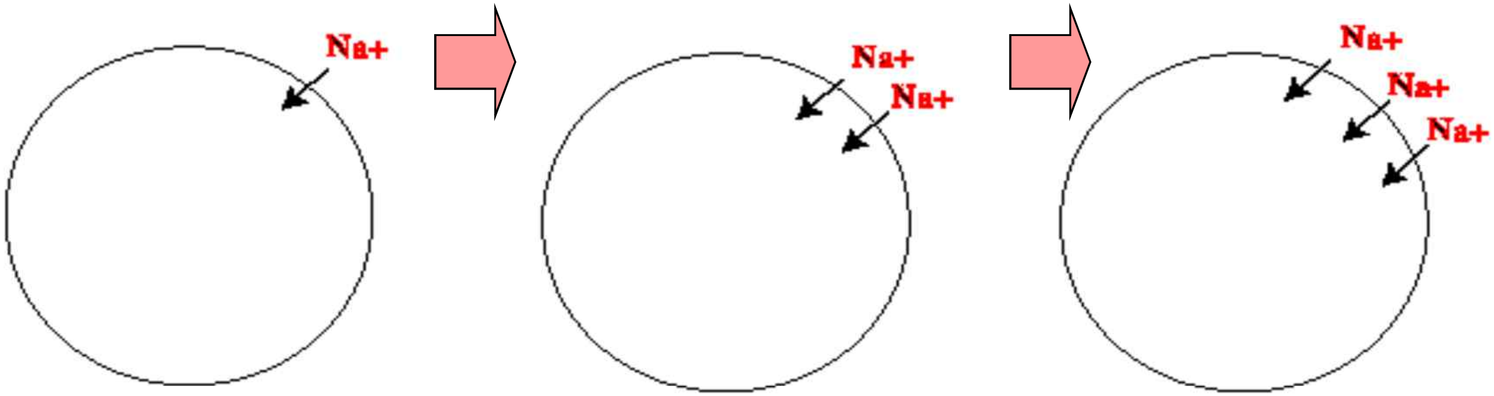


Here is another illustration of the same concept.

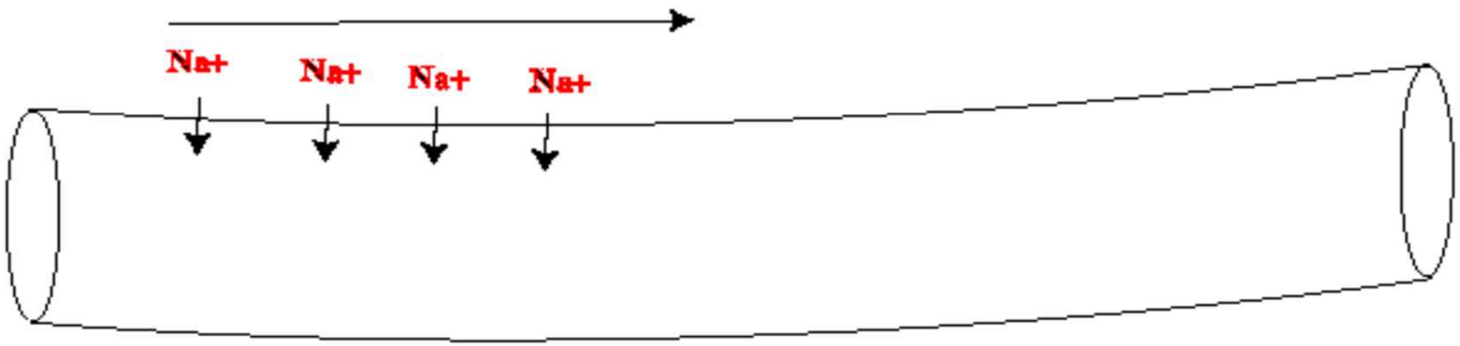


The permeability changes result in the large swings of membrane potential which are shown above.

Propagation of the Action Potential



Thus an increase in permeability at one spot can spread to neighboring sites.



Axons have these electrically excitable Na+ channels, so the excitation can travel from one end to the other.

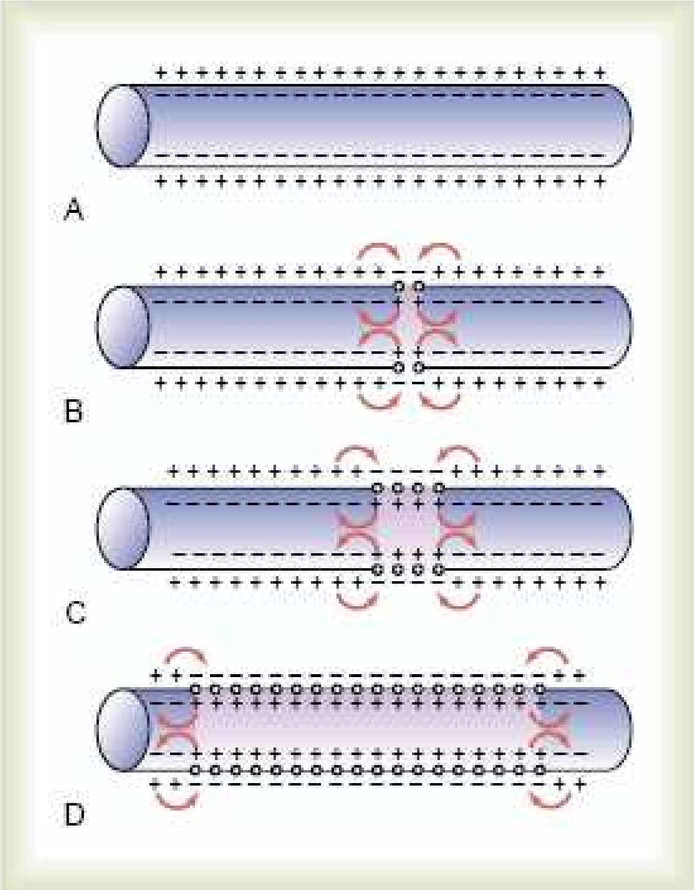
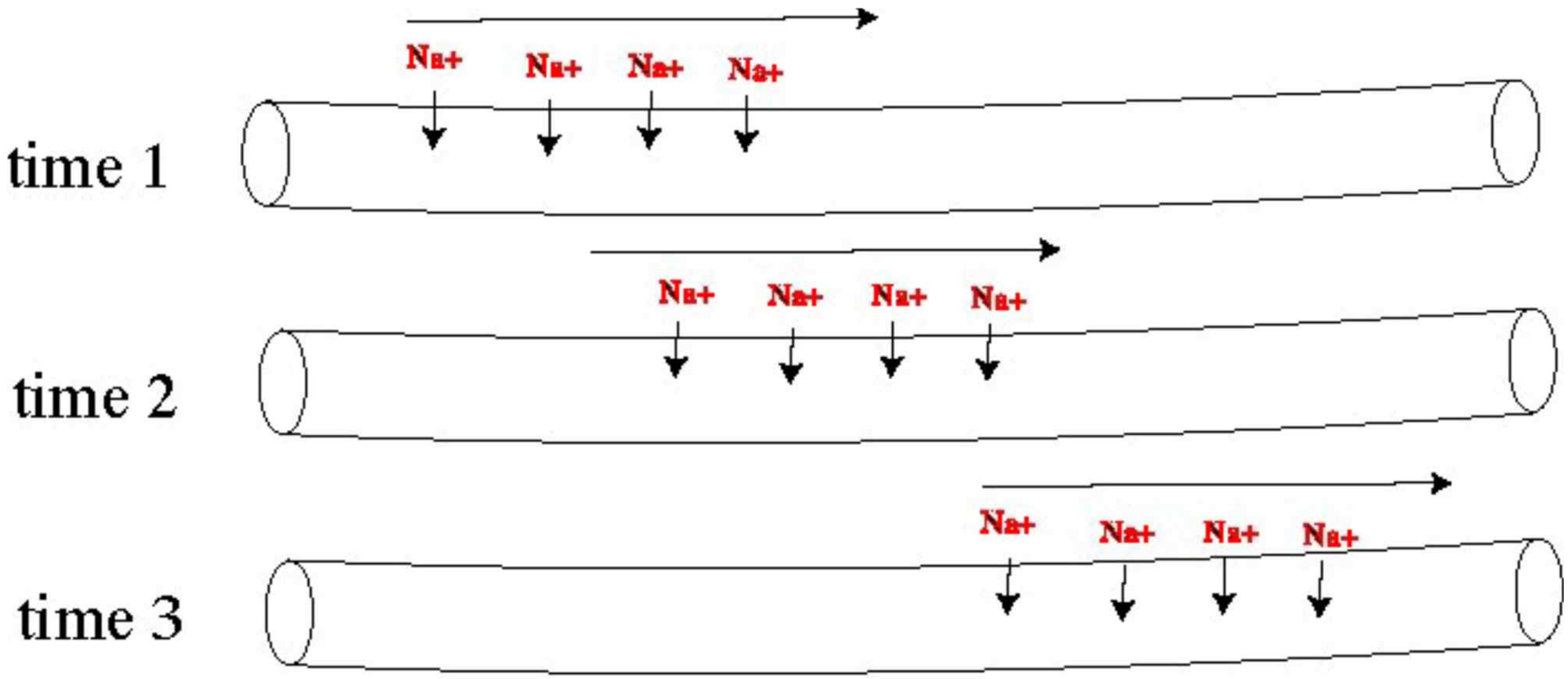


Figure 5–11

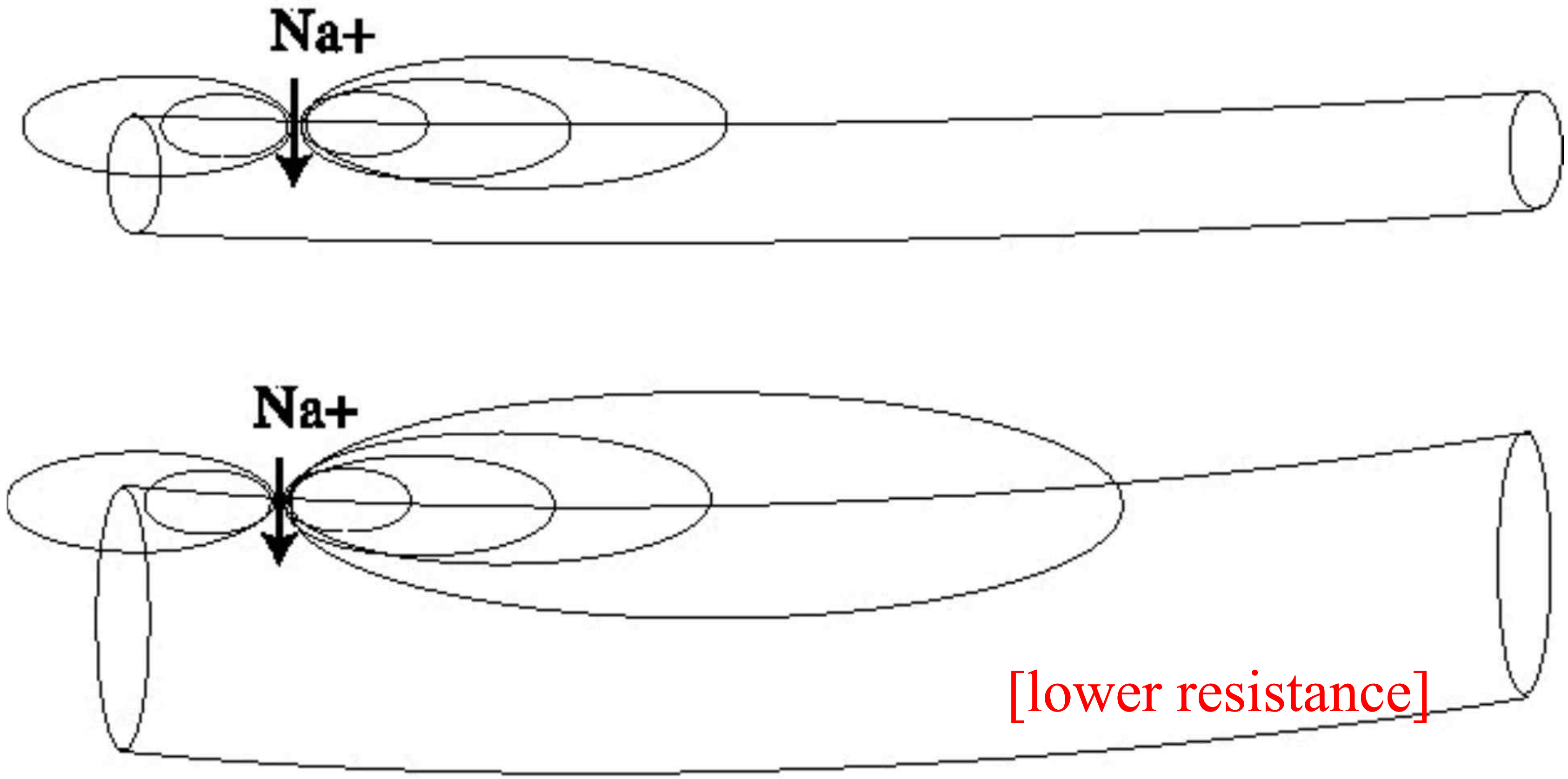
Propagation of action potentials in both directions along a conductive fiber.



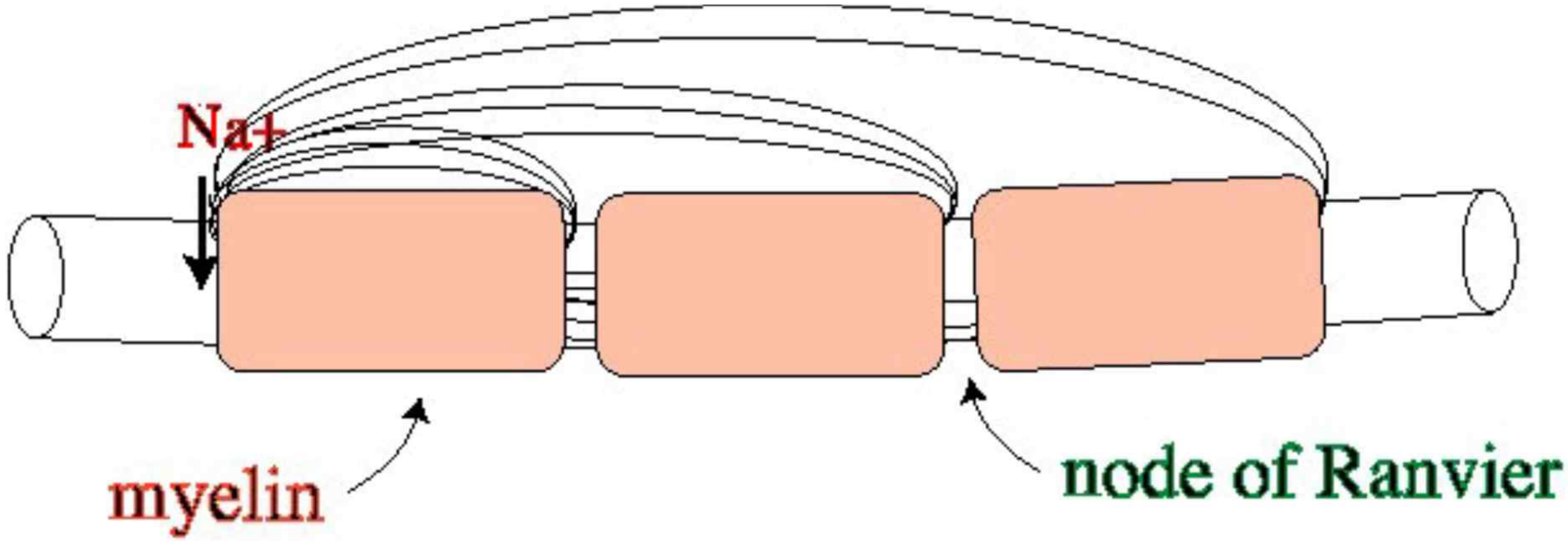
The permeability increase for Na+ lasts only about one millisecond, then the membrane becomes impermeable again. Thus the excitation spreads like a burning fuse.

Here is another meaning of the all or none concept -- that is, once a spike is initiated in an axon, the spike will travel down the full length of the axon without growing smaller.

In other words, unlike electrical signals sent down copper wires, the spike pulse does not grow weaker as it travels.



The electrical spread is greater with large axons, because there are more ions to carry the electrical current. Therefore the spike travels faster in larger axons.



Vertebrates have developed another method of getting speed, which is to add a wrapping of myelin. This forces the electric current farther down the axon, as it can only escape where the resistence is low --- that is, at the nodes of Ranvier.

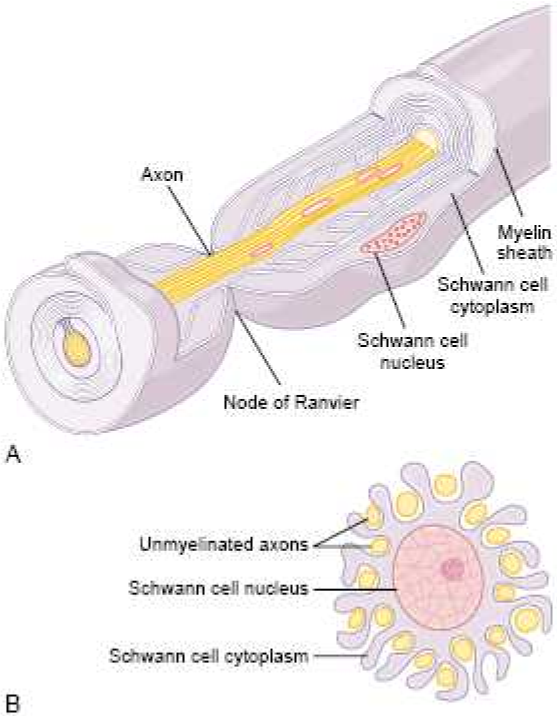


Figure 5–16

Function of the Schwann cell to insulate nerve fibers. *A*, Wrapping of a Schwann cell membrane around a large axon to form the myelin sheath of the myelinated nerve fiber. *B*, Partial wrapping of the membrane and cytoplasm of a Schwann cell around multiple unmyelinated nerve fibers (shown in cross section). (*A*, Modified from Leeson TS, Leeson R: Histology. Philadelphia: WB Saunders, 1979.)

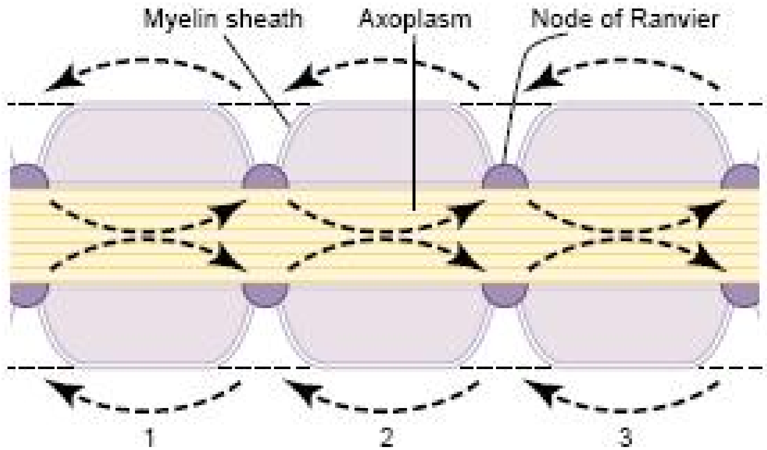
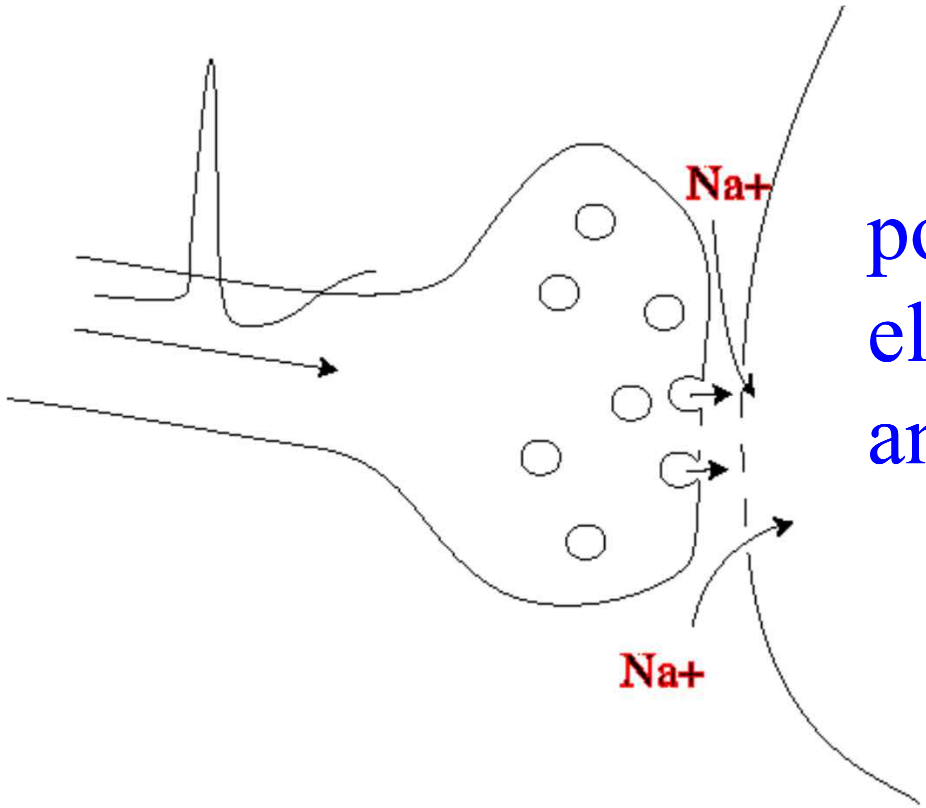


Figure 5–17

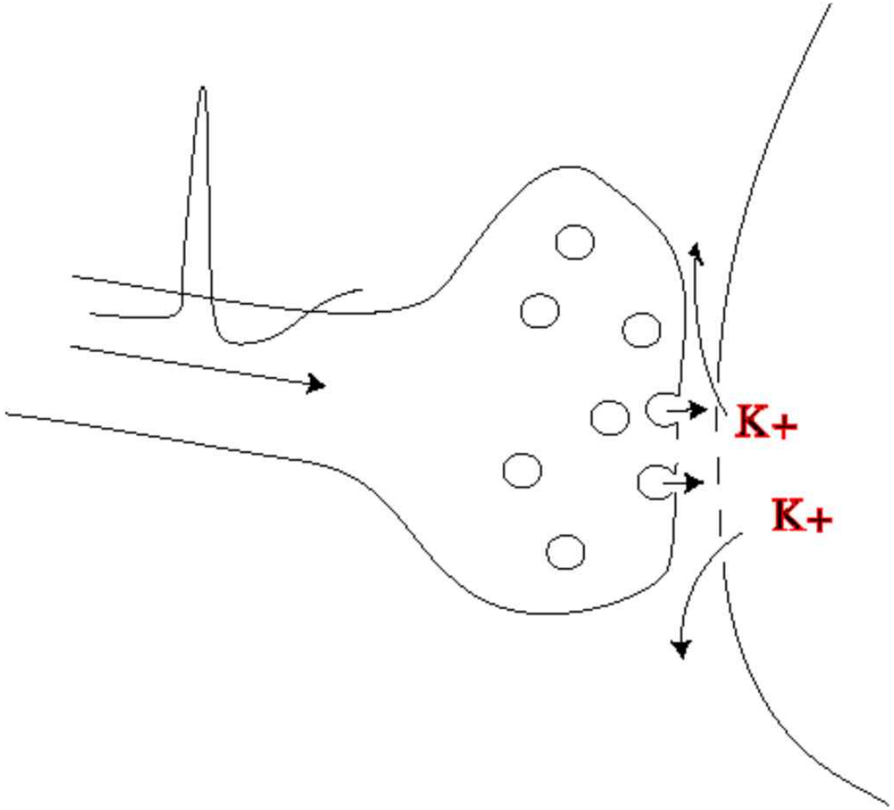
Saltatory conduction along a myelinated axon. Flow of electrical current from node to node is illustrated by the arrows.



postsynaptic element, such as another neuron

When a spike arrives at the synapse, transmitter substance is released which opens ion channels in the postsynaptic membrane. If they are Na+ channels, the receiving cell will depolarize.

The synaptic response is called an epsp -- excitatory postsynaptic potential.



But the postsynaptic membrane can contain K+ channels, in which case the spike which arrives produces hyperpolarization.

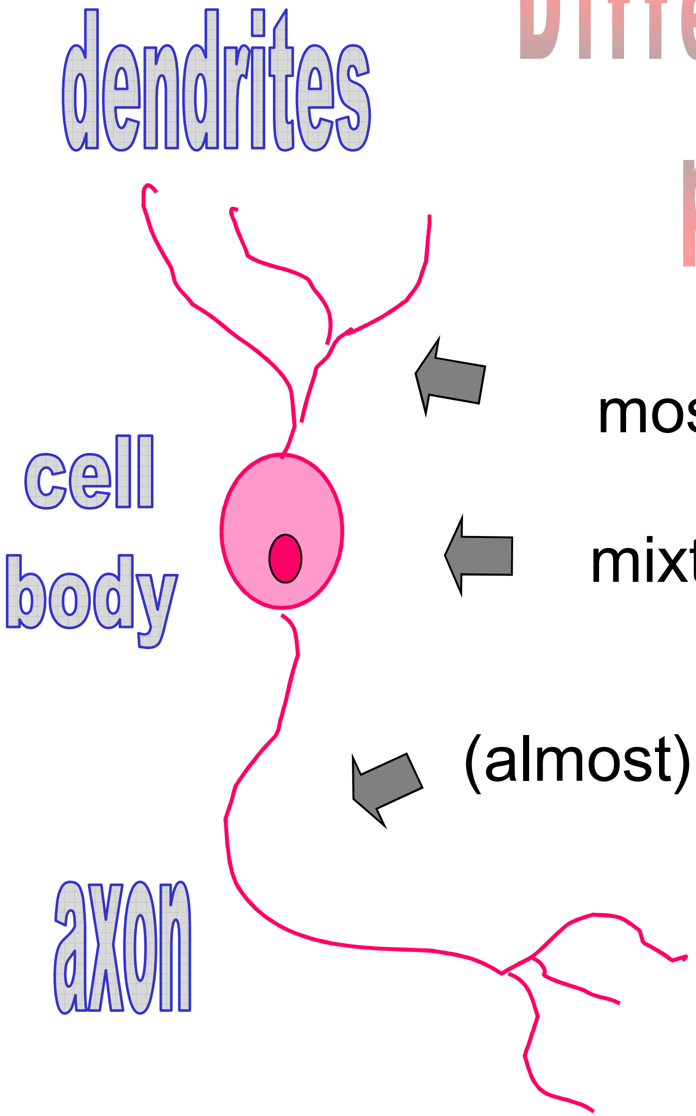
Response is called an ipsp -- inhibitory postsynaptic potential.

Responses of the synapse are thus completely determinedby what kind of receptors are present in the postsynaptic membrane.

If sodium pores are there, the postsynaptic element will be depolarized, and this is generally excitatory.

If potassium pores are there, the postsynaptic element will be hyperpolarized, and this is generally inhibitory.

Different pores for different parts of the neuron --



mostly chemically sensitive (synaptic) pores

mixture of both

(almost) only electrically sensitive pores