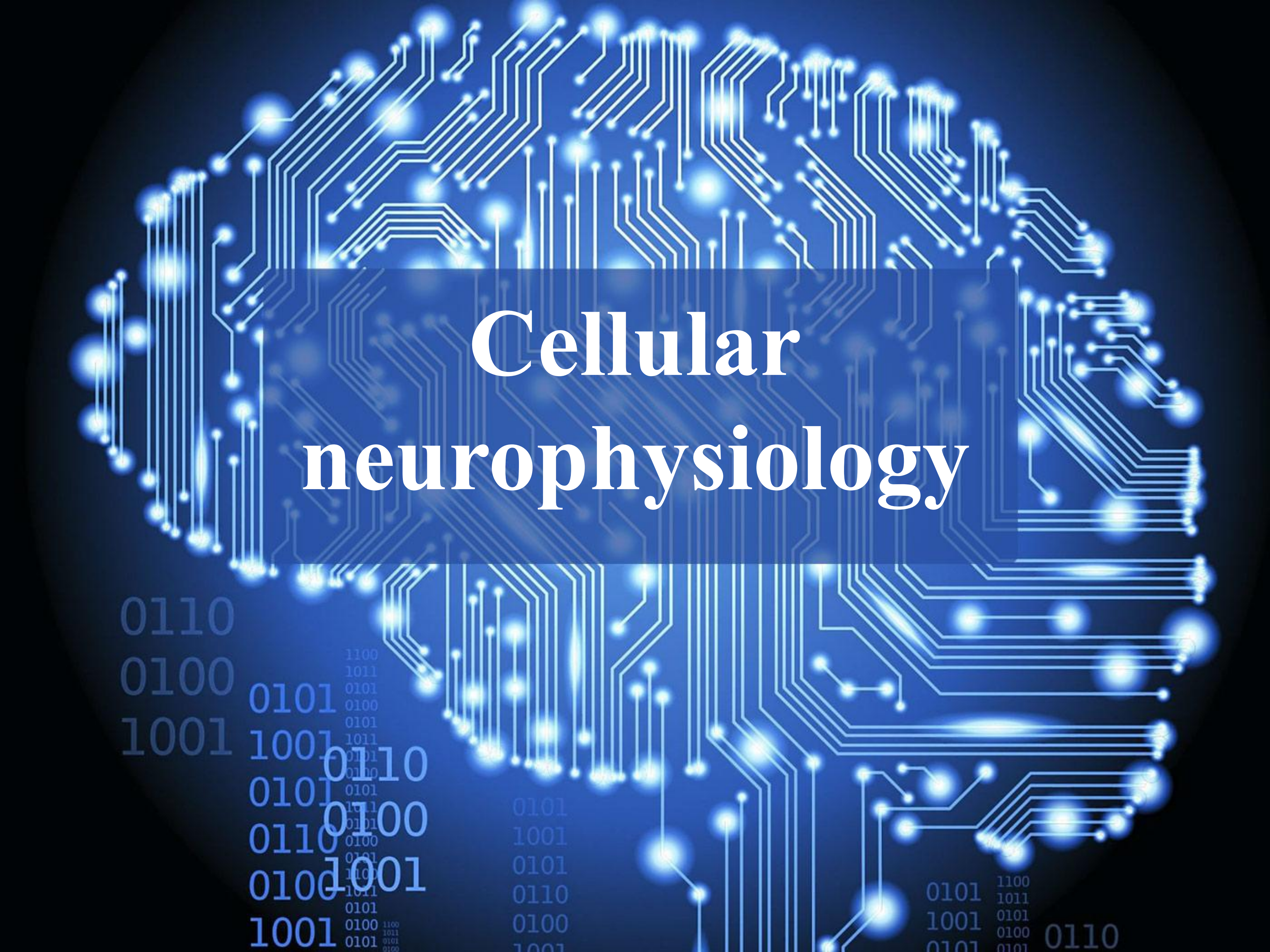
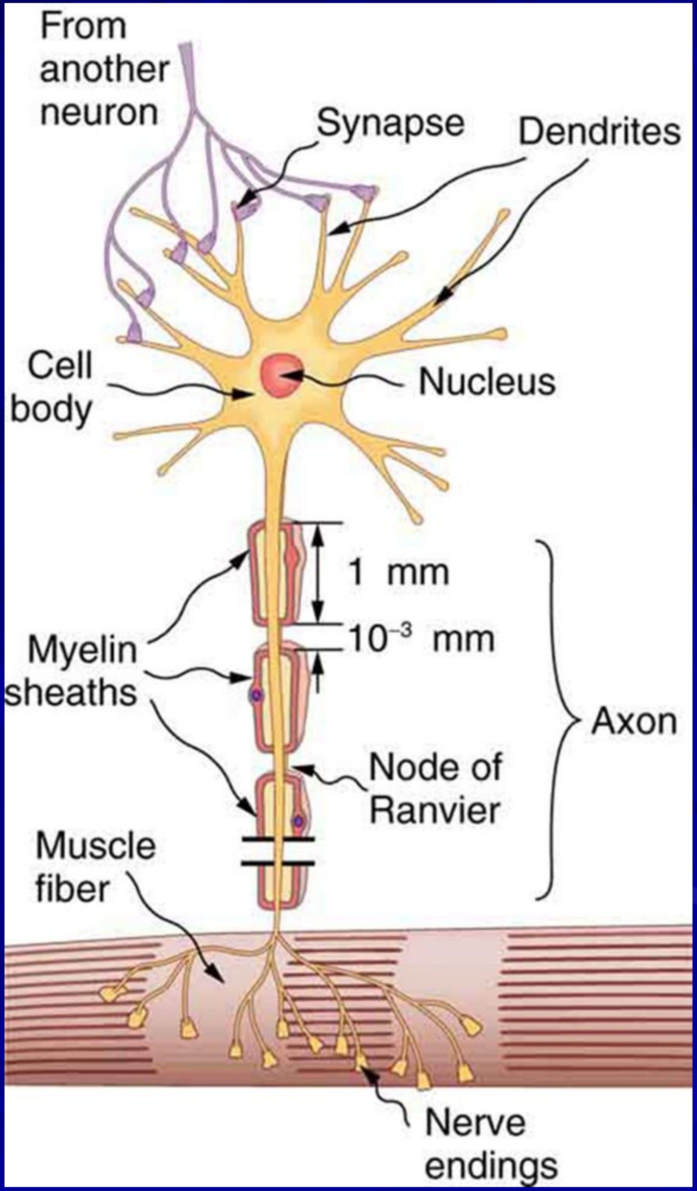
Cellular neurophysiology



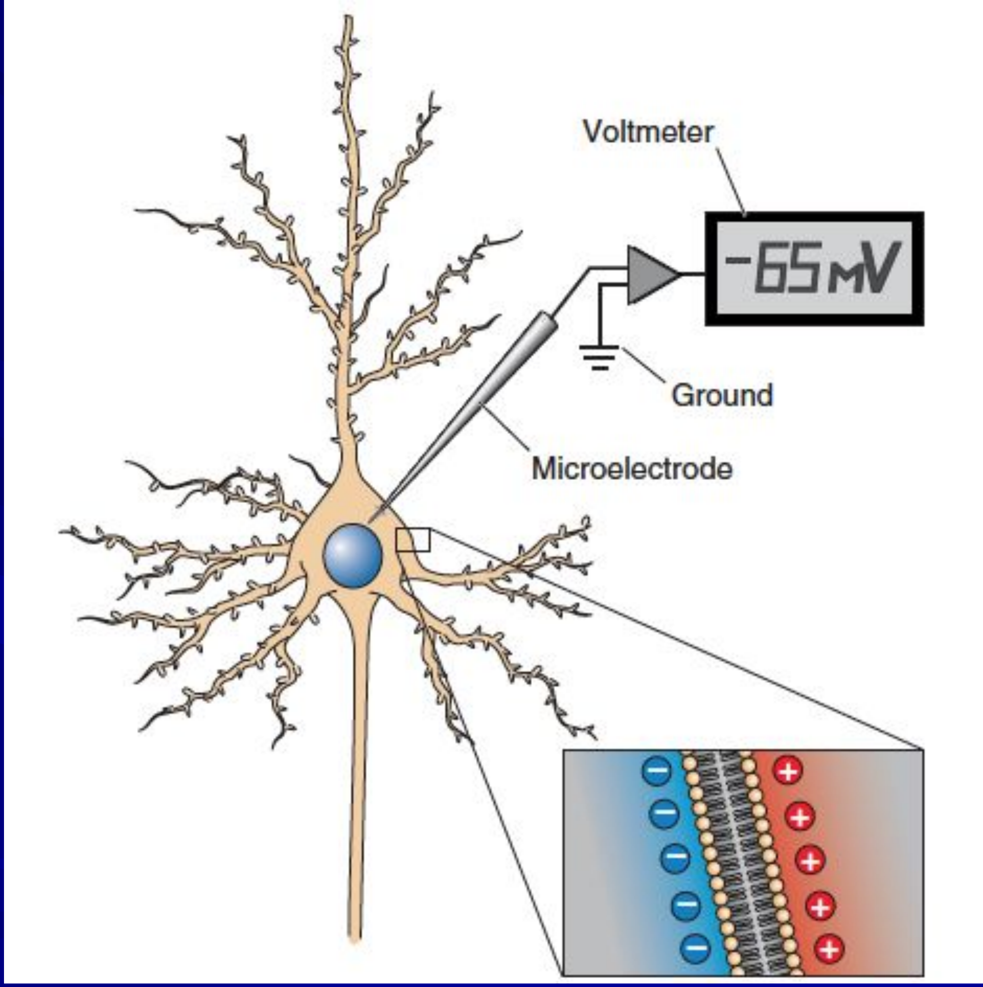
Cellular neurophysiology

- A goal of cellular neurophysiology is to understand the biological mechanisms of collection, distribution and integration information in nervous system
- The neuron solves the problem of conducting information over a distance by using electrical signals that sweep along the axon.
- The axonal membrane has properties that enable it to conduct a special type of signal — the nerve impulse, or action potential.
- Cells capable of generating and conducting action potentials are said to have excitable membrane



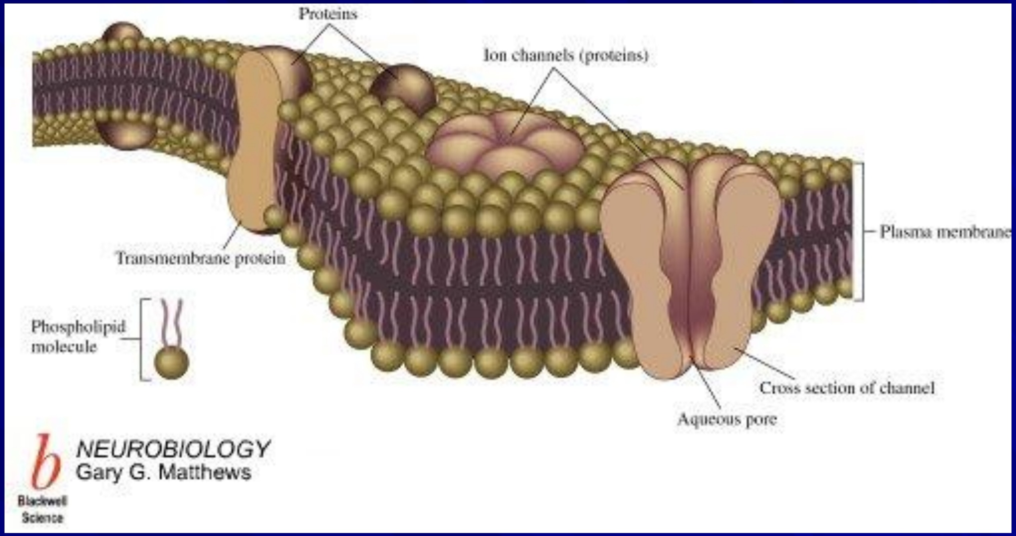
Cellular neurophysiology

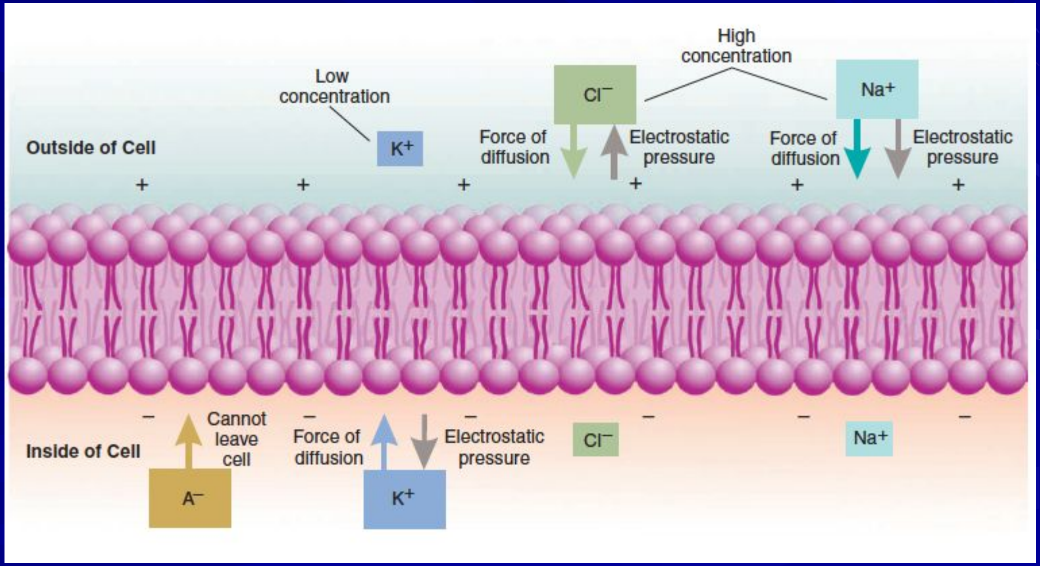
- When a cell with excitable membrane is not generating impulses, it is said to be at rest.
- In the resting neuron, the cytosol along the inside surface of the membrane has a negative electrical charge compared to the outside.
- This difference in electrical charge across the membrane is called the resting membrane potential (or resting potential).
- The action potential is simply a brief reversal of this condition—the inside of the membrane becomes positively charged relative to the outside.



Cellular neurophysiology

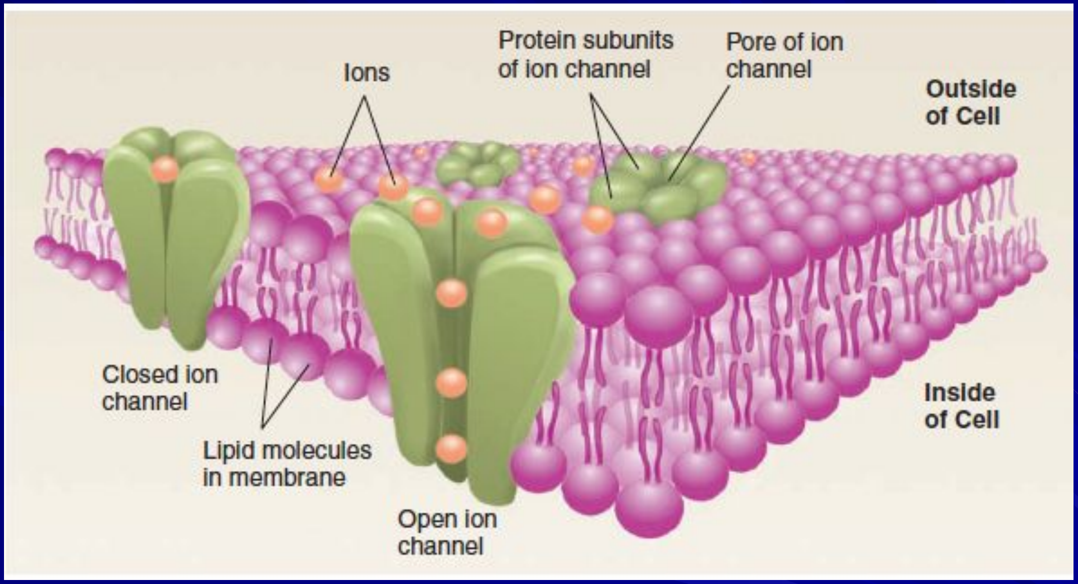
- The cell membrane of the neuron acts as a barrier separating ions (electrically charged particles) on the inside from those on the outside.
- These ions (such as sodium and potassium) can traverse the cell membrane only through special ion channels.
- These channels are formed by protein molecules embedded in the cell membrane.





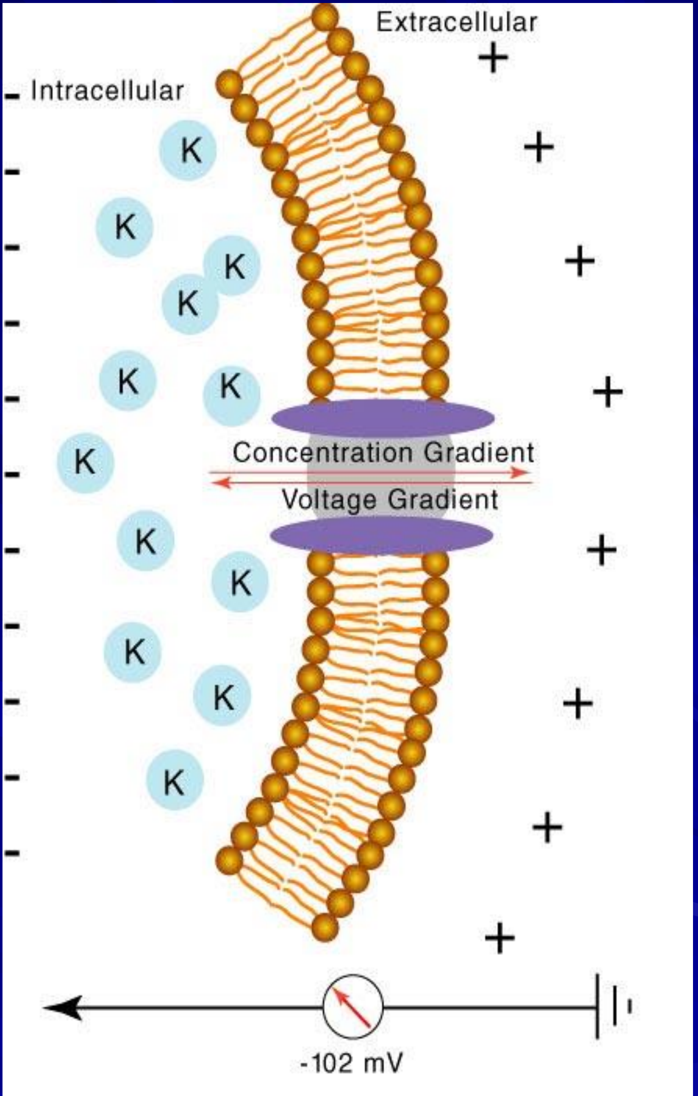
Cellular neurophysiology

- In specific configurations, ion channels create a passageway that allows ions to flow in and out of the cell.
- In other configurations, the passageway is blocked, and ions cannot move from one side of the cell membrane to the other.
- Ion channels are selective, allowing only certain ions to traverse them.
- The cell membrane contains several types of ion channels, including channels for sodium and potassium ions.



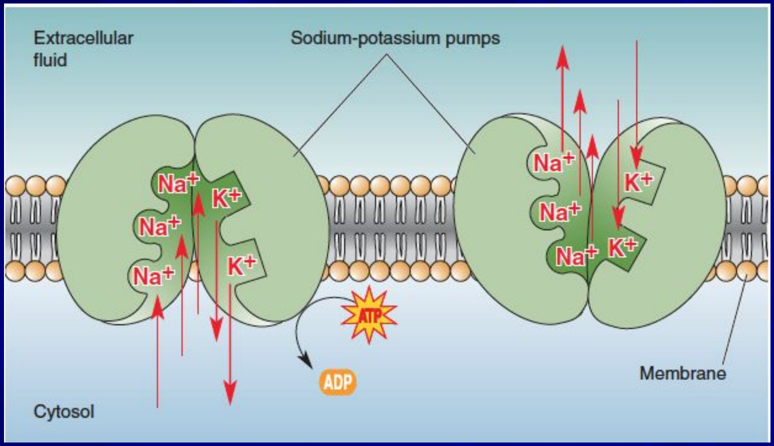
Cellular neurophysiology

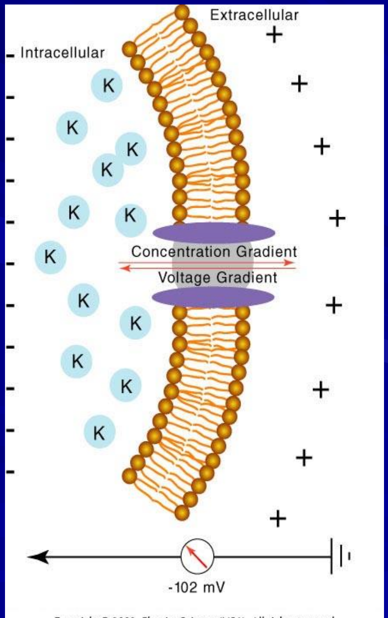
- Ions are found in different concentrations on either side of the membrane
- When the channels are open, the ions begin to diffuse in the direction that will allow the concentration on both sides of the membrane to reach an equilibrium.
- Potassium, which has a higher concentration inside the cell than outside, travels out of the cell,
- Sodium, which has a higher concentration outside the cell than inside, flows inward.



Cellular neurophysiology

- Eventually, diffusion would cause these ions to be equally distributed between the inside and outside
- However, an active mechanism known as the sodium-potassium pump works to prevent equal distribution of ions, thereby maintaining the resting potential.
- This pump sends more positively charged sodium ions out of the cell while allowing fewer positively charged potassium ions into the cell.
- The net result is that the inside of a neuron stays more negatively charged than the outside.
- This net imbalance causes a potential, or electrical charge, across the membrane of approximately –65 millivolts.





Cellular neurophysiology

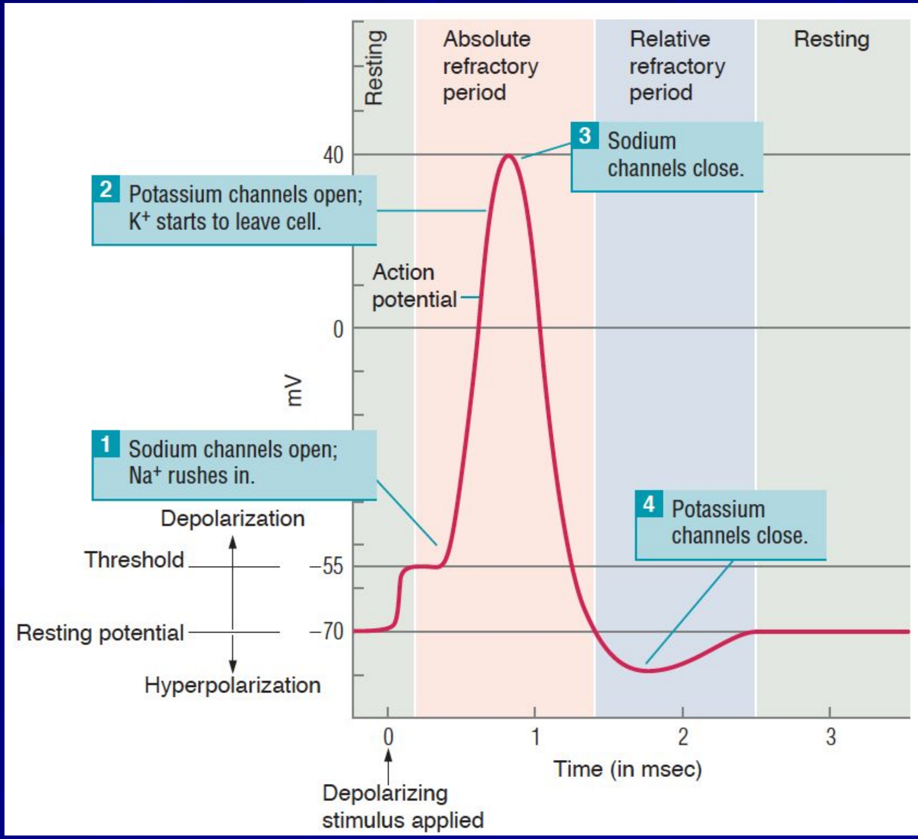
- Input from other neurons can affect the opening and closing of ion channels.

- The resulting change in the ion concentrations on each side of the membrane drives the neuron's electrical charge away from its resting potential, making it either more negative or more positive.

Cellular neurophysiology

Action potential

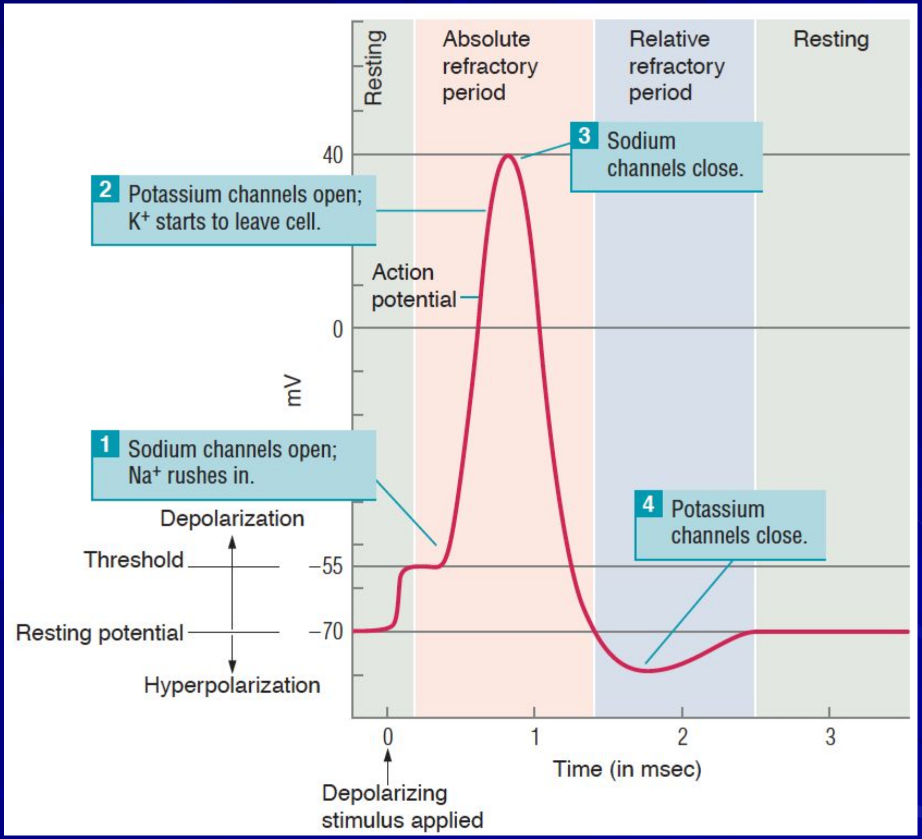
- If the cell receives enough stimulation to reduce the voltage across the membrane to about –55 mV, a threshold is passed and the cell "fires."
- When a cell fires, the electrical charge of the neuron reverses quite rapidly from –55 mV to a peak of 40 mV.
- After reaching the peak—a state known as depolarization—the electrical charge then retreats toward the baseline resting potential, which is known as repolarization.
- The voltage then briefly becomes even more negative than the resting potential, a phase known as hyperpolarization.
- Following hyperpolarization, the neuron returns to the resting potential.
- The whole sequence of events from resting potential and back again, is known as an action potential.



Cellular neurophysiology

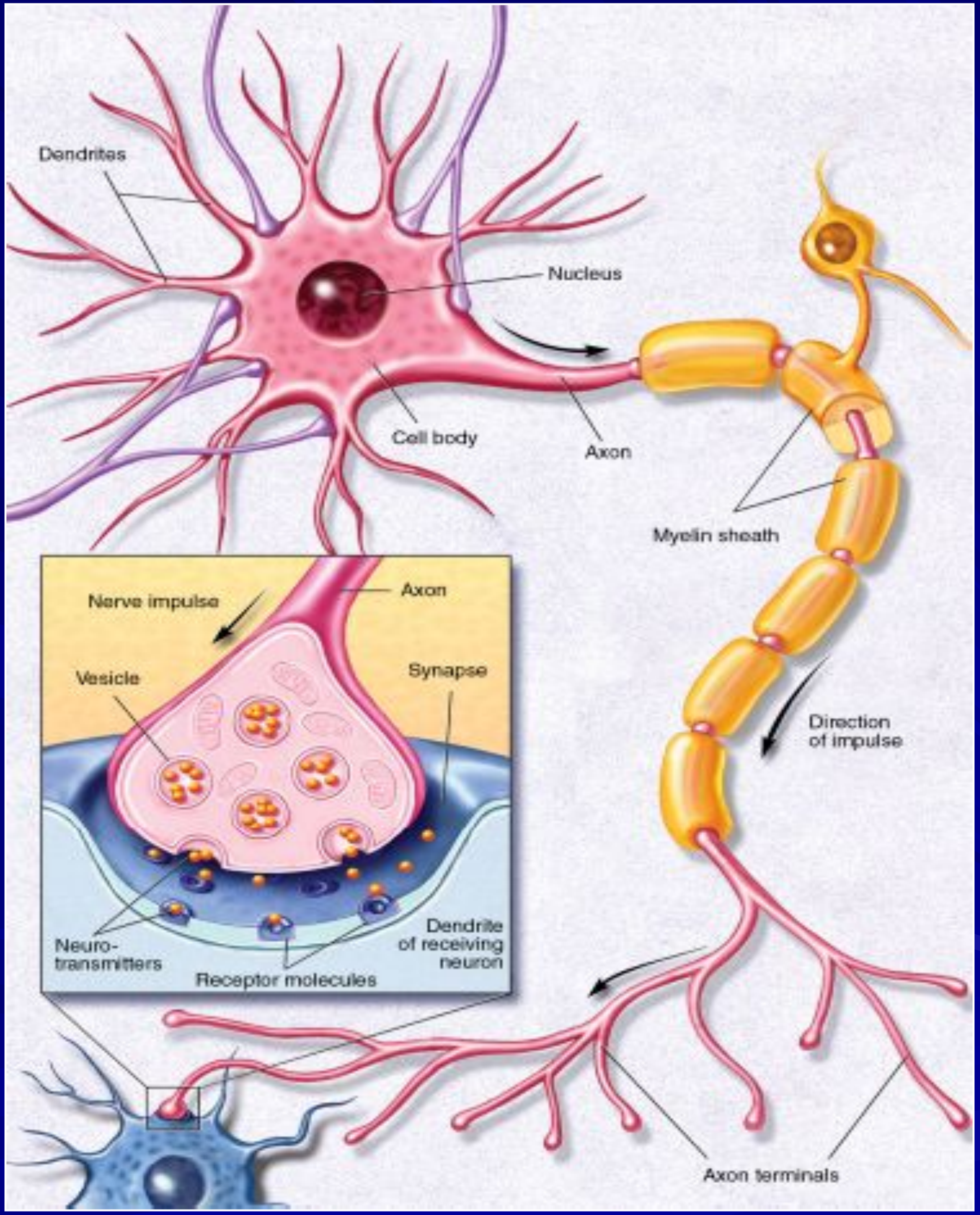
- This action potential has three very important properties.

1. First, it is self-propagating, which means that once it is set in motion nothing else need be done.
2. Second, strength of action potential does not dissipate with the distance that it travels. The peak of the action potential remains 40 mV for its entire trip down the axon.
3. Third, the action potential is an all-or-nothing response: either the cell “fires” (i.e., has an action potential) or it doesn’t.



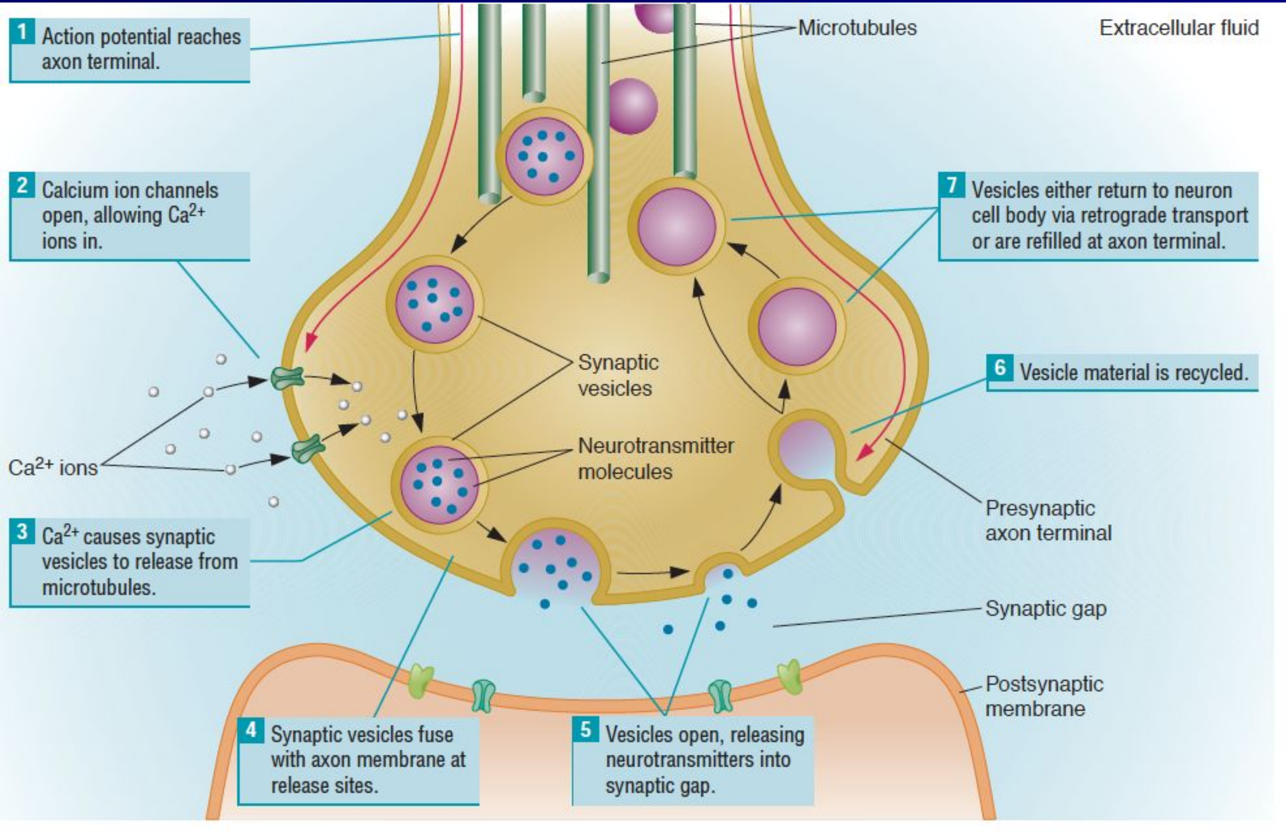
Cellular neurophysiology

- The action potential is first produced at a specific part of the neuron near the cell body called the axon hillock.
- From there, the action potential is carried along the entire length of the axon to the terminal bouton
- Here the electrical signal gets transformed into a chemical message.



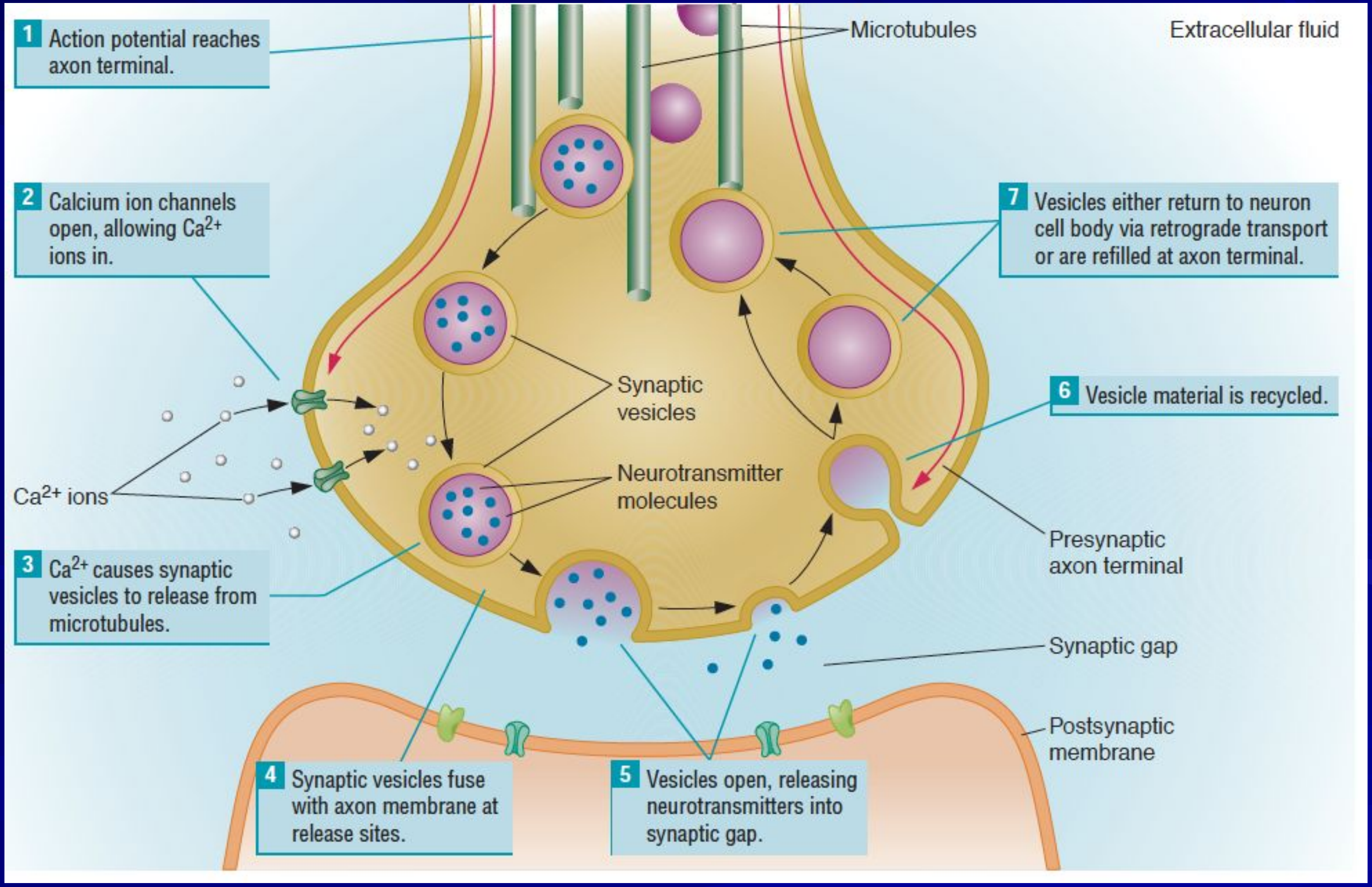
Cellular neurophysiology

- The terminal bouton contains little balloons, known as synaptic vesicles which are filled with neurotransmitter.
- The action potential causes synaptic vesicles that are fused to the outside walls of the neuron to burst open, pouring their contents into the area between neurons known as the synaptic cleft.



Cellular neurophysiology

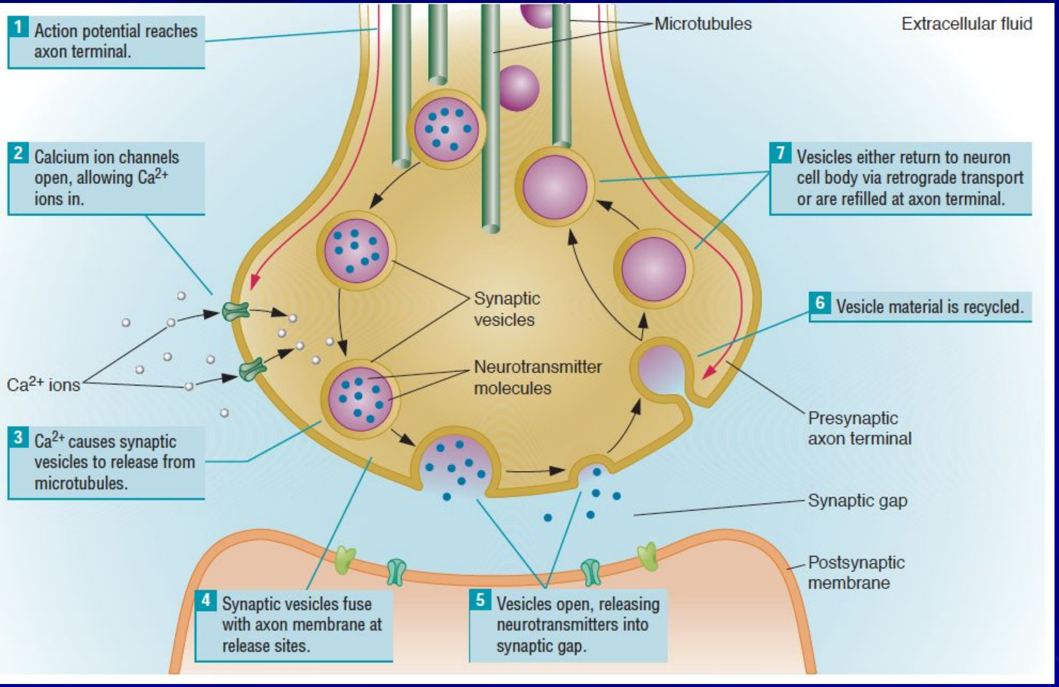
- Neurotransmitter molecules diffuse across the cleft into the postsynaptic membrane of neighboring neuron.
- The side of the cleft that releases the neurotransmitter is known as the presynaptic side.

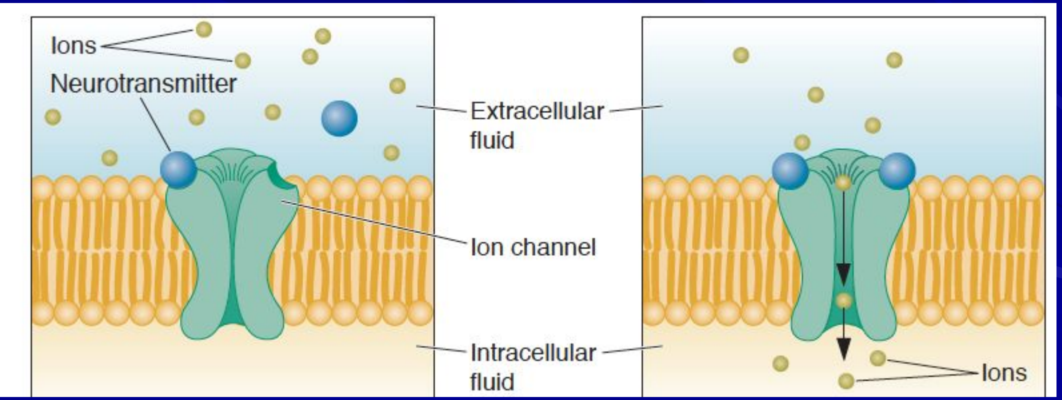


Cellular neurophysiology

How Information Is Transferred between Neurons

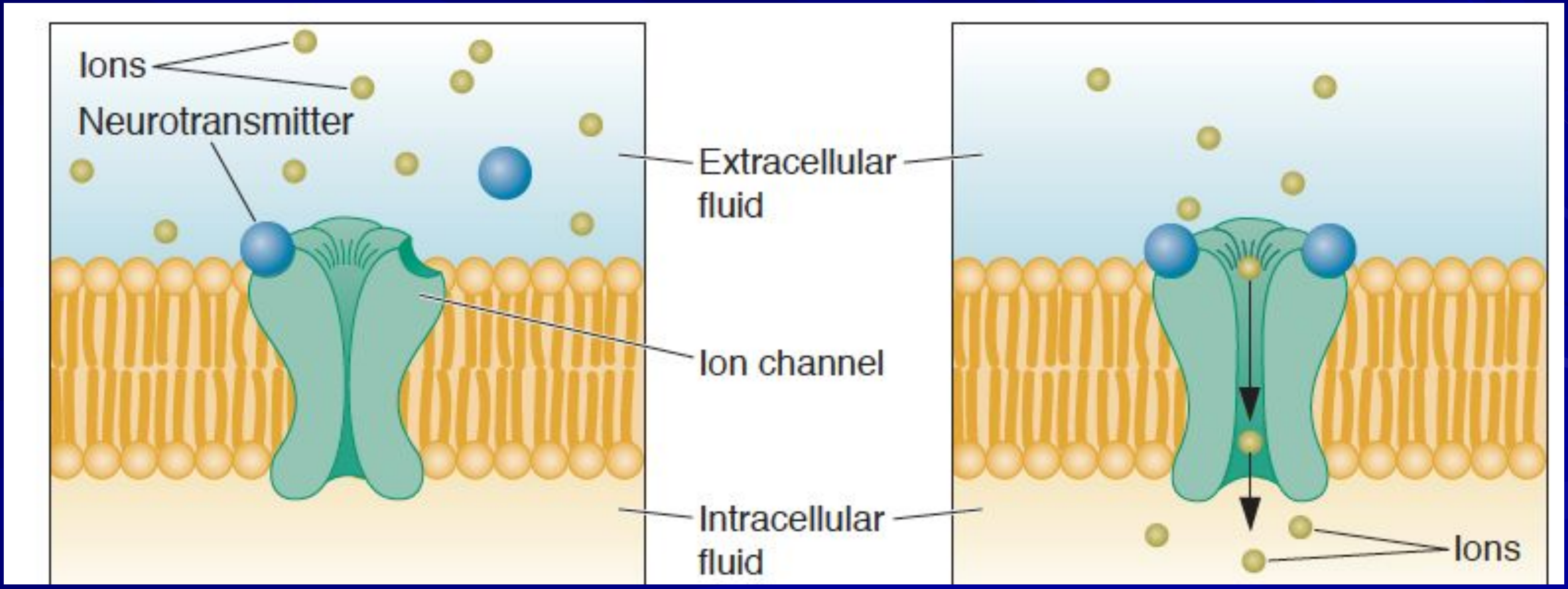
- Neurotransmitter molecules are released from the presynaptic neuron and received by the postsynaptic neuron.
- The membrane of the postsynaptic neuron contains receptors.
- The receptors are specially configured proteins that are embedded within the postsynaptic membrane.





Cellular neurophysiology

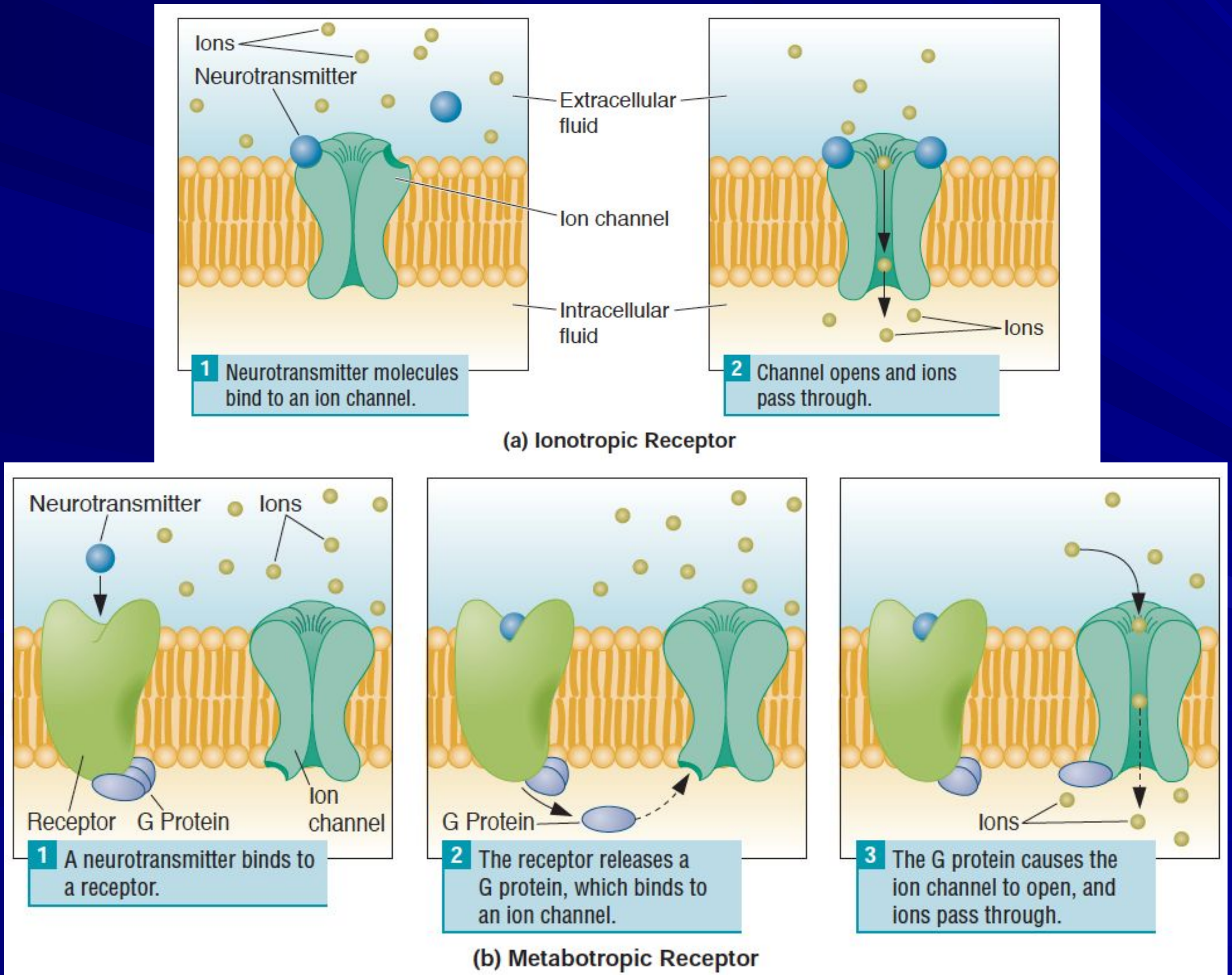
- When neurotransmitter reaches the postsynaptic membrane, it fits into a specific region of the receptor (called the binding site)
- The binding of the neurotransmitter changes the configuration of the receptor, which in turn changes the electrical charge of the postsynaptic neuron in a small local area near the receptor site by altering the flow of ions across the membrane.
- At this point, the chemical signal is transformed back into an electrical one.



Cellular neurophysiology

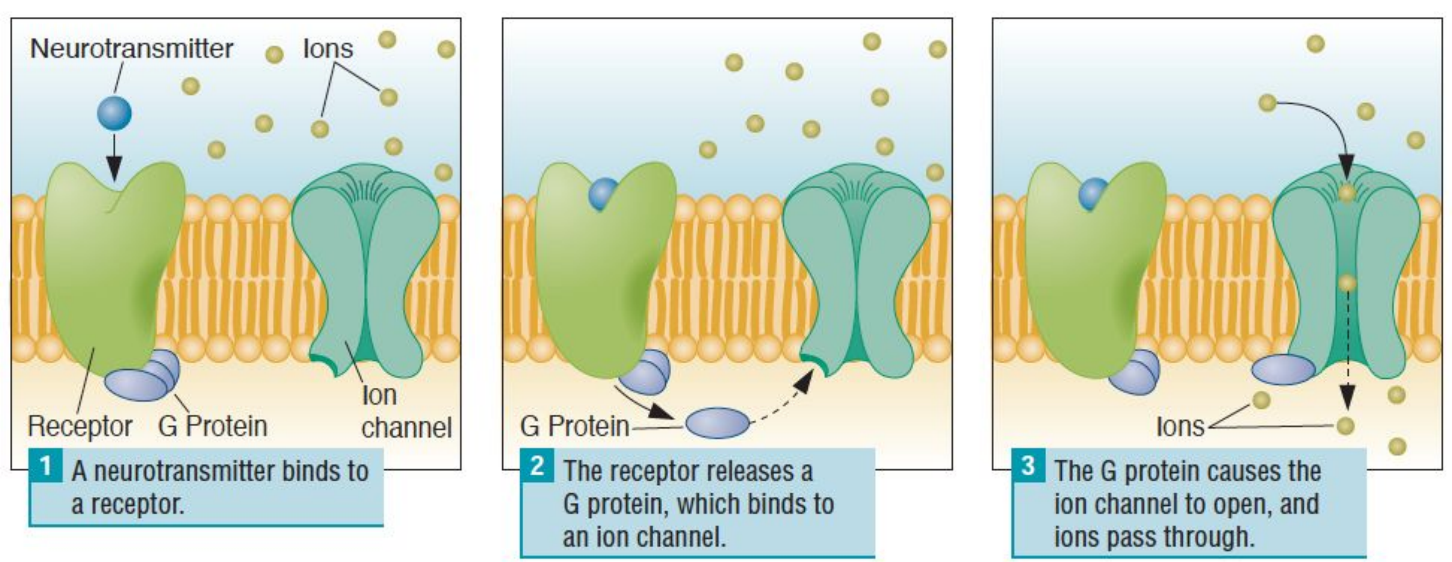
There are two main classes of receptors

1. Ionotropic receptors work directly to either open or close an ion channel.
2. In contrast, metabotropic receptors indirectly control the ion channels.



Cellular neurophysiology

- Metabotropic receptors are linked to a protein called G protein.
- When the neurotransmitter binds to the receptor, it causes a subunit of the protein, known as the alpha subunit, to break away.
- The alpha subunit either binds directly to an ion channel, opening it so that ions can pass, or it activates the channel by attaching to and activating an enzyme situated in the postsynaptic membrane.
- Although the postsynaptic potentials produced by metabotropic receptors are slower to start, they end up being longer lasting than those produced by ionotropic receptors.

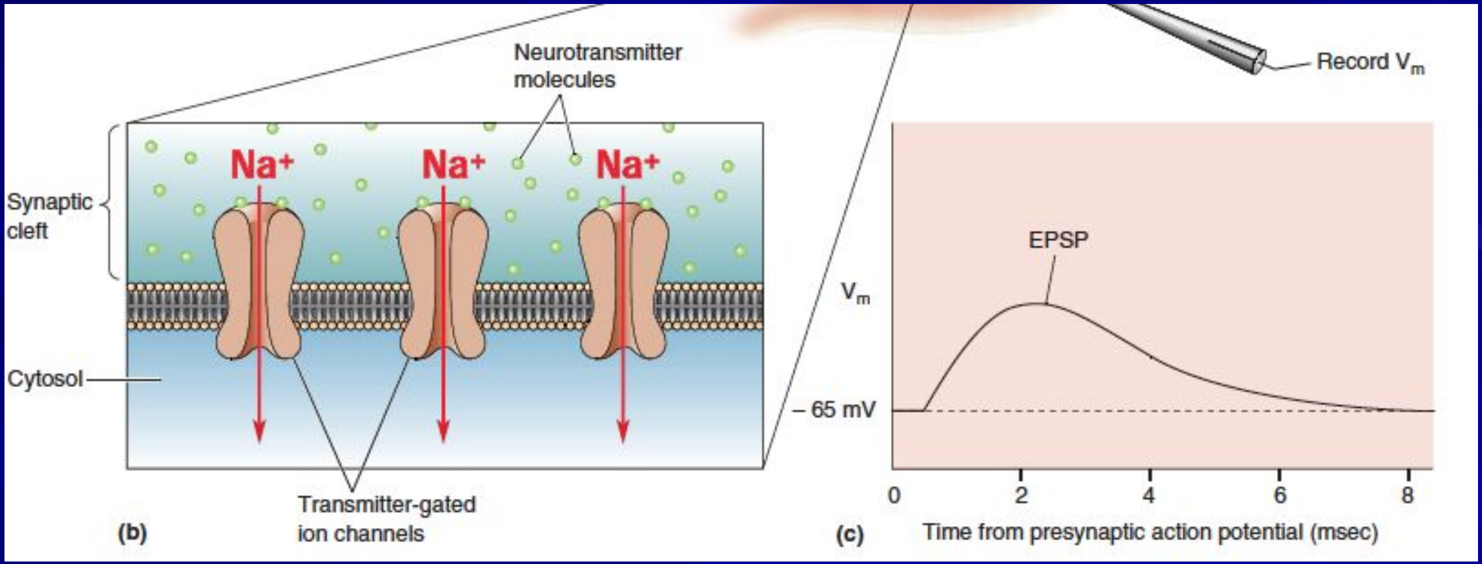


(b) Metabotropic Receptor

Cellular neurophysiology

How Postsynaptic Potentials Can Cause an Action Potential

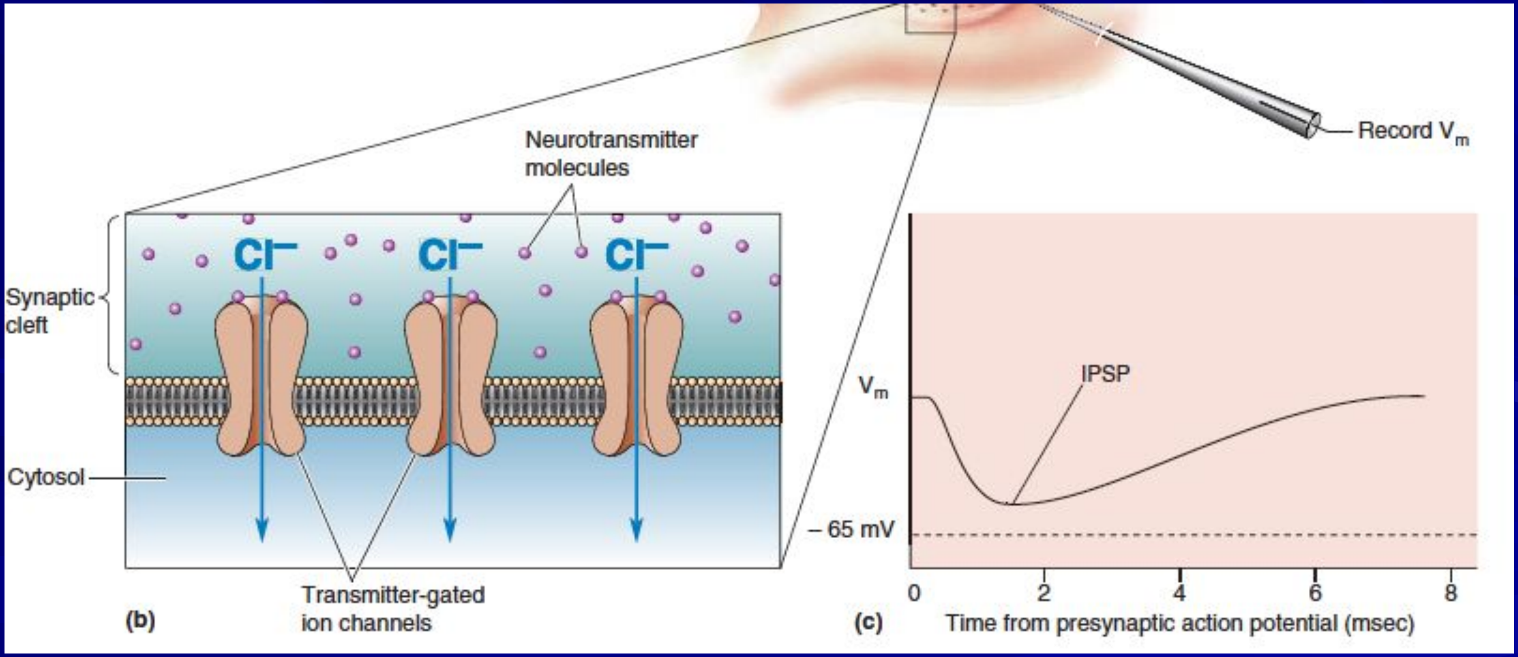
- The local changes in the electrical potential that occur near the receptor sites can make the electrical charge of the cell either more positive or more negative than the resting potential.
- An excitatory postsynaptic potential (EPSP) makes the cell's electrical charge a bit more positive—that is, it reduces the difference in electrical charge between the inside and the outside of the cell.
- This reduction brings the differential closer to the threshold value of 55 mV at which the cell will fire.



Cellular neurophysiology

How Postsynaptic Potentials Can Cause an Action Potential

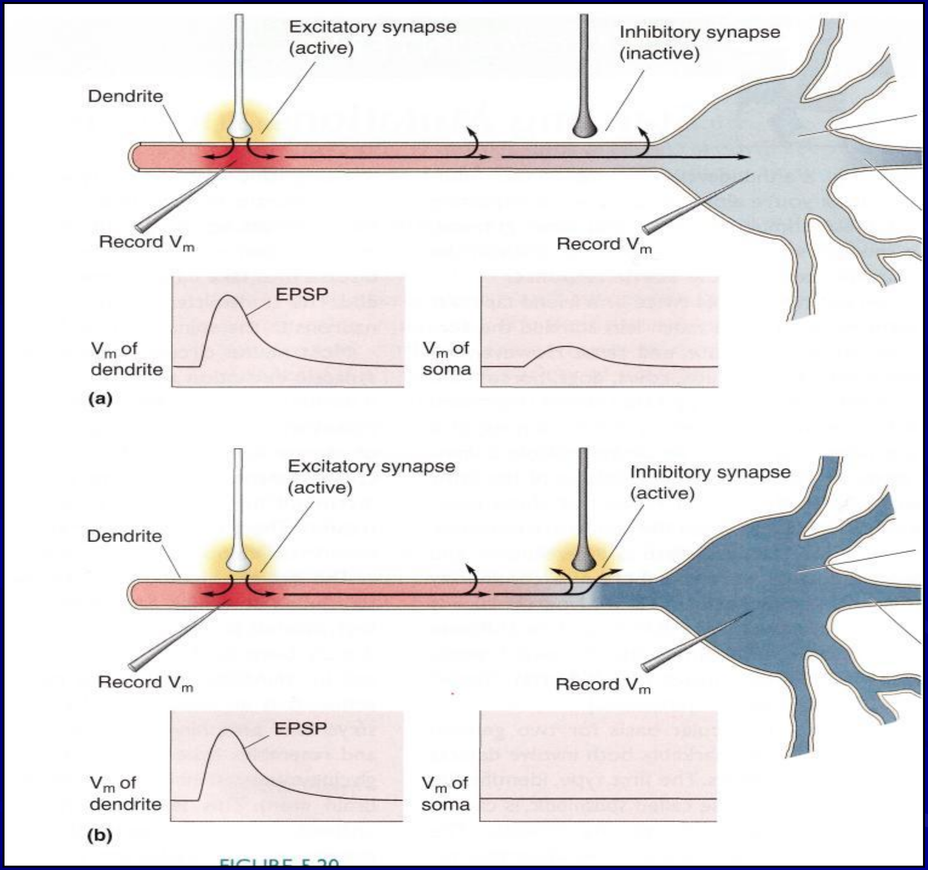
- In contrast, an inhibitory postsynaptic potential (IPSP) makes the inside of the cell a bit more negative than the outside and moves the cell farther away from the threshold at which it will fire.
- Whether a particular neurotransmitter has an excitatory or inhibitory effect depends not on the neurotransmitter but rather on the receptor type to which it binds.



Cellular neurophysiology

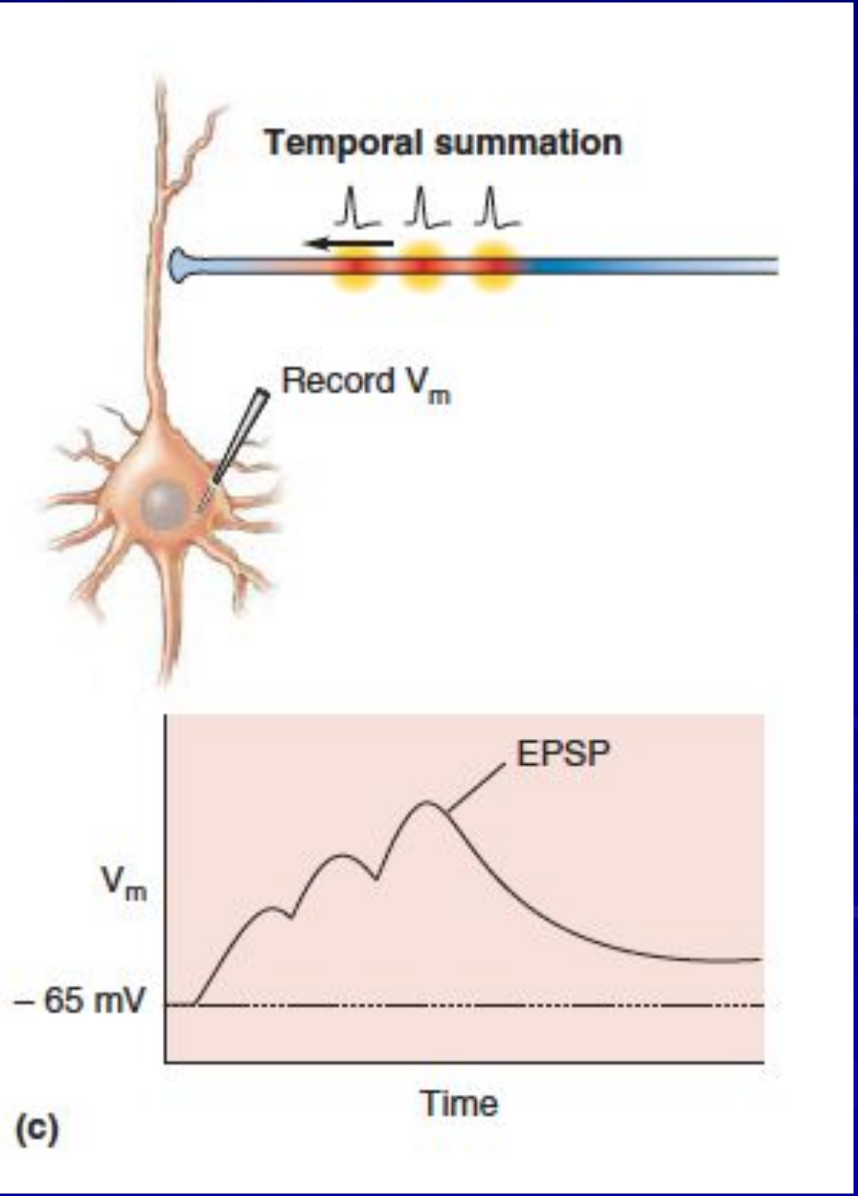
- Postsynaptic potentials differ from action potentials in three important ways.

1. First, they are graded: The farther they travel from their source, the more they dissipate.
2. Second, postsynaptic potentials are much smaller in magnitude than an action potential, usually in the range of 0.5 to 5 mV.
3. Third, whereas action potentials are always “excitatory,” in that they make the cell fire, postsynaptic potentials can be either excitatory or inhibitory.



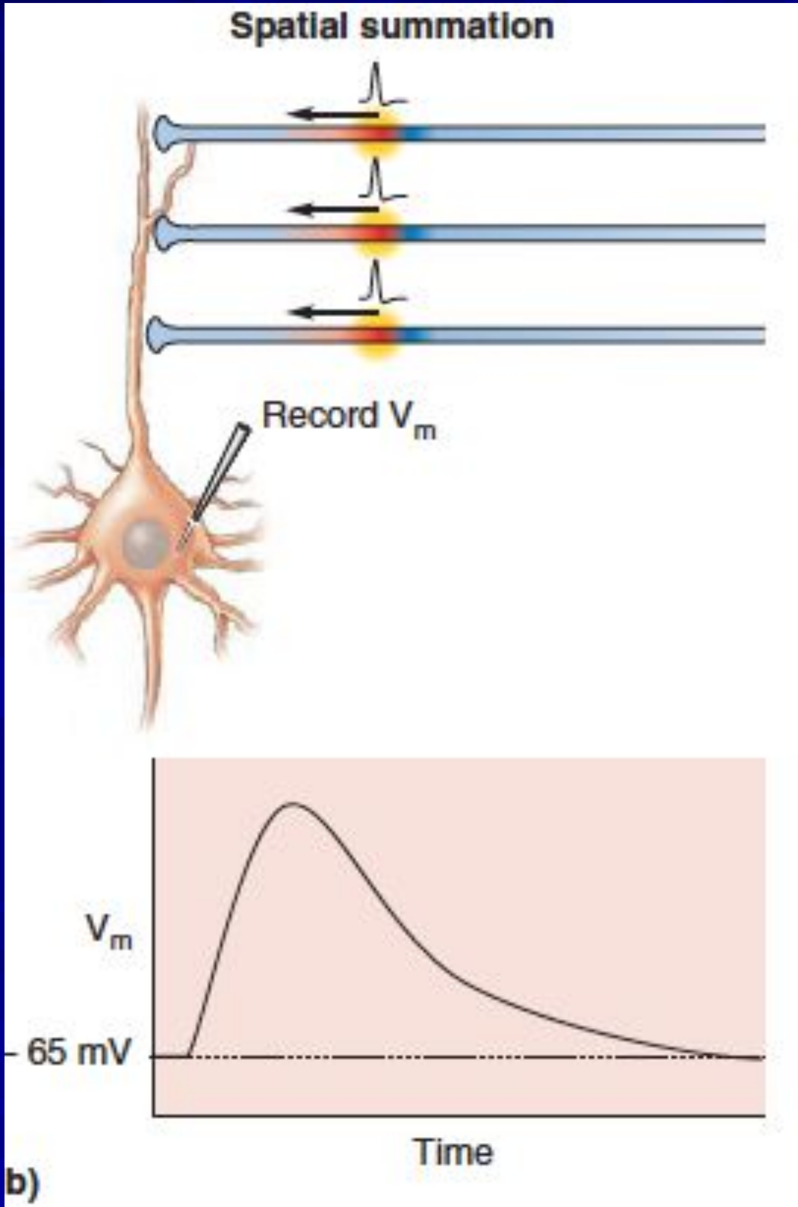
Cellular neurophysiology

- Because postsynaptic potentials are small and dissipate over space, a single one of them is highly unlikely to cause a cell to fire.
- Rather, it requires the combined effect of these potentials, both across time and across space, to make a neuron fire.
- For example, two EPSPs have a greater influence if they occur close together in time than if a gap in time separates them.



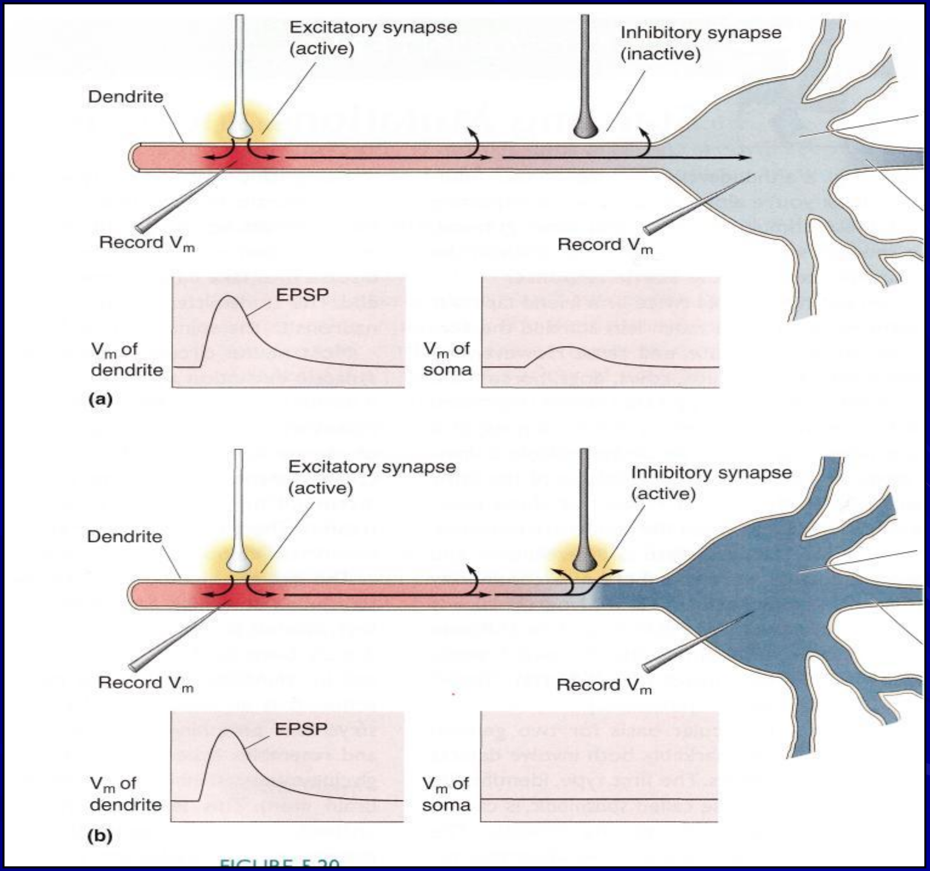
Cellular neurophysiology

- Likewise, if two EPSPs occur at the same part of the dendritic tree, they are likely to have a larger influence than if they occurred in spatially disparate regions of the dendrite.
- Thus, whether a single cell fires depends not on a single voice from a neighboring neuron, but rather on the chorus of EPSPs and IPSPs produced by its neighbors and on whether those voices occur close together in time and space.



Cellular neurophysiology

- The cacophony of postsynaptic potentials is summated at the axon hillock.
- If the summed value of EPSPs and IPSPs manages to change the differential in charge across the membrane at the axon hillock from its resting potential of –70 mV to around –55 mV, the cell will fire.
- If this value is not reached, the cell will not fire.



Cellular neurophysiology

- The cacophony of postsynaptic potentials is summated at the axon hillock.
- If the summed value of EPSPs and IPSPs manages to change the differential in charge across the membrane at the axon hillock from its resting potential of –70 mV to around –55 mV, the cell will fire.
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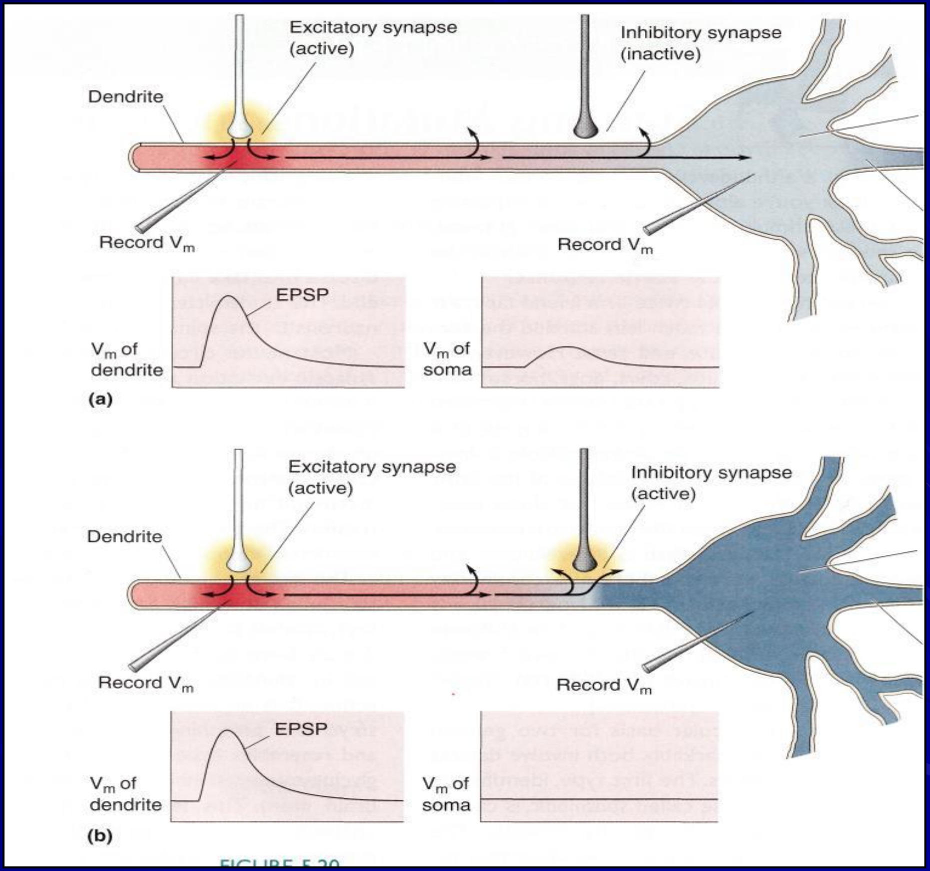
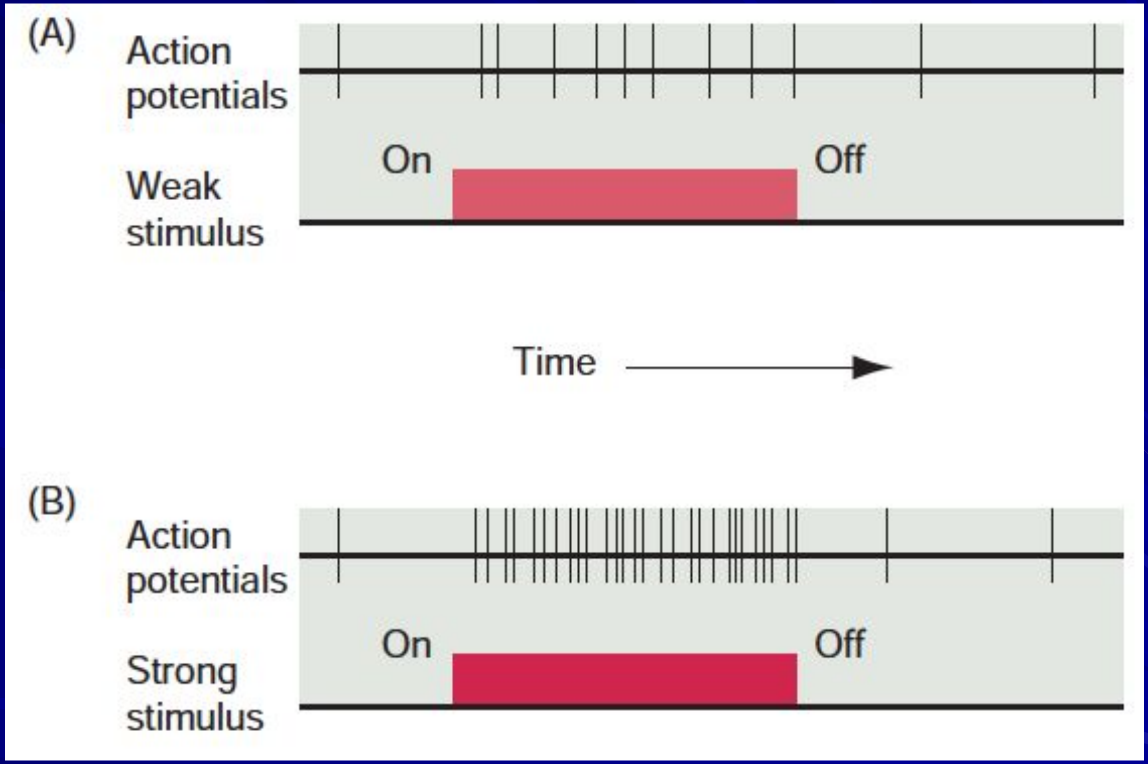


Cellular neurophysiology

How do neurons code the intensity of stimulus?

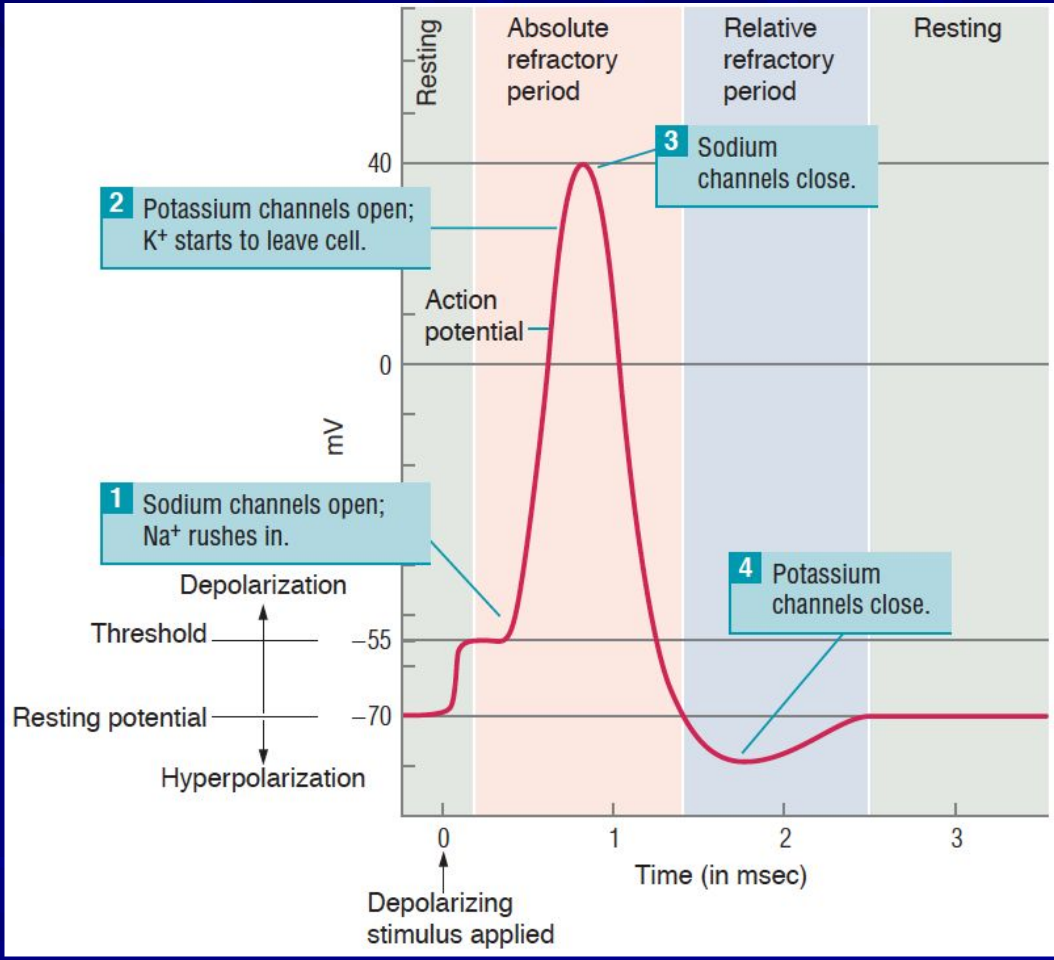
- Neurons code the intensity of a stimulus via the rate of its firing.

1. When there is a strong stimulus, the cell fires many times in succession.
2. When there is a relatively weak stimulus, the cell fires relatively infrequently.



Cellular neurophysiology

- The firing rate does have an upper limit, which is generally about 200 times per second.
- The ceiling exists because once an action potential has been initiated, it is impossible to generate another one during the depolarization and repolarization phases.
- After an ion channel opens and allows the movements of ions, it then becomes blocked and cannot reopen until it is "reset."
- This is known as the absolute refractory period



Cellular neurophysiology

- During the hyperpolarization phase, another action potential can be produced, but stimulation must be substantially higher than for the prior action potential.
- This is known as the relative refractory period.