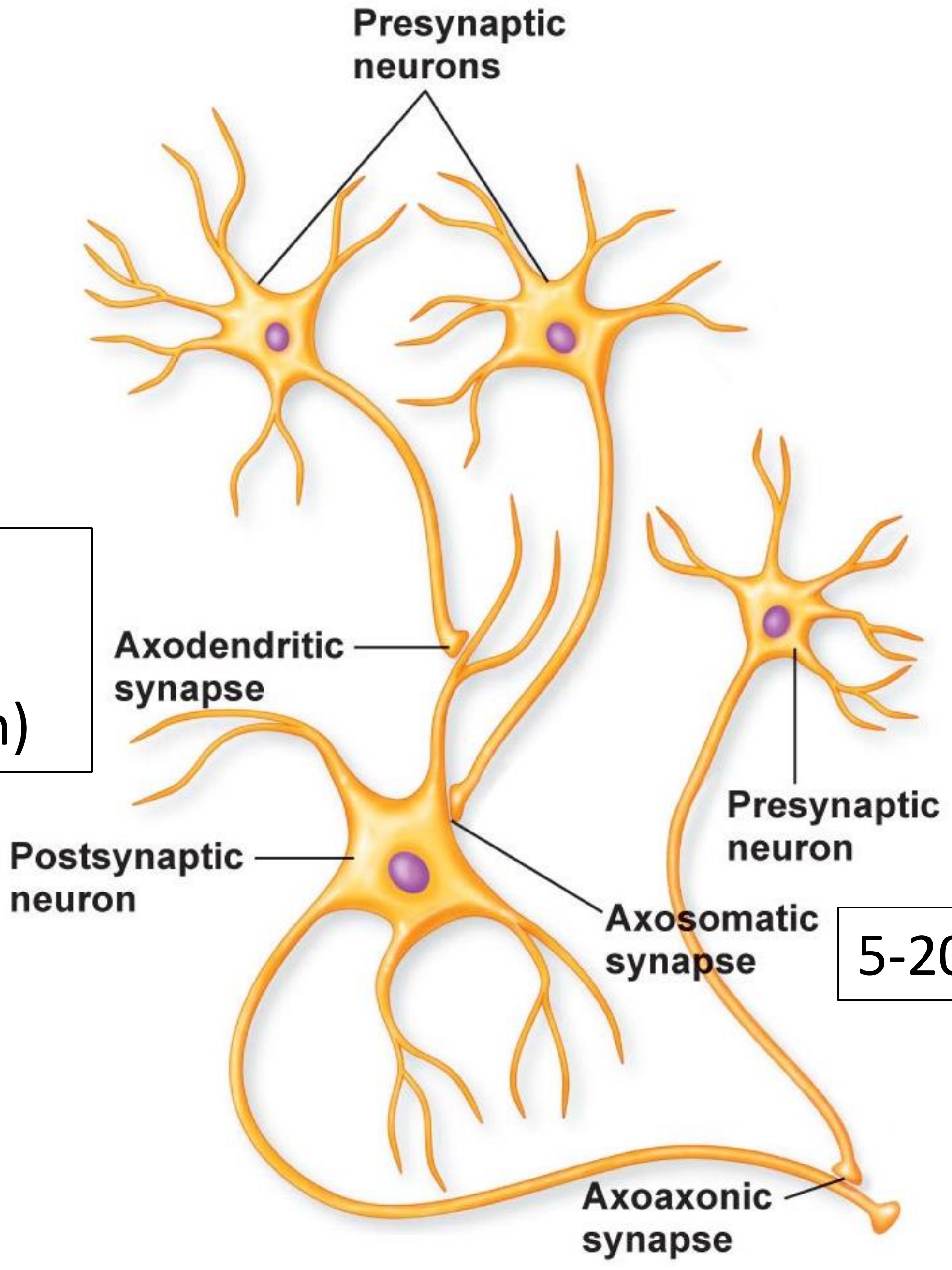
Introduction to Physiology for medical students 2021-2022

Electrical events in neurons

Fatima Ryalat, MD, PhD

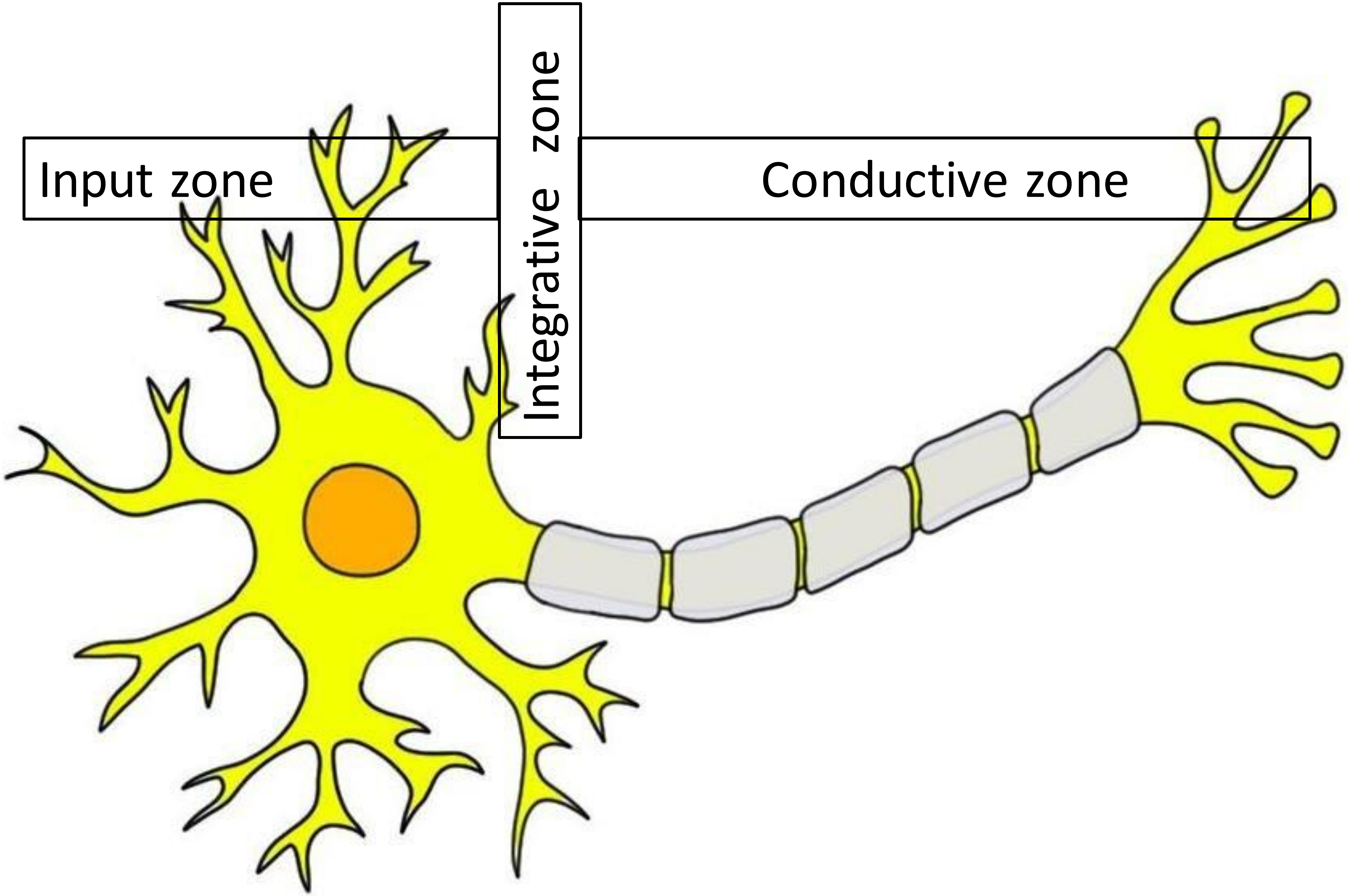
Assistant Professor, Physiology and Biochemistry Department,
School of Medicine, University of Jordan

5-31-2022

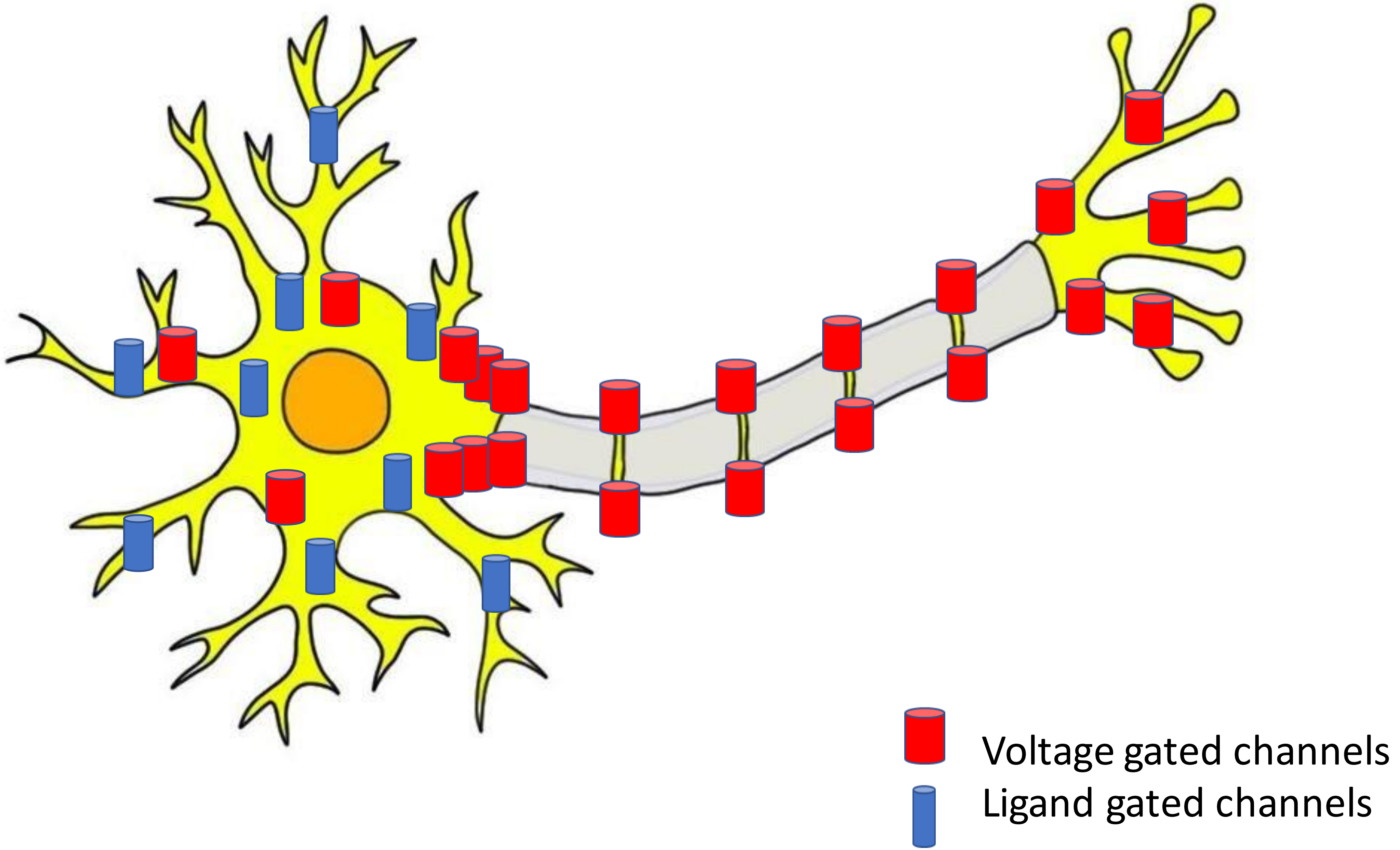


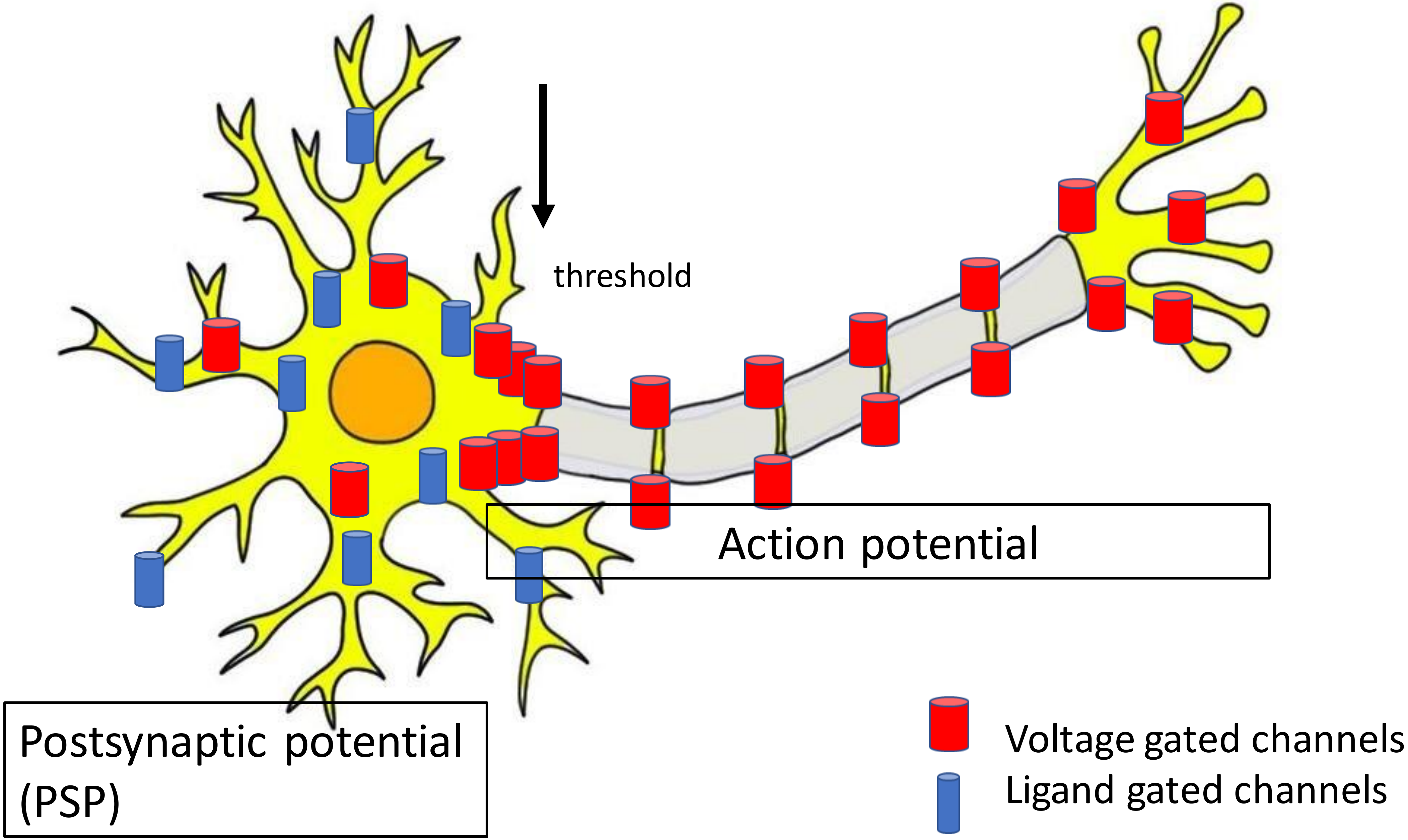
80-95%
(in anterior motor neuron)

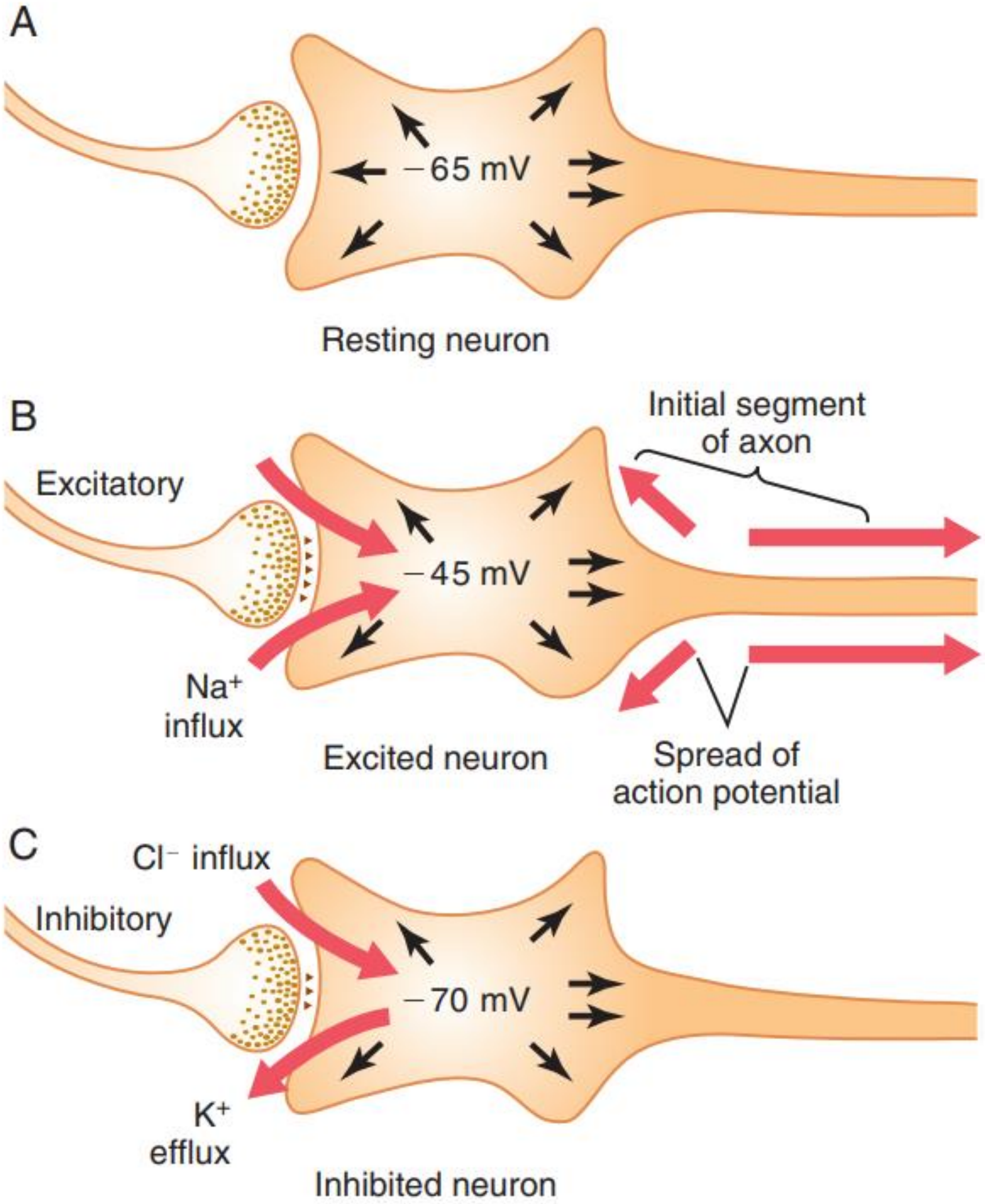
5-20%



https://journals.physiology.org/doi/full/10.1152/advan.00051.2003


Voltage gated channels
Ligand gated channels


threshold
Action potential
Postsynaptic potential (PSP)
Voltage gated channels
Ligand gated channels


A
−65 mV
Resting neuron
B
Initial segment of axon
Excitatory
−45 mV
Na+ influx
Excited neuron
Spread of action potential
C
Cl− influx
Inhibitory
−70 mV
K+ efflux
Inhibited neuron

Action potential in the axon

Action potential does not begin adjacent to the excitatory synapses. Instead, it begins in the initial segment of the axon.

The main reason is that the soma has relatively few voltage gated sodium channels in its membrane, which makes it difficult for the EPSP to open the required number of sodium channels to elicit an action potential.

Action potential in the axon

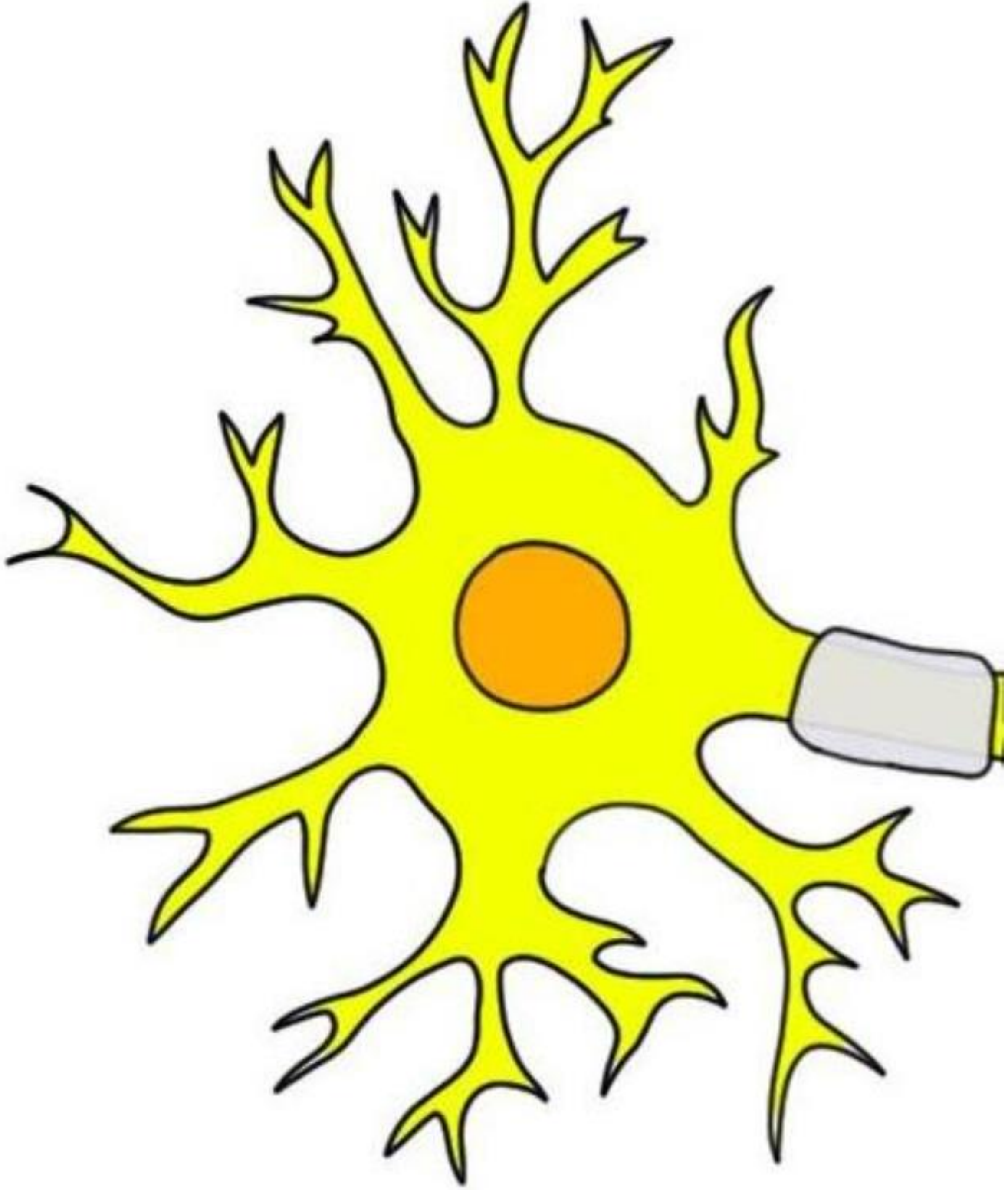
- The membrane of the initial segment of the axon has 7 times as great a concentration of voltage-gated Na+ channels as does the soma and, therefore, can generate an action potential with much greater ease than can the soma.

- The threshold is lower in the axon initial segment than the soma.

Dendrites:

Large spatial field of excitation.

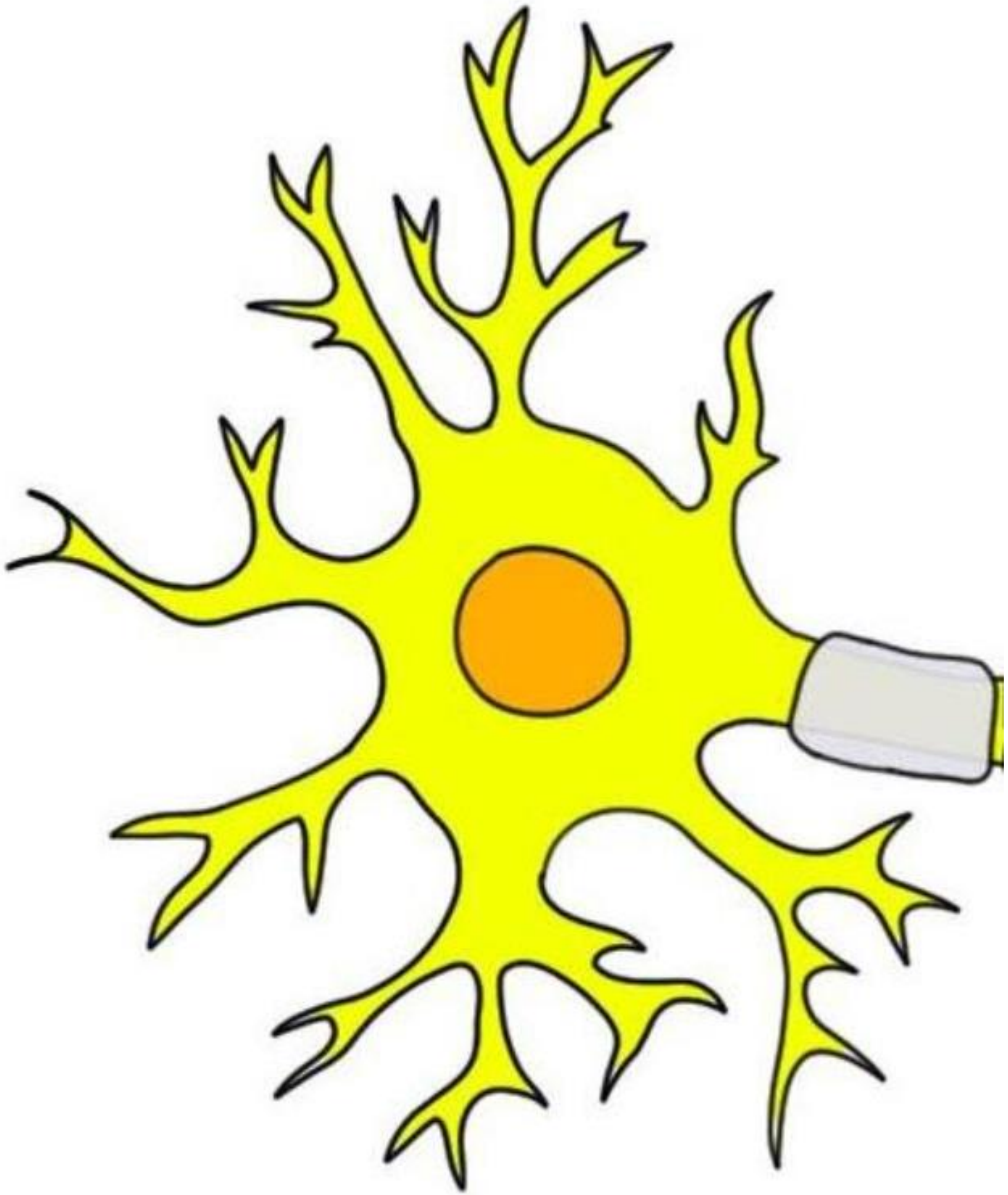
A great opportunity for summation of signals from many neurons.



Most dendrites can not transmit action potentials.

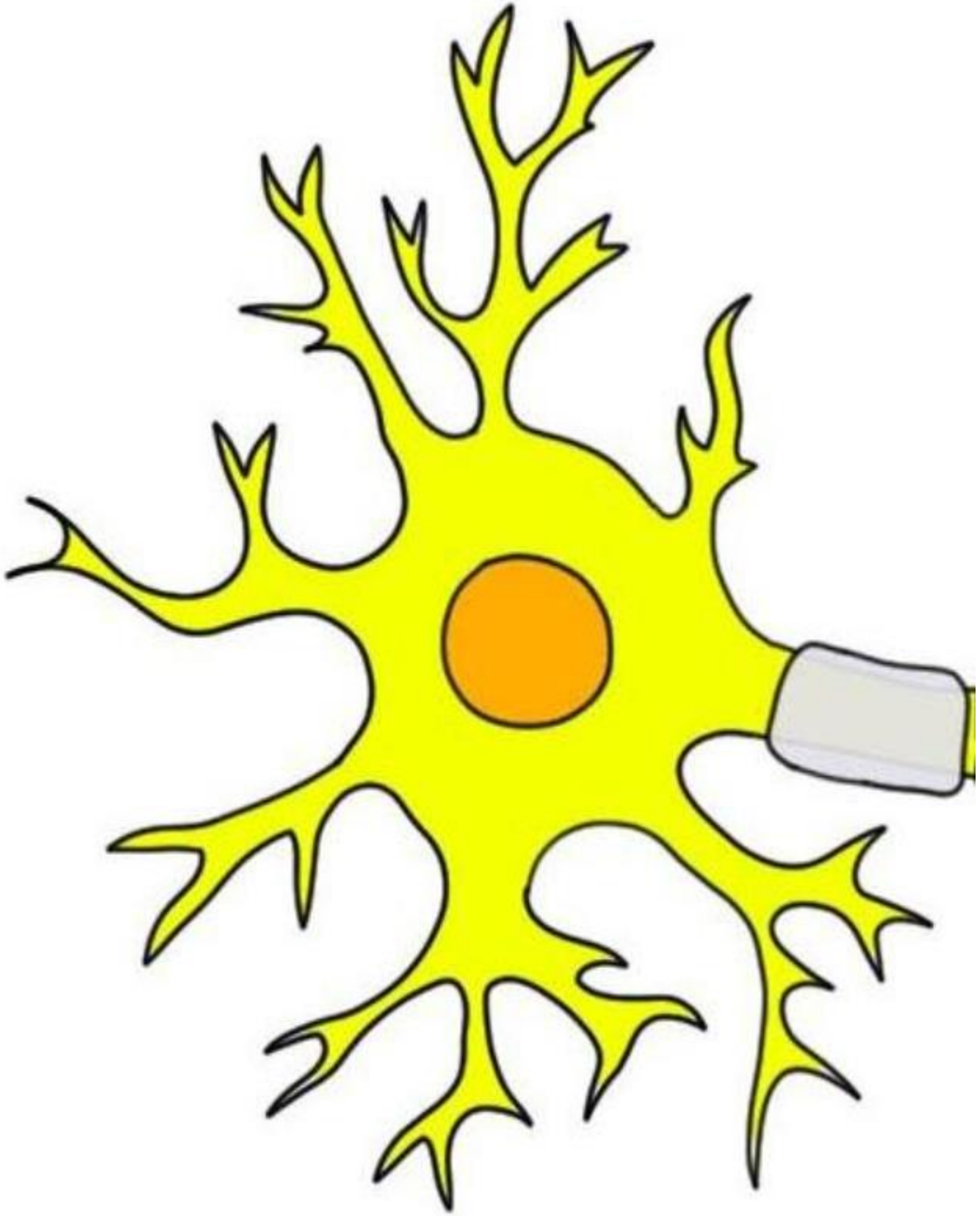
Decremental conduction:

decrease in membrane potential as it spreads electrotonically along dendrites toward the soma.

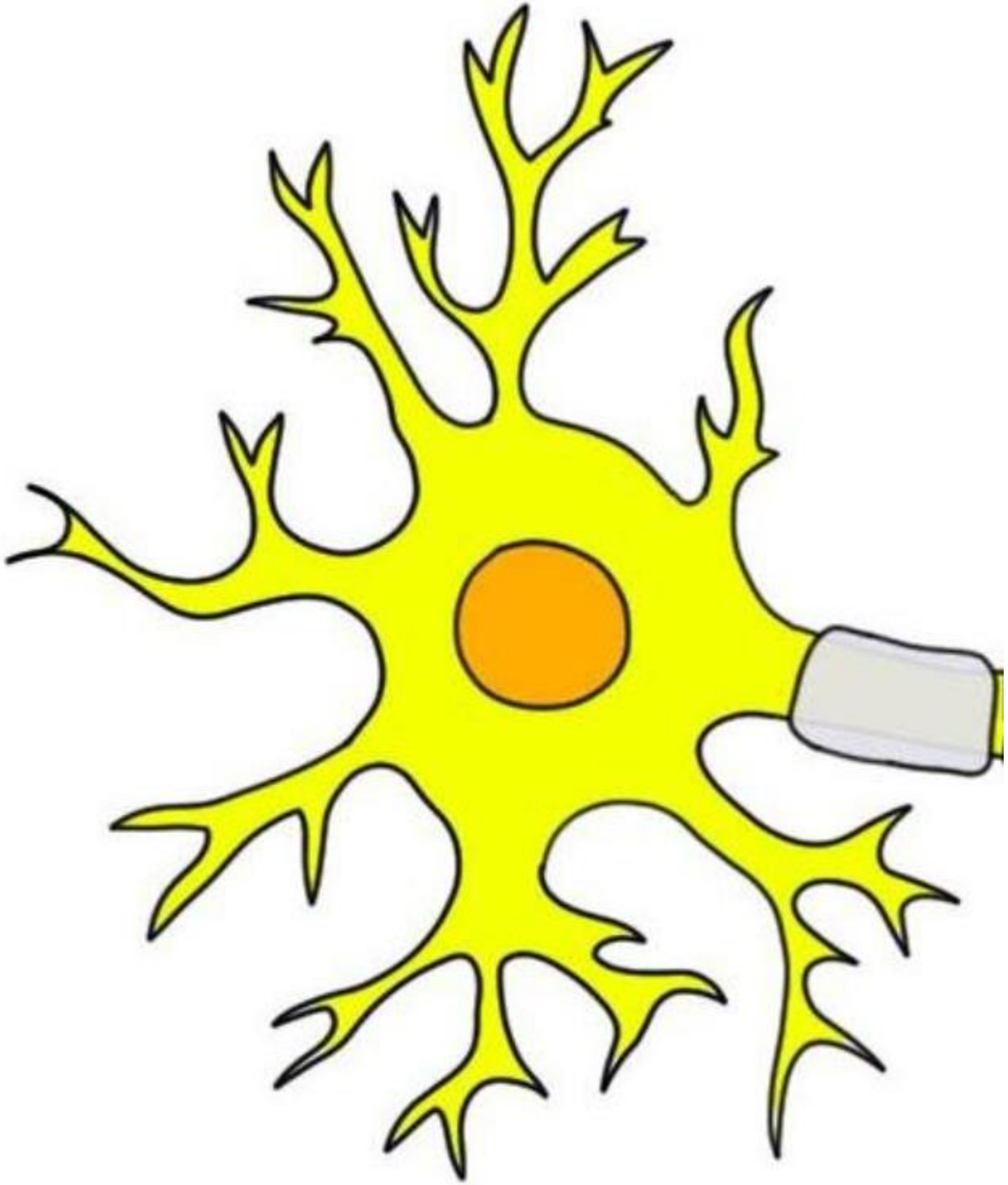


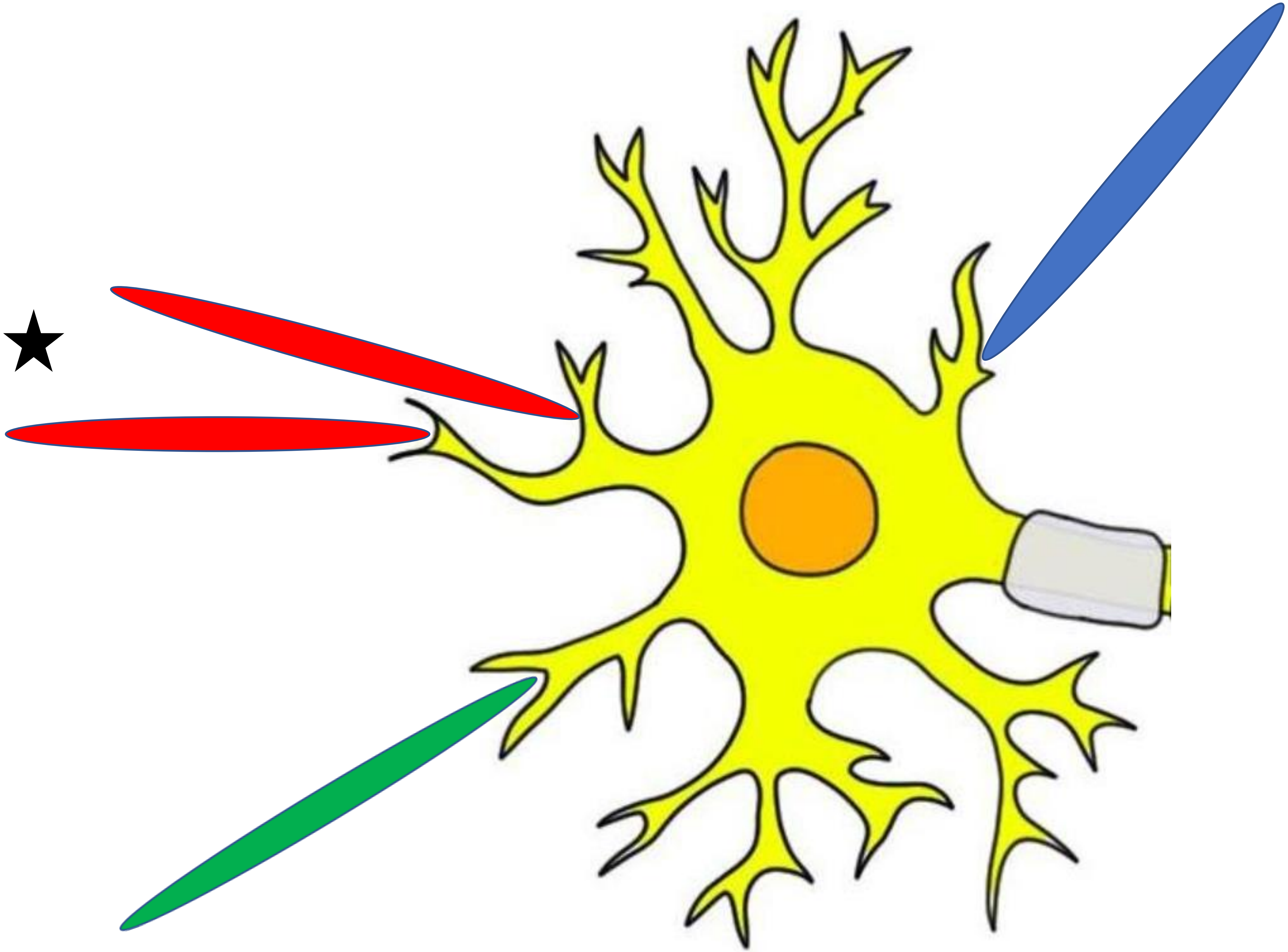
Dendrites are long.
Their membranes are thin and at least partially permeable to K+ and Cl-, making them “leaky” to electric current.

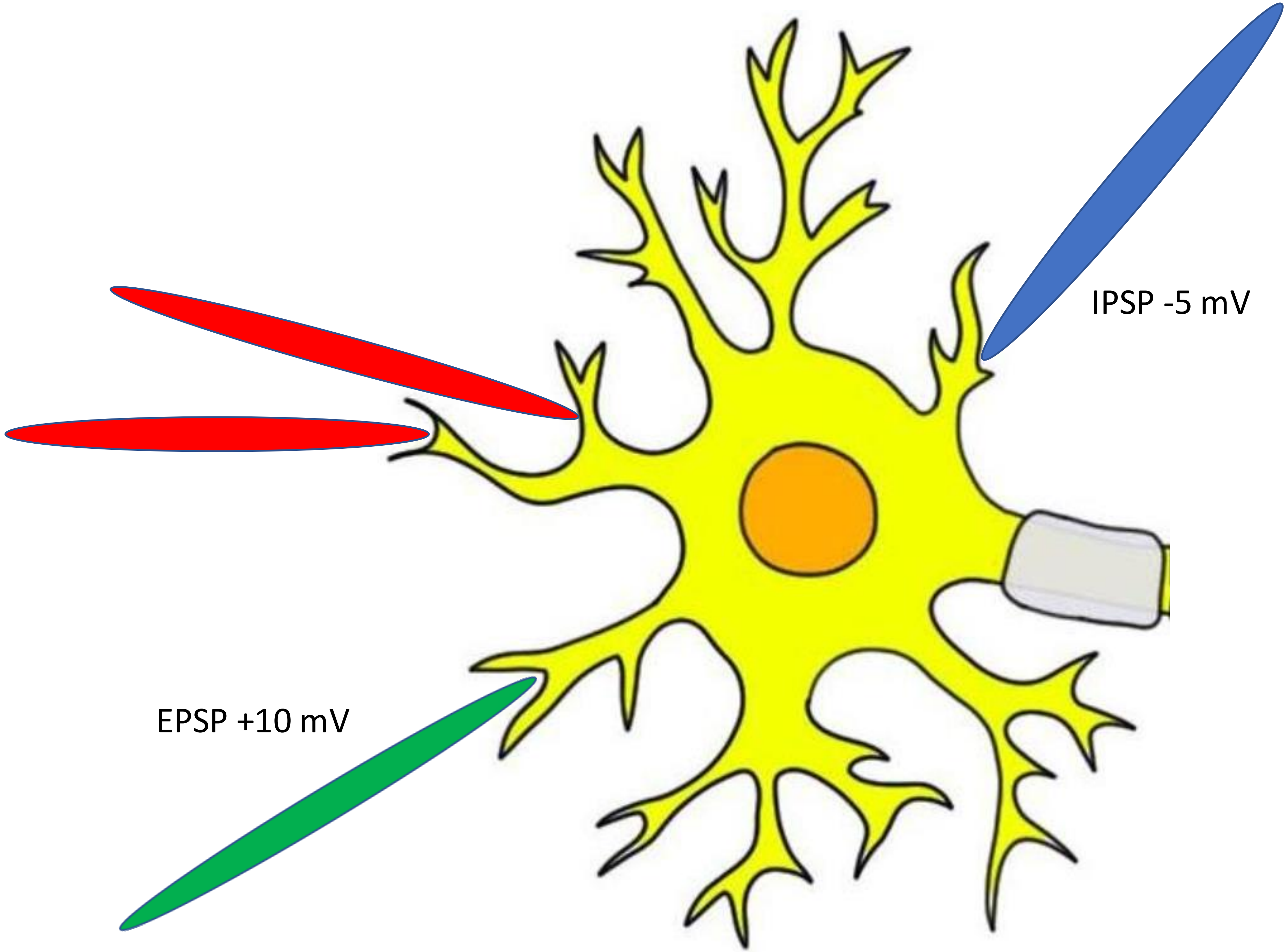
Therefore, before the excitatory potentials can reach the soma, a large share of the potential is lost.



The farther the excitatory synapse is from the soma, the greater the decrement and the lesser the excitatory signal reaching the soma.






IPSP -5 mV
EPSP +10 mV

Excitatory postsynaptic potential (EPSP)

- This positive increase in voltage above the normal resting neuronal potential— that is, to a less negative value—is called the excitatory postsynaptic potential (or **EPSP)**, because if this potential rises high enough in the positive direction, it will elicit an action potential in the postsynaptic neuron, thus exciting it.

- EPSP is +20 millivolts means 20 millivolts more positive than the resting value.

Inhibitory postsynaptic potential (IPSP)

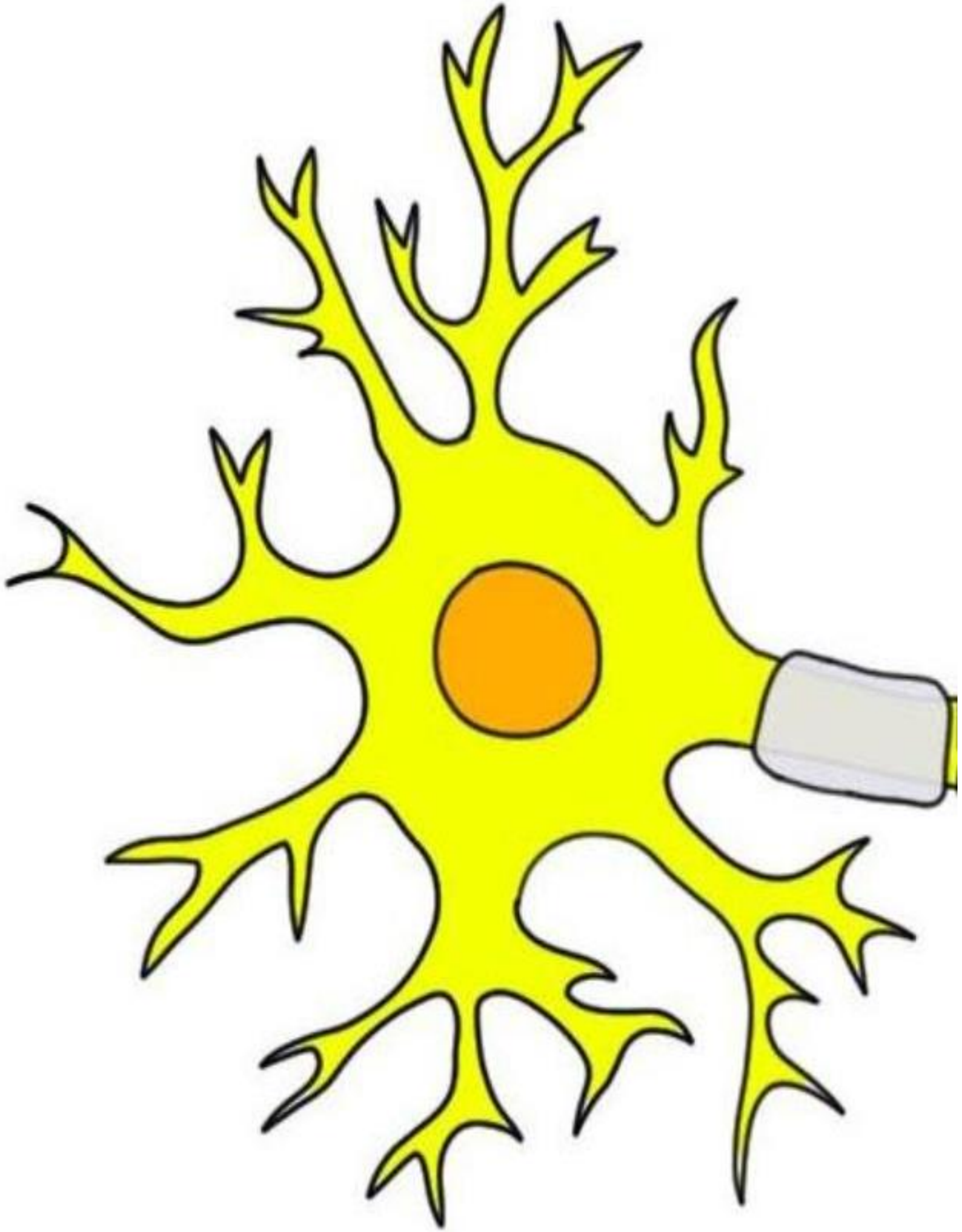
- Opening potassium or chloride channels.
- An increase in negativity beyond the normal resting membrane potential level is called an inhibitory postsynaptic potential (IPSP).
- IPSP is -20 millivolts means 20 millivolts more negative than the resting value.

Soma:
uniform distribution of electrical potential:

Large diameter (less resistance to conductance).

Highly conductive electrolytic fluid.

(change in membrane potential will be transmitted equally to all parts of the soma.)

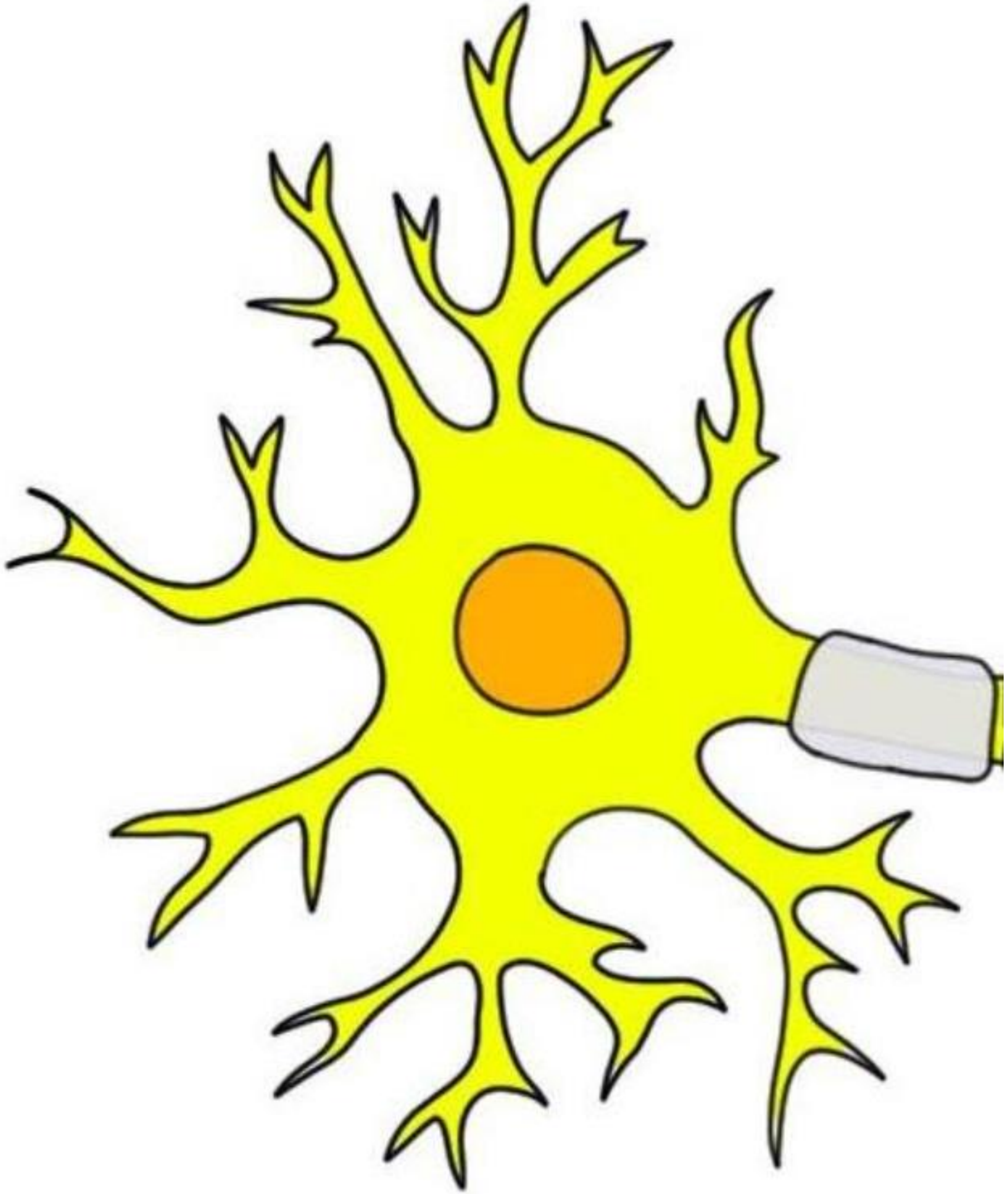


Resting membrane potential of neuronal soma

- Any change in potential in any part of the intra-somal fluid causes an almost exactly equal change in potential at all other points inside the soma.
- This principle is important because it plays a major role in "summation" of signals entering the neuron from multiple sources.

Resting membrane potential in soma of AMN is -65.

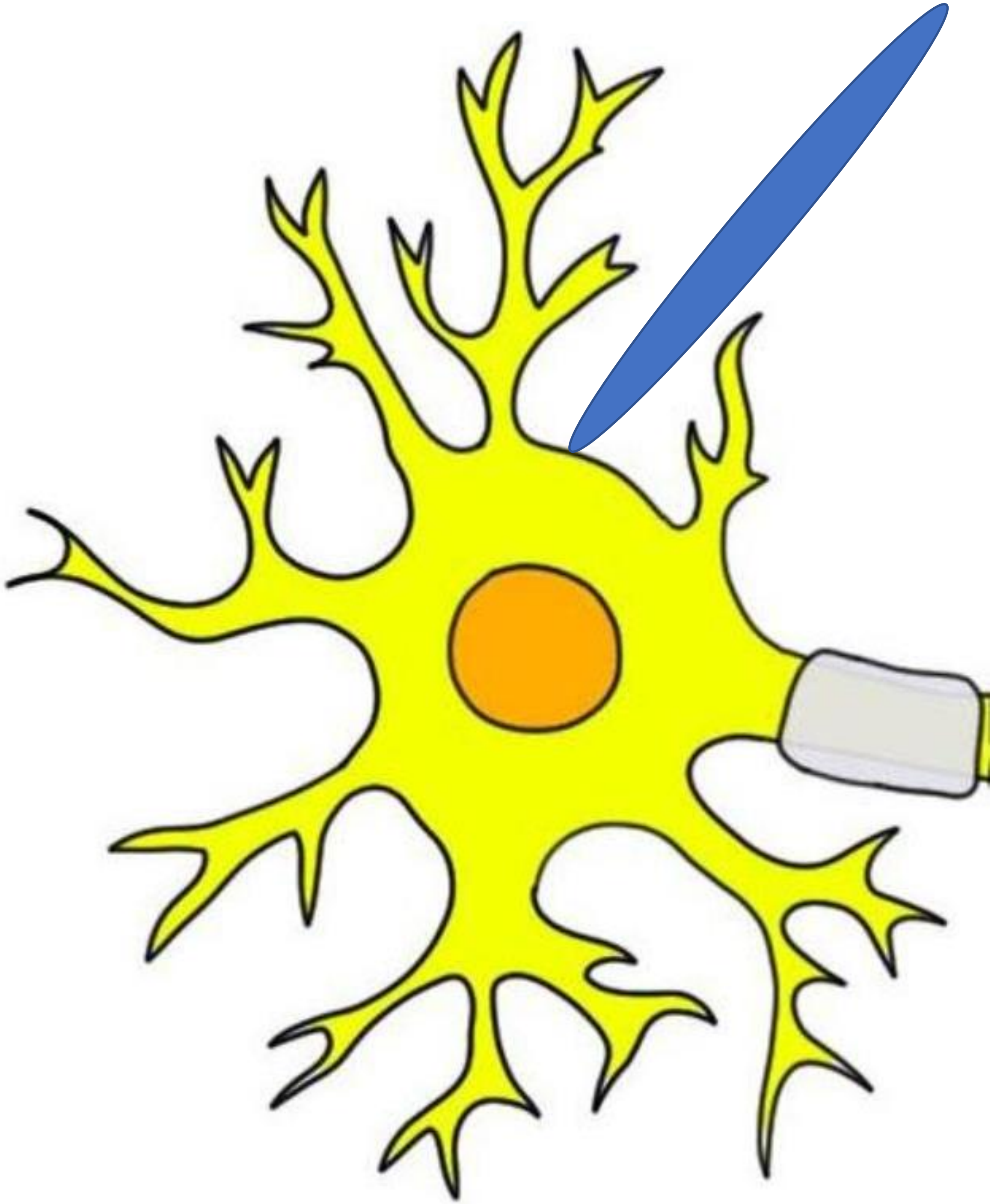
Allows both positive and negative control of the degree of excitability of the neuron.

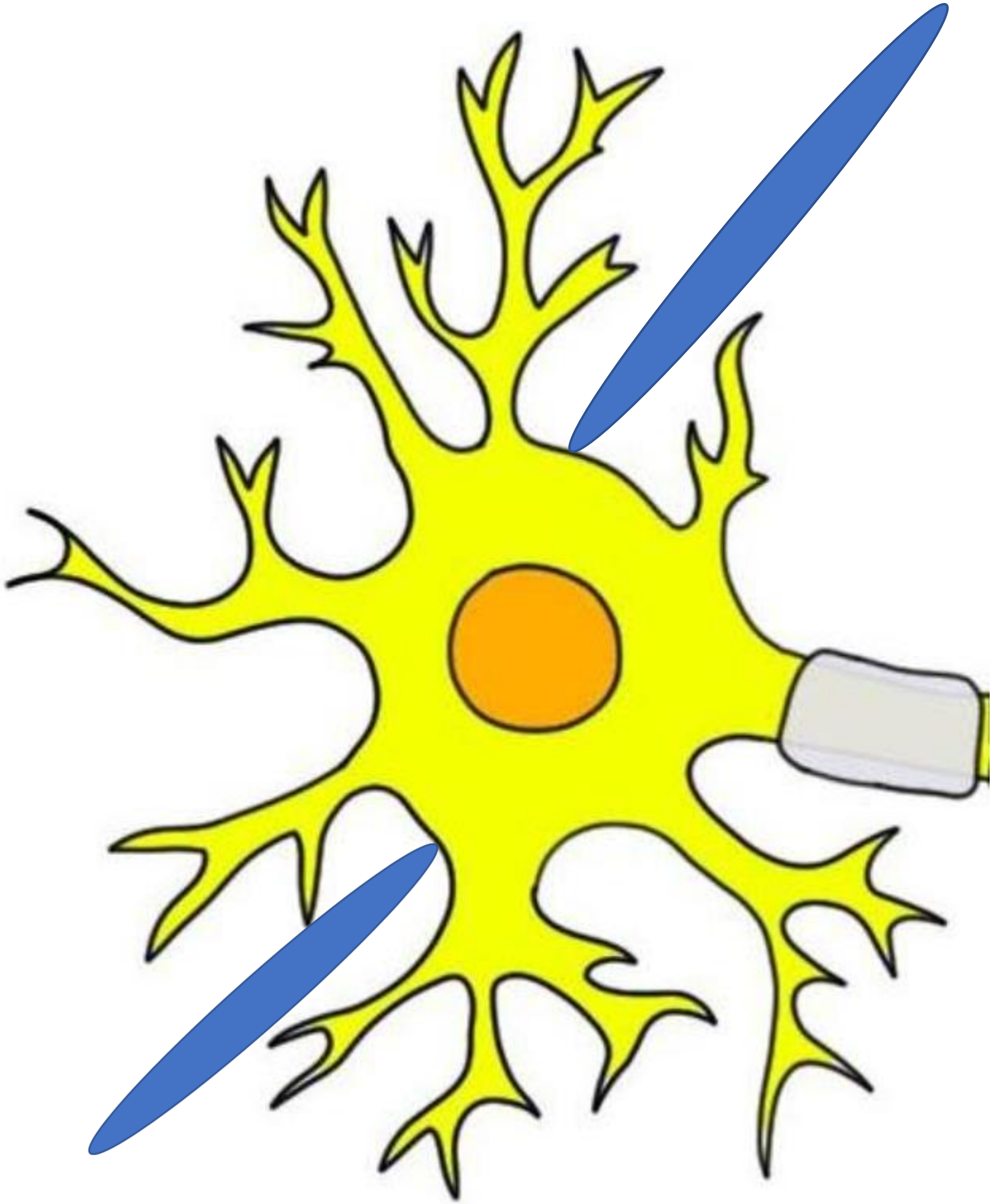


Summation in neurons

- Excitation of a single presynaptic terminal on the surface of a neuron almost never excites the neuron.

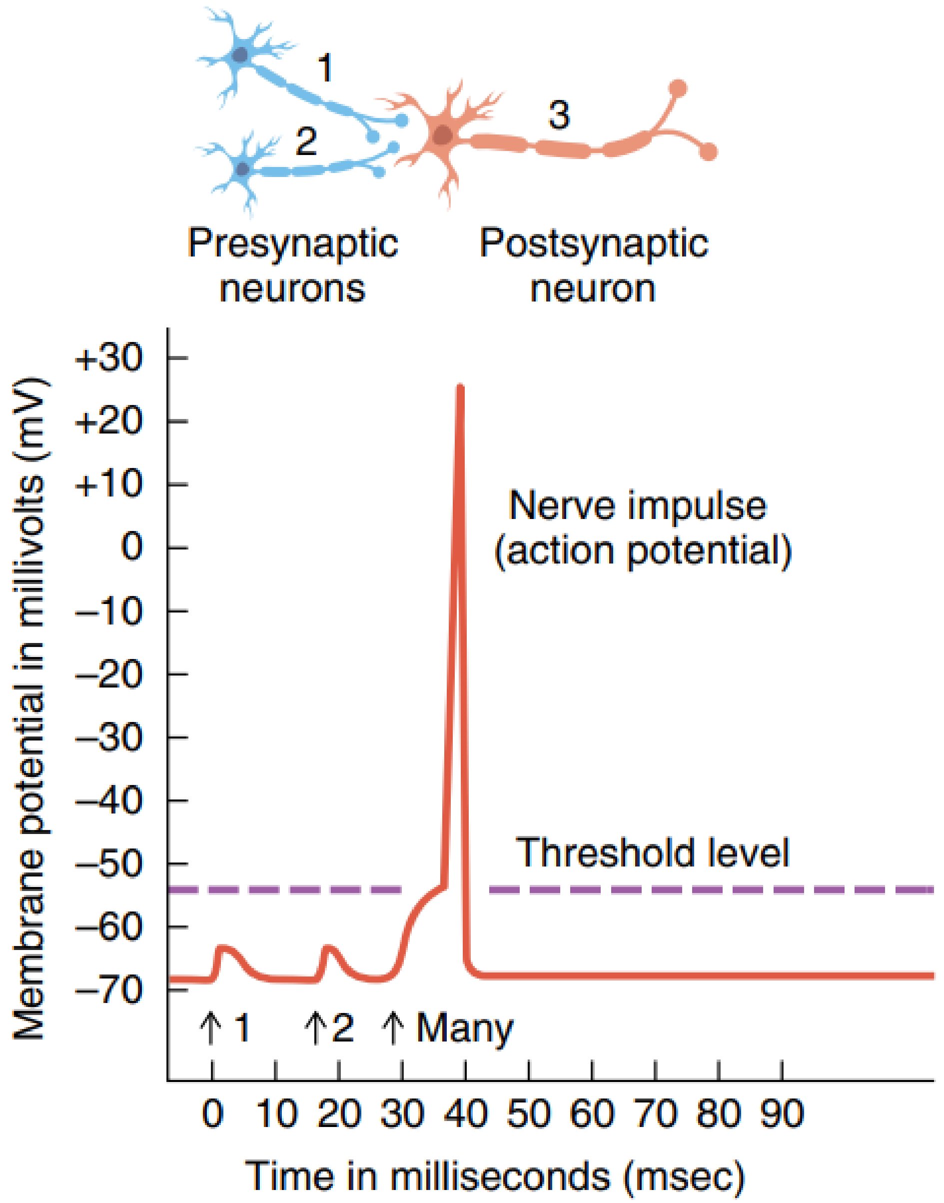
- The reason is that the amount of transmitter substance released by a single terminal to cause an EPSP is usually no greater than 0.5 to 1 millivolt, instead of the 10 to 20 millivolts normally required to reach threshold for excitation.





Spatial summation in neurons

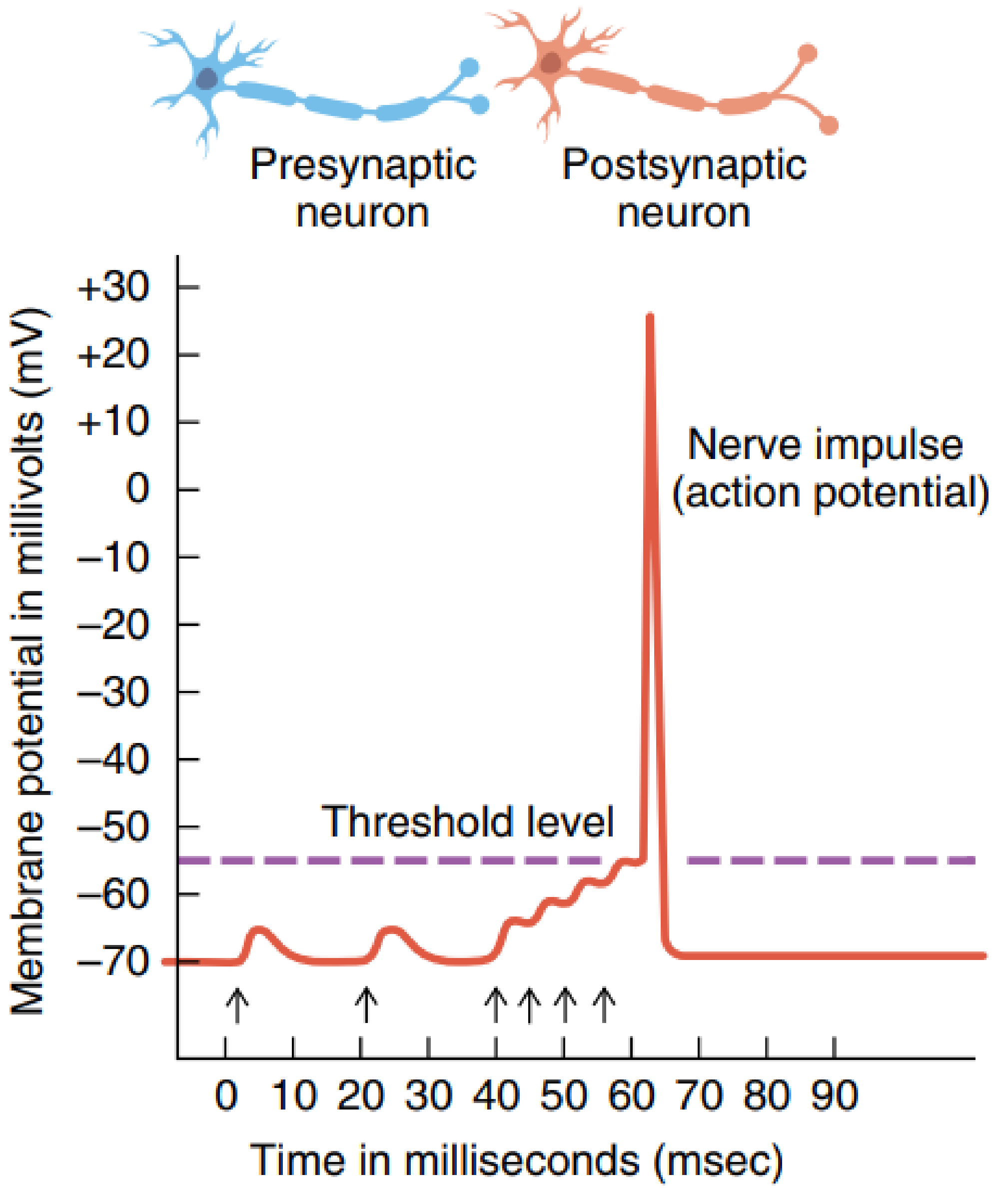
- The effect of summing simultaneous postsynaptic potentials by activating multiple terminals on widely spaced areas of the neuronal membrane is called **spatial summation**.



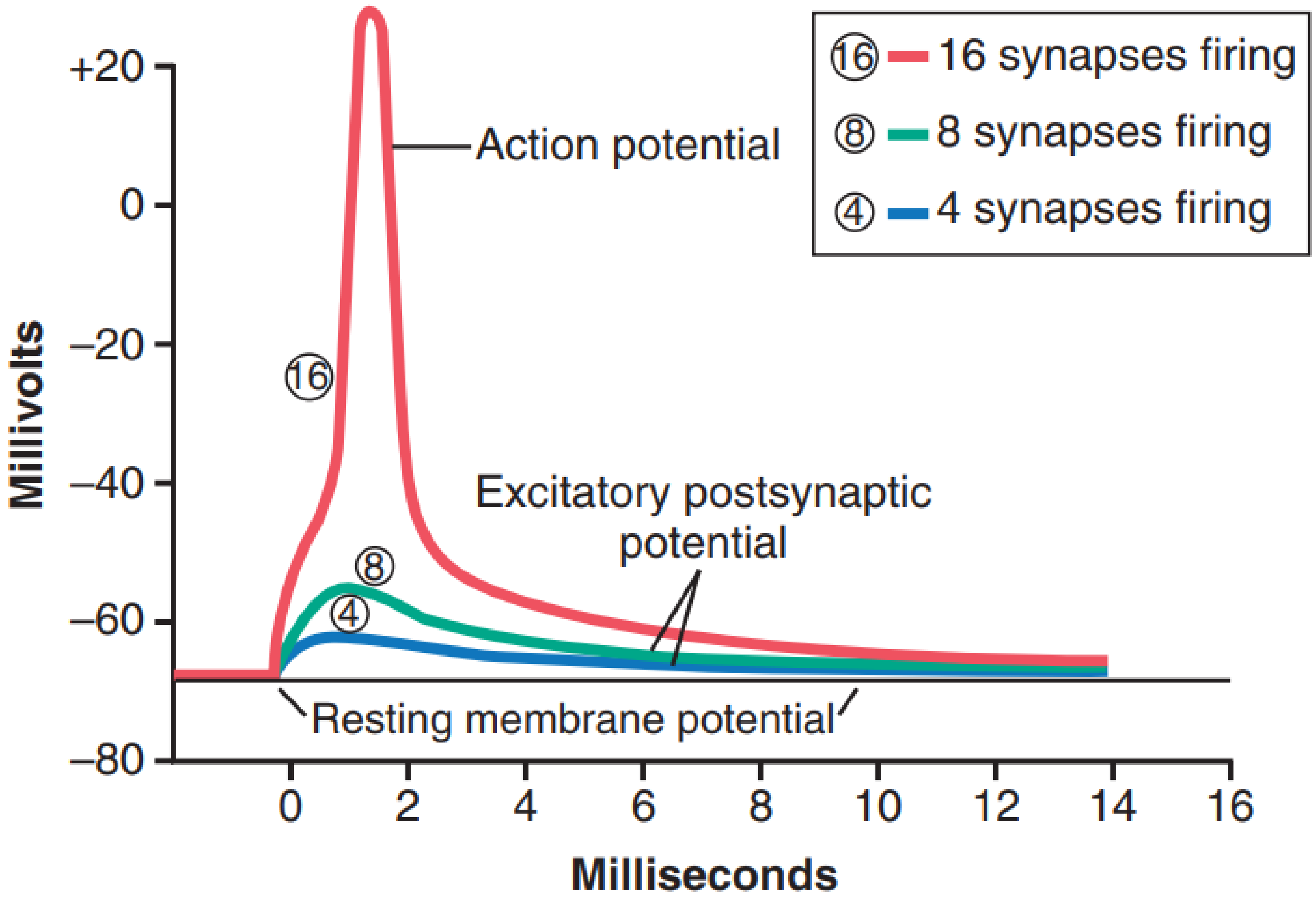
(a) Spatial summation

Temporal summation in neurons

- Each time a presynaptic terminal fires, the released transmitter substance opens the membrane channels for at most a millisecond or so. However, the changed postsynaptic potential lasts up to 15 milliseconds after the synaptic membrane channels have already closed.
- Therefore, a second opening of the same channels can increase the postsynaptic potential to a still greater level, and the more rapid the rate of stimulation, the greater the postsynaptic potential becomes. Thus, successive discharges from a single presynaptic terminal, if they occur rapidly enough, can add to one another; that is, they can "summate." This type of summation is called temporal summation.



(b) Temporal summation



16 synapses firing
8 synapses firing
4 synapses firing
Action potential
Excitatory postsynaptic potential
Resting membrane potential
Millivolts
+20
0
−20
−40
−60
−80
0
2
4
6
8
10
12
14
16
Milliseconds
16
8
4

Time course of postsynaptic potentials

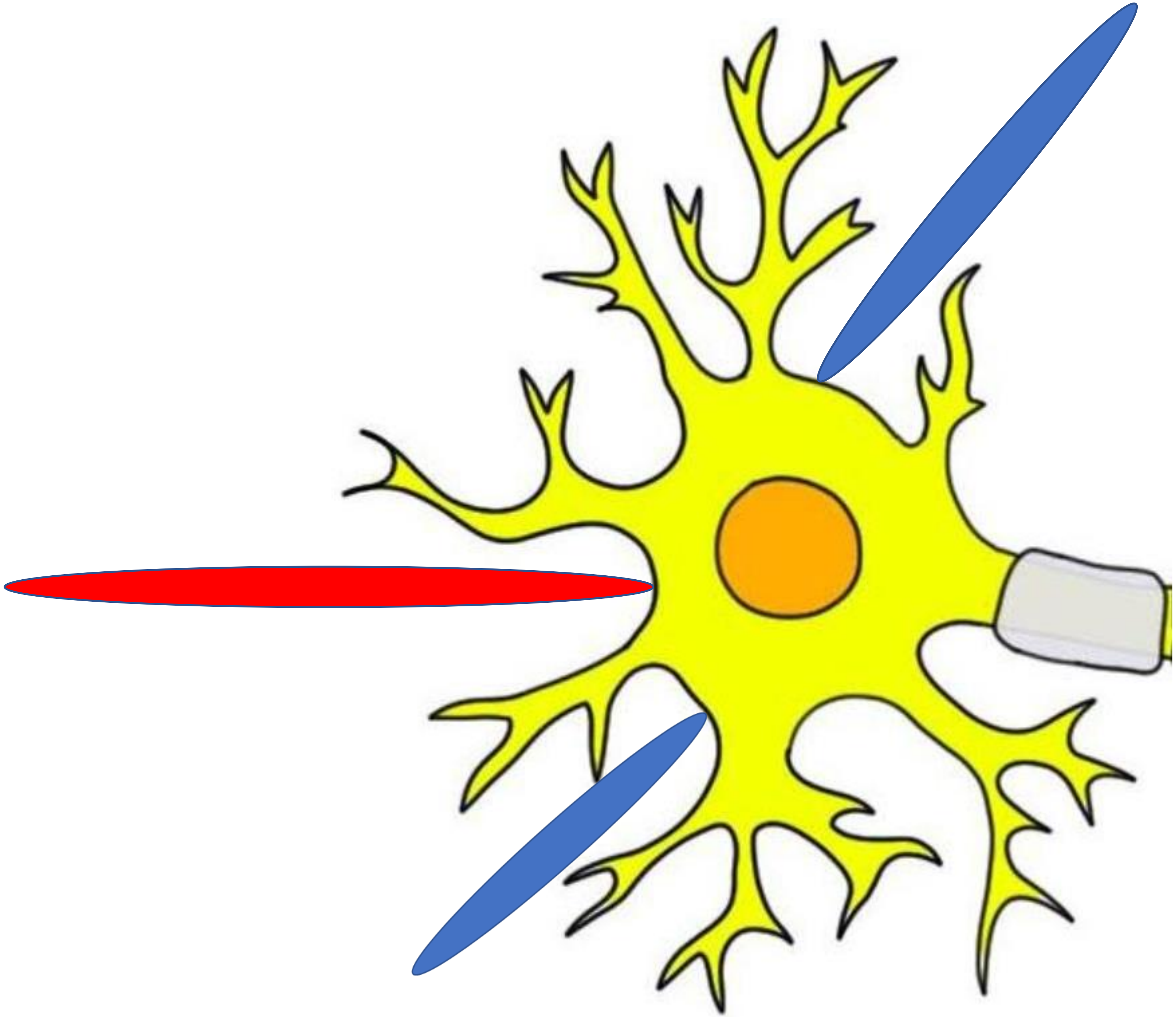
- When an excitatory synapse excites the anterior motor neuron, the neuronal membrane becomes highly permeable to sodium ions for 1 to 2 milliseconds.
- During this very short time, enough sodium ions diffuse rapidly to the interior of the postsynaptic motor neuron to increase its intraneuronal potential by a few millivolts, thus creating the EPSP.
- This potential then slowly declines over the next 15 milliseconds because this is the time required for the excess positive charges to leak out of the excited neuron and to re-establish the normal resting membrane potential.

Time course of postsynaptic potentials

- The opposite effect occurs for an **IPSP**;
- The inhibitory synapse increases the permeability of the membrane to potassium or chloride ions, or both, for 1 to 2 milliseconds, and this action decreases the intraneuronal potential to a more negative value than normal, thereby creating the IPSP.
- This potential also dies away in about 15 milliseconds.

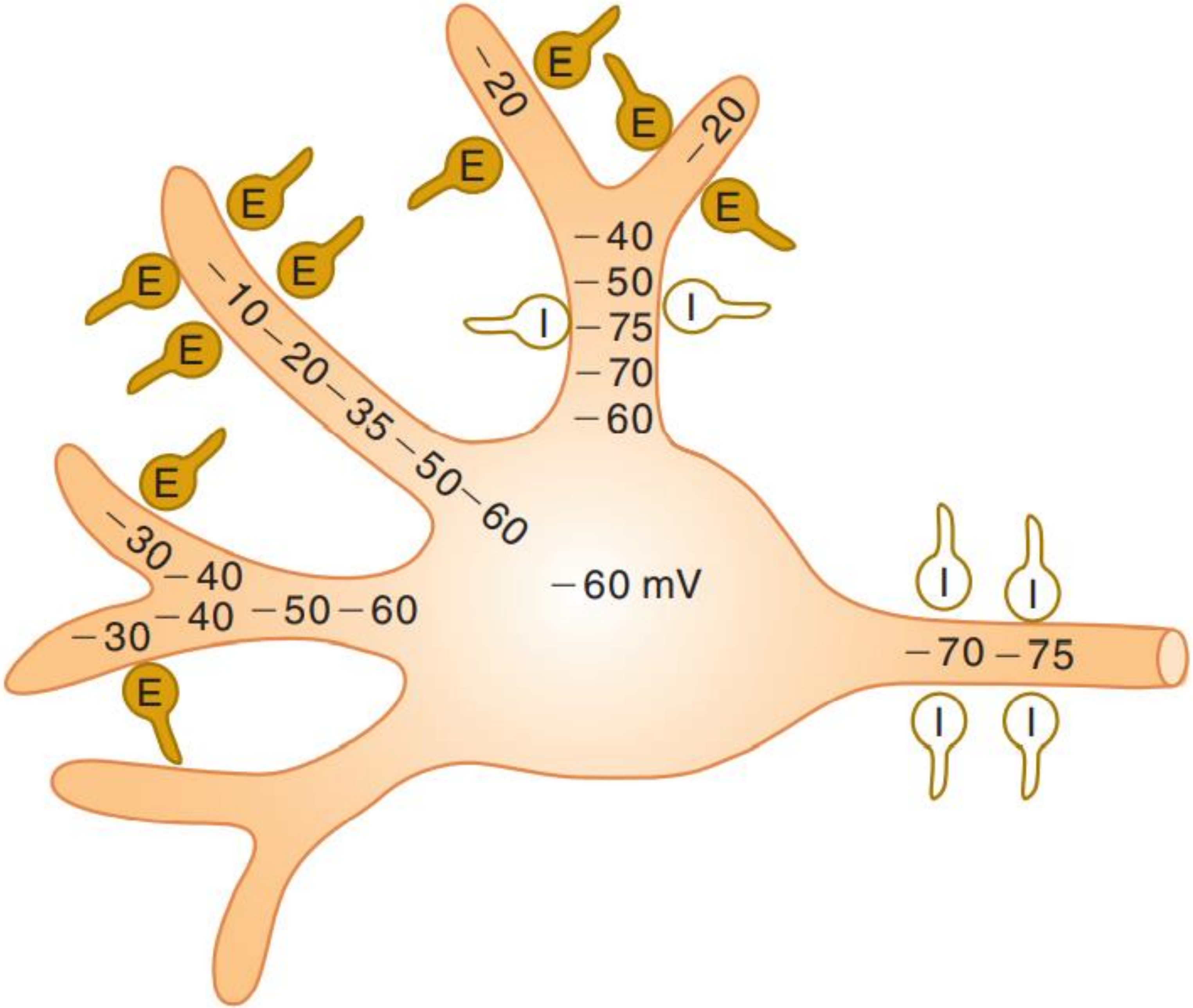
Time course of postsynaptic potentials

- Other types of transmitter substances can excite or inhibit the postsynaptic neuron for much longer periods — for hundreds of milliseconds or even for seconds, minutes, or hours. This is especially true for some of the **neuropeptide transmitters**.



Summation of IPSP and EPSP

- If an IPSP is tending to decrease the membrane potential to a more negative value while an EPSP is tending to increase the potential at the same time, these two effects can either completely or partially nullify each other.


E
E
E
E
E
E
E
E
E
E
E
I
I
I
I
I
I
−20
−20
−40
−50
−75
−70
−60
−10
−20
−35
−50
−60
−30
−40
−30
−40
−50
−60
−60 mV
−70
−75

Presynaptic inhibition

- In addition to inhibition caused by inhibitory synapses operating at the neuronal membrane, which is called **postsynaptic inhibition**.

- **Presynaptic inhibition** is caused by release of an inhibitory substance onto the outsides of the presynaptic nerve fibrils before their own endings terminate on the postsynaptic neuron.
- In most instances, the inhibitory transmitter substance is GABA.
- This release has a specific effect of opening anion channels, allowing large numbers of Cl- ions to diffuse into the terminal fibril.

Presynaptic inhibition

- The negative charges of these ions inhibit synaptic transmission because they cancel much of the excitatory effect of the positively charged sodium ions that also enter the terminal fibrils when an action potential arrives.

- Presynaptic inhibition occurs in many of the sensory pathways in the nervous system, such as, adjacent sensory nerve fibers often mutually inhibit one another, which minimizes sideways spread and mixing of signals in sensory tracts.

Facilitation of neurons

- Often the summated postsynaptic potential is excitatory but has not risen high enough to reach the threshold for firing by the postsynaptic neuron.
- When this situation occurs, the neuron is said to be facilitated.
- That is, its membrane potential is nearer the threshold for firing than normal but is not yet at the firing level.

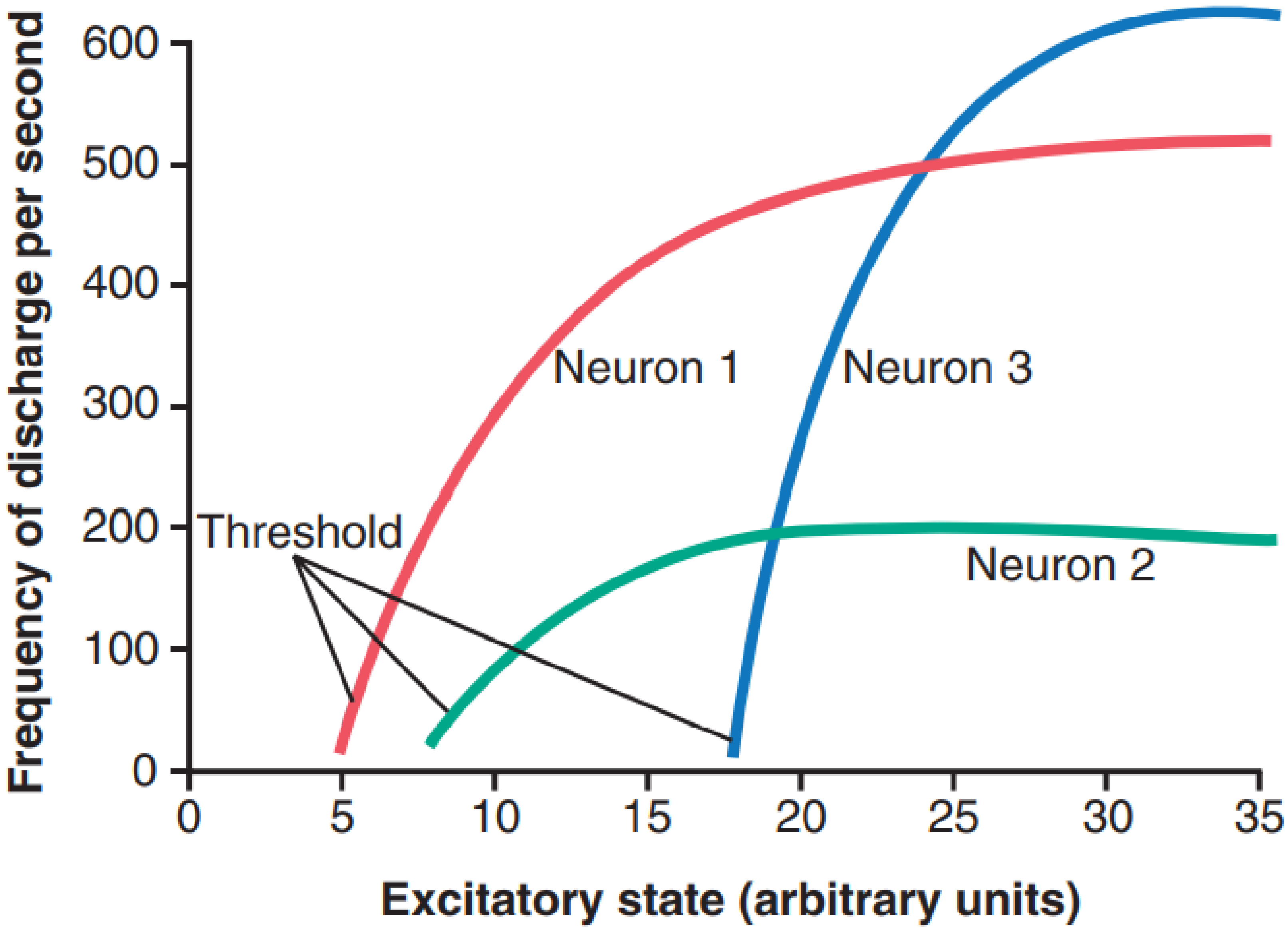
Facilitation of neurons

- Consequently, another excitatory signal entering the neuron from some other source can then excite the neuron very easily.

- Diffuse signals in the nervous system often do facilitate large groups of neurons so that they can respond quickly and easily to signals arriving from other sources.

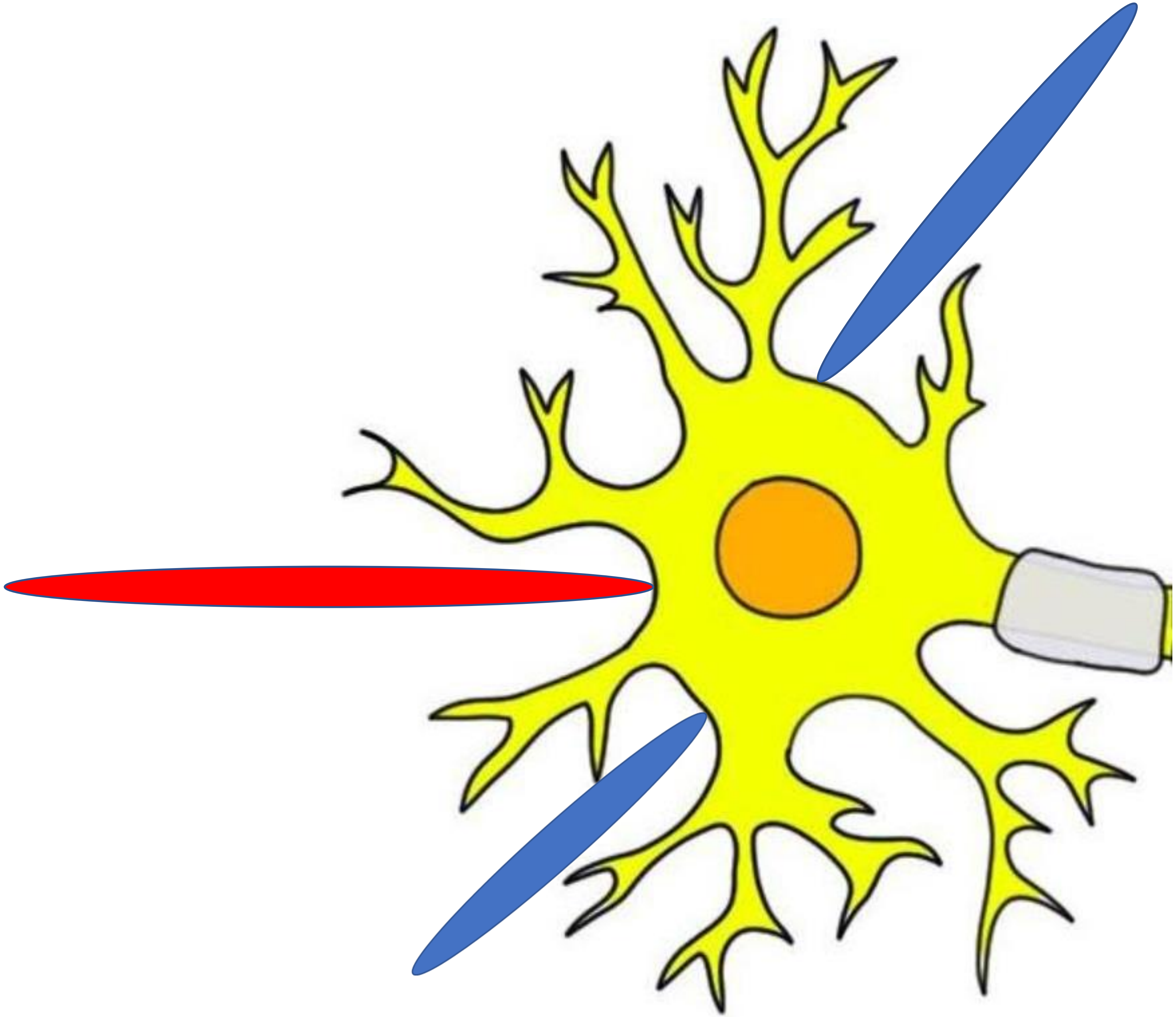
State of excitation and rate of firing

- **Excitatory State** Is the Summated Degree of Excitatory Drive to the Neuron.
- If there is a higher degree of excitation than inhibition of the neuron at any given instant, then it is said that there is an excitatory state.
- Conversely, if there is more inhibition than excitation, then it is said that there is an **inhibitory state**.
- When the excitatory state of a neuron rises above the threshold for excitation, the neuron will fire repetitively as long as the excitatory state remains at that level.


Frequency of discharge per second
600
500
400
300
200
100
0
Threshold
Neuron 1
Neuron 3
Neuron 2
0
5
10
15
20
25
30
35
Excitatory state (arbitrary units)

State of excitation and rate of firing

- Figure shows responses of three types of neurons to varying levels of excitatory state.
- Neuron 1 has a low threshold for excitation, whereas neuron 3 has a high threshold.
- Neuron 2 has the lowest maximum frequency of discharge, whereas neuron 3 has the highest maximum frequency.



Questions? Feedback?

Thank you