Neuro B2: Excitatory-Inhibitory Pair

By Shaivi Nandi, Ruthvik CSS,
Utkarsh Goyal, Navya Balaji

01

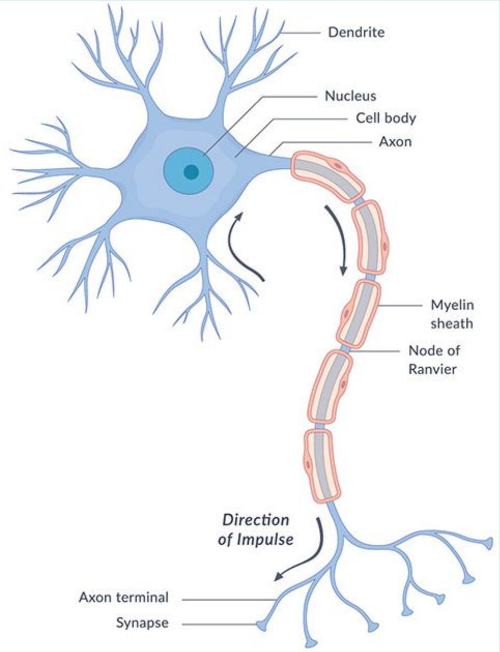
A Biological Background

Generation and Transmission of
Nerve Signals

Nerve Structure

1. **Dendrite** - Receives and integrates multiple incoming signals from neurons through receptor on its ends.
2. **Axon** - The long part of the neuron through which the signal propagates quickly and covers a long distance.
3. **Synapse** - The part where ions / molecules that act as neurotransmitters are released acting as messengers for the next neuron.

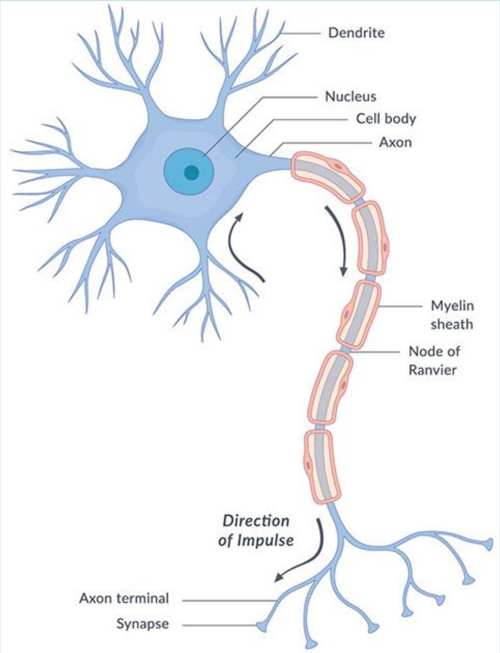
Dendrite -> Axon -> Synapse



Nerve Structure

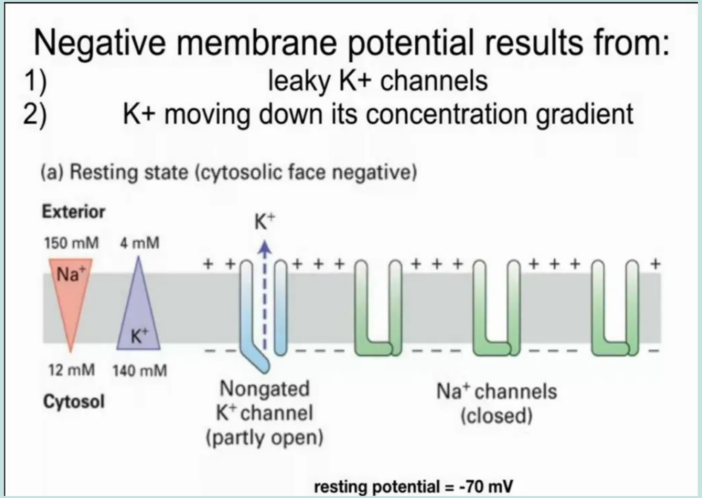
4. **Myelin Sheath** - Fatty insulating layer wraps around the axon, preventing ion leakage and allowing the signal to travel faster, just like insulation on a wire.

5. **Axon Hillock -** The decision center of the neuron where all incoming excitatory and inhibitory signals are combined; if they add up to exceed the threshold, an action potential is triggered.



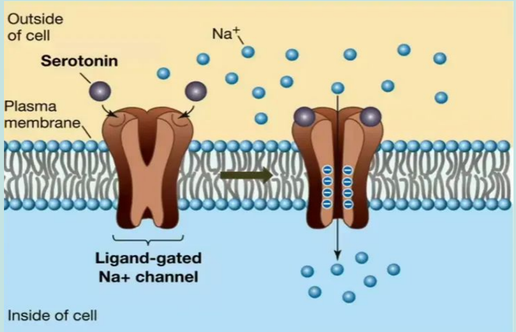
What happens inside a neuron?

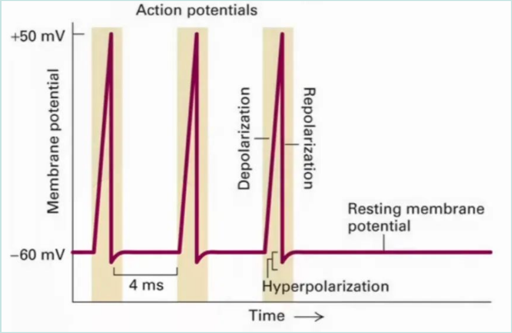
1. Inside the cell
   a. Conc. of K+ ⬆️
   b. Conc. of Na+ ⬇️
2. Outside the cell
   a. Conc. of K+ ⬇️
   b. Conc. of Na+ ⬆️
3. The passage of K+ is kept slightly open causing imbalance of charges.
4. What happens if we open Na+ gates? How do we "repolarize"?



Generation of Nerve Impulses

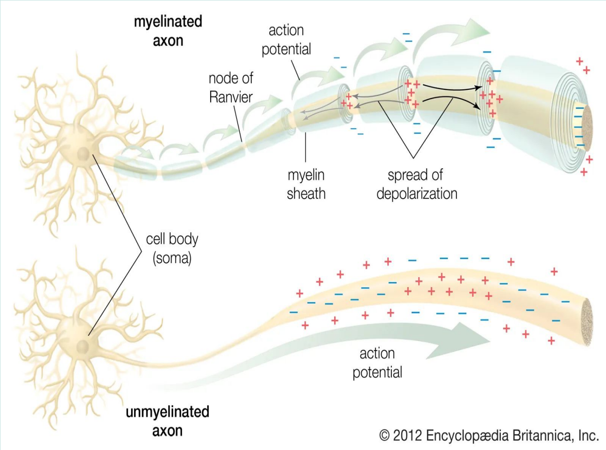
1. Neurotransmitters bind to their respective receptors signalling the corresponding channels to open.
2. This opening of channel causes “depolarization” or “repolarization” of the membrane.
3. How is the “strength” of the signal decided? How is it controlled?





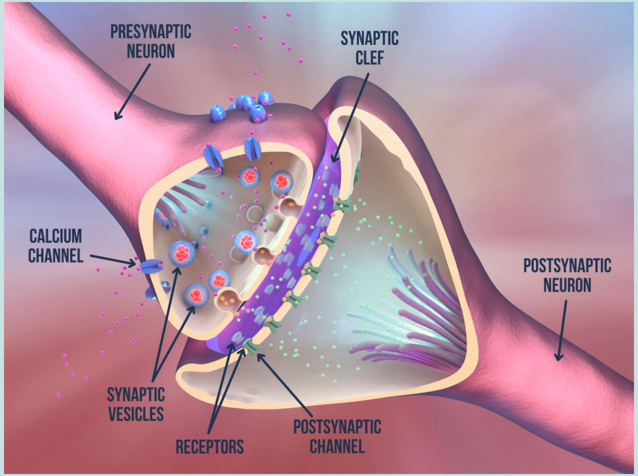
Propagation of action potential

1. The axon is insulated by “myelin” sheaths. That means there are no Na+ or K+ channels in that region.
2. There are gaps in the sheath known as “Nodes of Ranvier”.
3. The voltage is regenerated at each of these nodes exponentially increasing the speed of transmission.
4. But how and why?



Communication Between Neurons

1. Action potential arrives → triggers calcium ions to enter presynaptic neuron
2. Calcium causes vesicles to release neurotransmitters into synaptic cleft
3. Neurotransmitters bind to receptors on postsynaptic neuron
4. Receptor type determines: Excitatory or Inhibitory signal



Excitatory Synapse

1. Excitatory neurotransmitters (glutamate) released
2. Positive ions (Na^+) enter postsynaptic neuron
3. Membrane potential becomes more positive
4. Postsynaptic neuron fires action potential → signal passes forward ✓

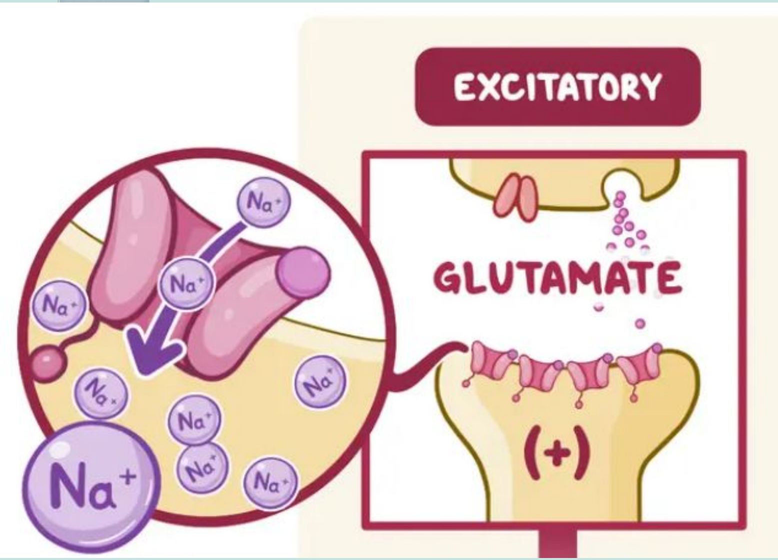
Inhibitory Synapse

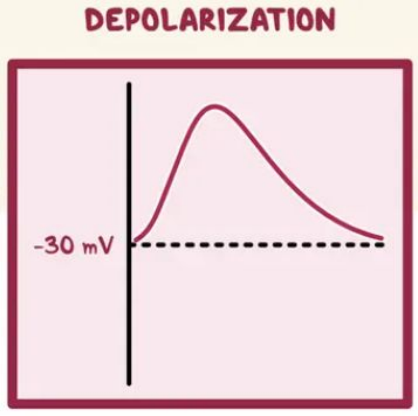
1. Inhibitory neurotransmitters (GABA, glycine) released
2. Negative ions (Cl^-) enter OR positive ions (K^+) exit postsynaptic neuron
3. Membrane potential becomes more negative
4. Postsynaptic neuron less likely to fire → signal is blocked ✗

02

Excitatory Vs Inhibitory

Types of Nerve Signals and the action that causes them

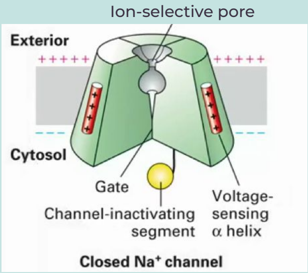

EXCITATORY
GLUTAMATE
(+)
Na+


DEPOLARIZATION
-30 mV

Propagation of <u>Excitatory</u> signal

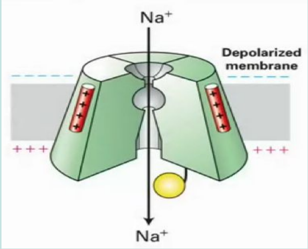
01 Excitatory Neurotransmitter Release

Excitatory neurotransmitters(Ex. Serotonin) bind to ligand-gated Na^+ channels on the postsynaptic membrane.



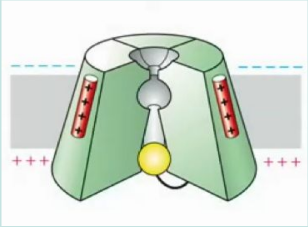
02 Opening of ion channel

Na^+ channels open, sodium rushes in, causing depolarization.



03 Action potential threshold

Membrane crosses threshold; voltage-gated Na^+ channels open and create the action potential.

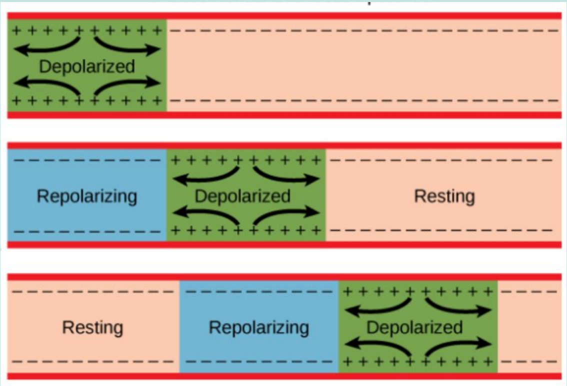


Propagation of Excitatory signal

04

Axon propagation

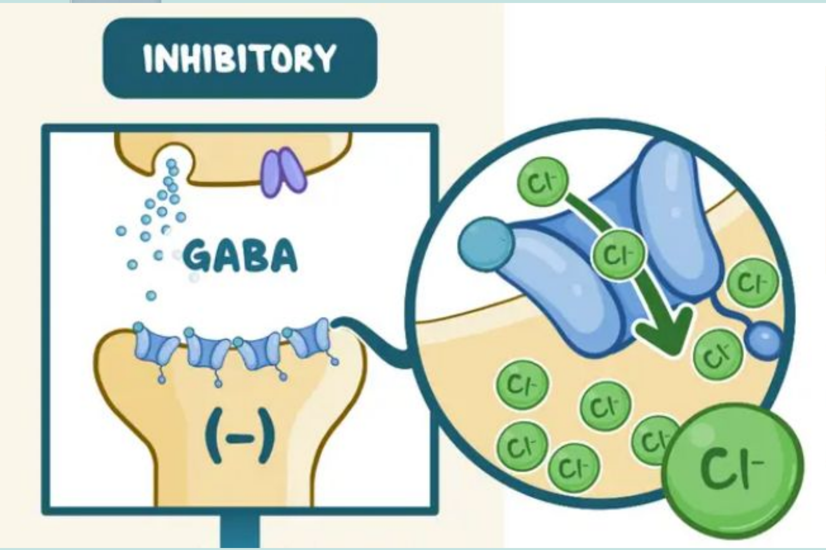
The Action Potential travels with great speed along the axon. Unidirectionality is maintained by ion channel inactivation.

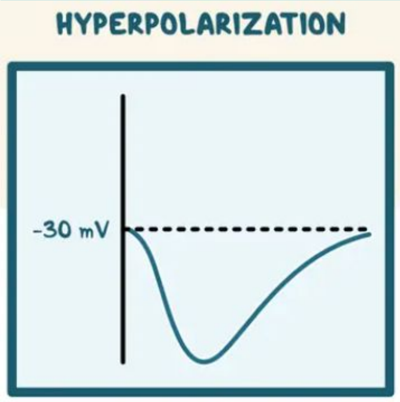


05

Repolarization

K^+ leaves the cell down its gradient, and its channel opens later than Na^+ due to a naturally slower protein structure.


INHIBITORY
GABA
(–)
Cl-

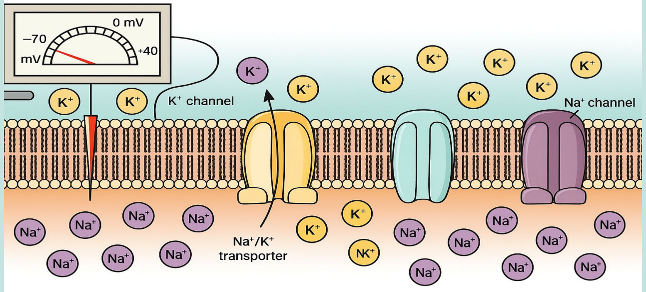

HYPERPOLARIZATION
-30 mV

Propagation of <u>Inhibitory</u> signal

01

Inhibitory Neurotransmitter Release

An inhibitory neurotransmitter(Ex. glycine) is released that activate Cl^- or K^+ channels on the postsynaptic membrane.



02

Opening of Cl^- / K^+ Channels

K+ ions are let out of the cytoplasm. Also implying the same as letting Cl- ions inside.

03

Hyperpolarization of the Membrane

Making the inside of the membrane more negative causes hyperpolarization.

Propagation of Inhibitory signal

04

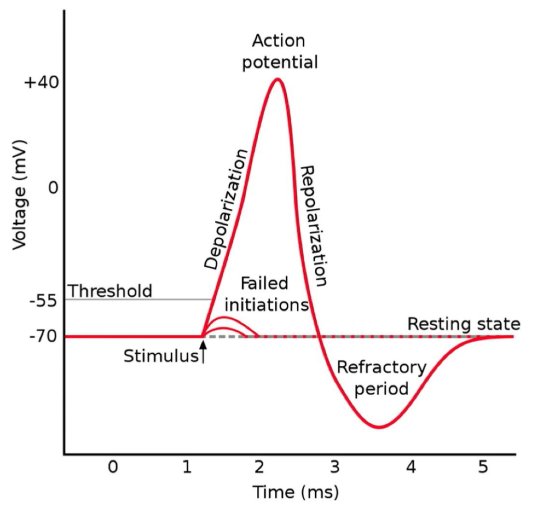
Shunting of Excitatory Inputs

Excitatory signals are counteracted upon thus reduced the chances of reaching the axon hillock and triggering action potential.

05

Refractory Recovery Phase

Restoration of resting potential; K+ and Cl- ion channels close, resting potential is re-established. Sodium-Potassium conc are reset.



Excitatory and Inhibitory signal at axon hillock

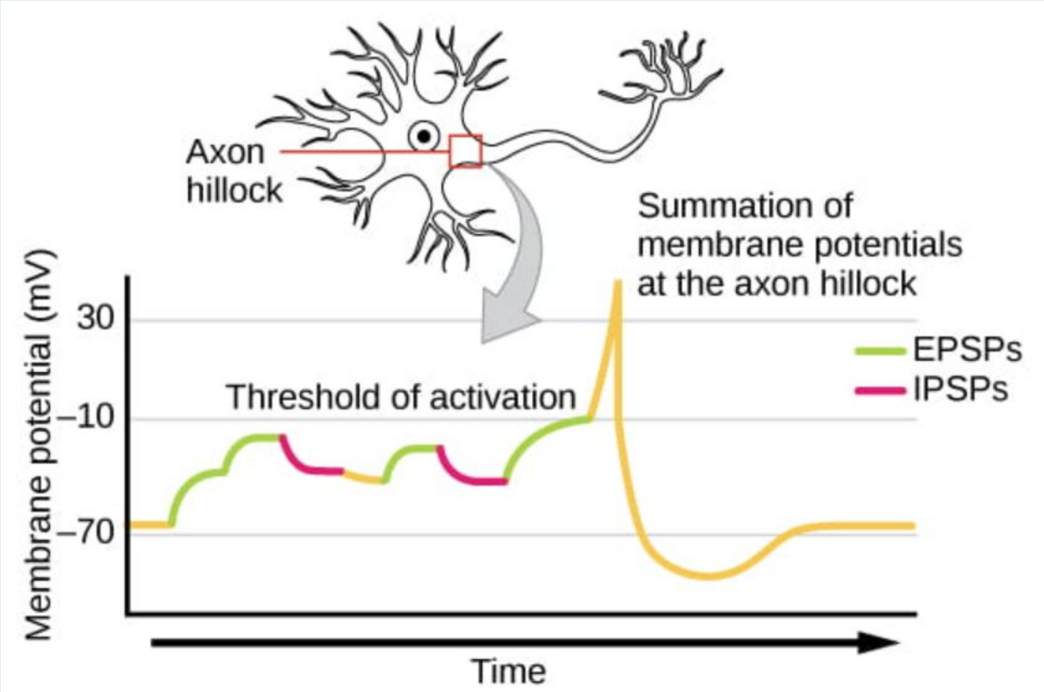


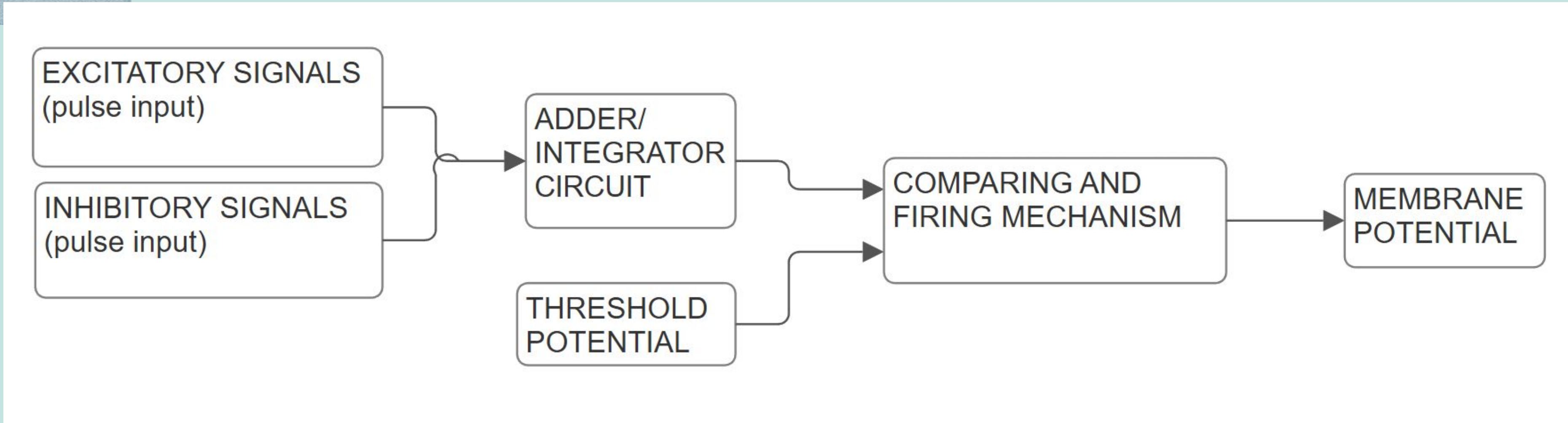
Fig. Summation of EPSPs and IPSPs at the Axon Hillock

03

Electronic Equivalents

Modelling the nerve using basic electronic components.

BLOCK DIAGRAM



PASSIVE ELEMENTS THAT CAN BE USED

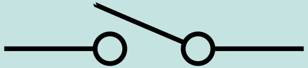
Capacitor:

- Models the cell membrane and stores charge
- Integrates excitatory and inhibitory inputs over time

Resistors:

- Control current flow and synaptic resistance
- Set the integration time constant

Switches:

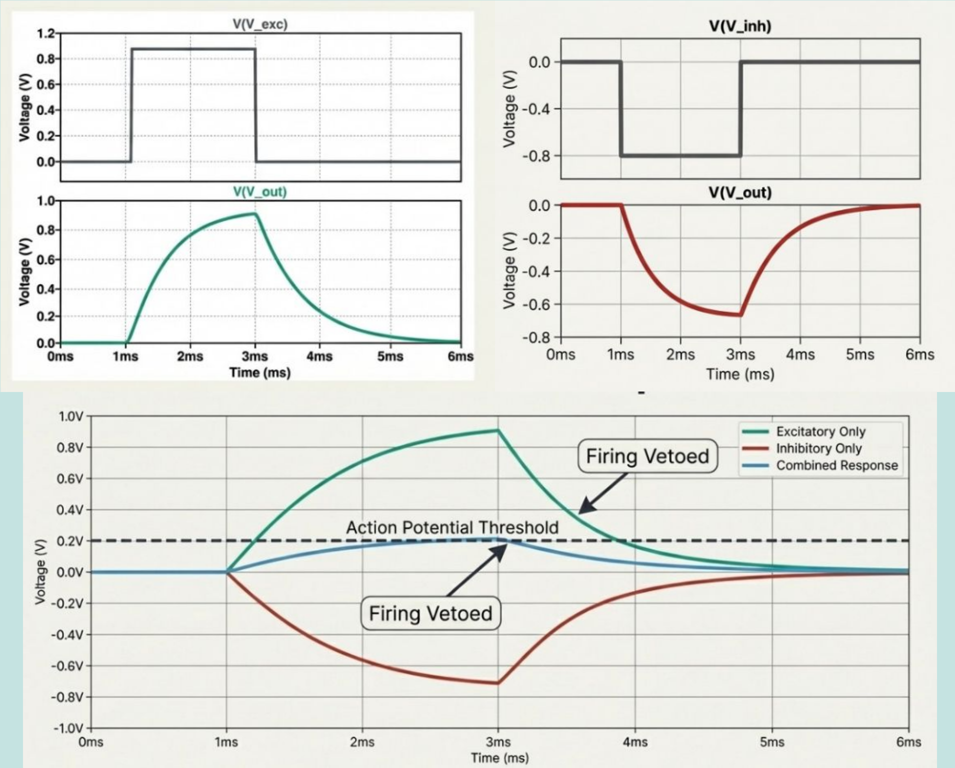


- Model synaptic ion channels opening/closing
- Enable/disable excitatory and inhibitory pathways

Voltage Sources:

- Represent presynaptic electrochemical driving forces
- Create differential excitation/inhibition on the membrane

PASSIVE ELEMENTS THAT CAN BE



Why Passive Elements Alone Cannot Generate Action Potentials

No Threshold Detection:

- Passive circuits respond proportionally to inputs; they cannot detect threshold

No Regenerative Feedback:

- Action potentials need amplification, but passive components only store/dissipate energy passively

Cannot Reset Automatically:

- Passive R-C circuits decay exponentially; they cannot actively repolarize the membrane as real neurons do

BIBLIOGRAPHIC REFERENCES

- MIT 7.016 Introductory Biology, Fall 2018
- Ion Channels and the Electrical Properties of Membranes
- Construction and Application of a Neuromorphic Circuit With Excitatory and Inhibitory Post-Synaptic Conduction Channels Implemented Using Dual-Gate Thin-Film Transistors
- Programmable Analog Pulse-firing Neural Networks
- Neural Circuits and Their Electronic Models