HUBS 191 Lecture Material

This pre-lecture material is to help you prepare for the lecture and to assist your note-taking within the lecture,
it is NOT a substitute for the lecture !

Please note that although every effort is made to ensure this pre-lecture material corresponds to the live-lecture there may be differences / additions.

HUBS 191

Jeff Erickson – Department of Physiology

Lecture 18
Neurophysiology 1: Action Potentials

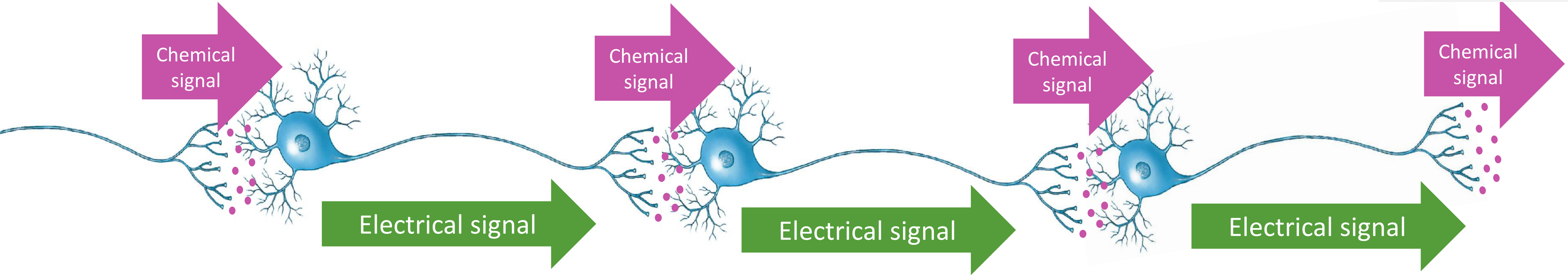
Objectives and Study Guide

After this lecture you should be able to:

- Describe three types of gated ion channels associated with neurons
- Define a local potential
- Describe (<u>not calculate</u>) how summation occurs at the axon hillock
- Describe the five steps that comprise an action potential

Related reading: Martini et al. Modules **9.5** (p. 365), **11.6-11.11** (p. 455-465), and **11.13** (p. 468-469)

Neurons communicate with each other using chemical signals

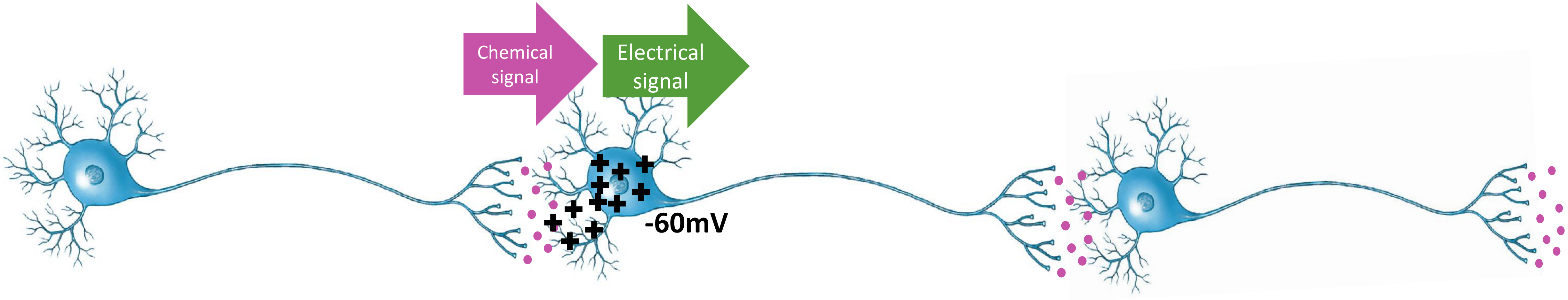


Every neuron to neuron synapse has:

- a **pre-synaptic** neuron that releases neurotransmitter
- a **post-synaptic** neuron that senses neurotransmitters and reacts by opening ion channels

Note: Neurons can be both pre-synaptic and post-synaptic at the same time!

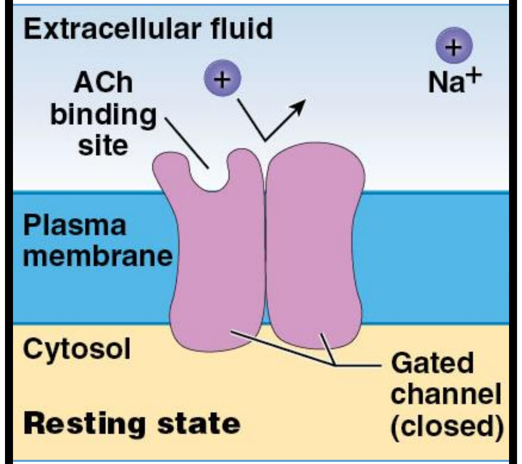
How does a chemical signal get converted into an electrical signal?



- A chemical signal (neurotransmitter) binds to and opens chemically-gated ion channels
- Ions flow in or out, changing the voltage at a localized area of membrane
- If the membrane voltage reaches -60mV at the axon hillock…
- …an electrical signal (action potential) begins

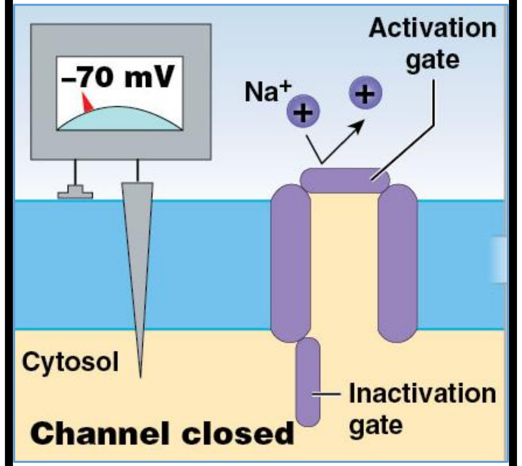
Gated ion channels are opened by a stimulus

Chemically-gated ion channel



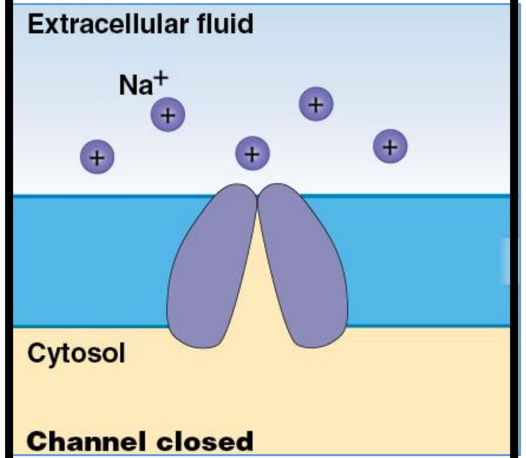
Stimulus: a chemical
(e.g. neurotransmitter)

Voltage-gated ion channel



Stimulus: a voltage
(e.g. -60mV)

Mechanically-gated ion channel

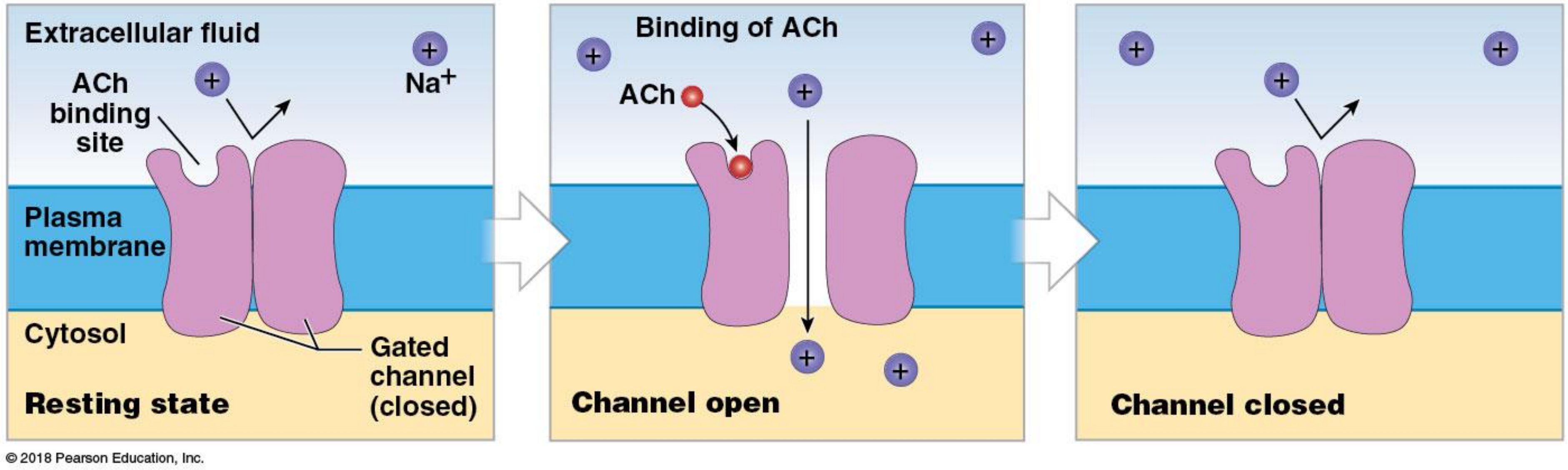


Stimulus: membrane deformation
(e.g. stretch)

- Think of the stimulus as the ‘key’ that opens a channel
- Think of the channel as a ‘door’
- Think of the ‘ions’ as the people that walk through the door if it opens

Martini - Visual Anatomy and Physiology (2018) Module 11.8 p. 458-9.

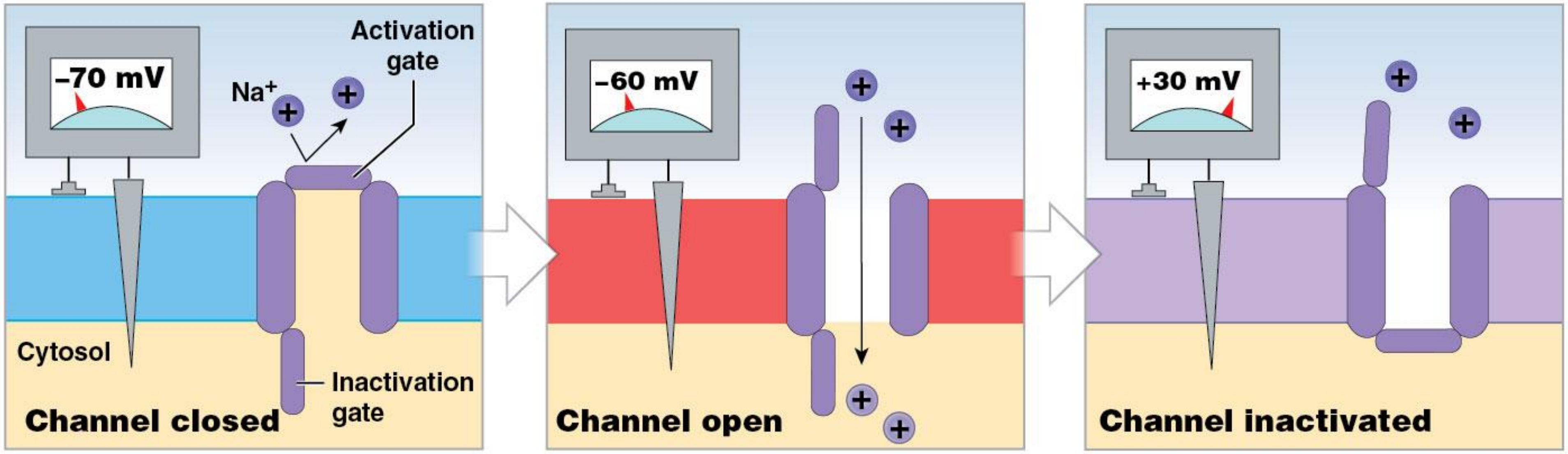
Chemically-gated ion channels are opened by a chemical stimulus



1. **Stimulus = chemical neurotransmitter** binds to ion channel
2. Channel changes shape (i.e opens)
3. Ions cross the membrane driven by their electrochemical gradient
4. **The neurotransmitter unbinds,** causing the channel to close

Martini - Visual Anatomy and Physiology (2018) Module 11.8 p. 458.

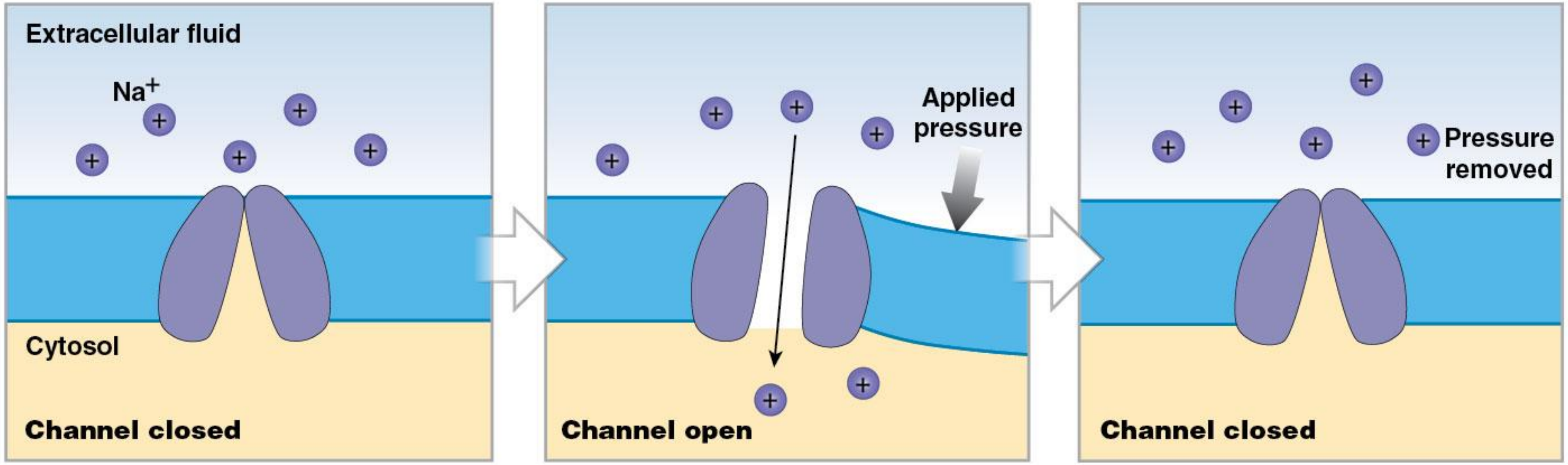
Voltage-gated ion channels open when they sense a (sufficiently large) change in voltage



1. **Stimulus = membrane depolarizes to threshold voltage (e.g. -60mV)**
2. Channel changes shape (i.e opens)
3. Ions cross the membrane driven by their electrochemical gradient
4. **Membrane potential changes** will cause the channel to inactivate or close

Martini - Visual Anatomy and Physiology (2018) Module 11.8 p. 458.

Mechanically-gated ion channels are opened by stretching or deformation of the membrane

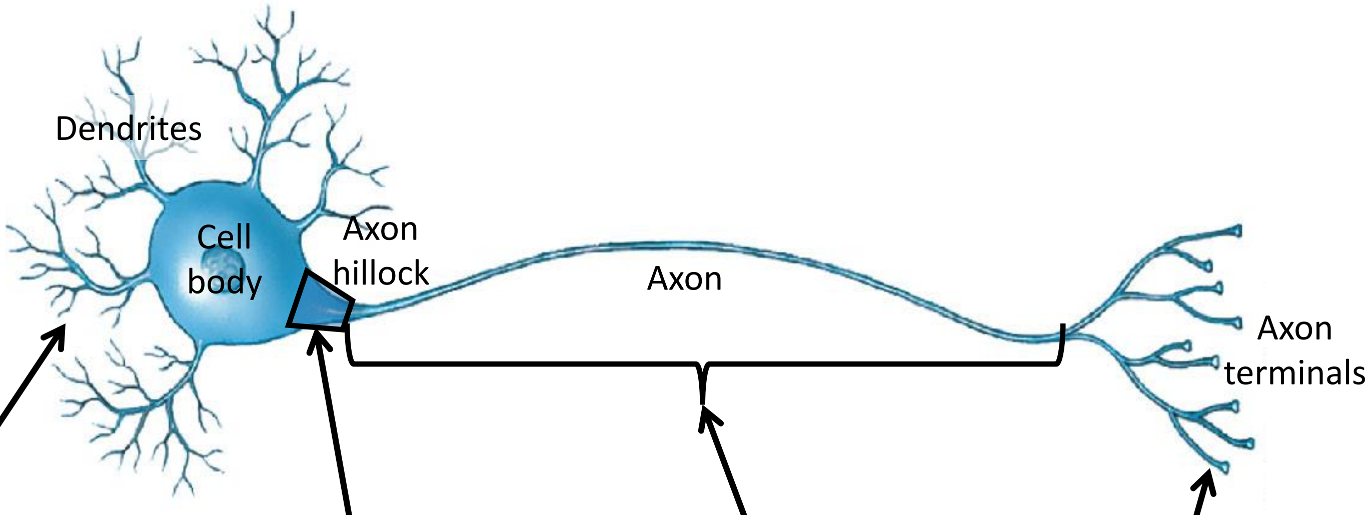


1. **Stimulus = deformation of the membrane** (e.g. stretch or squish)
2. Channel changes shape (i.e opens)
3. Ions cross the membrane driven by their electrochemical gradient
4. **When the membrane returns to original shape the channel closes**

Martini - Visual Anatomy and Physiology (2018) Module 11.8 p. 459.

Where are the various types of gated ion channels on a neuron?

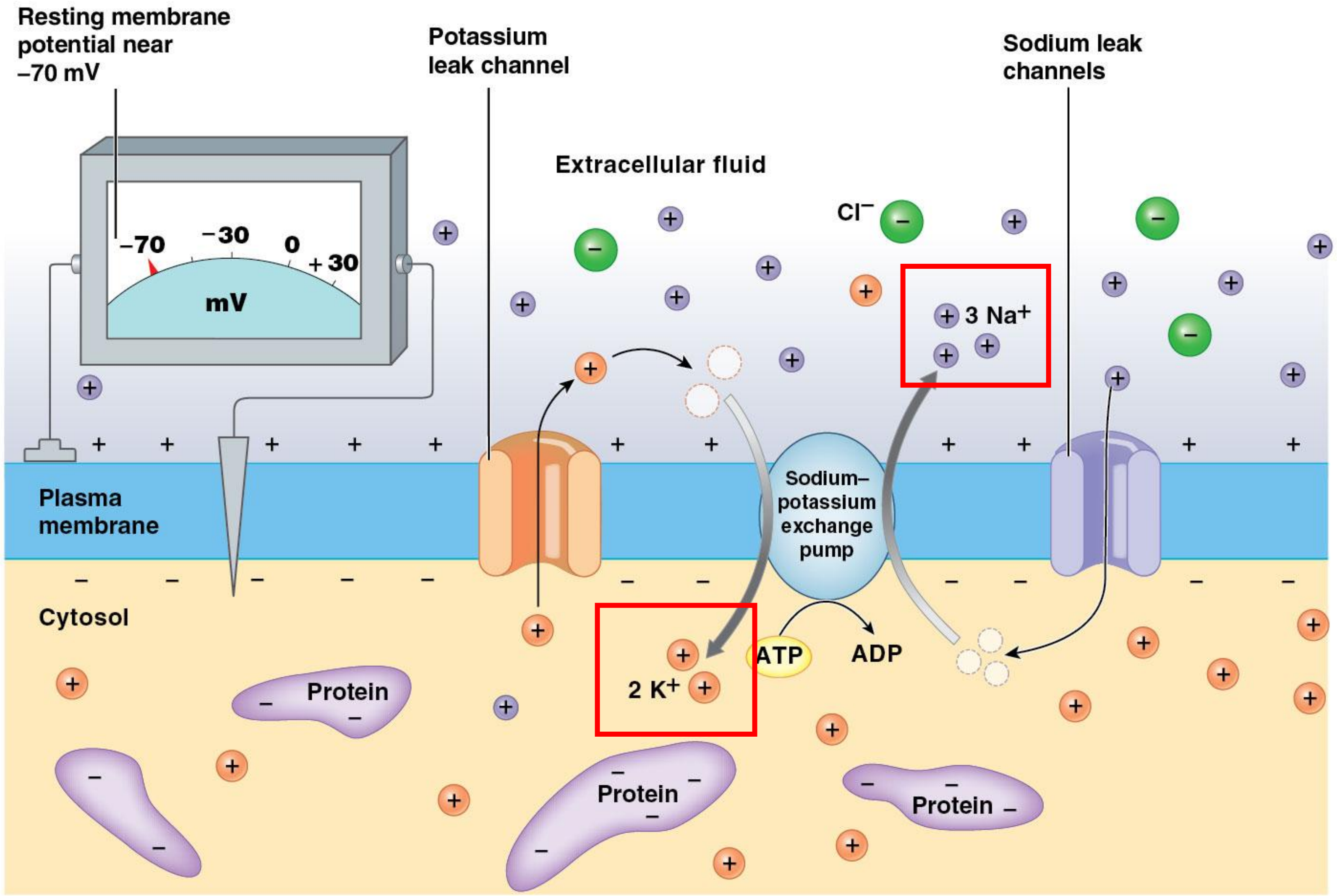
Na^+ = Sodium
K^+ = Potassium
Cl^- = Chloride
Ca^{2+} = Calcium



Dendrites & Cell body	Axon hillock	Axon	Axon terminals
Chemically-gated Na^+ and Cl^- (& others) channels	Voltage-gated Na^+ and K^+ channels	Voltage-gated Na^+ and K^+ channels	Voltage-gated Ca^{2+} channels

Note:
Mechanically-gated ion channels are found on dendrites of some sensory neurons. More detail in Lec 23.

At rest, the intracellular space has more negative charge than the extracellular space, creating an "electrical gradient":
Resting Membrane Potential

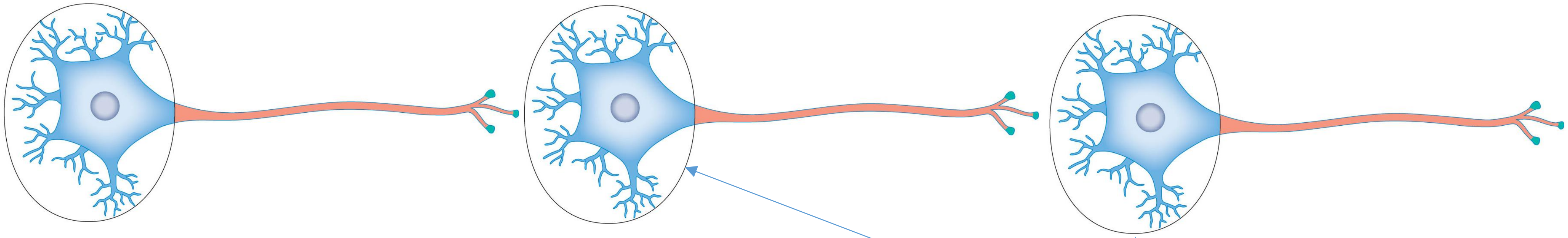


High Na^+
Low K^+

High K^+
Low Na^+

Martini - Visual Anatomy and Physiology (2018) Module 11.7 p. 457.

Local potentials are a change in voltage (charge) in a specific area of the cell



What is a local potential?

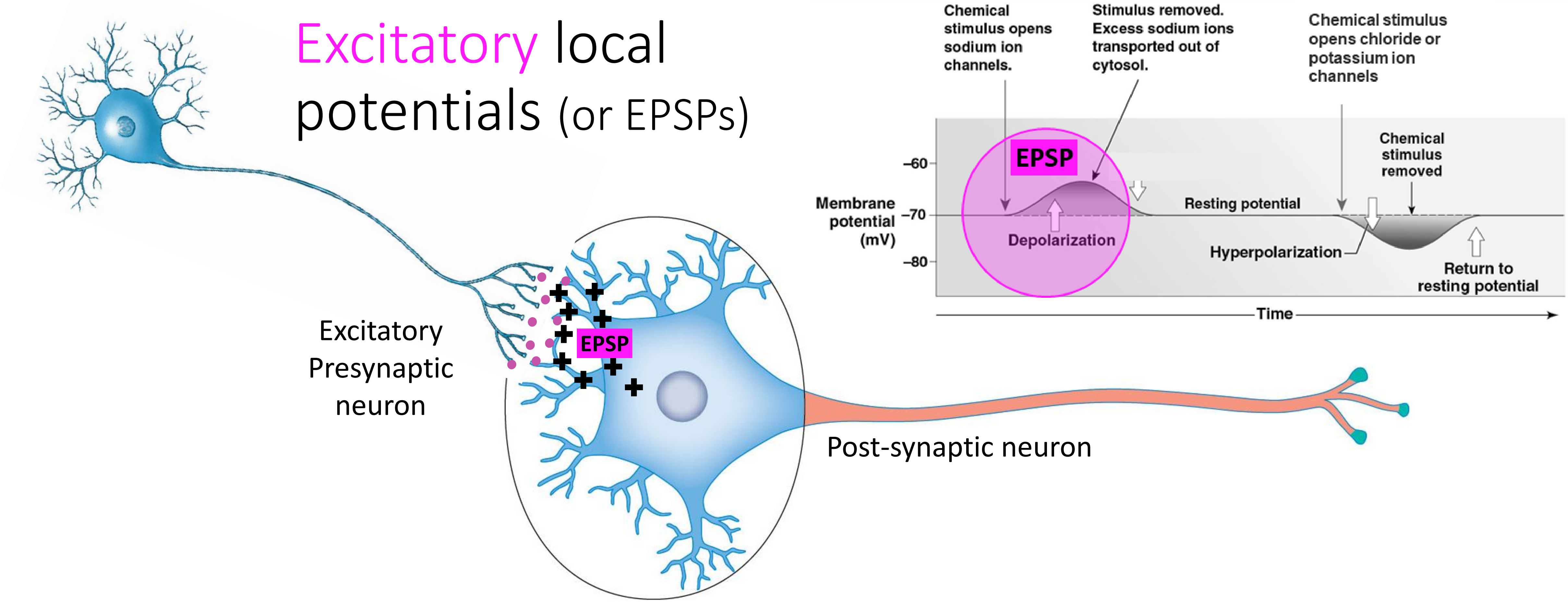
- An excitatory or inhibitory change in voltage…
- …in a small location (localised area) somewhere on the dendritic/cell body membrane…
- …of a post-synaptic cell

(Note: it depends on which synapse you're looking at to determine if a cell is pre- or post-synaptic)

Local potentials **can also be called:**

- Post-synaptic potentials (PSP)
  - Because they occur on the membrane of the post-synaptic cell
- Graded potentials
  - Because they vary in size depending on how many ions enter/exit

Excitatory local potentials (or EPSPs)

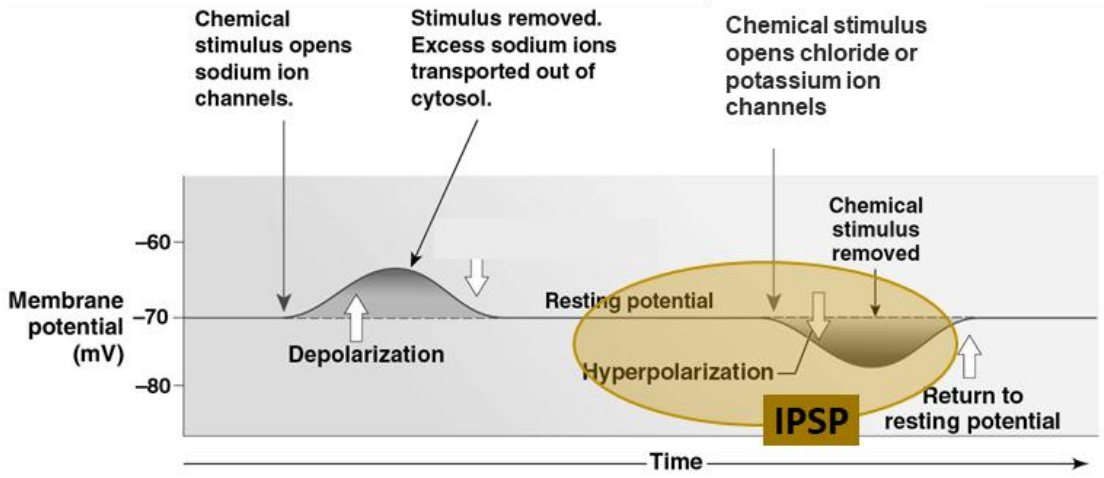


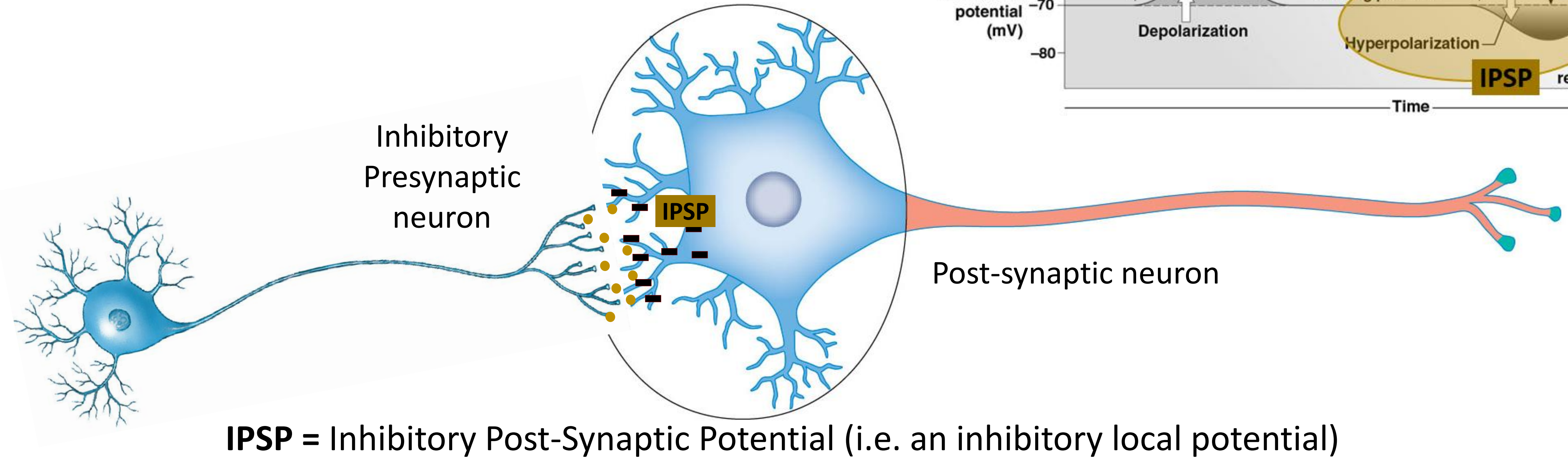
EPSP = Excitatory Post-Synaptic Potential (i.e. an excitatory local potential)

How do EPSPs form?

- A presynaptic neuron releases excitatory neurotransmitter (example: acetylcholine - ACh)
- When neurotransmitter binds, it opens chemically-gated Na^+ channels
- Na^+ enters post-synaptic cell, causing depolarization (membrane becomes more positive/+)

Inhibitory local potentials (or IPSPs)



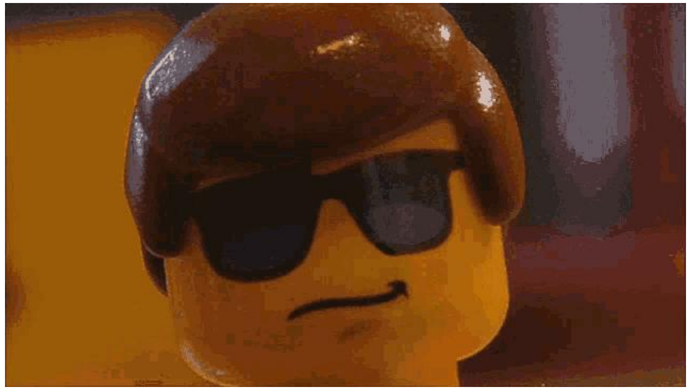


IPSP = Inhibitory Post-Synaptic Potential (i.e. an inhibitory local potential)

How do IPSPs form?

- A presynaptic neuron releases inhibitory neurotransmitter (example: GABA)
- When neurotransmitter binds, it opens chemically-gated K^+ or Cl^- channels
- K^+ exits or Cl^- enters post-synaptic cell, causing hyperpolarization (membrane becomes more negative/-)

Did you catch it?



Warner Bros. Pictures

- What is a local potential? At what part of a neuron does it occur?

- What are excitatory local potentials? What are inhibitory local potentials? Are they associated with depolarization or hyperpolarization events, and what does this mean for the charge at that area of the neuron?

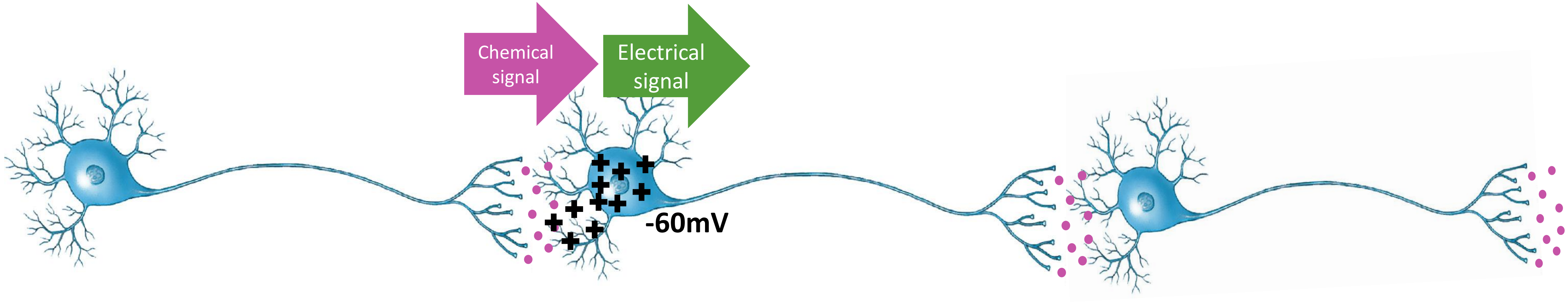
- What ion channels are associated with excitatory and inhibitory local potentials, and which way are the ions moving?

Example exam question

Chemically-gated channels in neurons are:

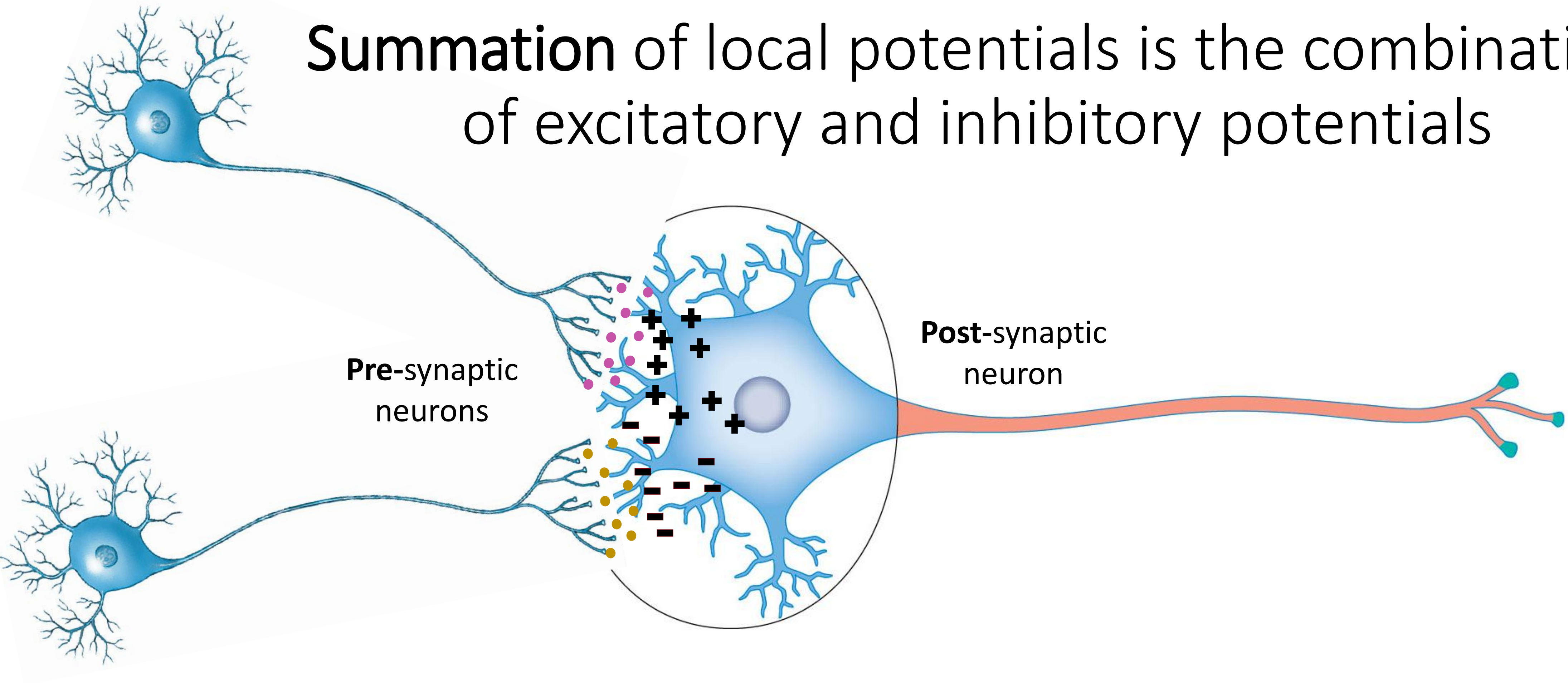
A. very sensitive to membrane deformation.
B. highly concentrated in the axon.
C. typically opened when neurotransmitters bind.
D. constantly open.

How does a chemical signal get converted into an electrical signal?



- ✔ A chemical signal (neurotransmitter) binds to and opens chemically-gated ion channels
- ✔ Ions flow in or out, changing the voltage at a localized area of membrane
- If the membrane voltage reaches -60mV at the axon hillock…
- …an electrical signal (action potential) begins

Summation of local potentials is the combination of excitatory and inhibitory potentials



Local potentials are summed in two ways:

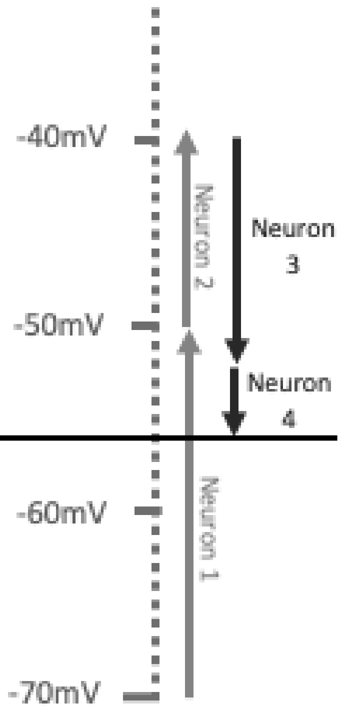
- **Spatial summation** – summed input from multiple pre-synaptic neurons
- **Temporal summation** – summed input from repeated firing of one pre-synaptic neuron

Note: usually both are occurring simultaneously in a complex neural network

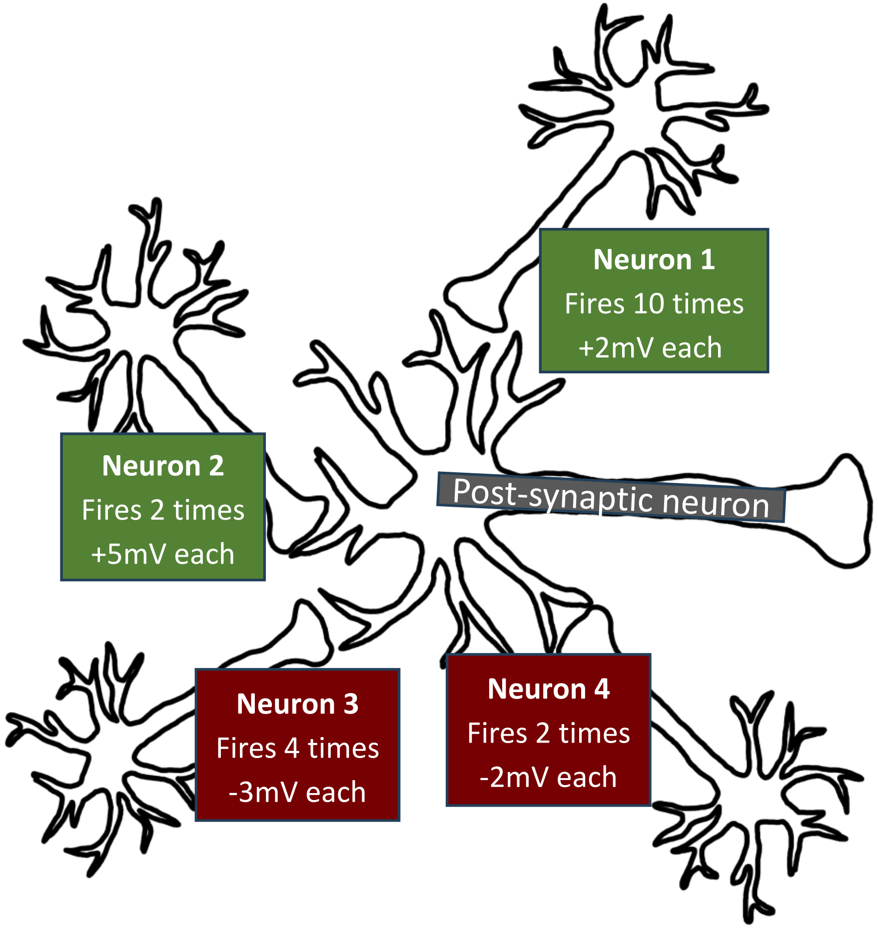
Example of summation in a post-synaptic neuron

Neuron 1	10 x +2mV =	**+20mV**
Neuron 2	2 x +5mV =	**+10mV**
Neuron 3	4 x -3mV =	**- 12mV**
Neuron 4	2 x -2mV =	**- 4mV**
Total		**+14mV**

Example: summed inputs depolarize post-synaptic membrane to **-56mV**

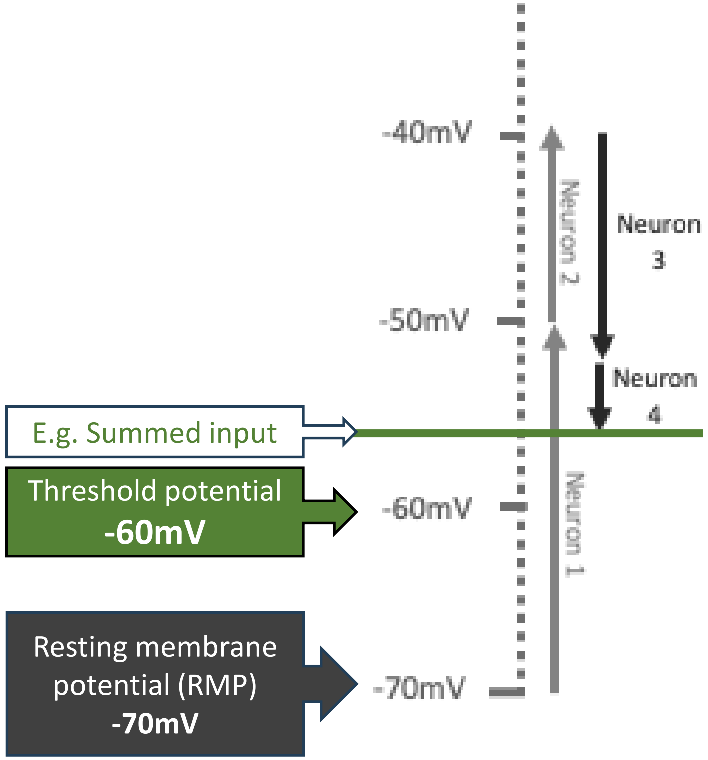


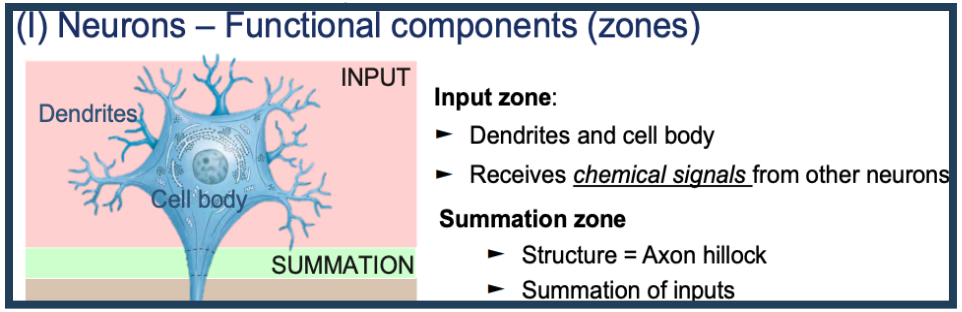
Resting membrane potential (RMP) of post-synaptic neuron

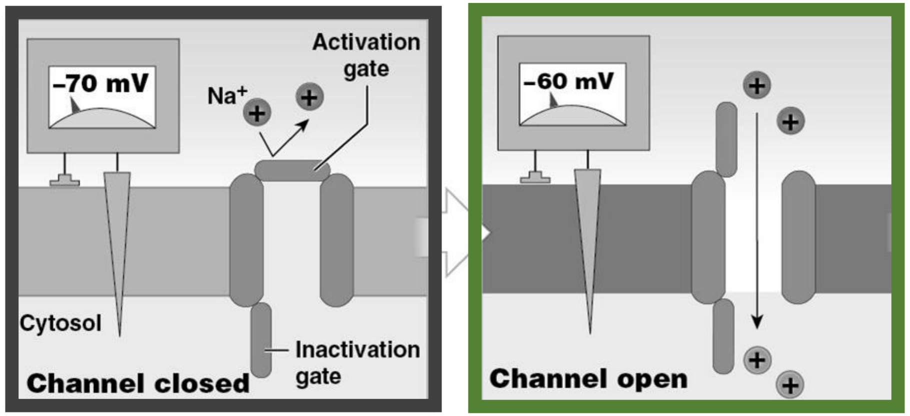


Note: you don't need to <u>calculate</u> this in HUBS191!

Summation at the axon hillock can lead to an action potential



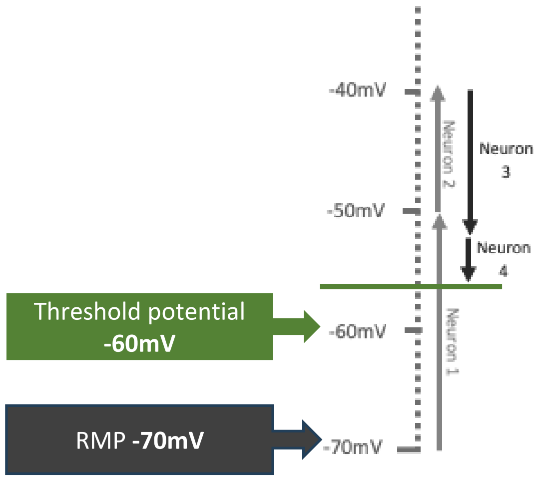




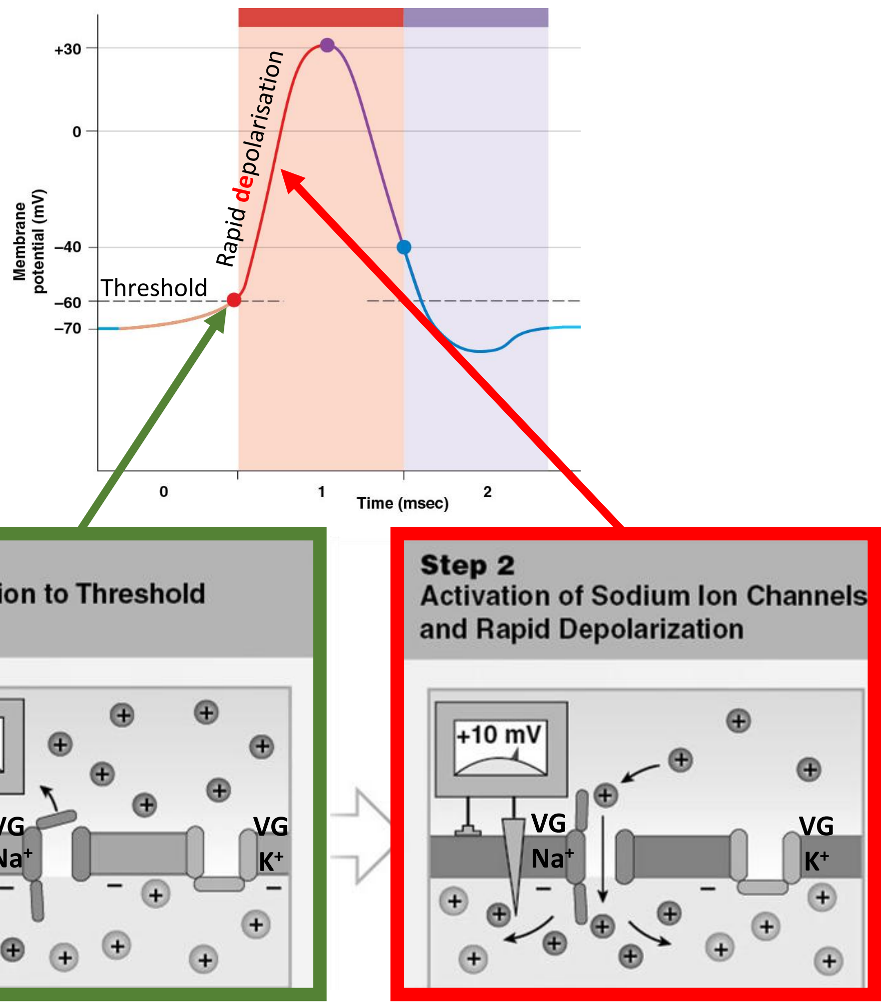
Why are pre-synaptic inputs summed at the axon hillock?

- The axon hillock has a high density of voltage-gated channels
- Threshold potential (**-60mV**) is the key that opens voltage-gated channels
- Thus, if summation occurs, to or above -60mV, voltage-gated Na^+ channels open at the axon hillock (recall -56mV example from last slide)

Action potential - steps 1 & 2



Changes in membrane potential during an action potential



Step 1 – Voltage-gated (VG) Na^+ channels open when membrane depolarizes to -60mV

Step 2 – Massive influx of Na^+ causes '**rapid depolarization phase**' of the action potential

Martini - Visual Anatomy and Physiology (2018) Module 11.10 p. 462-3.

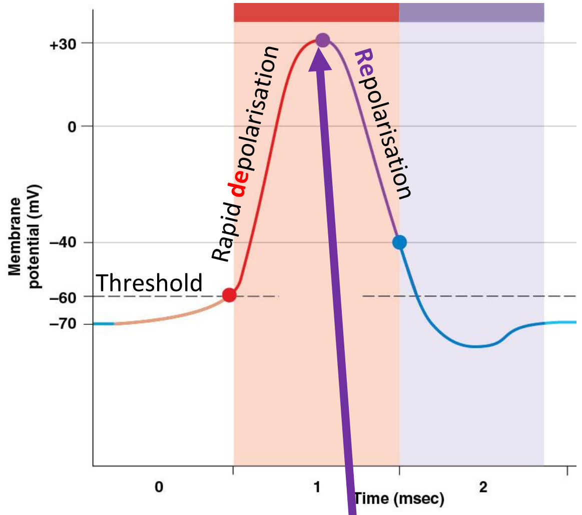
Action potential - step 3

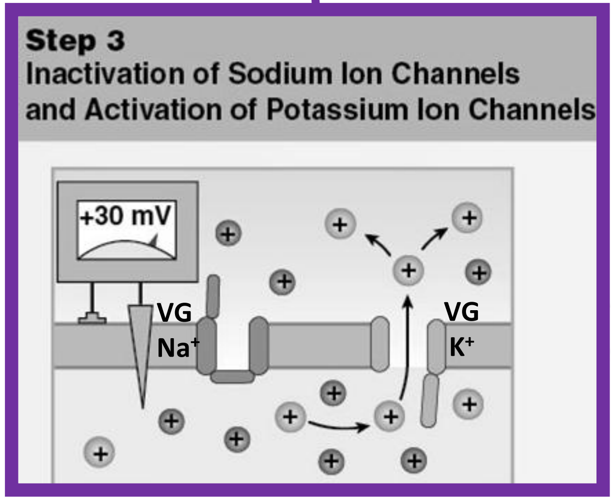
Step 3 – Roughly +30mV

- VG Na^+ channels inactivate (get blocked) - Na^+ entry stops
- VG K^+ channels open - K^+ exits
- K^+ exiting causes the '**repolarization phase**' of the action potential

Note: VG K^+ channels are triggered to open at -60mV but open more slowly than VG Na^+ channels.

Changes in membrane potential during an action potential





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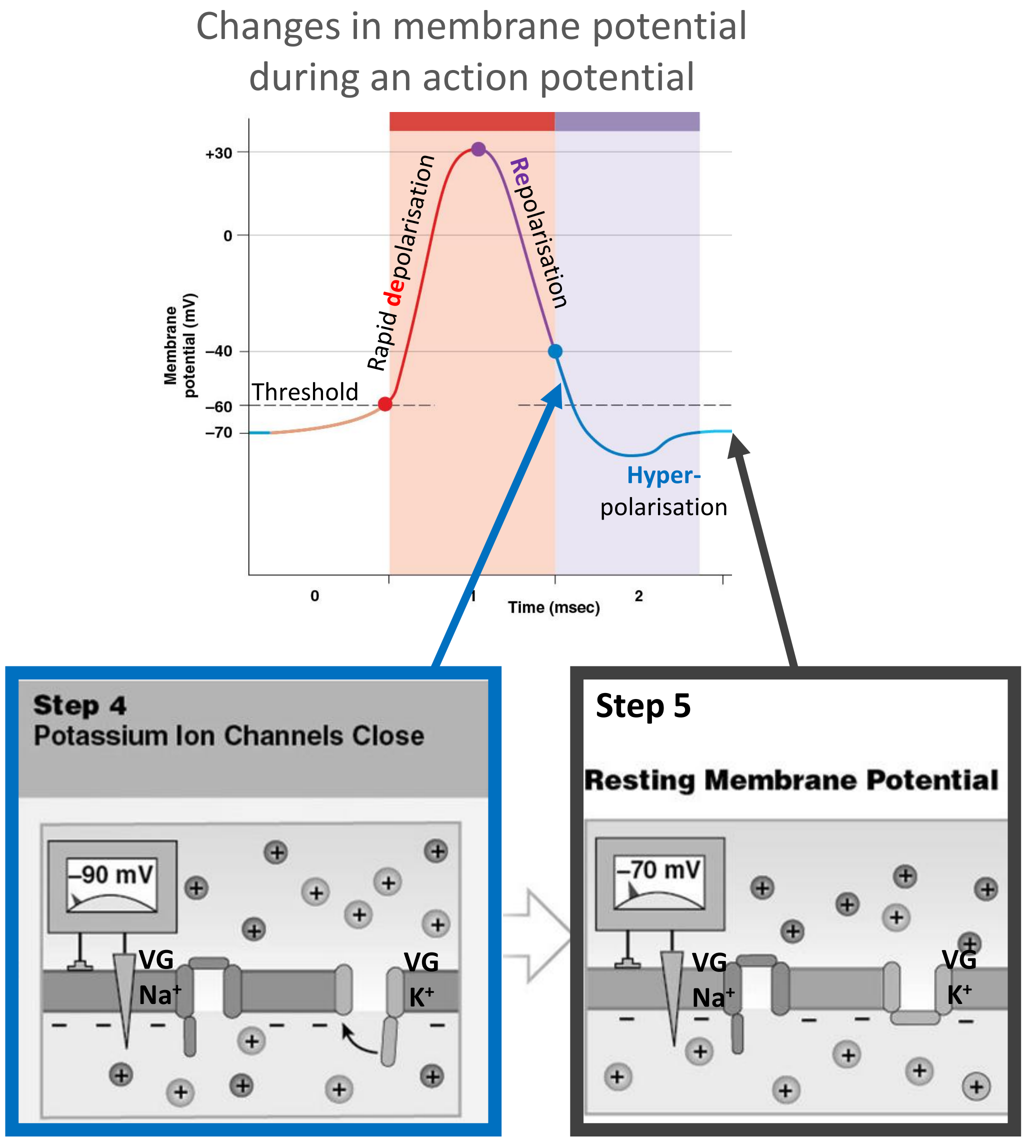
Action potential - steps 4 & 5

Step 4 – VG K^+ channels begin to close, but close slowly

- This permits excess K^+ to exit, causing the '**hyperpolarisation phase**' of the action potential
- Membrane potential goes as low as about -90mV

Step 5 – All VG K^+ channels close, the membrane returns to -70mV



Martini - Visual Anatomy and Physiology (2018) Module 11.10 p. 462-3.

Did you catch it?

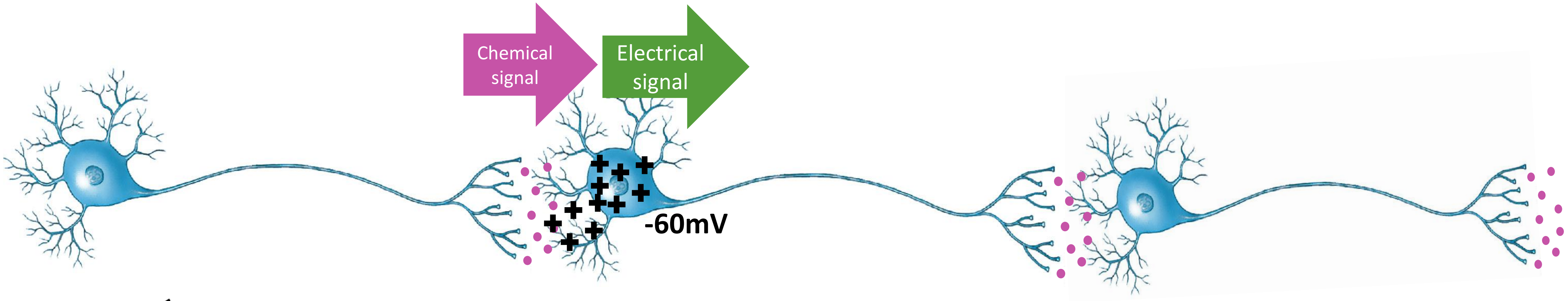
GifsRC.blogspot.com

- What are the five steps that make up an action potential? What approximate voltage is associated with each step?

- What is the open/closed status of the Na^+ and K^+ channels during each step of the action potential?

- If I pointed to an area on the action potential, could you describe what's happening?

How does a chemical signal get converted into an electrical signal?



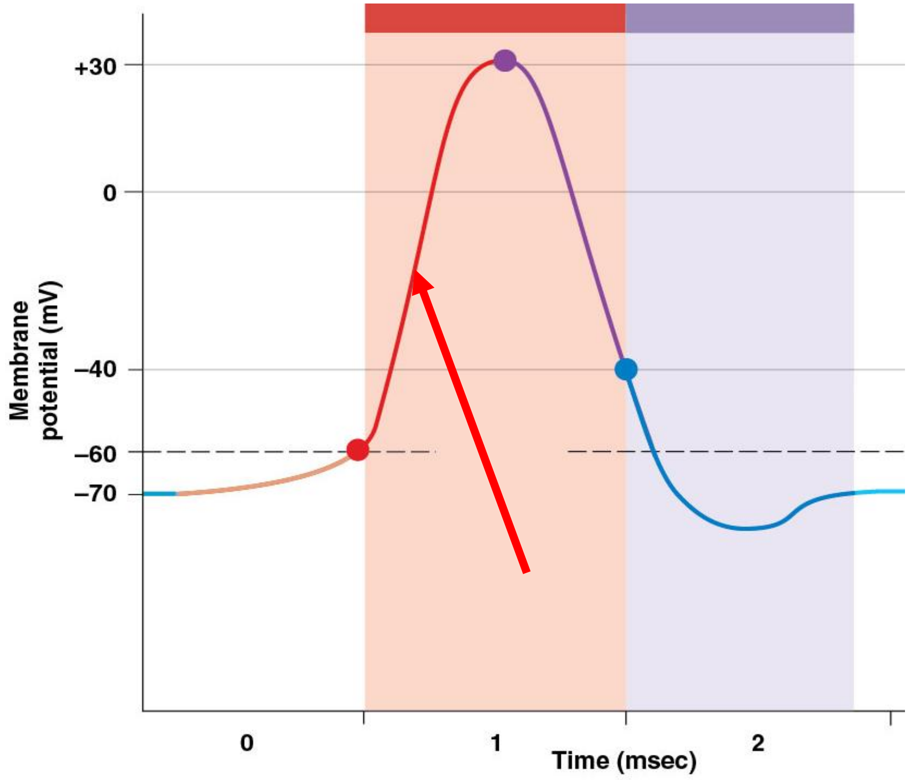
- ✓ A chemical signal (neurotransmitter) binds to and opens chemically-gated ion channels.
  - Can be inhibitory or excitatory
- ✓ Ions flow in or out, changing the voltage at a localized area of membrane.
  - Adding these ion movements together is called summation
- ✓ If the membrane voltage reaches -60mV at the axon hillock…
  - The axon hillock contains lots of voltage-gated Na^+ channels
- ✓ …an electrical signal (action potential) begins.
  - Coordinated movement of ions leads to depolarization, repolarization, and hyperpolarization

Example exam question

At the point indicated by the red arrow:

A. the neuron is hyperpolarizing.
B. voltage-gated Na^+ channels have opened.
C. the neuron is waiting for sufficient summation at the axon hillock.
D. the rapid repolarization phase has begun.

Changes in membrane potential during an action potential



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