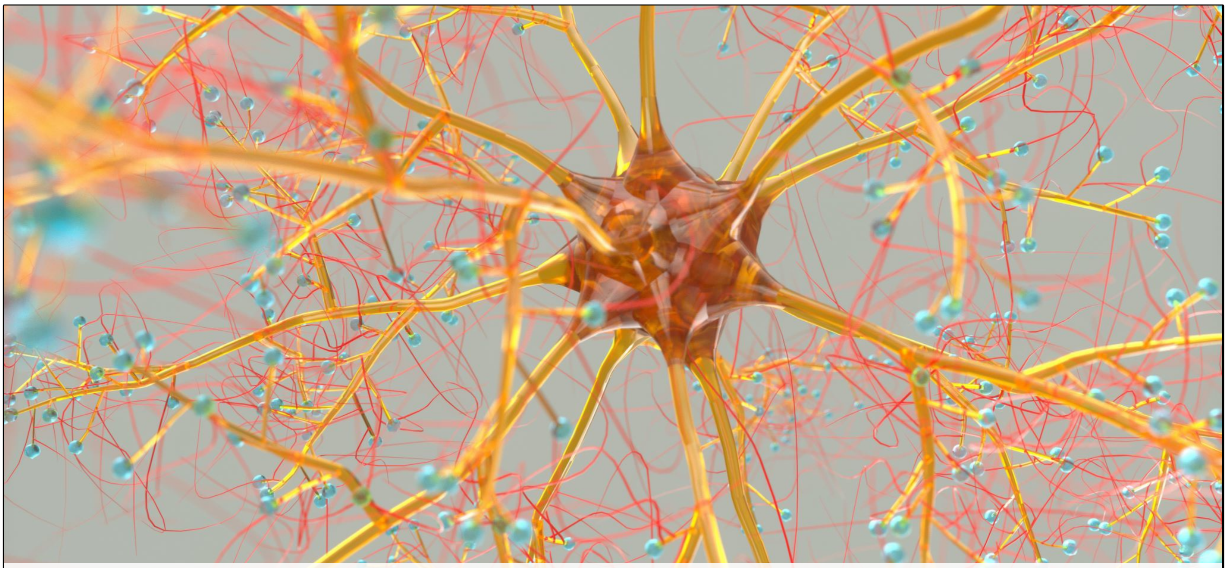
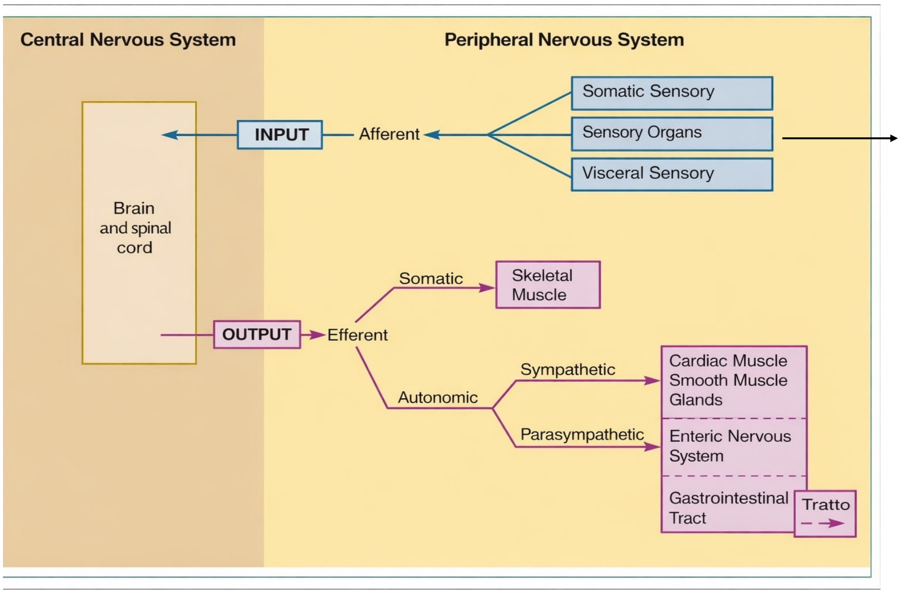
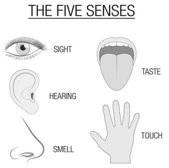


Nervous System

Division of the Nervous System





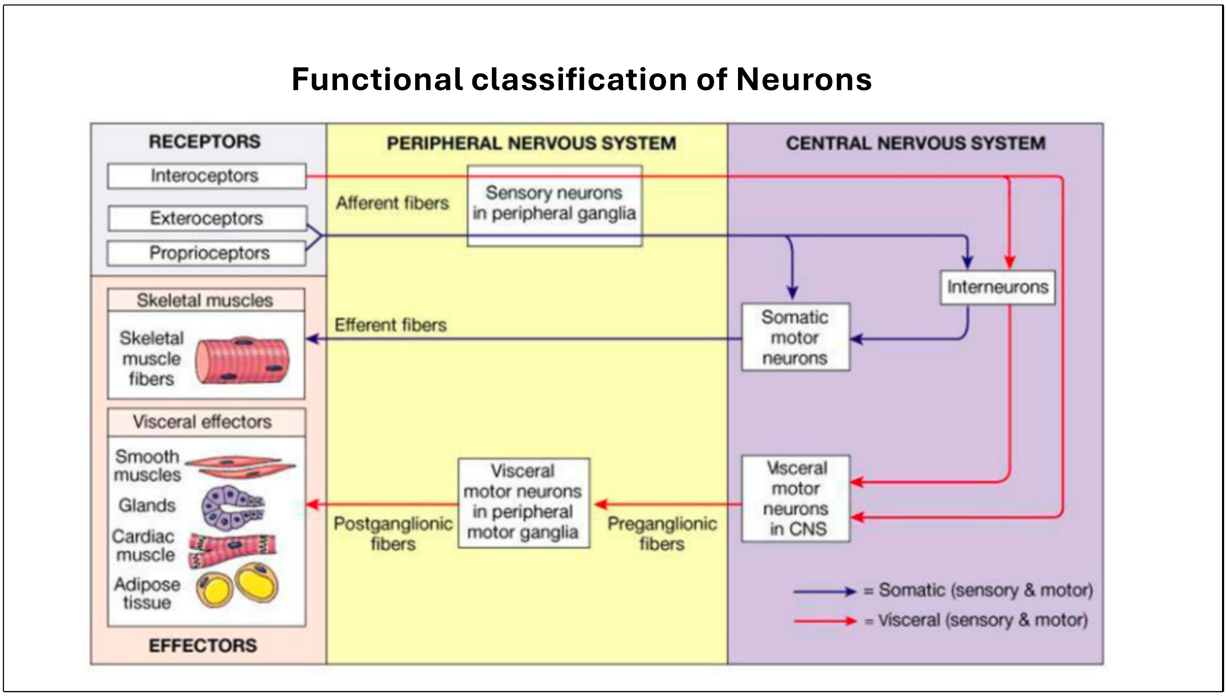
This image summarizes the functional organization of the nervous system.

Sensory information, called **afferent input**, comes from receptors and travels to the central nervous system, where it is processed.
Then, the central nervous system sends back a response through efferent pathways.
The afferent pathway carries information from sensory receptors, such as the skin, muscles, internal organs, and sense organs.
It includes signals like touch, temperature, pain, body position, and special senses like vision and hearing.

In the central nervous system, this information is integrated and transformed into a response.

The **efferent pathway** carries motor commands to the effectors.

There are two types of effectors:
Skeletal muscle, controlled by the somatic nervous system (voluntary control)
Smooth muscle, cardiac muscle, and glands, controlled by the autonomic nervous system (involuntary control), which includes the sympathetic and parasympathetic divisions.



Functional classification of Neurons

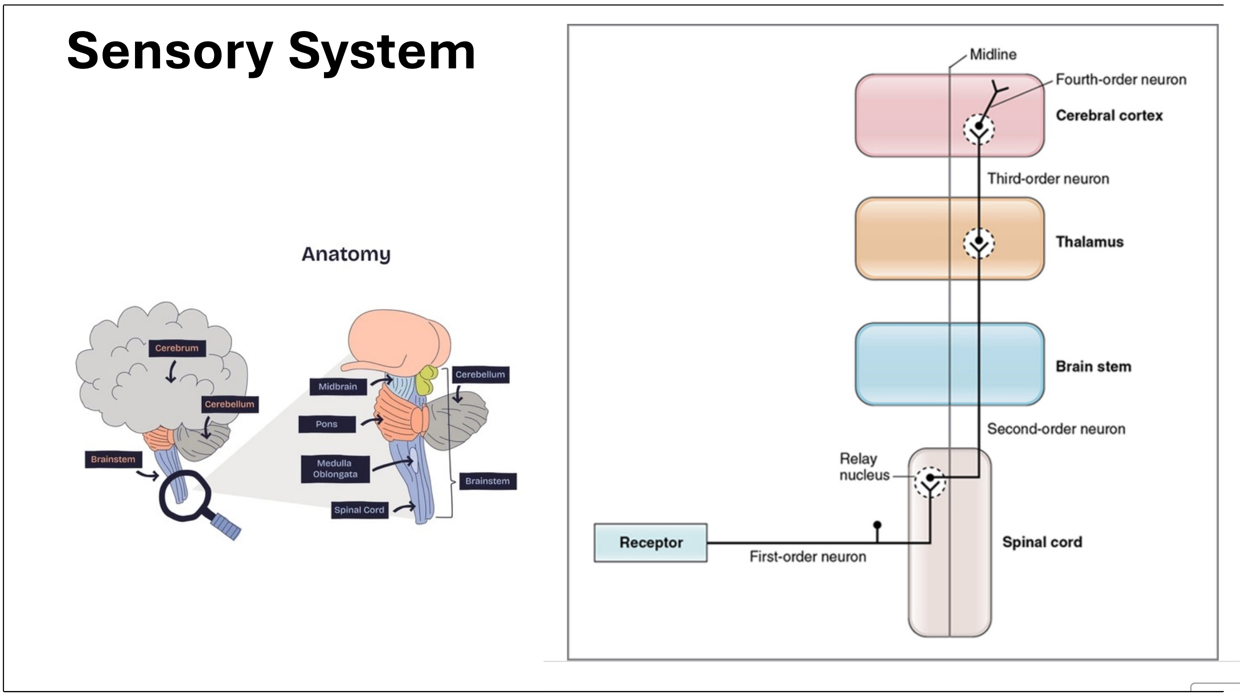
Let’s look in a bit more detail at how neurons are organized in the nervous system and how the peripheral and central nervous systems are connected.

On the left, we see the receptors. Information starts from these receptors and travels through afferent fibers, which are sensory neurons that carry the signal to the central nervous system.
In the central nervous system, the information is processed by interneurons.
Then a response is generated and travels through efferent fibers, which are motor neurons.

At this point, we can distinguish two pathways:
Somatic pathway (in blue)
controls skeletal muscles
responsible for voluntary movement

Visceral or autonomic pathway (in red)
controls smooth muscle, cardiac muscle, glands, and adipose tissue
regulates involuntary functions

In the autonomic pathway, the signal passes through two neurons:
a preganglionic neuron
a postganglionic neuron.

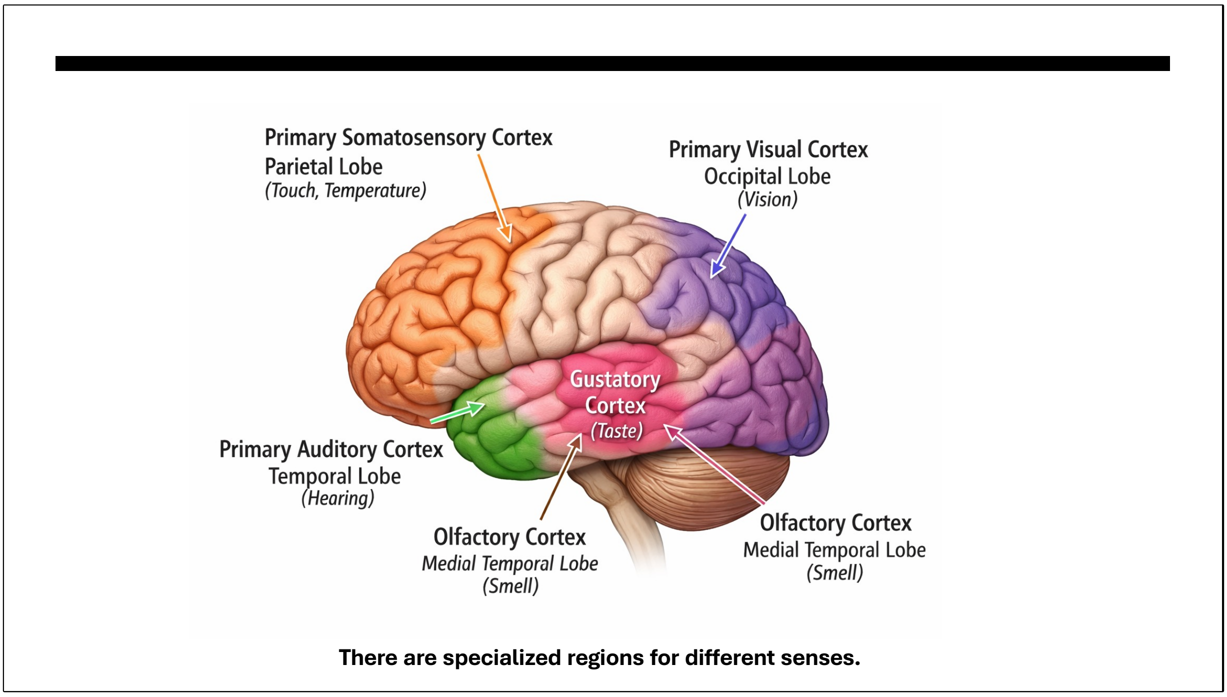


Sensory System

Sensory systems collect information from the environment through specialized receptors located in the body's periphery. These receptors convert physical or chemical stimuli into electrical signals through a process called **sensory transduction**, which involves changes in the membrane potential (receptor potential).

The information is then transmitted to the central nervous system through a chain of afferent neurons organized in a hierarchical order:

First-order neurons: receive input from the receptors
Second-order neurons: located in the spinal cord or brainstem
Third-order neurons: located in the thalamus
Fourth-order neurons: located in the sensory cortex



There are specialized regions for different senses.

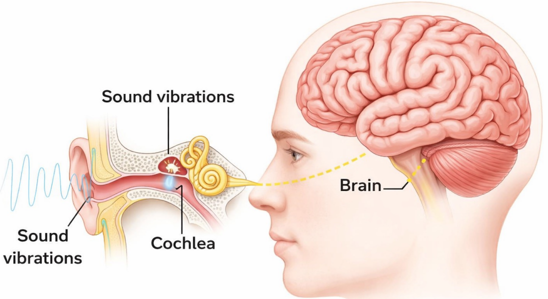
Along this pathway, the information is modified, integrated, and filtered through synapses and interneurons.

Final processing occurs in the cortical sensory areas, where the stimulus is consciously perceived.

Sensory Receptors

Structures specialized to respond to stimuli activating an electrical signal in a sensory neuron:

- Activation of sensory receptors results in depolarizations that trigger impulses to the CNS
- The realization of these stimuli, sensation and perception, occur in the brain



For example, the cochlea in the ear responds to **sound vibrations** and sends signals to the brain through a **cranial nerve.** The brain processes these signals, allowing us to hear.

A sensory receptor is a structure that responds to a specific stimulus and activates an electrical signal (action potential) in a sensory neuron.

For example, the cochlea in the ear responds to sound vibrations and sends signals to the brain through a cranial nerve. The brain processes these signals, allowing us to hear.
Sensory receptors are specialized to detect stimuli. When activated, they generate signals that travel to the central nervous system.

The final processing of these signals (sensation and perception) occurs in the brain.

Classification of Receptors

Three criteria used to describe receptors:

1. **receptor distribution**
2. **modality of stimulus**
3. **stimulus origin**

Receptors can be classified according to different features

DISTRIBUTION

General sense receptors are distributed throughout the skin and organs:
Somatic receptors – skin, muscles, tendons
Visceral receptors – internal organs

Special sense receptors are housed within complex organs in the head:
taste, smell, hearing, balance, vision

MODALITY OF STIMULUS

Mechanoreceptors – respond to touch, pressure, vibration, stretch, and itch

Thermoreceptors – sensitive to changes in temperature

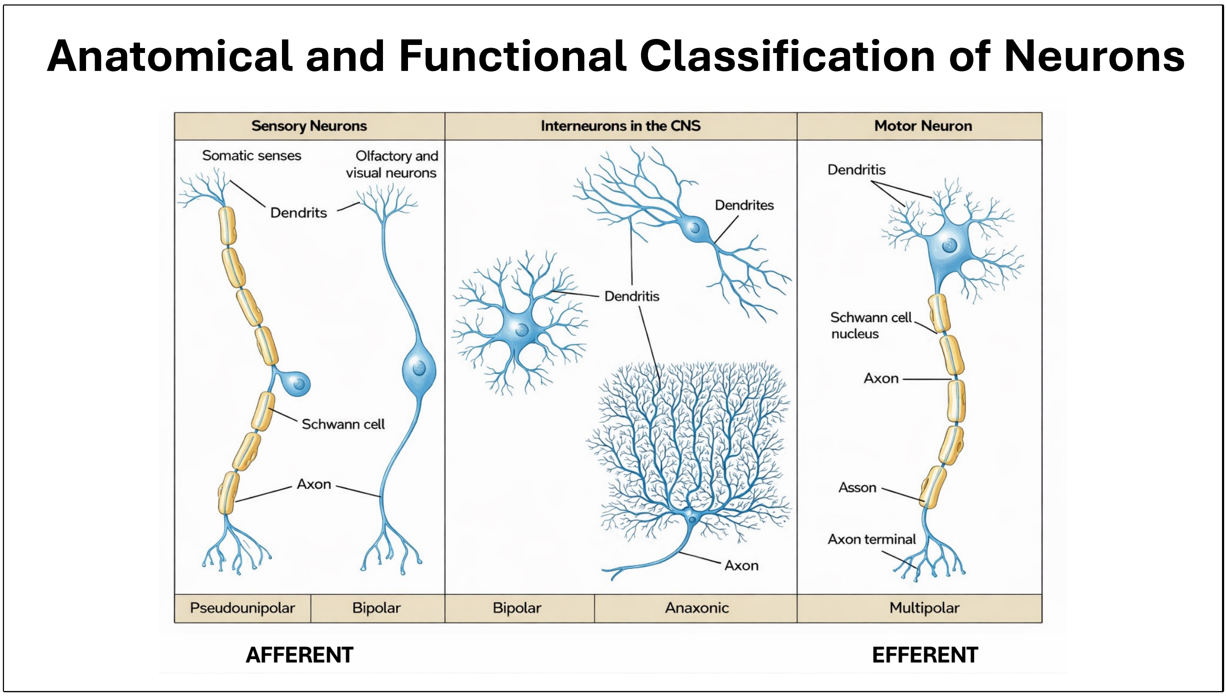
Photoreceptors – respond to light energy (e.g., retina)

Chemoreceptors – respond to chemicals (e.g., smell, taste, changes in blood chemistry)

Nociceptors – sensitive to pain-causing stimuli

STIMULUS ORIGIN

Exteroceptors	Interoceptors (Visceroceptors)	Proprioceptors
WHAT THEY DO Detect stimuli coming from the external environment.	**WHAT THEY DO** Detect stimuli in internal organs (viscera).	**WHAT THEY DO** Perceive position and movement
WHERE THEY ARE Body surface Also in mucous membranes that open to the outside of the body (e.g. nasal cavity, oral cavity, vagina, anal canal)	**WHERE THEY ARE** In internal organs	**WHERE THEY ARE** Located in muscles, tendons, and joints
THEY SENSE THE EXTERNAL WORLD	**THEY MONITOR INTERNAL ORGANS**	**THEY TELL THE NERVOUS SYSTEM BODY POSITION**



Anatomical and Functional Classification of Neurons

Sensory information travels in the nervous system thorugh specialized cells, called as neurons.
Three main types of neurons can be recognized:
Sensory neurons (afferent)
Interneurons (in the central nervous system)
Motor (efferent) neurons
These three types represent the pathway of nervous information.

1. Sensory neurons (afferent)
On the left side, we see sensory neurons.
They carry information from sensory receptors to the central nervous system (spinal cord or brain).
There are two main types:
Pseudounipolar neurons: typical of touch, pain, and temperature
  They have one process that splits into two branches
  One branch receives information, the other sends it to the CNS
Bipolar neurons: found in special senses like smell and vision
  They have one dendrite and one axon

In both cases, their function is the same:
to send sensory information to the CNS

2. Interneurons (central nervous system)
In the center, we see interneurons.
They are located only in the central nervous system.
Their function is to process and integrate information.
They:
receive signals from sensory neurons

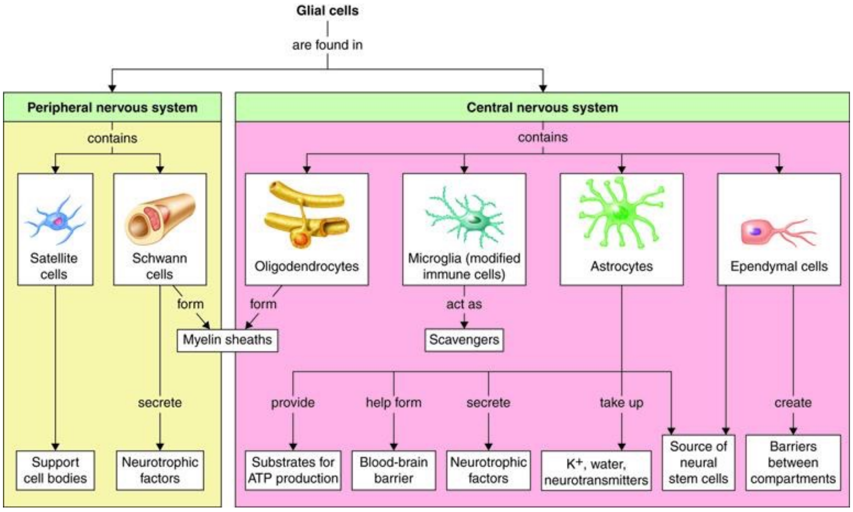
process the information
send it to motor neurons
They have:
many dendrites
many connections
different shapes
Their role is:
to integrate and process information

3. Motor neurons (efferent)
On the right side, we see motor neurons.
They carry information from the CNS to effectors:
muscles
glands
They have:
many dendrites
one long axon
terminals that contact the effector

Their role is:
to produce a response

Conclusion
The pathway of information is:
receptor → sensory neuron → interneurons → motor neuron → response
This is the basic scheme of how the nervous system works.

Glial cells: Structure and Function

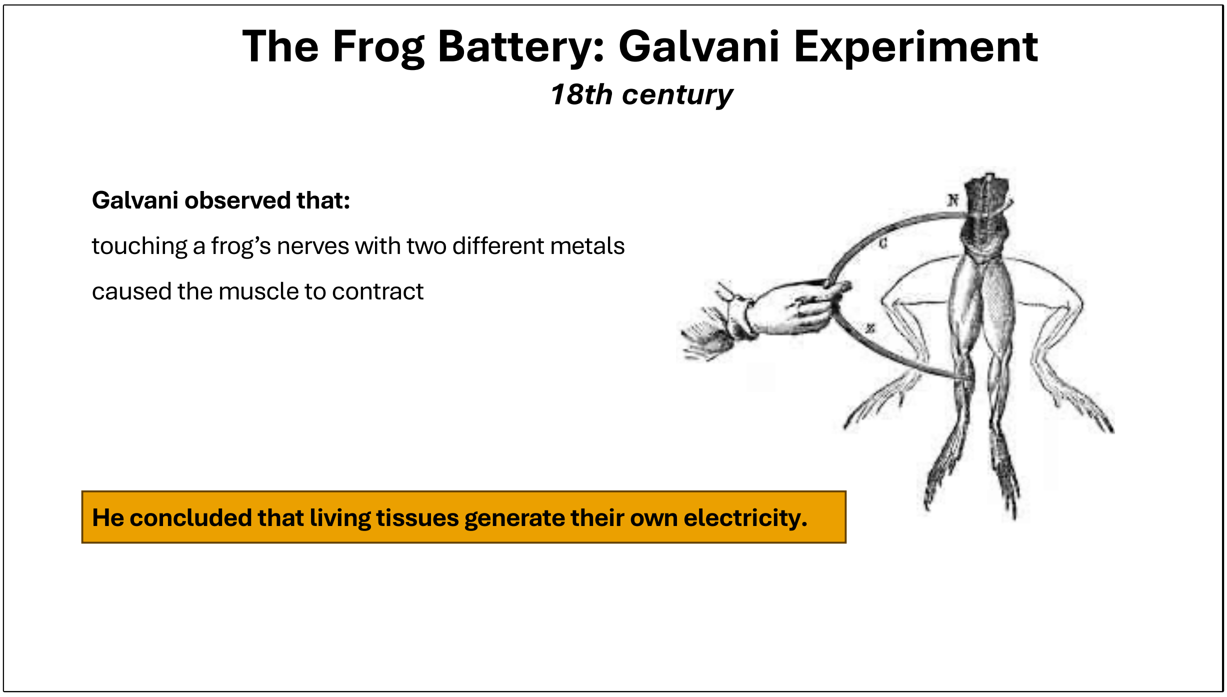


So far, we have talked about neurons, which are the cells that transmit the nervous signal. However, nervous tissue is not composed only of neurons, but also of another very important cell type: glial cells.

Glial cells do not directly transmit electrical signals, but they perform support, protection, and regulatory functions for neuronal activity.
We can classify glial cells based on their location in the central nervous system or the peripheral nervous system.

In the **central nervous system**, we find:
Oligodendrocytes, which form myelin around axons
Microglia, which have immune and defense functions
Astrocytes, which provide structural and metabolic support to neurons
Ependymal cells, involved in the production and circulation of cerebrospinal fluid

In the **peripheral nervous system**, we find:
Schwann cells, which form myelin in peripheral nerves
Satellite cells, which support neuronal cell bodies in ganglia
It is important to remember that, although glial cells do not generate action potentials, they are essential for the proper functioning of neurons.
In summary, neurons transmit information, while glial cells support and regulate neuronal activity.



The Frog Battery: Galvani Experiment

18th century

Galvani observed that:

touching a frog’s nerves with two different metals

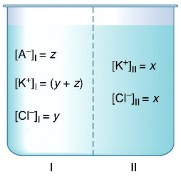
caused the muscle to contract

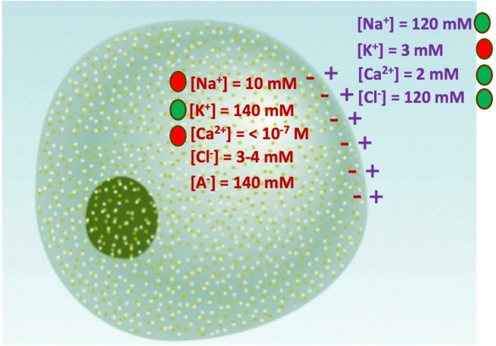
He concluded that living tissues generate their own electricity.

Who was to suggest that electrical signals could be a means of communication?
Luigi **Galvani.** He was an Italian physician, physicist, biologist and philosopher who studied animal electricity.
Using a frog, he discovered that the muscles of dead frogs' legs twitched when struck by an electrical spark.

Today we know that neurons transmit information through electrical signals.
These electrical signals depend on the difference in potential across the cell membrane.

Electrical Activity Depends on Membrane Potential





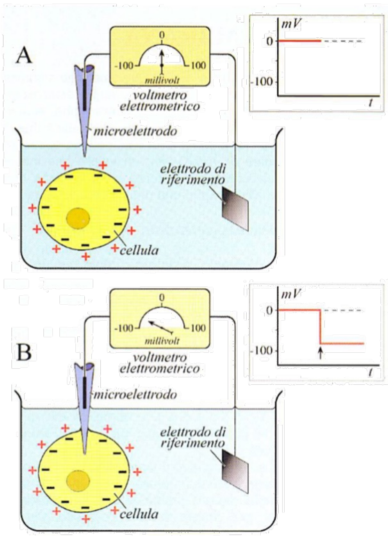
All electrical phenomena in excitable cells depend on the potential difference across the plasma membrane.
This difference exists because ion concentrations are different inside and outside the cell.

Inside the cell
High potassium (K^+)
Low sodium (Na^+)
Very low calcium (Ca^{2+})
Negative intracellular anions

Outside the cell
High sodium (Na^+)
High chloride (Cl^-)
Low potassium (K^+)
More calcium (Ca^{2+}) than inside

This unequal distribution of charges creates an electrical separation between the inside and outside of the membrane.
As a result, the cell membrane behaves like a small battery.

Recording the Resting Membrane Potential



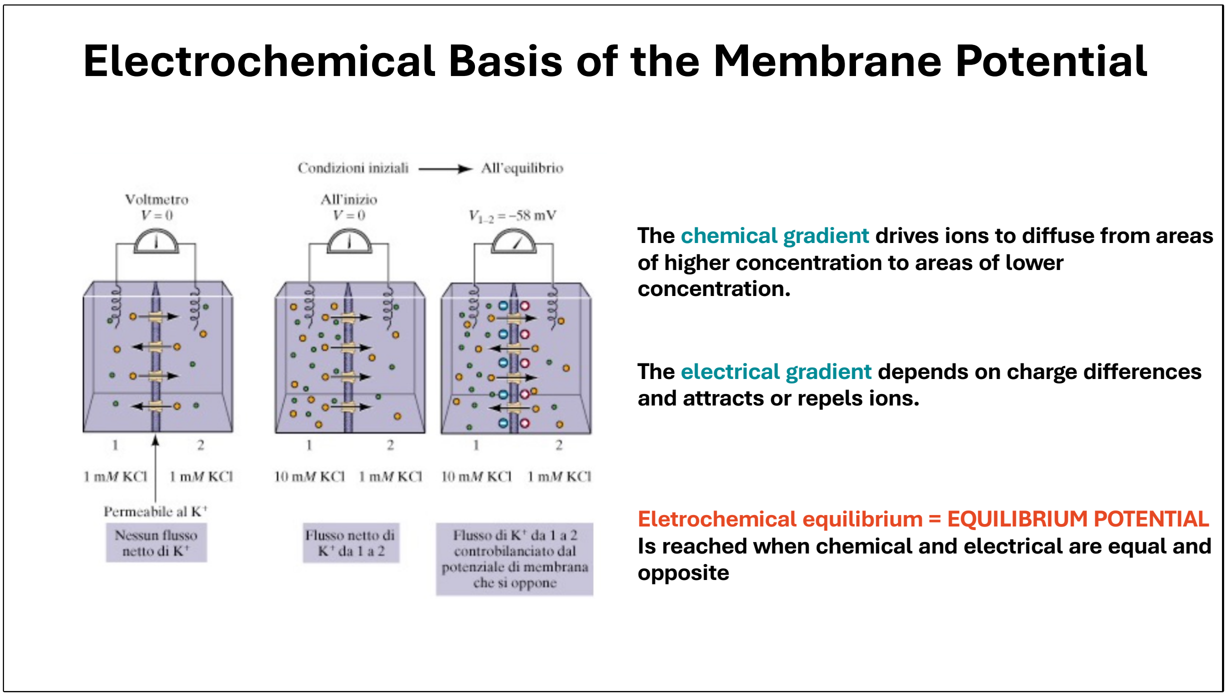
$$E = \frac{V}{d}$$

E= electric field

V= voltage

d= distance

This figure shows how membrane potential is measured.
If both electrodes are placed in the extracellular fluid, the voltmeter reads zero because there is no potential difference (A).
When a microelectrode is inserted inside the cell and the reference electrode remains outside, the voltmeter records a potential difference (B).
This means that the inside of the cell is electrically different from the outside.
In particular, the inside of the cell is negative compared to the outside.
In many excitable cells, this value is about −70 millivolts and is called the resting potential.
So, **membrane potential is simply the electrical difference between the inside and the outside of the cell.**



Electrochemical Basis of the Membrane Potential

The chemical gradient drives ions to diffuse from areas of higher concentration to areas of lower concentration.

The electrical gradient depends on charge differences and attracts or repels ions.

Eletrochemical equilibrium = EQUILIBRIUM POTENTIAL
Is reached when chemical and electrical are equal and opposite

The transmembrane potential difference is an electrochemical potential.
This means it depends on two forces:
chemical gradient
electrical gradient

The **chemical gradient** pushes ions to move from areas of high concentration to low concentration.
The **electrical gradient** depends on charge differences and attracts or repels ions.

When the membrane is permeable to an ion (for example potassium), the ion moves according to its concentration gradient.
However, as ions move, a separation of charges is created, generating an opposite electrical force.

Electrochemical equilibrium is reached when:
the chemical and electrical forces are equal and opposite.
At this point, there is no net movement of the ion.
This value is called the **equilibrium potential** for that ion.

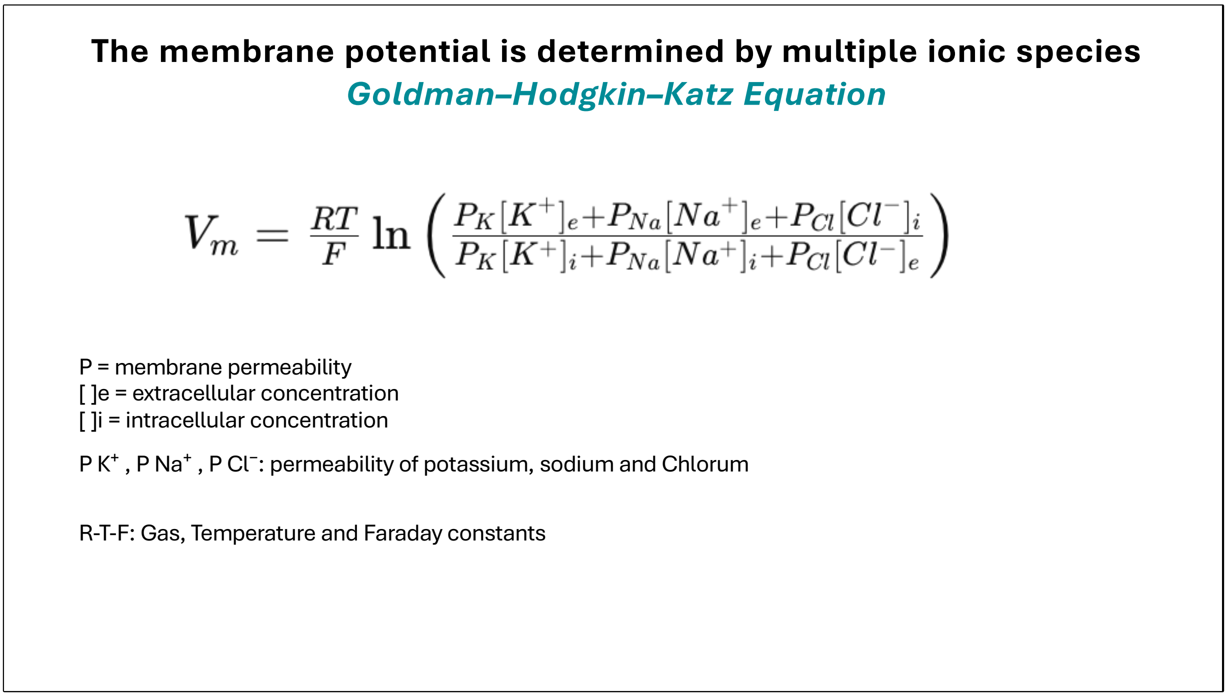
Each ion has its own equilibrium potential

The Nernst Equation

The Nernst equation establishes a quantitative relationship between the electrical potential difference and the concentration ratio of a single ion across the plasma membrane.

$$E_x = \frac{RT}{zF} \ln \frac{[X]_e}{[X]_i}$$

Ex: equilibrium potential for ion X
R: gas constant (8.314 Joule/mol × K)
T: absolute temperature (Kelvin)
F: Faraday constant (96,485 coulomb/mol)
z: valence of the ion
[X]e and [X]i: ion concentrations on the two sides of the membrane
At a temperature of 311.15 K (38 °C), and converting ln to log (ln = 2.302 log).



The membrane potential is determined by multiple ionic species

Goldman–Hodgkin–Katz Equation

$$V_m = \frac{RT}{F} \ln \left(\frac{P_K[K^+]_e + P_{Na}[Na^+]_e + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_e} \right)$$

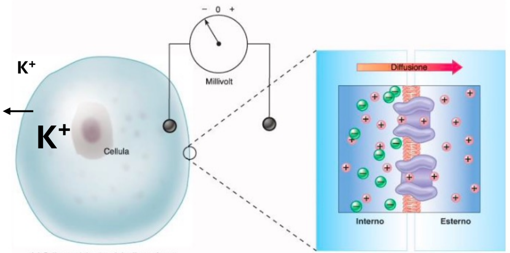
P = membrane permeability
[ ]e = extracellular concentration
[ ]i = intracellular concentration

P K^+ , P Na^+ , P Cl^-: permeability of potassium, sodium and Chlorum

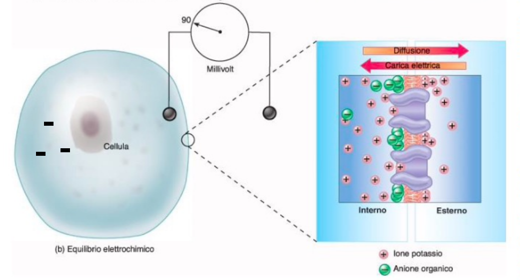
R-T-F: Gas, Temperature and Faraday constants

So far, we have seen that each ion has its own equilibrium potential, calculated using the Nernst equation.
However, the real membrane is permeable to multiple ions at the same time.
The **Goldman–Hodgkin–Katz equation** allows us to calculate the membrane potential by considering multiple ions and their permeability.

How Does the Membrane Potential Arise?



(a) Sviluppo del potenziale di membrana

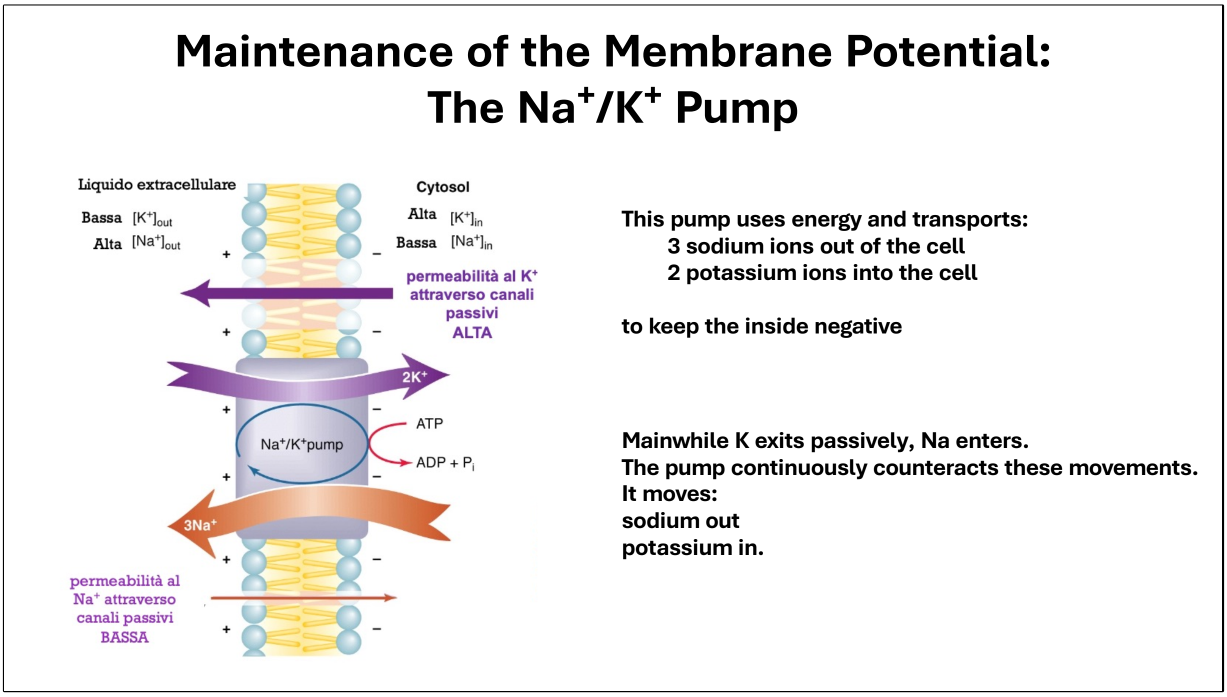


(b) Equilibrio elettrochimico

Let’s see how the membrane potential is generated.
Inside the cell there is a lot of potassium, while outside there is less.
For this reason, potassium tends to move out of the cell following its concentration gradient.
The resting membrane is very permeable to potassium, so potassium can leave the cell.
When potassium leaves, it leaves behind negative charges inside the cell, because intracellular anions cannot exit.
As a result, the inside of the cell becomes more negative.
This negative charge attracts potassium back into the cell.

Now we have two opposite forces:
the chemical gradient pushes potassium out
the electrical force pulls it back in

When these two forces balance each other, potassium stops moving.
At this point, the membrane potential is established.



Maintenance of the Membrane Potential:
The Na^+/K^+ Pump

This pump uses energy and transports:
3 sodium ions out of the cell
2 potassium ions into the cell

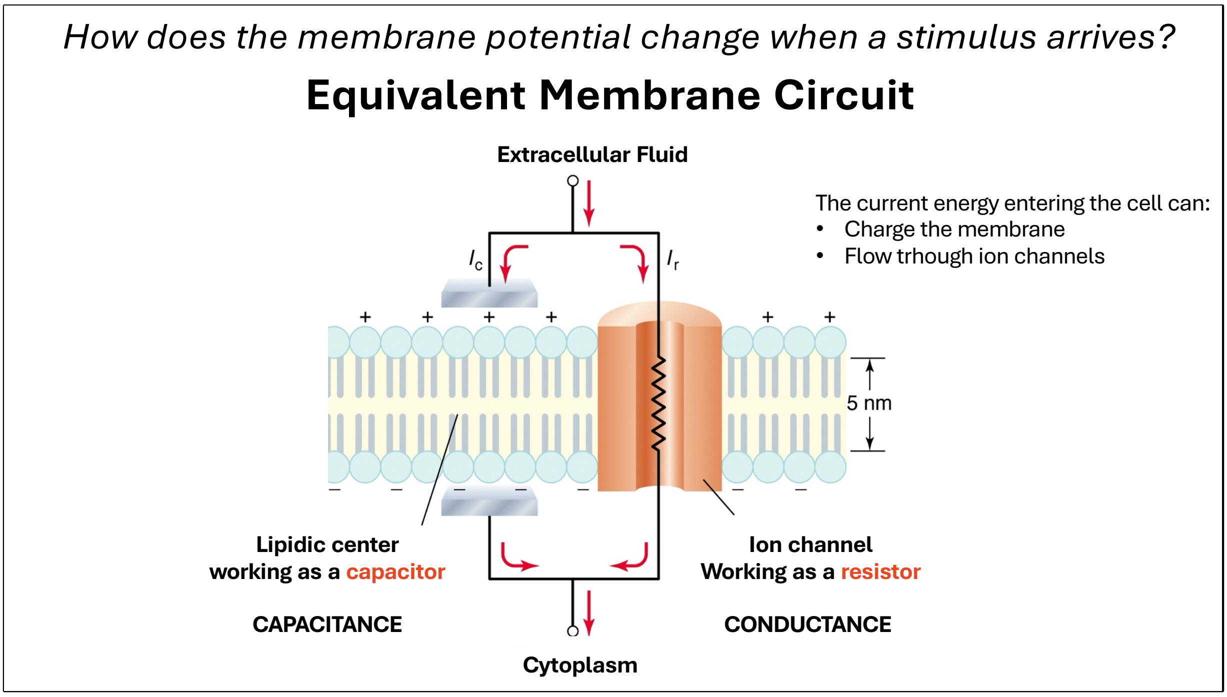
to keep the inside negative

Mainwhile K exits passively, Na enters.
The pump continuously counteracts these movements.
It moves:
sodium out
potassium in.

The membrane potential must be maintained stable over time.
This is possible thanks to the sodium–potassium pump.
This pump uses energy and transports:
3 sodium ions (Na^+) out of the cell
2 potassium ions (K^+) into the cell
So, more positive charges leave the cell than enter.
This helps keep the inside of the cell negative.

At the same time:
potassium tends to leave passively
a small amount of sodium enters
The pump continuously corrects these movements:
it moves sodium out
it brings potassium back in

In this way, it maintains a stable resting potential.



How does the membrane potential change when a stimulus arrives?

Equivalent Membrane Circuit

The current energy entering the cell can:
- Charge the membrane
- Flow trhough ion channels

Lipidic center
working as a capacitor

CAPACITANCE

Ion channel
Working as a resistor

CONDUCTANCE

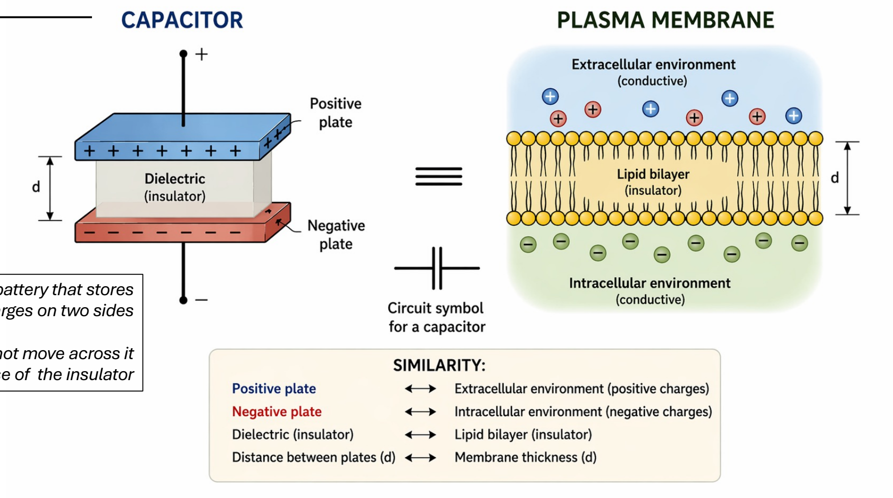
To understand how a sensory signal — such as light, sound, or pressure — is converted into nervous activity, we must first understand how the cell membrane behaves electrically.
All sensory receptors and neurons communicate through changes in membrane potential.
So the question is:
how does the membrane potential change when a stimulus arrives?

To answer this, we use a simple model: the **equivalent circuit of the membrane**.
The membrane behaves like two elements:
a **capacitor** (lipids)
a **resistor** (ion channels)

This is important because it shows that the current entering the cell can:
charge the membrane
flow through ion channels
This determines how the membrane potential changes.

This is exactly what happens when a sensory receptor is activated:
stimulus → channels open → current enters → membrane potential changes

The membrane acts as a capacitor



SIMILARITY:

Positive plate	⟷	Extracellular environment (positive charges)
Negative plate	⟷	Intracellular environment (negative charges)
Dielectric (insulator)	⟷	Lipid bilayer (insulator)
Distance between plates (d)	⟷	Membrane thickness (d)

small battery that stores opposite charges on two sides

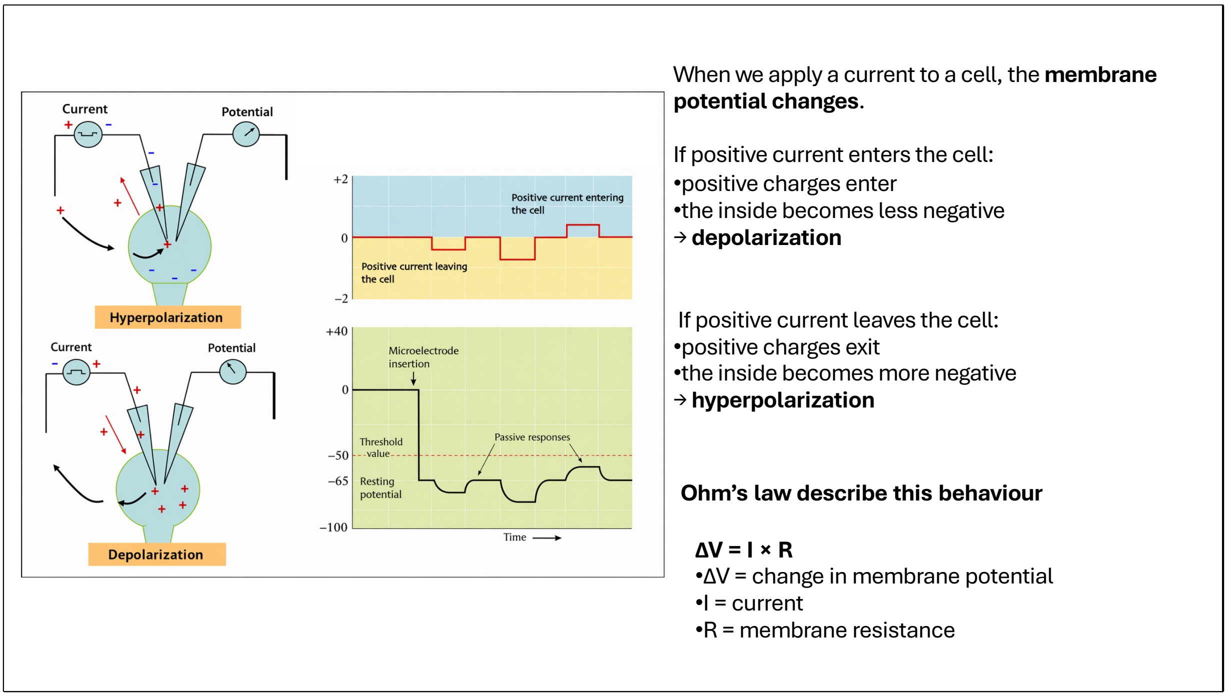
charges can not move across it easly because of the insulator

The membrane separates positive and negative charges. This means it can be described as a **biological capacitor**.

This is because it is made of a lipid bilaye**r**, which is an insulator, placed between two conductive solutions:
intracellular fluid
extracellular fluid
In this situation, electric charges cannot easily cross the membrane, so they accumulate on the two sides.

As a result, there is a separation of charges:
positive charges on one side
negative charges on the other
This separation occurs only near the membrane, while the rest of the fluids remains electrically neutral.

This is exactly how a **capacitor** works: it stores opposite charges on two sides separated by an insulator.
For this reason, the membrane behaves like a capacitor:
it stores charges and generates a membrane potential.



When we apply a current to a cell, the **membrane potential changes**.

If positive current enters the cell:
- positive charges enter
- the inside becomes less negative
→ **depolarization**

If positive current leaves the cell:
- positive charges exit
- the inside becomes more negative
→ **hyperpolarization**

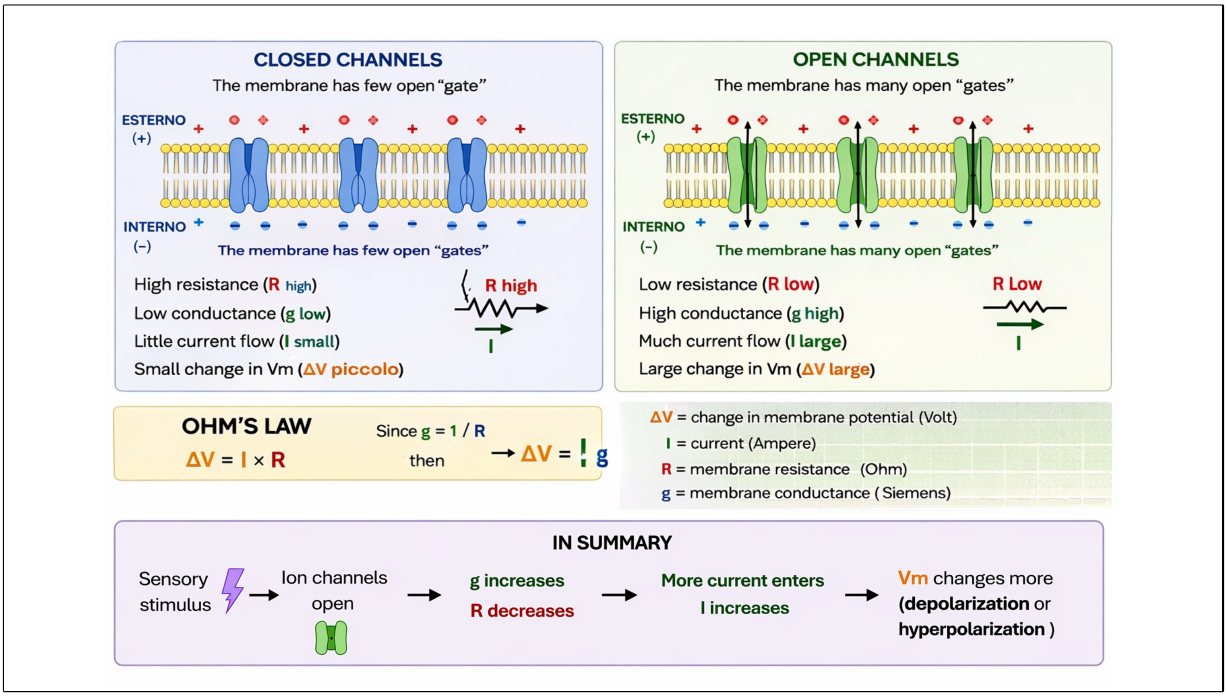
Ohm's law describe this behaviour

ΔV = I × R
- ΔV = change in membrane potential
- I = current
- R = membrane resistance

This means that the change in membrane potential depends on the **current entering the cell** and the **membrane resistance.**

If positive current **enters** the cell:
I > 0 → ΔV increases → **depolarization**

If positive current **leaves** the cell:
I < 0 → ΔV decreases → **hyperpolarization**



CLOSED CHANNELS

The membrane has few open “gate”

The membrane has few open “gates”

High resistance (R high)
Low conductance (g low)
Little current flow (I small)
Small change in Vm (ΔV piccolo)

OPEN CHANNELS

The membrane has many open “gates”

The membrane has many open “gates”

Low resistance (R low)
High conductance (g high)
Much current flow (I large)
Large change in Vm (ΔV large)

OHM’S LAW

ΔV = I × R

Since g = 1 / R then → ΔV = I g

ΔV = change in membrane potential (Volt)
I = current (Ampere)
R = membrane resistance (Ohm)
g = membrane conductance (Siemens)

IN SUMMARY

Sensory stimulus → Ion channels open → g increases R decreases → More current enters I increases → Vm changes more (depolarization or hyperpolarization)

Membrane resistance depends on ion channels.
When channels are closed, resistance is high and little current flows.
When channels open, resistance decreases and current increases.
Since conductance is the inverse of resistance:
g = 1 / R
Ohm’s law can also be written as:
ΔV = I / g

Therefore:
High conductance → more current flows → membrane potential changes more easily
Low conductance → less current flows → membrane potential changes less

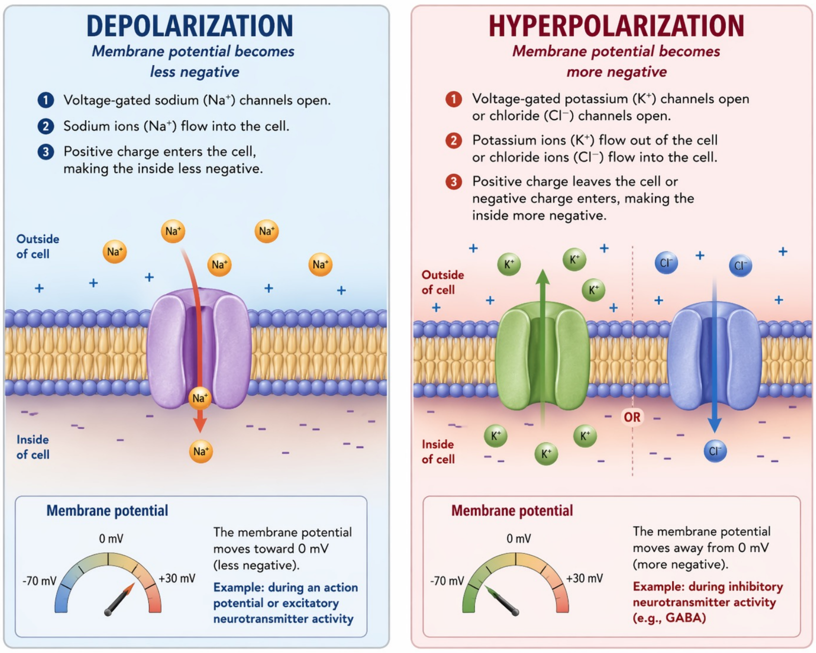
In sensory receptors, the stimulus acts through this mechanism:
it opens ion channels, increases conductance, allows current to enter, and changes the membrane potential, producing depolarization or hyperpolarization.

Example
Imagine the membrane as a wall with doors (ion channels):

Closed channels
few doors open
difficult to pass
high resistance (high R)
little current flows
small change in membrane potential

Open channels
many doors open
easy to pass
low resistance (low R)
high conductance (high g)
a lot of current flows
large change in membrane potential

Typical biological stimuli



DEPOLARIZATION

Membrane potential becomes less negative

1. Voltage-gated sodium (Na^+) channels open.
2. Sodium ions (Na^+) flow into the cell.
3. Positive charge enters the cell, making the inside less negative.

The membrane potential moves toward 0 mV (less negative).

Example: during an action potential or excitatory neurotransmitter activity

HYPERPOLARIZATION

Membrane potential becomes more negative

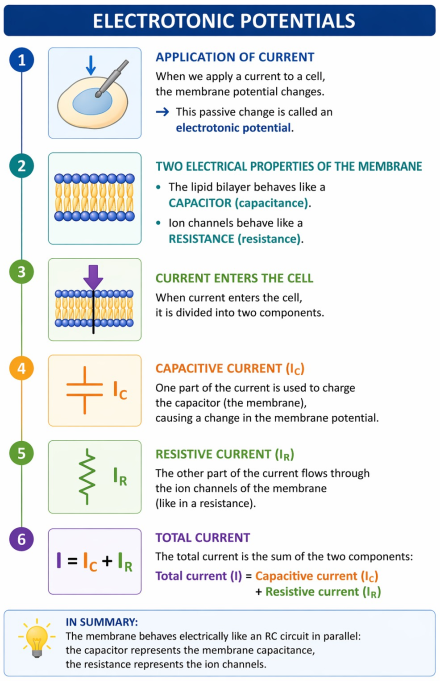
1. Voltage-gated potassium (K^+) channels open or chloride (Cl^-) channels open.
2. Potassium ions (K^+) flow out of the cell or chloride ions (Cl^-) flow into the cell.
3. Positive charge leaves the cell or negative charge enters, making the inside more negative.

The membrane potential moves away from 0 mV (more negative).

Example: during inhibitory neurotransmitter activity (e.g., GABA)

Why hyperpolarization and depolarization are not instantaneous?

Membrane Passive Reply
(**The Electrotonic potential**)



ELECTROTONIC POTENTIALS

1 **APPLICATION OF CURRENT**

When we apply a current to a cell,
the membrane potential changes.
→ This passive change is called an **electrotonic potential**.

2 **TWO ELECTRICAL PROPERTIES OF THE MEMBRANE**

- The lipid bilayer behaves like a **CAPACITOR (capacitance)**.
- Ion channels behave like a **RESISTANCE (resistance)**.

3 **CURRENT ENTERS THE CELL**

When current enters the cell,
it is divided into two components.

4 **CAPACITIVE CURRENT (I_C)**

One part of the current is used to charge
the capacitor (the membrane),
causing a change in the membrane potential.

5 **RESISTIVE CURRENT (I_R)**

The other part of the current flows through
the ion channels of the membrane
(like in a resistance).

6 **TOTAL CURRENT**

$I = I_C + I_R$

The total current is the sum of the two components:
Total current (I) = **Capacitive current (I_C)**
+ **Resistive current (I_R)**

IN SUMMARY:
The membrane behaves electrically like an RC circuit in parallel:
the capacitor represents the membrane capacitance,
the resistance represents the ion channels.

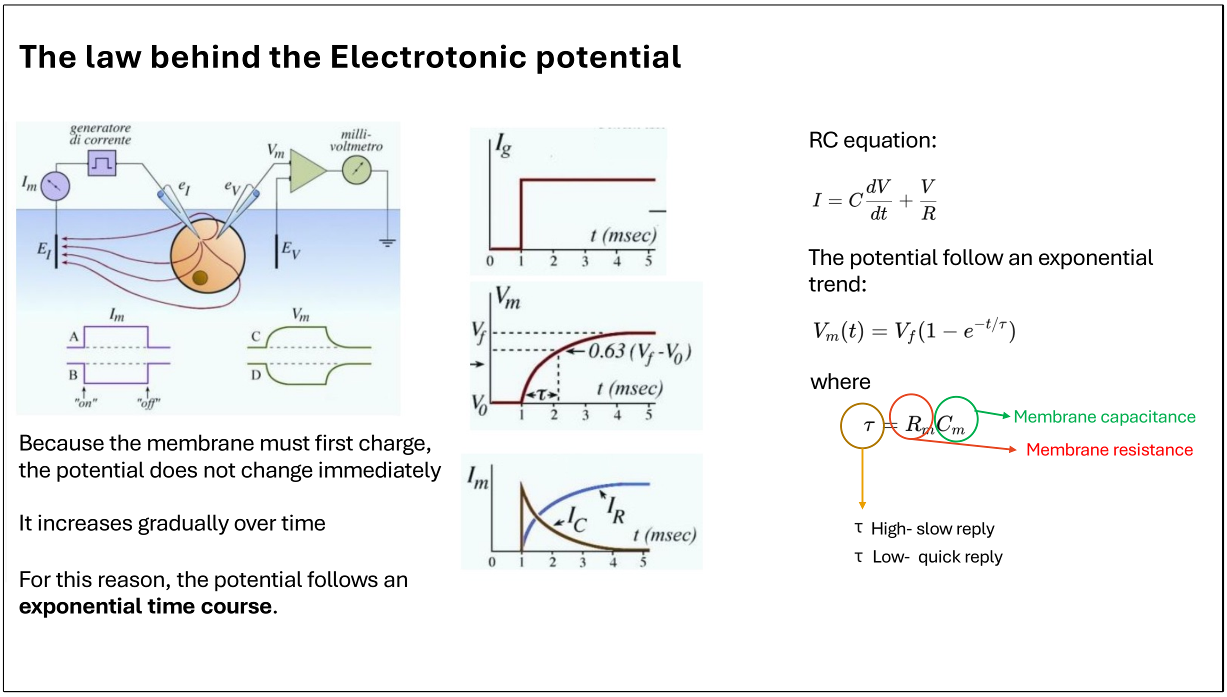
We have seen that when we apply a current to a cell, the membrane potential changes. This passive change is called an electrotonic potential.
The change is not instantaneous because the membrane has two electrical properties:
the lipid bilayer behaves like a **capacitor**
ion channels behave like a **resistance**
Therefore, when current enters the cell, it is divided into two components:
one part charges the membrane → **capacitive current**
one part flows through ion channels → **resistive current**
So, the total current is the sum of these two components:
total current = capacitive current + resistive current

Because the membrane must first charge, the potential does not change immediately but increases gradually over time.
For this reason, the potential follows an **exponential time course**.
The speed of this change depends on the **time constant**:
$\tau = Rm \times Cm$
This depends on:
Rm → membrane resistance (ion channels)
Cm → membrane capacitance (lipid bilayer)

Physical meaning
Large τ → membrane charges slowly → slow response
Small τ → membrane charges quickly → fast response

In other words, when we apply a step of current:
first, the current charges the membrane
then, the current flows through ion channels

For this reason, the membrane potential does not change instantly, but increases progressively until it reaches its final value.



The law behind the Electrotonic potential

Because the membrane must first charge, the potential does not change immediately

It increases gradually over time

For this reason, the potential follows an **exponential time course**.

RC equation:

$$I = C\frac{dV}{dt} + \frac{V}{R}$$

The potential follow an exponential trend:

$$V_m(t) = V_f(1 - e^{-t/\tau})$$

where

$$\tau = R_m C_m$$

Membrane capacitance

Membrane resistance

τ High- slow reply

τ Low- quick reply

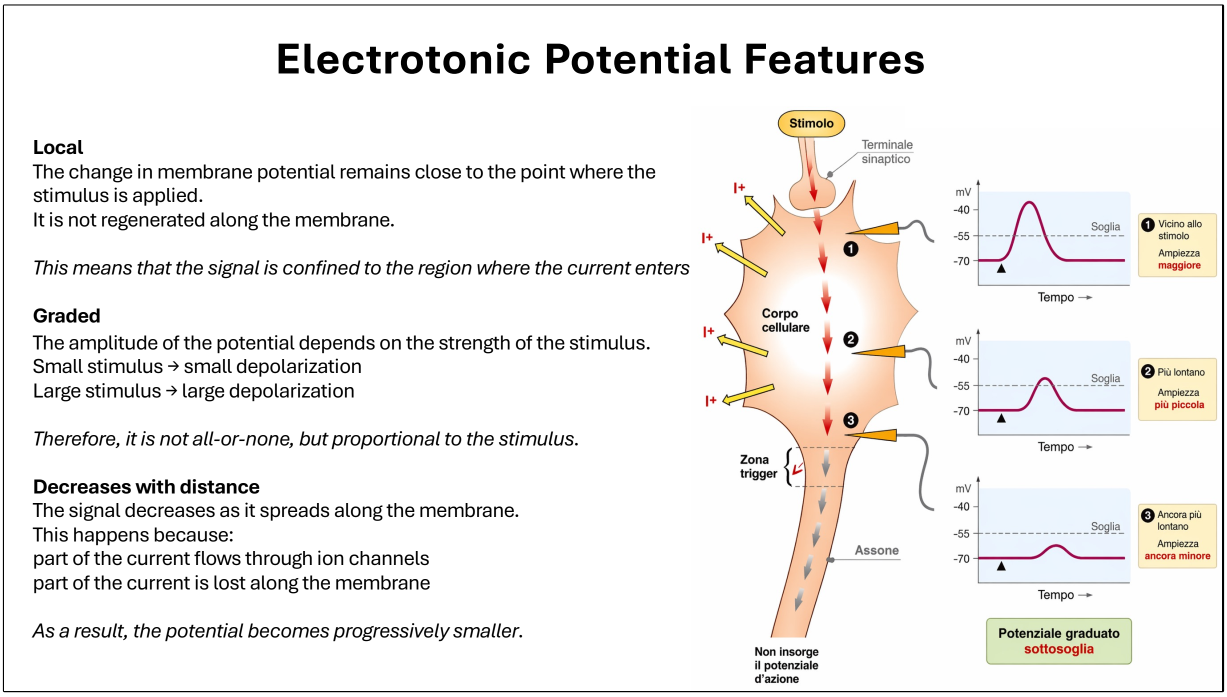
We have seen that when we apply a current to a cell, the membrane potential changes. This passive change is called an electrotonic potential.
The change is not instantaneous because the membrane has two electrical properties:
the lipid bilayer behaves like a **capacitor**
ion channels behave like a **resistance**
Therefore, when current enters the cell, it is divided into two components:
one part charges the membrane → **capacitive current**
one part flows through ion channels → **resistive current**
So, the total current is the sum of these two components:
total current = capacitive current + resistive current

Because the membrane must first charge, the potential does not change immediately but increases gradually over time.
For this reason, the potential follows an **exponential time course**.
The speed of this change depends on the **time constant**:
τ = Rm × Cm
This depends on:
Rm → membrane resistance (ion channels)
Cm → membrane capacitance (lipid bilayer)

Physical meaning
Large τ → membrane charges slowly → slow response
Small τ → membrane charges quickly → fast response

In other words, when we apply a step of current:
first, the current charges the membrane
then, the current flows through ion channels

For this reason, the membrane potential does not change instantly, but increases progressively until it reaches its final value.



Electrotonic Potential Features

Local
The change in membrane potential remains close to the point where the stimulus is applied.
It is not regenerated along the membrane.

This means that the signal is confined to the region where the current enters

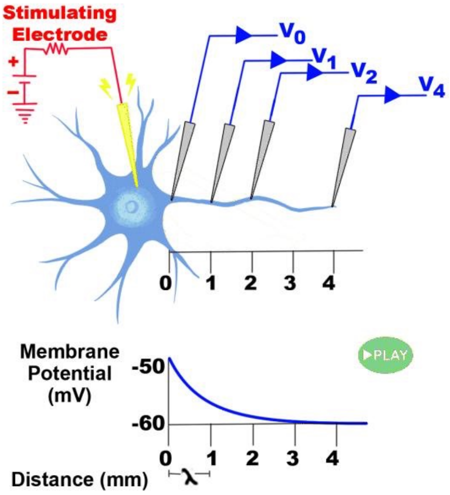
Graded
The amplitude of the potential depends on the strength of the stimulus.
Small stimulus → small depolarization
Large stimulus → large depolarization

Therefore, it is not all-or-none, but proportional to the stimulus.

Decreases with distance
The signal decreases as it spreads along the membrane.
This happens because:
part of the current flows through ion channels
part of the current is lost along the membrane

As a result, the potential becomes progressively smaller.

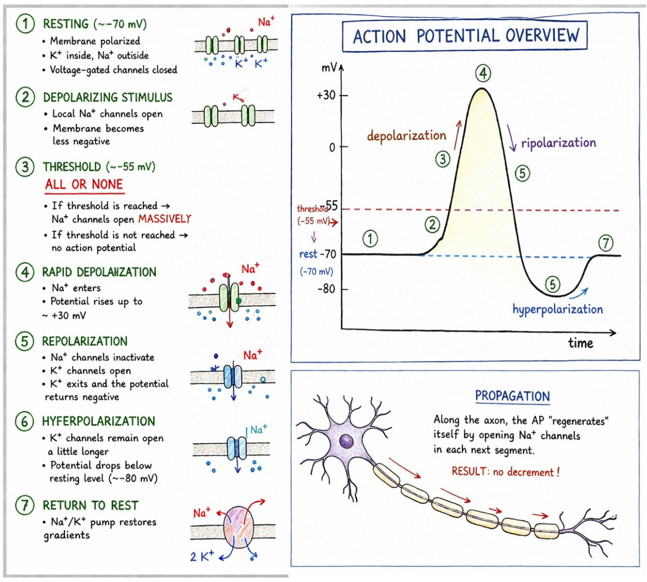
We have seen that when current enters the cell, the membrane charges and the potential changes gradually over time.
This passive change in membrane potential is called an electrotonic potential.
Now, let's look at its main characteristics.
see slide



- Electrotonic potential cannot travel long distances.

To transmit a signal along the neuron, a different mechanism is needed

Action Potential: How it is generated and propagated



① RESTING (~−70 mV)
- Membrane polarized
- K^+ inside, Na^+ outiside
- Voltage-gated channels closed

② DEPOLARIZING STIMULUS
- Local Na^+ channels open
- Membrane becomes less negative

③ THRESHOLD (~−55 mV)

ALL OR NONE
- If threshold is reached → Na^+ channels open MASSIVELY
- If threshold is not reached → no action potential

④ RAPID DEPOLANZATION
- Na^+ enters
- Potential rises up to ~ +30 mV

⑤ REPOLARIZATION
- Na^+ channels inactivate
- K^+ channels open
- K^+ exits and the potential returns negative

⑥ HYFERPOLARIZATION
- K^+ channels remain open a little longer
- Potential drops below resting level (~−80 mV)

⑦ RETURN TO REST
- Na^+/K^+ pump restores gradients

ACTION POTENTIAL OVERVIEW

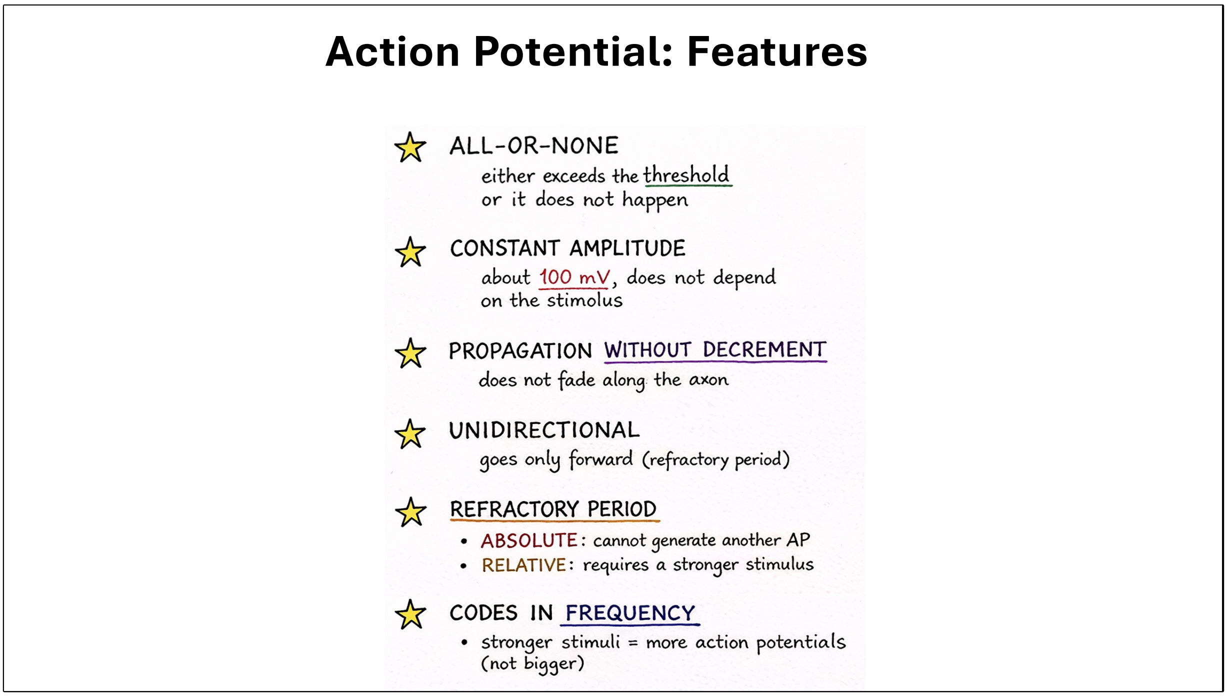
PROPAGATION

Along the axon, the AP "regenerates" itself by opening Na^+ channels in each next segment.

RESULT: no decrement !

The action potential, an active signal that can travel without decreasing.

The action potential is an active electrical signal that propagates along the neuron without fading, unlike the electrotonic potential, which is passive and decreases with distance.
The process starts from the resting potential, about −70 mV.
When a depolarizing stimulus arrives, the membrane becomes less negative.
If depolarization reaches the threshold (about −55 mV), voltage-gated sodium channels open.
Sodium enters the cell, causing a rapid depolarization up to about +30 mV.
Then, sodium channels inactivate and potassium channels open.
Potassium leaves the cell, leading to repolarization.
Because potassium channels stay open longer, a brief hyperpolarization occurs.
Finally, the membrane returns to the resting potential thanks to channel closure and the sodium–potassium pump.



Action Potential: Features

- ALL-OR-NONE
  either exceeds the threshold
  or it does not happen
- CONSTANT AMPLITUDE
  about 100 mV, does not depend
  on the stimolus
- PROPAGATION WITHOUT DECREMENT
  does not fade along the axon
- UNIDIRECTIONAL
  goes only forward (refractory period)
- REFRACTORY PERIOD
  - ABSOLUTE: cannot generate another AP
  - RELATIVE: requires a stronger stimulus
- CODES IN FREQUENCY
  - stronger stimuli = more action potentials (not bigger)

The action potential has some key properties:
it follows the all-or-none law, has a constant amplitude, propagates without decreasing along the axon, is unidirectional due to the refractory period, and the stimulus intensity is coded in the frequency of action potentials.

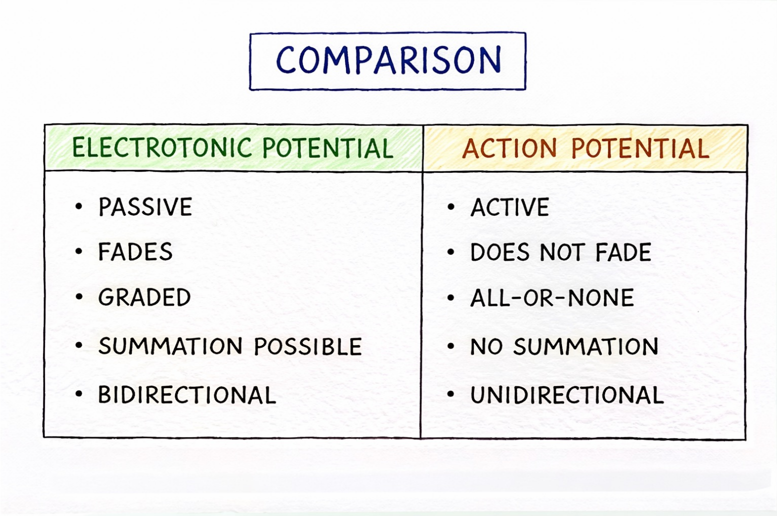
Focus on some concepts:

All-or-none
If threshold is not reached → nothing happens
If threshold is reached → full action potential
There are no partial responses.

Not graded
The amplitude is always the same
(about **100 mV**)
This is different from the electrotonic potential.

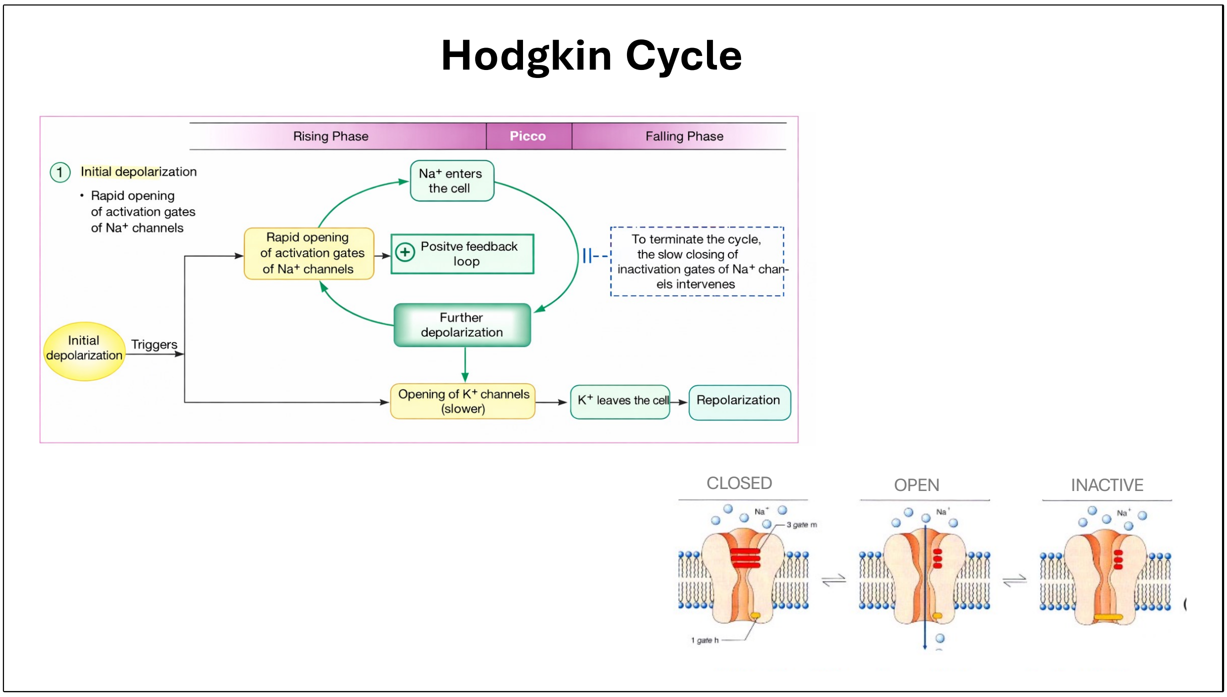
Does not decrease with distance
The signal is regenerated along the axon
so it does not fade
This allows propagation.

Self-regenerating
Each segment of the membrane
activates the next one
This creates the propagation.



COMPARISON

ELECTROTONIC POTENTIAL	ACTION POTENTIAL
• PASSIVE	• ACTIVE
• FADES	• DOES NOT FADE
• GRADED	• ALL-OR-NONE
• SUMMATION POSSIBLE	• NO SUMMATION
• BIDIRECTIONAL	• UNIDIRECTIONAL



Hodgkin Cycle

Rising Phase | Picco | Falling Phase

① Initial depolarization

- Rapid opening of activation gates of Na⁺ channels

Initial depolarization

Triggers

Rapid opening of activation gates of Na⁺ channels

Na⁺ enters the cell

Positve feedback loop

Further depolarization

To terminate the cycle, the slow closing of inactivation gates of Na⁺ chan-els intervenes

Opening of K⁺ channels (slower)

K⁺ leaves the cell

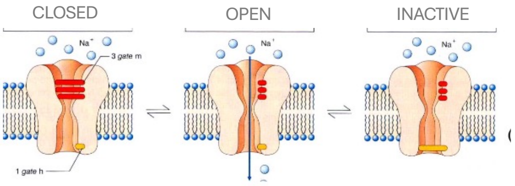
Repolarization

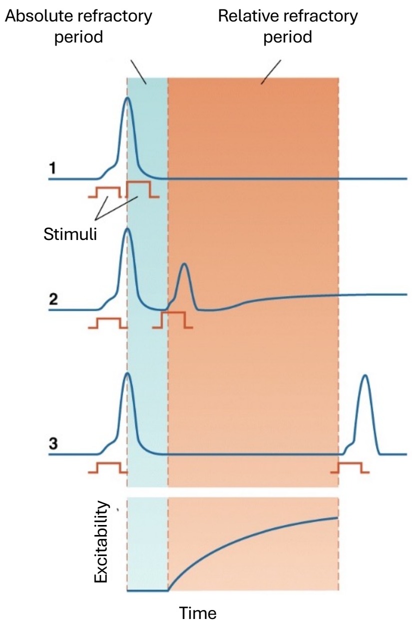
So, the stimulus reaches the axon hillock.
If it is strong enough, it reaches a threshold.
At that point, something very fast and automatic happens: a cycle is activated that generates the action potential.
This is the Hodgkin cycle.

Let’s look at it step by step:
At the beginning, there is a small depolarization, called an **electrotonic potential**.
If this depolarization is strong enough to reach the threshold, voltage-gated sodium channels open.
Sodium enters the cell and makes the inside more positive.
This causes more sodium channels to open:
this is a positive feedback loop.

At this point, depolarization increases very rapidly:
this is the rising phase of the action potential.
Soon after, sodium channels inactivate (they do not simply close), and potassium channels open.
Potassium leaves the cell, and the potential returns toward negative values:
this is **repolarization**.

The Na^+ channel has two “gates»:
Activation gate (red) → opens with depolarization
Inactivation gate (orange) → closes automatically after a short time
So, the sodium channel opens in response to voltage, but then inactivates on its own after a short time, independently of voltage.





As long as sodium channels are inactivated, they cannot be used.
The time window during which they are unavailable is called the **absolute refractory period.**
During this period, a new action potential cannot be generated.
The neuron is completely unexcitable.

This is followed by a period in which some sodium channels become available again, but potassium channels are still open.
This causes the membrane to be more negative (hyperpolarized).
This phase is called the **relative refractory period.**
During this period, generating a new action potential is not impossible,
but a stronger stimulus is required to reach the threshold.

This property is fundamental because it allows the action potential to propagate in only one direction along the axon.

Where does the action potential originate?

From the **graded potential**

small local electrical signal, proportional to the stimulus

1️⃣ **Graded**

not all-or-none

✔ stronger stimulus → larger response

2️⃣ **Local**

does not travel far

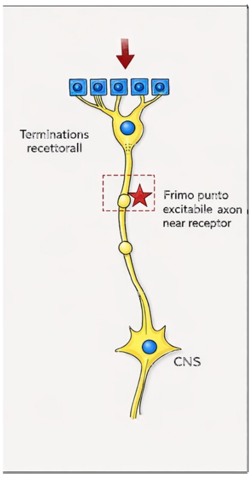
✔ decreases with distance

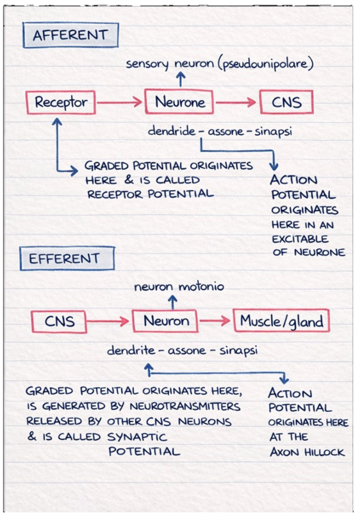
3️⃣ **Can generate an action potential**

if it reaches threshold

The action potential originates from a graded potential.

Sensory Neuron





AFFERENT

sensory neuron (pseudounipolare)

Receptor → Neurone → CNS

dendride - assone - sinapsi

GRADED POTENTIAL ORIGINATES HERE & IS CALLED RECEPTOR POTENTIAL

ACTION POTENTIAL ORIGINATES HERE IN AN EXCITABLE OF NEURONE

EFFERENT

neuron motonio

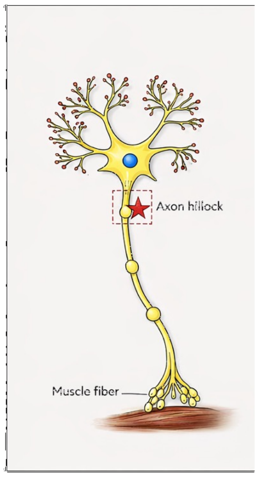
CNS → Neuron → Muscle/gland

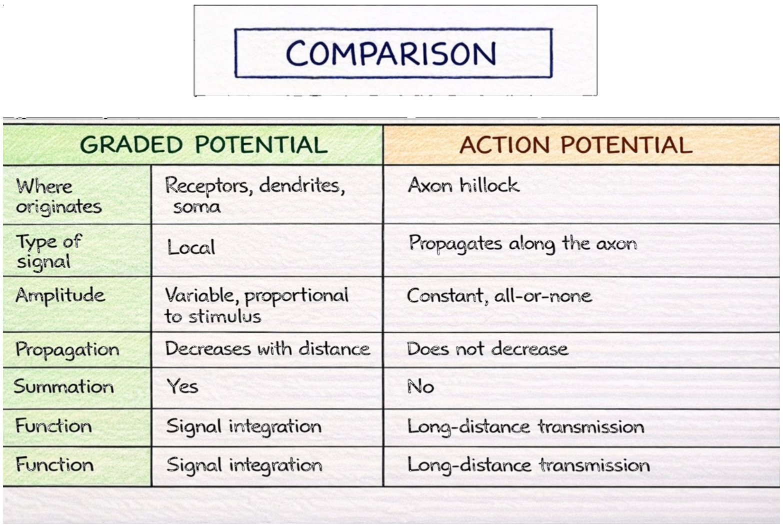
dendrite - assone - sinapsi

GRADED POTENTIAL ORIGINATES HERE, IS GENERATED BY NEUROTRANSMITTERS RELEASED BY OTHER CNS NEURONS & IS CALLED SYNAPTIC POTENTIAL

ACTION POTENTIAL ORIGINATES HERE AT THE AXON HILLOCK

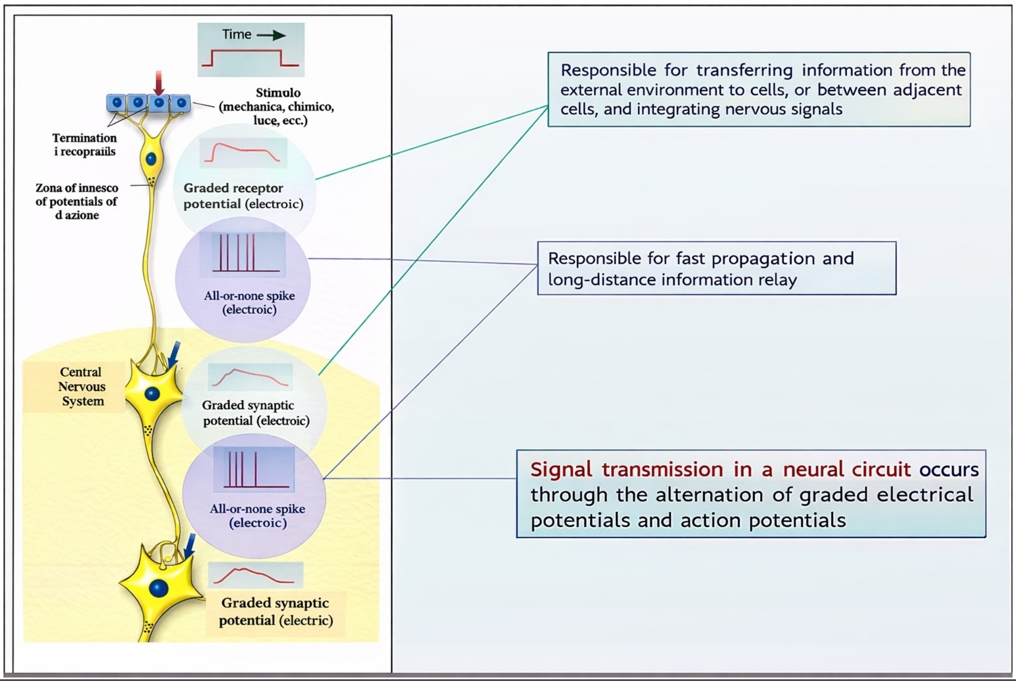
Motor Neuron





COMPARISON

GRADED POTENTIAL		ACTION POTENTIAL
Where originates	Receptors, dendrites, soma	Axon hillock
Type of signal	Local	Propagates along the axon
Amplitude	Variable, proportional to stimulus	Constant, all-or-none
Propagation	Decreases with distance	Does not decrease
Summation	Yes	No
Function	Signal integration	Long-distance transmission
Function	Signal integration	Long-distance transmission



Responsible for transferring information from the external environment to cells, or between adjacent cells, and integrating nervous signals

Responsible for fast propagation and long-distance information relay

Signal transmission in a neural circuit occurs through the alternation of graded electrical potentials and action potentials

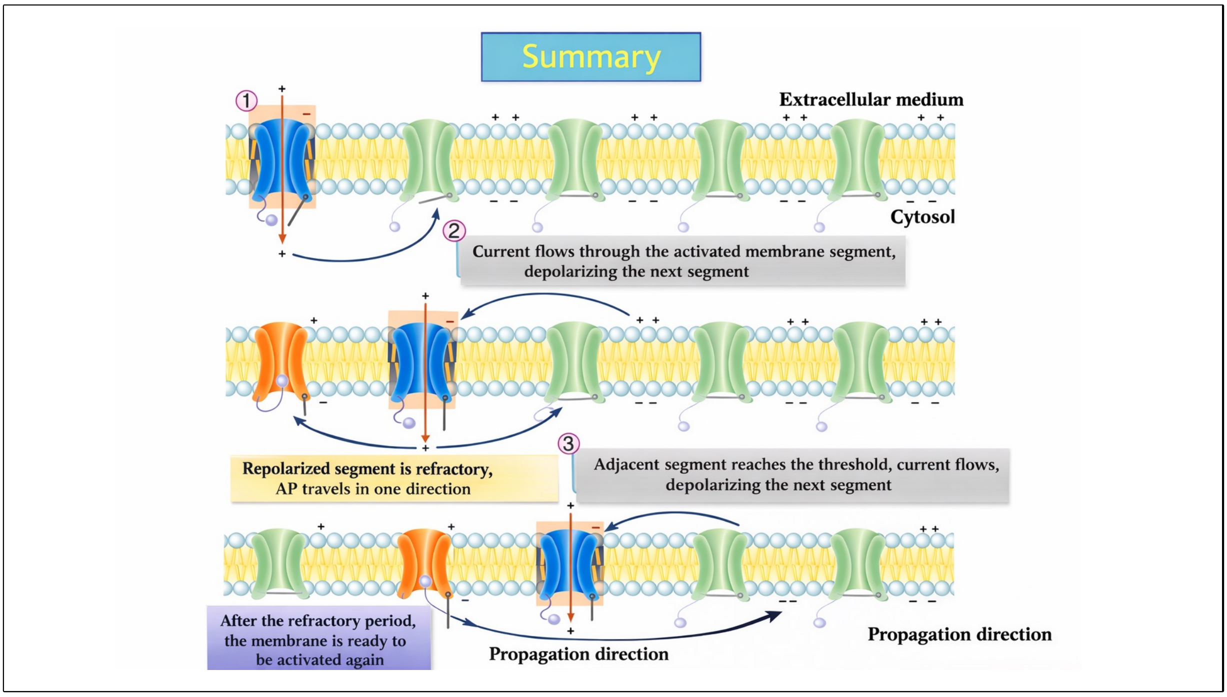
Graded Potential *vs.* Electrotonic Potential

- The graded potential is the local signal that originates in the membrane
- The electrotonic potential is the passive way in which this signal spreads along the neuron

Graded is the *what*, electrotonic is the *how*

Imagine throwing a stone into water:
the point where the stone hits is the graded potential (the signal originates there)
the waves that spread out are the electrotonic propagation
and as they move away, they become weaker

So we can say that:
The action potential always originates from an electrotonic potential
The action potential is a regenerative, all-or-none event
The action potential propagates anterogradely (that is, it moves forward—from the point where it originates toward the synaptic terminals)



Summary

Current flows through the activated membrane segment, depolarizing the next segment

Repolarized segment is refractory, AP travels in one direction

Adjacent segment reaches the threshold, current flows, depolarizing the next segment

After the refractory period, the membrane is ready to be activated again

The action potential starts in one segment of the membrane, and the incoming current depolarizes the next segment. If this segment reaches the threshold, it becomes activated as well, allowing the signal to propagate along the axon. The segment that has just been activated enters a refractory period, so it cannot be activated again immediately. This prevents the signal from going backward and ensures forward propagation.