Sensory receptors

Action potential

- Sensory receptors
- Phases of the action potential
- Changes of ion fluxes corresponding to the different phases

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Sensory receptors

Special type of cells which can collect and transfer different informations from the environment.

Function: „translation”, signal processing.

Receptors → Nerve fibre → Central nervous system

**Stimulus:** (physico-chemical) effect from the environment → metabolic changes inside the cells induced by a stimulus.

**Sensation:** will involve the work of the CNS.
Classification of sensory receptors

- **Type** of stimulus
  - light-photoreceptors
  - temperature-thermoreceptors
  - pressure-mechanoreceptors...

- **Localisation** of the receptors
  - head, ear...

- **The origin** of the information
  - Exteroceptor (informations form the environment)
  - Interoceptor (informations from the body)
  - Proprioceptor (position of the different parts of the body)

Work of the receptors I.

- Local change in the receptor-potential threshold
- Action-potential frequency ~ strength of the stimulus

"ALL OR NOTHING"
Work of the receptors II.

(Strength of the) stimulus

Below the **threshold** level there is no sensation (no action potential).

The origin of the resting membrane potential

- **Bernstein** potassium hypothesis
- **Nernst-equilibrium** potential (electro-chemical potential)
- **Donnan** equilibrium: the membrane is **impermeable** for some components (e.g. intracellular proteins).
- **Goldman** equation: The membrane potential is the result of a „compromise” between the various **equilibrium potentials**, each weighted by the membrane **permeability** and absolute **concentration** of the ions.
**Equilibrium potential**

**Nernst equation:** What membrane potential $(E)$ can compensate (balance) the concentration gradient $(X_1/X_2)$.

$$E = \frac{RT}{zF} \ln \frac{X_1}{X_2}$$

The inward and outward flows of the ions are balanced (net current = zero → equilibrium = stable, balanced, or unchanging system).

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**Ionic concentrations inside and outside of a muscle cell**

- $Na^+ : 120 \text{ mM}$
- $K^+ : 139 \text{ mM}$
- $Cl^- : 120 \text{ mM}$
- $Na^+ : 20 \text{ mM}$
- $K^+ : 139 \text{ mM}$
- $Cl^- : 3.8 \text{ mM}$

$[Na^+] \Rightarrow E_{mV} = -58/1 \log (20/120) = +45.1 \text{ mV}$

$[K^+] \Rightarrow E_{mV} = -58/1 \log (139/2.5) = +101.2 \text{ mV}$

$[Cl^-] \Rightarrow E_{mV} = -58/1 \log (3.8/120) = +86.9 \text{ mV}$

$E_{mV} = 30.8 \text{ mV}$

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$E_{mV} = -92 \text{ mV}$
Passive or leakage channels

→ a membrane-potential is not equal with any of the equilibrium potentials for the different ions
  • $E_{mV_{K^+}} = -101.2 \text{ mV}$
  • $E_{mV_{Na^+}} = +45.1 \text{ mV}$
  • $E_{mV_{Cl^-}} = +86.9 \text{ mV}$

→ the ions are trying to move through the membrane $\Rightarrow$ "leakage"

"LEAKAGE CHANNELS"

• Slow movement of the ions.
• Has to be compensated somehow.
Na-K ATPase

- The passive flux of Na\(^+\) and K\(^+\) (leakage) is balanced by the active work of Na-K pump → contribution to the membrane potential.

- 3 Na\(^+\) move out vs. 2 K\(^+\) move in (exchanger)

- **ATP** (energy source) is needed

Potassium channels

- Ca\(^{2+}\) sensitive potassium channels (K\(_{Ca}\))
- Inwardly rectifying potassium channels (K\(_{IR}\))
- “Tandem pore domain potassium channel” – “leak channel” (K\(_{2p}\))

- **Voltage-gated potassium channels (K\(_{V}\))**
  - Sensitive (dependent) to voltage changes in the membrane potential

Sodium channels

- Ligand gated sodium channels
- Voltage gated (sensitive, dependent) sodium channels
  - contains a voltage sensor
  - Sensitive (dependent) to voltage changes in the membrane potential

Action potential

- **Action potential**: a momentary reversal of membrane potential (-65 mV to +40 mV) that will be followed by the restoration of the original membrane potential after a certain time period (1-400 ms).

- Action potentials happen in **different phases** (depolarisation and repolarisation).

- Action potentials are triggered by the depolarization of the membrane if it can reach a critical value (**voltage threshold**).

- Action potentials are **all or none** phenomena
  - any stimulation above the voltage threshold results in the same action potential response.
  - any stimulation below the voltage threshold will not result in an action potential response.

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**Action potential (nerve cell)**

![Diagram of action potential](image)
**Resting phase**

Equilibrium state

\[ \text{Na}_V \] channels:
- activation gate closed
- inactivation gate open

**Rising phase (depolarization)**

The voltage-gated sodium channels will open-up if the voltage threshold reached by a stimulus

\[ \text{Na}_V \] channels:
- activation gate open
- inactivation gate open

→ \( \text{Na}^+ \) will move into the cell
→ the inner surface of the cell will be positively charged
**Overshoot**

- The movement of the Na\(^+\) will slow down
- \(E_{\text{mV}_{\text{Na}^+}} = +45.1\) mV (Nernst – **equilibrium potential**)
- Na\(^+\) channels will start to form an inactive conformation
- K\(^+\) channels are starting to open-up

![Overshoot Diagram](Image)

**Falling phase (repolarization)**

- All the voltage gated K\(^+\) channels are open
- K\(^+\) move out from the cell
- Na\(_{\text{V}}\) channels:
  - activation gate open
  - inactivation gate closed
  → refractory period

![Falling Phase Diagram](Image)
**Undershoot (hyperpolarization)**

- The movement of the $K^+$ ions will slow down
- $E_{mV,K^+} = -101.2 \text{ mV}$ (Nernst-equilibrium potential)
- The $K^+$ channels will get into a closed conformation
- The numerous and slowly inactivating $K^+$ channels will cause some hyperpolarisation

**Resting phase**
Recovery after the AP

- Intracellular ion concentrations change only a small amount with each AP (0.0001% - 1%).

- Na⁺/K⁺ ATPases will slowly restore the original ion concentrations.

- If the Na/K ATPases of a squid giant axon is poisoned, it can still generate 100,000 impulses while the internal sodium concentration is increased only by 10%.

Refractory period

The cell is resistant to a stimulus. It is hard to get a response (action potential).

- **Absolute refractory period:** The formation of a new AP is totally blocked.

- **Relative refractory period:** Larger depolarisation is needed than the threshold to initialize an AP.
Action potential in the cardiac muscle cells

1. Depolarisation:
   - Na⁺ moving into the cell
   - Membrane potential: ~+35mV

2. Plateau phase:
   - Equilibrium between the Ca²⁺ release and the outward movement of the K⁺ ions
   - Membrane potential: ~+35mV
   - Plateau: can help to direct the flow of the APs.

3. Repolarisation:
   - K⁺ ion moving out from the cell
   - Membrane potential: ~-90mV

4. Resting membrane potential

The end!!!