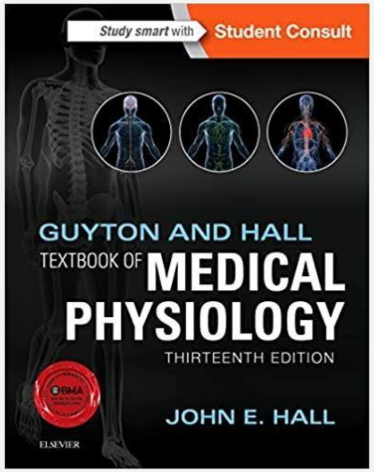
Lecture - 02

# RESTING AND ACTION POTENTIALS

# TEXTBOOK




13TH EDITION

Guyton and Hall
Textbook of Medical Physiology

# Bioelectric potentials

- Bioelectric potentials are actually ionic voltages produced as a result of the electrochemical activity of certain special types of cells.
- Bioelectric potentials are associated with:

-nerve conduction

-brain activity

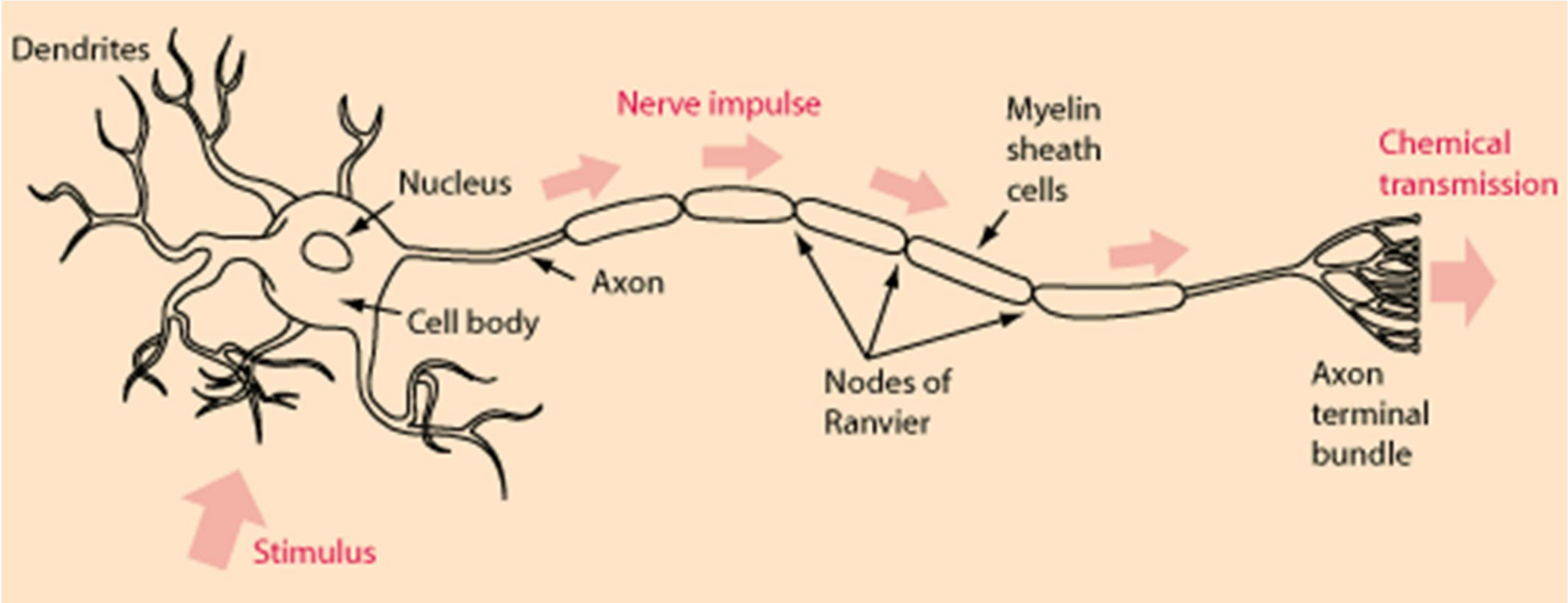
-heart beat

-muscle activity

and so on

# Nerve Cell :

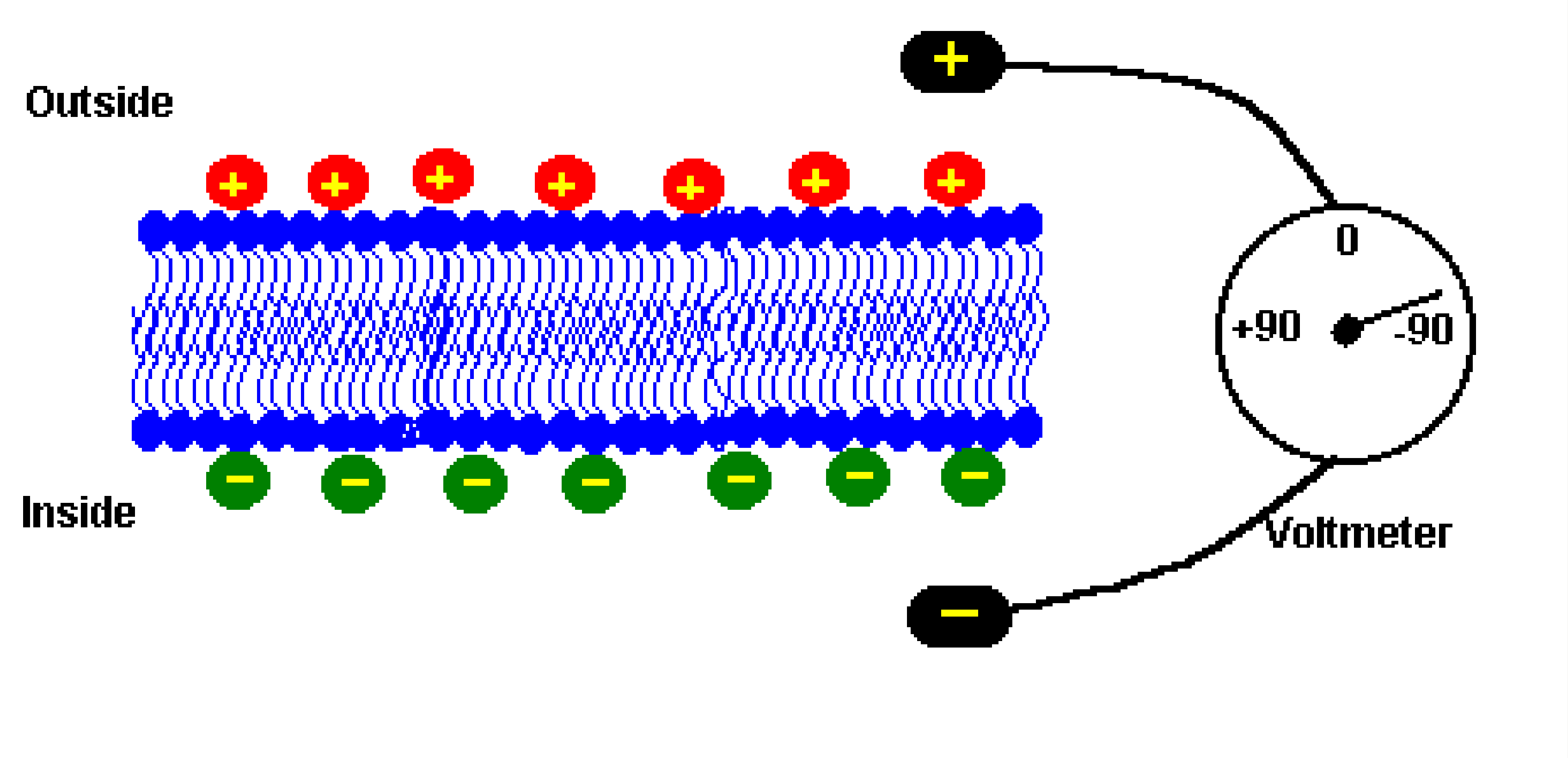
## Transmission of a nerve impulse along an axon



# MEMBRANE POTENTIAL

- The body as a whole is electrically neutral.
- All of the cells in the body have an electrical potential across their membrane (voltage difference) known as the membrane potential.
- Membrane potentials develop because of differing ion concentrations between the inside and outside of the cell.

# MEMBRANE POTENTIAL…



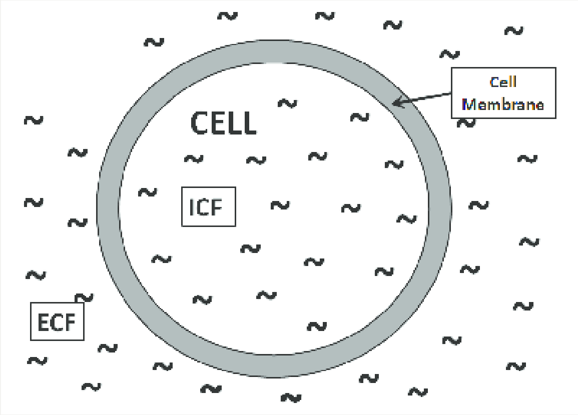
# MEMBRANE POTENTIAL…

- Surrounding the cells of the body are the body fluids. These fluids are conductive solutions containing charged atoms known as ions. The principal ions are sodium ($Na^+$), potassium ($K^+$), and chloride ($Cl^-$).
- The membrane of excitable cells readily permits entry of potassium and chloride ions but effectively blocks the entry of sodium ions.
- Since the various ions seek a balance between the inside of the cell and the outside, both according to concentration and electric charge, the inability of the sodium to penetrate the membrane results in an equilibrium with a potential difference across the membrane, negative on the inside and positive on the outside.

# MEMBRANE POTENTIAL…

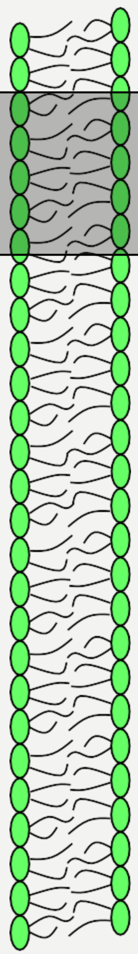
- By convention outside of the cell is assigned a voltage of zero
- Polarity of the membrane is stated in terms of the sign of the excess charge inside of the cell

Intracellular fluid (ICF)
Extracellular fluid (ECF)



# MOLECULAR GRADIENTS

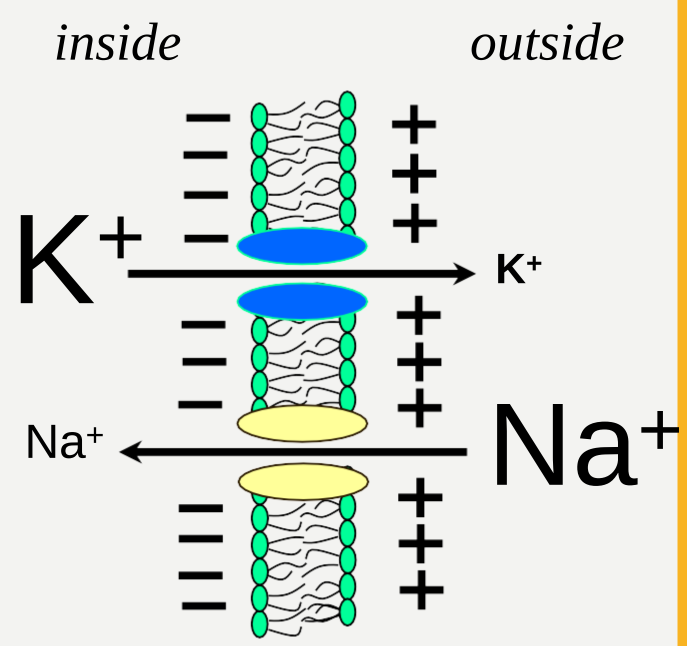
| | *inside* (in mM) | *outside* (in mM) |
|---|---|---|
| $Na^+$ | 14 | 142 |
| $K^+$ | 140 | 4 |
| $Mg^{2+}$ | 0.5 | 1-2 |
| $Ca^{2+}$ | $10^{-4}$ | 1-2 |
| $H^+$ | (pH 7.2) | (pH 7.4) |
| $HCO_3^-$ | 10 | 28 |
| $Cl^-$ | 5-15 | 110 |
| $SO_4^{2-}$ | 2 | 1 |
| $PO_3^-$ | 75 | 4 |
| protein | 40 | 5 |



# RESTING POTENTIAL

An equilibrium is reached with a potential difference across the membrane, negative on the inside and positive on the outside. This membrane potential is called the **resting potential**, $V_M$ of the cell and is maintained until disturbance upsets the equilibrium.

A cell in the resting state is said to be *polarized*.



# NERNST'S EQUATION

- Equilibrium potential is the electrical potential at which ion movements in both directions across the membrane are exactly balanced (net movement = zero)
- Given the ion concentration gradient the Nernst potential for any ion can be calculated. The Nernst equation is used to determine the electrochemical potential for any ion across the biological membrane.

Nernst Equation:

$$E(x) = KT/Zq \ln [x]inside/[x]outside$$

Here, K = Boltzmann constant

T = Temp. degrees Kelvin

Z = Charge on ion (Valance)

q = magnitude of electron charge

# NERNST'S EQUATION…

A more simplified form of the Nernst's equation at room temperature is -

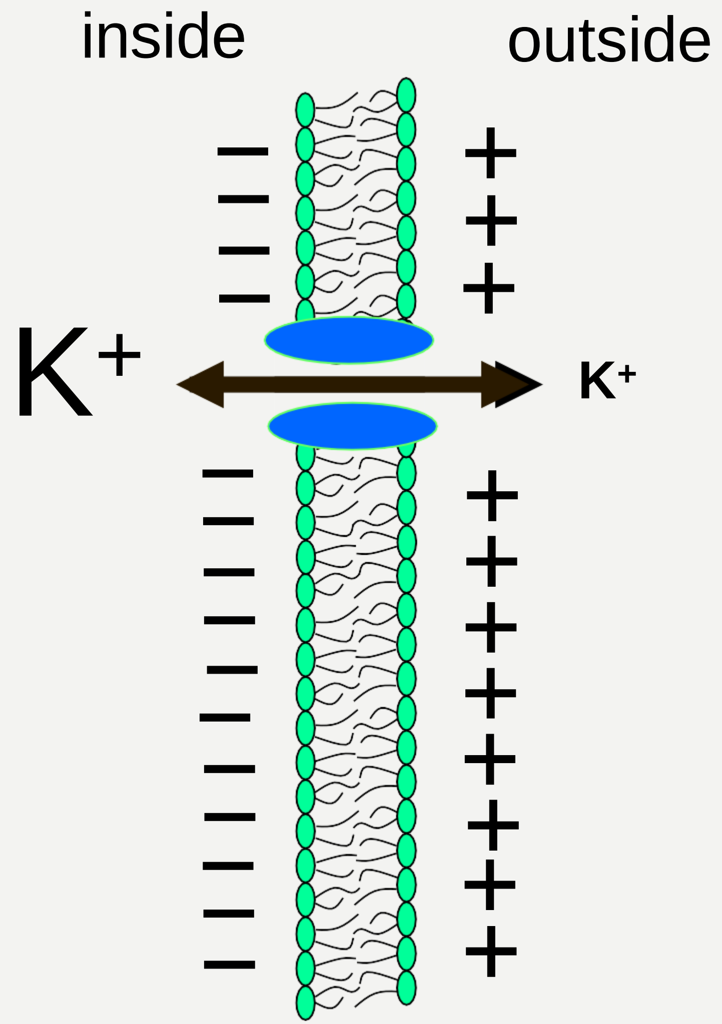
$$E(x) = -26mV \ln [X]inside / [X]outside$$

or

$$= 26\ mV \ln [X]outside / [X]inside$$

# SIMPLEST CASE SCENARIO: 1

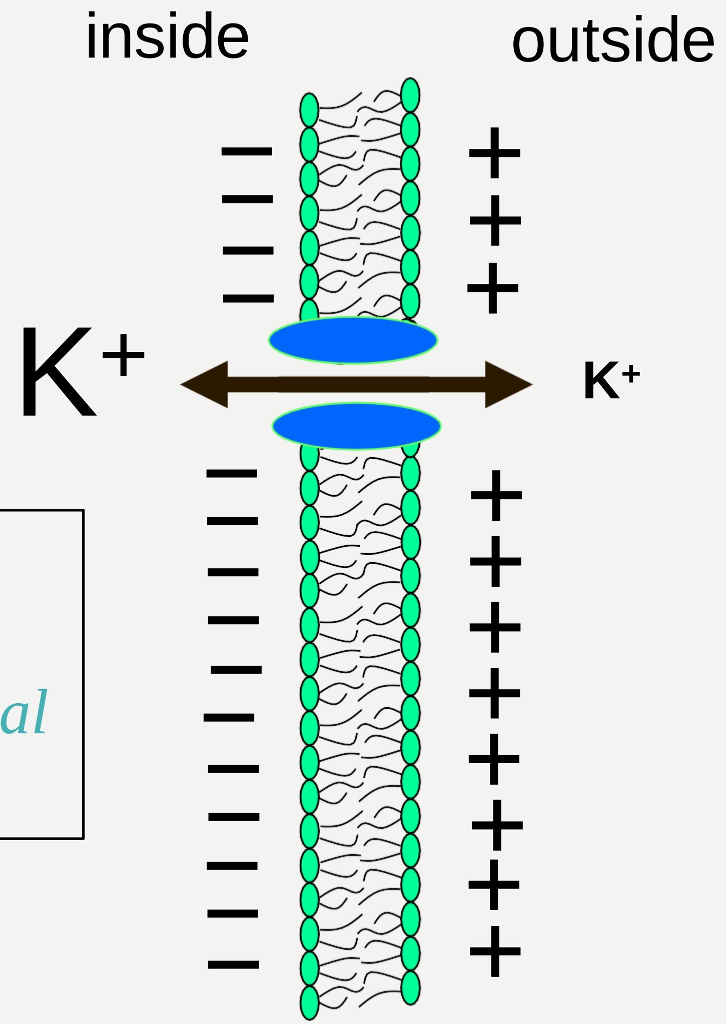
*If a membrane were permeable to only $K^+$ then…*




*$K^+$ would diffuse down its concentration gradient until the electrical potential across the membrane countered diffusion.*

# SIMPLEST CASE SCENARIO: 1 (CONT.)

*If a membrane were permeable to only $K^+$ then…*




*The electrical potential that counters net diffusion of $K^+$ is called the $K^+$ equilibrium potential ($E_K$).*

# THE POTASSIUM NERNST POTENTIAL

*...also called the equilibrium potential*

$$E_K = 26 \ln \frac{[K^+]_o}{[K^+]_i} mV$$

Example: If $K_o$ = 4 mM and $K_i$ = 140 mM

$E_K = 26 \ln(4/140)$

$E_K = -92.44$ mV

*So, if the membrane were permeable only to K+,*

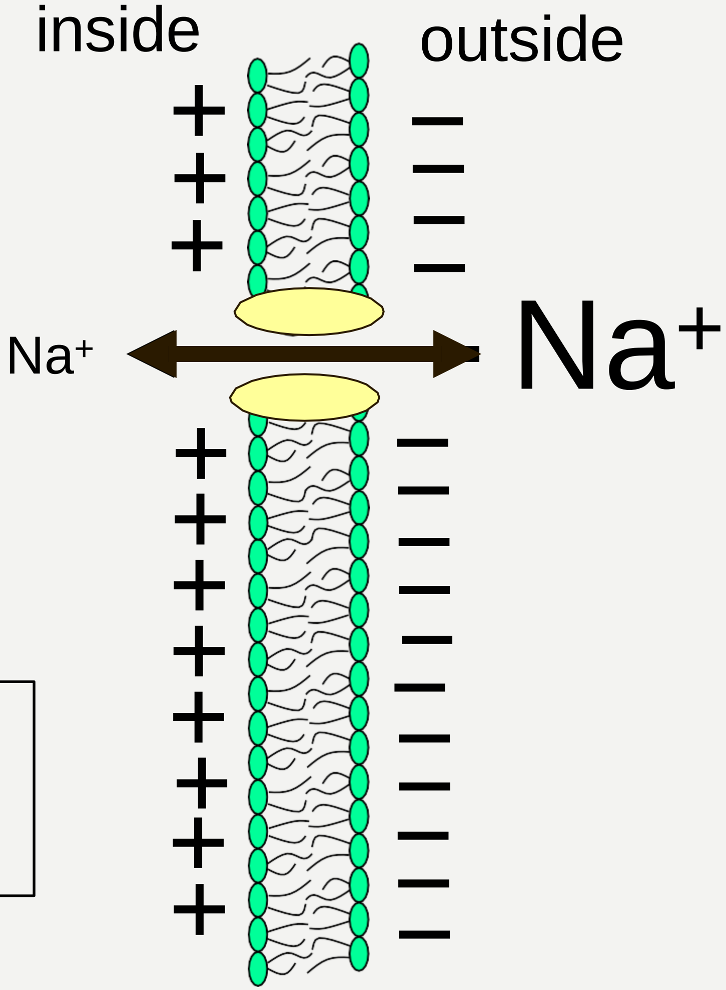
*$V_M$ would be -92.44 mV*

# SIMPLEST CASE SCENARIO: 2

*If a membrane were permeable to only $Na^+$ then…*

$Na^+$ would diffuse down its concentration gradient until potential across the membrane countered diffusion.

The electrical potential that counters net diffusion of $Na^+$ is called the $Na^+$ equilibrium potential ($E_{Na}$).



# THE SODIUM NERNST POTENTIAL

$$E_K = 26 \ln \frac{[Na^+]_o}{[Na^+]_i} mV$$

Example: If $Na_o$ = 142 mM and $Na_i$ = 14 mM

$E_K$ = 26 ln(142/14)

$E_K$ = +60.24 mV

*So, if the membrane were permeable only to $Na^+$,*
*$V_M$ would be +60.24 mV*

# Goldman Equation

- To calculate the overall potential of *multiple* ions
- use the Goldman Equation
- Considers the permeability of ions and their concentrations
- The resting membrane potential of most cells is predicted by the Goldman equation

# Goldman equation

Voltage

$$V_m = \frac{KT}{q} \ln\left(\frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}\right)$$

Permeability

Ion concentration

# Goldman equation

- Example, typical mammalian cell:
    1. Assume permeability for Na is 1/100 of permeability for K, and permeability of Cl is 0
    2. Assume $[K]_{in}$= 140, $[K]_{out}$=5
       $[Na]_{in}$ =10, $[Na]_{out}$=120

$$Vm = \quad 26 \text{ X } \ln \frac{1[5]+0.01[120]+0}{1[140]+0.01[10]+0}$$

$$Vm = -81 mV$$

# Goldman equation

Approximate Intracellular and Extracellular Concentrations of the Important Ions across a Squid Giant Axon, Ratio of Permeabilities, and Nernst Potentials

| Ion | Cytoplasm (mM) | Extracellular Fluid (mM) | Ratio of Permeabilities | Nernst Potential (mV) |
|---|---|---|---|---|
| $K^+$ | 400 | 20 | 1 | −74 |
| $Na^+$ | 50 | 440 | 0.04 | 55 |
| $Cl^-$ | 52 | 560 | 0.45 | −60 |

Note: Permeabilities are relative—that is, $P_K$:$P_{Na}$:$P_{Cl}$—and not absolute. Data were recorded at 6.3°C, resulting in KT/q approximately equal to 25.3 mV.

Calculate $V_m$ for the squid giant axon at 6.3°C.

$$V_m = 25.3 \times \ln\left(\frac{1 \times 20 + 0.04 \times 440 + 0.45 \times 52}{1 \times 400 + 0.04 \times 50 + 0.45 \times 560}\right) mV = -60\, mV$$

# RESTING MEMBRANE POTENTIAL

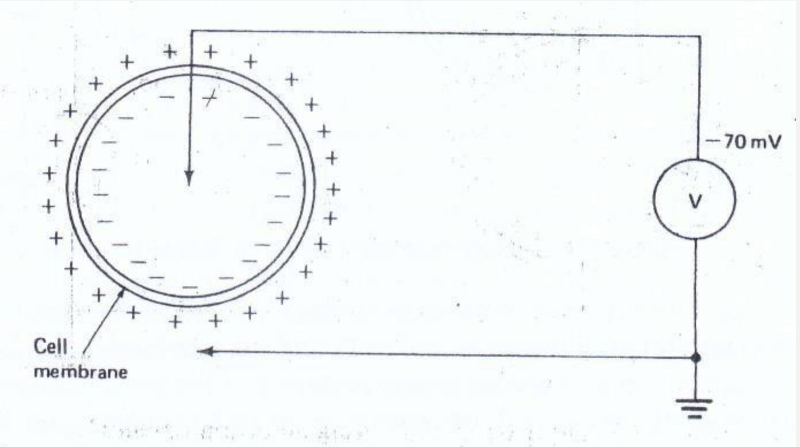
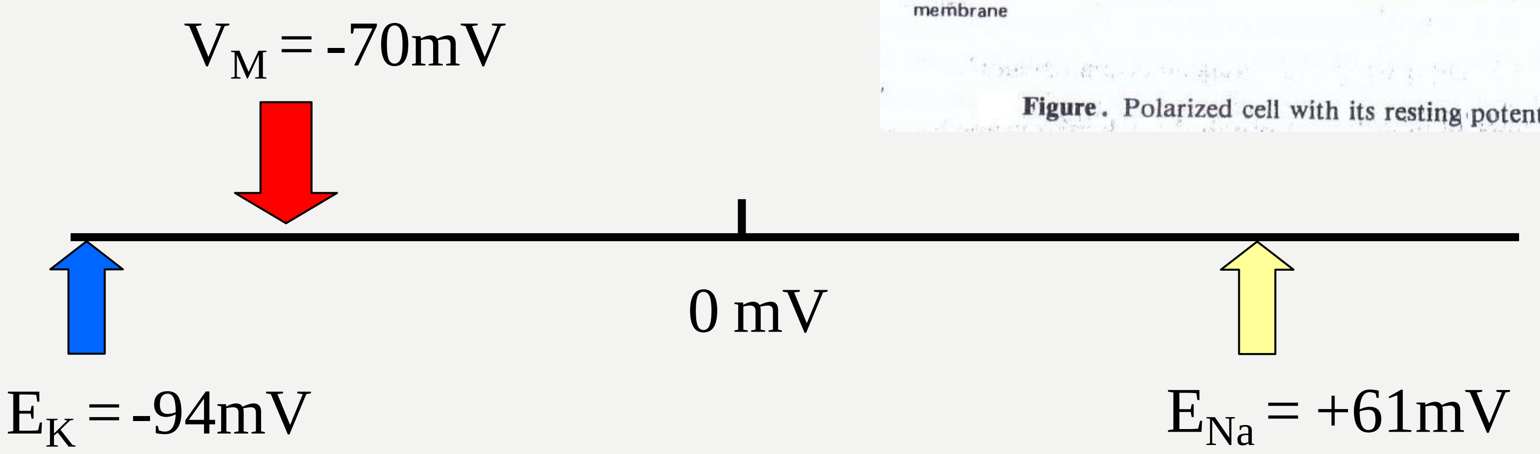



**Figure.** Polarized cell with its resting potential.




*Why is $V_M$ closer to $E_K$?*

# ACTION POTENTIAL

- When a section of the cell membrane is excited by the flow of ionic current or by some form of externally applied energy, the membrane changes its characteristics and begins to allow some of the sodium ions ($Na^+$) to enter.
- This ionic movement causes a current flow which further reduces the membrane barrier to sodium ions.
- The net result in an avalanche effect in which $Na^+$ ions rush into the cell,

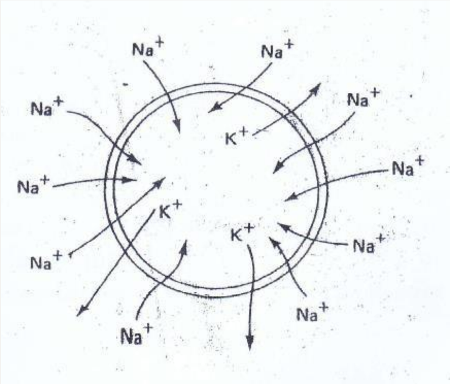



Fig. *Depolarization* of a cell

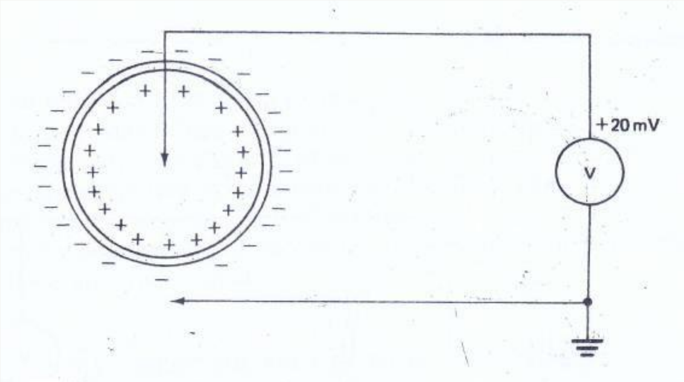



**Figure.** Depolarized cell during an action potential.

As a result, the cell has a slightly positive potential on the inside. This potential is known as the **action potential** *and* is approximately +20 mV.

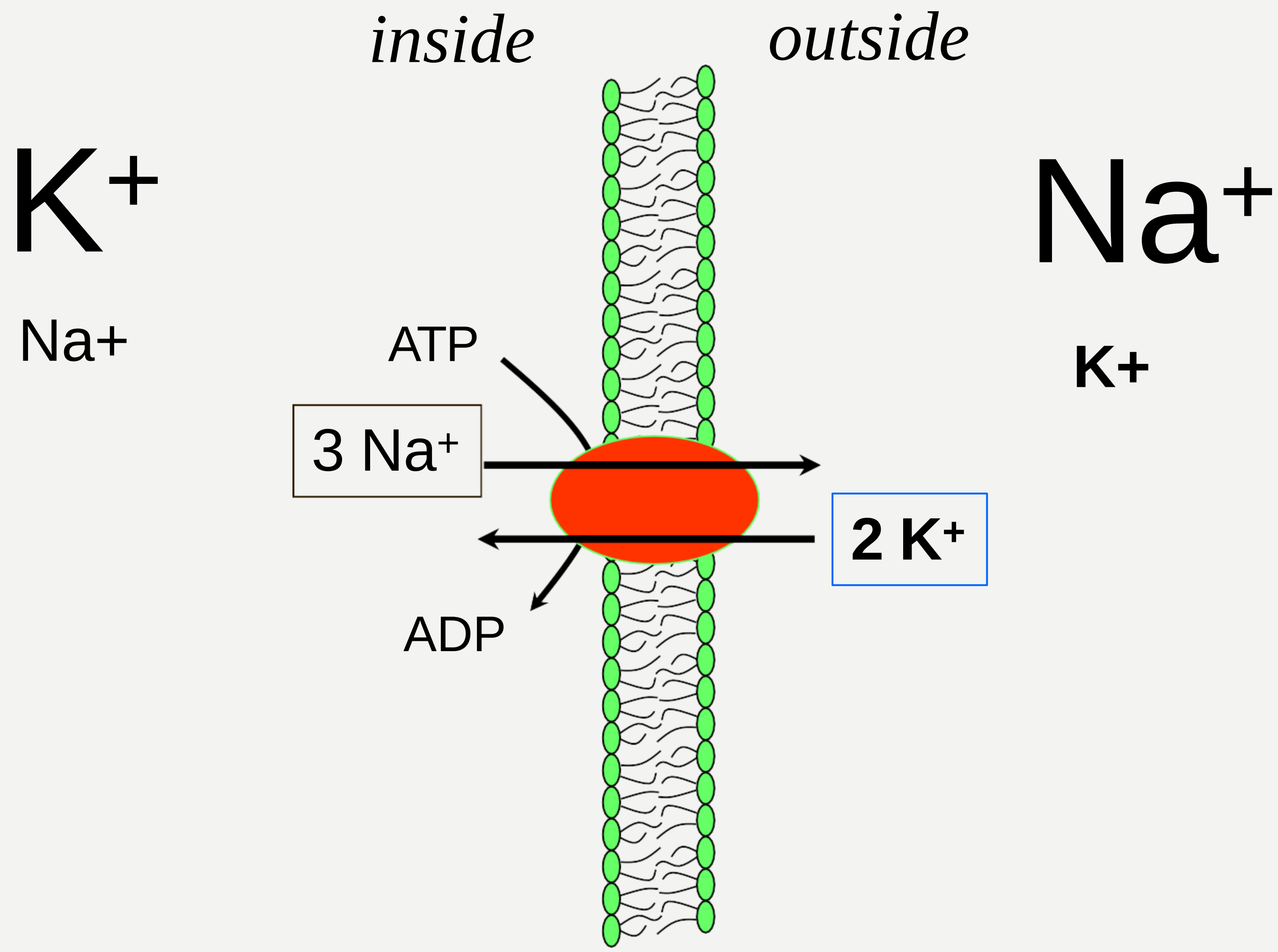
# REPOLARIZATION

- After $Na^+$ moves in passively until the $Na^+$ channels start to close
- At the same time $K^+$ permeability increases as **voltage-gated $K^+$ channels** open –they are a bit slower to respond to the depolarisation than the $Na^+$ channels
- The $K^+$ ions move out
- This makes the cell negative inside with respect to outside again
- The membrane potential falls

# HYPERPOLARIZATION & REFRACTORY PERIOD

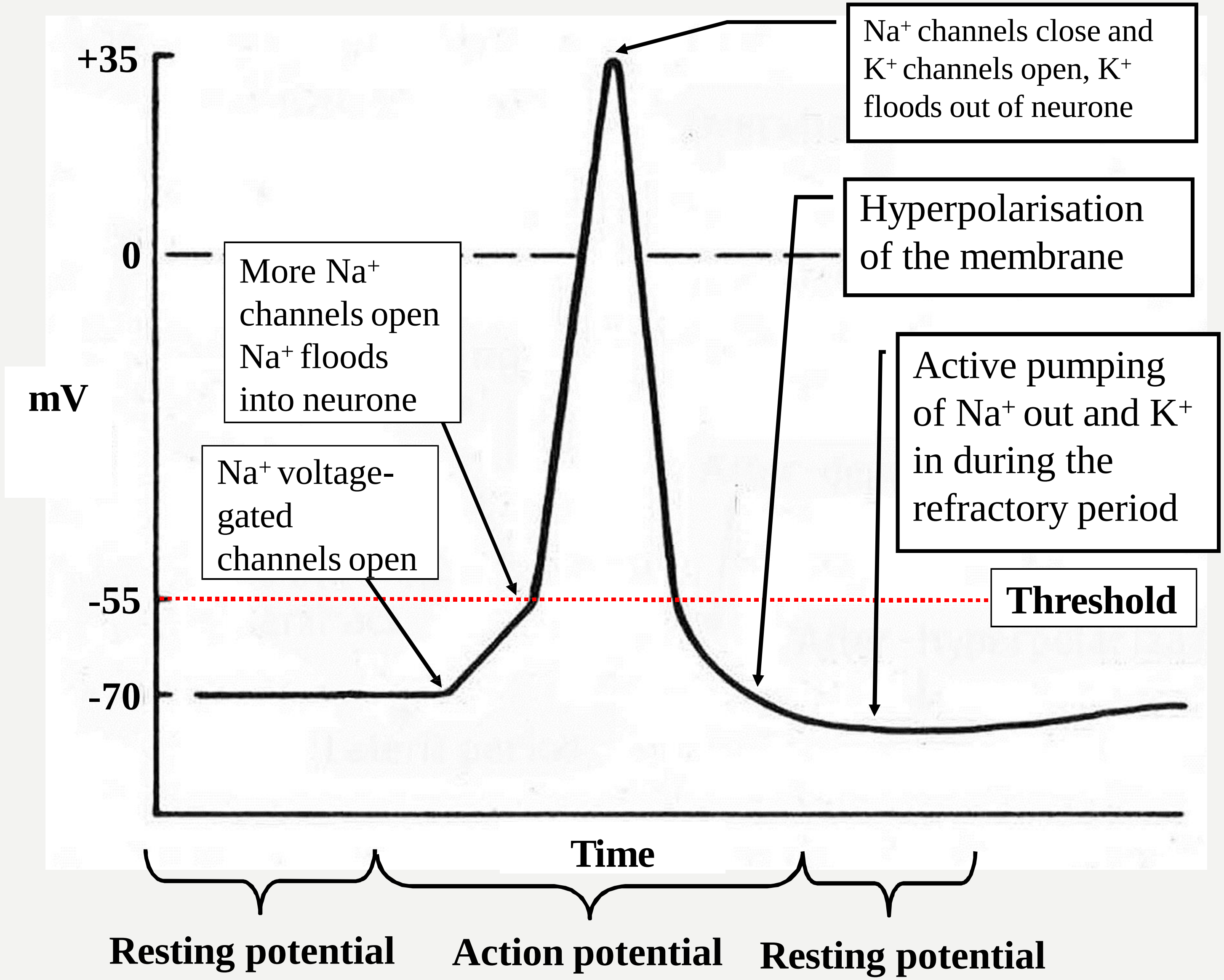
- The membrane potential falls below the resting potential of –70mV
- It is said to be **hyperpolarised**
- Gradually active pumping of the ions ($K^+$ in and $Na^+$ out) restores the resting potential
- During this period no impulses can pass along that part of the membrane
- This is called **the refractory period**

# HYPERPOLARIZATION & REFRACTORY PERIOD



# WAVEFORM OF THE ACTION POTENTIAL

*- scale may vary with type of cell*

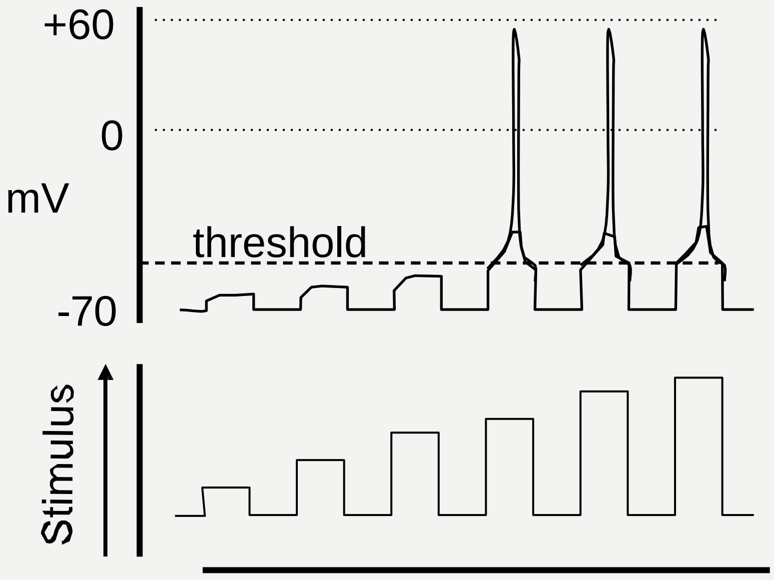



[Summary]

# PROPERTIES OF ACTION POTENTIALS

**Action potentials:**

- ➢ are all-or-none events
  - ❑ threshold voltage (usually 15 mV positive to resting potential)
- ➢ are initiated by depolarization
- ➢ have constant amplitude
- ➢ have constant conduction velocity



# PROPAGATION OF ACTION POTENTIALS

Opening of $Na^+$ channels generates local current circuit that depolarizes adjacent membrane, opening more $Na^+$ channels…

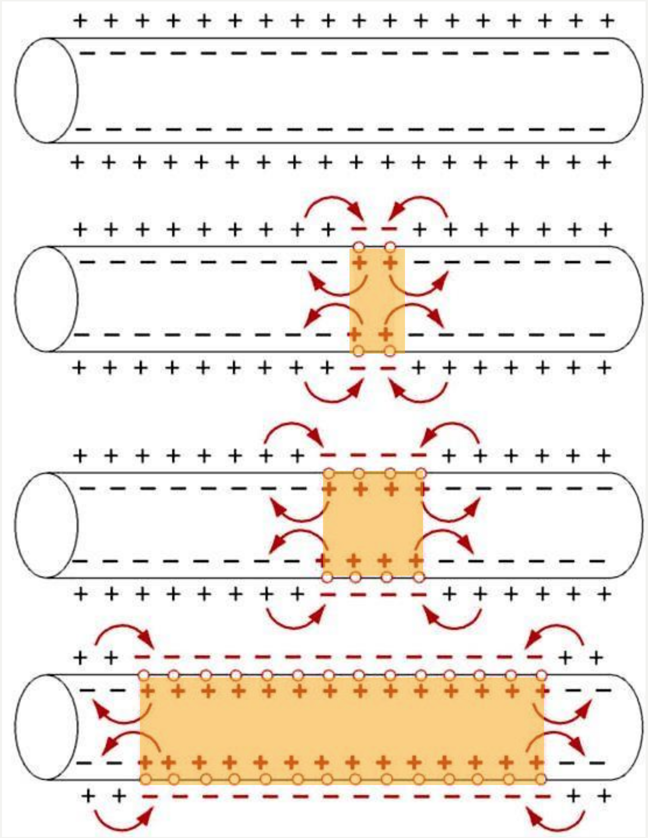
**Rest**

**Stimulated**

(local depolarization)

**Propagation**

(current spread)




Thank you