EXCITABLE TISSUES: Nerve And Muscle

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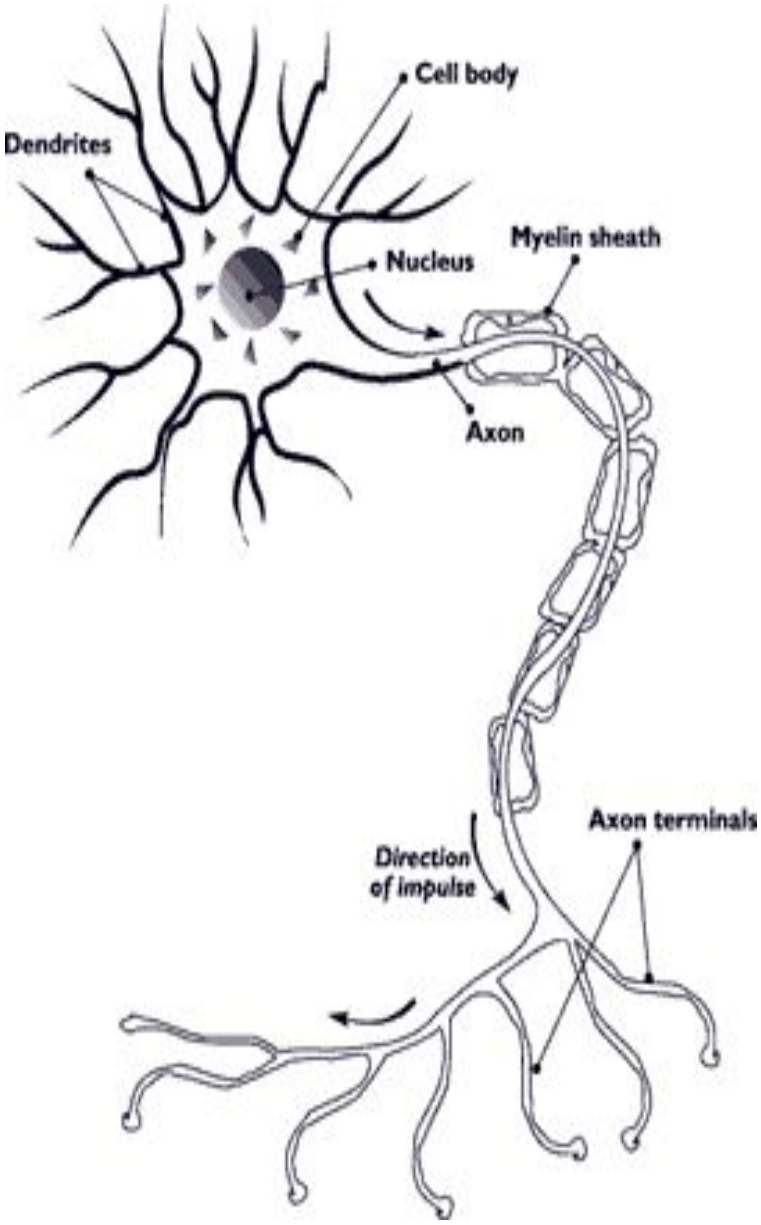
Learning objectives:

by the end of these lectures the student should know

- Morphology of the nerve cell & functional organization of neurons
- Excitation & conduction along the nerve (local & propagated action potentials)
- Resting membrane potential (causes & recording)
- Action potential (ionic bases & recording) electrical changes that occur on a nerve on stimulation.
- Compound action potential
- Changes in excitability during electronic potential (local) & action potential
- All or non law
- Saltatory conduction
- Energy sources & metabolism of nerve
- Properties of mixed nerve
- Nerve types & functions

Nerve cells:

- The neurons are the basic building blocks of the nervous system, their axons may or may not myelinated.
- The myelin sheath is produced by the Schwan cells. It envelops the axon except at the ends & **the nodes of Ranvier**
- The impulse is conducted faster in myelinated than unmyelinated nerves.



Resting Membrane Potential

Definition: it is the potential difference recorded across the cell membrane at rest.

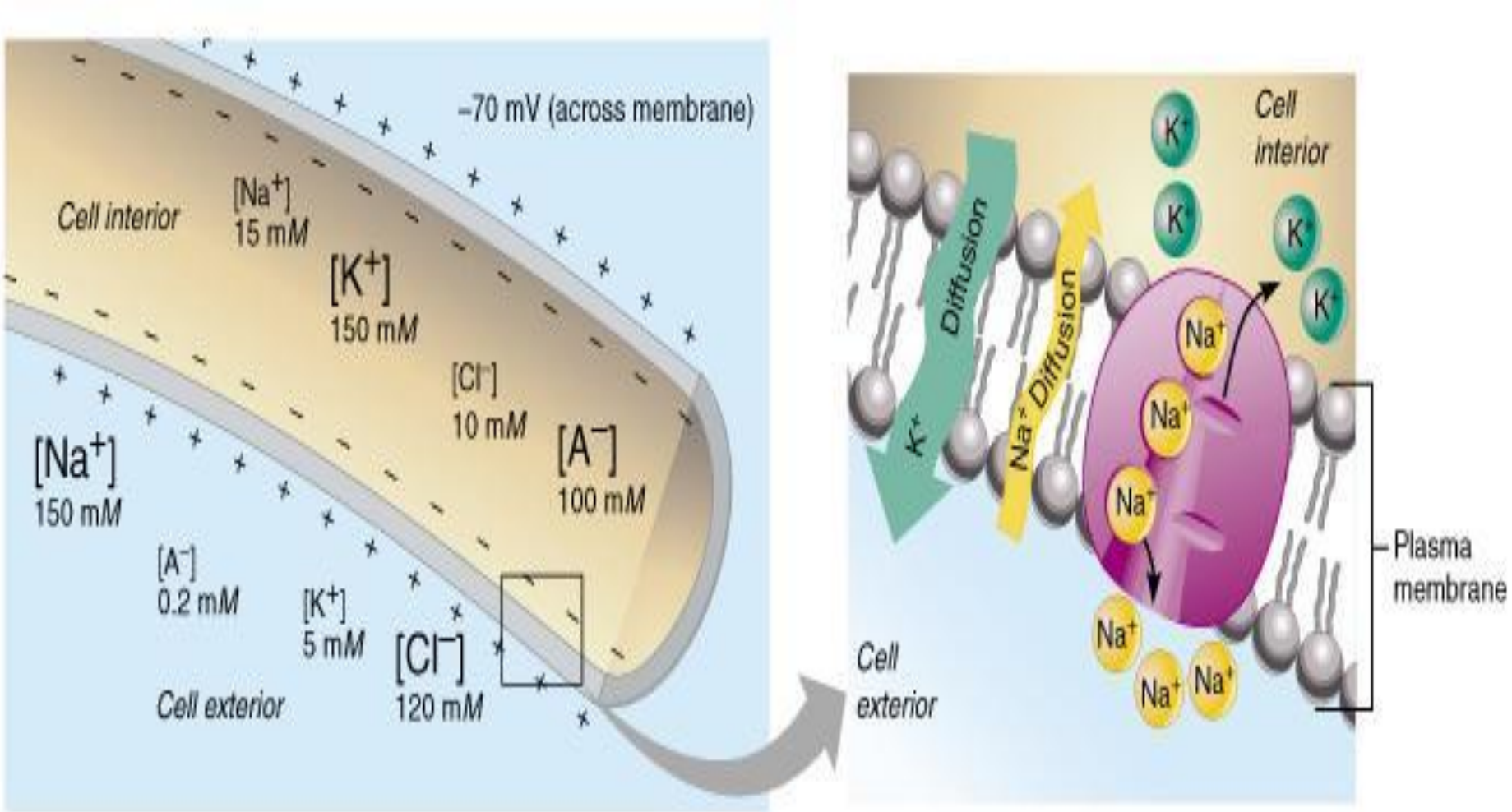
- **Causes:**
- 80% caused by selective permeability of the cell membrane

The K+ diffuses out the cell & Na+ diffuses inside the cell according to concentration gradient. The K+ permeability is 50-75 folds more than Na+

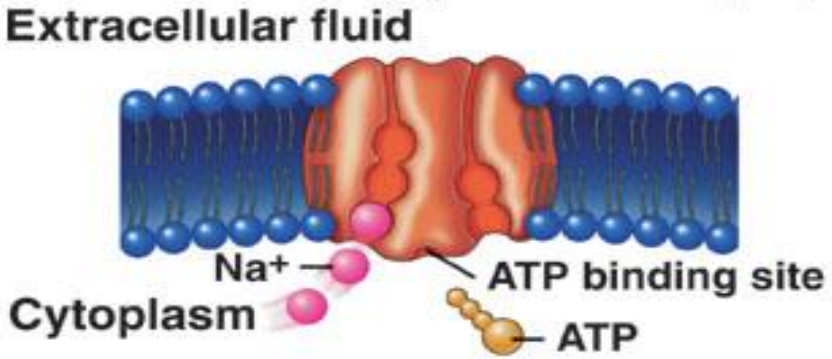
- 20% is caused by the Na+ K+ pump

an active process that needs energy taken from ATP. This is very important to maintain the concentration gradient across the cell membrane

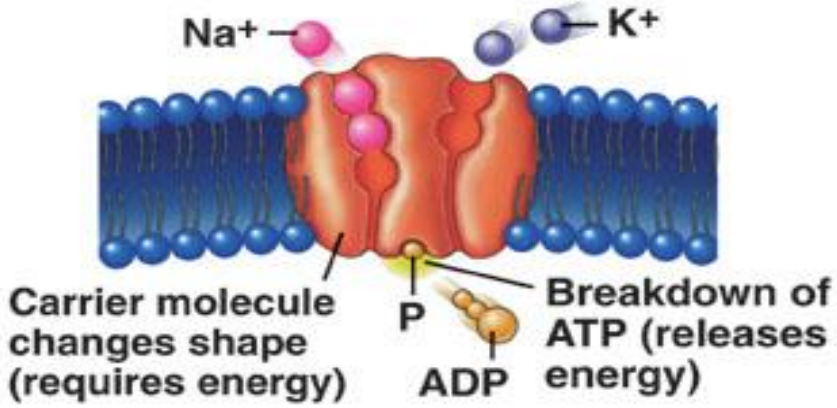
Resting Membrane Potential (V_r)



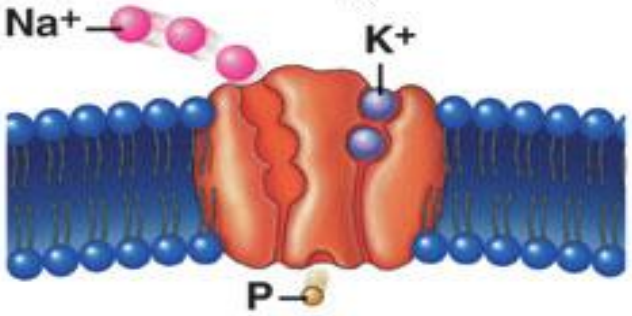
Sodium-Potassium Exchange Pump



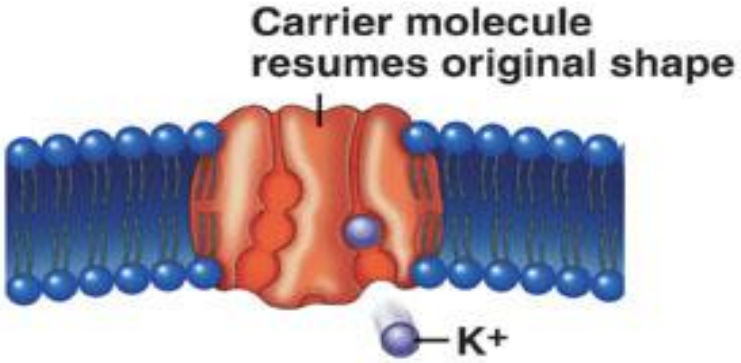
1. Three Na^+ and ATP bind to the carrier molecule.



2. The ATP breaks down to ADP and phosphate and releases energy. The carrier molecule changes shape, and Na^+ are transported across the membrane.



3. Na^+ diffuse away from the carrier molecule, two K^+ bind to the carrier molecule, and the phosphate is released.



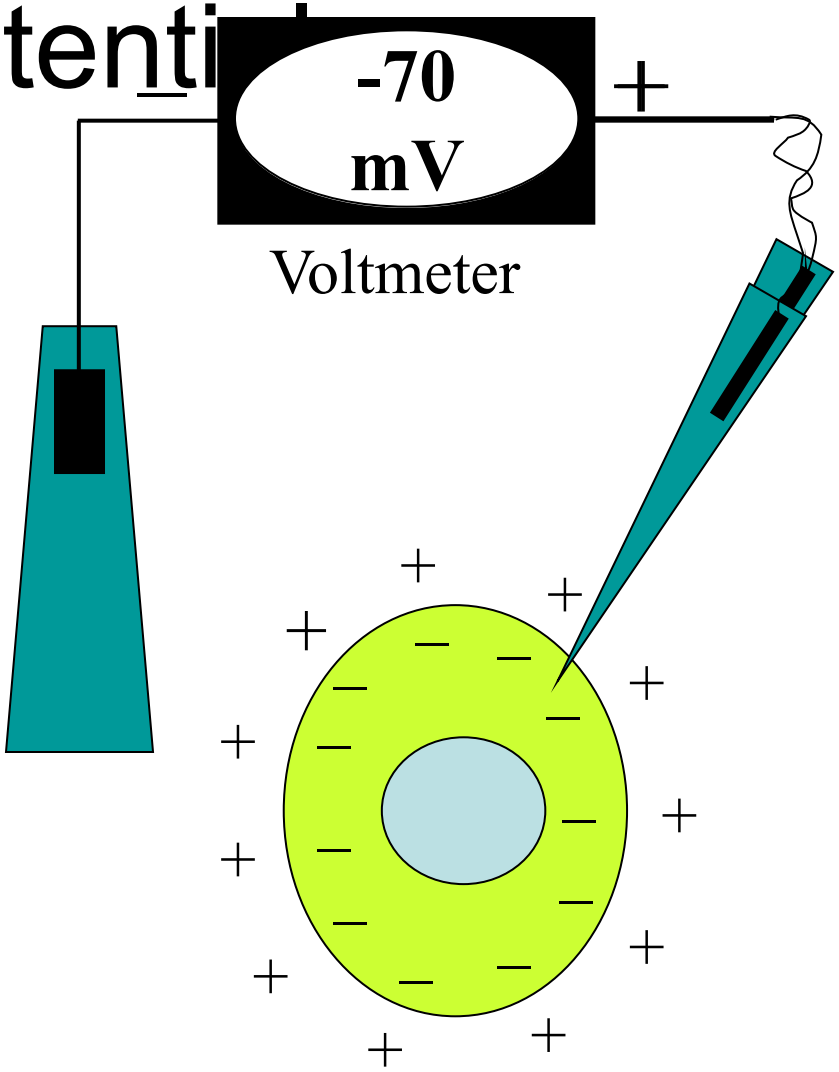
4. The carrier molecule resumes original shape, transporting K^+ across the membrane, and K^+ diffuse away from the carrier molecule. The carrier molecule can again bind to Na^+ and ATP.

- **Significance:**
- PROTEINS have a negative charge & can not leave the cell to the outside
- K+ efflux is not accompanied by an equal influx of anions & membrane is maintained in a polarized state with the outside positive relative to the inside making the RMP for a nerve to be - 70 mV

Recording of Resting and action potential

- It is recorded by cathode ray oscilloscope

it is negative in polarized (*resting, the membrane can be excited*) state with the potential difference inside the cell membrane is negative relative to the outside.



Excitation & conduction:

Nerve cells have low threshold for excitation.

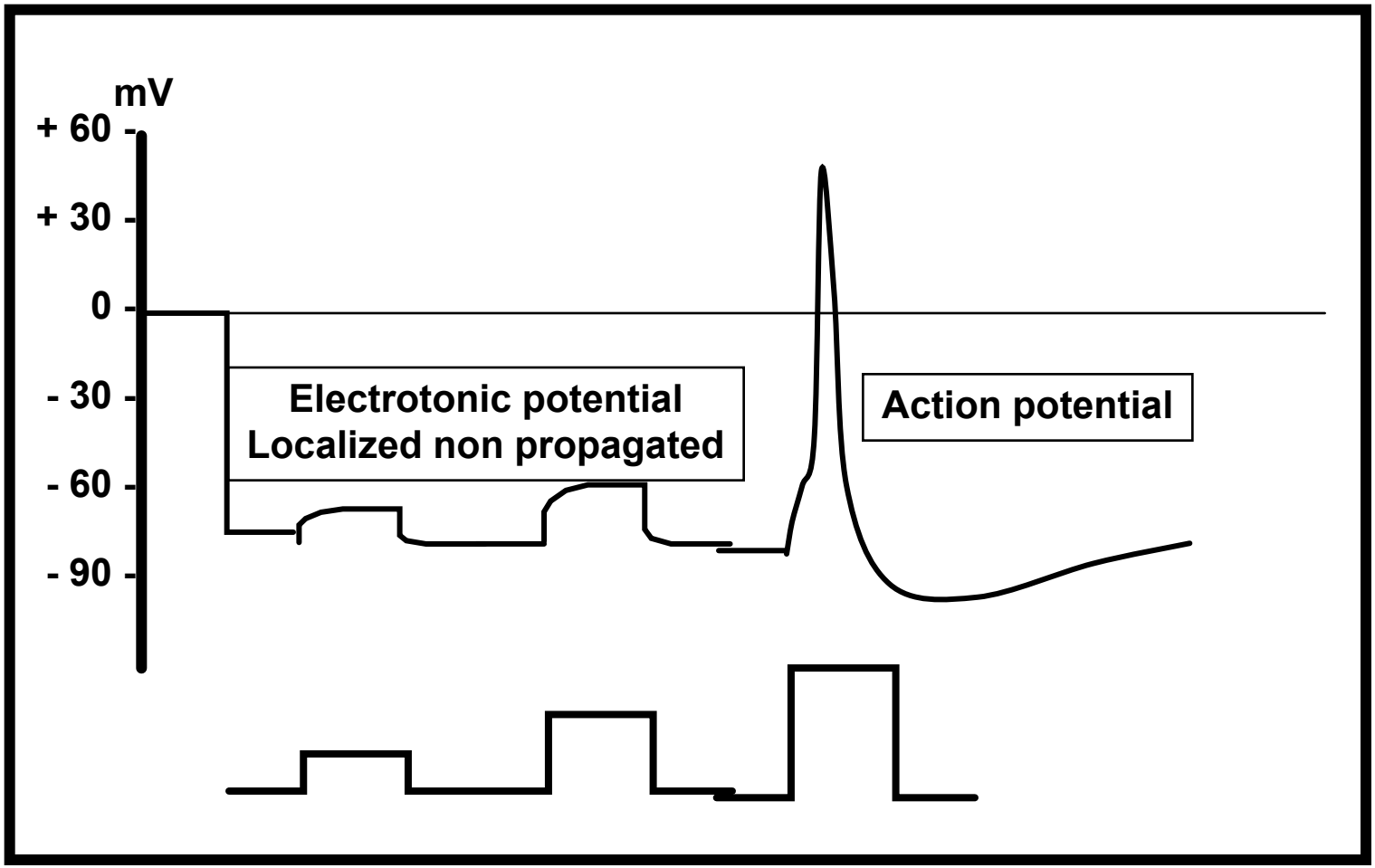
The stimulus may be electrical, chemical or mechanical.

Two types of potentials may be produced

- Local (Non-propagated action potential) named after its location **synaptic, generator or electronic** potential
- PROPAGATED ACTION POTENTIAL (nerve impulse).

Both are due to changes in the conduction of ions across the cell membrane that are produced by alternations in the ion channels

Recording membrane potential



- **All or non law:**
- Application of a threshold stimulus either produces a full response or not at all.
- Further increase in the intensity of a stimulus produces no increment or other changes in action potential.
- The action potential failed to occur if the stimulus is sub-threshold, it produces only local changes with no propagation.
- **Latent period in a nerve**: it is a period corresponding to the time taken from the site of simulation till the recording electrode.

Stimulation of a nerve produces:

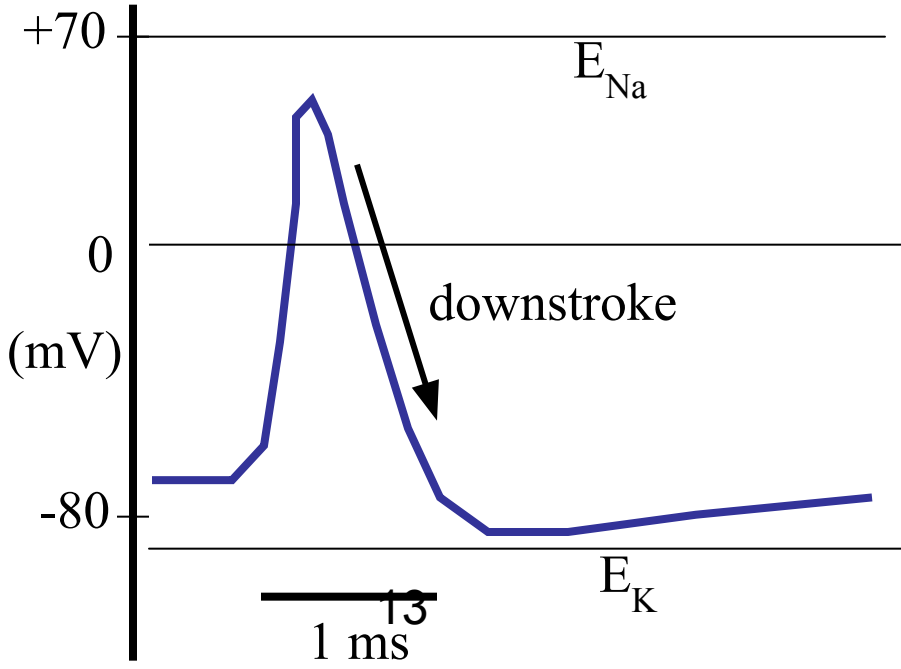
- ELECTRICAL CHANGES CALLS ACTION POTENTIAL
- EXCITABILITY CHANGES.
- THERMAL CHANGES

The action potential (AP)

- An action potential is:
  - A regenerating depolarization of membrane potential that ***propagates*** along an ***excitable*** membrane.

[propagates = conducted without decrement (an 'active' membrane event)]
[excitable = capable of generating action potentials]

- **Action potentials:**
  - **are all-or-none events**
    - **need to reach threshold**
  - **have constant amplitude**
    - **do not summate**
  - **are initiated by depolarization**
  - **involve changes in permeability**
  - **rely on voltage-gated ion channels**

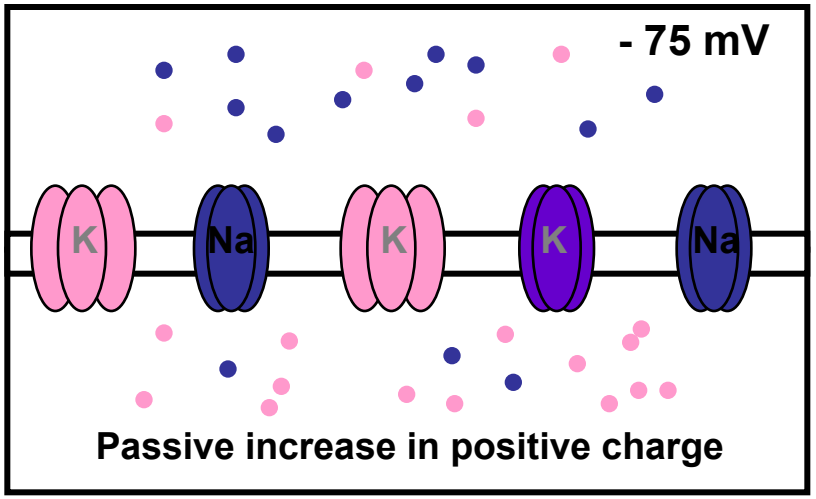


Threshold and Action Potentials

- Threshold – membrane is depolarized by 15 to 20 mV
- Established by the total amount of current flowing through the membrane
- Weak (subthreshold) stimuli are not relayed into action potentials
- Strong (threshold) stimuli are relayed into action potentials
- All-or-none phenomenon – action potentials either happen completely, or not at all

The Action Potential

Equilibrium potential of sodium (+60 mV)



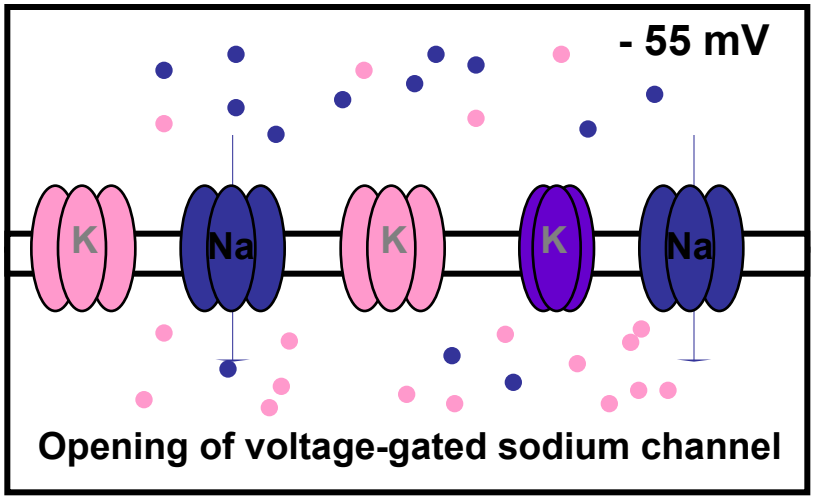
Electrotonic potential

Resting potential (-75 mV)

Equilibrium potential of potassium (-95 mV)

The Action Potential

Equilibrium potential of sodium (+60 mV)



threshold

Electrotonic potential

Resting potential (-75 mV)

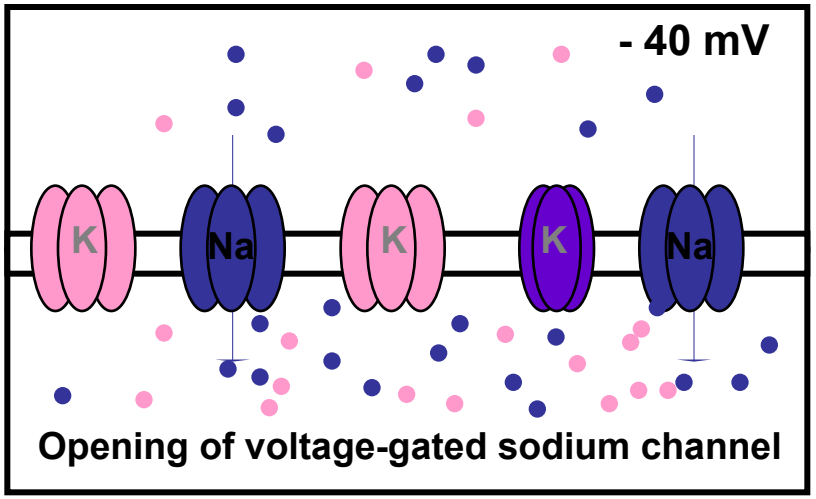
Equilibrium potential of potassium (-95 mV)

The Action Potential

Equilibrium potential of sodium (+60 mV)

Depolarisation due to sodium influx

Electrotonic potential



Resting potential (-75 mV)

Equilibrium potential of potassium (-95 mV)

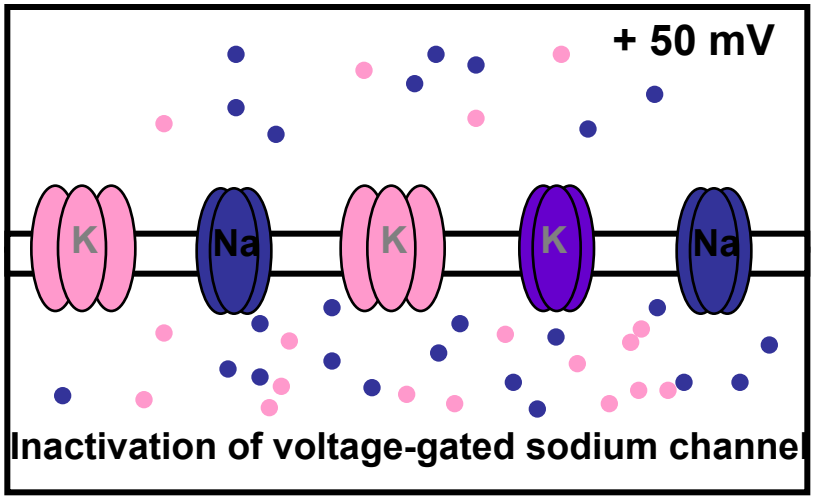
The Action Potential

voltage-gated sodium channels turn to the inactivation phase

Equilibrium potential of sodium (+60 mV)

Depolarisation due to sodium influx

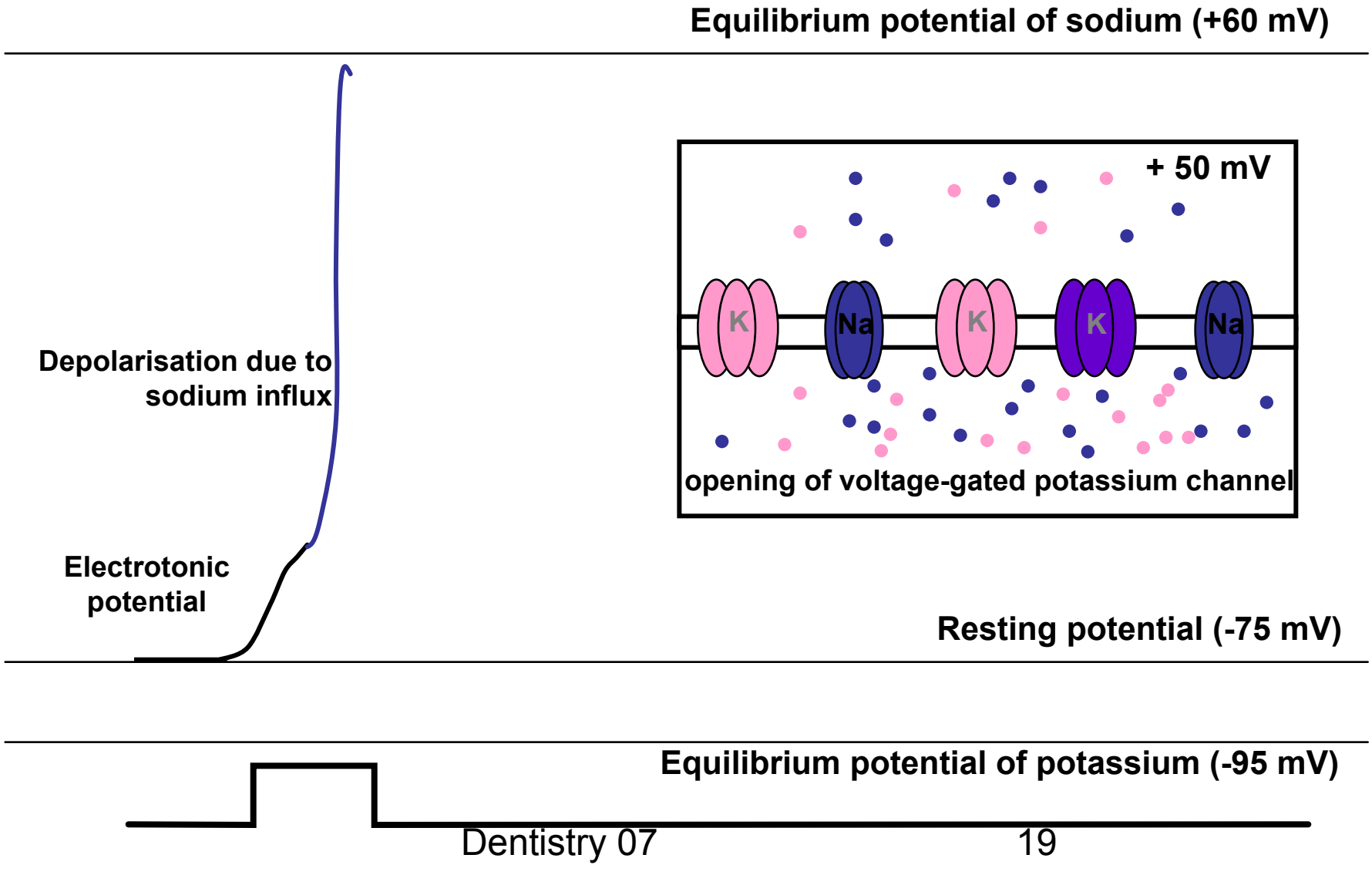
Electrotonic potential



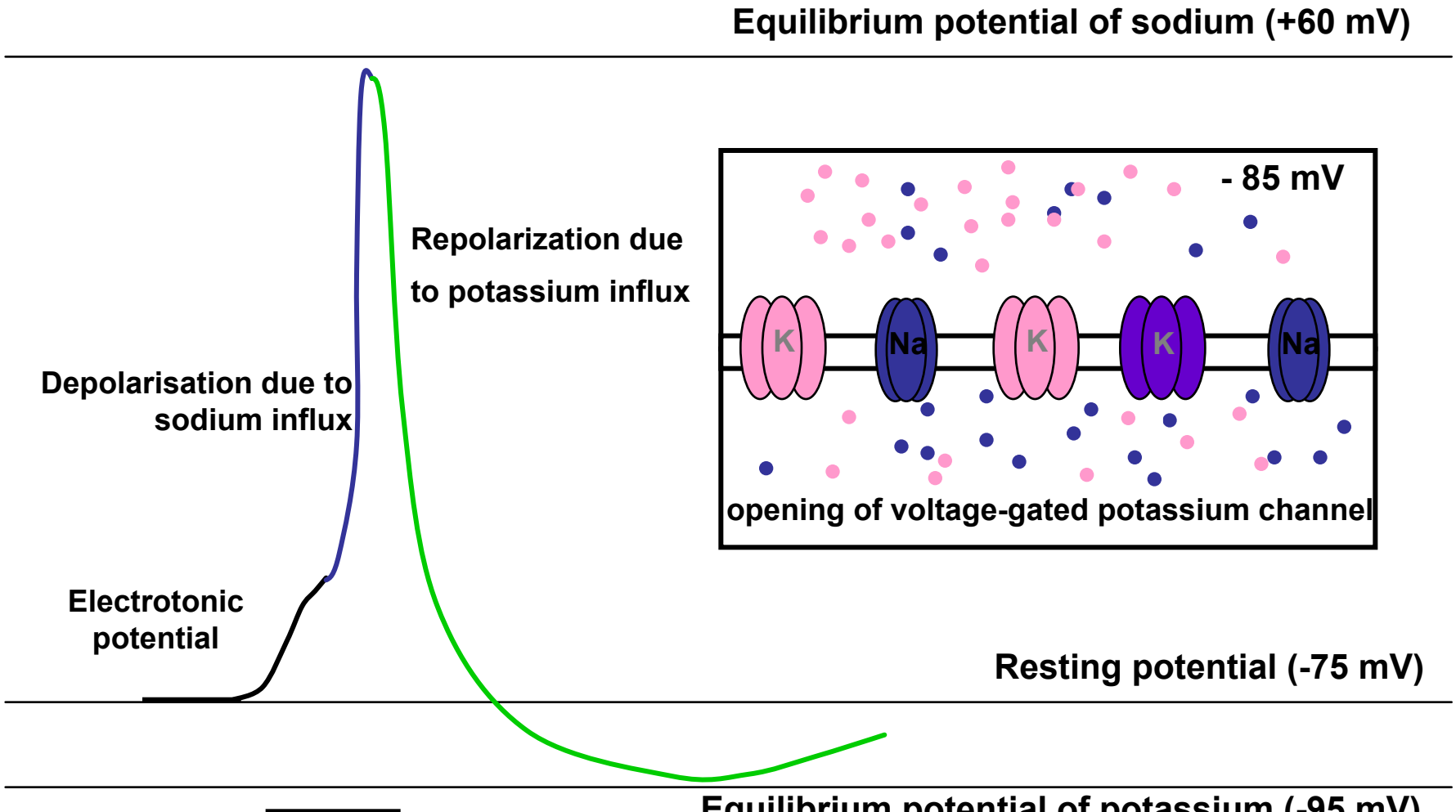
Resting potential (-75 mV)

Equilibrium potential of potassium (-95 mV)

The Action Potential



The Action Potential



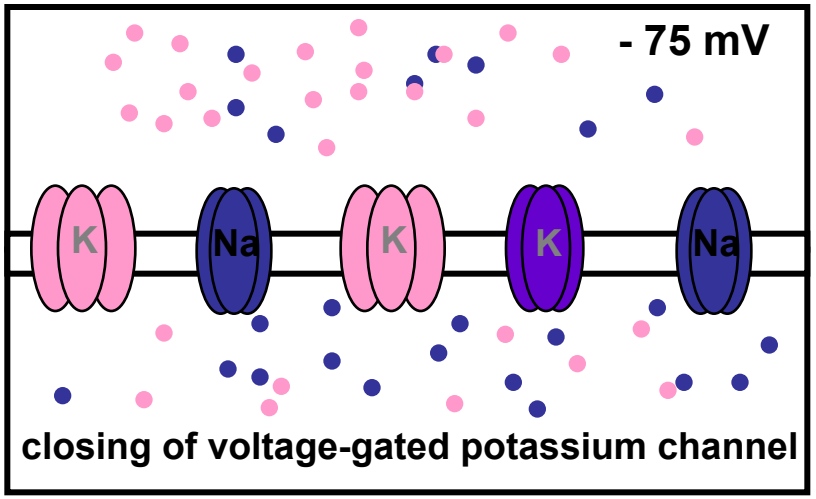
The Action Potential

Membrane potential approaches the E_{Na} and voltage-gated sodium channels turn to the inactivation phase

Equilibrium potential of sodium (+60 mV)

repolarization due to potassium influx

Depolarisation due to sodium influx



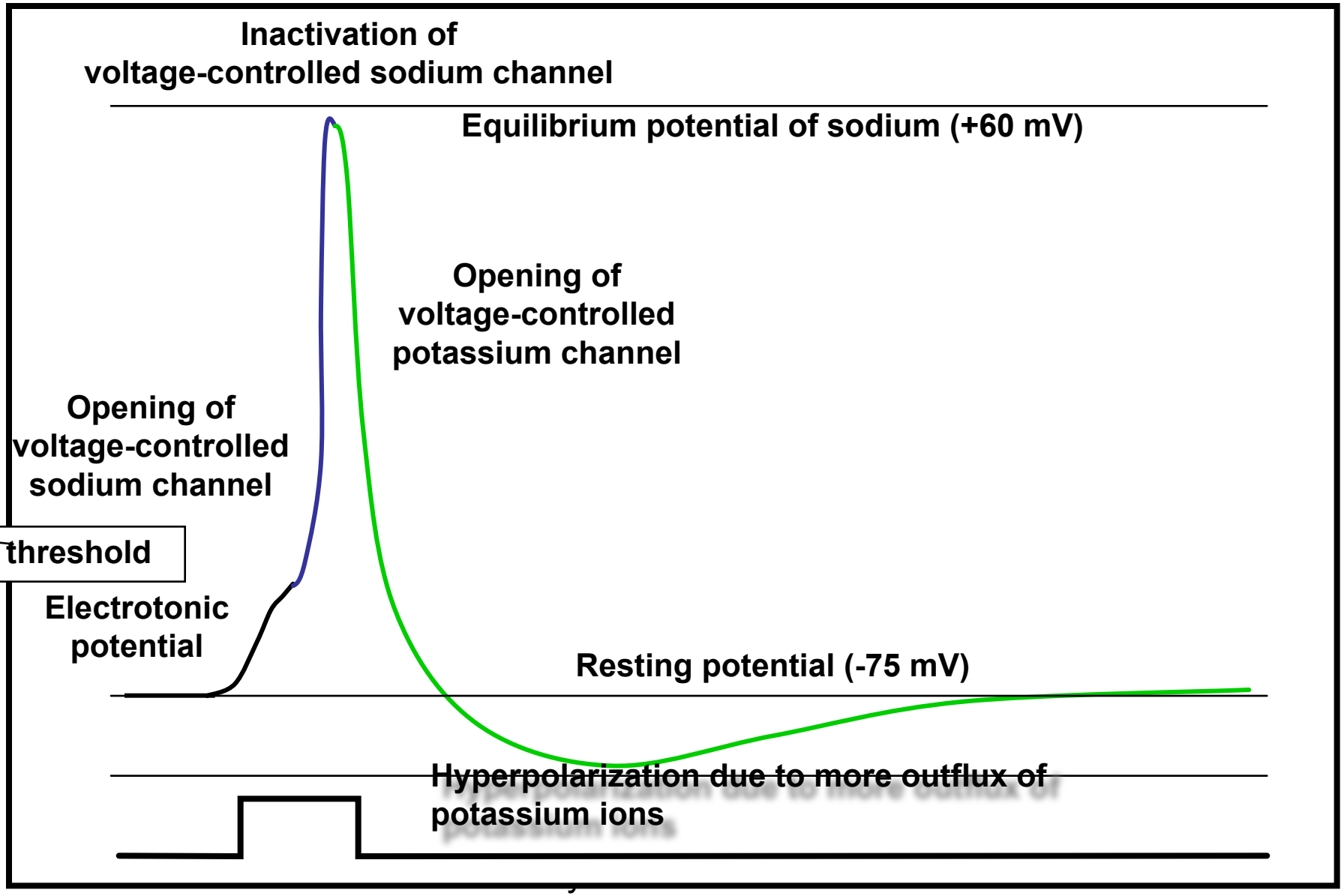
Electrotonic potential

Resting potential (-75 mV)

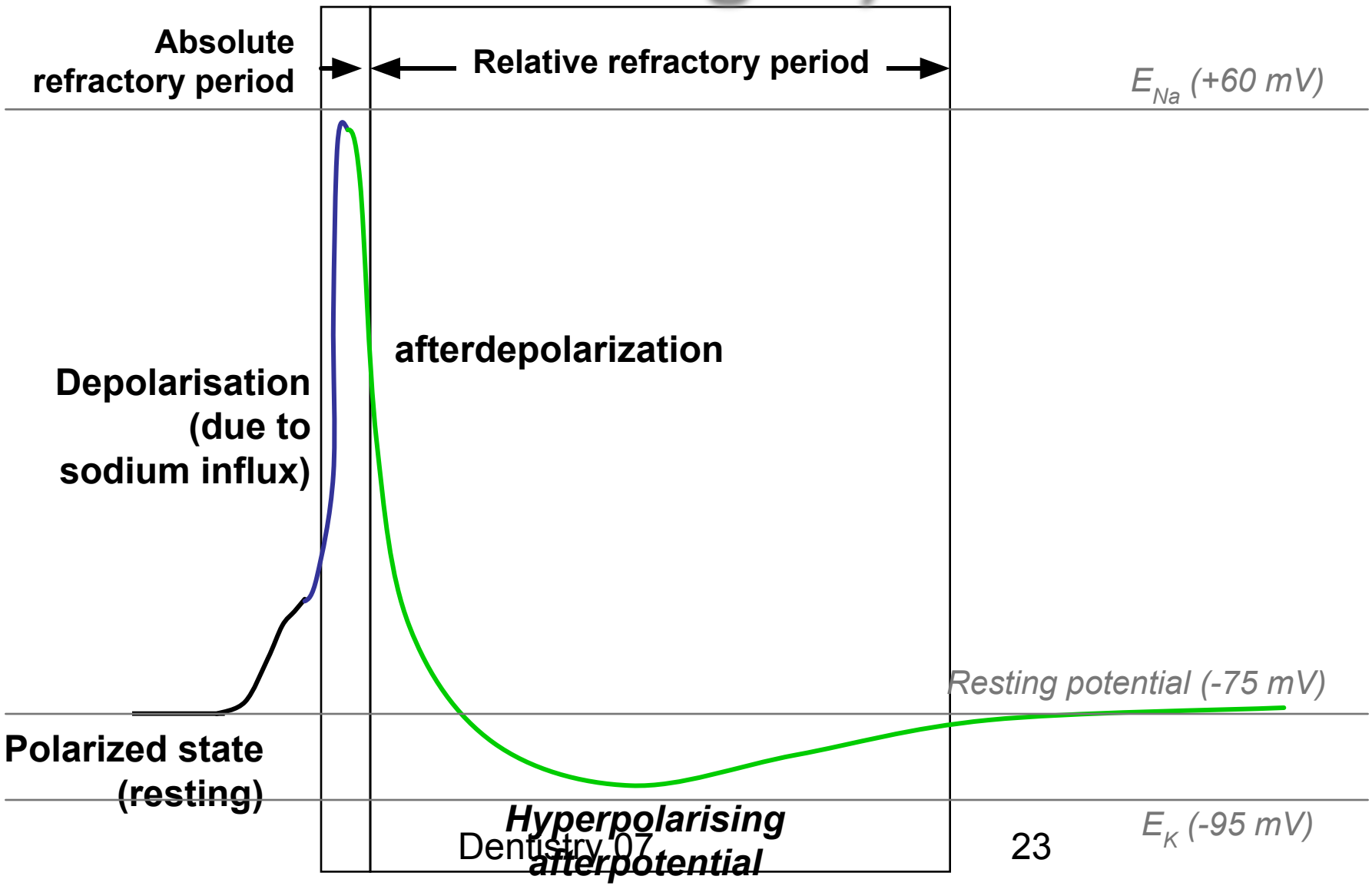
Hyperpolarising afterpotential

Repolarisation due to potassium influx

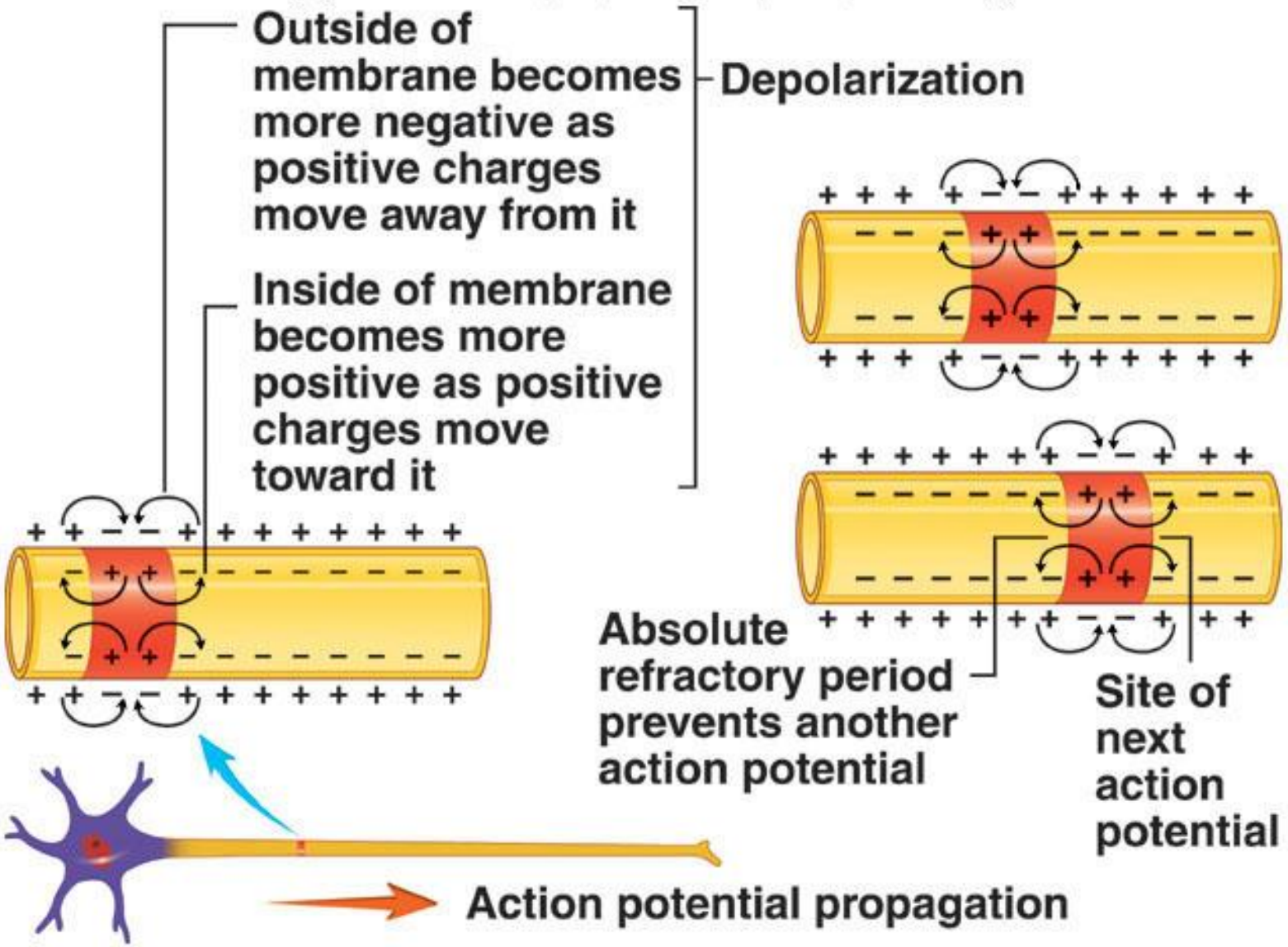
The Action Potential



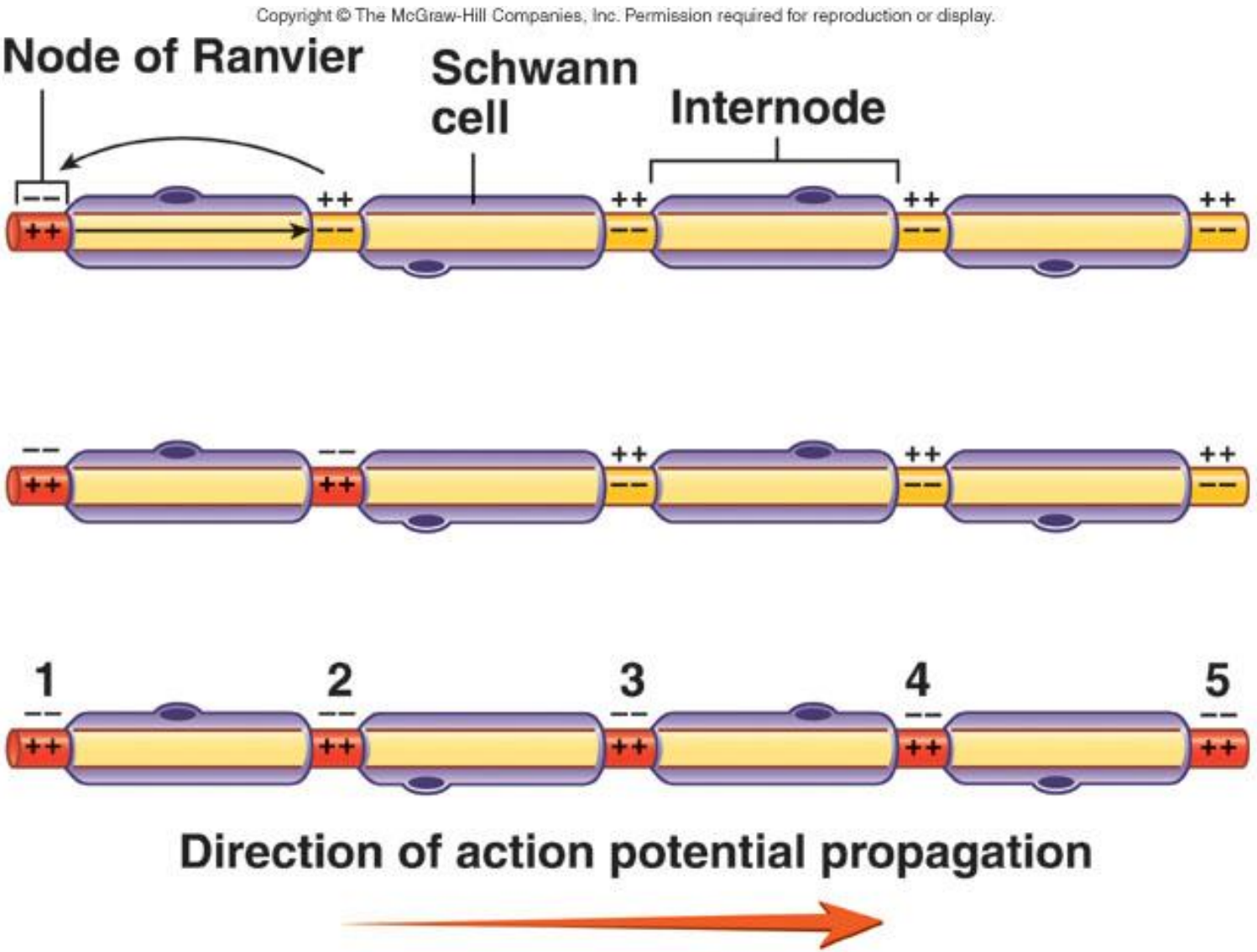
The Action Potential (excitability changes)



Action Potential Propagation



Saltatory Conduction: Action Potential Propagation in a Myelinated Axon

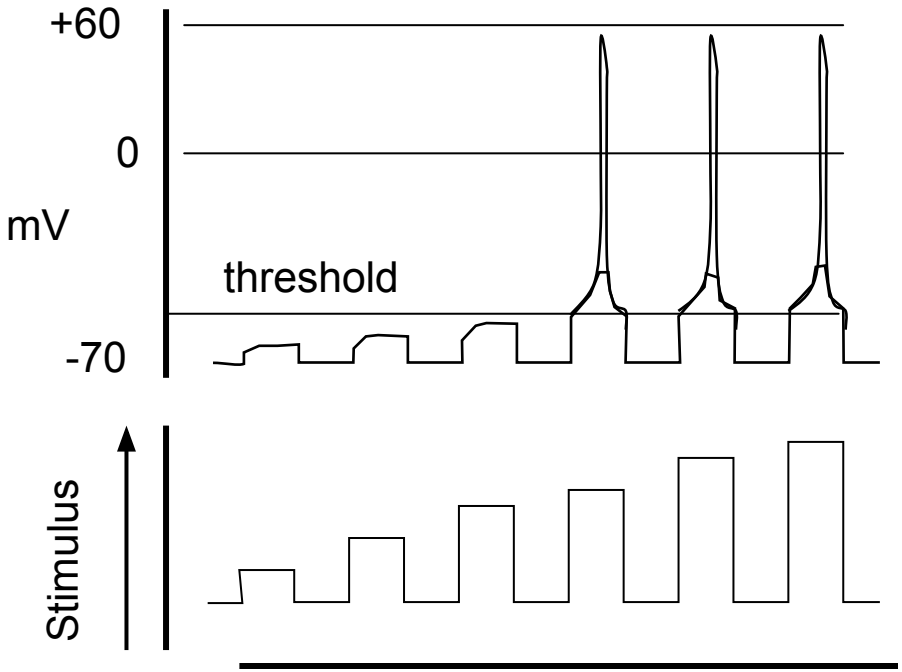


Propagation of an Action Potential (Time = 1ms)

- **Ions of the extracellular fluid move toward the area of greatest negative charge**
- **A current is created that depolarizes the adjacent membrane in a forward direction**
- **The impulse propagates away from its point of origin**

Properties of action potentials

- **Action potentials:**
- **are all-or-none events**
- **threshold voltage (usually 15 mV positive to resting potential)**

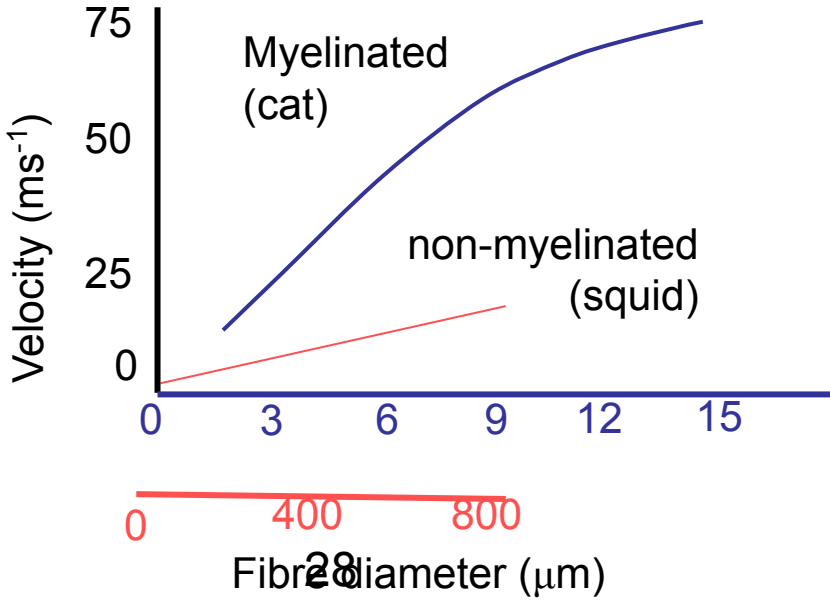


- **are initiated by depolarization**
- **action potentials can be induced in nerve and muscle by extrinsic (percutaneous) stimulation –**
- **APs do not summate - information is coded by frequency not amplitude.**

Properties of action potentials

- **have constant conduction velocity**
- **True for given fibre. Fibres with large diameter conduct faster than small fibres. As general rule:**

- **Impulses are conducted faster in myelinated fibre than non- myelinated fibre**



Functions of action potentials

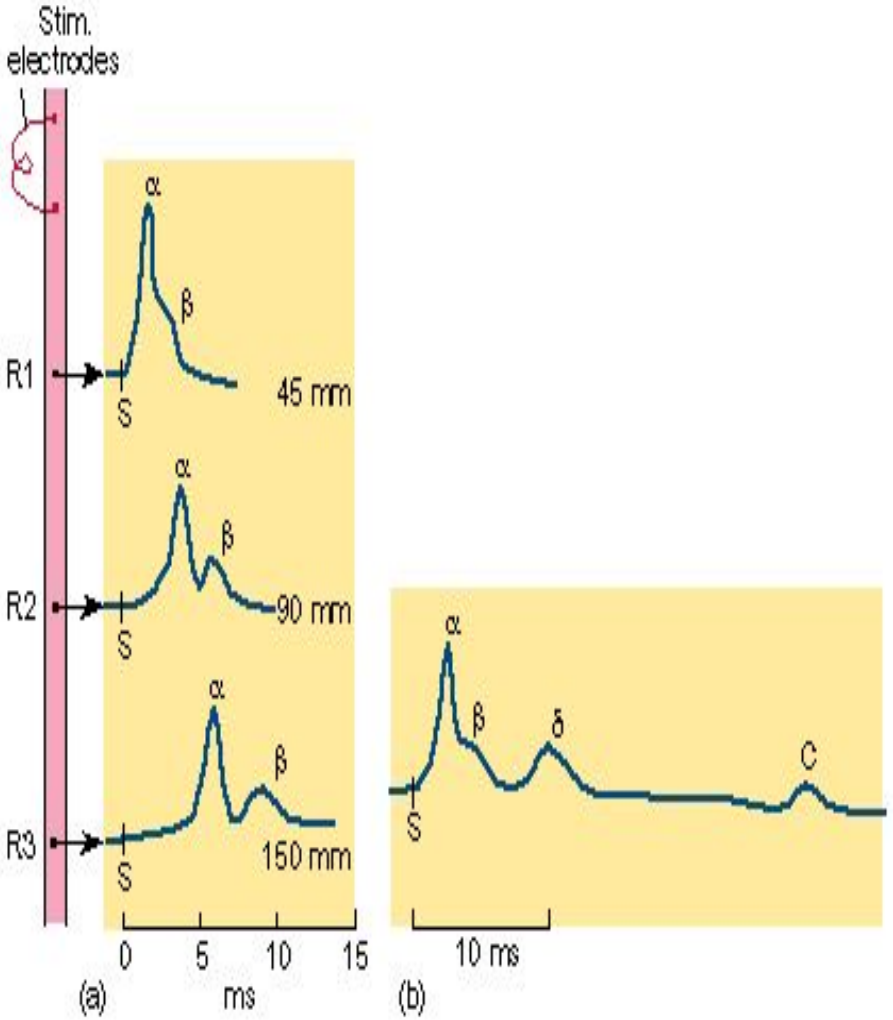
- Information delivery to CNS
  - carriage of all sensory input to CNS. Consider block APs in sensory nerves by local anaesthetics. This usually produces analgesia without paralysis. This is because LAs are more effective against small diameter (large surface area to volume ratio) C fibers than a-motorneurones.
- Information encoding
  - The frequency of APs encodes information (remember amplitude cannot change) - *covered in lecture 3.3.*

Functions of action potentials

- Rapid transmission over distance (nerve cell APs)
  - Note: speed of transmission depends on fiber size and whether it is myelinated. Information of lesser importance carried by slowly conducting unmyelinated fibers.
- In non-nervous tissue APs are the initiators of a range of cellular responses
  - muscle contraction
  - secretion (eg. Adrenalin from chromaffin cells of medulla)

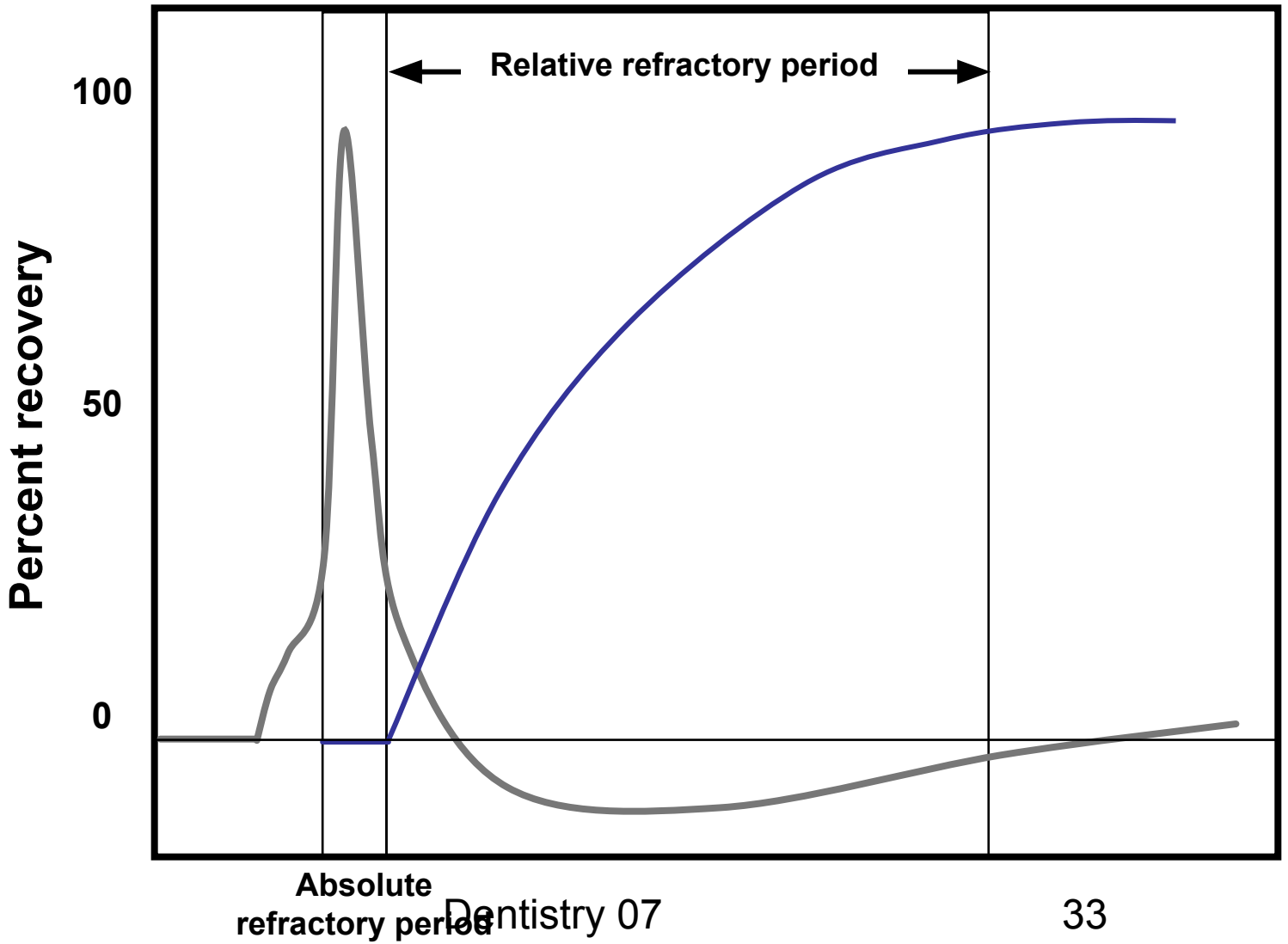
Conduction velocity of AP

- Compound action potentials can be recorded from nerve truncks
- usually done percutaneously from nerves that are close to the surface (eg. Ulnar nerve)
- The passage of an action potentials in all the axons in the nerves is seen as a small (μV) voltage signal on body surface



- as recordings are made further from the site of stimulation the waveform develops into several discrete peaks
- Each peak was named: **alpha** - the first to appear; **beta** - the next, and so on.
- The first signal to arrive at a distant recording site has travelled the fastest!
- So each peak represents a set of axons with similar conduction velocity
- velocity is calculated from the distance between R1 and R3 and the time taken to traverse that distance - distance/time = velocity (ranges from 0.5 to ~100 ms-1)

Recovery of membrane excitability during the refractory period

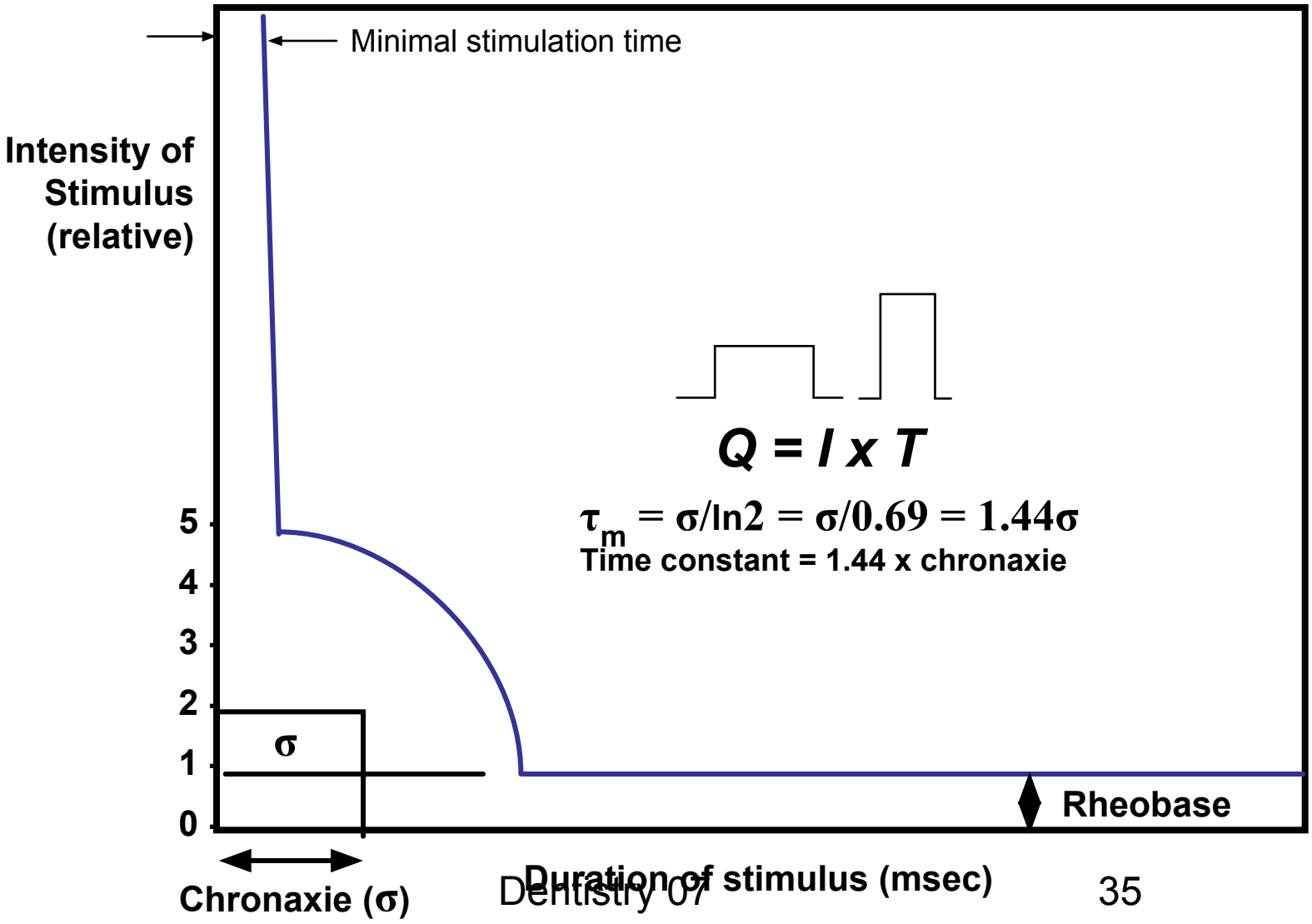


- **Rheobase:** It the least minimal threshold current, needed to excite the nerve, below it no excitation occurs whatever the duration of application of the stimulus

- ***Utilization time:*** It is the time needed by Rheobase to excite

- **Chronaxie:** It is the time needed by a stimulus double Rheobase strength to excite. It is the measure of excitability, the shorter the Chronaxie, the greater is the excitability of tissue (it is longer in smooth muscles than in skeletal)

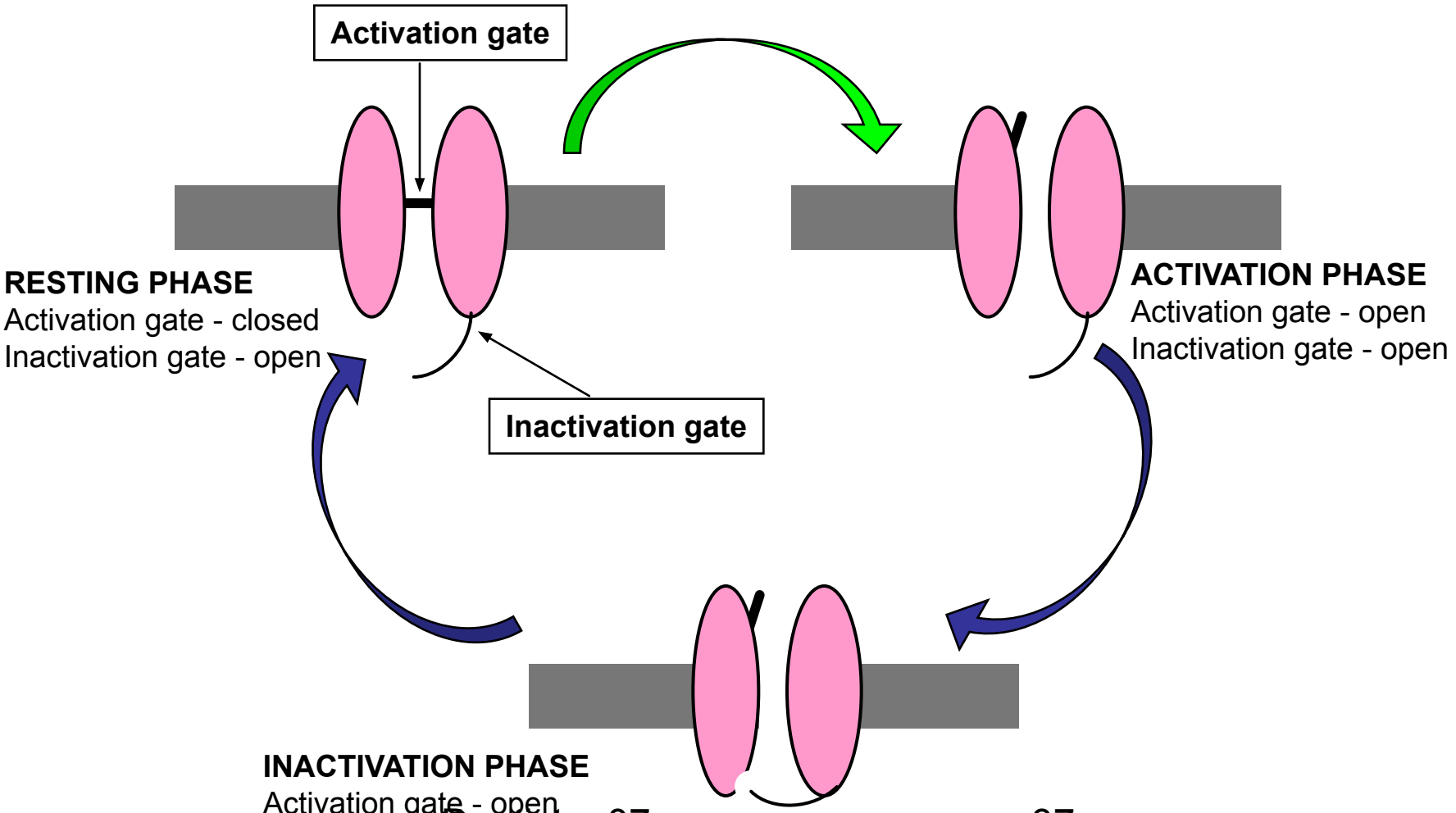
Strength-Duration Curve for Action Potential Initiation



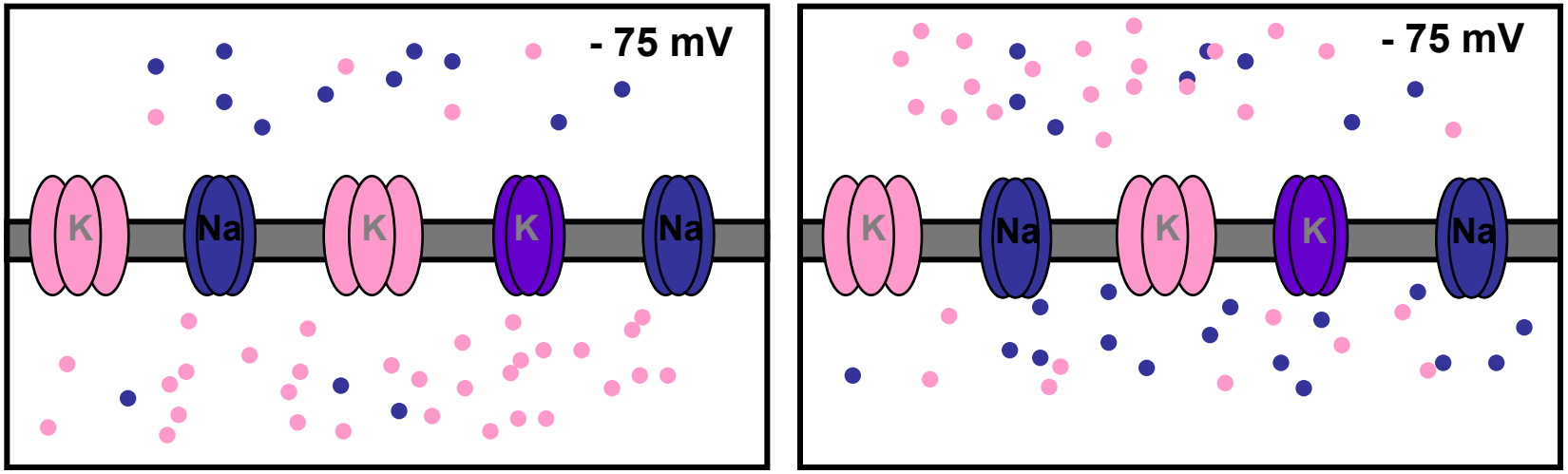
Characteristics of Action Potential

- Threshold
- All-or-none property

Cycle of Ion Channel



Ionic Concentration Before and After Action Potential



Before action potential **After action potential**

● *Potassium ion* ● *Sodium ion*

Pump and Maintenance of Membrane Potential