Department of Anesthesia Techniques
Title of the lec2 : Cardiovascular system

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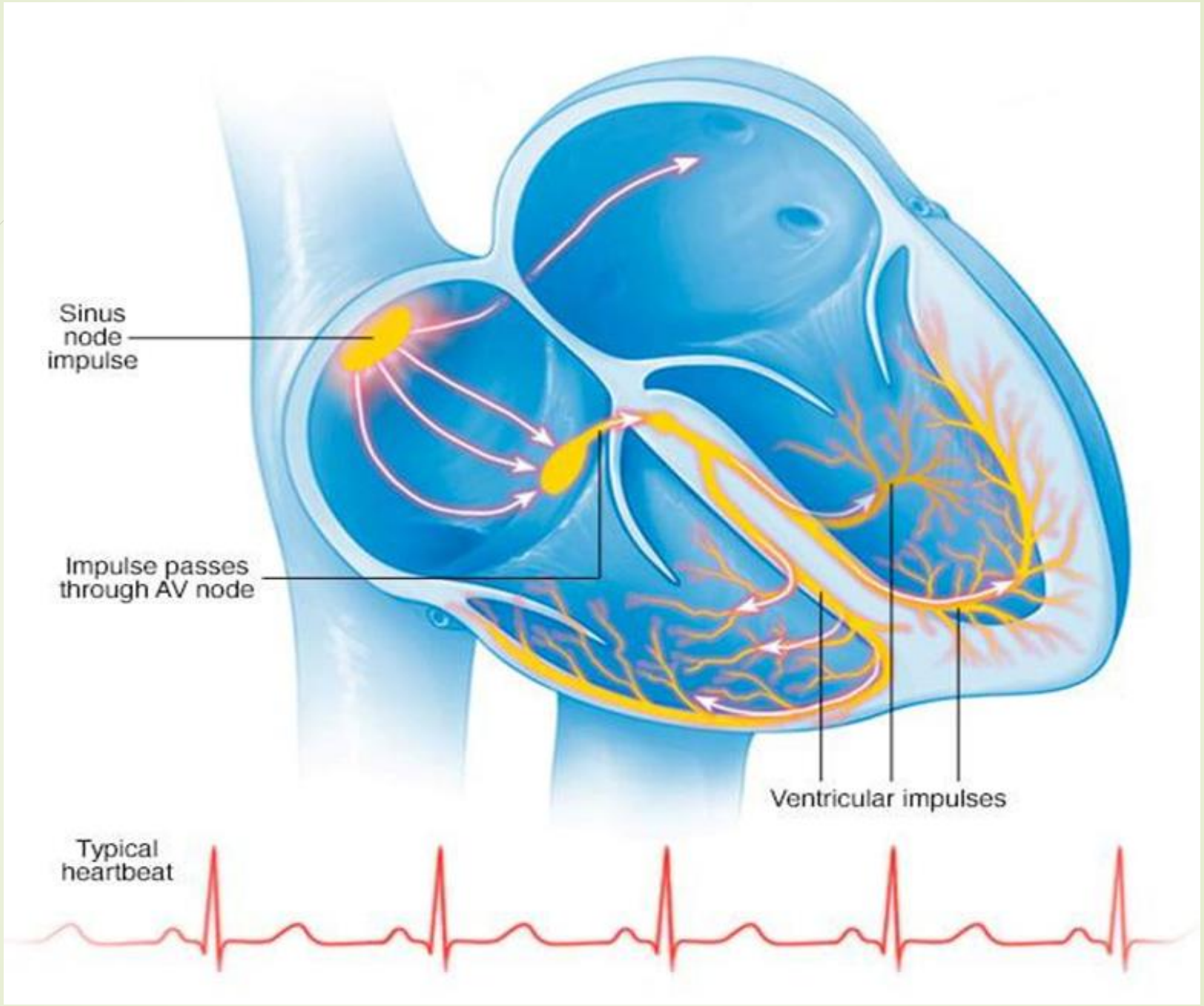
Learning Objectives:

- Cardiac action potential in cardiomyocytes and pacemaker tissue.
- Mechanism of cardiac muscle contraction.
- Excitation-contraction coupling.

- The primary function of cardiac muscle is to pump blood into circulation at a regular manner. Each pump represent one heartbeat.
- The mechanism behind each heartbeat, each pump involves:

- **action potential and**
- **cardiac muscle contraction**


Sinus node impulse
Impulse passes through AV node
Ventricular impulses
Typical heartbeat

Action potential and Electricity of the cardiac muscle:

- The contraction of cardiac muscle (heart muscle) is initiated by electrical impulses known as action potentials.
- These impulses control the rate of cardiac contraction.
- **The cardiac action potential (AP)** is a brief change in voltage (membrane potential) across the cell membrane or sarcolemma. This is caused by the movement of charged cations between the inside and outside of the cell, through protein structures called ion channels.

- The cells that create these rhythmic impulses are called pacemaker cells, and they directly control the **heart rate (60-100)**

- All cardiac muscle cells are electrically linked to one another, by intercalated discs which allow the action potential to pass from one cell to the next. This means that all atrial cells can contract together, and then all ventricular cells.

- During diastole (when the heart is relaxed), the cells are in their most extended state.
- **Resting membrane potential is** : the difference between inside and outside of the cell which is always **negative**
- Myocardial fibers have a resting membrane potential of approximately **(-90)**
- Resting potential for **nodal (pacemaker) cells** is **−60 mV**

- **The action potential cardiac muscles is divided into 5 phases:**

- The cardiac action potential lasts approximately 200 millisecond.
- Divided into 5 phases: (4) resting, (0) upstroke, (1) early repolarization, (2) plateau, and (3) final repolarization.

Cardiac action potential phases:

Phase 4 –**Resting potential (RMP) (-90 mV)** :
Potassium leaks out of cells … negative intracellular potential.

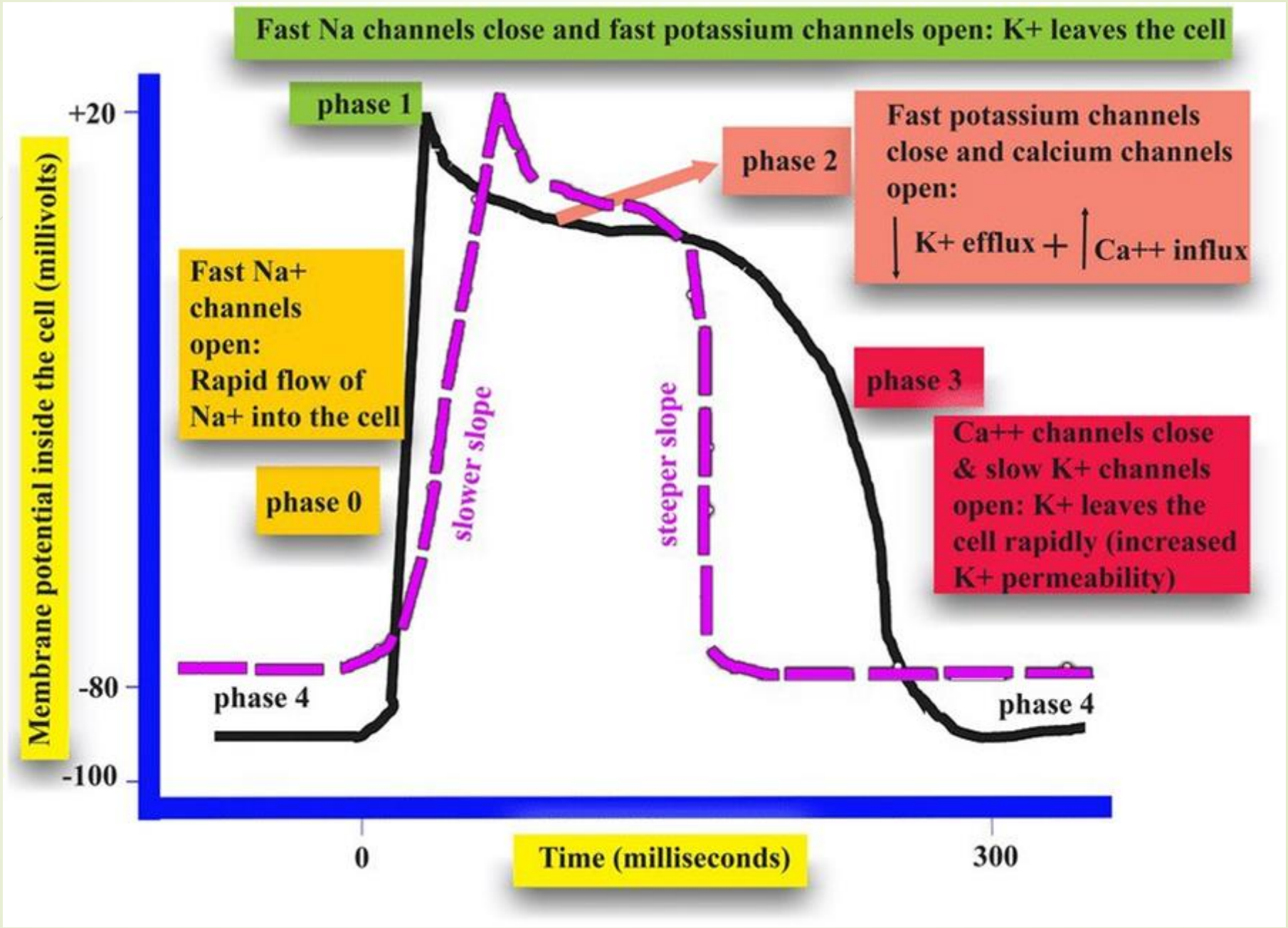
Phase 0 - Depolarization to approximately +52 mv due to sodium influx (into the cells) via fast sodium channels.

Phase 1 - Partial repolarization due to the **closure** of fast sodium channels and opening of potassium (K) channels …so efflux (leaves the cell) of **potassium.**

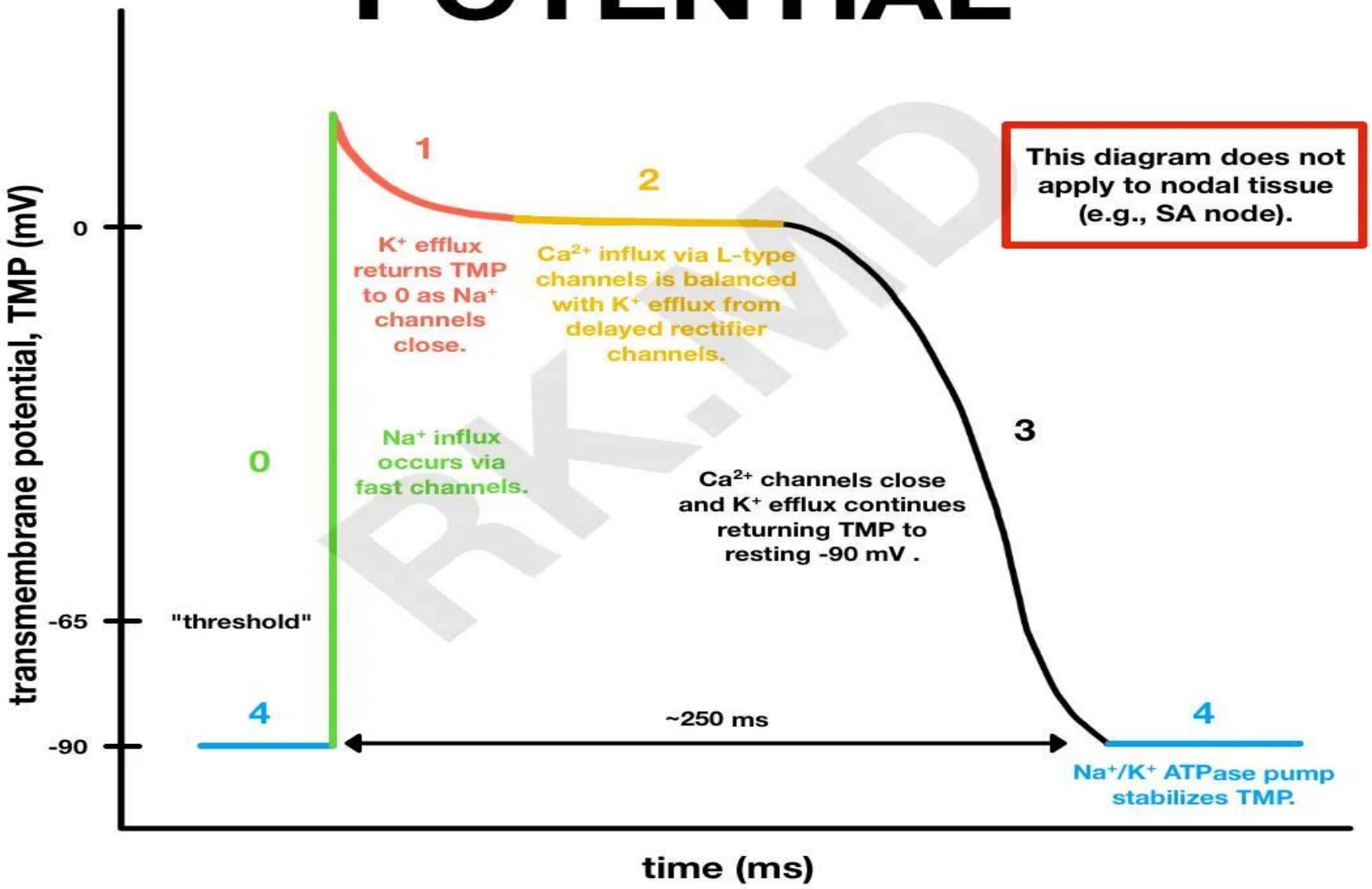
Phase 2 - plateau phase maintained by the influx (in) of calcium. Potassium efflux(out) also occurs.

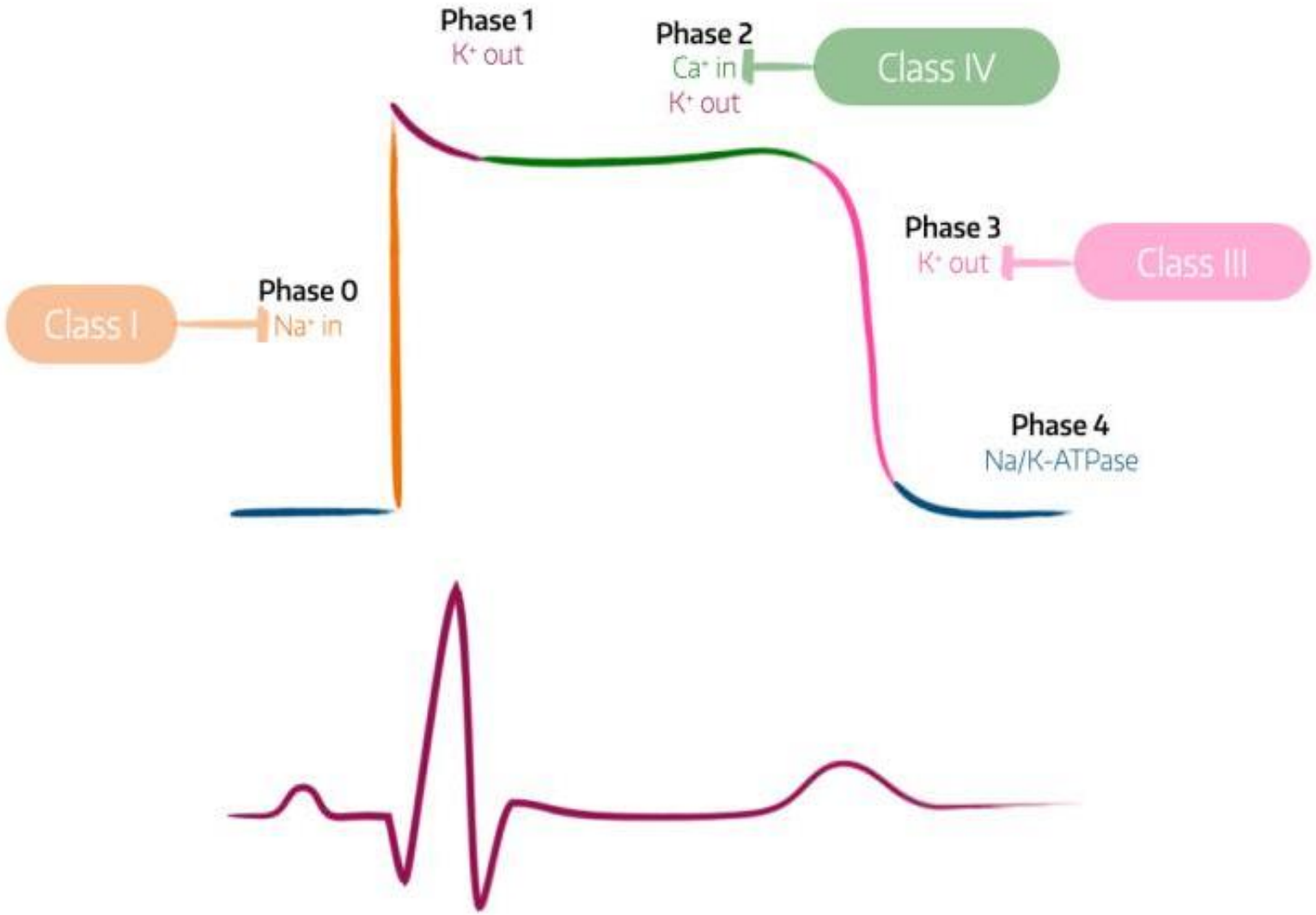
Phase 3 - Repolarization back to RMP due to potassium efflux and closure of sodium and calcium channels

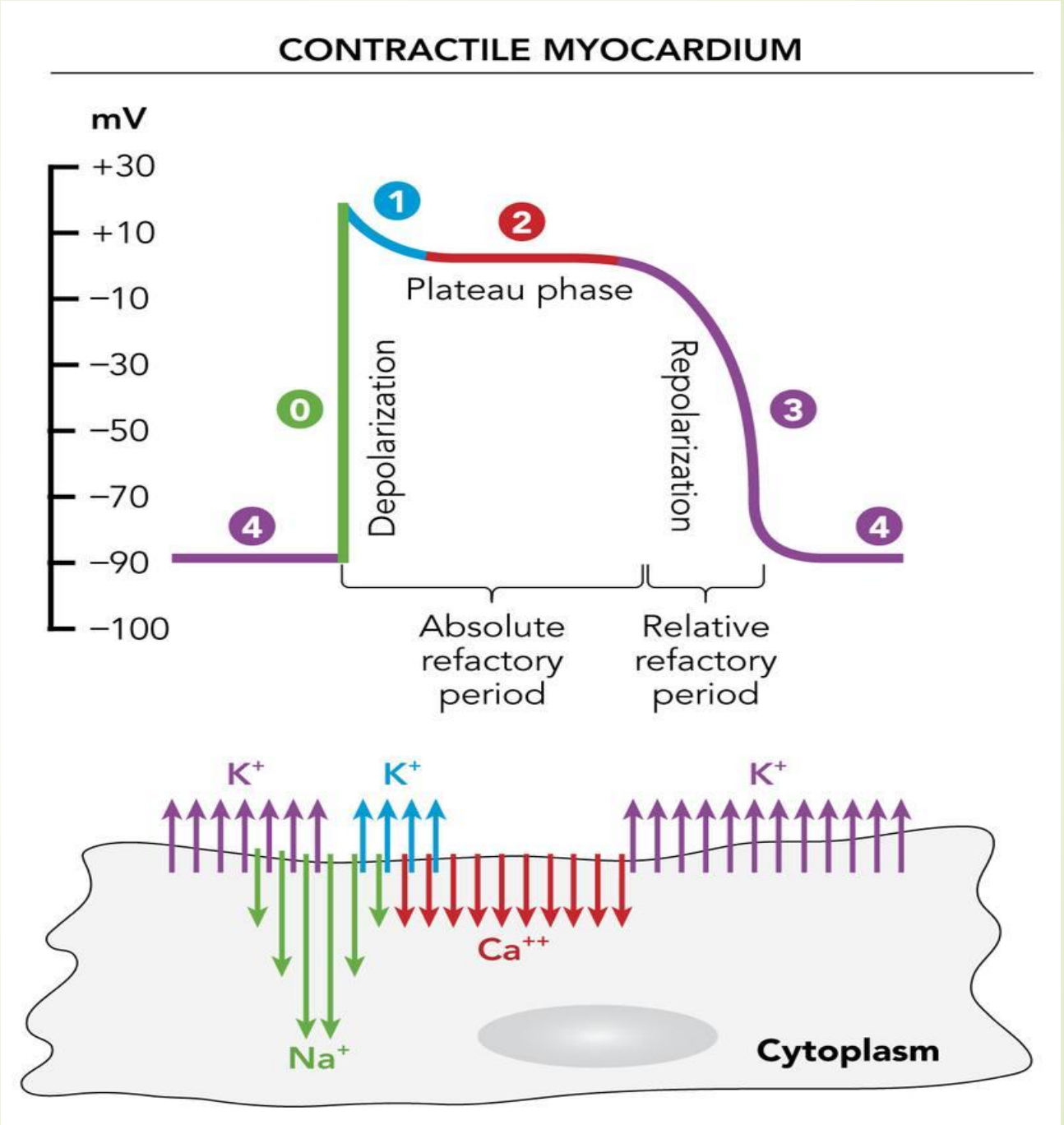
(k channels when opened >>> k efflux outside the cell always)


Fast Na channels close and fast potassium channels open: K+ leaves the cell
phase 1
phase 2
Fast potassium channels close and calcium channels open:
K+ efflux +
Ca++ influx
Fast Na+ channels open: Rapid flow of Na+ into the cell
phase 0
slower slope
steeper slope
phase 3
Ca++ channels close & slow K+ channels open: K+ leaves the cell rapidly (increased K+ permeability)
phase 4
phase 4
+20
-80
-100
Membrane potential inside the cell (millivolts)
0
Time (milliseconds)
300

CARDIAC ACTION POTENTIAL




Phase 1
K+ out
Phase 2
Ca+ in
K+ out
Class IV
Phase 3
K+ out
Class III
Class I
Phase 0
Na+ in
Phase 4
Na/K-ATPase


CONTRACTILE MYOCARDIUM
mV
+30
+10
−10
−30
−50
−70
−90
−100
0
1
2
3
4
4
Depolarization
Plateau phase
Repolarization
Absolute refactory period
Relative refactory period
K+
K+
K+
Ca++
Na+
Cytoplasm

Cardiomyocytes contraction (excitation-contraction coupling):

- Cardiac muscle fibers contract via **excitation-contraction coupling.**
- **Excitation-contraction coupling** describes the process of converting an electrical stimulus (action potential) into a mechanical response (muscle contraction).
- The contraction of cardiac muscle (heart muscle) is initiated by electrical impulses known as action potentials .
- These impulses controls the rate of cardiac contraction.

- The cells that create these rhythmic impulses are called pacemaker cells, and they directly control the **heart rate.**

- Electrical stimulation in the form of a cardiac action potential triggers the release of **calcium** from the cell's internal calcium store, the sarcoplasmic reticulum.

- The **rise in calcium** inside the cell causes the cell's myofilaments to slide past each other in a process called **excitation-contraction coupling**.

- Contraction in cardiac muscle occurs due to the binding of the myosin head to adenosine triphosphate (ATP), which then pulls the actin filaments to the center of the sarcomere

Pathway of Cardiac Muscle Contraction

- The pathway of contraction can be described in five steps:

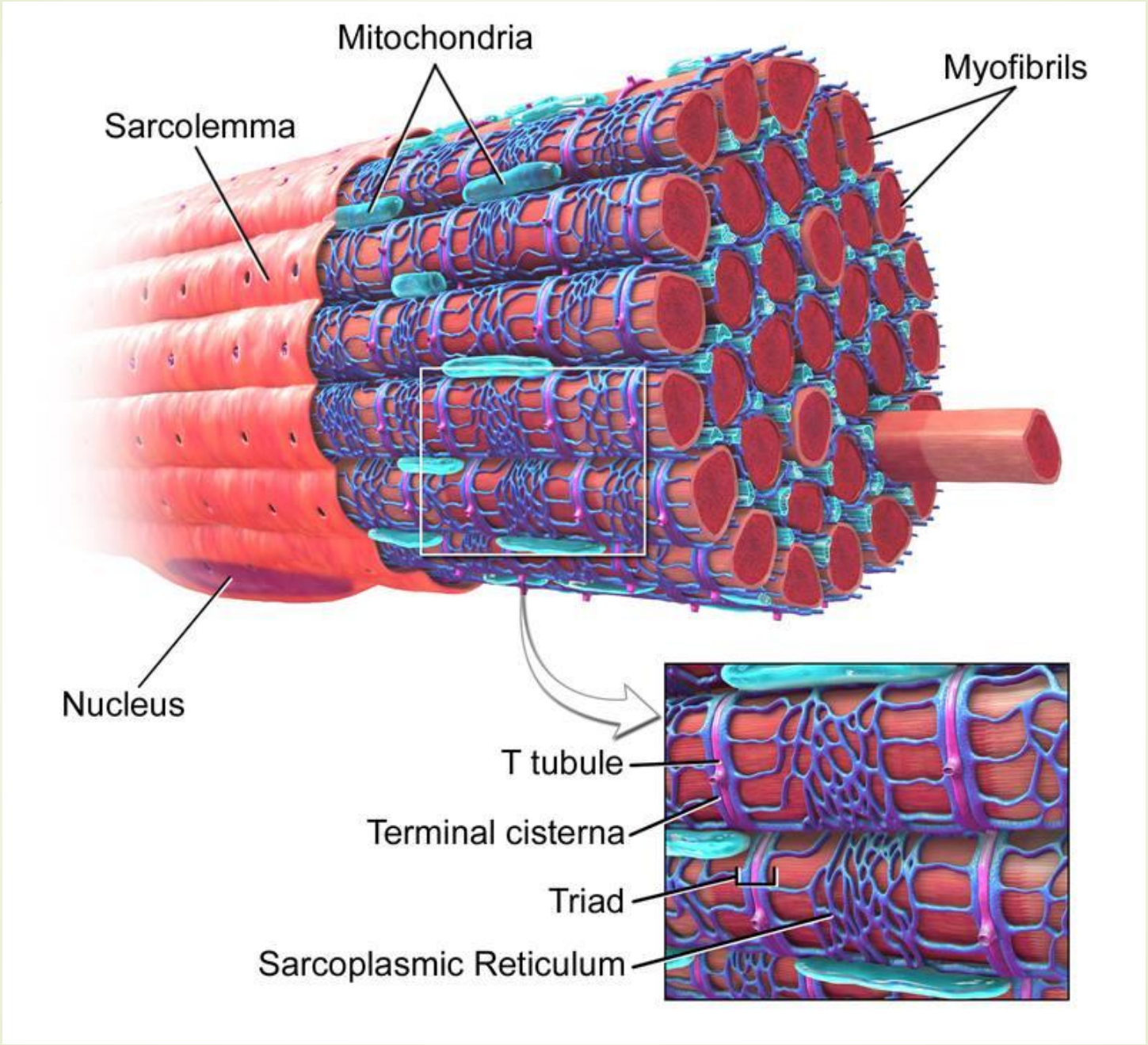
1. An action potential, induced by the pacemaker cells in the sinoatrial (SA) and atrioventricular (AV) nodes.

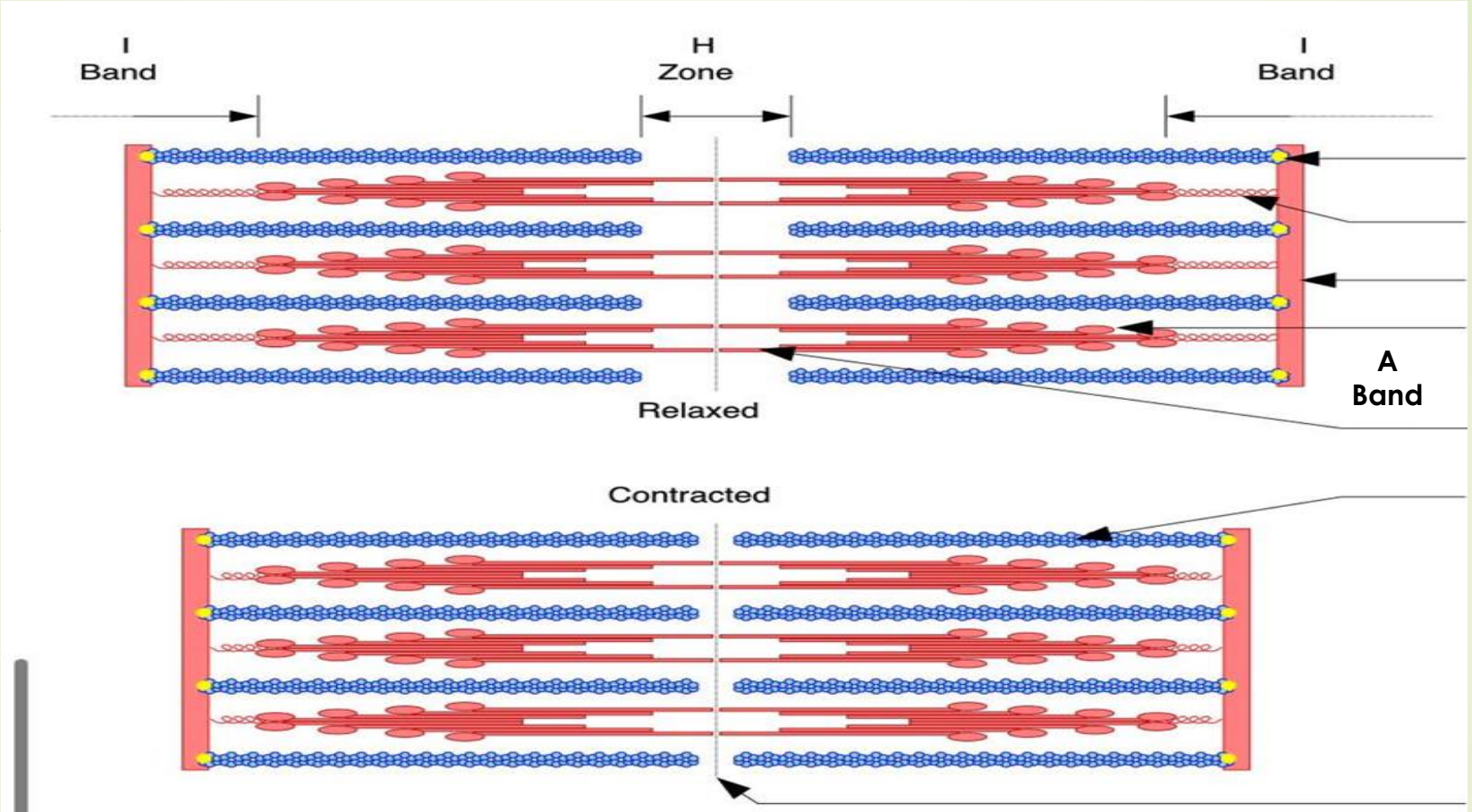
2. Action potential travels between sarcomeres, it activates the calcium channels in the T-tubules, resulting in an influx of calcium ions into the cardiomyocyte.

3. Calcium in the cytoplasm initiates contraction.

4. The myosin head binds and pulls the actin filaments toward the center of the sarcomere, contracting the muscle.

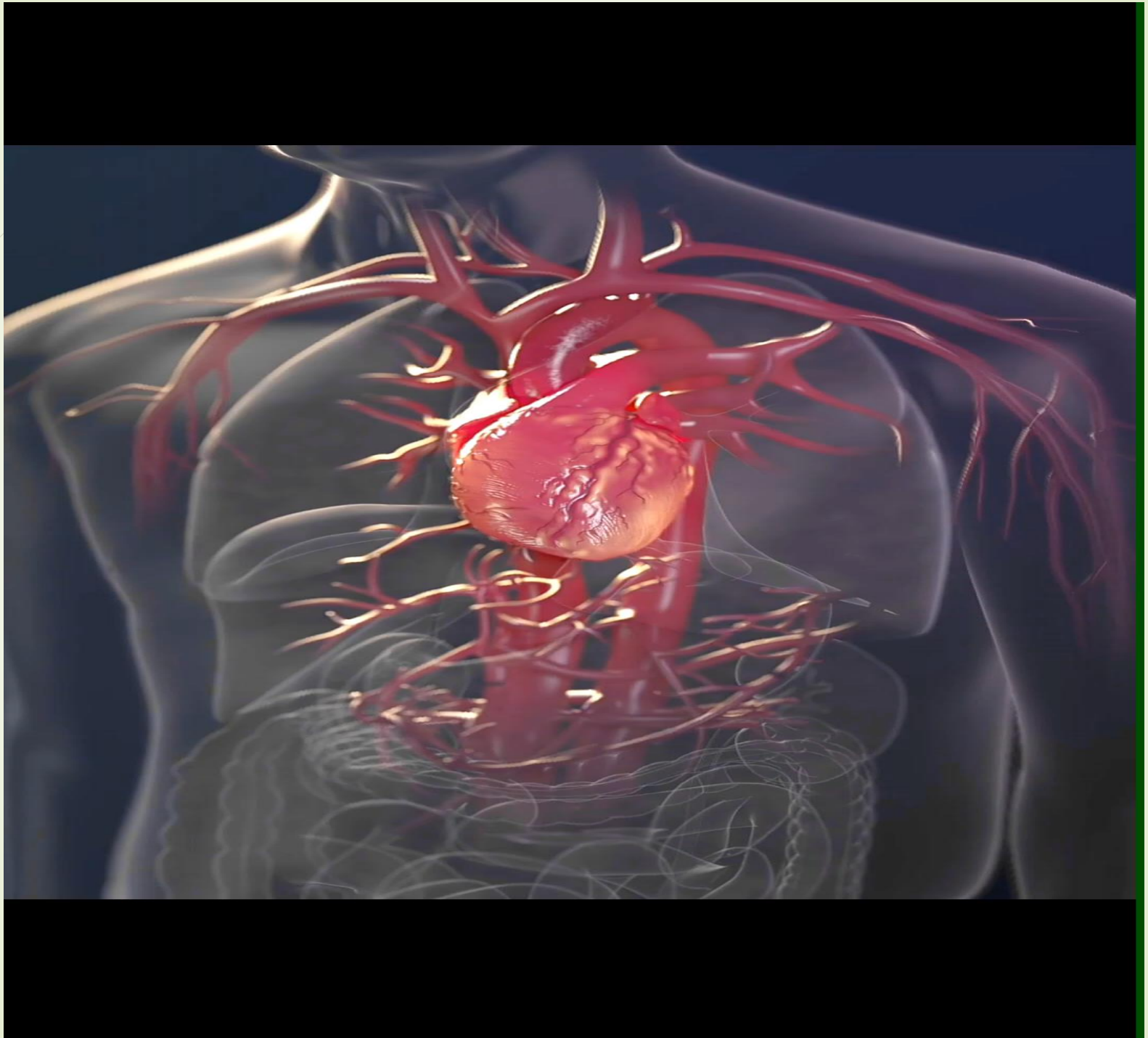
5. Intracellular calcium is then removed by the sarcoplasmic reticulum,


Mitochondria
Myofibrils
Sarcolemma
Nucleus
T tubule
Terminal cisterna
Triad
Sarcoplasmic Reticulum



Sliding Filament Model of Contraction

Muscle fibers in relaxed (above) and contracted (below) positions



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