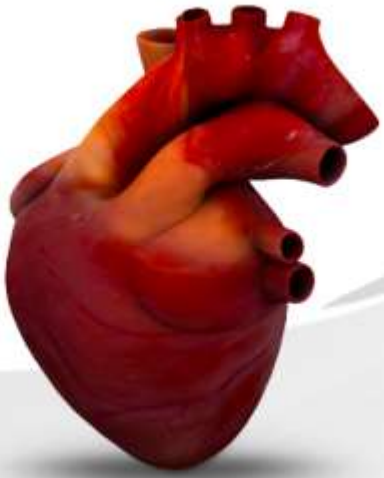


Cardiac muscle

Learning objectives

- Define the terms; Rhythmicity, Excitability, Conductivity and Contractility.
- Describe cardiac syncytium.
- Outline the normal pathway of the cardiac impulse.
- Describe the excitation-contraction coupling in cardiac muscles and compare it to excitation-contraction coupling in skeletal muscles.
- Compare and contrast action potential in sino-atrial node and ventricular muscle.
- Explain the significance of the plateau and refractory period in ventricular muscle action potential.

The Heart

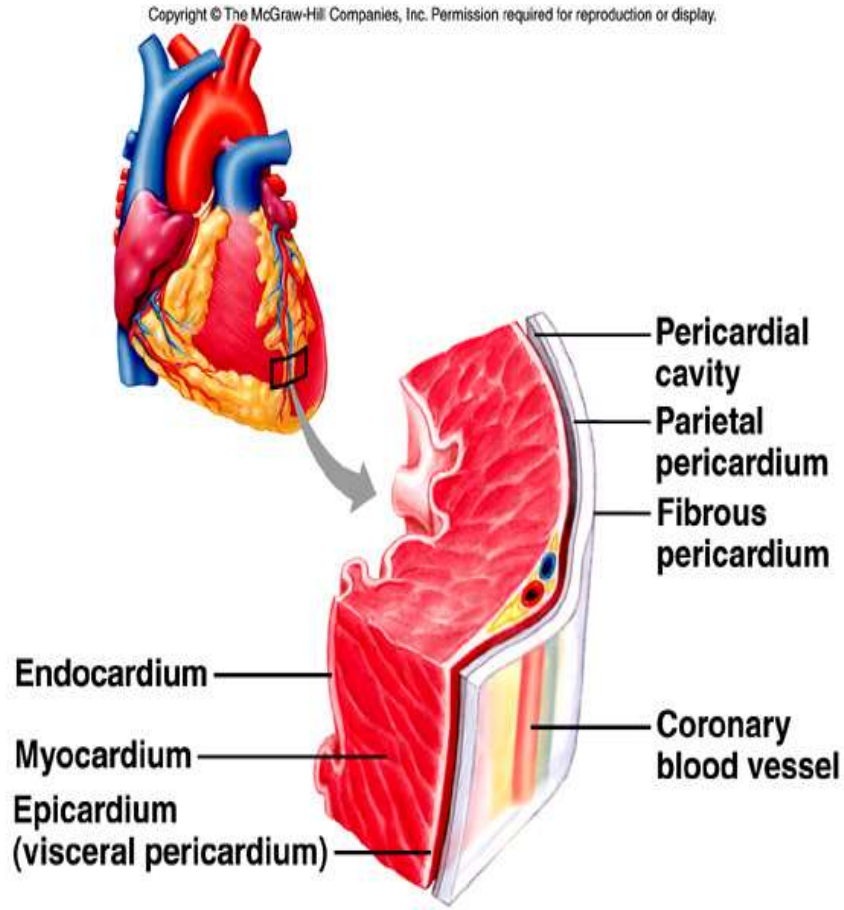
- Heart is a muscular organ that pumps blood throughout the circulatory system
- It is situated in between two lungs in the mediastinum
- It is made up of four chambers, two atria and two ventricles
- The musculature of ventricles is thicker than that of atria. Force of contraction of heart depends upon the muscles

The Heart: Coverings

- Pericardium – a double serous membrane
  - Visceral pericardium
    - Next to heart
  - Parietal pericardium
    - Outside layer
- Serous fluid fills the space between the layers of pericardium

The Heart: Heart Wall

- Three layers
  - Epicardium
    - Outside layer
    - This layer is the parietal pericardium
    - Connective tissue layer
  - **Myocardium**
    - **Middle layer**
    - **Mostly cardiac muscle**
  - Endocardium
    - Inner layer
    - Endothelium



The Heart: Chambers

- Right and left side act as separate pumps
- Four chambers
  - Atria
    - Receiving chambers
      - Right atrium
      - Left atrium
  - Ventricles
    - Discharging chambers
      - Right ventricle
      - Left ventricle

The Heart: Valves

- Allow blood to flow in only one direction
- Four valves
  - Atrioventricular valves – between atria and ventricles
    - Bicuspid valve (left)
    - Tricuspid valve (right)
  - Semilunar valves between ventricle and artery
    - Pulmonary semilunar valve
    - Aortic semilunar valve

THE CARDIAC MUSCLE

- Myocardium has three types of muscle fibers:

- i. Muscle fibers which form contractile unit of heart (99%)
- ii. Muscle fibers which form pacemaker
- iii. Muscle fibers which form conductive system

Muscle Fibres which Form the Contractile unit

- Striated and resemble the skeletal muscle fibre

- Cardiac muscle fibre is bound by **sarcolemma.** It has a centrally placed nucleus. **Myofibrils** are embedded in the sarcoplasm.

- **Sarcomere** of the cardiac muscle has all the contractile proteins, namely actin, myosin, troponin and tropomyosin.

- **Sarcotubular system** in cardiac muscle is slightly different to that of skeletal muscle.

Sarcotubular system in cardiac & skeletal muscle

	Cardiac muscle	Skeletal muscle
Location of T tubules	At Z line	At A-I junction
Diameter of T tubules	More (5times)	Less
L tubules	Narrow tubular cistern	Large dilated cistern
Association of T tubule (Tubule & cistern)	Diad (1 Tubule & 1cistern)	Triad (1 Tubule & 2cistern)
Sarcomeric organisation	Less regular	More regular

- Exhibit branching
- Adjacent cardiac cells are joined end to end by specialized structures known as intercalated discs

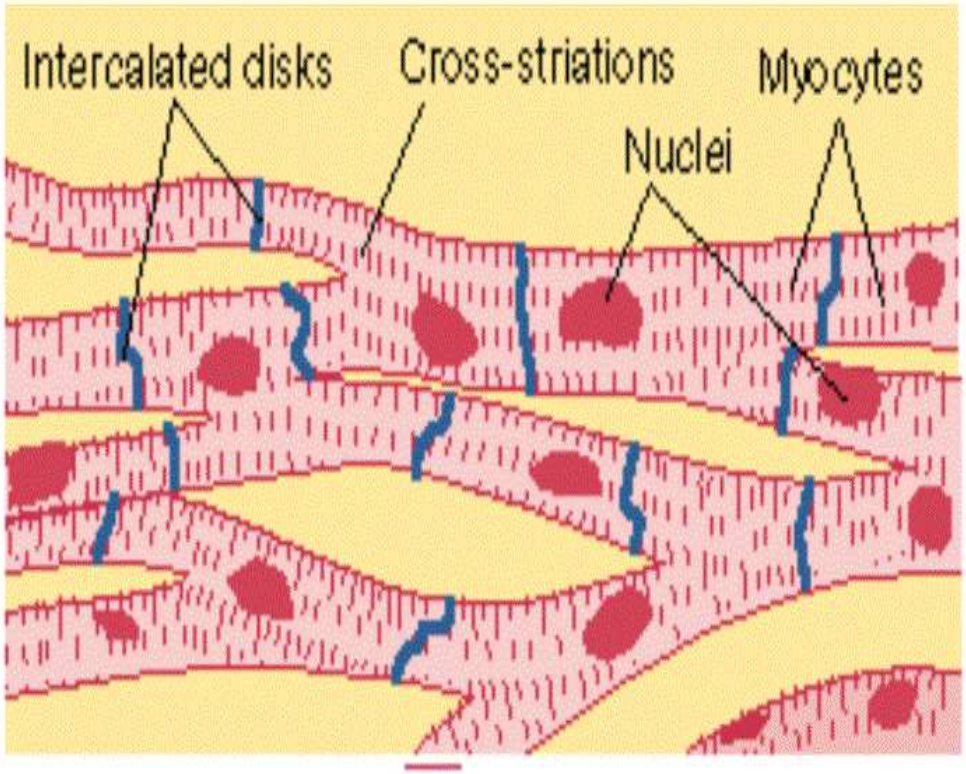
- Within intercalated discs there are two types of junctions
  - Desmosomes
  - Gap junctions that allow action potential to spread from one cell to adjacent cells

- Heart function as syncytium

  when one cardiac cell undergoes an action potential, the electrical impulse spreads to all other cells that are joined by gap junctions so they become excited and contract as a single functional syncytium

Atrial syncytium and ventricular syncytium

Cardiac Muscle Tissue



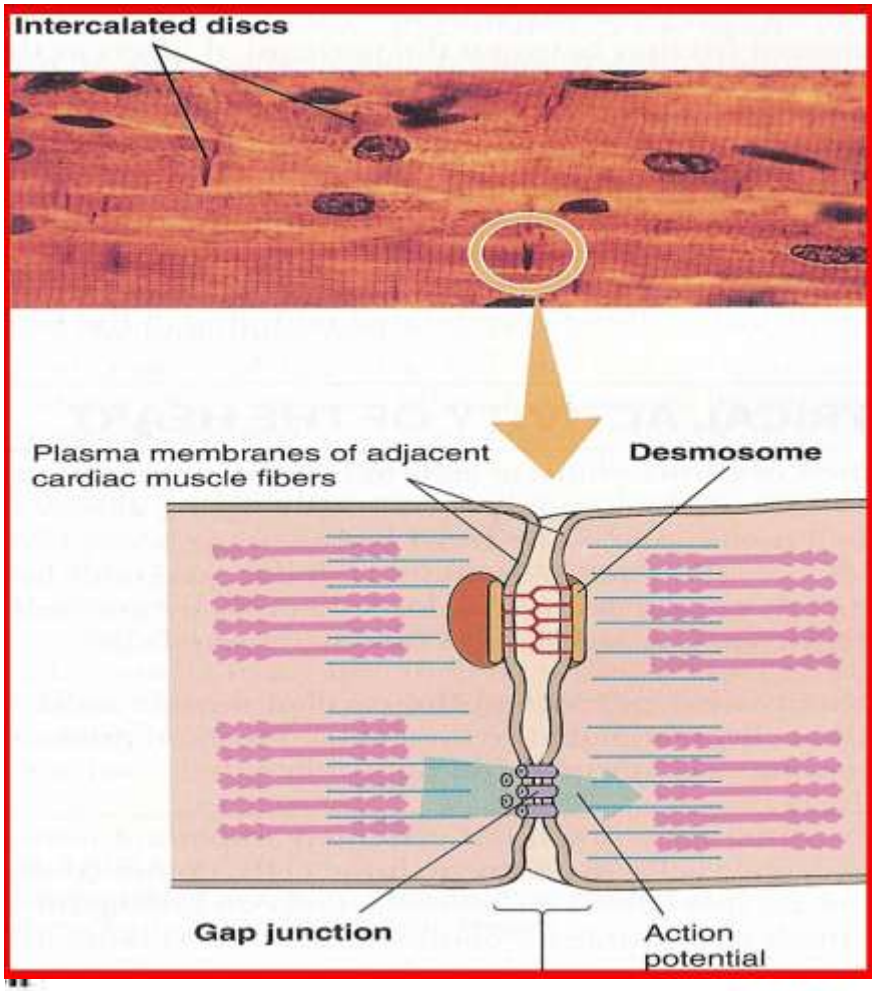
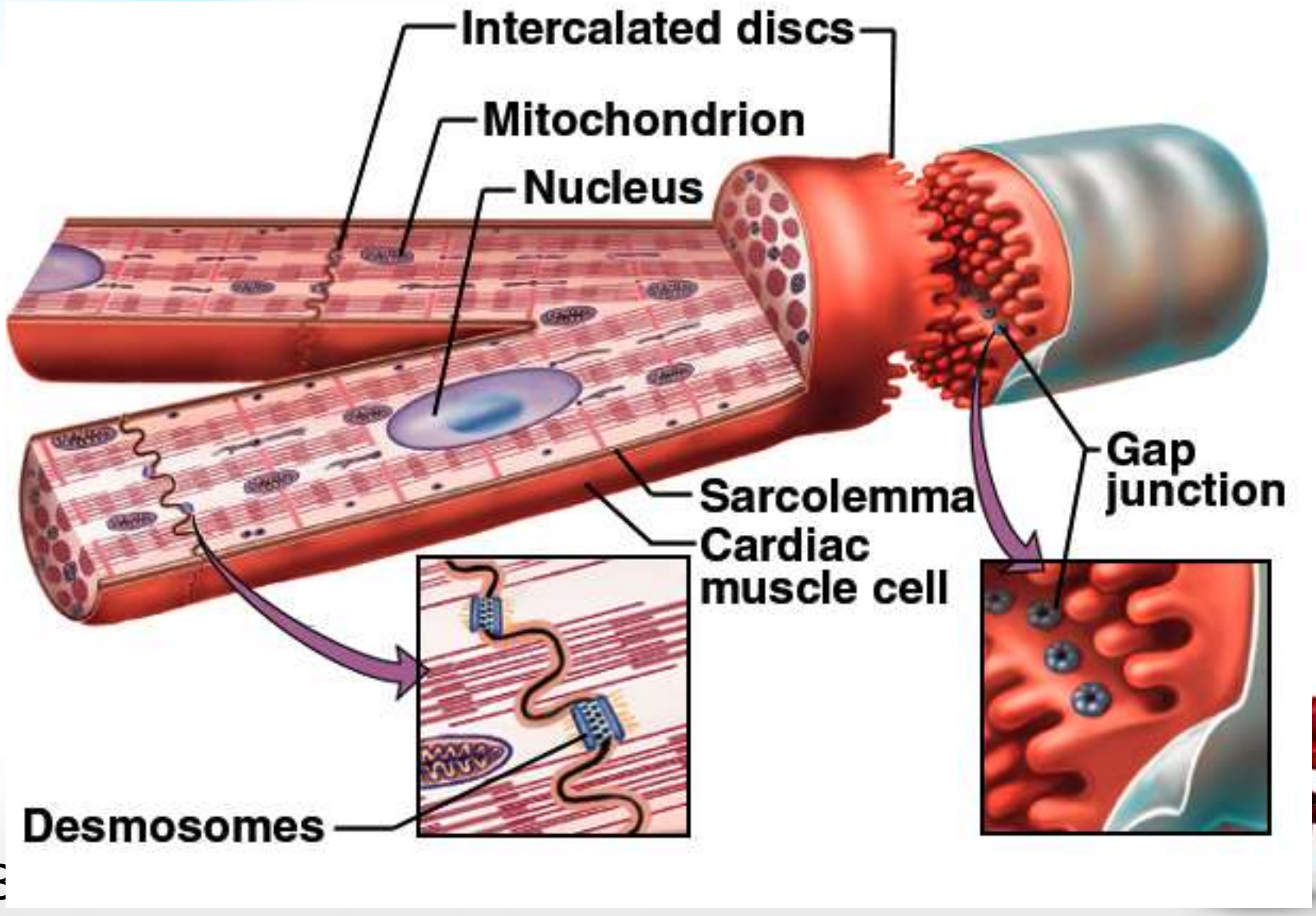
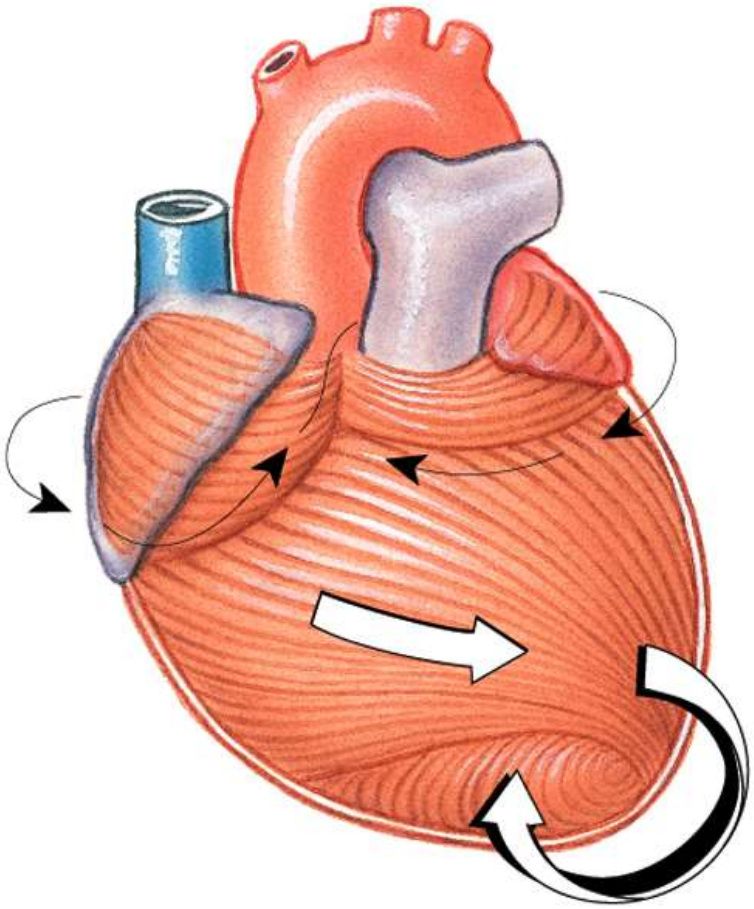


Figure 10.10a

Structure of Cardiac Muscle Cell



Orientation of cardiac muscle fibres:



Unlike skeletal muscles, cardiac muscles have to contract in more than one direction.

Cardiac muscle cells are striated, meaning they will only contract along their long axis. In order to get contraction in two axis, the fires wrap around.

Muscle Fibres which Form the Pacemaker

- Some of the muscle fibres of heart are modified into a specialized structure known as pacemaker.
- These muscle fibres forming the pacemaker have less striation.
- They are named **pacemaker cells** or **P cells.**
- Sino-atrial (SA) node forms the pacemaker in human heart.

Muscle Fibres which Form Conductive System

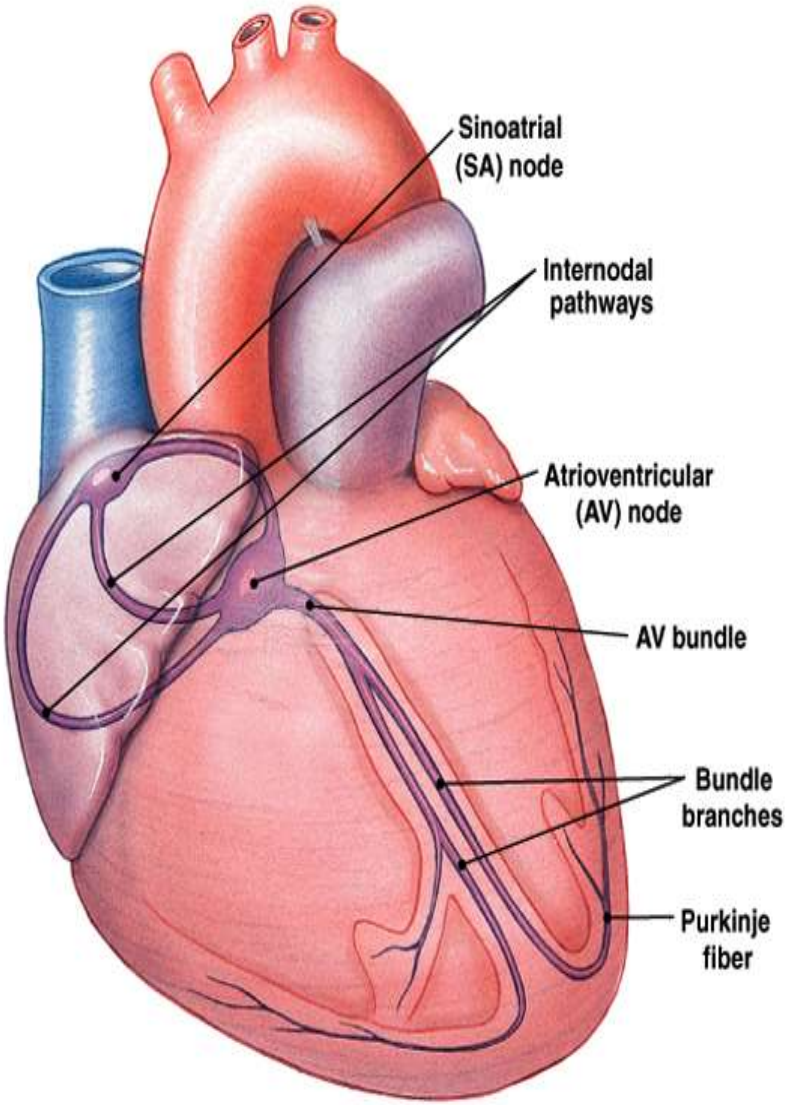
- Conductive system of the heart is formed by modified cardiac muscle fibres

- Impulses from SA node are transmitted to the atria directly. However, the impulses are transmitted to ventricles through various components of conducting system

Conducting system of heart

Cardiac Conduction System Overview

- Sinoatrial node
- Atrial syncytium
- Junctional fibers
- Atrioventricular node
- A-V bundle
- Bundle branches
- Purkinje fibers
- Ventricular syncytium



The conducting system

Properties of cardiac muscle

- Electrical
  - Excitability (Bathmotropic action)
  - Auto rhythmicity
  - Conductivity (Dromotropic action)

- Mechanical
  - Contractility (Inotropic action)
  - Refractory period
  - Staircase / treppe effect

Resting Membrane Potential

- **Definition**: it is the potential difference across cell membrane at rest:
- it is negative inside with respect to outside.

Potential

- values of RMP vary in various excitable tissues:
- In nerve fiber: -90 mV
- In skeletal muscle: -90 mV
- In cardiac muscle: -85 mV
- SA node: -55 mV
- In nerve cell body: -70 mV
- In smooth muscle: -55 mV to -60 mV

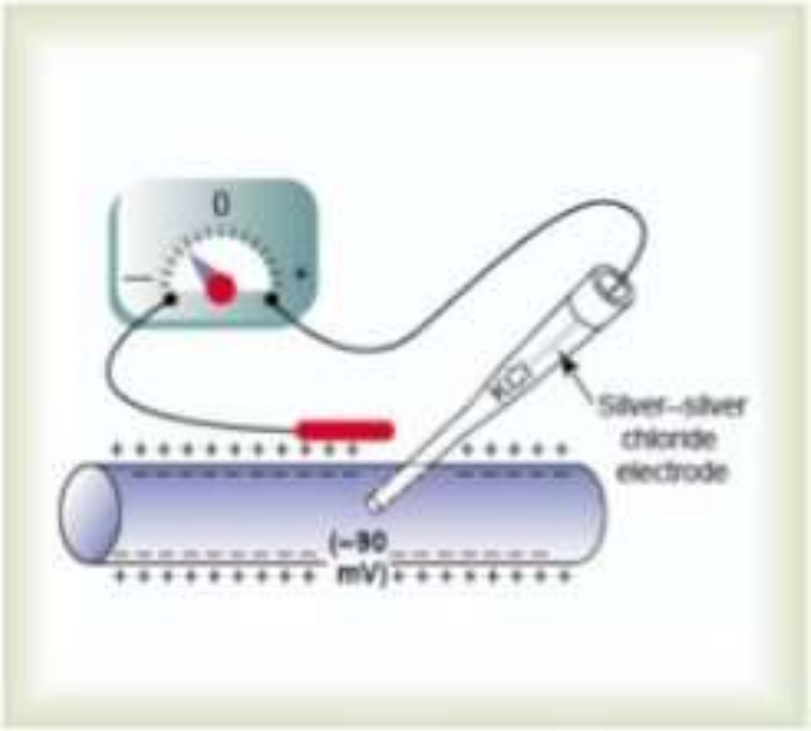
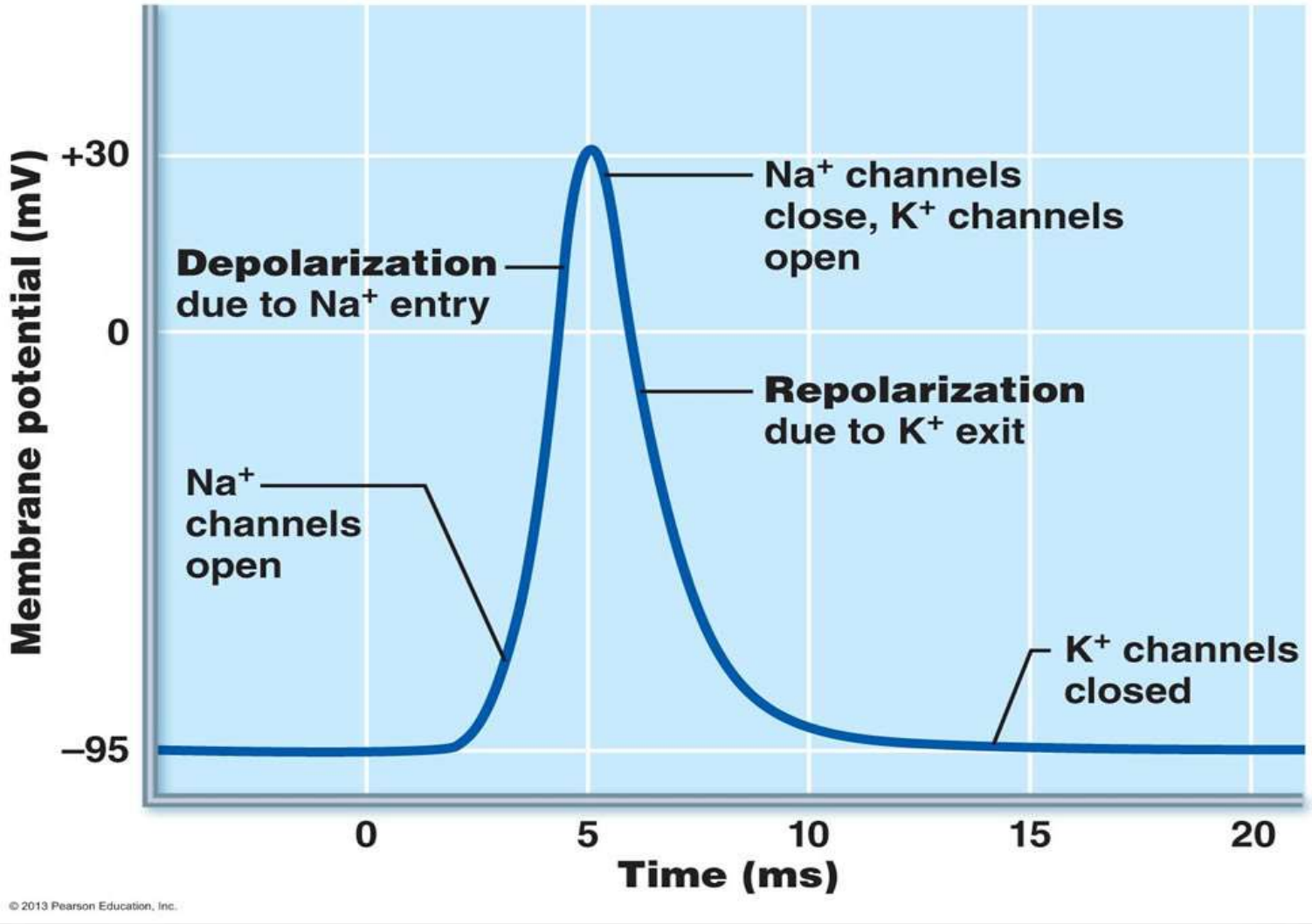


Figure 5-2

Measurement of the membrane potential of the nerve fiber using a microelectrode.

Action potential- the change in electrical potential associated with the passage of an impulse along the membrane of a muscle cell or nerve cell.



1. Autorhythmicity

Definition: the ability of the heart to initiate its beat continuously and regularly without external stimulation

- **myogenic (independent of nerve supply)**
- **due to the specialized excitatory & conductive system of the heart**

↓

intrinsic ability of self-excitation (waves of depolarization)

↓

cardiac impulses

Autorythmic fibers

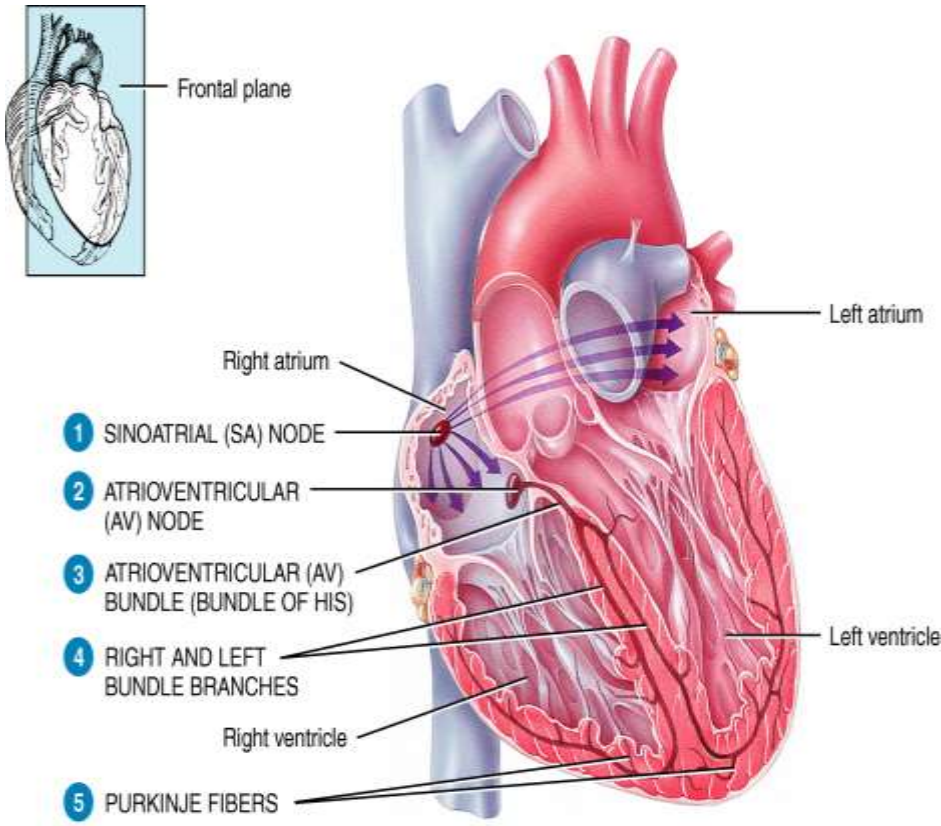
Forms 1% of the cardiac muscle fibers

Have two important functions

1. Act as a pacemaker (set the rhythm of electrical excitation)
2. Form the conductive system (network of specialized cardiac muscle fibers that provide a path for each cycle of cardiac excitation to progress through the heart)

Locations of autorhythmic cells

- Sinoatrial node (SA node)
  Specialized region in right atrial wall near opening of superior vena cava.
- Atrioventricular node (AV node)
  Small bundle of specialized cardiac cells located at base of right atrium near septum
- Bundle of His (atrioventricular bundle)
  Cells originate at AV node and enters interventricular septum
  Divides to form right and left bundle branches which travel down septum, curve around tip of ventricular chambers, travel back toward atria along outer walls
- Purkinje fibers
  Small, terminal fibers that extend from bundle of His and spread throughout ventricular myocardium

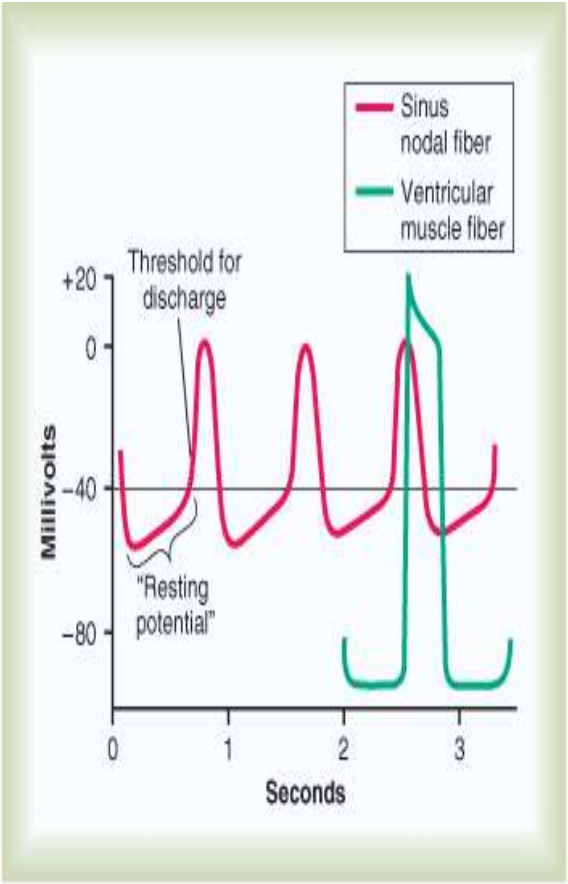


(a) Anterior view of frontal section

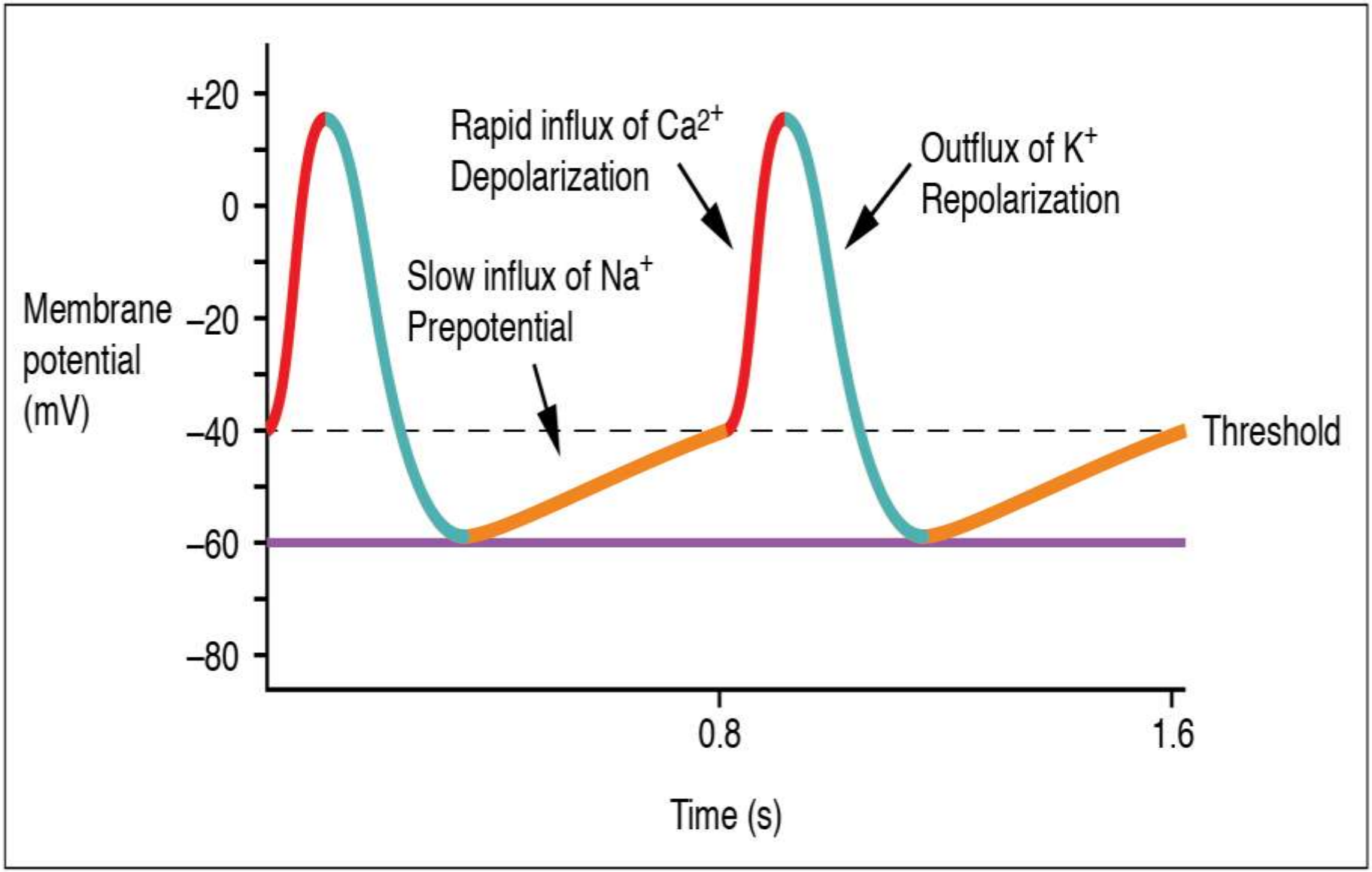
20.10a

Mechanism of Autorhythmicity

- Autorhythmic cells do not have stable resting membrane potential (RMP)
- Natural leakiness to Na & Ca→ spontaneous and gradual depolarization
- Unstable resting membrane potential (= pacemaker potential)
- Gradual depolarization reaches threshold (-40 mv) → spontaneous AP generation



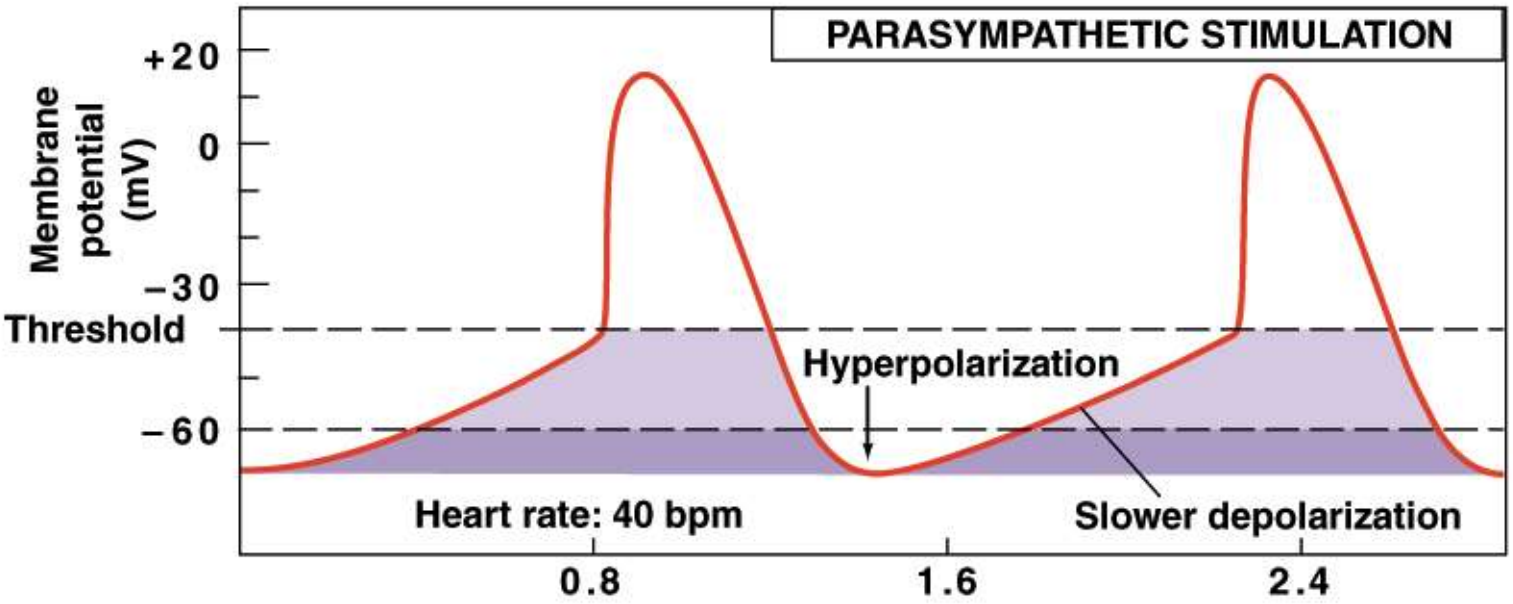
Prepotential / pacemaker potential/ Diastolic potential

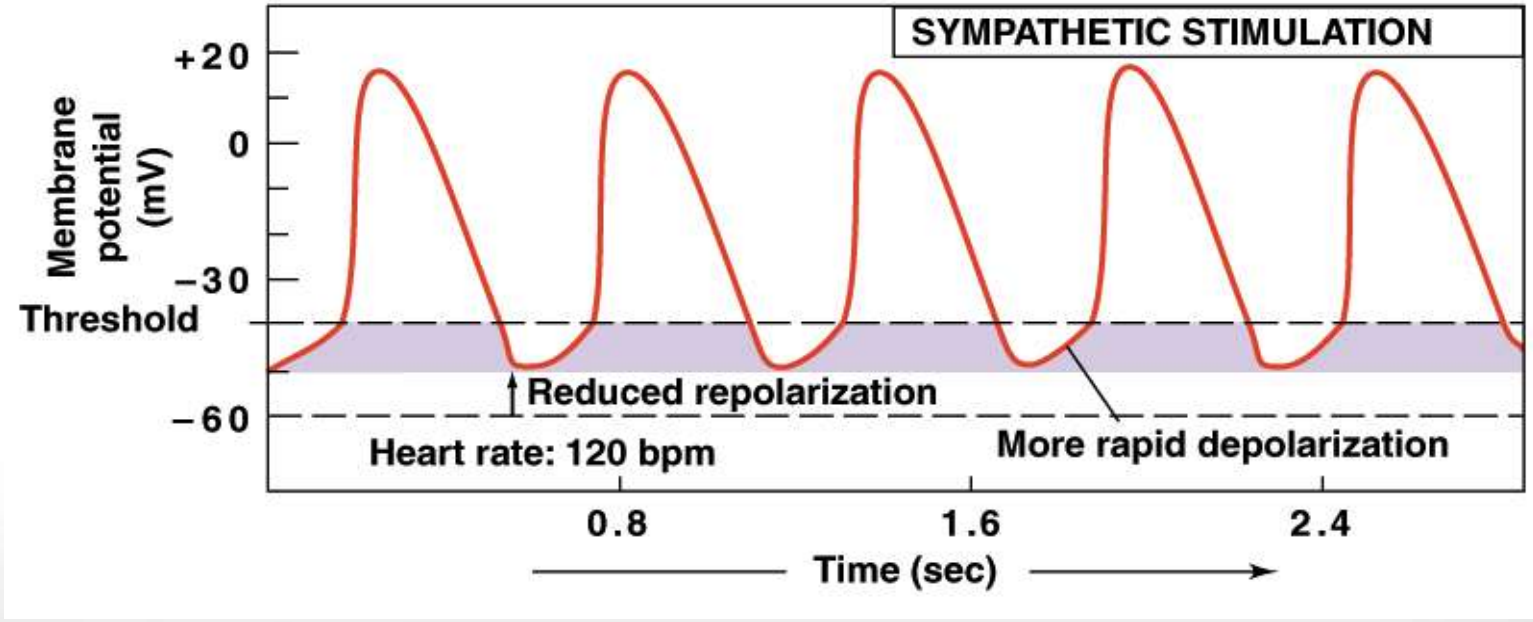


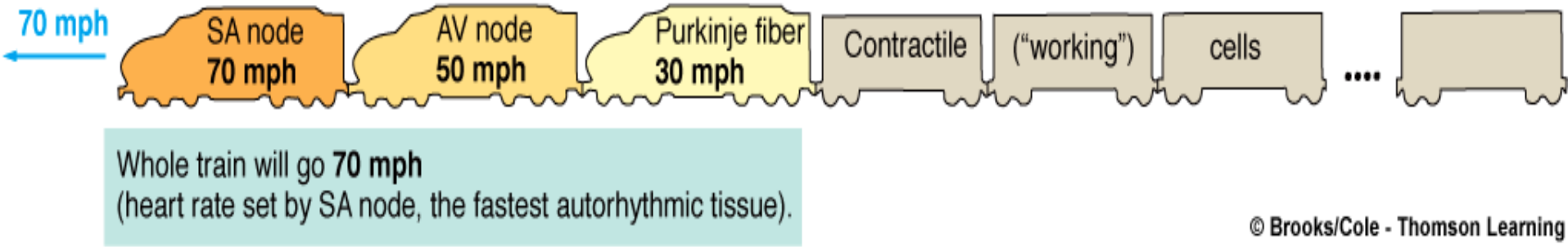
Rate of generation of AP at different sites of the heart

SITE	RATE (Times/min)
SA node	70 - 80
AV node	40 - 60
AV bundle, bundle branches,& Purkinje fibres	20 - 35

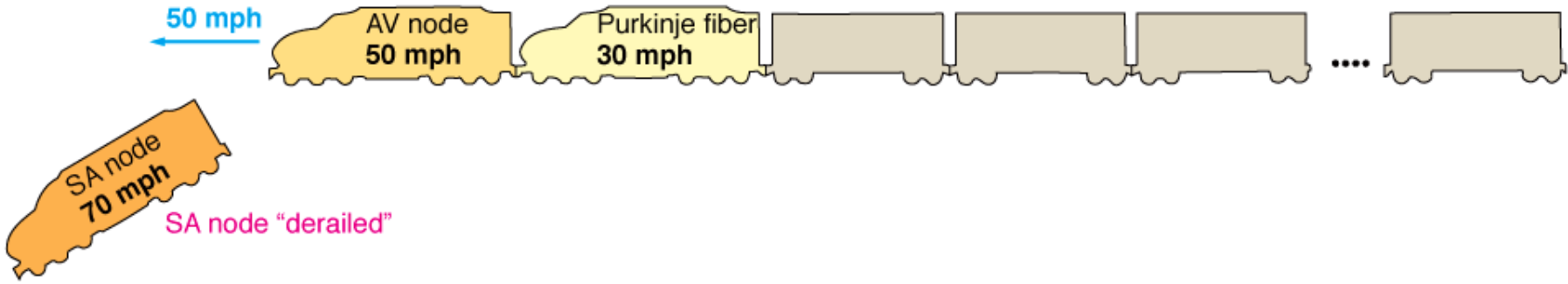
- SA node acts as heart pacemaker because it has the fastest rate of generating action potential
- Nerve impulses from autonomic nervous system and hormones **modify** the timing and strength of each heart beat but do not establish the fundamental rhythm.


PARASYMPATHETIC STIMULATION
Membrane potential (mV)
+20
0
−30
−60
Threshold
Hyperpolarization
Heart rate: 40 bpm
Slower depolarization
0.8
1.6
2.4


SYMPATHETIC STIMULATION
Membrane potential (mV)
+20
0
−30
−60
Threshold
Reduced repolarization
Heart rate: 120 bpm
More rapid depolarization
0.8
1.6
2.4
Time (sec)



Whole train will go **70 mph**
(heart rate set by SA node, the fastest autorhythmic tissue).



Train will go **50 mph**
(the next fastest autorhythmic tissue, the AV node, will set the heart rate).

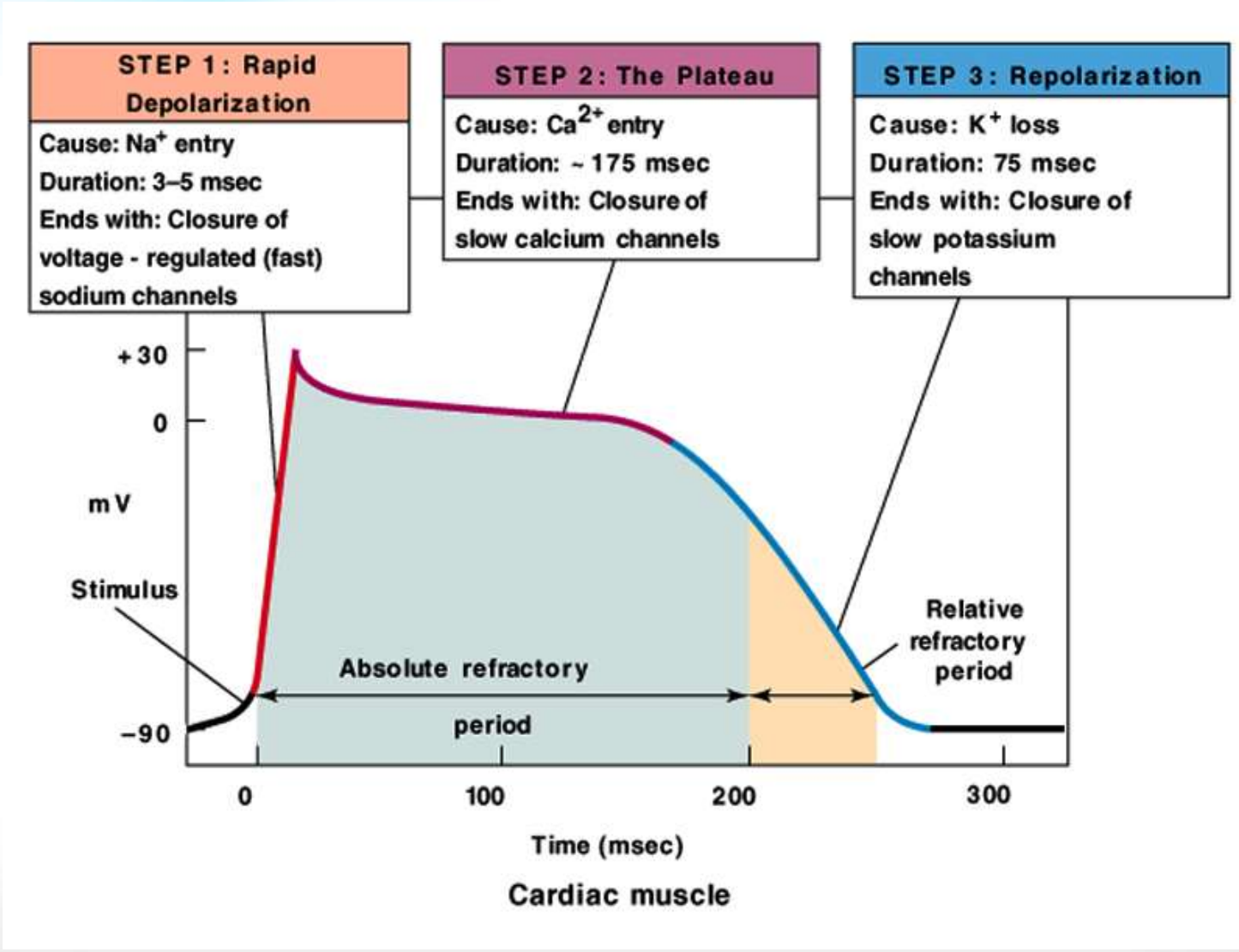
- ∴ **Non-SA nodal tissues are *latent pacemakers* that can take over (at a slower rate), should the normal pacemaker (SA node) fail**

2. Excitability

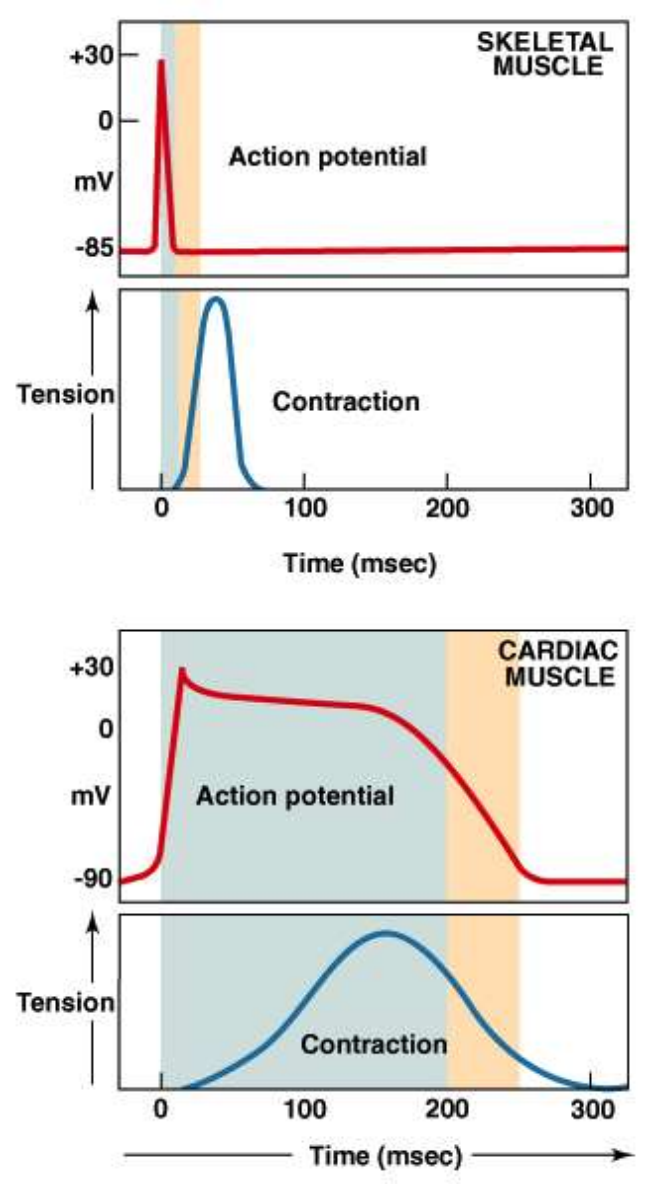
Definition: The ability of cardiac muscle to respond to a stimulus of adequate strength & duration by generating an AP

- AP initiated by SA node→ travels along conductive pathway→ excites atrial &ventricular muscle fibres

Action potential in contractile fibers

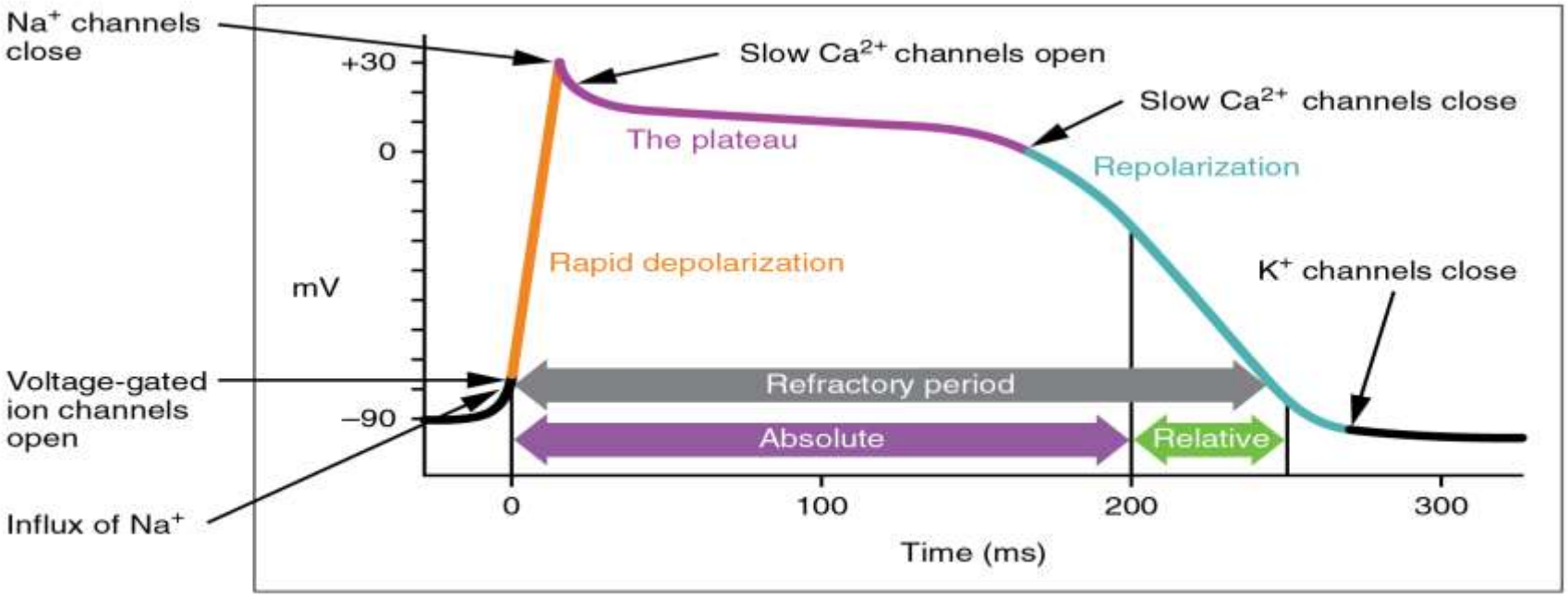


AP-contraction relationship:

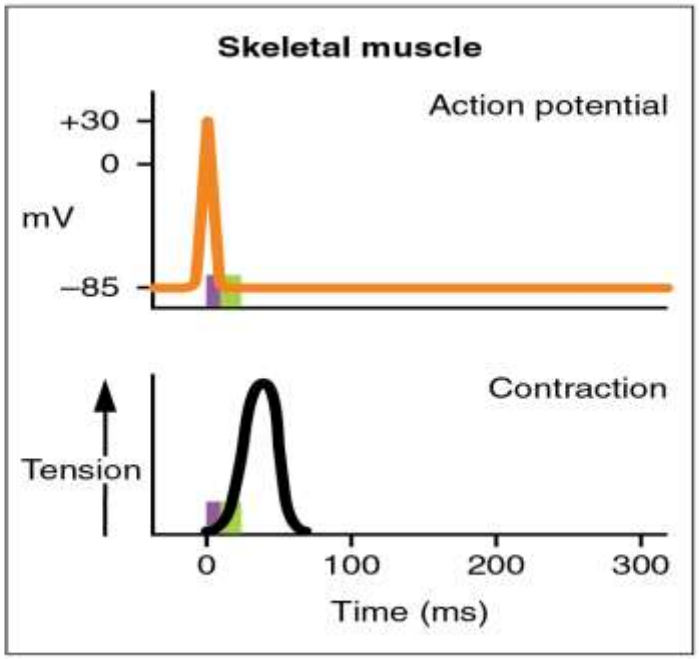


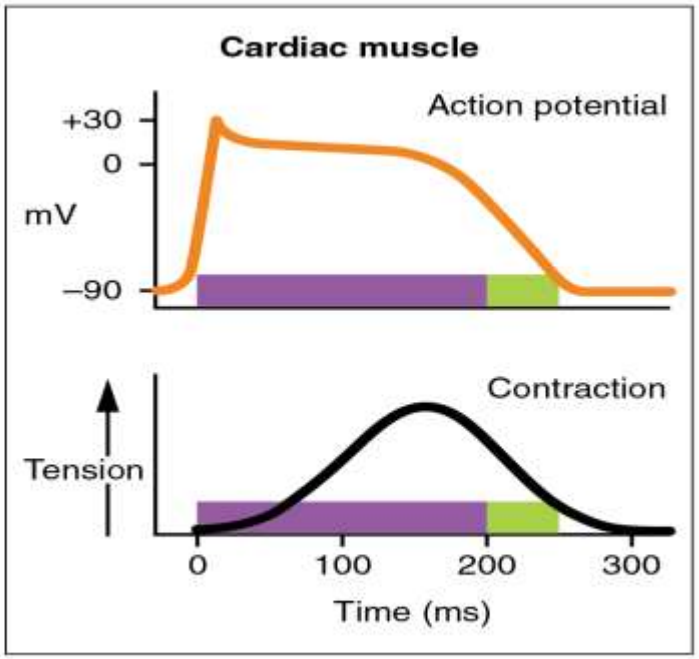
- AP in skeletal muscle is very short-lived-AP is basically over before an increase in muscle tension can be measured

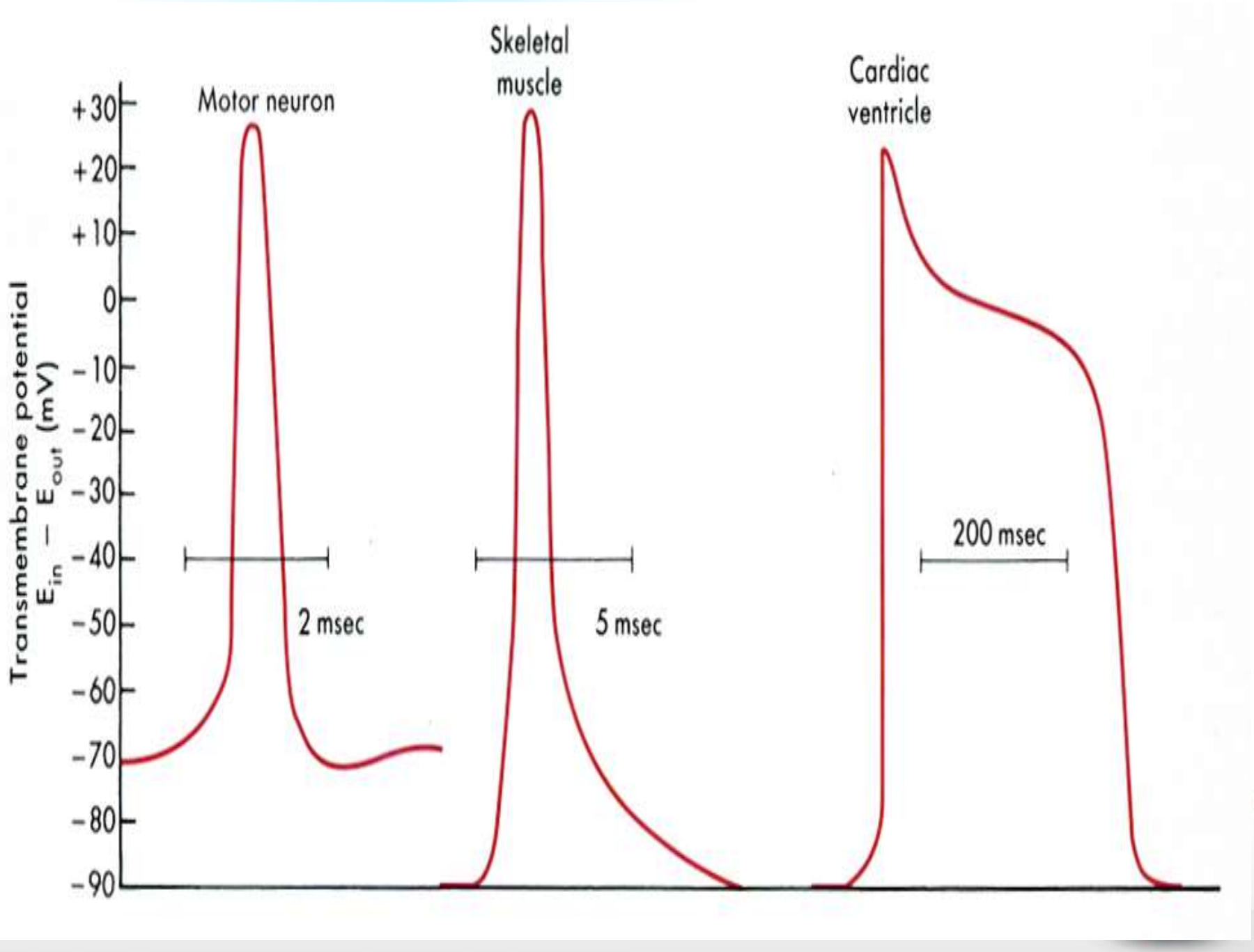
- AP in cardiac muscle is very long-lived
  - AP has an extra component ,which extends the duration .
  - The contraction is almost over before the action potential has finished.


Na+ channels close
Slow Ca2+ channels open
Slow Ca2+ channels close
The plateau
Repolarization
+30
0
mV
Rapid depolarization
K+ channels close
Voltage-gated ion channels open
Refractory period
–90
Absolute
Relative
Influx of Na+
0
100
200
300
Time (ms)

(a)


Skeletal muscle
Action potential
+30
0
mV
–85
Contraction
Tension
0
100
200
300
Time (ms)


Cardiac muscle
Action potential
+30
0
mV
–90
Contraction
Tension
0
100
200
300
Time (ms)

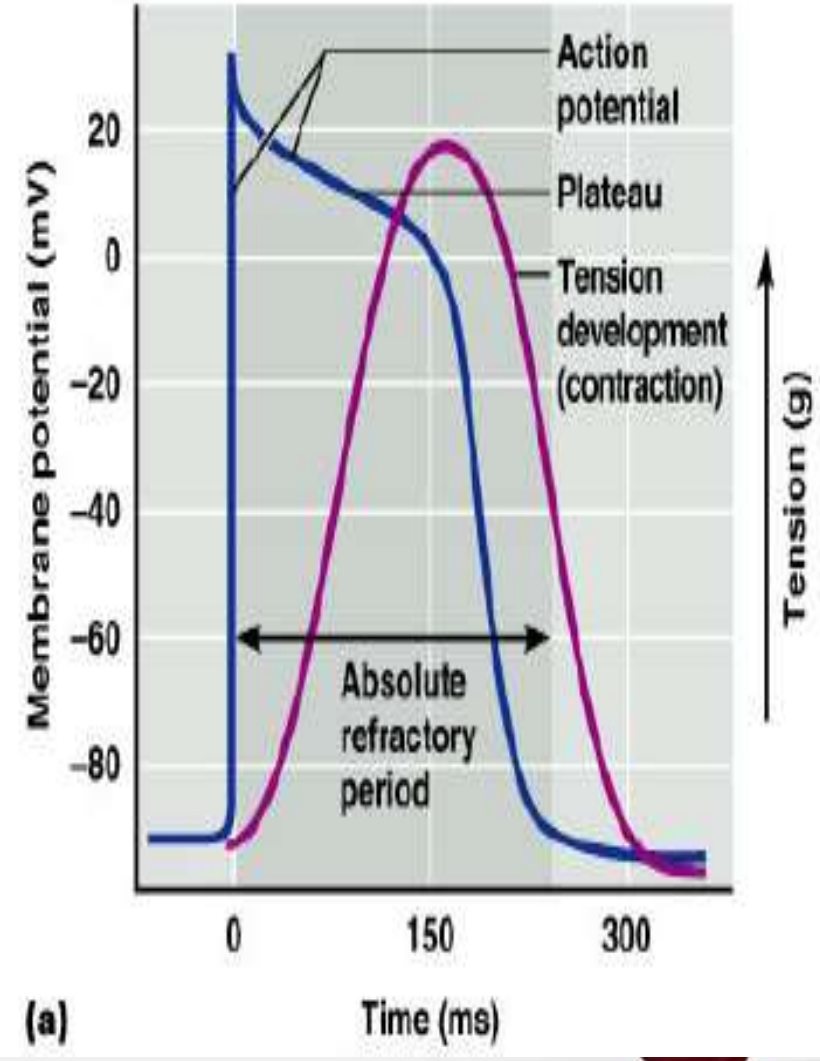

Motor neuron
Skeletal muscle
Cardiac ventricle
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Transmembrane potential
$E_{in} - E_{out}$ (mV)
2 msec
5 msec
200 msec

Refractory Period

- It is that period during which a second stimulus fails to evoke a response.
- Absolute Refractory Period : It is that period during which a second stimulus however high it is fails to evoke a response.
- Relative Refractory Period **:** It is that period during which a second stimulus evokes a response if it is sufficiently high.

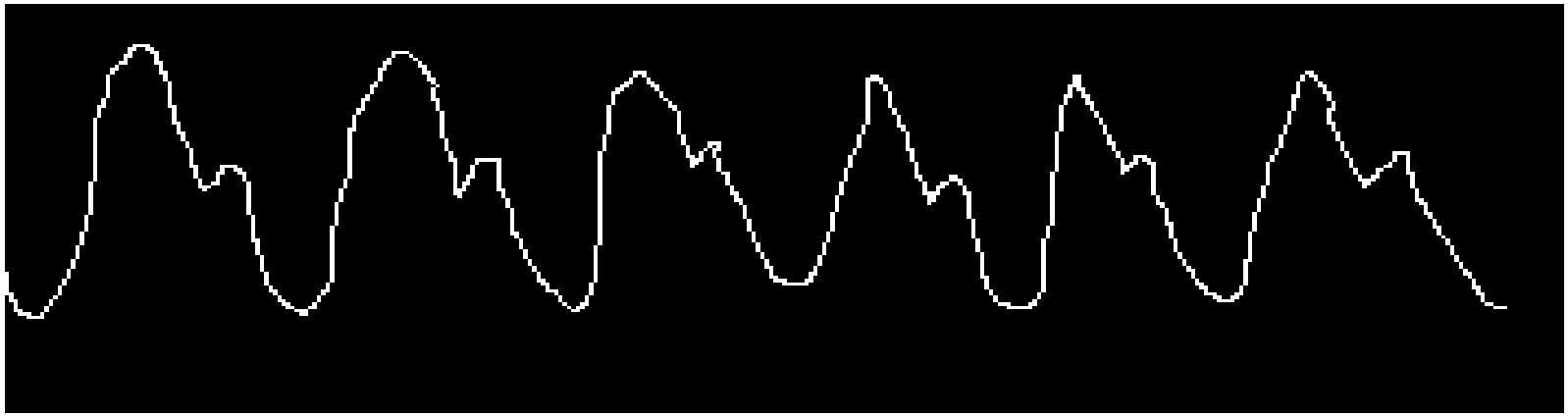
Refractory period

- **Long** refractory period (250 msec) compared to skeletal muscle (3msec)
- During this period membrane is refractory to f urther stimulation until contraction is over.
- It lasts longer than muscle contraction, prevents tetanus
- Gives time to heart to relax after each contract ion, prevent fatigue
- It allows time for the heart chambers to fill during diastole before next contraction



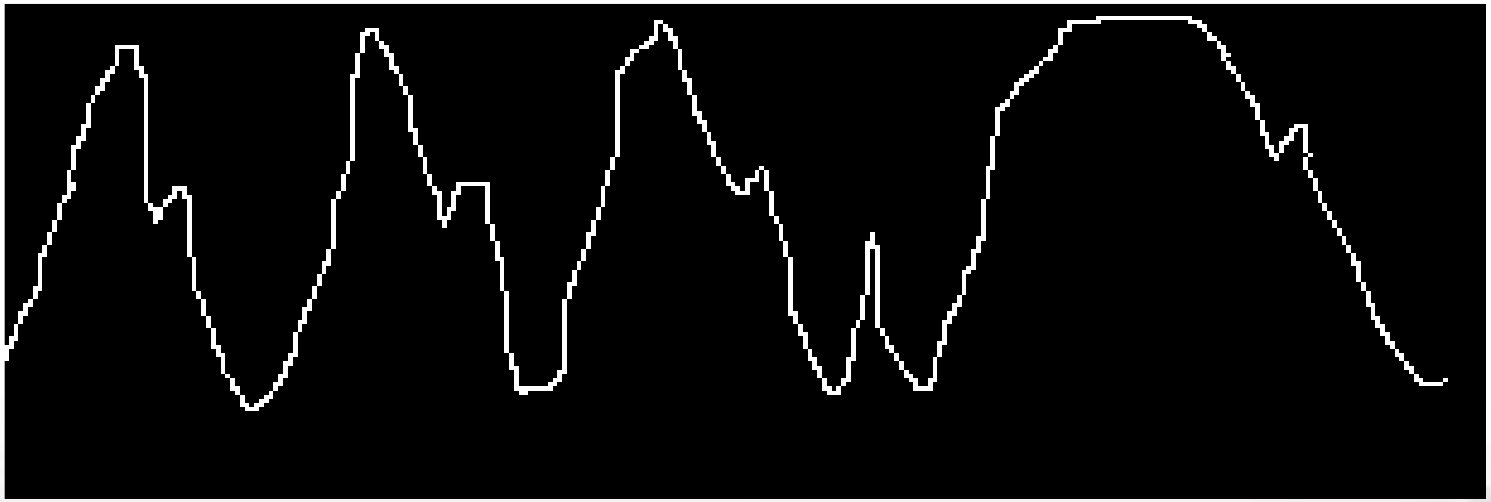
Normal Cardiogram

- It is a recording of the mechanical activity of the heart
- Systole- Contraction Diastole- Relaxation



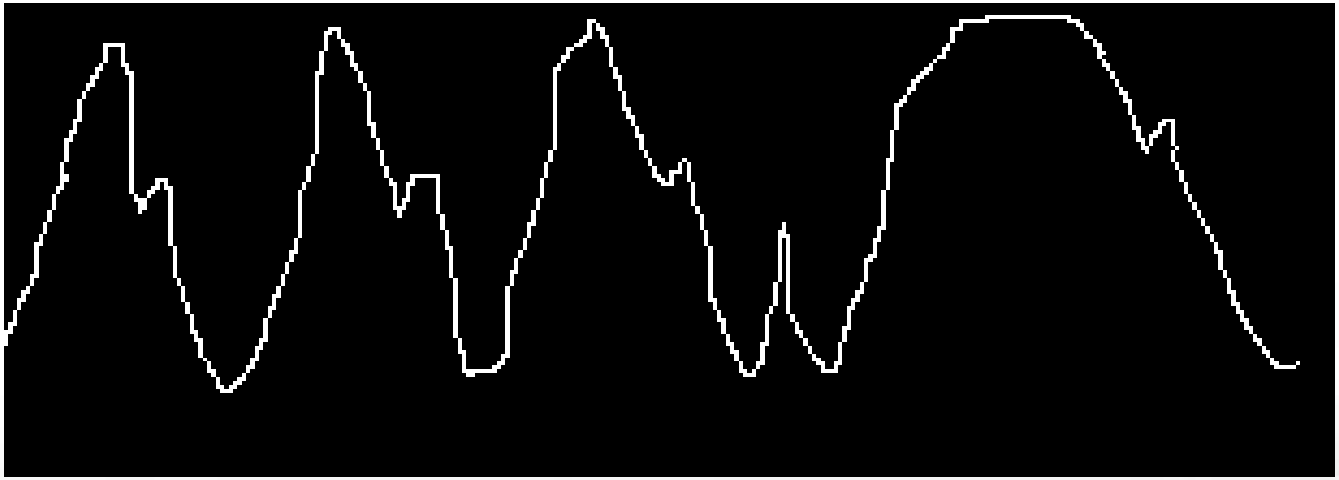
Extra systole

- It is an extra contraction seen when the second stimulus falls during the relative refractory period.
- Systole-Down stroke
- Diastole-Up stroke

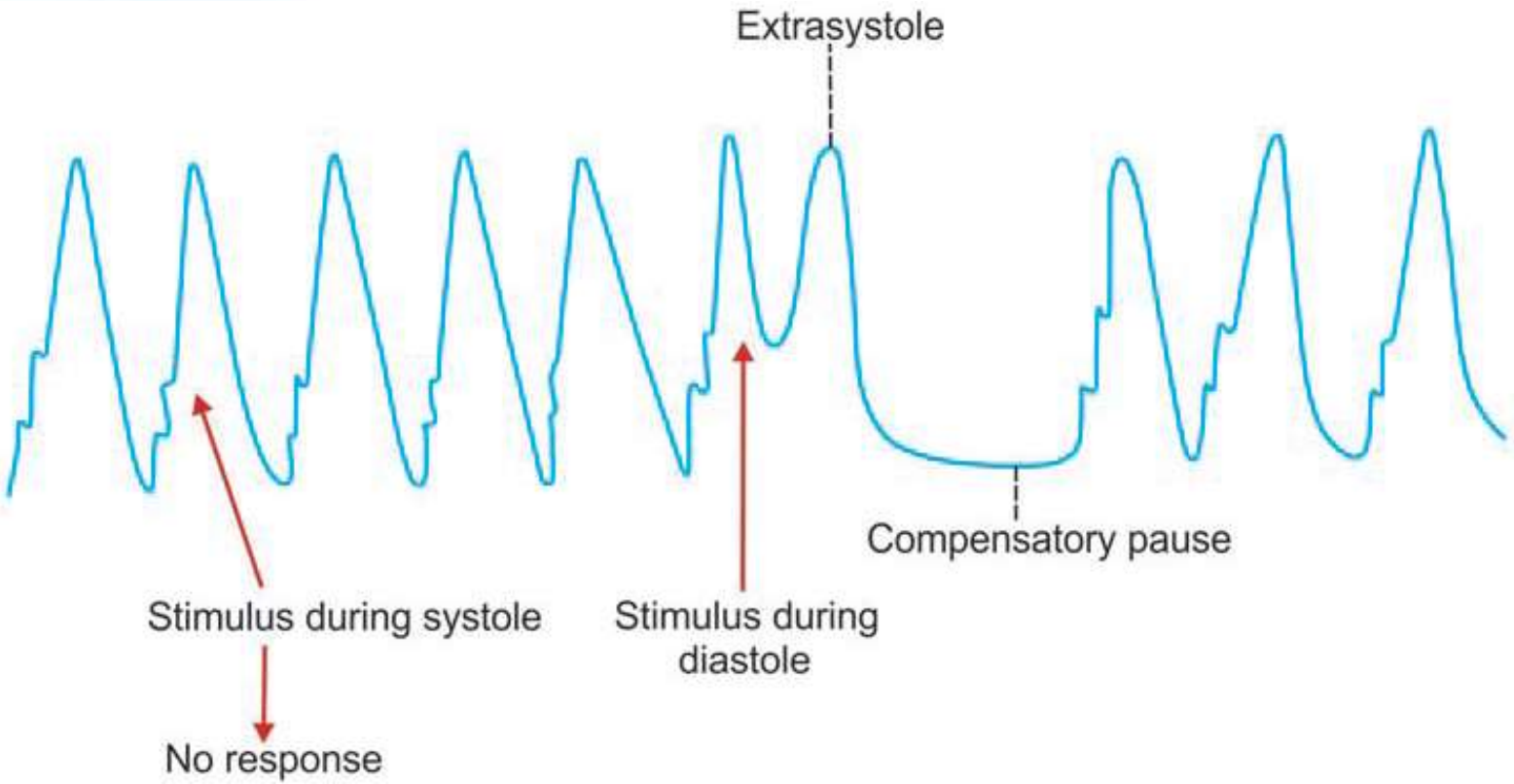


Compensatory Pause

- When an external stimulus is applied during the later 2/3 of diastole an extra contraction is observed.
- This is followed by a compensatory pause.
- Extra systole + Compensatory pause = 2 cardiac cycles



Extrasystole & compensatory pause



3. Contractility

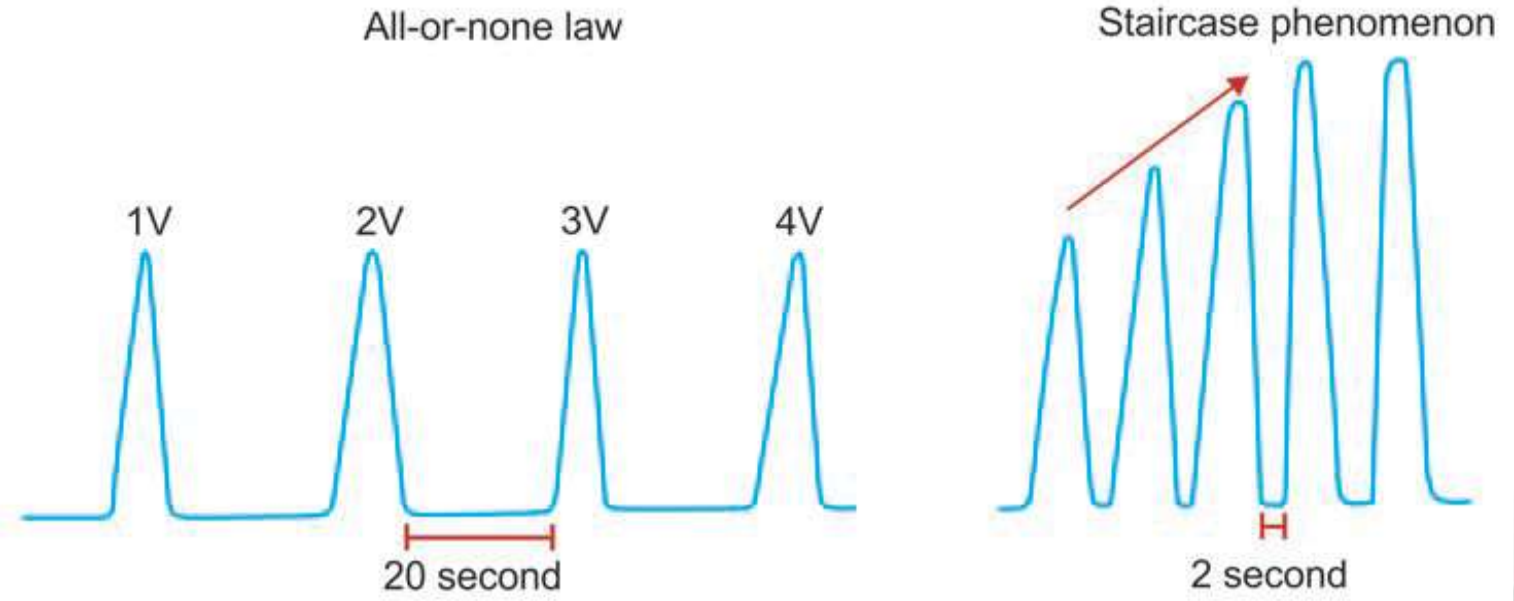
Definition: ability of cardiac muscle to contract in response to stimulation

All Or None Law

- The response to a threshold stimulus is maximal. If the stimulus is below threshold there is no response provided the physiological conditions remain constant
- The cardiac muscle follows the all or none law as a whole.
- In the case of skeletal muscle, all-or-none law is applicable only to a single muscle fiber.

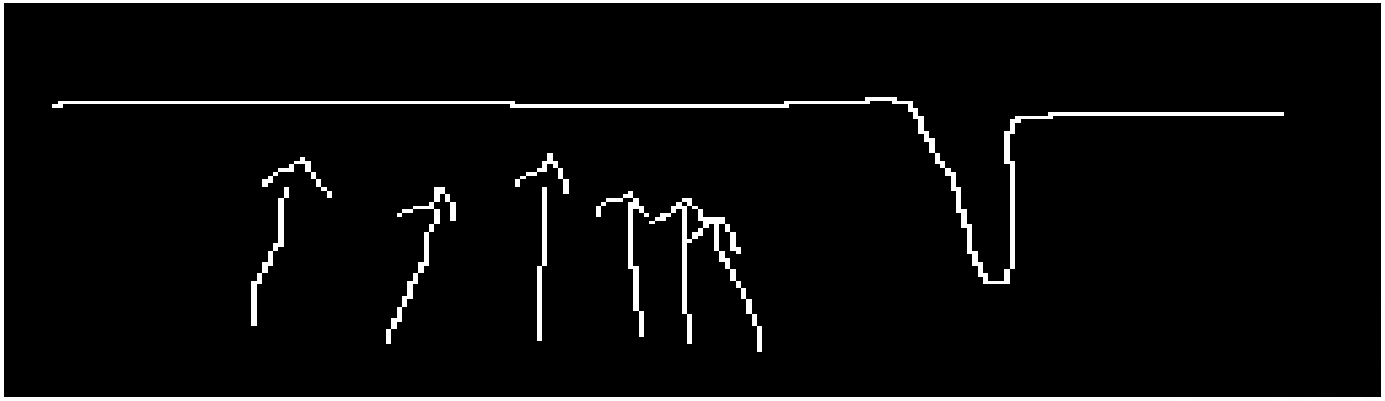
Treppe or Stair-case Phenomenon

- When stimuli of same strength are applied at short intervals, an increase in the height of contraction is observed.
- This is due to the **BENEFICIAL EFFECT** - decrease in viscosity, mild increase in temperature and increase in the level of calcium ions.



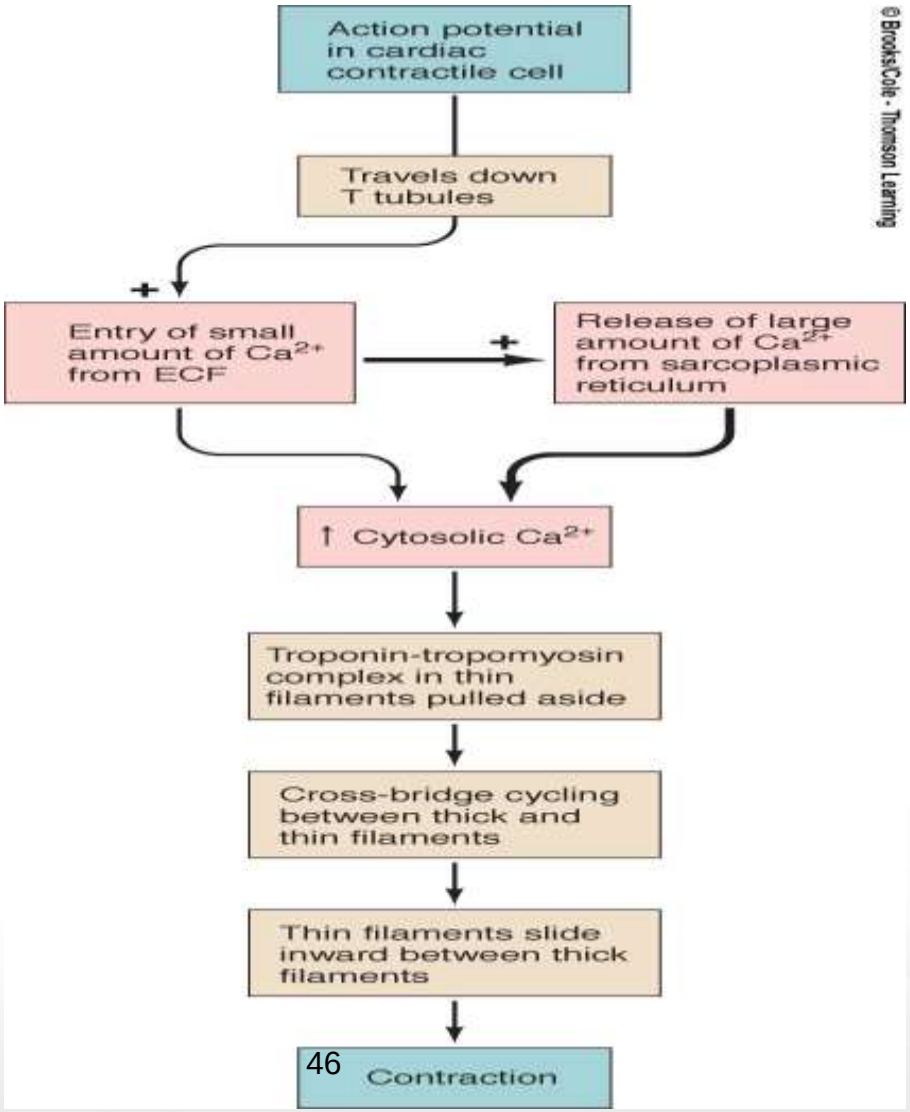
Summation of Sub-minimal Stimuli

When a series of sub-minimal stimuli are applied to the cardiac muscle, it responds with a contraction once all the sub –minimal add up to produce a threshold stimulus.



Excitation-Contraction Coupling in Cardiac Contractile Cells

Similar to that in skeletal muscles



The cardiac muscle stores much more calcium in its tubular system than skeletal muscle and is much more dependent on extracellular calcium than the skeletal muscle.

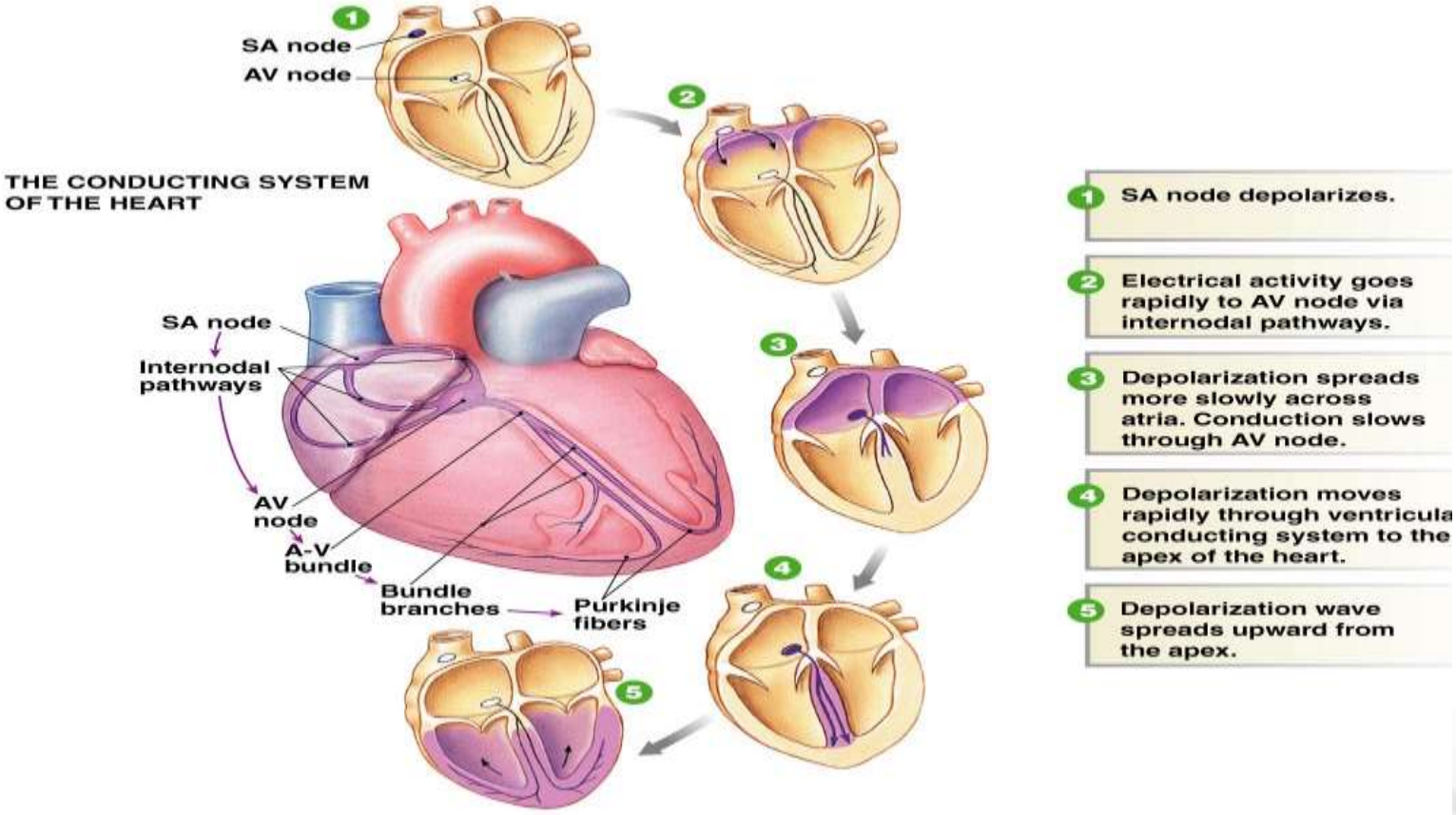
An abundance of calcium is bound by the mucopolysaccha -rides inside the T-tubule.

This calcium is necessary for contraction of cardiac muscle, and its strength of contraction depends on the calcium concentration surrounding the cardiac myocytes.

At the initiation of the action potential, the fast sodium channels open first, followed later by the opening of the slow calcium channels.

4. Conductivity

Definition: property by which excitation is conducted through the cardiac tissue



Tissue	Conduction rate (m/s)
Atrial muscle	0.3
Atrial pathways	1
AV node	0.05
Bundle of His	1
Purkinje system	4
Ventricular muscle	0.3-0.5

Thus, the velocity of impulses is maximum in Purkinje fibers and minimum at AV node

The atrial and ventricular muscles have a relatively rapid rate of conduction of the cardiac action potential, and the anterior internodal pathway also has fairly rapid conduction of the impulse.

However, the A-V bundle myofibrils have a slow rate of conduction because their sizes are considerably smaller than the sizes of the normal atrial and ventricular muscle.

Also, their slow conduction is partly caused by diminished numbers of gap junctions between successive muscle cells in the conducting pathway, causing a great resistance to conduction of the excitatory ions from one cell to the next.

Criteria for spread of excitation & efficient cardiac function

1. Atrial excitation and contraction should be complete before onset of ventricular contraction- ensures complete filling of the ventricles during diastole

2. Excitation of cardiac muscle fibres should be coordinated →ensure each heart chamber contracts as a unit → accomplish efficient pumping-smooth uniform contraction essential to squeeze out blood

3. Pair of atria & pair of ventricles should be functionally co-ordinated → both members contract simultaneously
   - permits synchronized pumping of blood into pulmonary & systemic circulation


Thank you!