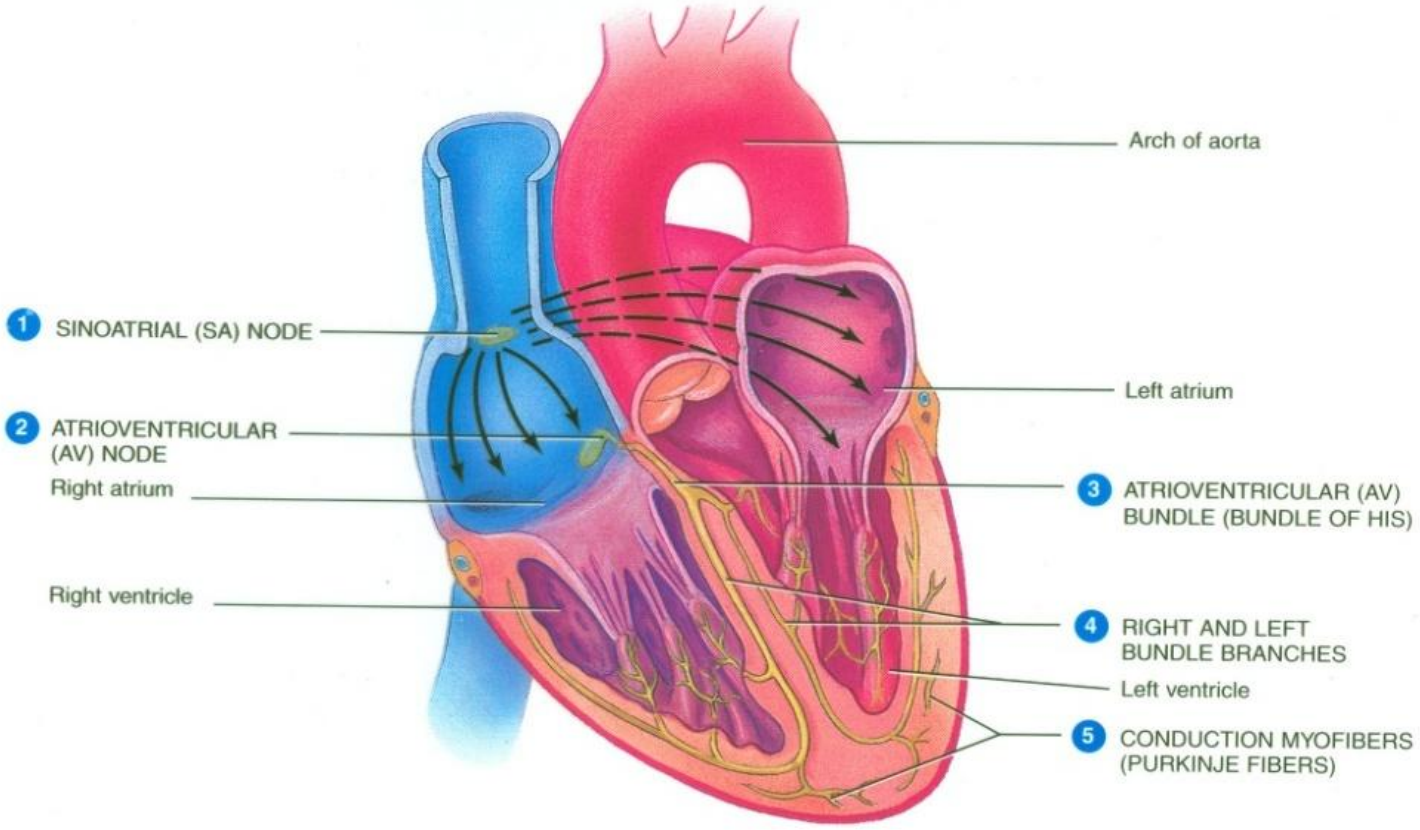
Conduction System of the Heart 4

Faisal I. Mohammed, MD, PhD

Objectives

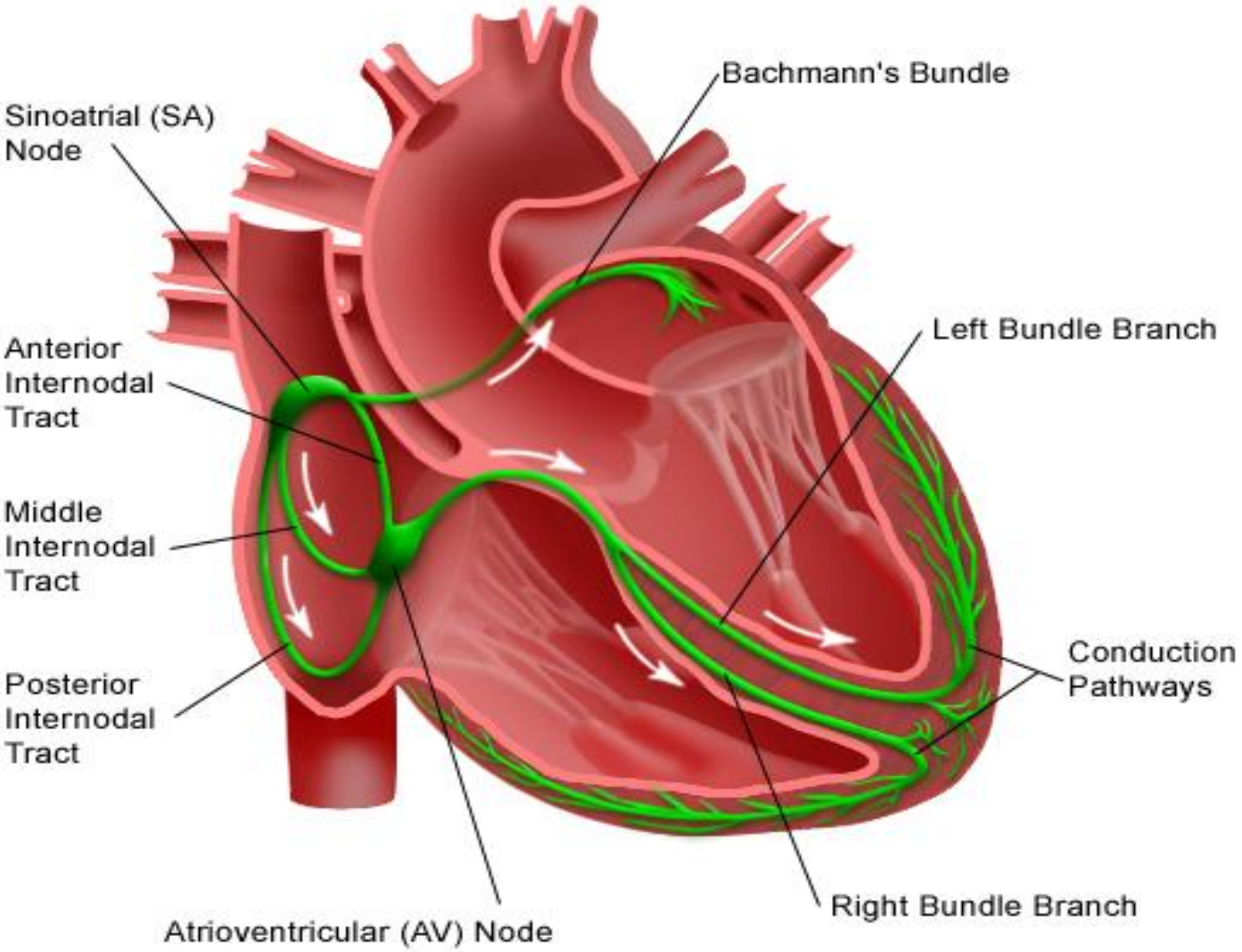
- List the parts that comprise the conduction system
- Explain the mechanism of slow response action potential (pacemaker potential)
- Point out the regulation of the conduction system potential by Autonomic Nerves
- Resource: Guyton's Textbook of Medical Physiology last edition.

Structures of the conduction system

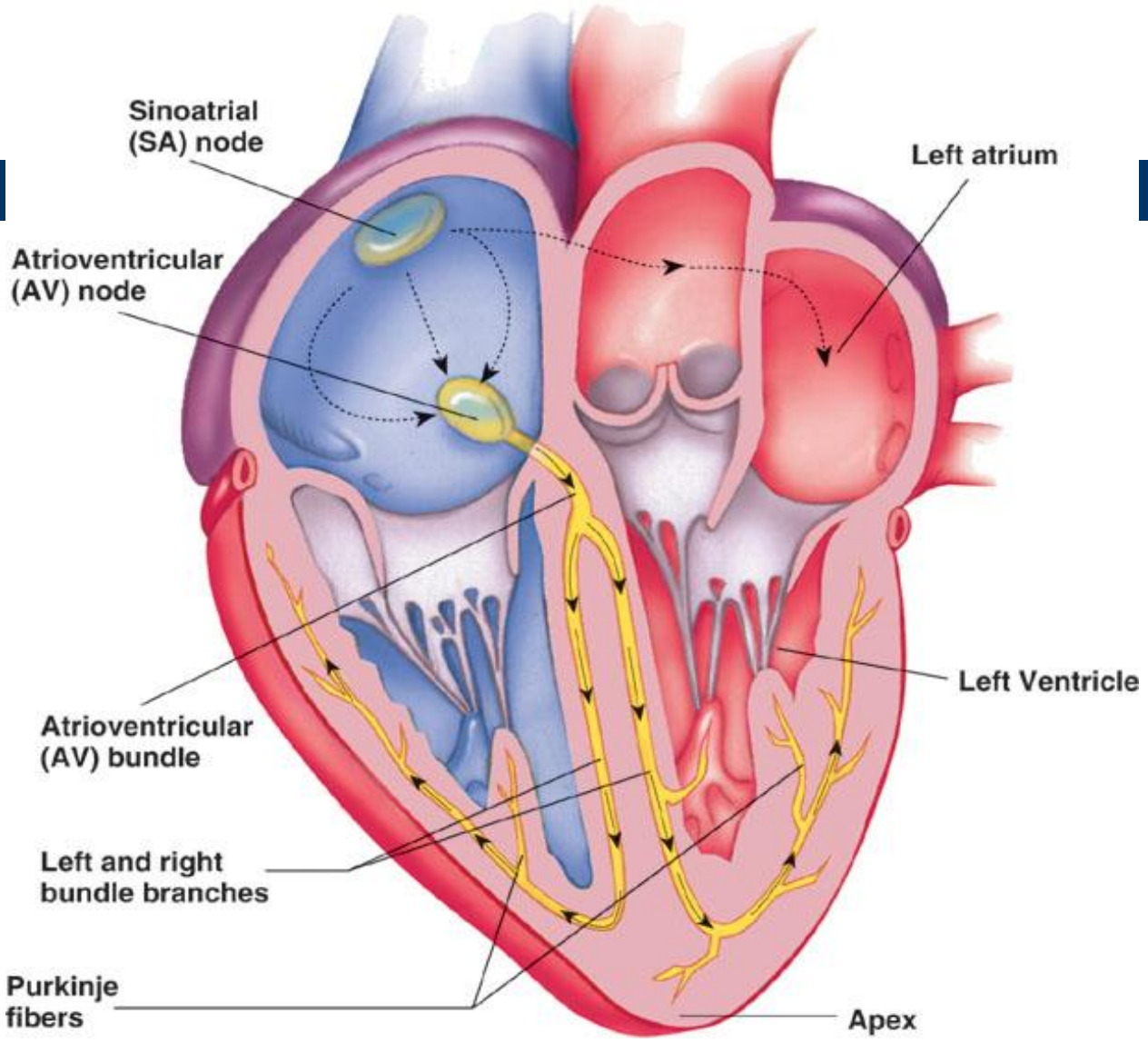


Anterior view of frontal section

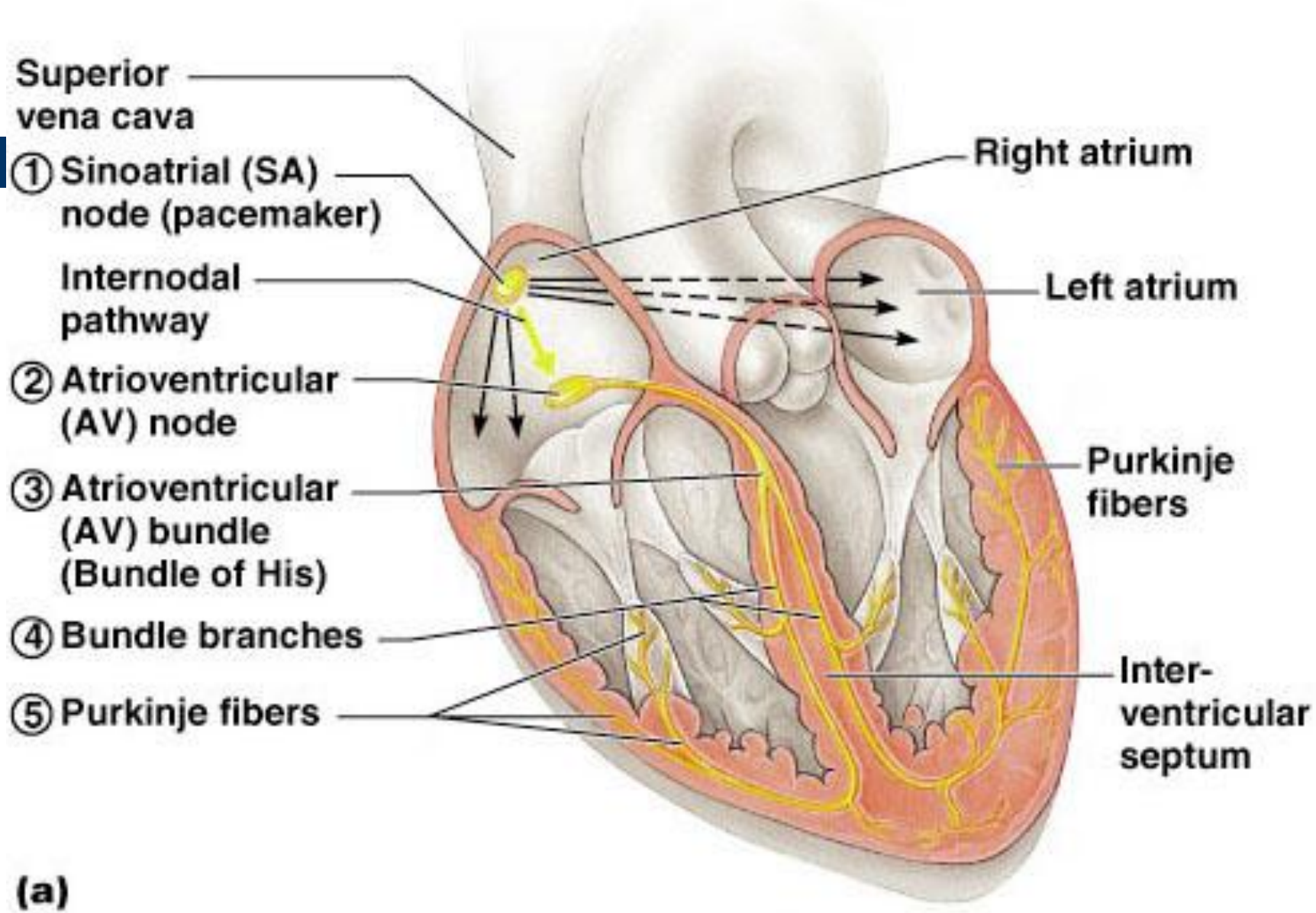
Electrical System of the Heart



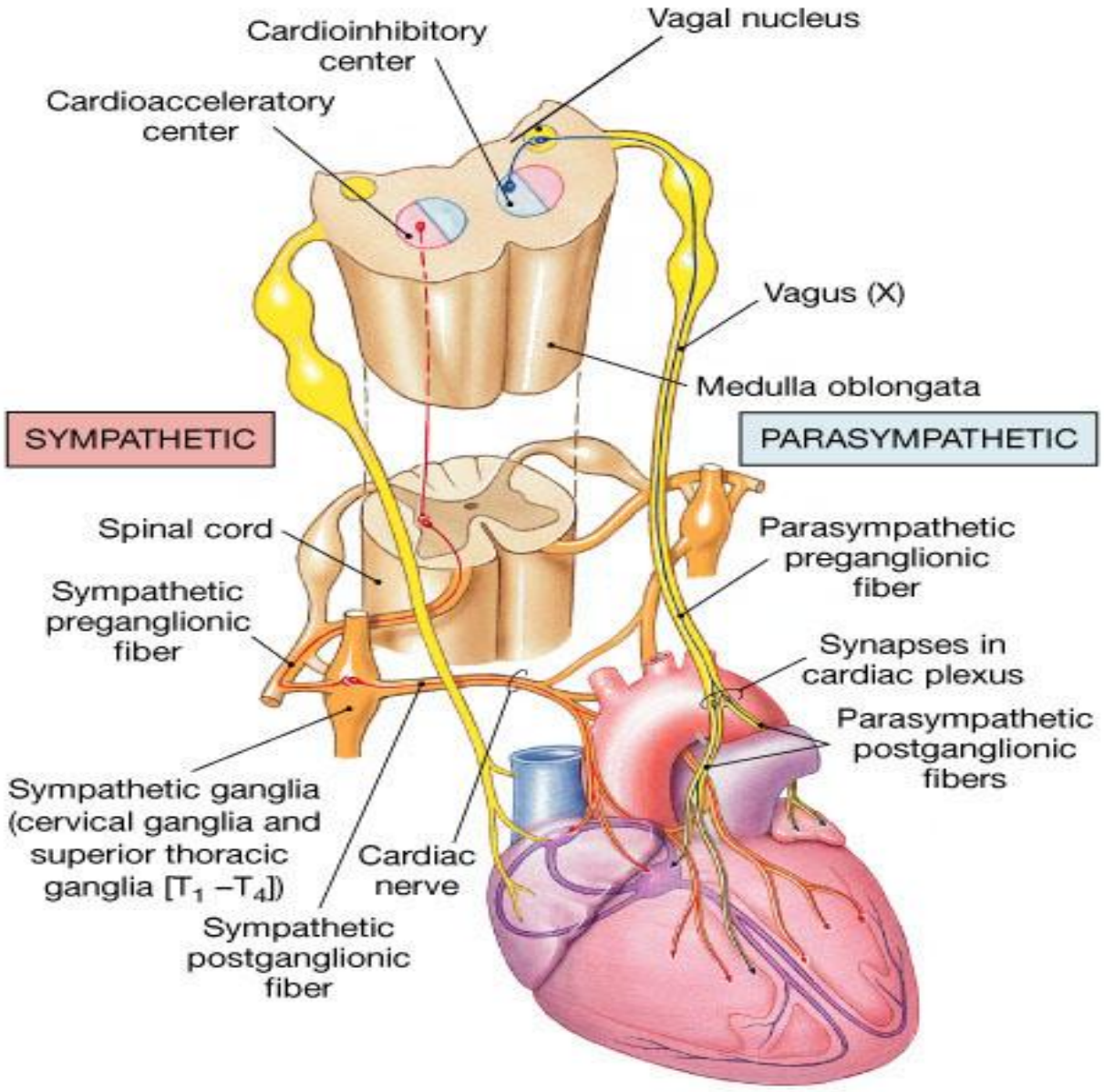
Conducting System of Heart



Heart Physiology: Sequence of Excitation



Autonomic Innervation of the Heart



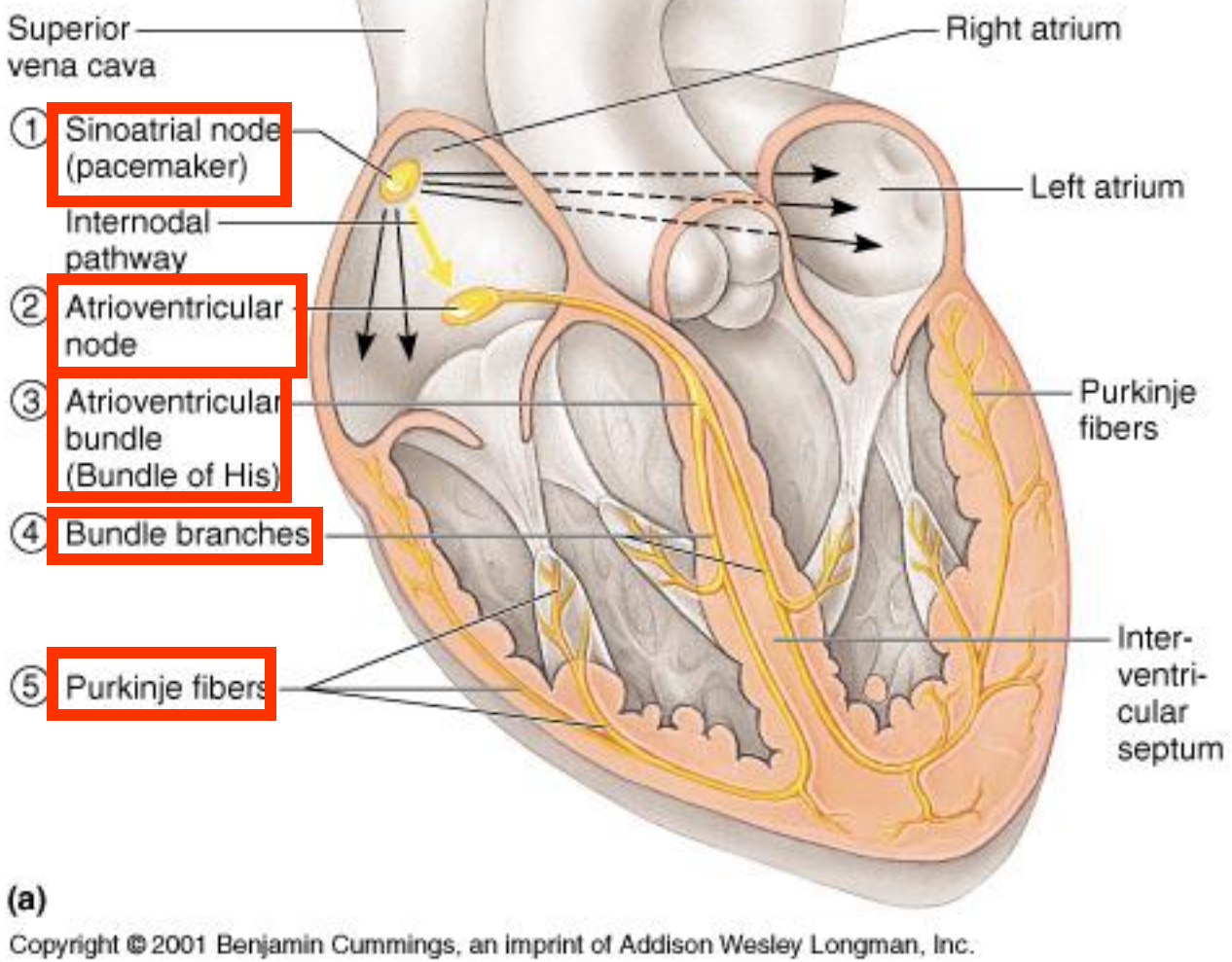
Intrinsic Cardiac Conduction System

Approximately 1% of cardiac muscle cells are autorhythmic rather than contractile

70-80/min

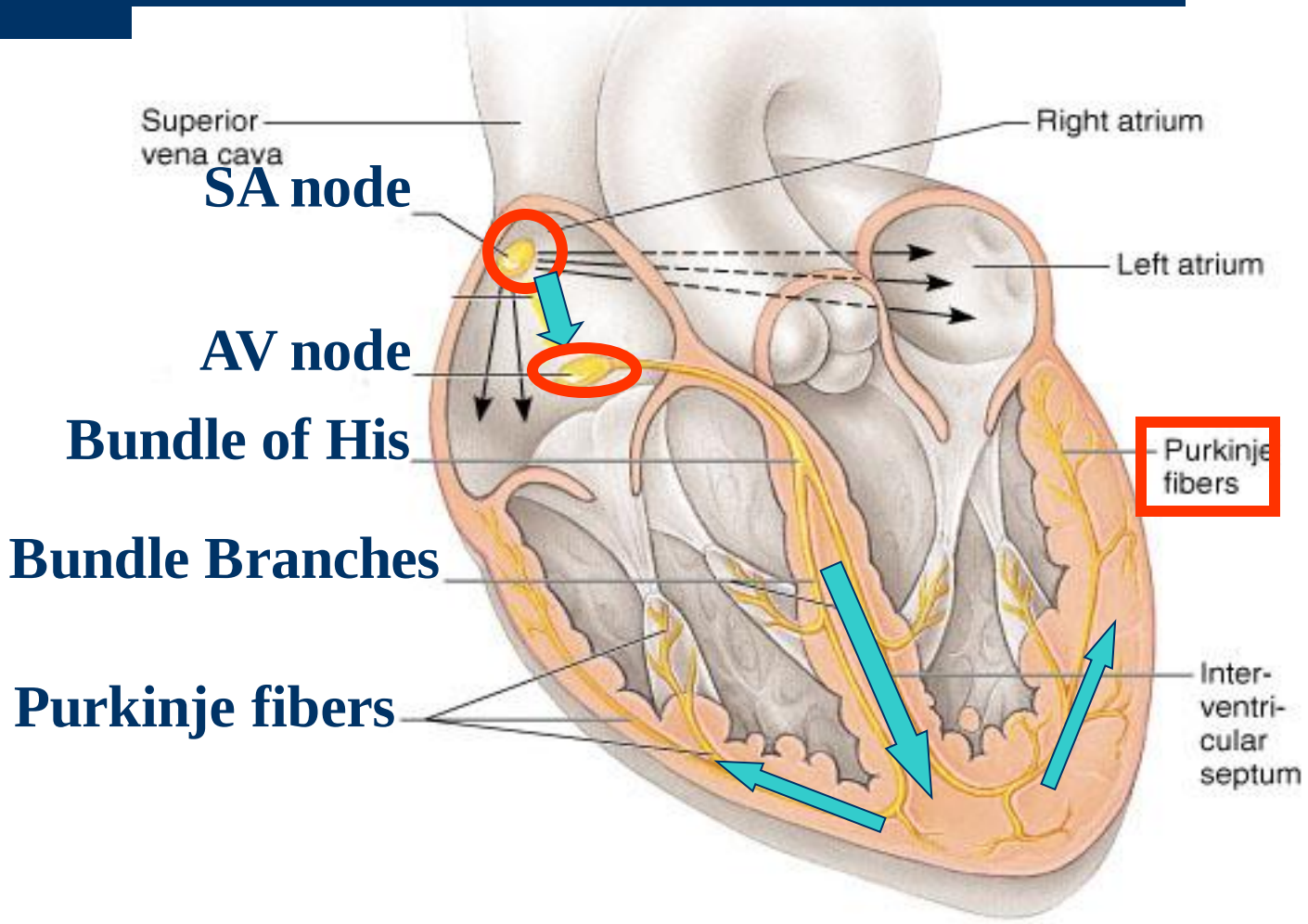
40-60/min

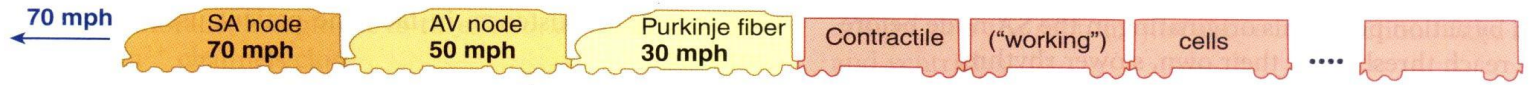
15-40/min



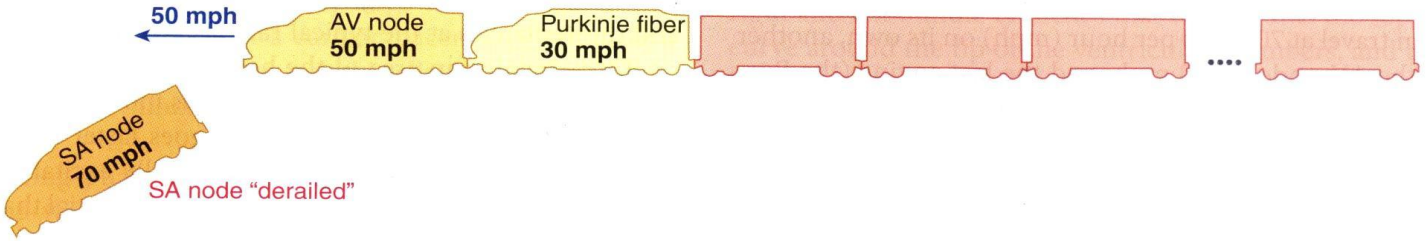
Intrinsic Conduction System

Function: initiate & distribute impulses so heart depolarizes & contracts in orderly manner from atria to ventricles.

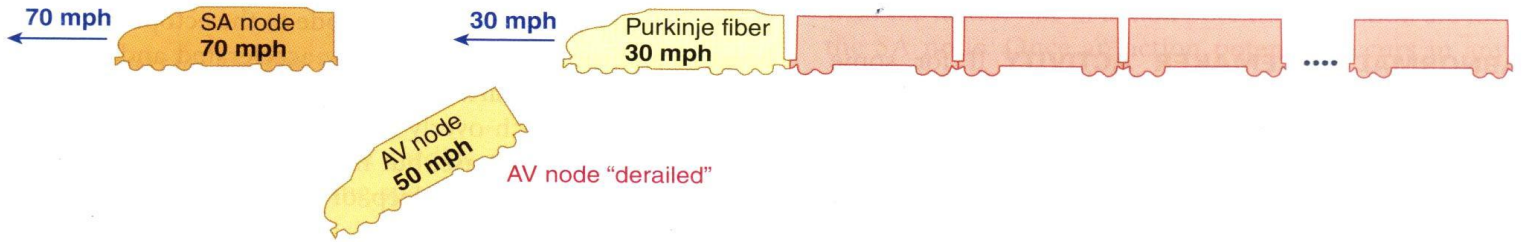




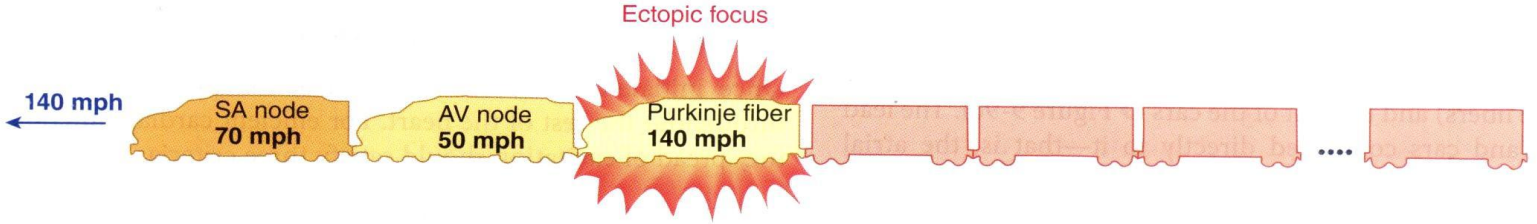
(a) Normal pacemaker activity: Whole train will go **70 mph** (heart rate set by SA node, the fastest autorhythmic tissue).



(b) Takeover of pacemaker activity by AV node when the SA node is nonfunctional: Train will go **50 mph** (the next fastest autorhythmic tissue, the AV node, will set the heart rate).



(c) Takeover of ventricular rate by the slower ventricular autorhythmic tissue in complete heart block: First part of train will go **70 mph**; last part will go **30 mph** (atria will be driven by SA node; ventricles will assume own, much slower rhythm).



(d) Takeover of pacemaker activity by an ectopic focus: Train will be driven by ectopic focus, which is now going faster than the SA node (the whole heart will be driven more rapidly by an abnormal pacemaker).

Components of the Conduction System of the Heart

- Conduction system parts are modified cardiac muscle cells consist of:
  - SA (sinoatrial) node (***Pacemaker***)
  - AV (atrioventricular) node
  - A-V (atrioventricular) bundle
  - Bundle branches (right and left bundle branches)
  - Purkinje fibers

Pathway of Heartbeat

- Begins in the sinoatrial (S-A) node
- Internodal pathway to atrioventricular (A-V) node ??
- Impulse delayed in A-V node (allows atria to contract before ventricles)
- A-V bundle takes impulse into ventricles
- Left and right bundles of Purkinje fibers take impulses to all parts of ventricles

Sinus Node

- Specialized cardiac muscle connected to atrial muscle.
- Acts as pacemaker because membrane leaks Na^{+} and membrane potential is -55 to -60mV
- When membrane potential reaches -40 mV, slow Ca^{++} channels open causing action potential.
- After 100-150 msec Ca^{++} channels close and K^{+}channels open more thus returning membrane potential to -55mV.

Internodal Pathways ??

- Transmits cardiac impulse throughout atria
- Anterior, middle, and posterior internodal pathways
- Anterior interatrial band carries impulses to left atrium.

A-V Node

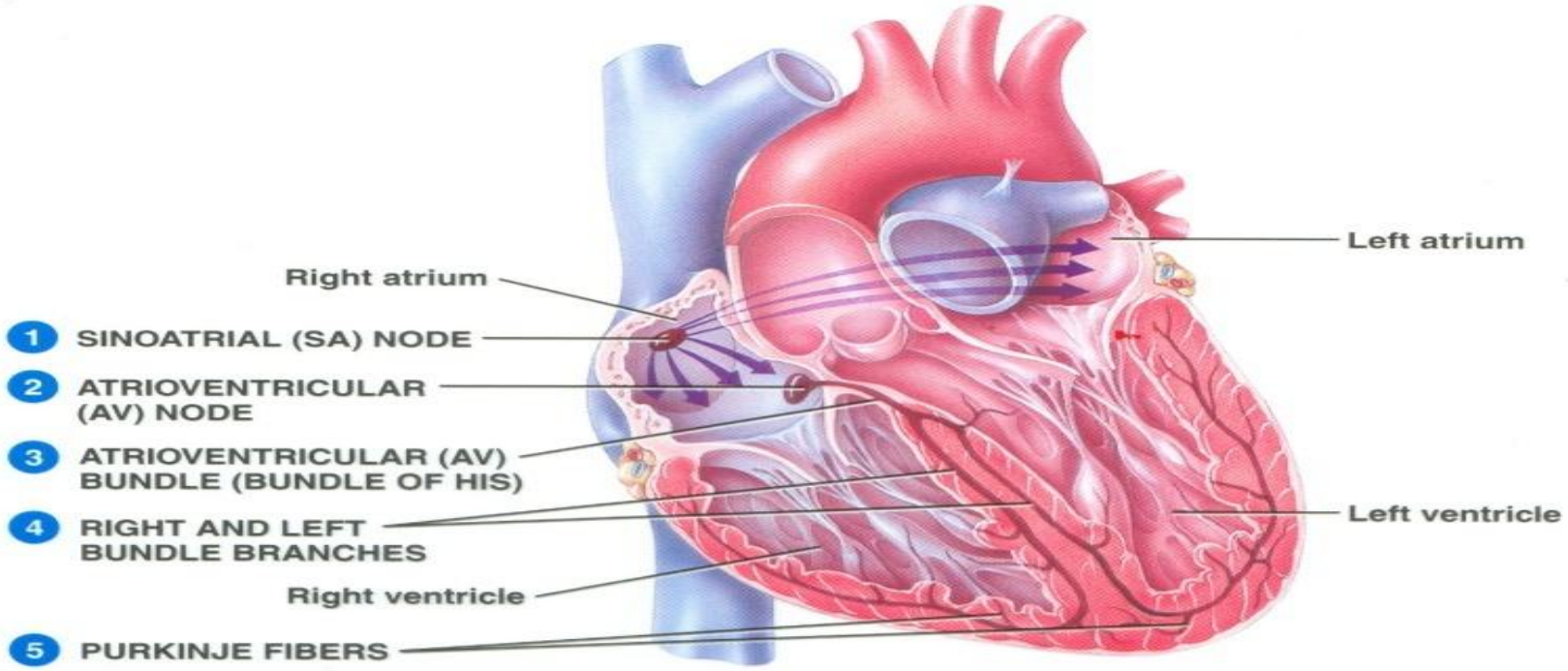
- Delays cardiac impulse
- Most delay is in A-V node
- Delay AV node---0.09 sec.
- Delay AV bundle--0.04 sec.

Purkinje System

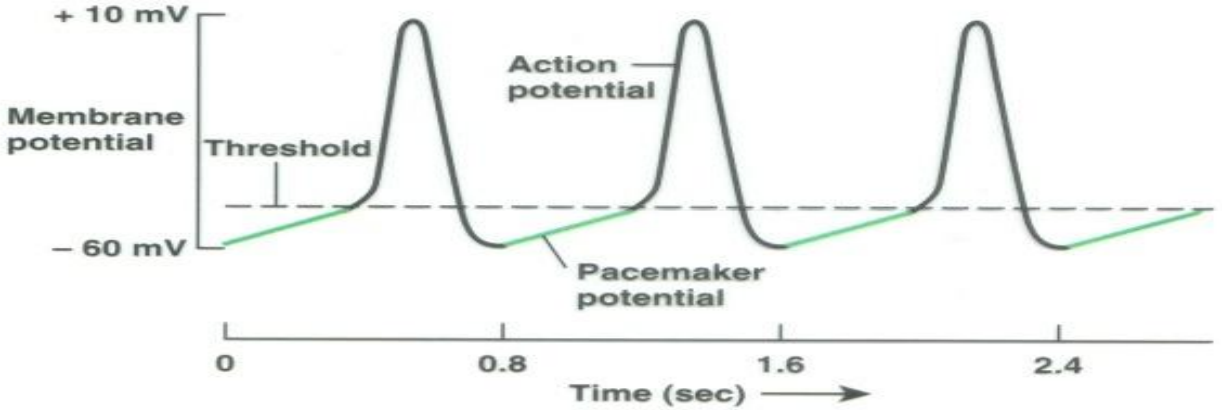
- Fibers lead from A-V node through A-V bundle into Ventricles
- Fast conduction; many gap junctions at intercalated disks

A-V Bundles

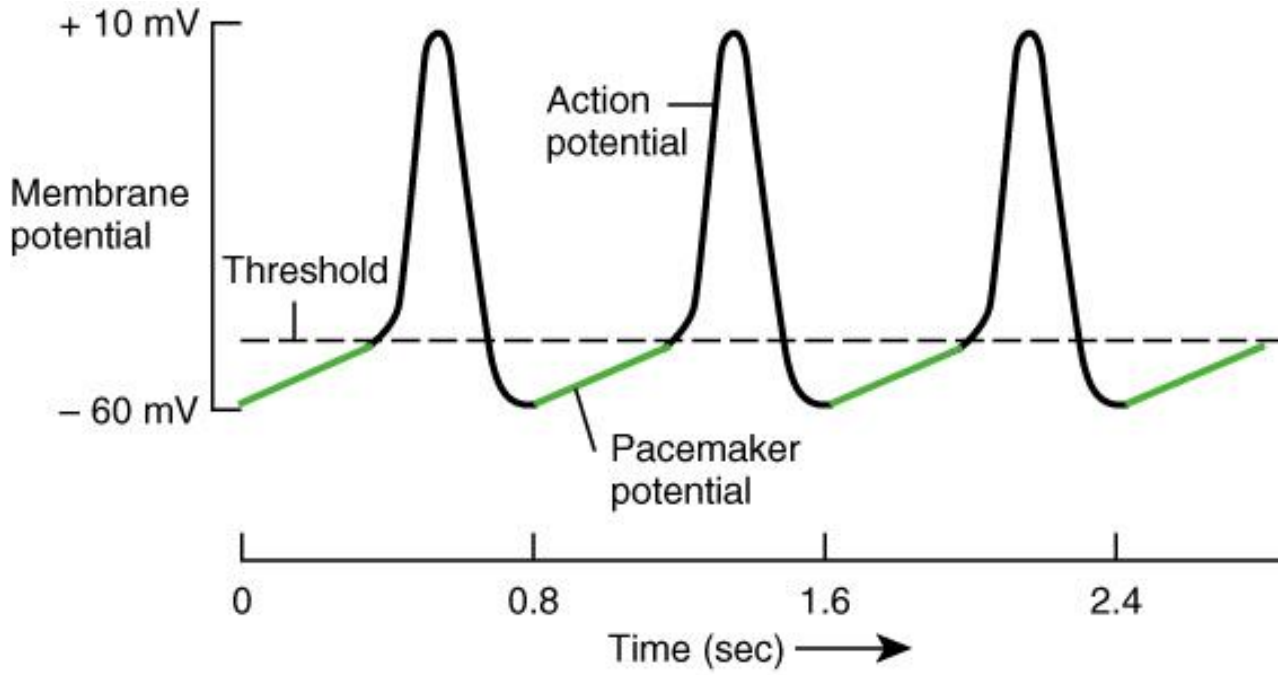
- Normally one-way conduction through the bundles
- Only conducting path between atria and ventricles is A-V node - A-V bundle
- Divides into left and right bundles
- Transmission time between A-V bundles and last of ventricular fibers is 0.06 second (QRS time)



(a) Anterior view of frontal section



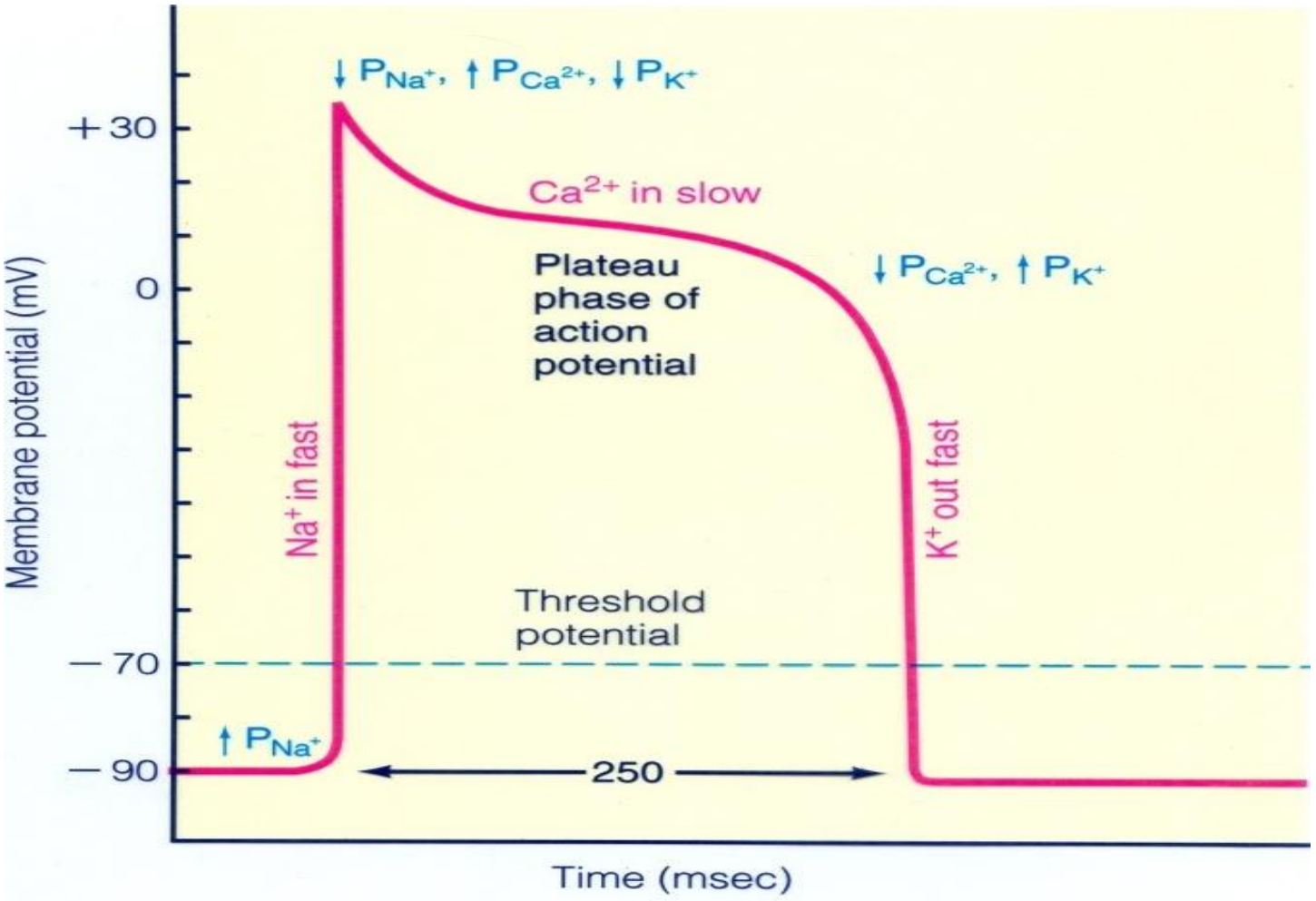
(b) Pacemaker potentials and action potentials in autorhythmic fibers of SA node



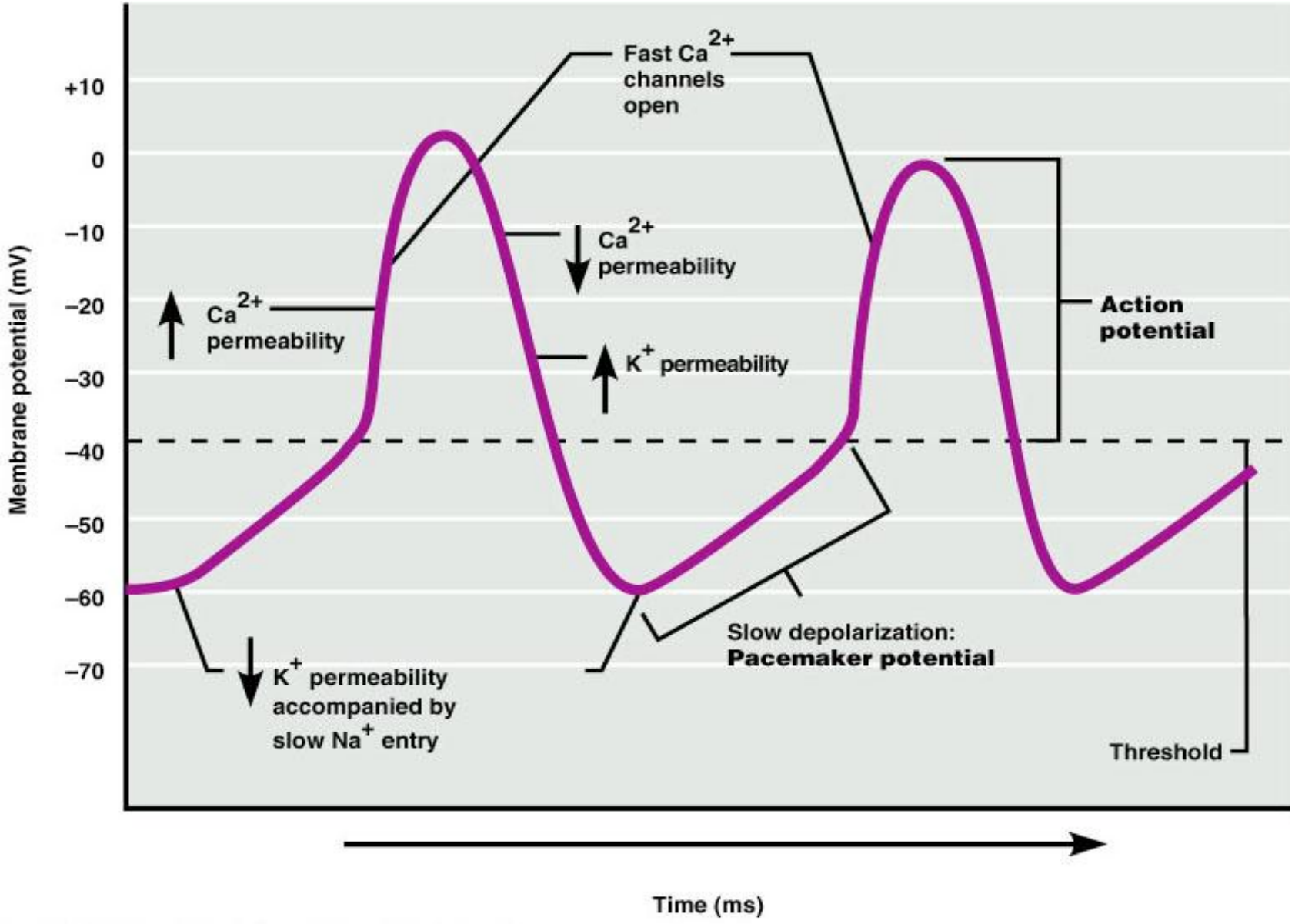
(b) Pacemaker potentials and action potentials in autorhythmic fibers of SA node

20.10b

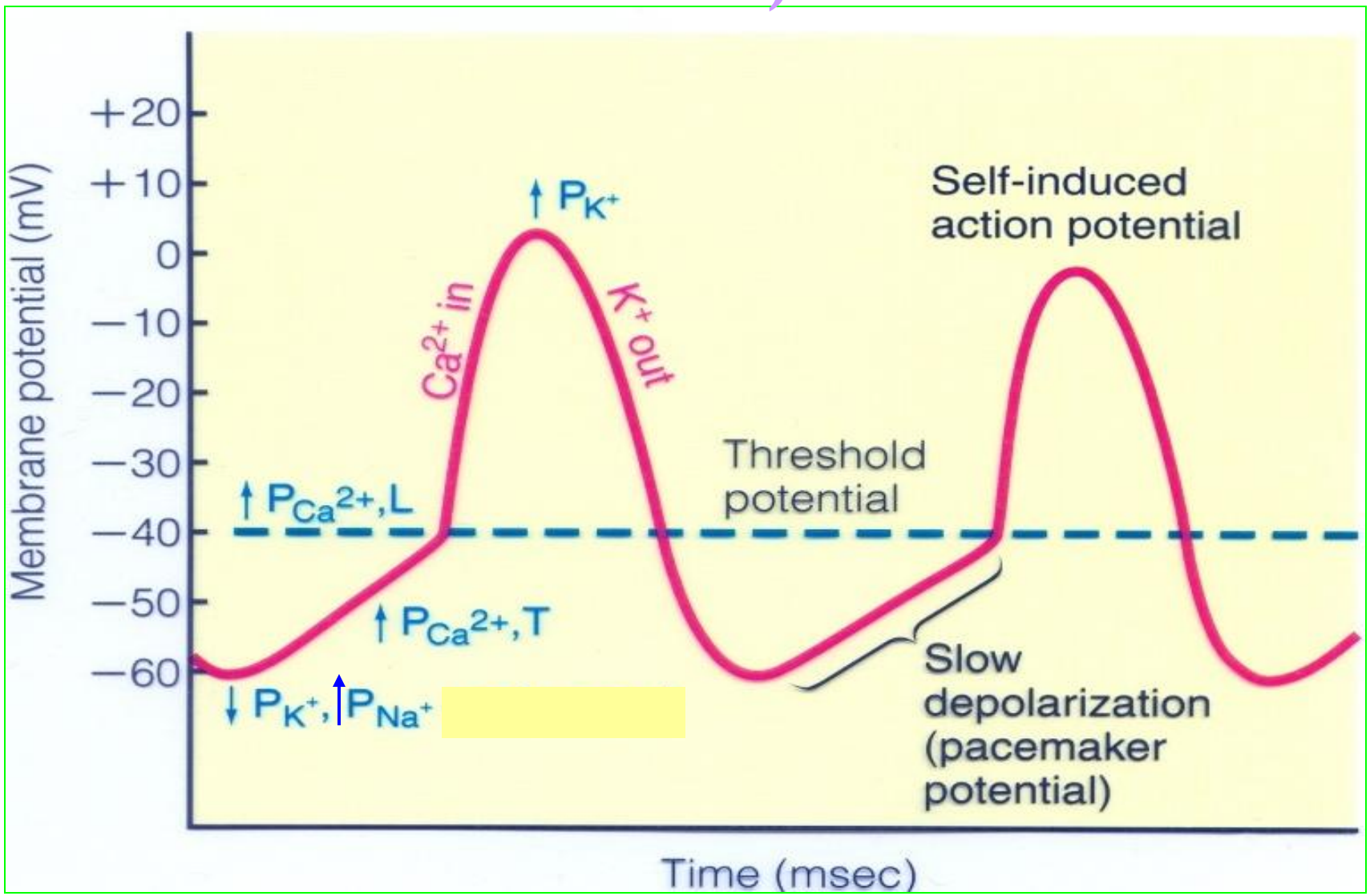
Fast Response Action Potential of Contractile Cardiac Muscle Cell



Pacemaker and Action Potentials of the Heart



Slow Response Action Potential (Pacemaker Potential)



Intrinsic rate and speed of conduction of the components of the system

- SA node 60-80 action potential /min (***Pacemaker***)
- AV node 40-60 action potential /min
- Purkinje 15-40 action potential /min

Conduction Speed

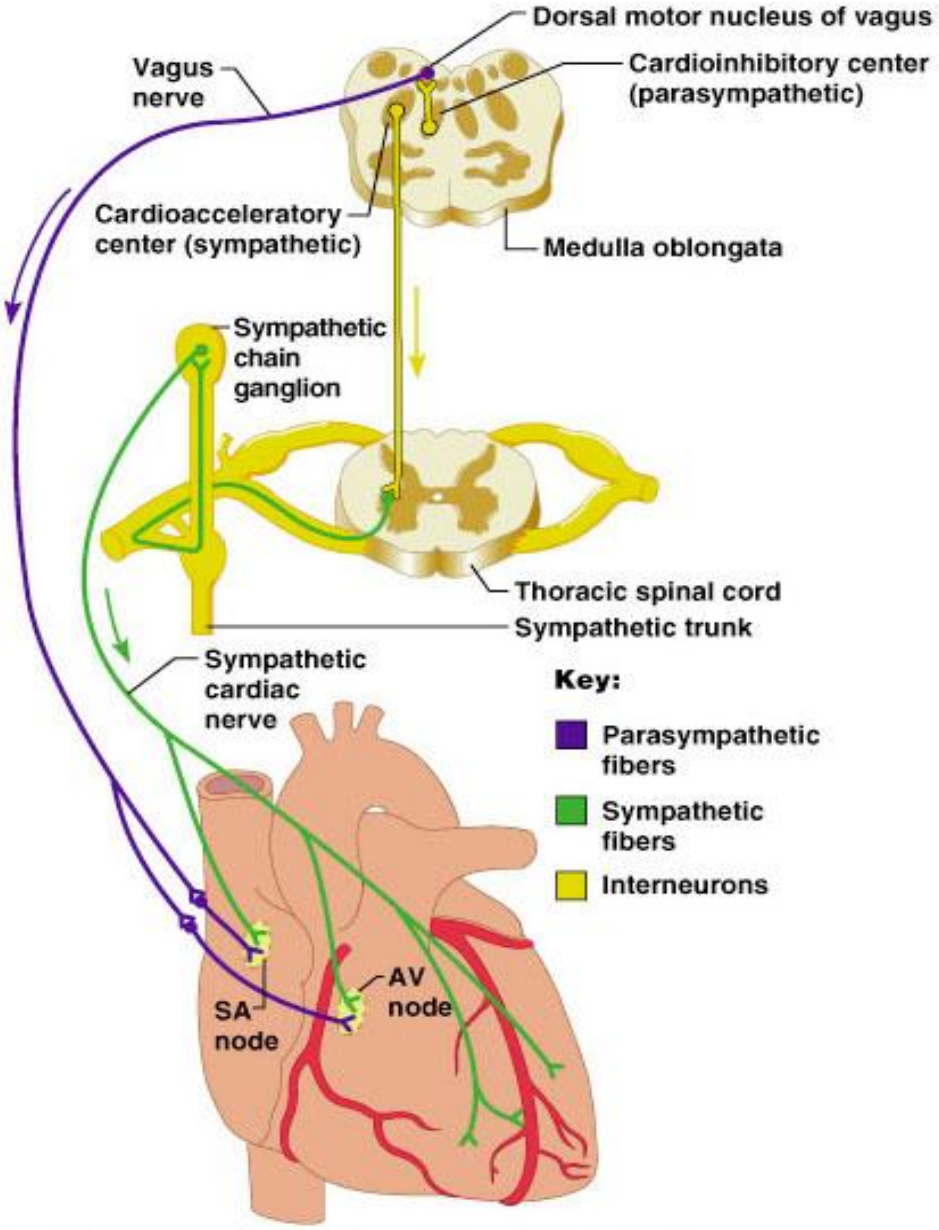
- SA node: slow speed of conduction
- Ventricular and Atrial muscle: Moderate speed
- AV node: slowest speed of conduction
- Purkinje fibers: Fastest speed of conduction
- ***Ectopic Pacemaker- Abnormal site of pacemaker***

Extrinsic Innervation of the Heart

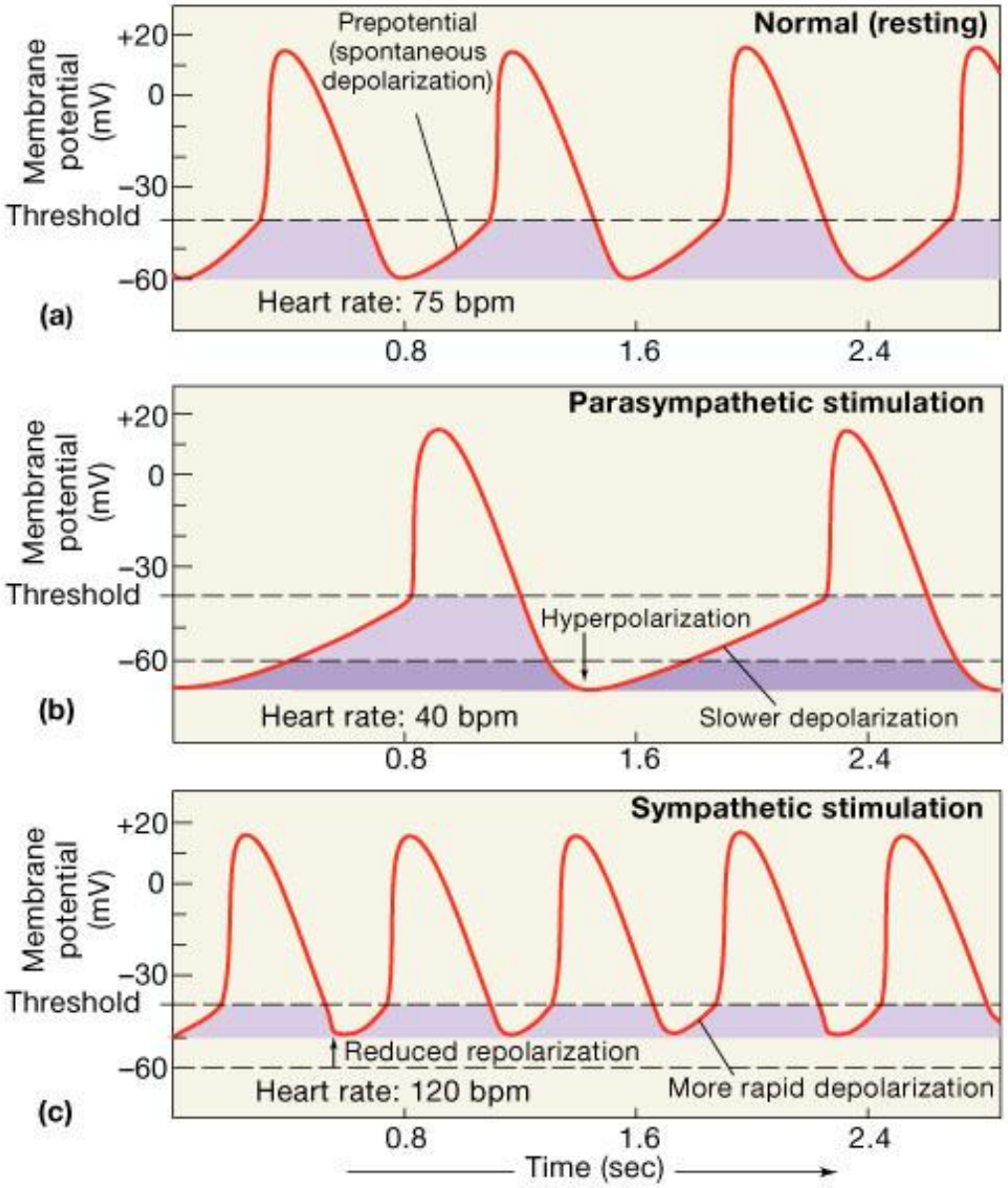
- **Vital centers of medulla**

  1. Cardiac Center
     - *Cardioaccelerator center*
       - Activates sympathetic neurons that increase HR
     - *Cardioinhibitory center*
       - Activates parasympathetic neurons that decrease HR

- Cardiac center receives input from higher centers (hypothalamus), monitoring blood pressure and dissolved gas concentrations



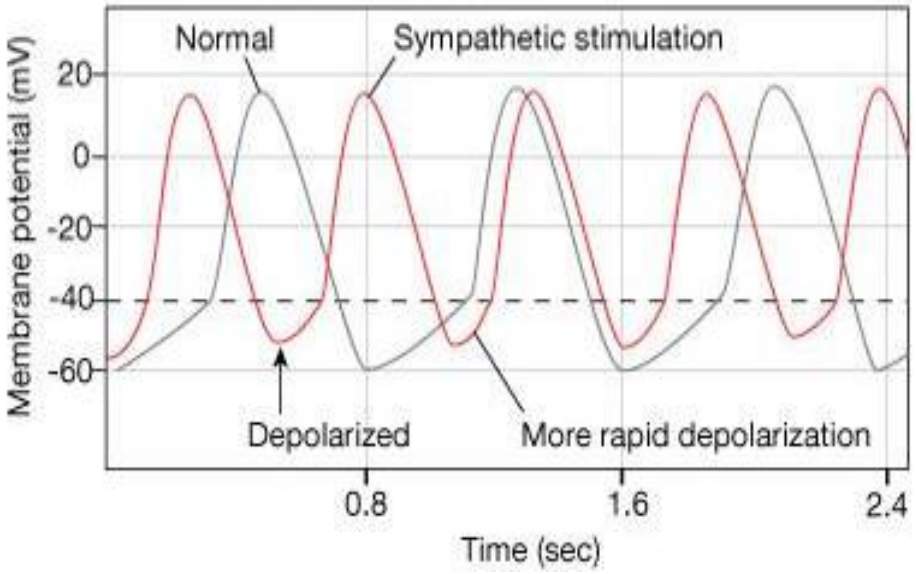
Pacemaker Function

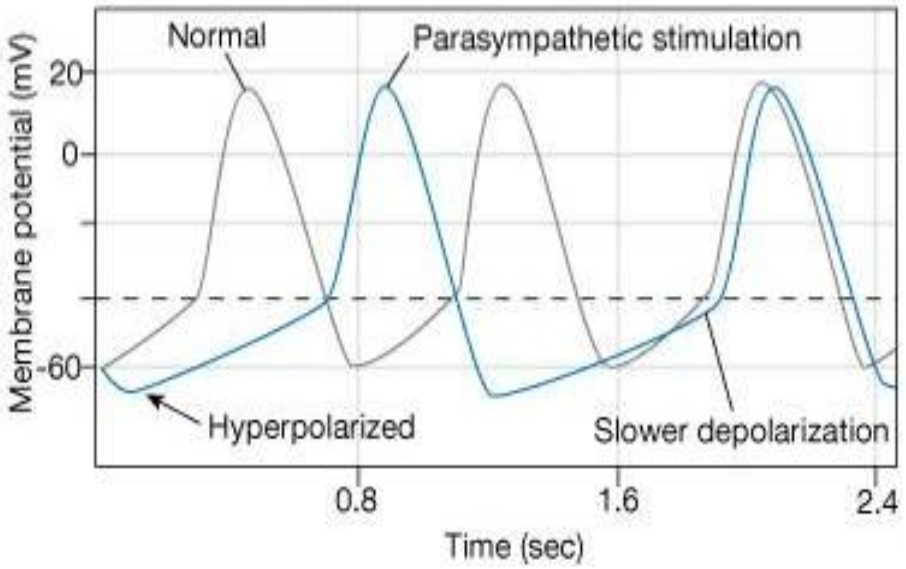


Autonomic neurotransmitters affect ion flow to change rate

- **Sympathetic** – increases heart rate by ↑ Ca^{+2} & I_f channel (net Na^+) flow
- **Parasympathetic** – decreases rate by ↑ K^+ efflux & ↓ Ca^{+2} influx

What part of the graph is <u>not</u> changed by autonomic influences?

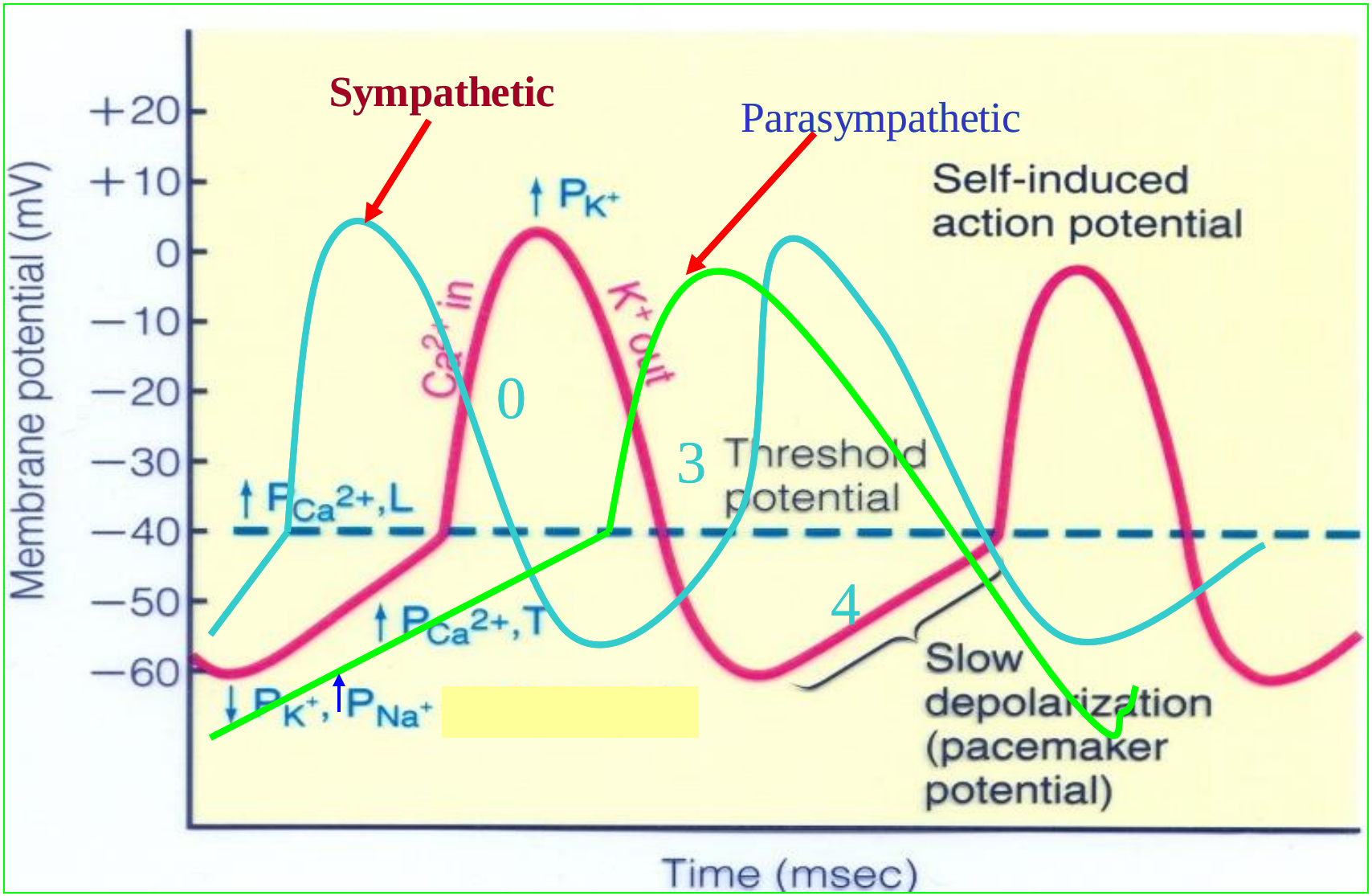




Effect of autonomic nerve activity on the heart

Region affected	Sympathetic Nerve	Parasympathetic Nerve
SA node	Increased rate of diastole depolarization ; increased cardiac rate	Decreased rate of diastole depolarization ; Decreased cardiac rate
AV node	Increase conduction rate	Decreased conduction rate
Atrial muscle	Increase strength of contraction	Decreased strength of contraction
Ventricular muscle	Increased strength of contraction	No significant effect

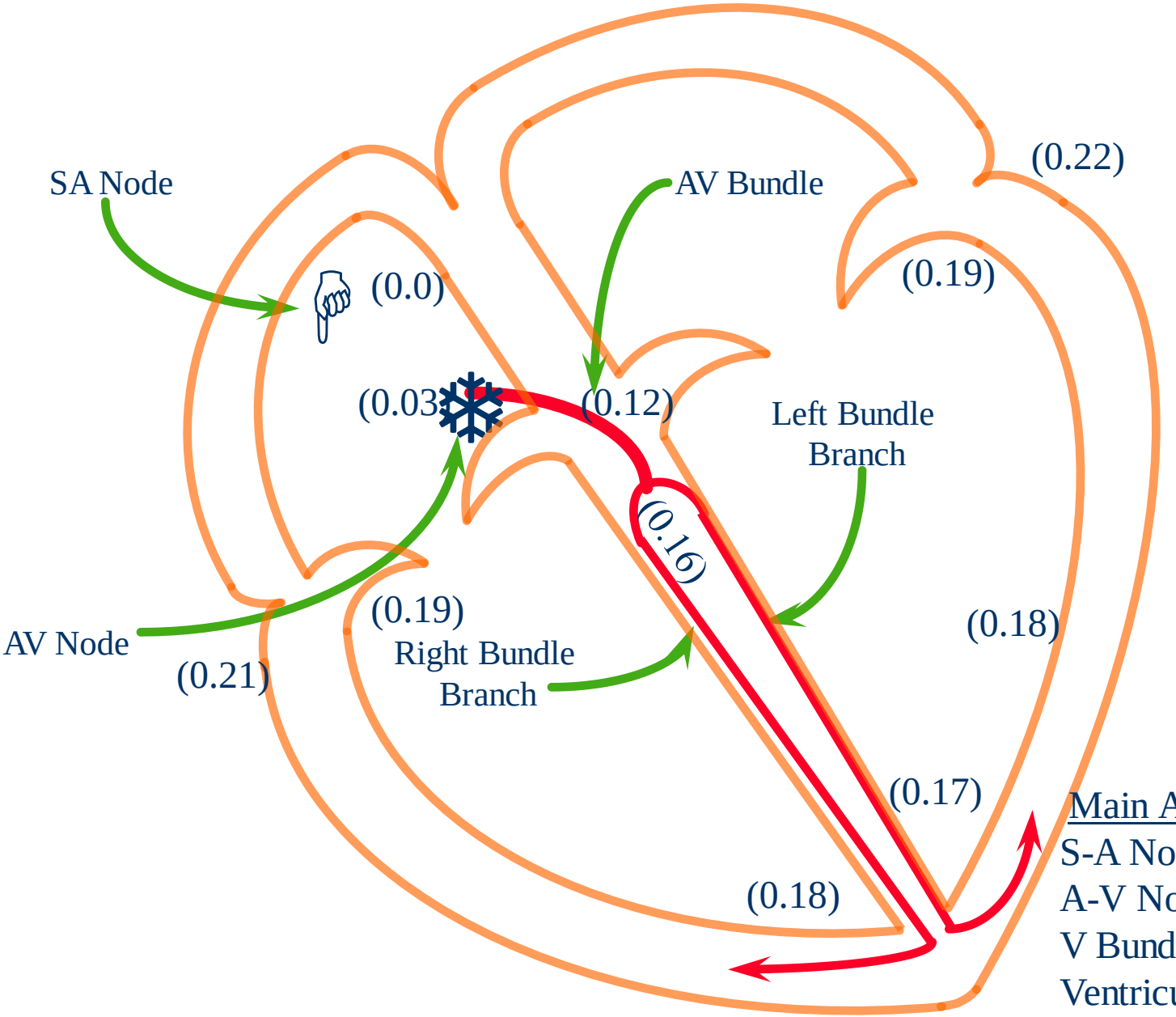
Effect of Sympathetic & Parasympathetic Stimulation



Regulation of the heart beat

- Sympathetic from the cardiac plexus supplies all parts of the heart (atria, ventricle and all parts of the conduction system)
- Parasympathetic from Vagus nerves supply mainly the atria, SA and AV nodes, very little supply to ventricles
- Sympathetic: increase the permeability of the cardiac cells to Na^{+} and Ca^{++} i.e Positive Chronotropic and positive Inotropic action
- Parasympathetic: Increase the permeability of the cardiac cells to K^{+} and decrease its permeability to Na^{+} and Ca^{++}
- Negative Chronotropic effect and ?? Inotropic effcet
- Ventricular Escape and Overdrive suppression-

Time of Arrival of Cardiac Impulse



Main Arrival Times

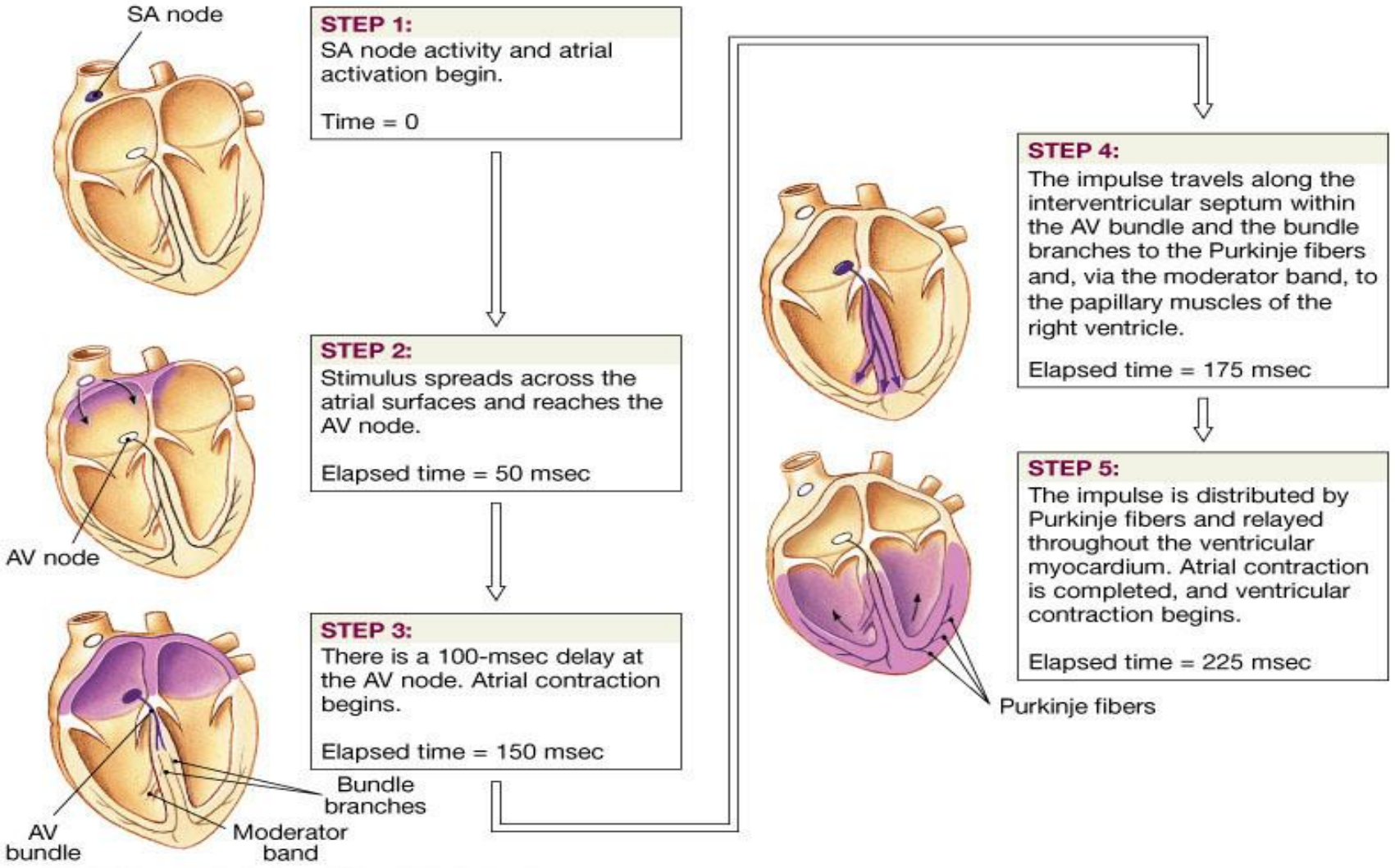
S-A Node 0.00 sec

A-V Node 0.03 sec

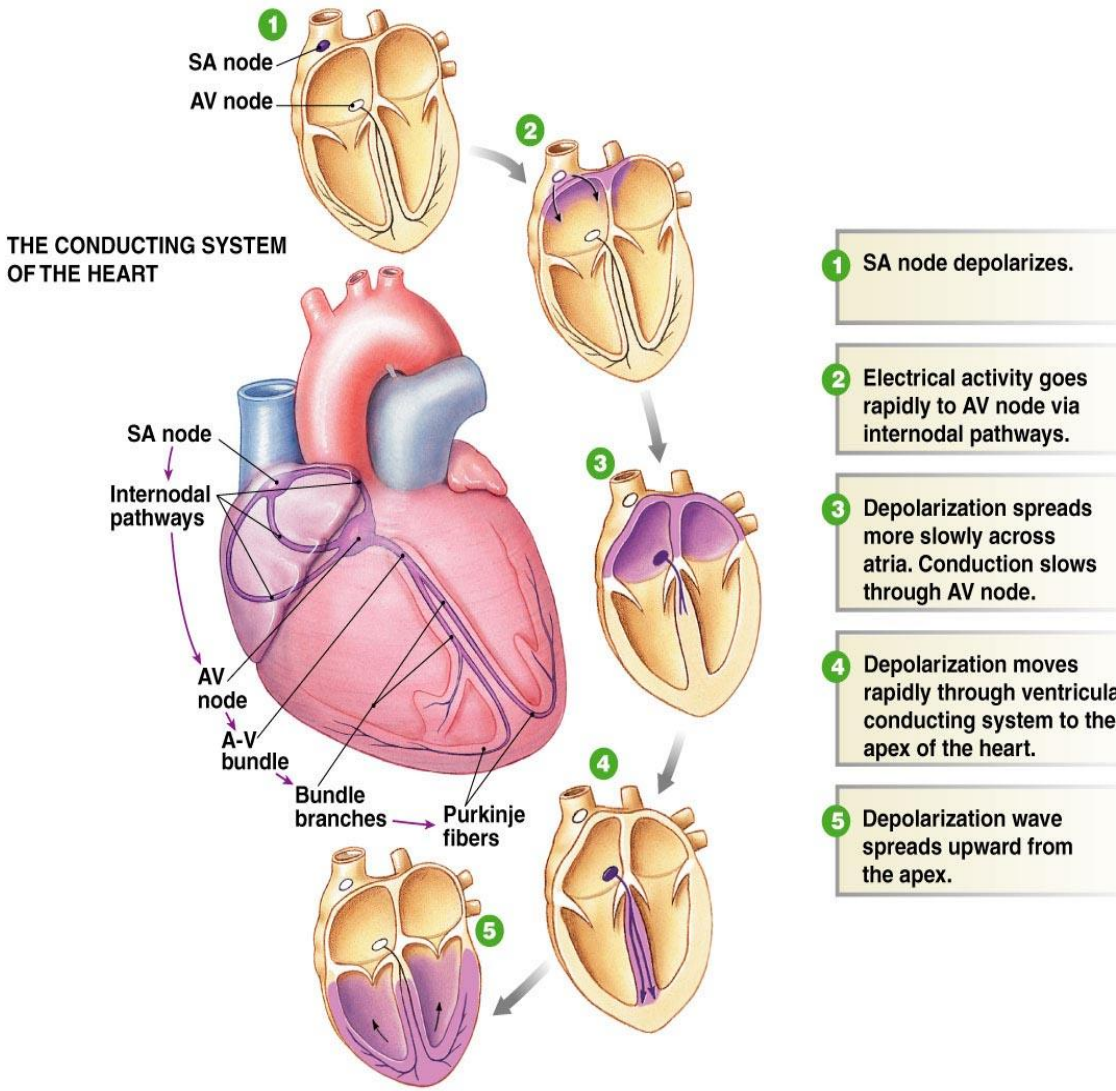
A-V Bundle 0.12 sec

Ventricular Septum 0.16 sec

Impulse Conduction through the Heart



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



Sinus Node is Cardiac Pacemaker

- Normal rate of discharge in sinus node is 70-80/min.; A-V node - 40-60/min.; Purkinje fibers - 15-40/min.
- Sinus node is pacemaker because of its faster discharge rate
- Intrinsic rate of subsequent parts is suppressed by “Overdrive suppression”

Ectopic Pacemaker

- This is a portion of the heart with a more rapid discharge than the sinus node.
- Also occurs when transmission from sinus node to A-V node is blocked (A-V block).

Ectopic Pacemaker (cont'd)

- During sudden onset of A-V block, sinus node discharge does not get through, and next fastest area of discharge becomes pacemaker of heart beat (Purkinje system).
- Delay in pickup of the heart beat is the "Stokes-Adams" syndrome. New pacemaker is in A-V node or penetrating part of A-V bundle.

Parasympathetic Effects on Heart Rate

- Parasympathetic (vagal) nerves, which release acetylcholine at their endings, innervate S-A node and A-V junctional fibers proximal to A-V node.
- Causes hyperpolarization because of increased K^+ permeability in response to acetylcholine.
- This causes decreased transmission of impulses maybe temporarily stopping heart rate.
- Ventricular escape occurs.

Sympathetic Effects on Heart Rate

- Releases norepinephrine at sympathetic ending
- Causes increased sinus node discharge (***Chronotropic effect***)
- Increases rate of conduction of impulse (***Dromotropic effect***)
- Increases force of contraction in atria and ventricles (***Inotropic effect***)

Thank You

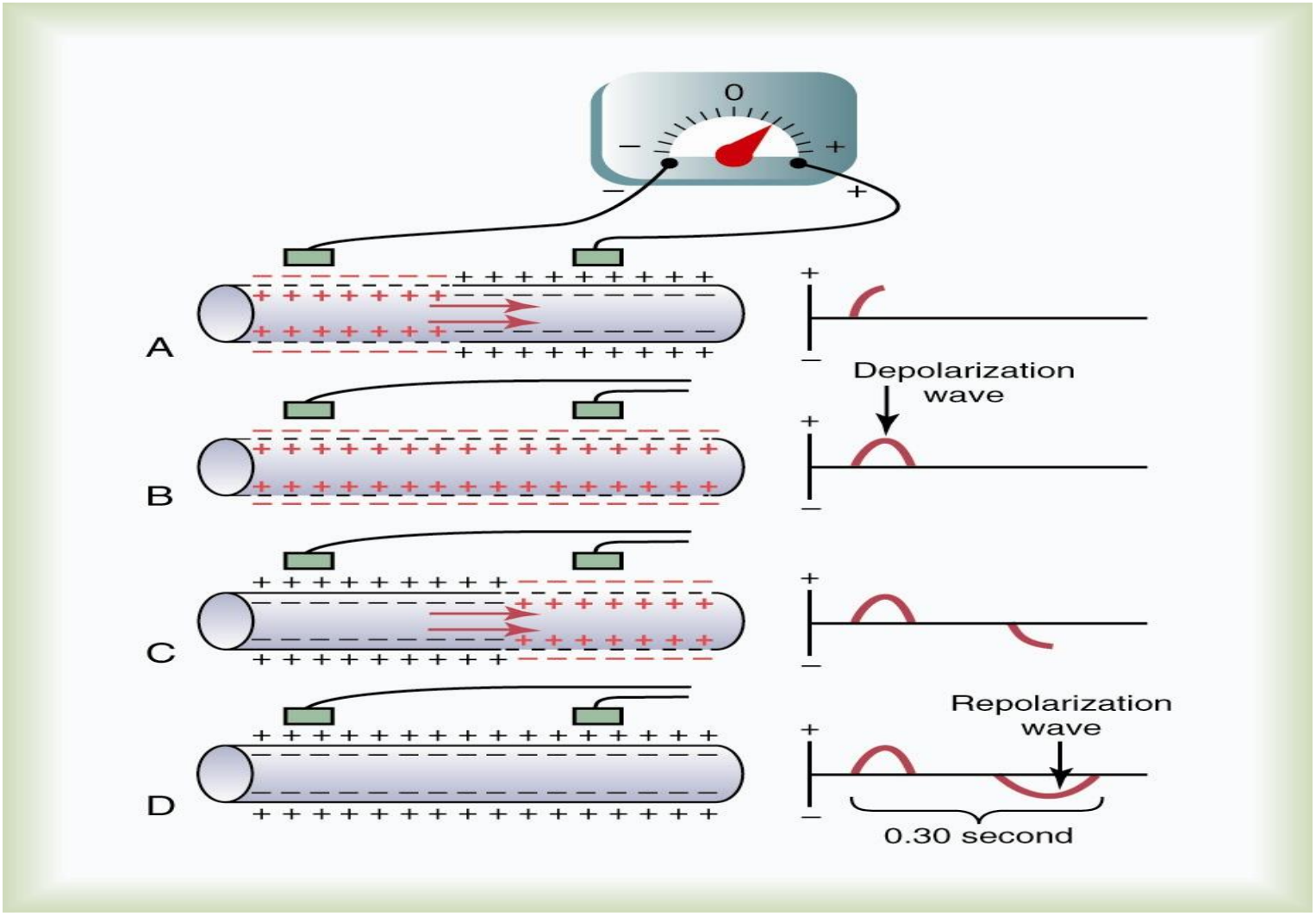
Electrocardiography – Normal 5

Faisal I. Mohammed, MD, PhD

Objectives

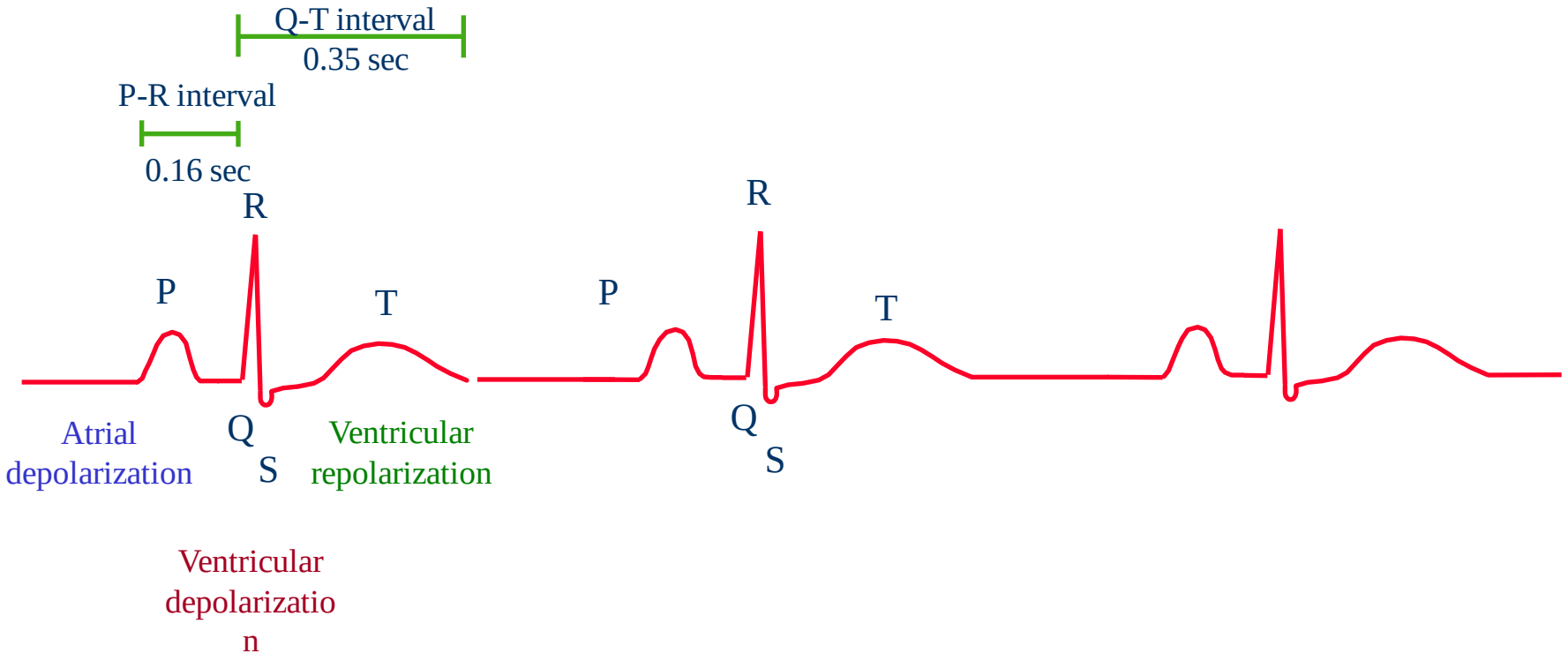
1. Describe the different “waves” in a normal electrocardiogram.
2. Recall the normal P-R and Q-T interval time of the QRS wave.
3. Distinguish the difference in depolarization and repolarization waves.
4. Recognize the voltage and time calibration of an electrocardiogram chart.
5. Point out the arrangement of electrodes in the bipolar limb leads, chest leads, and unipolar leads.
6. Describe Einthoven’s law.

Depolarization and Repolarization Waves

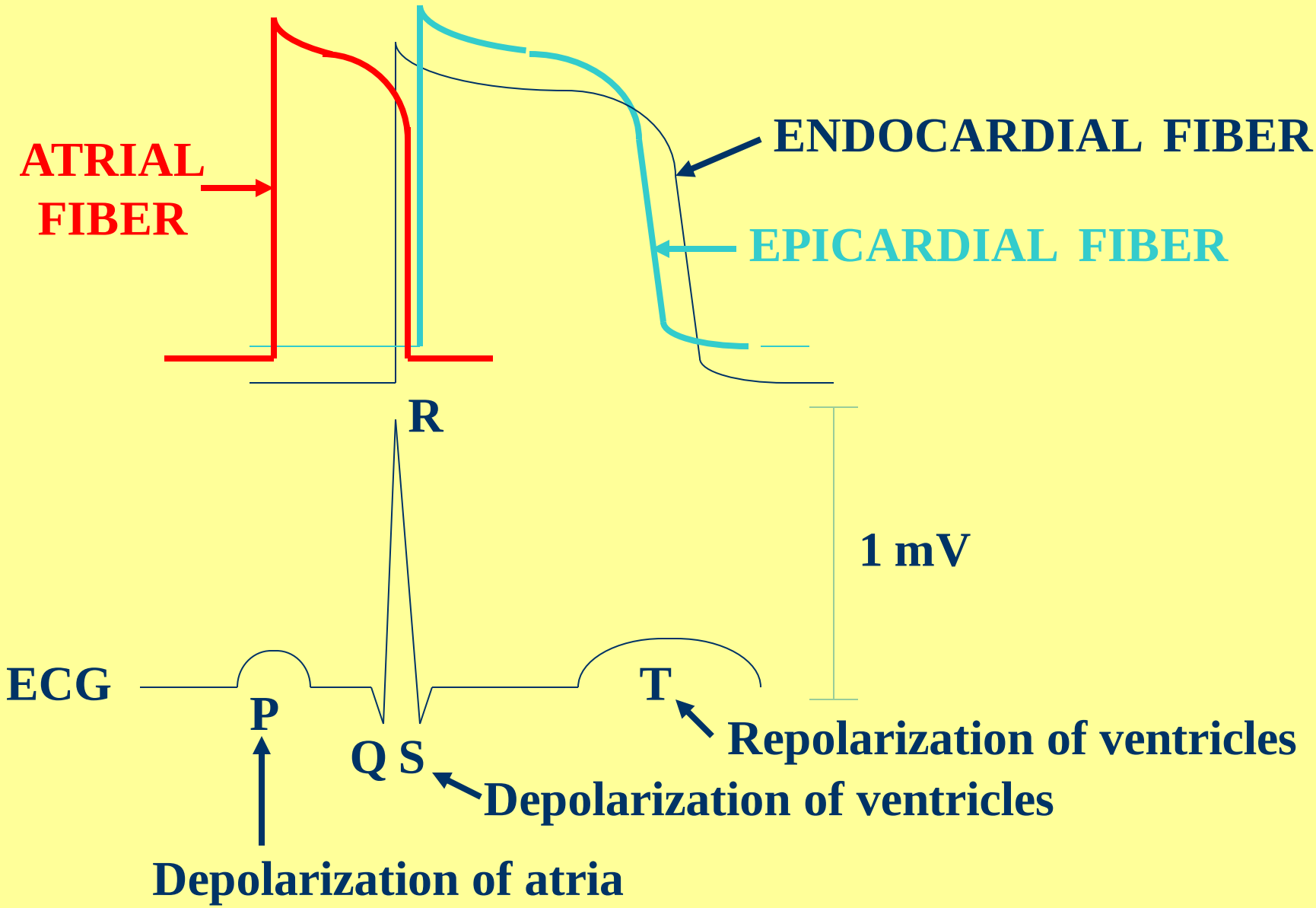


- Note that no potential is recorded when the ventricular muscle is either completely depolarized or repolarized.

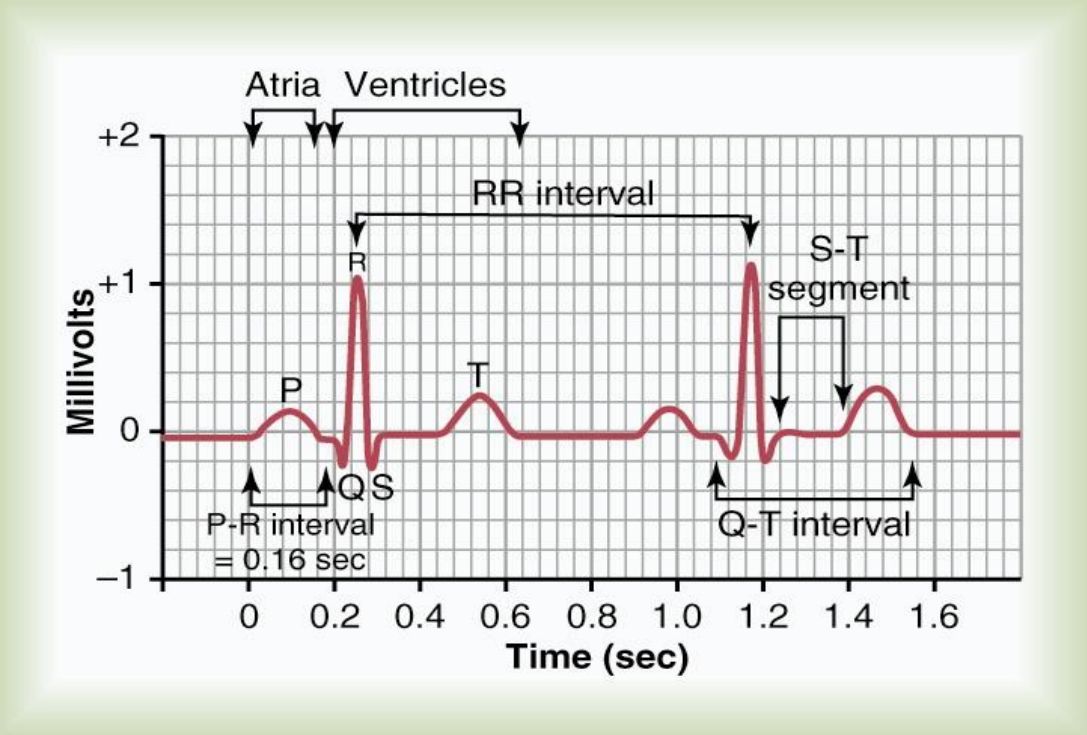
Normal EKG


Q-T interval
0.35 sec
P-R interval
0.16 sec
R
P
T
P
R
T
Atrial
depolarization
Q
S
Ventricular
repolarization
Q
S
Ventricular
depolarizatio
n

SINGLE VENTRICULAR ACTION POTENTIAL



Standardized EKG's

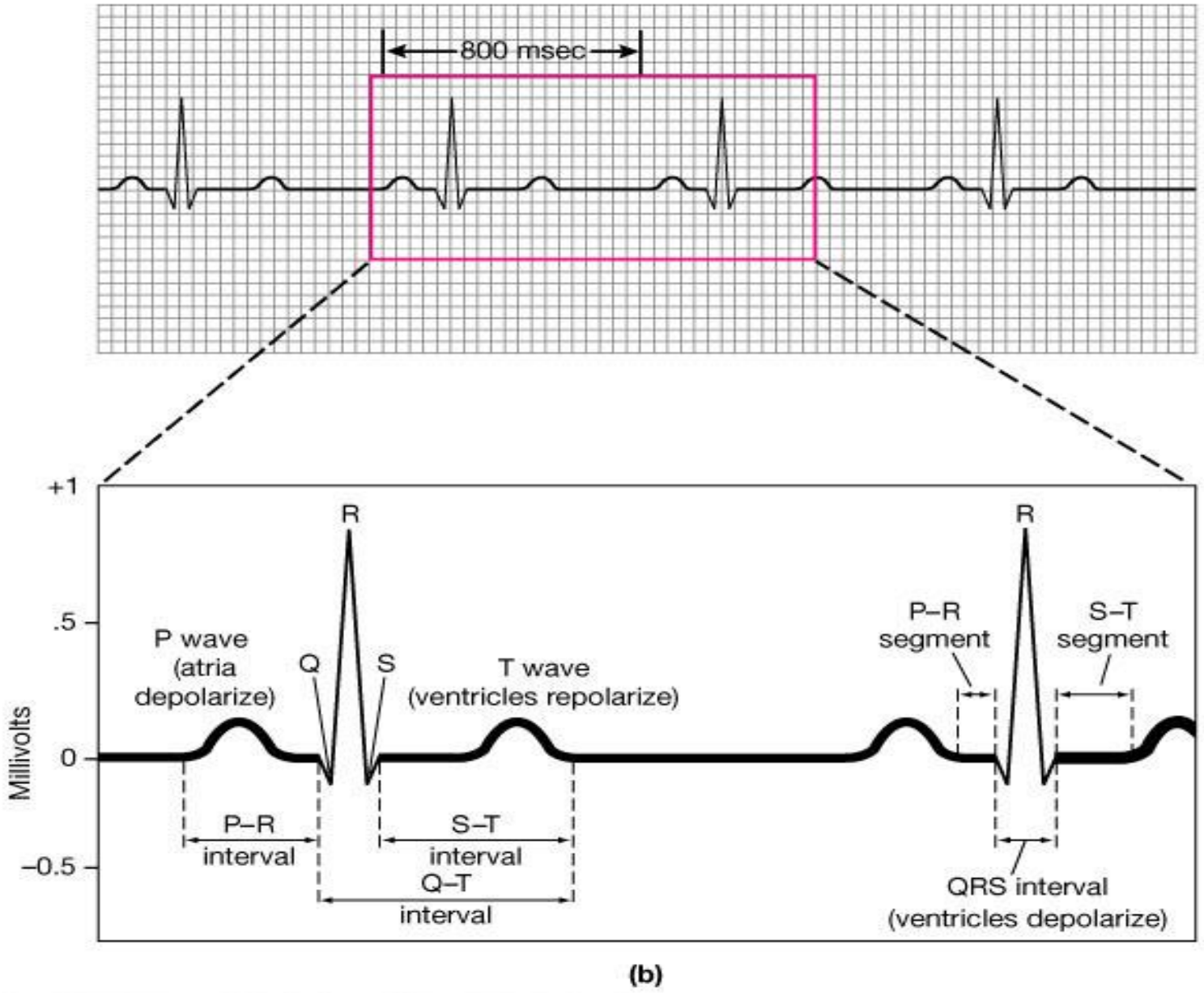


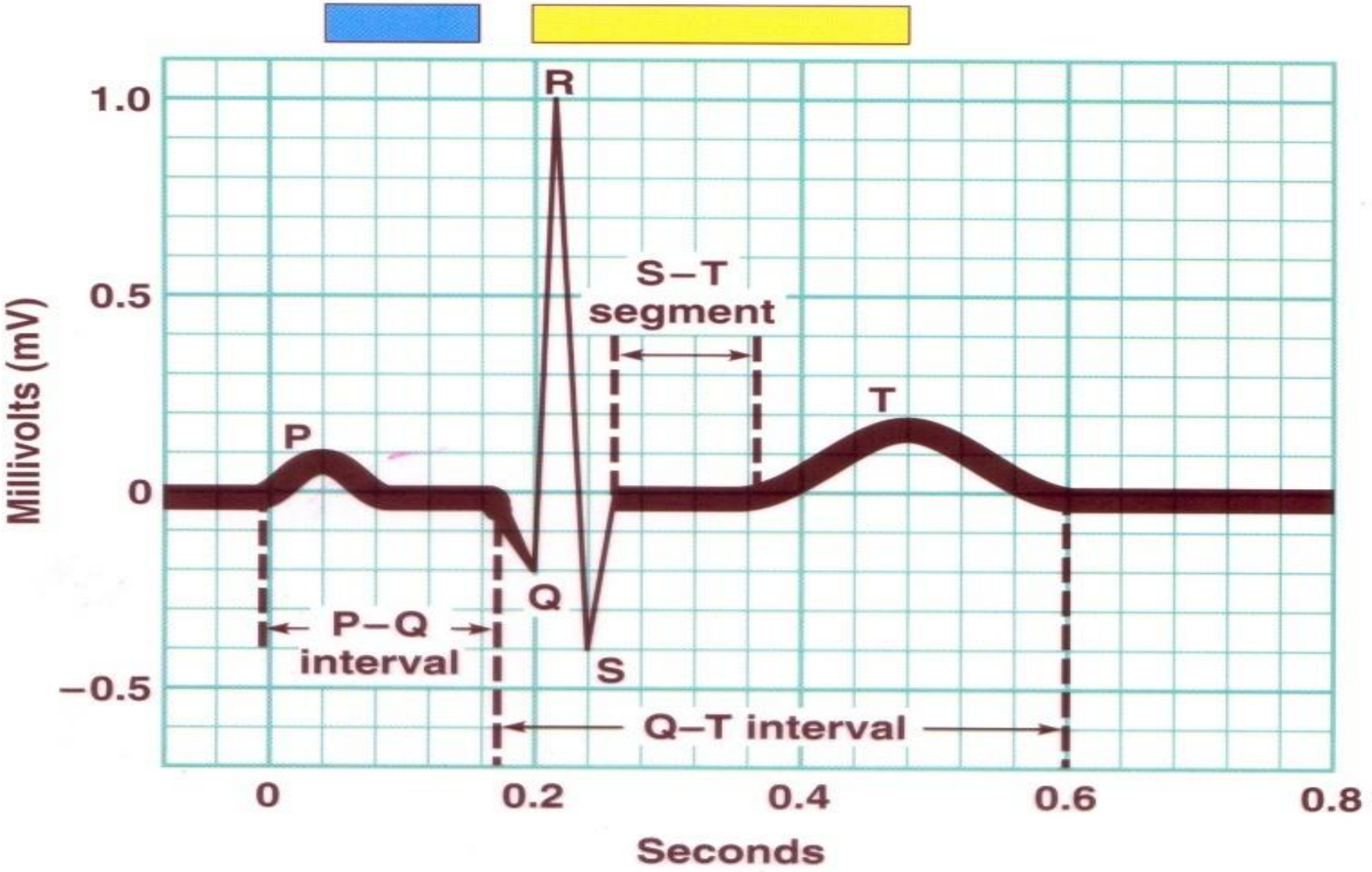
- Time and voltage calibrations are standardized

Electrocardiogram

- Record of electrical events in the myocardium that can be correlated with mechanical events
- **P wave**: depolarization of atrial myocardium.
  - Signals onset of atrial contraction
- **QRS complex**: ventricular depolarization
  - Signals onset of ventricular contraction..
- **T wave**: repolarization of ventricles
- **PR interval** or PQ interval: 0.16 sec
  - Extends from start of atrial depolarization to start of ventricular depolarization (QRS complex) contract and begin to relax
  - Can indicate damage to conducting pathway or AV node if greater than 0.20 sec (200 msec)
- **Q-T interval**: time required for ventricles to undergo a single cycle of depolarization and repolarization
  - Can be lengthened by electrolyte disturbances, conduction problems, coronary ischemia, myocardial damage

Electrocardiogram



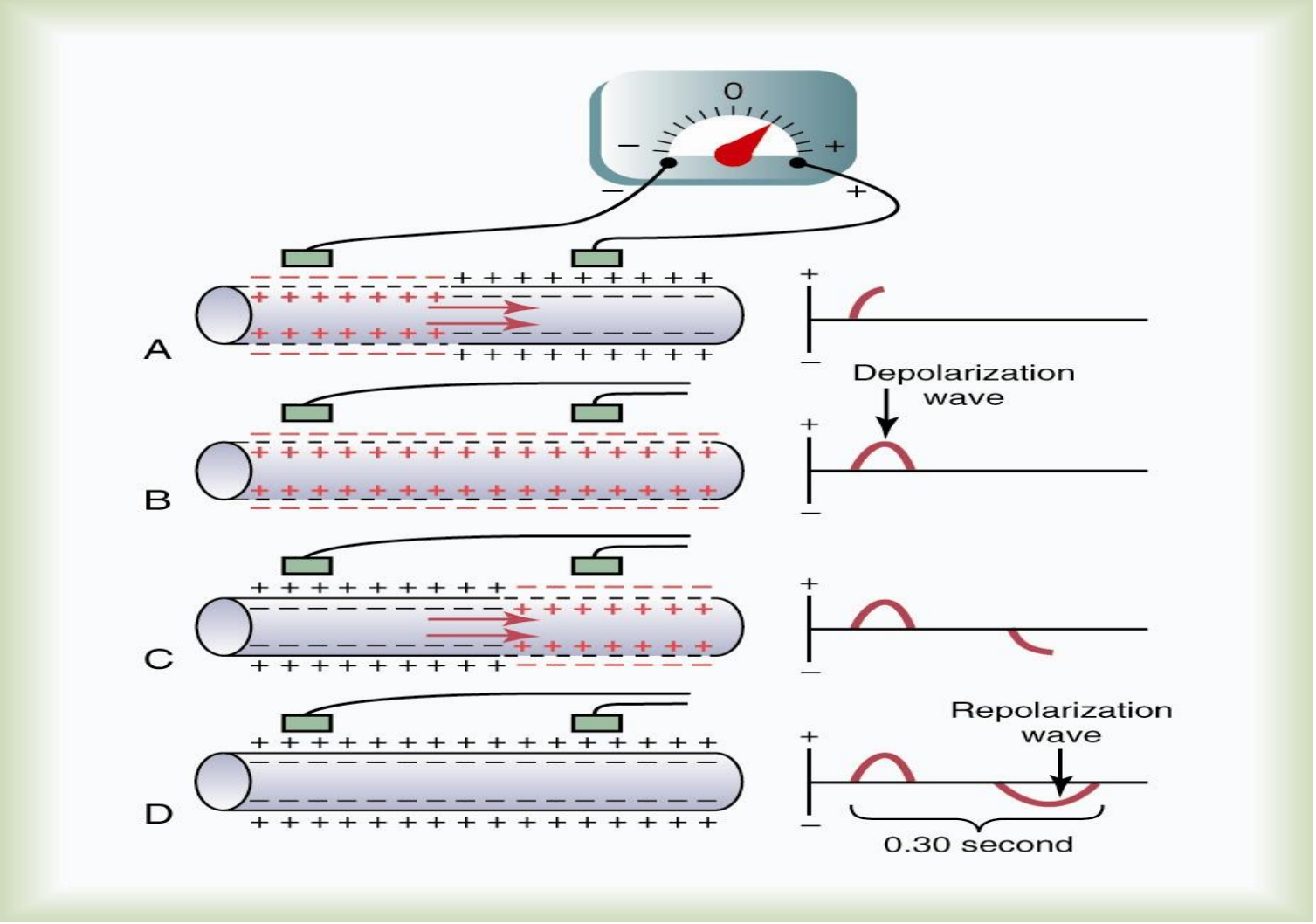


Key:

Atrial contraction

Ventricular contraction

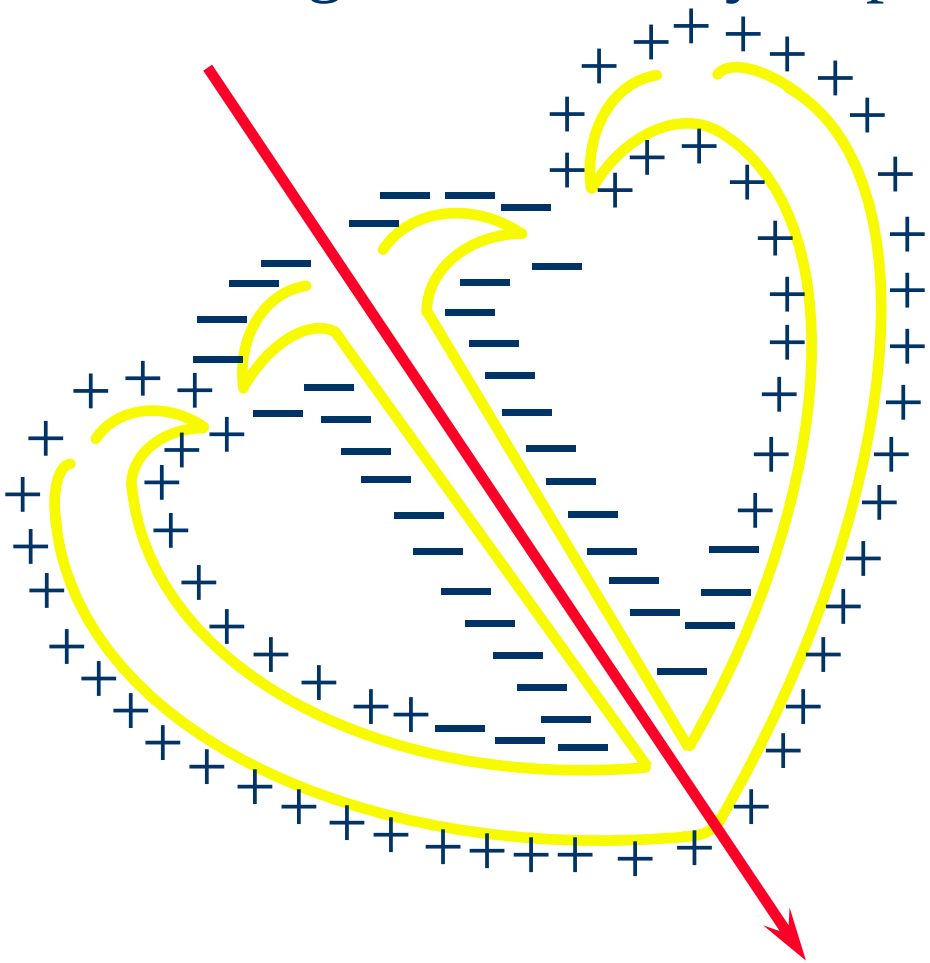
Depolarization and Repolarization Waves



- Note that no potential is recorded when the ventricular muscle is either completely depolarized or repolarized.

Flow of Electrical Currents in the Chest Around the Heart

Mean Vector Through the Partially Depolarized Heart



Flow of Electrical Currents in the Chest Around the Heart (cont'd)

- Ventricular depolarization starts at the ventricular septum and the endocardial surfaces of the heart.
- The average current flows positively from the base of the heart to the apex.
- At the very end of depolarization the current reverses from 1/100 second and flows toward the outer walls of the ventricles near the base (S wave).

EKG Concepts

- The P wave immediately precedes atrial contraction.
- The QRS complex immediately precedes ventricular contraction.
- The ventricles remain contracted until a few milliseconds after the end of the T repolarization wave.
- The atria remain contracted until the atria are repolarized, but an atrial repolarization wave cannot be seen on the electrocardiogram because it is masked by the QRS wave.

EKG Concepts (cont'd)

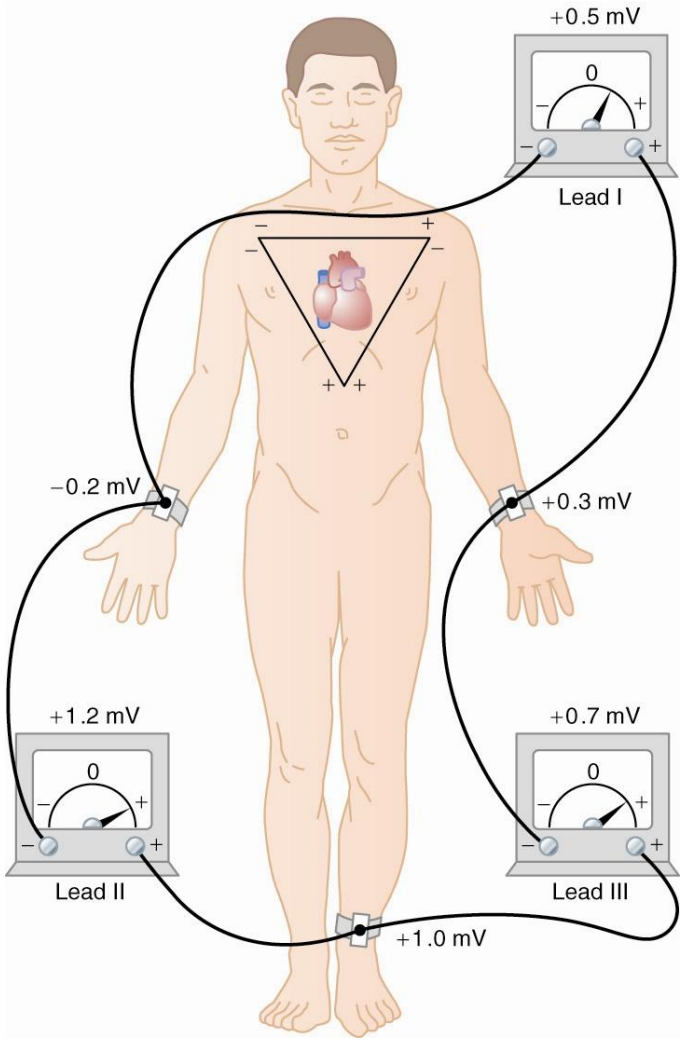
- The P-Q or P-R interval on the electrocardiogram has a normal value of 0.16 seconds and is the duration of time between the beginning of the P wave and the beginning of the QRS wave; this represents the time between the beginning of atrial contraction and the beginning of ventricular contraction.

EKG Concepts (cont'd)

- The Q-T interval has a normal value of 0.35 seconds and is the duration of time from the beginning of the Q wave to the end of the T wave; this approximates the time of ventricular contraction.
- The heart rate can be determined with the reciprocal of the time interval between each heartbeat.

Bipolar Limb Leads

- Bipolar means that the EKG is recorded from two electrodes on the body.



Bipolar Limb Leads (cont'd)

- Lead I - The negative terminal of the electrocardiogram is connected to the right arm, and the positive terminal is connected to the left arm.
- Lead II - The negative terminal of the electrocardiogram is connected to the right arm, and the positive terminal is connected to the left leg.

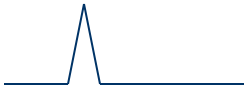
Bipolar Limb Leads (cont'd)

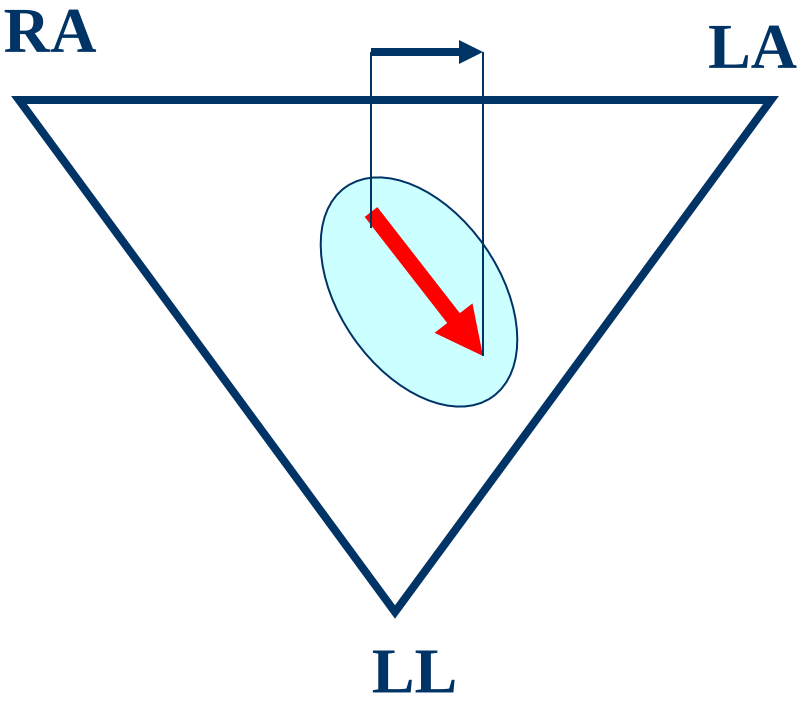
- Lead III - The negative terminal of the electrocardiogram is connected to the left arm, and the positive terminal is connected to the left leg.
- Einthoven's Law states that the electrical potential of any limb equals the sum of the other two (+ and - signs of leads must be observed). L II= L I + L III
- If lead I = 1.0 mV, Lead III = 0.5 mV, then Lead II = 1.0 + 0.5 = 1.5 mV
- Kirchoff's second law of electrical circuits LI+LII+LIII=0

ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

3 Bipolar Limb Leads:

I = RA vs. LA (+)



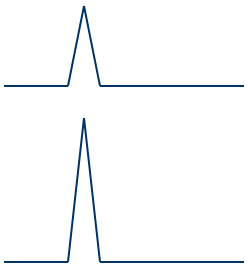


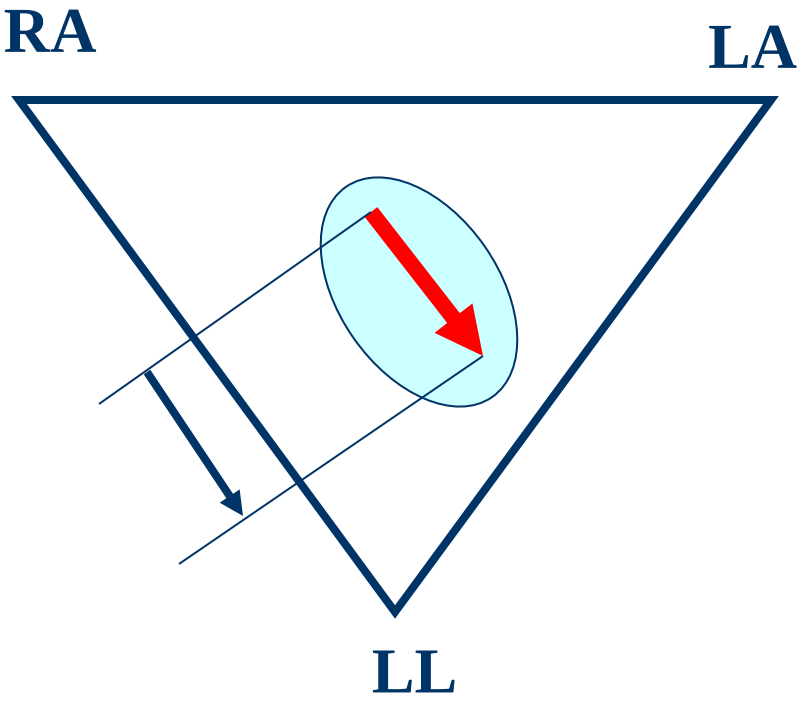
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)





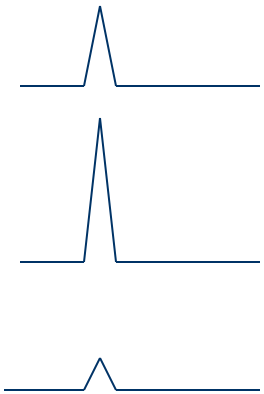
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

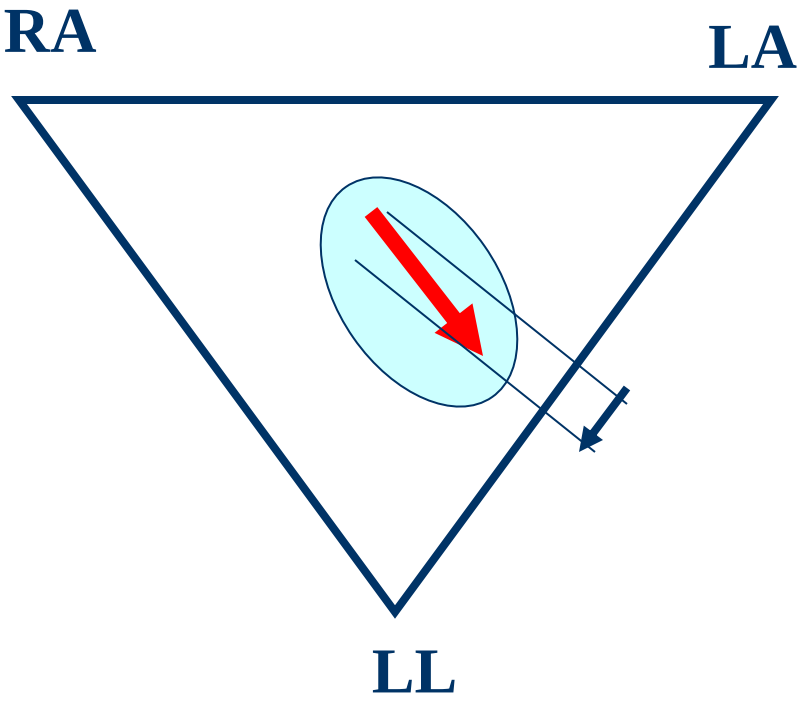
3 Bipolar Limb Leads:

I = RA vs. LA (+)

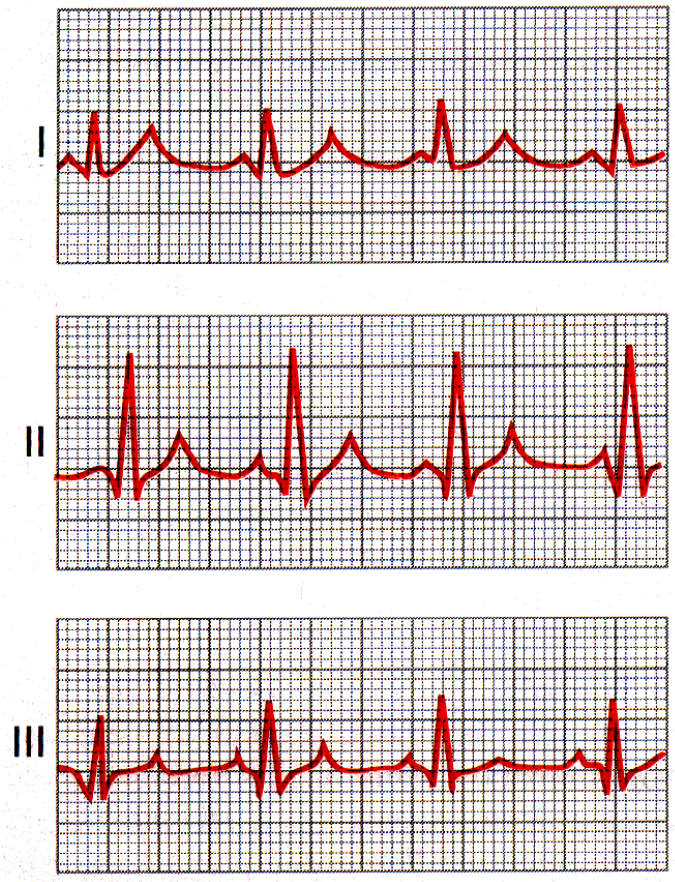
II = RA vs. LL (+)

III = LA vs. LL (+)





Bipolar Limb Leads (cont'd)

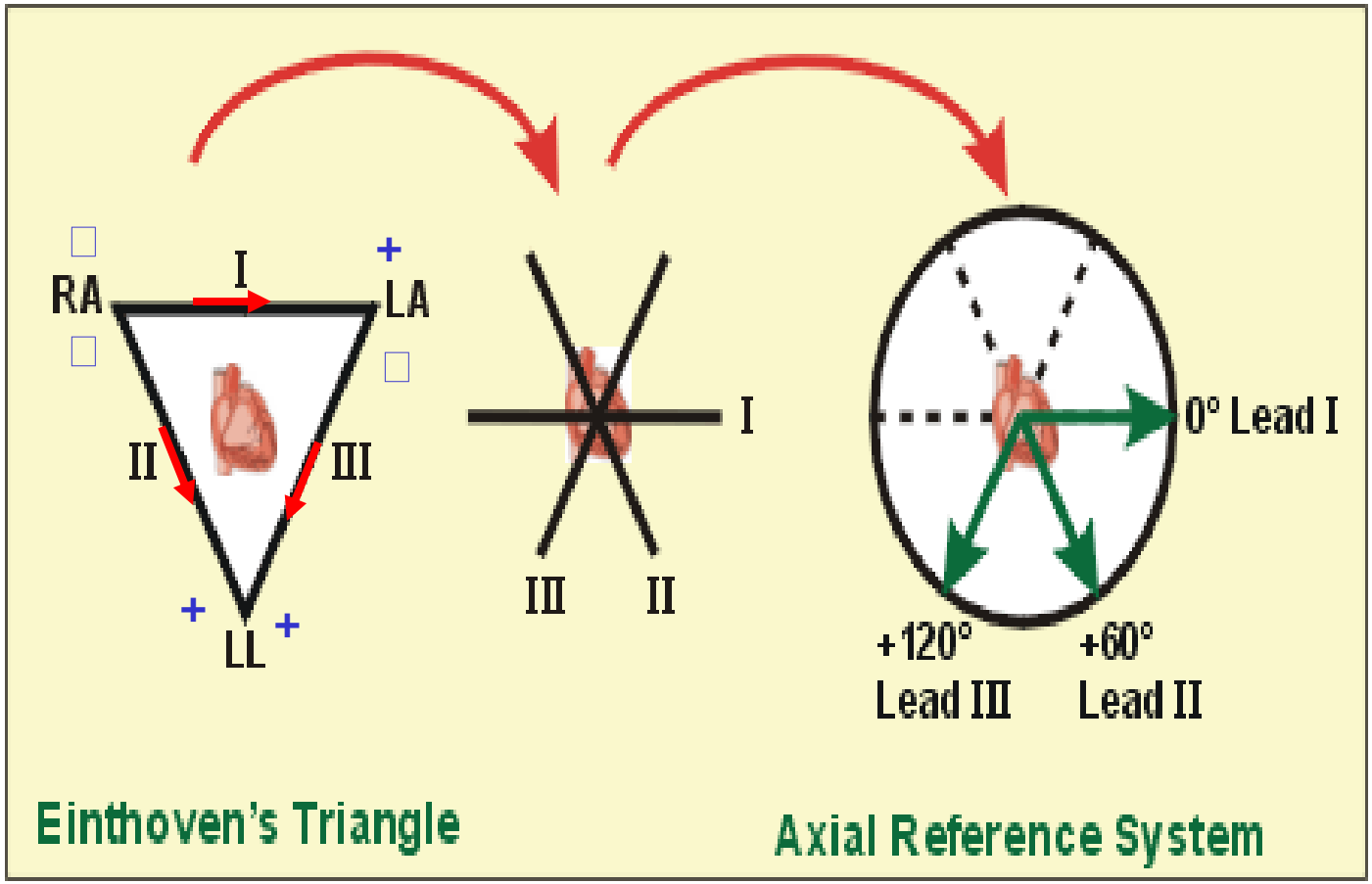


0.5 mV

1.2 mV

0.7 mV

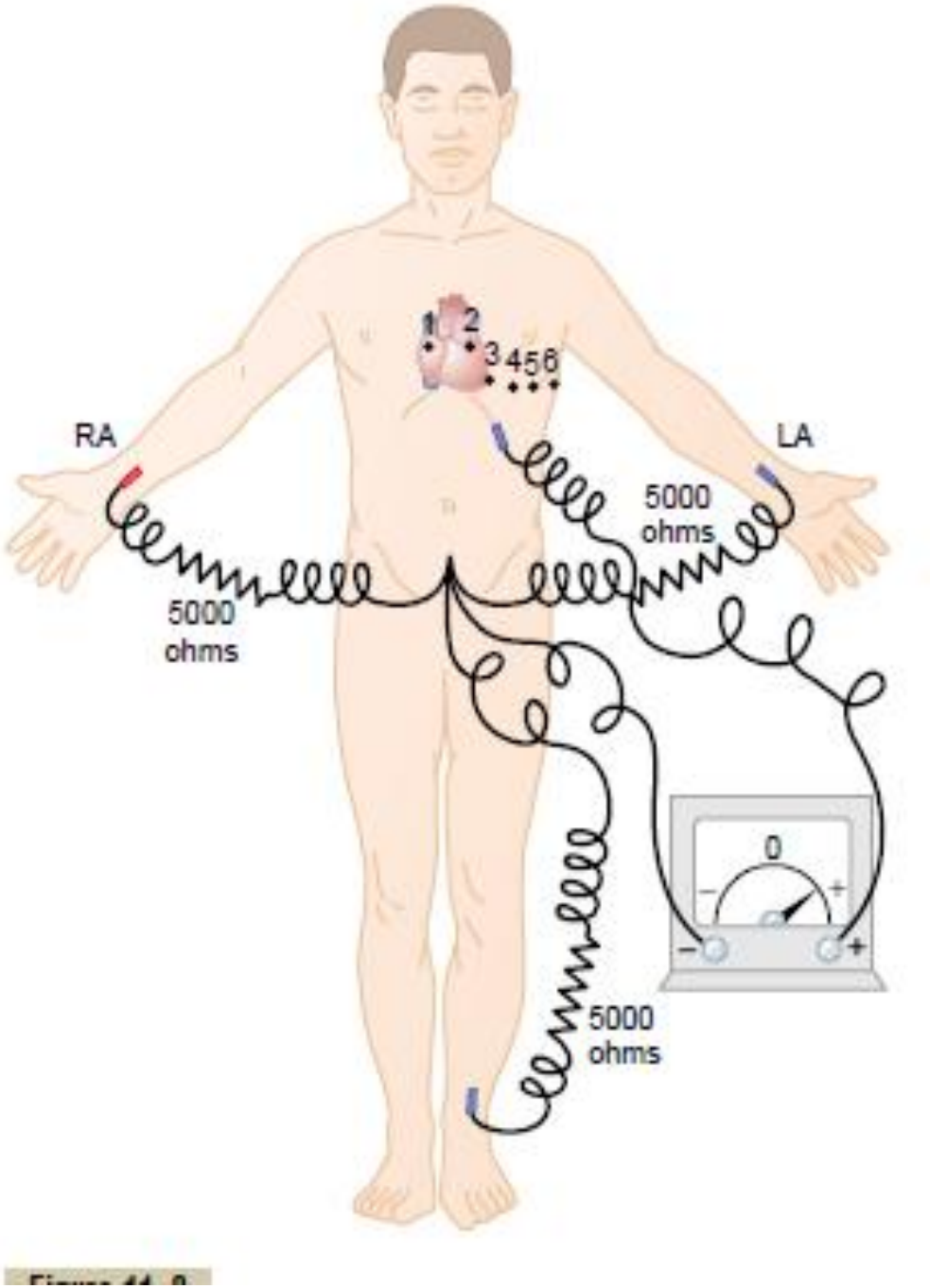
Einthoven's triangle and law



Other EKG Leads (cont'd)

- Augmented Unipolar Limb Leads aVR, aVL, and aVF are also in use. For aVR the + electrode is the right arm, and the - electrode is the left arm + left leg; aVL + electrode is left arm; aVF + electrode is left foot and the negative electrode is the other two limbs

Unipolar Limb Leads



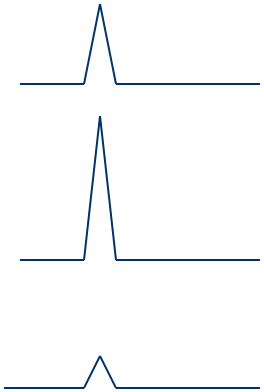
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

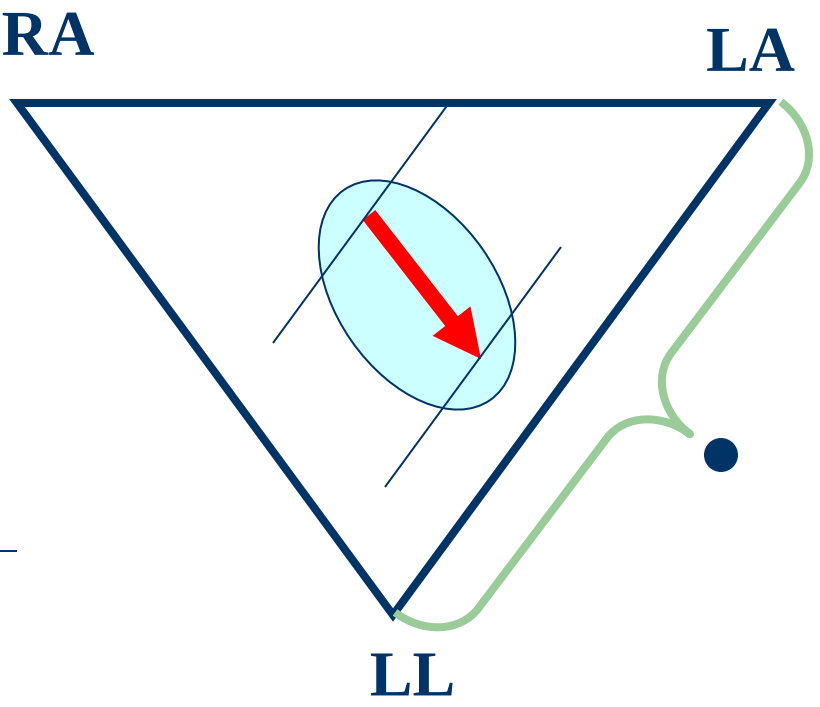
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

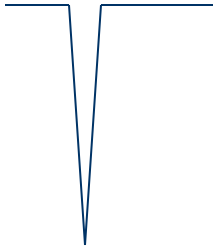
III = LA vs. LL (+)





3 Augmented Limb Leads:

aVR = (LA-LL) vs. RA(+)



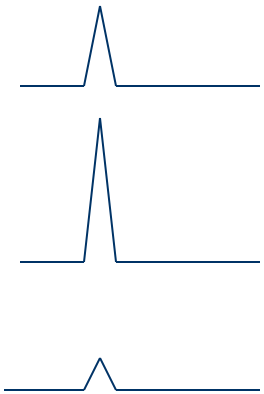
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

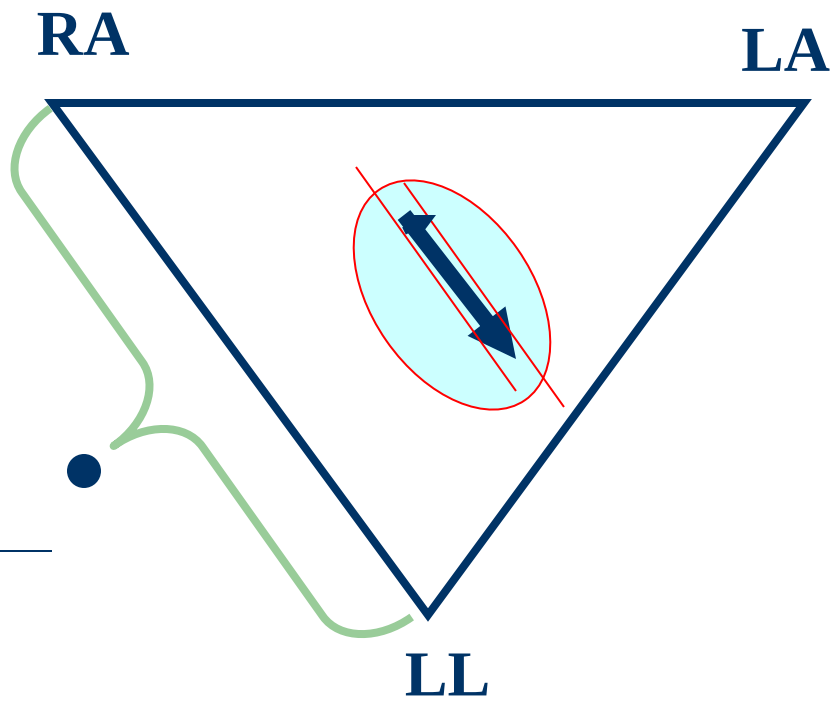
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

III = LA vs. LL (+)

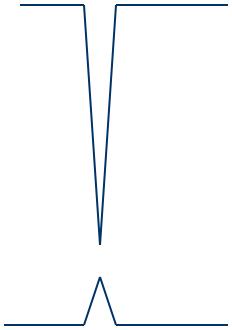




3 Augmented Limb Leads:

aVR = (LA-LL) vs. RA(+)

aVL = (RA-LL) vs. LA(+)



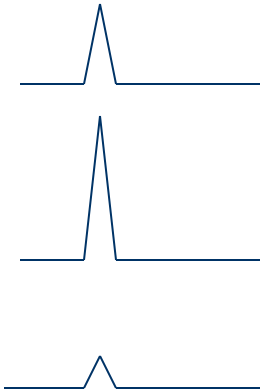
ECG Recordings (QRS Vector pointing leftward, inferiorly & anteriorly)

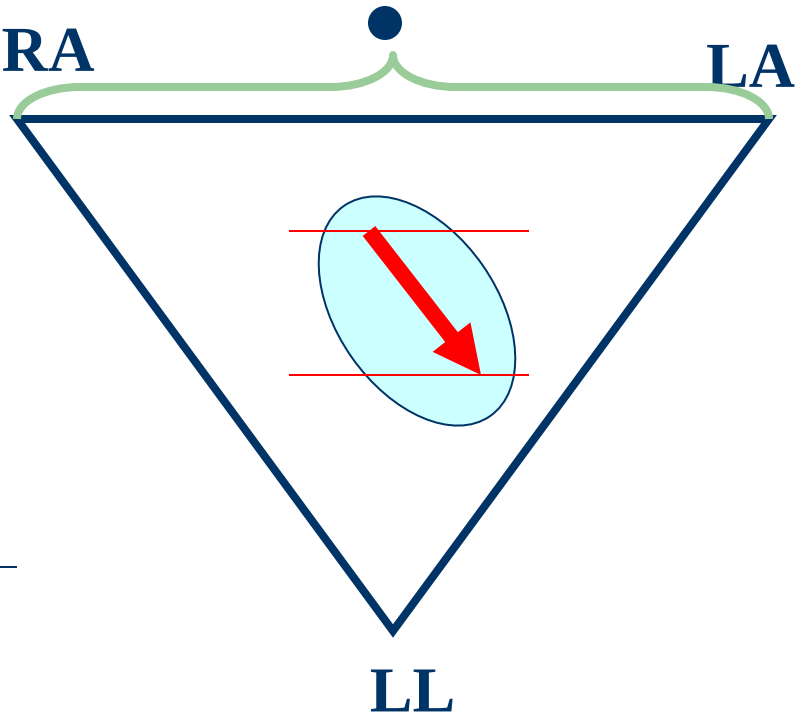
3 Bipolar Limb Leads:

I = RA vs. LA (+)

II = RA vs. LL (+)

III = LA vs. LL (+)



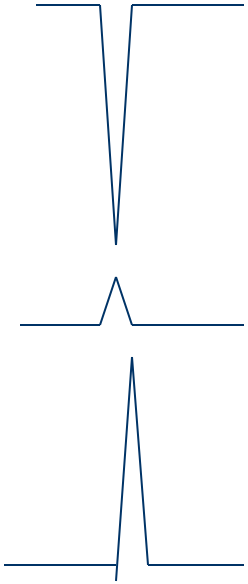


3 Augmented Limb Leads:

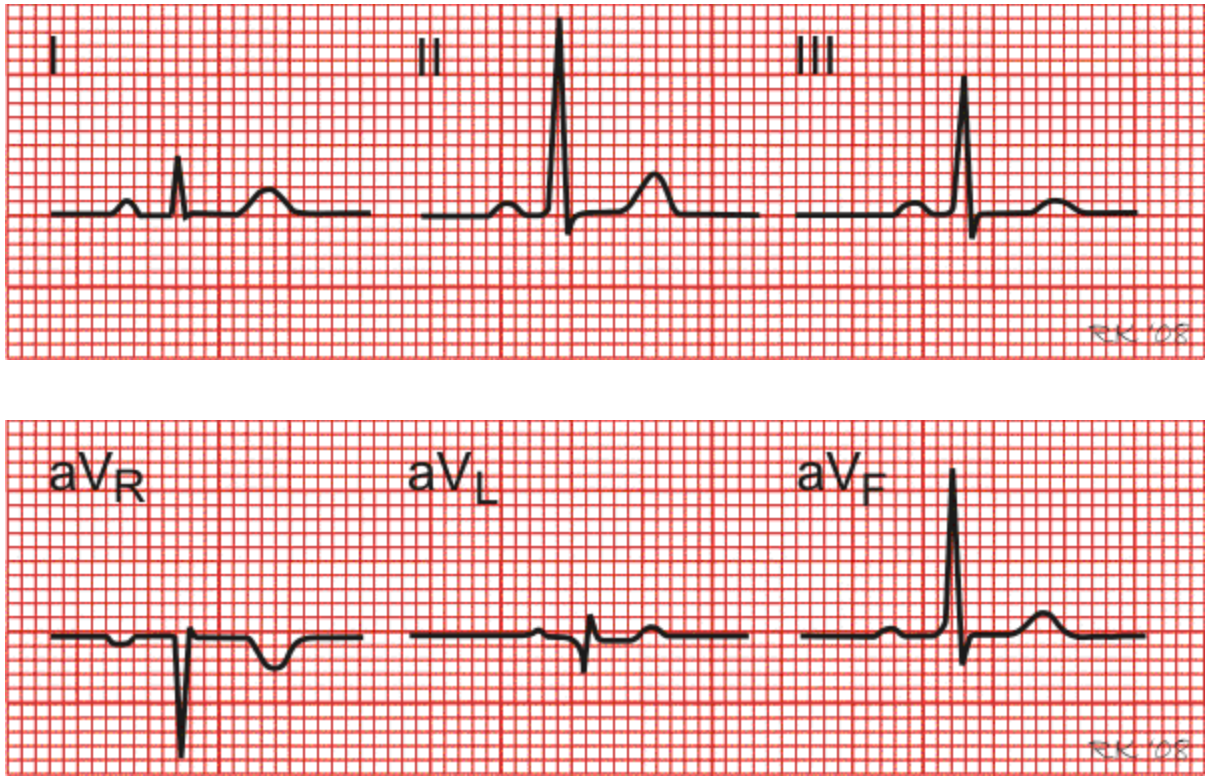
aVR = (LA-LL) vs. RA(+)

aVL = (RA-LL) vs. LA(+)

aVF = (RA-LA) vs. LL(+)

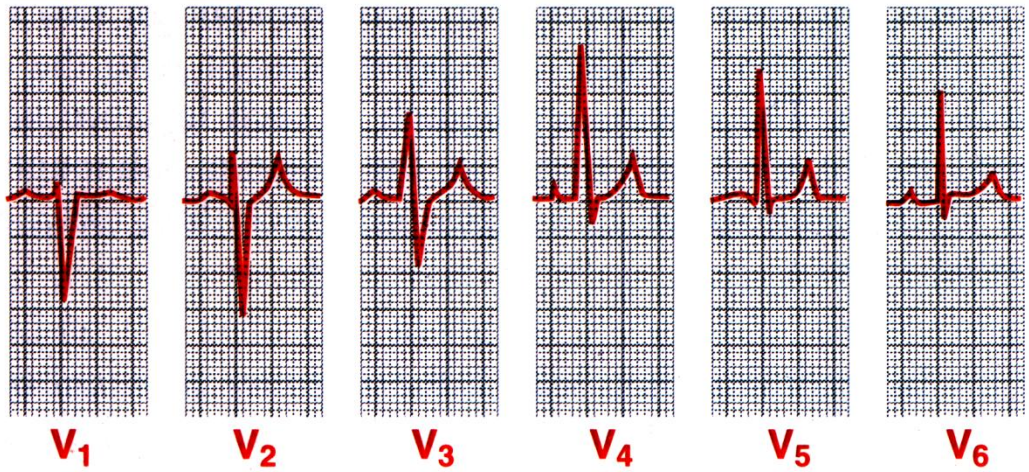


Bipolar and Uniploar Limb Leads

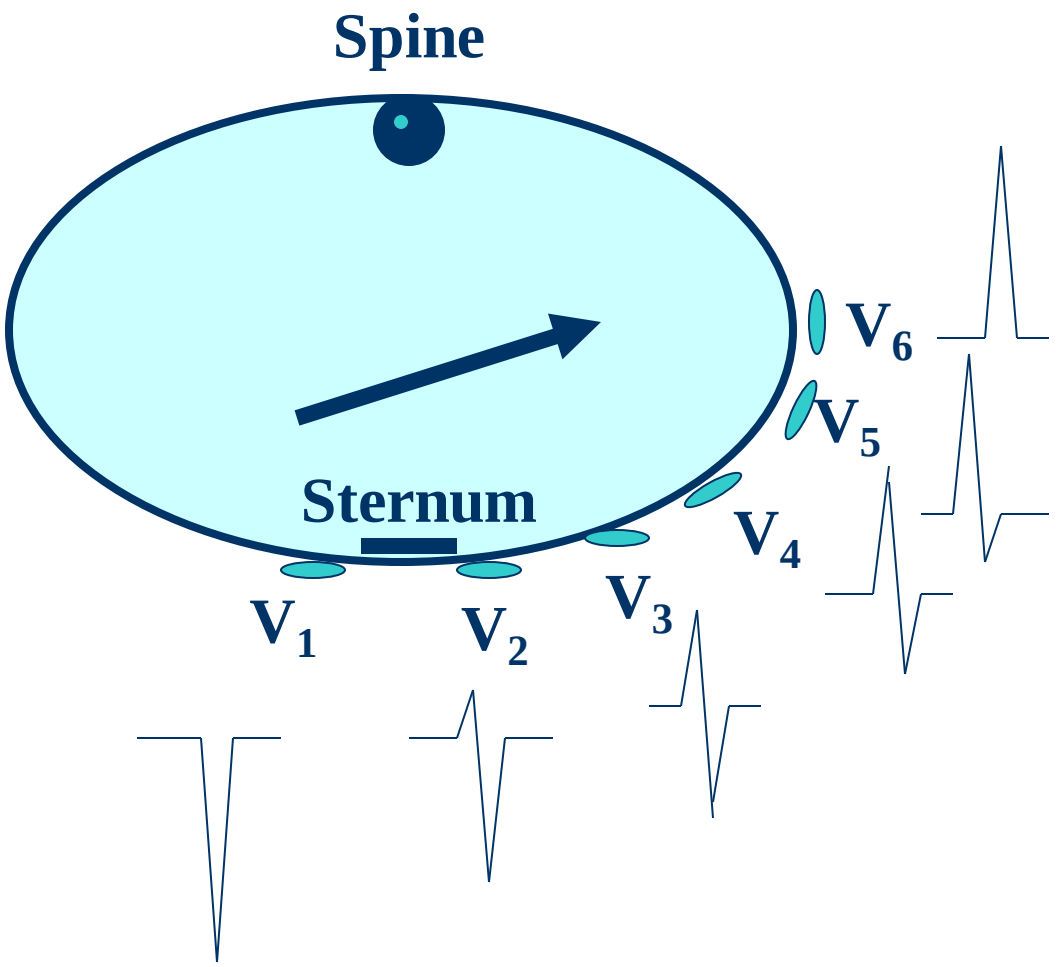


Other EKG Leads

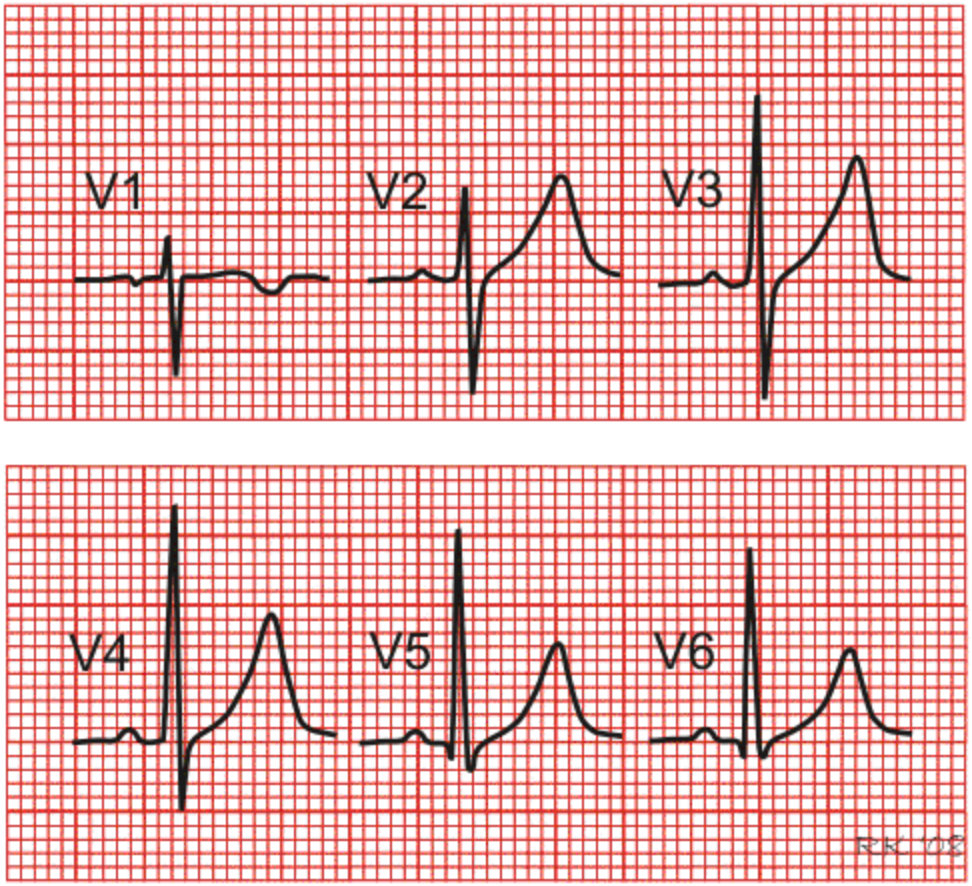
- Chest Leads (Precordial Leads) known as V_1-V_6 are very sensitive to electrical potential changes underneath the electrode.



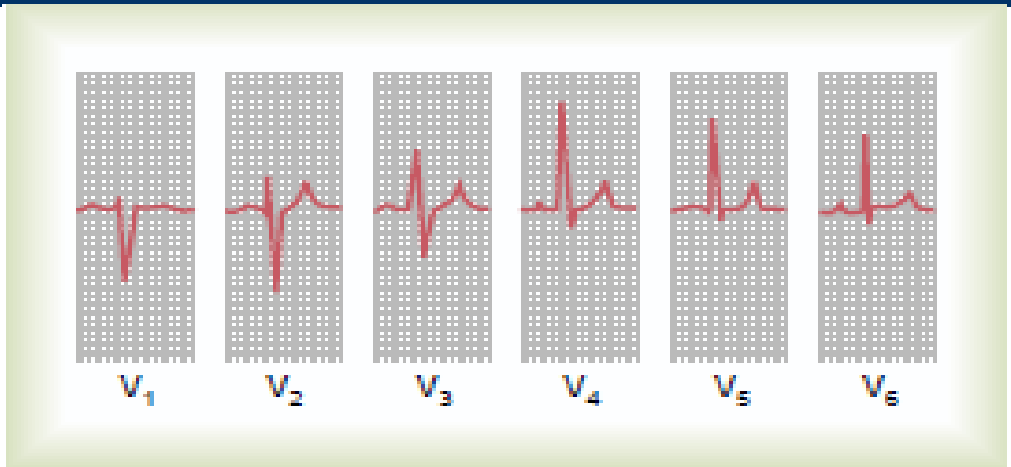
6 PRECORDIAL (CHEST) LEADS

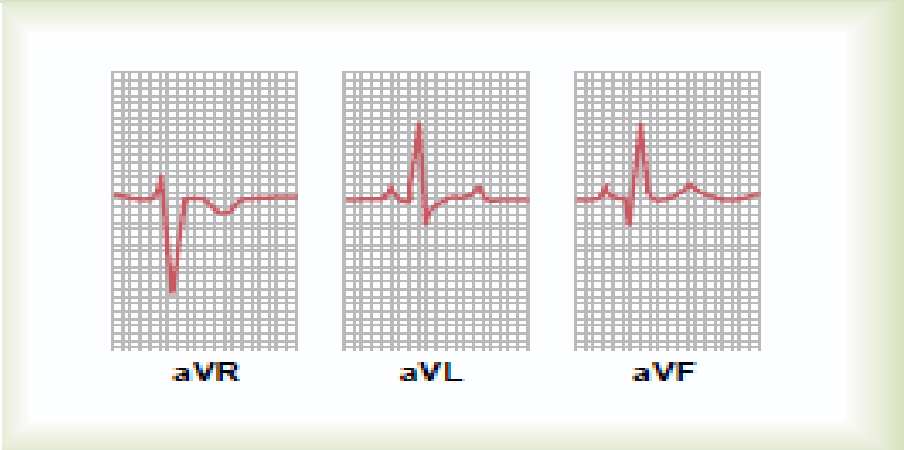


Chest leads (Unipolar)



Uniplolar Leads






I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6

ECG Recordings: (QRS vector---leftward, inferiorly and anteriorly

3 Bipolar Limb Leads

I = RA vs. LA(+)

II = RA vs. LL(+)

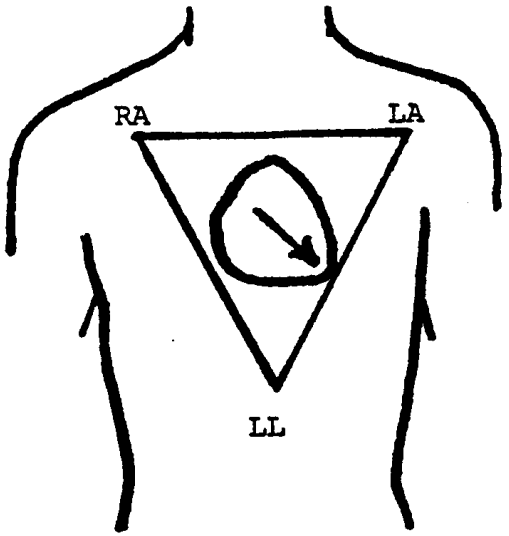
III = LA vs. LL(+)

3 Augmented Limb Leads

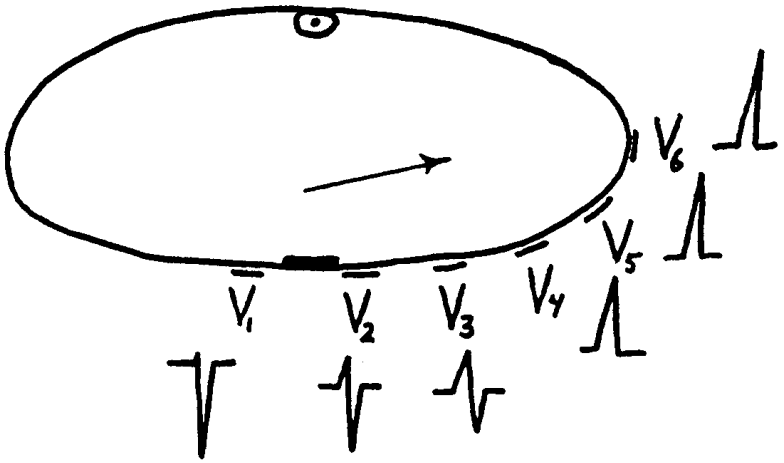
aVR = (LA-LL) vs. RA(+)

aVL = (RA-LL) vs. LA(+)

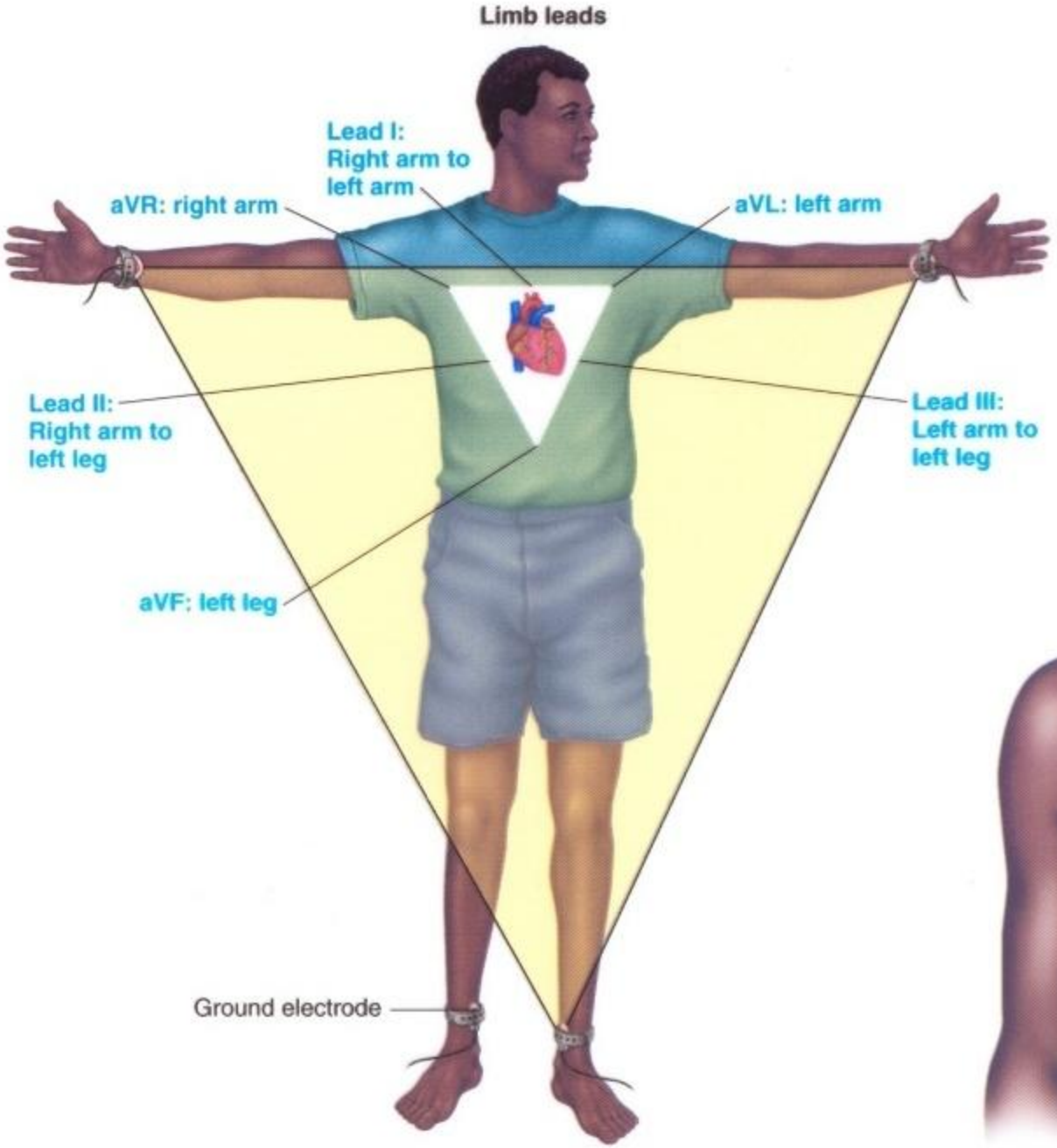
aVF = (RA-LA) vs. LL(+)



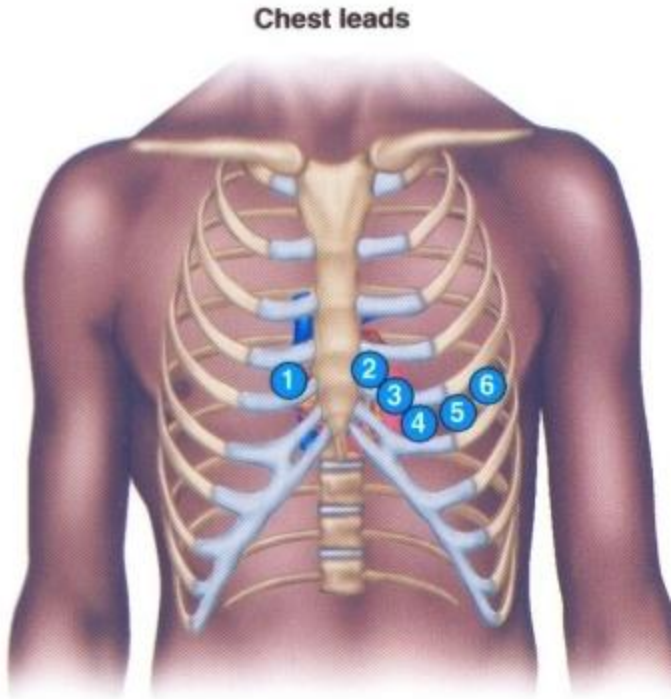
6 Precordial (Chest) Leads: Indifferent electrode (RA-LA-LL) vs. chest lead moved from position V_1 through position V_6.



Electrocardiogram leads



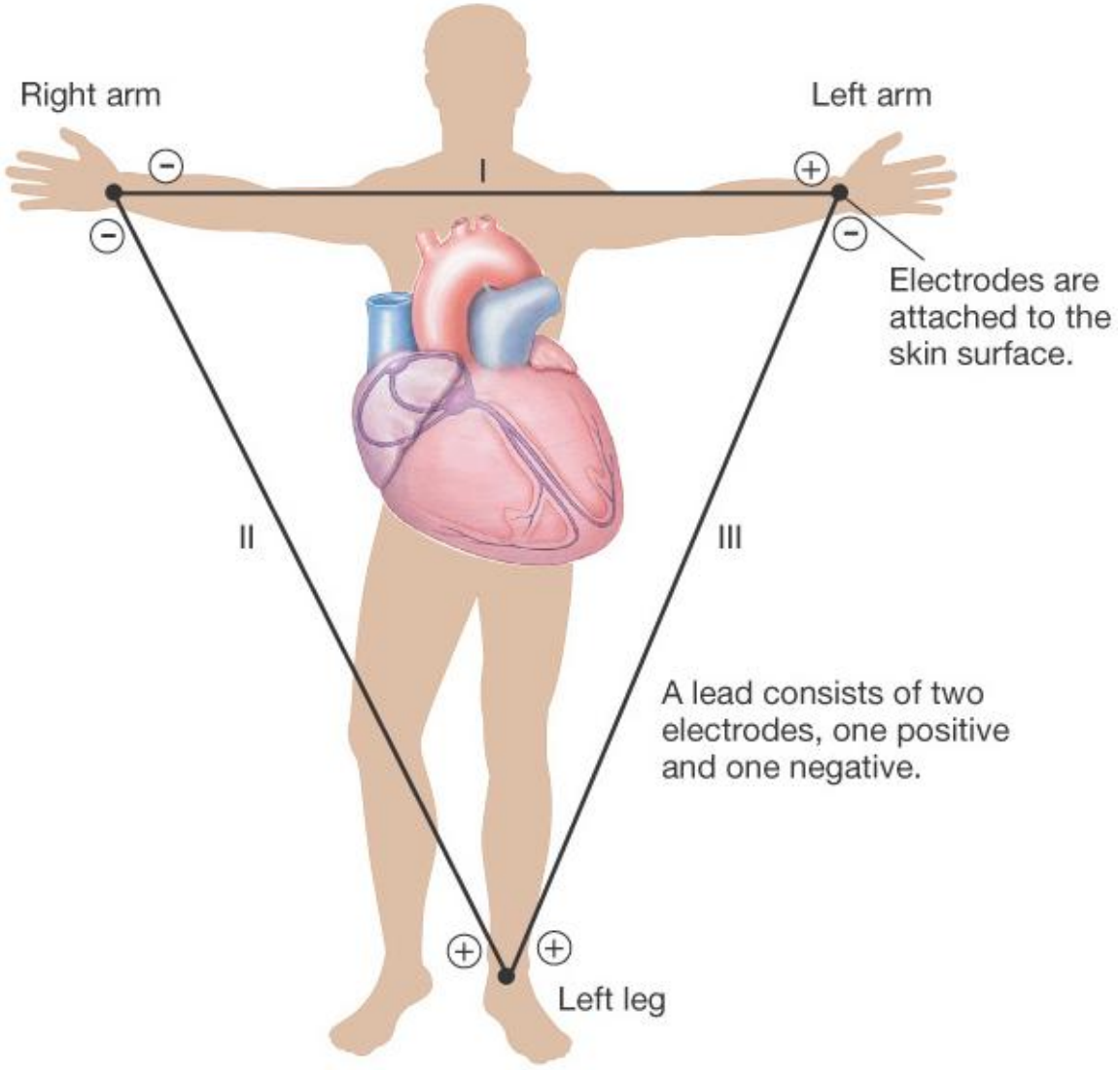
(a)



(b)

Electrocardiogram (ECG):Electrical Activity of the Heart

- Einthoven's triangle
- P-Wave – atria
- QRS- wave – ventricles
- T-wave – repolarization



Thank You