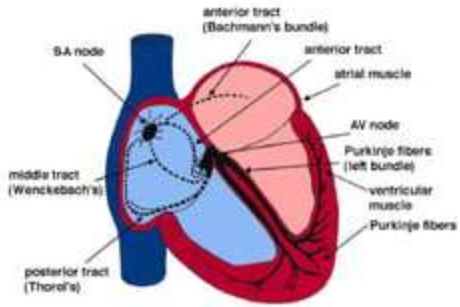
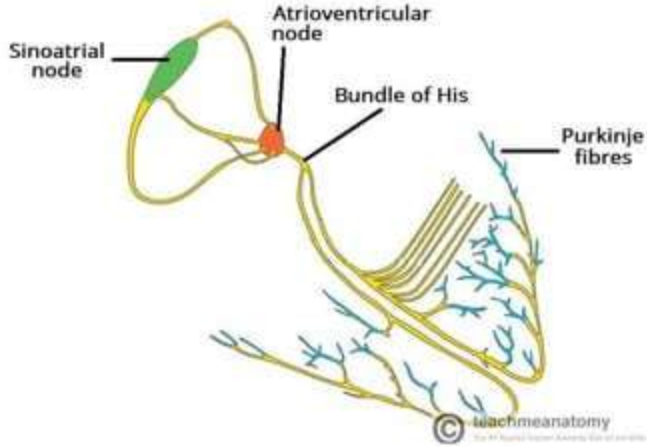
# Electrophysiology of heart

- The SA node
  - at the junction of superior vena cava and right atrium.
- AV node
  - in the right posterior portion of the inter atrial septum

# Internodal atrial pathway




Sinoatrial node
Atrioventricular node
Bundle of His
Purkinje fibres
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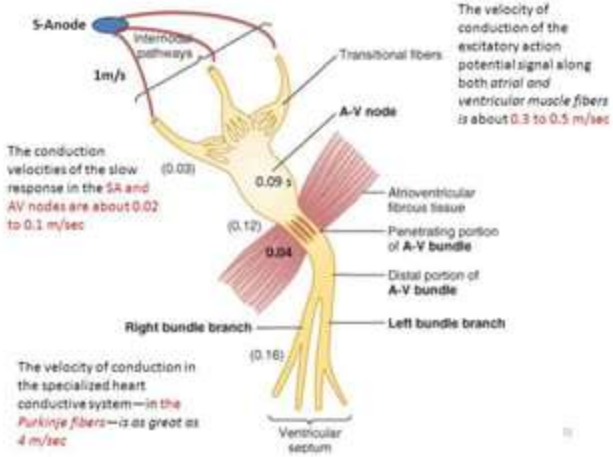
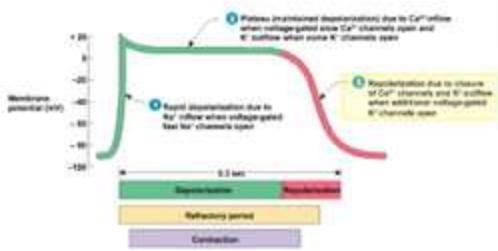

S-Anode
Internodal pathways
1m/s
Transitional fibers
A-V node
(0.03)
0.09 s
(0.12)
0.04
(0.16)
Atrioventricular fibrous tissue
Penetrating portion of A-V bundle
Distal portion of A-V bundle
Right bundle branch
Left bundle branch
Ventricular septum
The velocity of conduction of the excitatory action potential signal along both atrial and ventricular muscle fibers is about 0.3 to 0.5 m/sec
The conduction velocities of the slow response in the SA and AV nodes are about 0.02 to 0.1 m/sec
The velocity of conduction in the specialized heart conductive system—in the Purkinje fibers—is as great as 4 m/sec

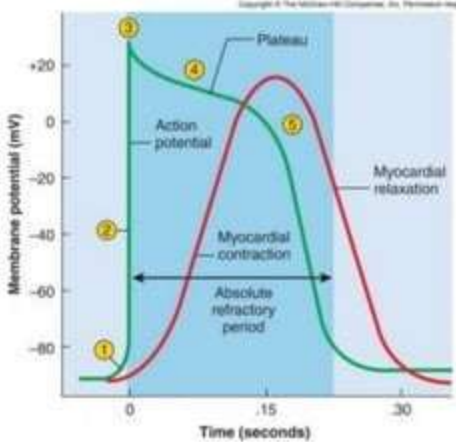
- RMP OF HEART = -90 mV

# NERNST POTENTIAL

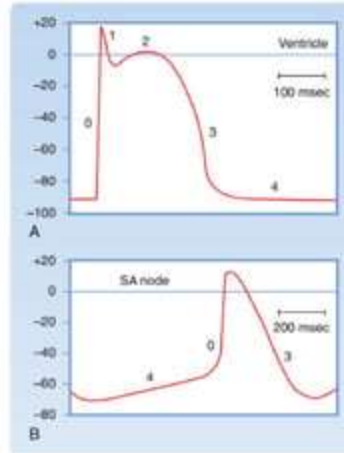
**Table 1.4-1** Equilibrium potential, $E_{ion}$, for important ions in a mammalian spinal motor neuron

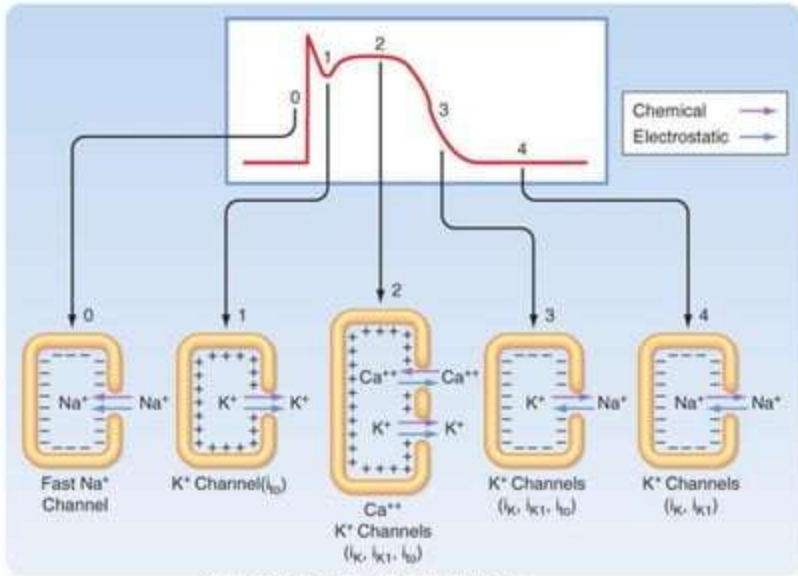
| Ion | Concentration (mmol/L of $H_2O$) | | Equilibrium potential (mV) |
|---|---|---|---|
| | Outside the cell | Inside the cell | |
| $Na^+$ | 150 | 15 | +60 |
| $K^+$ | 5.5 | 150 | −90 |
| $Cl^-$ | 125 | 9 | −70 |
| $Ca^{2+}$ | 5 | <1 | +130 |

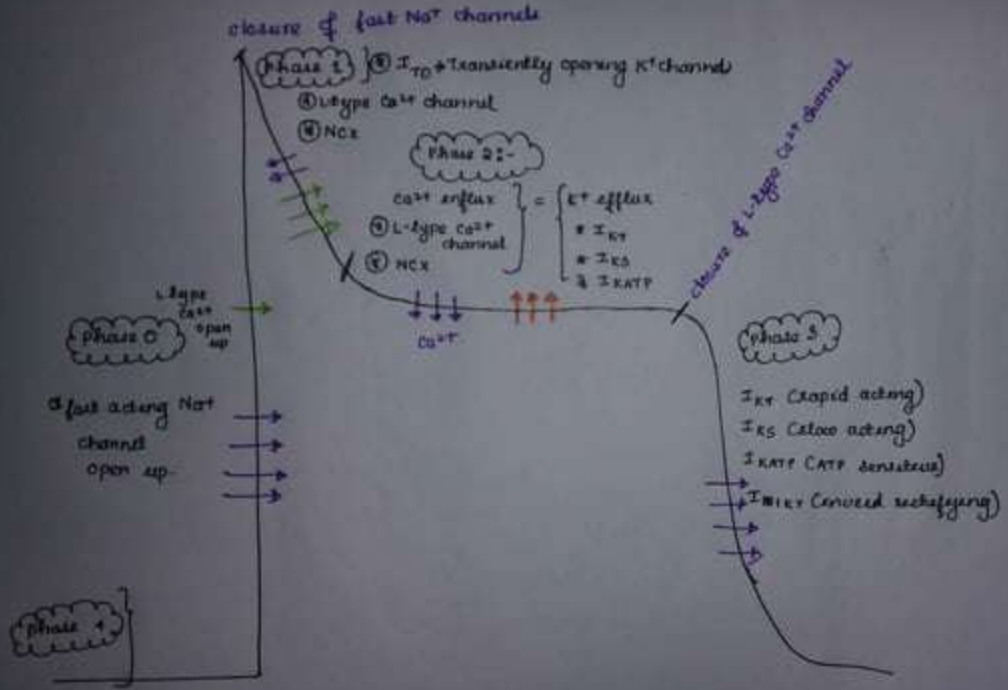

2 Plateau (maintained depolarization) due to Ca2+ inflow when voltage-gated slow Ca2+ channels open and K+ outflow when some K+ channels open
Membrane potential (mV)
+ 20
0
– 20
– 40
– 60
– 80
– 100
1 Rapid depolarization due to Na+ inflow when voltage-gated fast Na+ channels open
3 Repolarization due to closure of Ca2+ channels and K+ outflow when additional voltage-gated K+ channels open
0.3 sec
Depolarization
Repolarization
Refractory period
Contraction




1. Voltage-gated $Na^+$ channels open.
2. $Na^+$ inflow depolarizes the membrane and triggers the opening of still more $Na^+$ channels, creating a positive feedback cycle and a rapidly rising membrane voltage.
3. $Na^+$ channels close when the cell depolarizes, and the voltage peaks at nearly +30 mV.
4. $Ca^{2+}$ entering through slow $Ca^{2+}$ channels prolongs depolarization of membrane, creating a plateau. Plateau falls slightly because of some $K^+$ leakage, but most $K^+$ channels remain closed until end of plateau.
5. $Ca^{2+}$ channels close and $Ca^{2+}$ is transported out of cell. $K^+$ channels open, and rapid $K^+$ outflow returns membrane to its resting potential.


+20
0
−20
−40
−60
−80
−100
Ventricle
100 msec
0
1
2
3
4
A
+20
0
−20
−40
−60
−80
SA node
200 msec
0
3
4
B

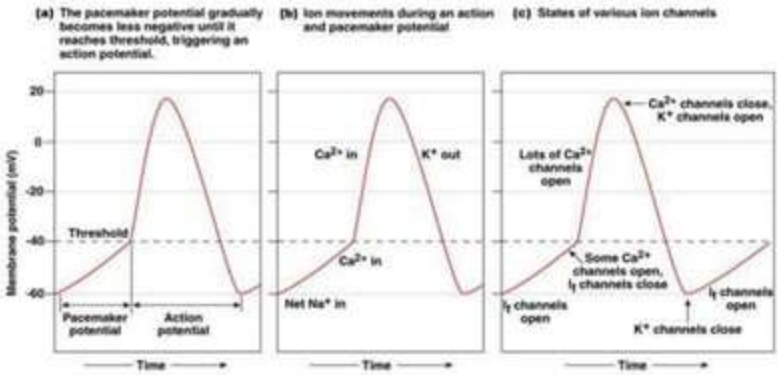



closure of fast Na+ channels
Phase 1
① $I_{TO}$ = Transiently opening $K^+$ channel
④ L-type $Ca^{2+}$ channel
⑤ NCX
Phase 2:-
$Ca^{2+}$ influx
④ L-type $Ca^{2+}$ channel
⑤ NCX
=
$K^+$ efflux
* $I_{Kr}$
* $I_{Ks}$
& $I_{KATP}$
closure of L-type $Ca^{2+}$ channel
L-type $Ca^{2+}$ open up
Phase 0
① fast acting Na+ channels open up
$Ca^{2+}$
Phase 3
$I_{Kr}$ (rapid acting)
$I_{Ks}$ (slow acting)
$I_{KATP}$ (ATP sensitive)
$I_{NCX}$ (removed recharging)
Phase 4

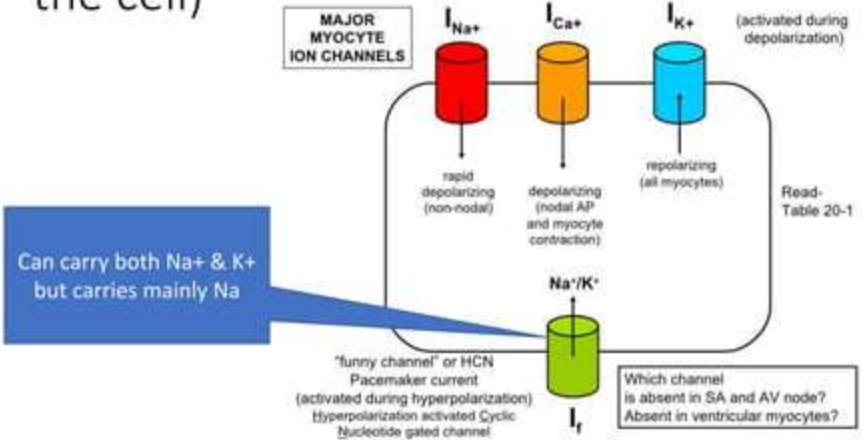
| PHASE 0 | PHASE 1 | PHASE 2 | PHASE 3 | PHASE 4 |
| --- | --- | --- | --- | --- |
| • OPENING OF FAST Na+ CHANNELS → RAPID DEPOLARISATION | • CLOSURE OF FAST Na+ CHANNELS →RAPID REPOLARISATIONN | • PLATEU PHASE<br>• OPENING OF VOLTAGE GATED Ca2+ CHANNELS<br>• OPENING OF CALCIUM –SODIUM EXCHANGER (CAUSES CALCIUM IFLUX) | • OPENING OF K+ CHANNELS | • RESTING MEMBRANE POTENTIAL |

# Pacemaker potential

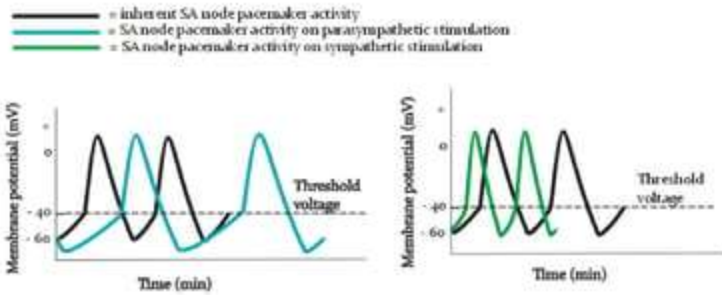
- Fluctuating RMP b/w-60mV to -50 mV
- Phase 4 phase 0 phase 3 present
- Absent phase 1 & 2


(a) The pacemaker potential gradually becomes less negative until it reaches threshold, triggering an action potential.
(b) Ion movements during an action and pacemaker potential
(c) States of various ion channels
Membrane potential (mV)
20
0
-20
-40
-60
Threshold
Pacemaker potential
Action potential
Time
Ca2+ in
K+ out
Ca2+ in
Net Na+ in
Time
Lots of Ca2+ channels open
Ca2+ channels close, K+ channels open
Some Ca2+ channels open, If channels close
If channels open
If channels open
K+ channels close
Time

Funny current → activated membrane hyperpolarisation beyond -50mV → HCN chaneel → carries both Na+ & K+ in same direction (inside the cell)



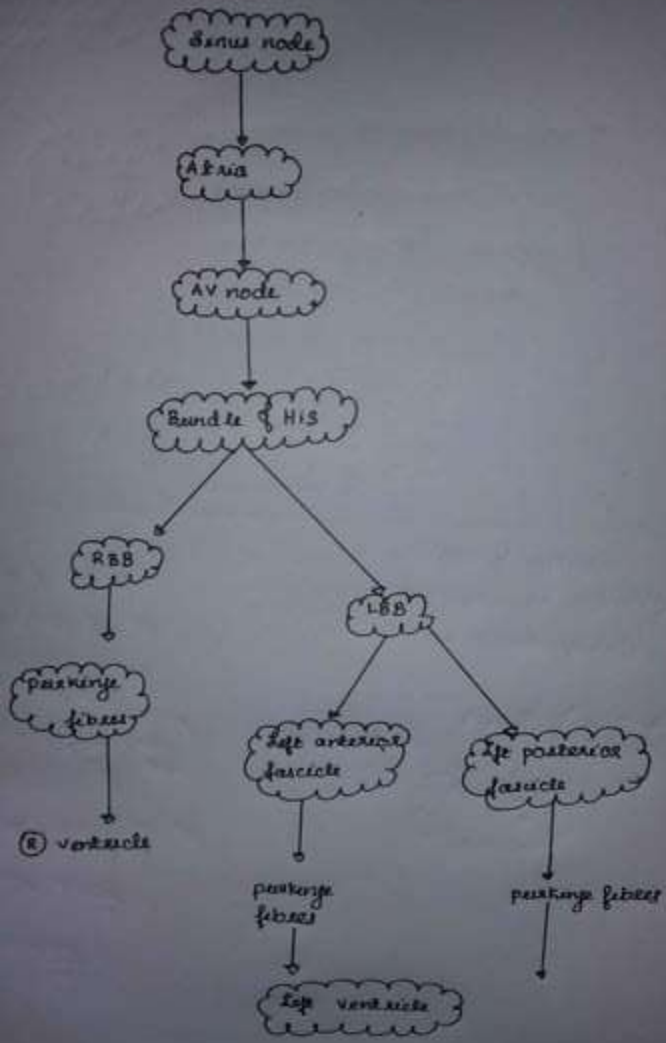
# Effect of autonomic stimulation on AP

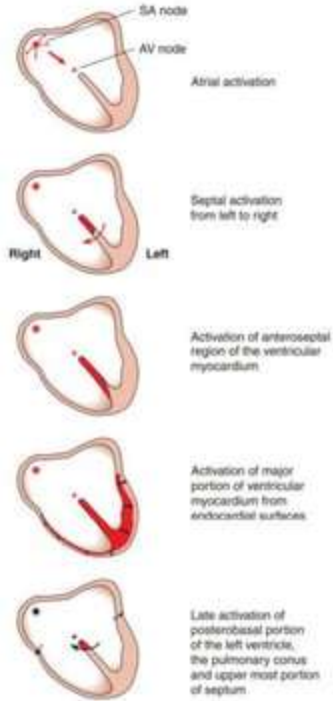


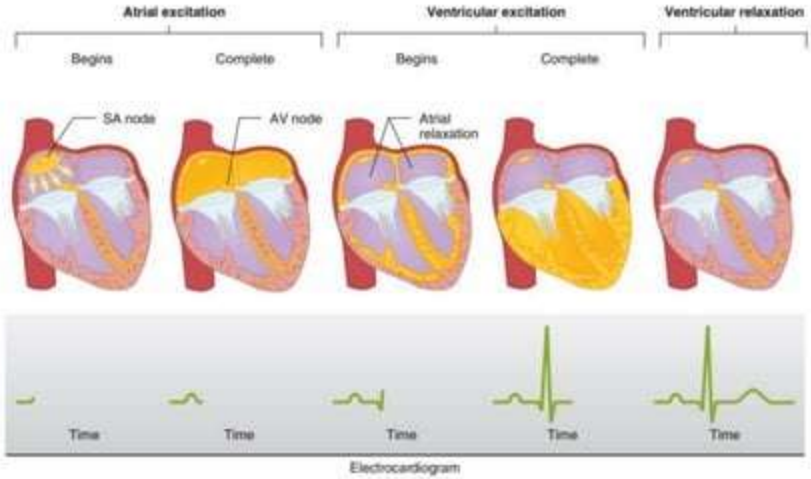

Autonomic control of the SA node activity and heart rate

| Effect of sympathetic stimulation | Effect of parasympathetic stimulation |
| --- | --- |
| • Stimulates opening of If current<br>• Opening of L type of ca2+ channels<br>• Increases slope of phase 4<br>• Positive chronotropic effect<br>• Positive ionotropic<br>• Positive dromotropic<br>• Positive bathmotropic<br>• Decrease in refractory period in all cardiac cells | • Vagal stimulation → decrease slope of prepotential<br>• Negative chronotropic<br>• Negative dromotropic<br>• Increased refractory period of all cells |

| TISSUE | RATE OF IMPULSE GENERATION |
| --- | --- |
| SA NODE | 70-80/MIN |
| AV NODE | 40 – 60/MIN |
| BUNDLE OF HIS | 40/MIN |
| PURKINJE SYSTEM | 24/MIN |


Sinus node
Atria
AV node
Bundle of His
RBB
LBB
Purkinje fibres
Left anterior fascicle
Left posterior fascicle
R ventricle
Purkinje fibres
Purkinje fibres
Left ventricle

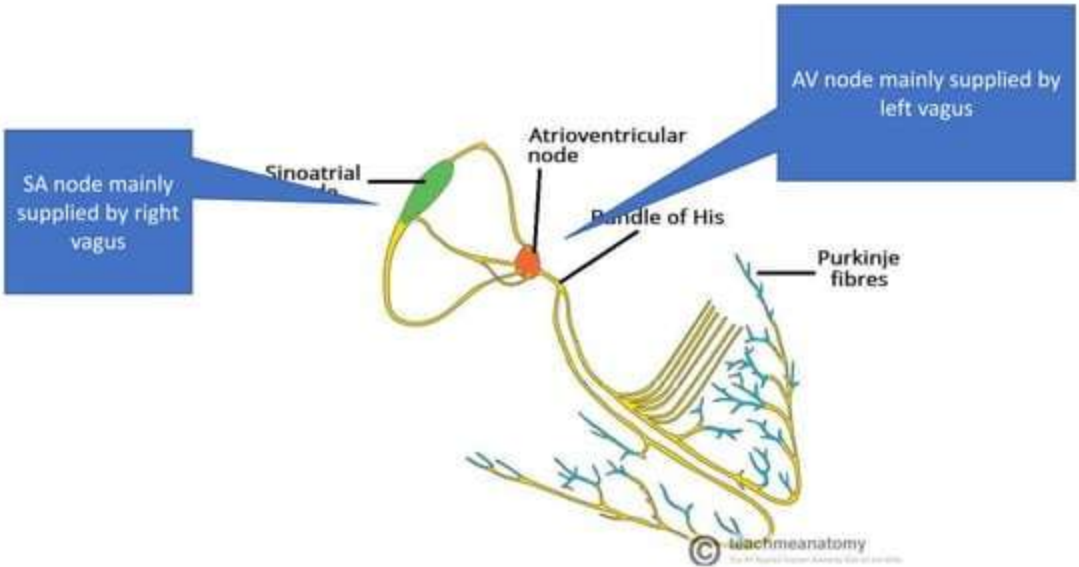

SA node
AV node
Atrial activation
Septal activation from left to right
Right
Left
Activation of anteroseptal region of the ventricular myocardium
Activation of major portion of ventricular myocardium from endocardial surfaces
Late activation of posterobasal portion of the left ventricle, the pulmonary conus and upper most portion of septum


Atrial excitation
Begins
Complete
Ventricular excitation
Begins
Complete
Ventricular relaxation
SA node
AV node
Atrial relaxation
Time
Time
Time
Time
Time
Electrocardiogram

# Conduction speed in cardiac tissue

| Tissue | Conduction Rate (m/s) |
|---|---|
| SA node | 0.05 |
| Atrial pathways | 1 |
| AV node | 0.05 |
| Bundle of His | 1 |
| Purkinje system | 4 |
| Ventricular muscle | 1 |

- MAXIMUM NUMBER OF GAP JUNCTIONS IN PURKINJE SYSTEM→ MAXMM VELOCITY
- MINIMUM VELOCITY IN PURKINJE FIBRE
  - Less no of gap junction
  - Small fibre diameter


SA node mainly supplied by right vagus
Sinoatrial
Atrioventricular node
AV node mainly supplied by left vagus
Bundle of His
Purkinje fibres
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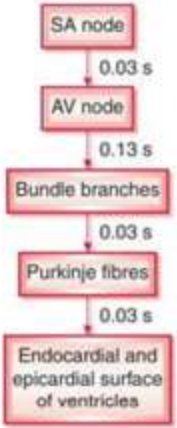
*Time taken for impulse to travel* through different tissue is depicted below:




Thus, total time required for conduction from the SA node to the endocardial surface is 0.22 s.

- SYMPATHETIC STIMULATION TO WHOLE OF HEART
- PARASYMOATHETIC
  - ATRIA
  - SA NODE → RT VAGI
  - AV NODE → LT Vagi

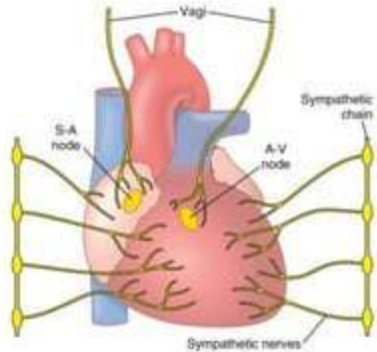



**Figure 9-13.** Cardiac *sympathetic and parasympathetic* nerves. (The vagus nerves to the heart are parasympathetic nerves.) A-V, atrioventricular; S-A, sinoatrial.