Collaboration

An important life skill - you should be able to work with *ANYONE*

- ☐ Communicate regularly. Every 1-2 days!
- ☐ Be Clear - assume there will be misunderstandings - double and triple check
- ☐ Share - everything - this requires Organization and a Plan (Google Drive)
- ☐ Respect - ask for input on all major decisions. Hear them out. Decide jointly
- ☐ Transparency - anytime you email, meet, or talk to anyone about the project, make sure you cc or include your collaborator
- ☐ Back each other up - Check your partner's work and vice versa. You must both do everything, this is the only way it works. When it works, it's amazing
- ☐ Trust - Have a thick skin! Believe that you are there to help each other.
- ☐ Be Reliable - Do your part! And come through, done well, and on time.
- ☐ Have fun - and be good to each other.

Electrical Activity of Hearts:Control

1. Neurogenic pacemaker

- heart beat initiated by neurons

2. Myogenic pacemaker

- heart beat initiated by modified muscle cell

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Myogenic Heart

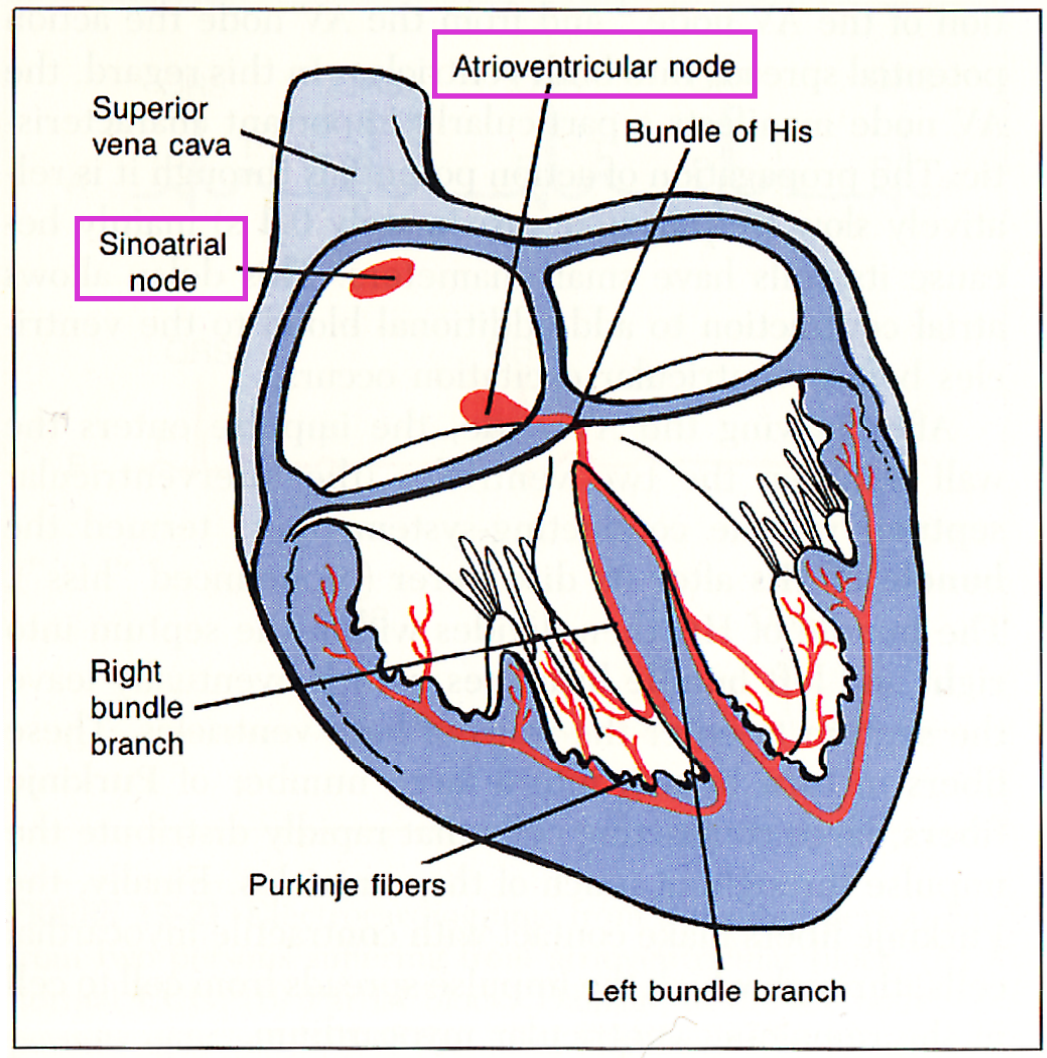
Pacemakers Cells

Beat on Own!

Found in two nodes

Sinoatrial

Atrioventricular



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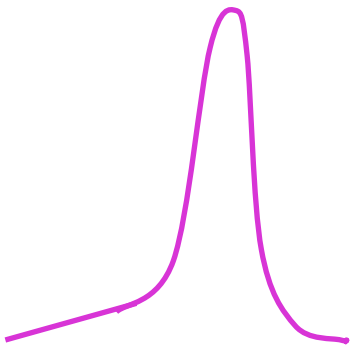
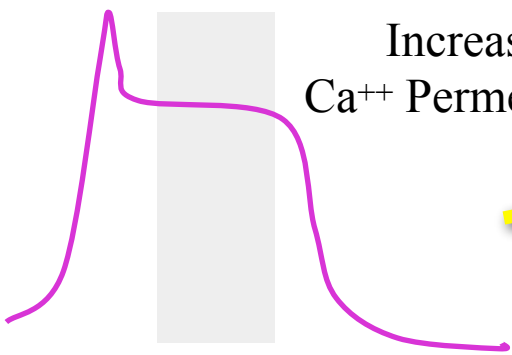
Pacemaker and Cardiac Potentials

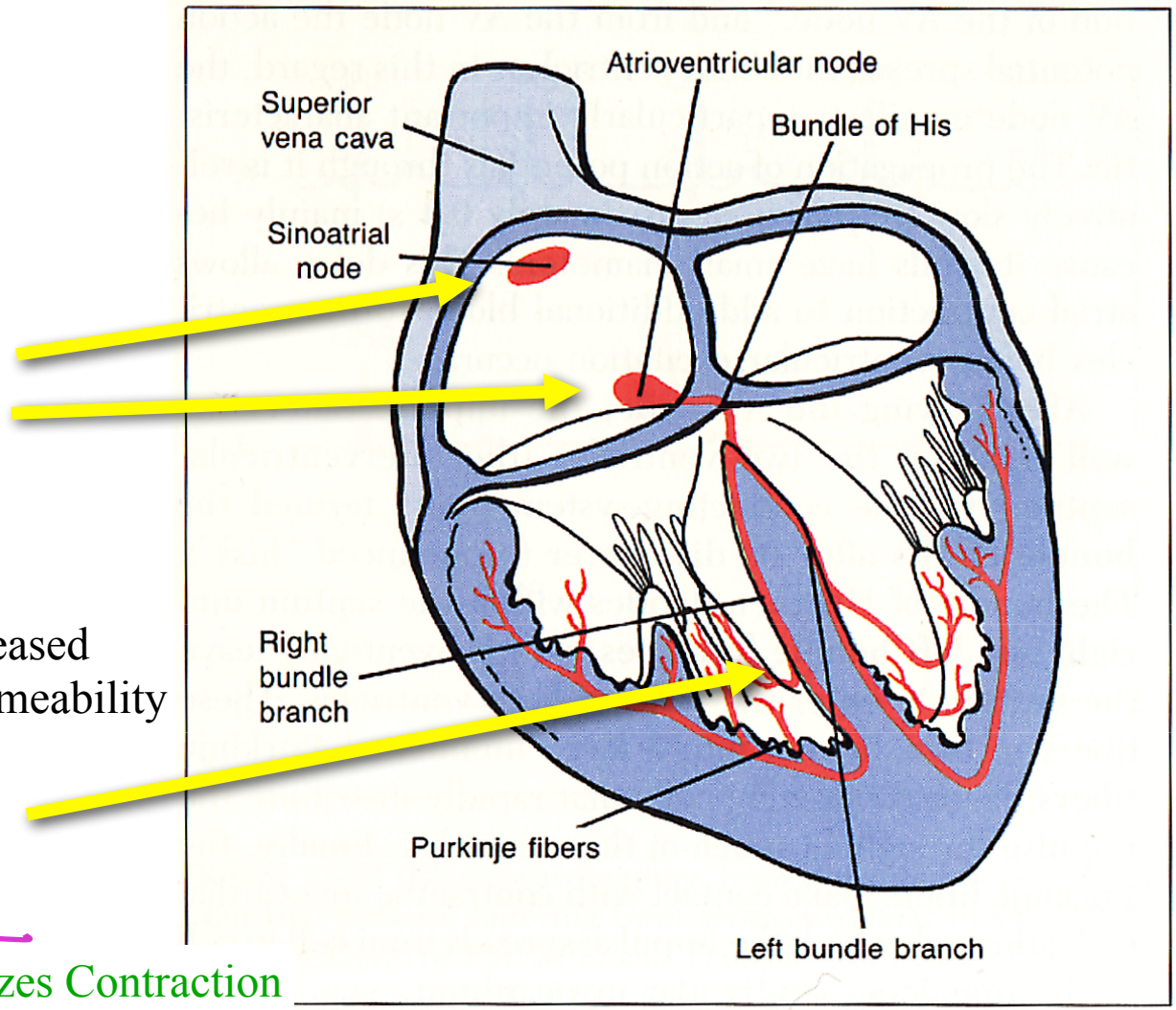
Pacemaker Potential



Cardiac Potential

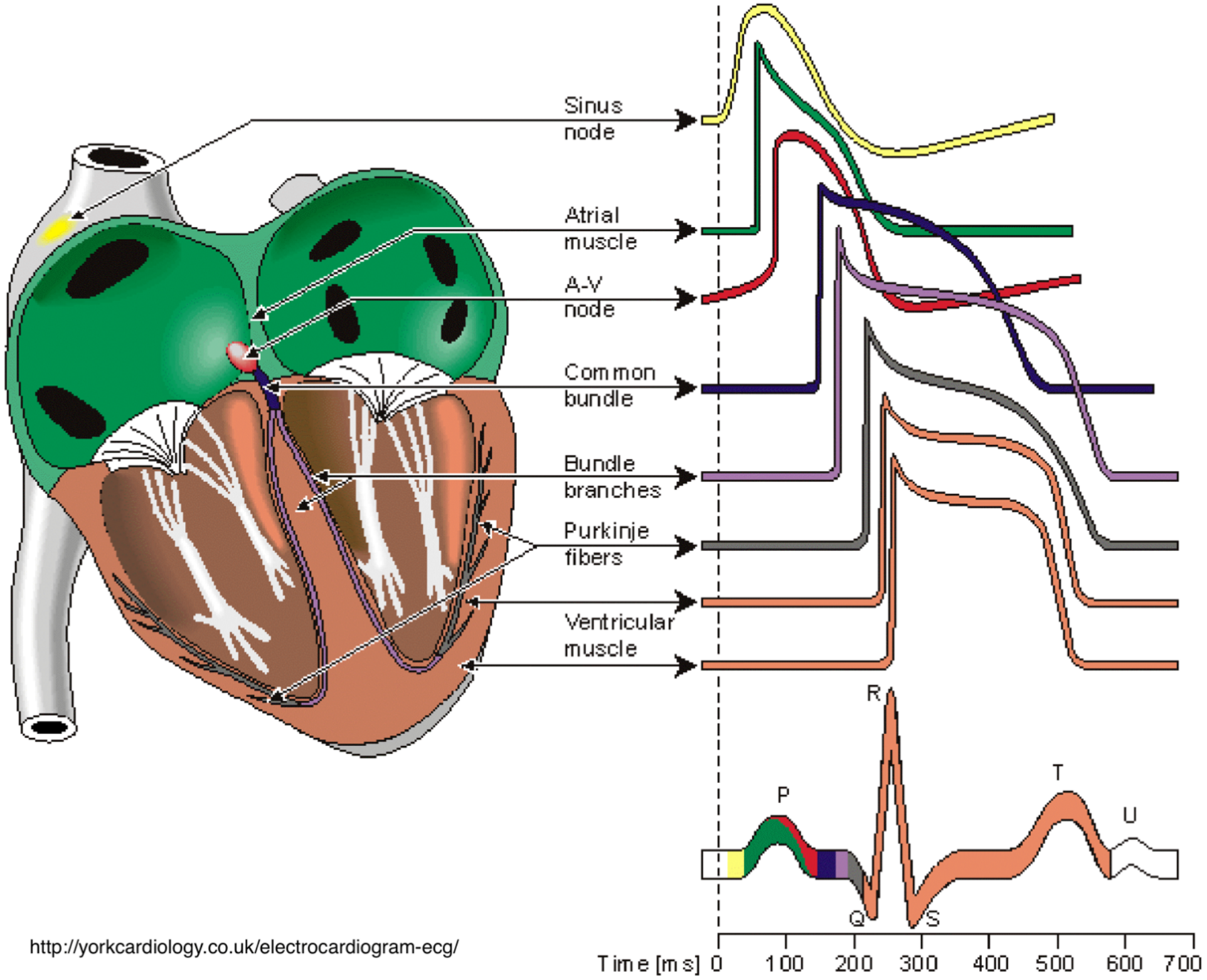


Increased
Ca^{++} Permeability



Prolonged Potential Synchronizes Contraction

15



http://yorkcardiology.co.uk/electrocardiogram-ecg/

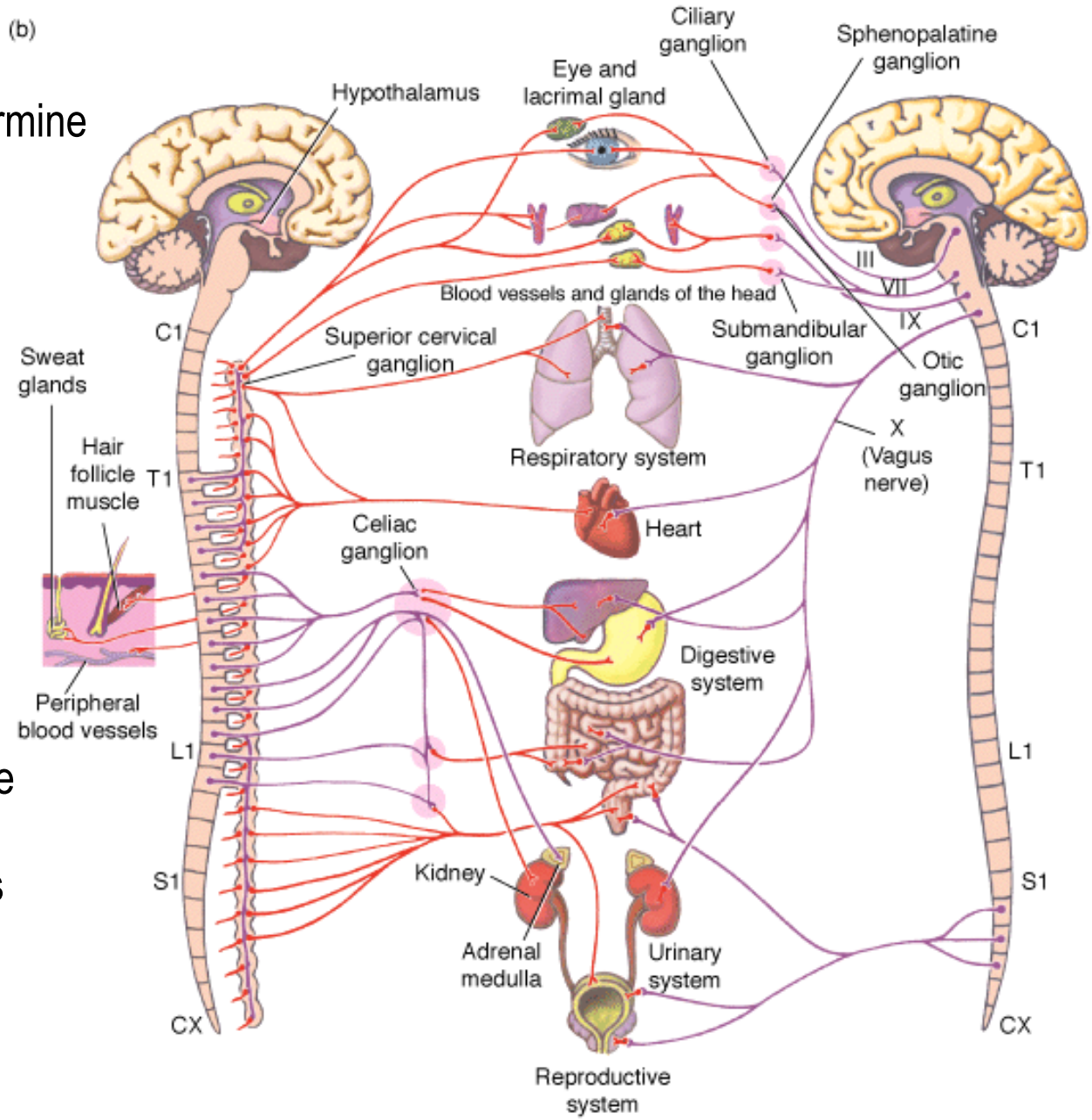
Fight or Flight vs. Rest and Digest

Fight-or-Flight=>Sympathetic stimulation and adrenal medulla secretion work together to adjust to stresses such as escaping a predator or chasing prey. Provides more energy to skeletal muscles (heart pumps stronger, blood pressure incr., lungs dilate, more bood to skeletal muscles, less to skin and viscera, blood sugar up ==> gut movement, digestive enzymes, sexual activity inhibited).

Rest and Digest=> Parasympathetic stimulation. Opposite effects.

Autonomic NS: Sympathetic & Parasympathetic

Generally work in opposition to determine state of organism



Sympathetic

Dominates when animal is frightened or very active

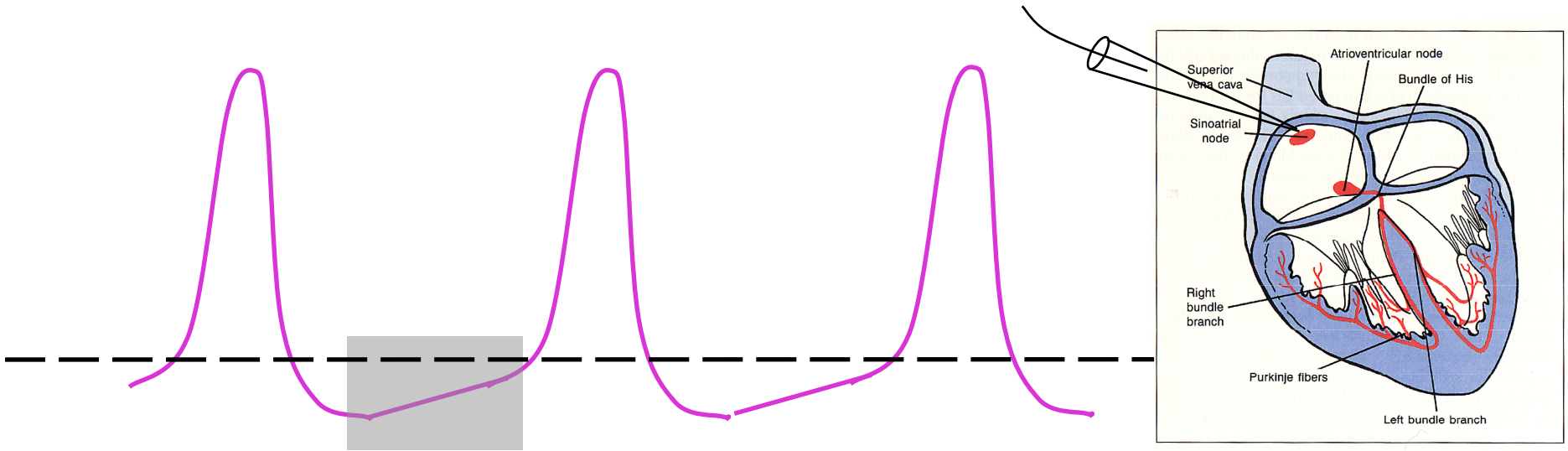
++ Heart Rate
++ blood glucose
++ blood flow to skeletal muscles
-- housekeeping functions (digestion)

Parasympathetic

Dominates in relaxed state

-- Heart Rate
-- blood glucose
-- blood flow to skeletal muscles
++ housekeeping functions
++ blood flow to digestive system

Pacemaker Potentials

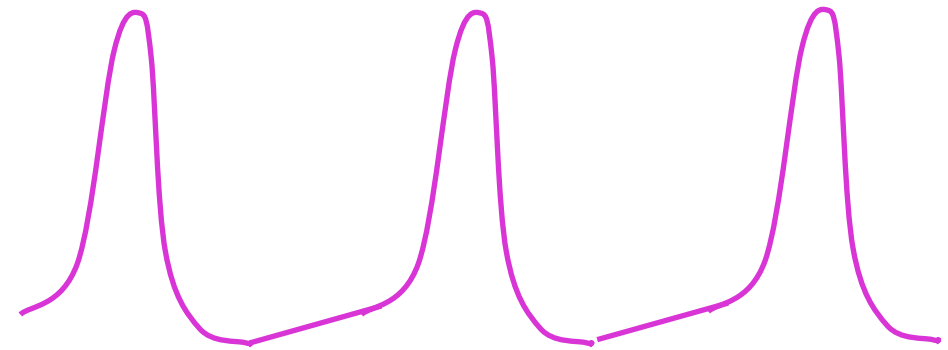


Slow decrease in K^+ permeability

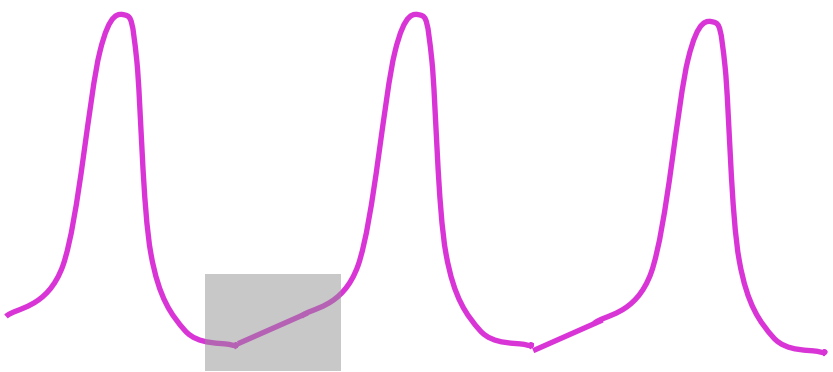
time

Heart rate = # beats / time

Pacemaker Potentials

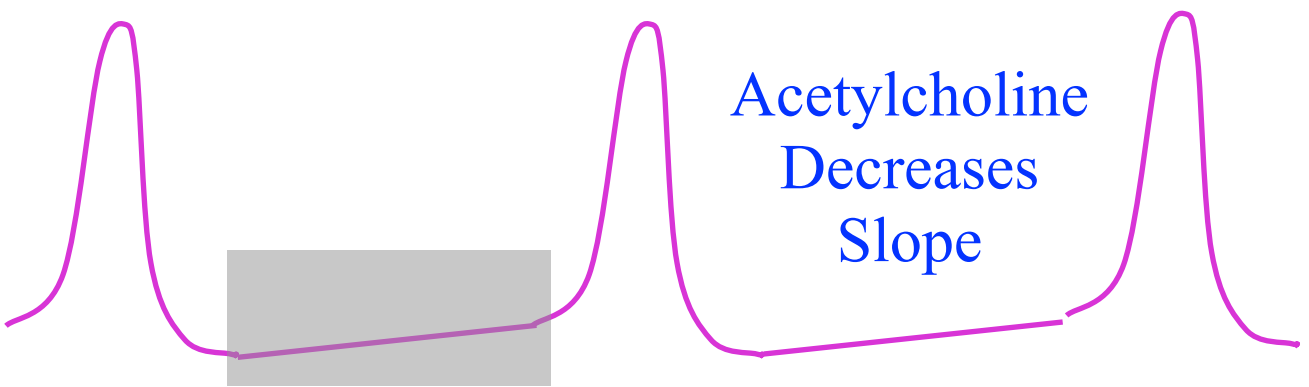


Normal



Epinephrine
Increases
Slope

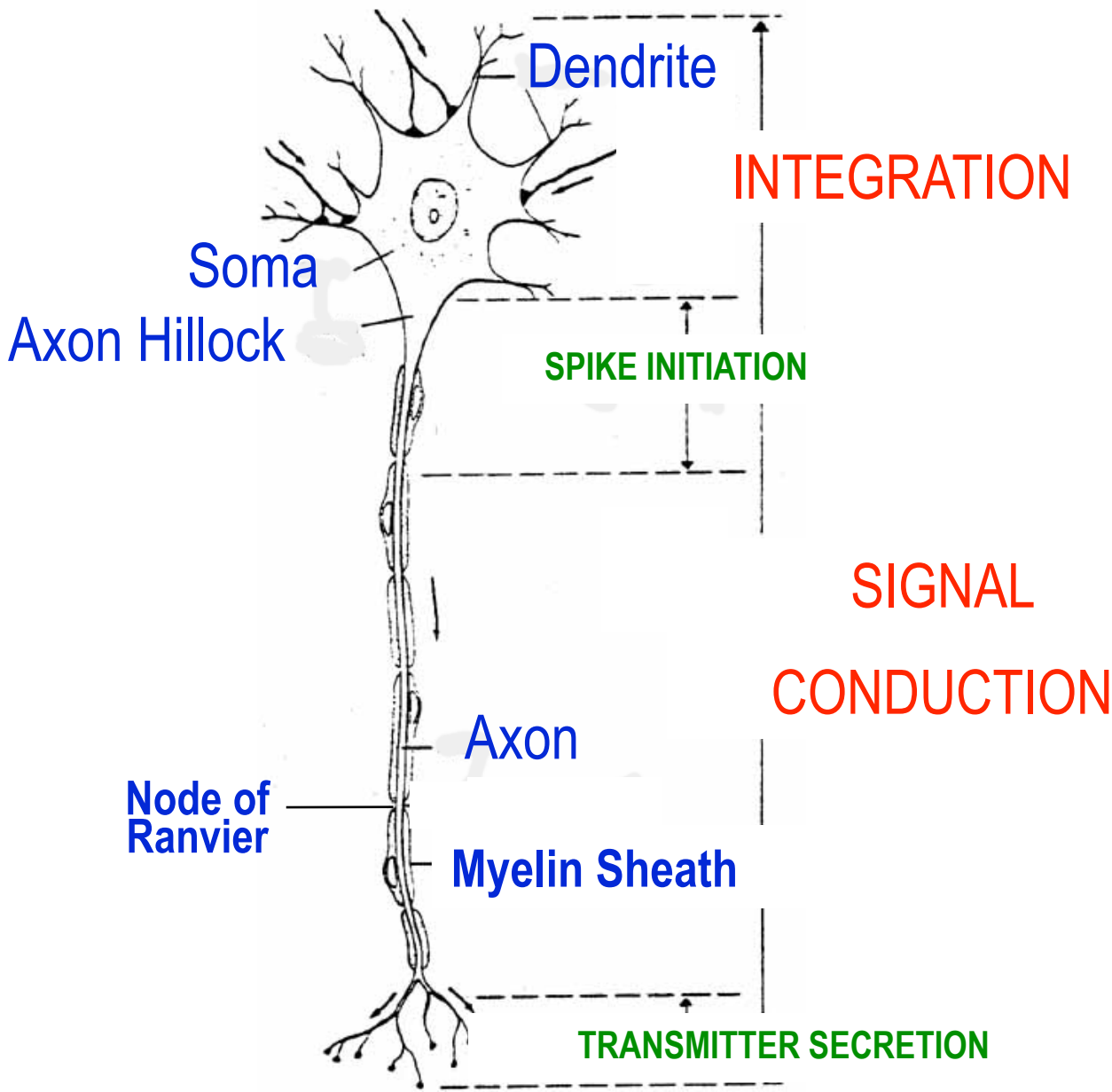
Increase
Heart Rate



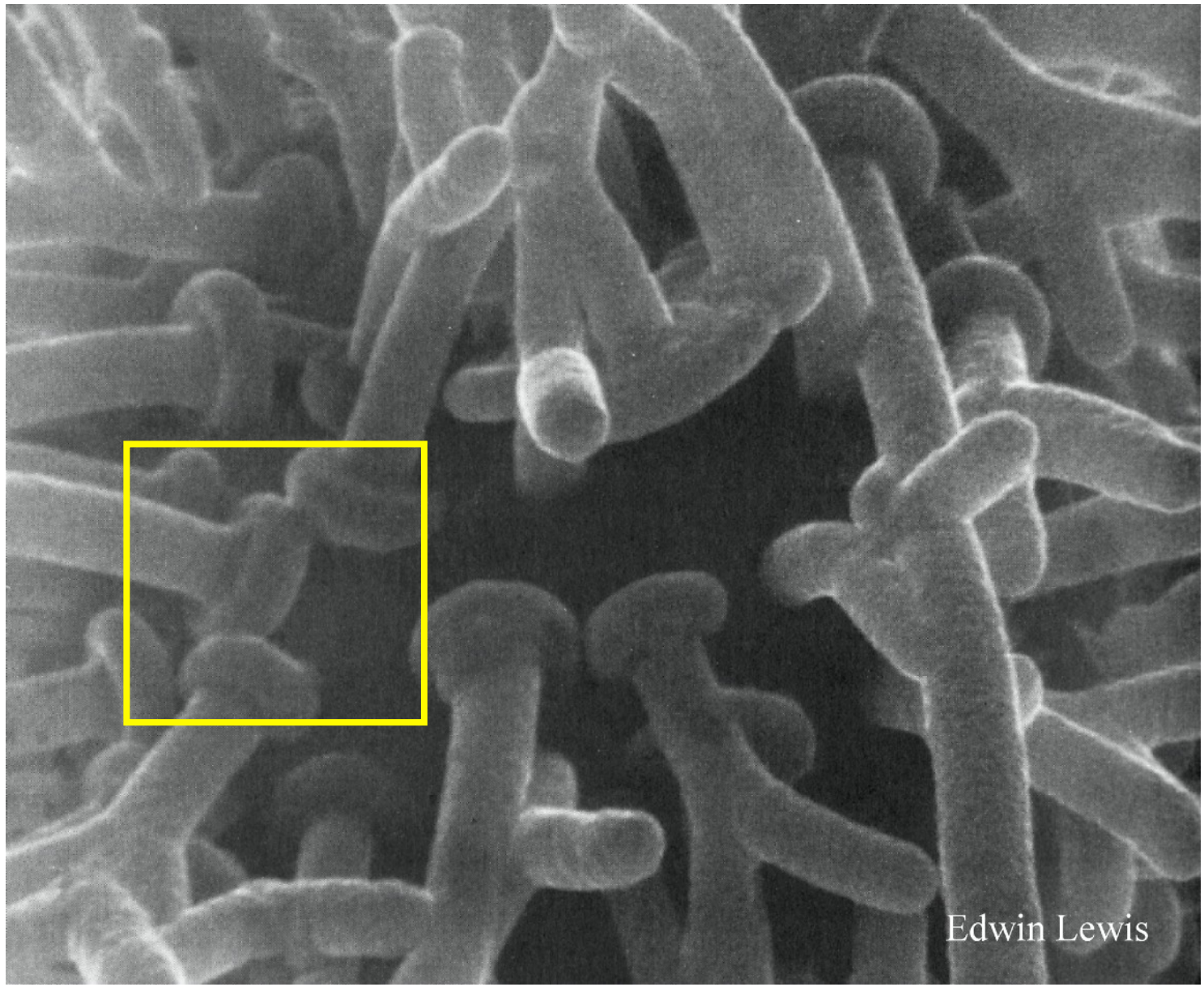
Acetylcholine
Decreases
Slope

Decrease
Heart Rate

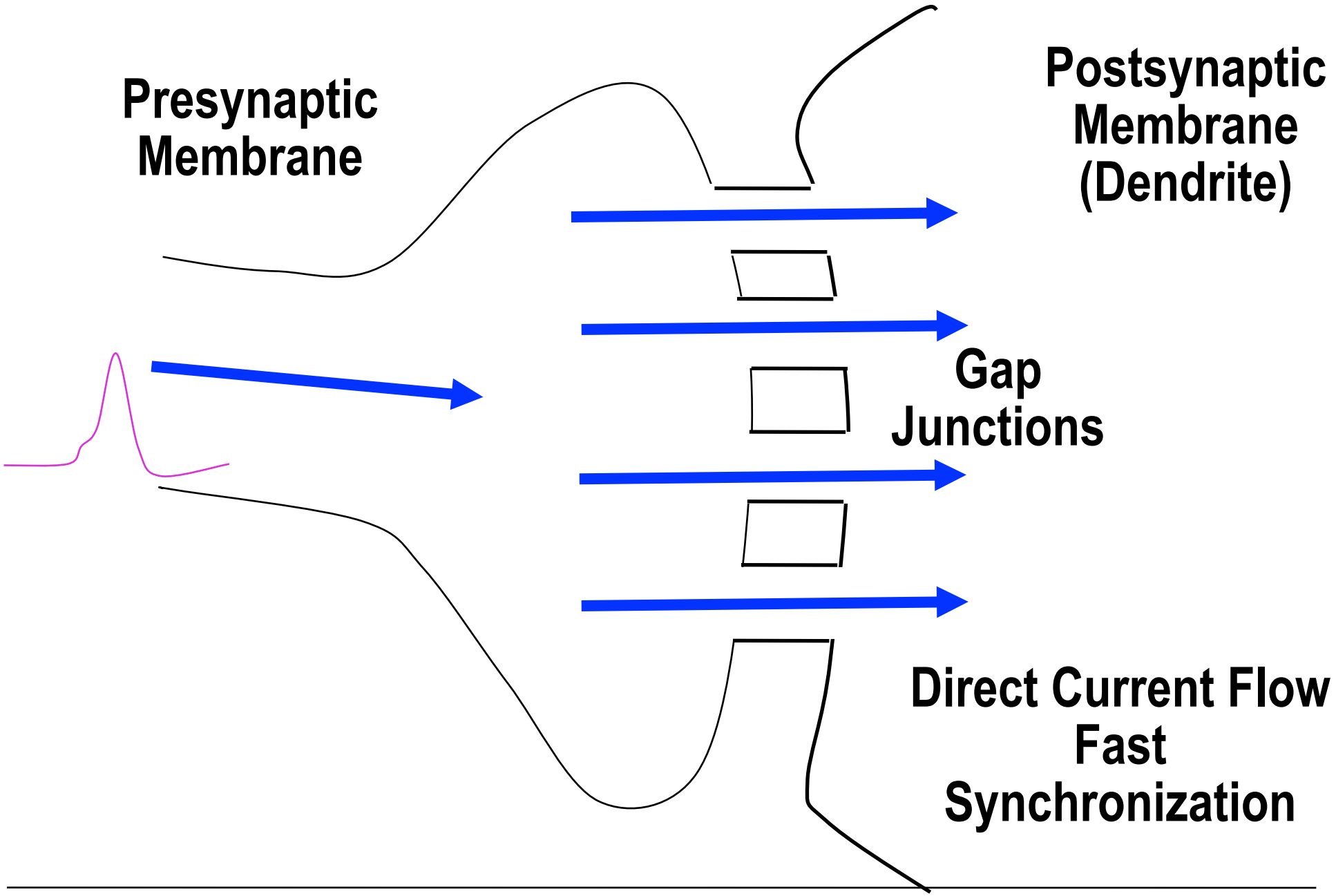
Structure of Neuron



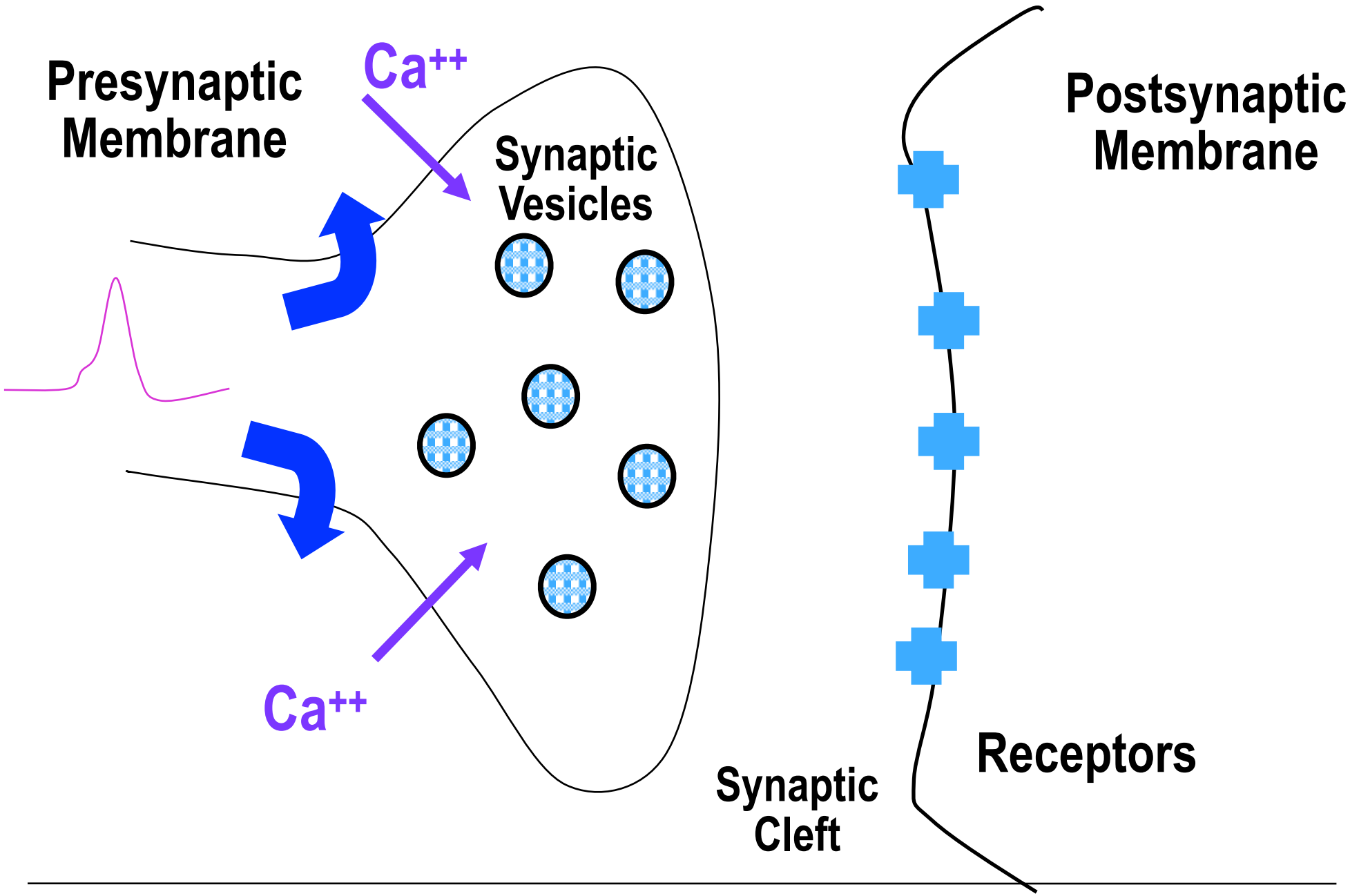
Synapatic Connections



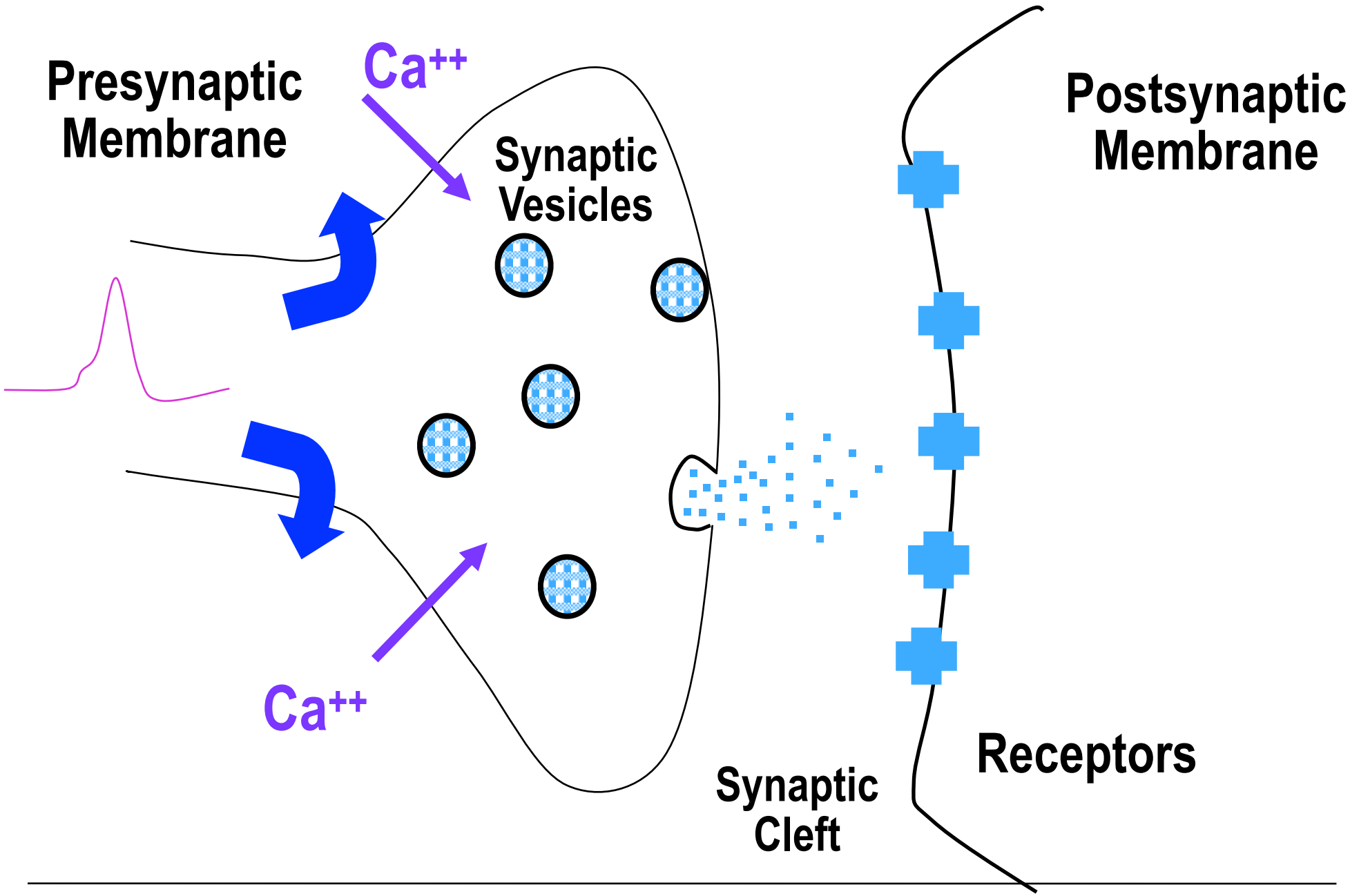
Electrical Synapse



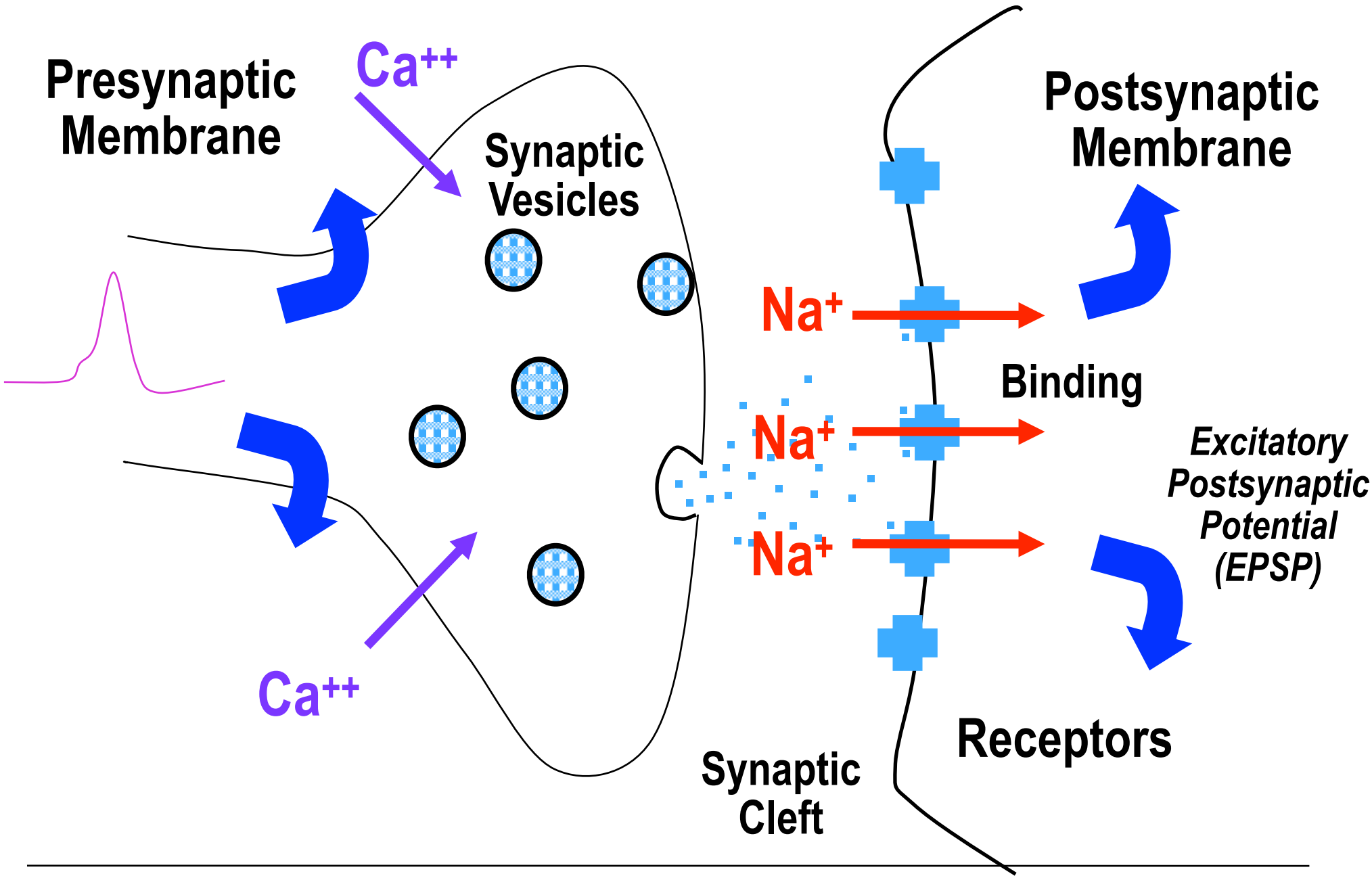
Chemical Synapse



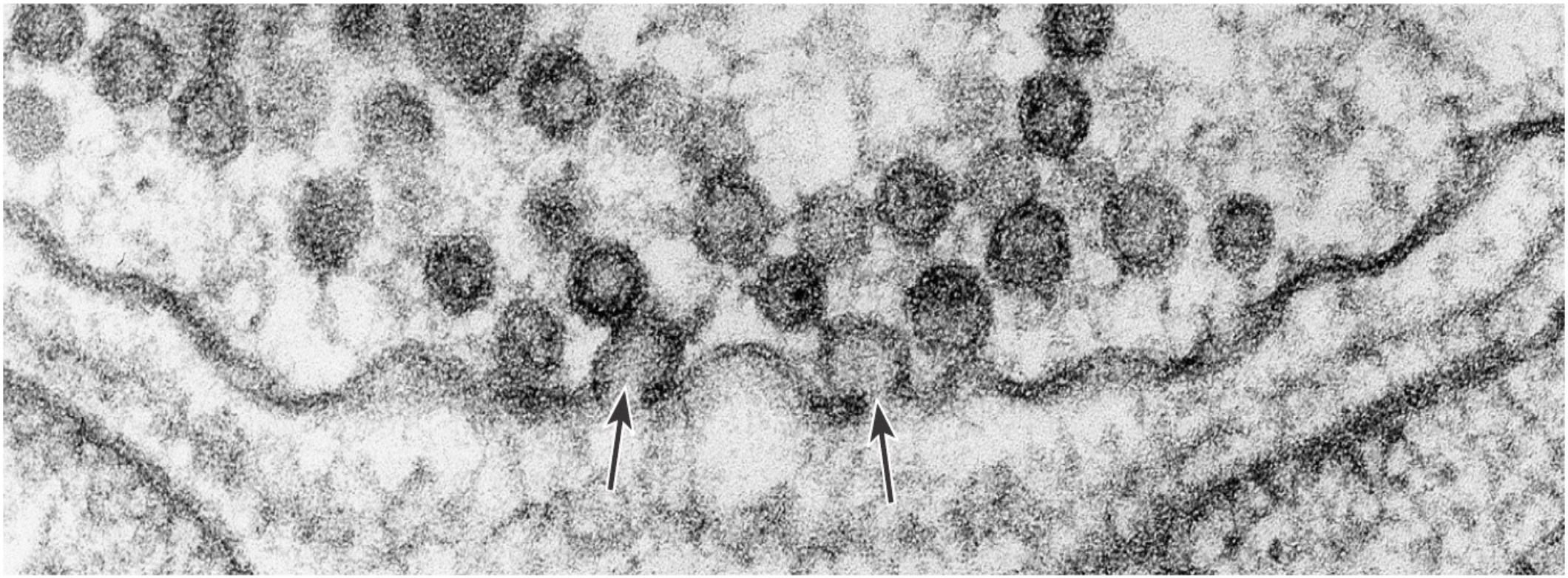
Chemical Synapse



Chemical Synapse



Vesicle Fusion



Neurotransmitters

E Excitatory

I Inhibitory

Widespread

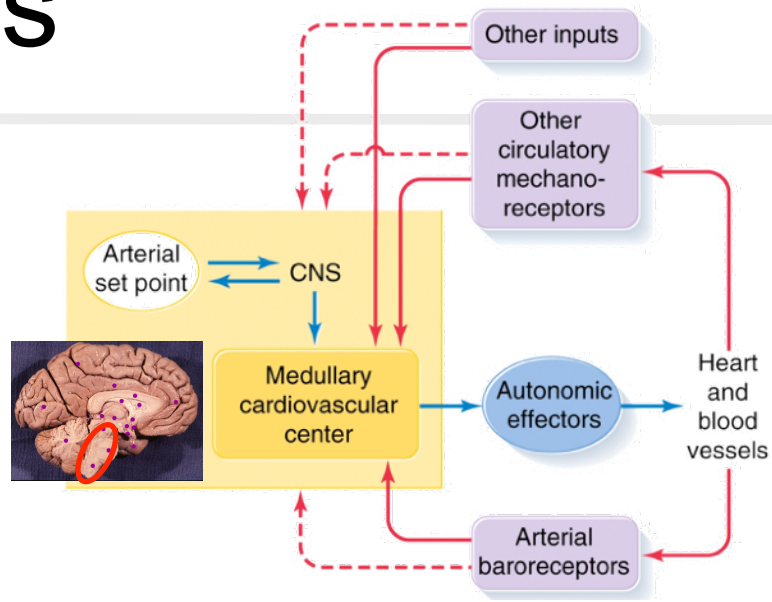
Transmitter	Animal	Action	
Acetylcholine	Vertebrate muscle	E	
	Vertebrate CNS	E	
	Invertebrate CNS	E or I	
Norepinephrine	Vertebrate CNS	E or I	Mimic (Amphetamines) Block inactivation (Cocaine)
Glutamic acid	Vertebrate CNS	E	
	Crustacean CNS	E	
GABA	Vertebrate CNS	I	
	Crustacean CNS	I	
	Annelid CNS	I	
Serotonin	Vertebrate CNS	I	Block re-uptake (Prozac)
	Invertebrate CNS	I	
Dopamine	Vertebrate CNS	E or I	Pleasure producing pathways (Addiction)
	Arthropod CNS	E or I	
	Annelid CNS	E or I	

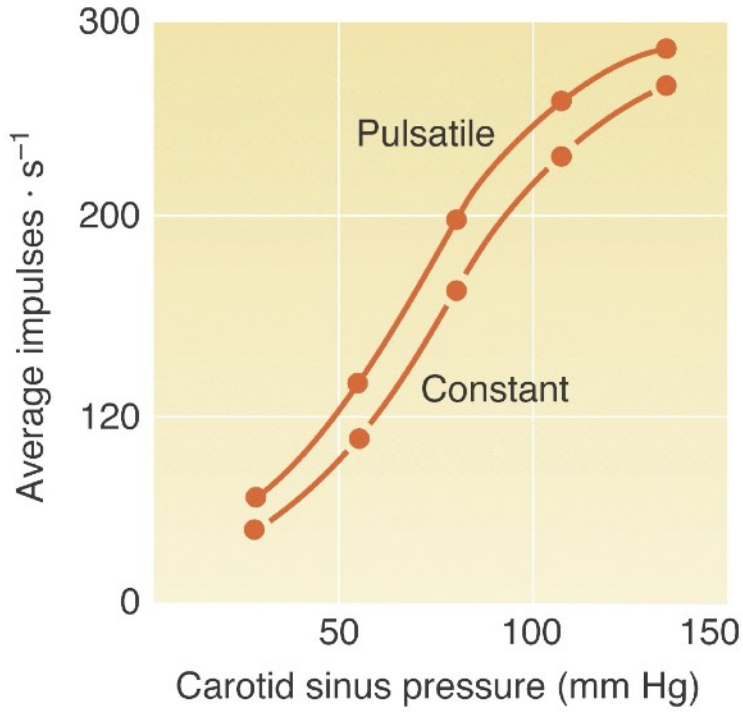
Regulation of Circulation

- Priorities:
  - Ensure adequate supply of blood to brain and heart
    - Stroke, Myocardial Infarction (heart attack)
  - Supply blood to other systemic organs
  - Control capillary pressure
    - Control tissue volume
    - Maintain interstitial fluid composition
- Control Mechanisms:
  - Baroreceptors: pressure sensitive sensory neurons
  - Chemoreceptors: ventilation AND circulation (esp CO2)
  - Endocrine (hormonal) and Chemical messengers (NO)

Arterial Baroreceptors

- Pressure-sensing mechanoreceptors
- Receptor signals transmitted to Medullary Cardiovascular Center (MCC) and integrated with signals from other neuronal circuits
- Baroreceptors activate or inhibit two MCC functional regions:
  - Pressor center (increases b.p.)
    - Sympathetic activation
  - Depressor center (decreases b.p.)
    - Parasympathetic activation
- Arterial baroreceptors:
  - Mammals: carotid sinus, aortic arch, clavian, common carotid, and pulmonary arteries
  - Increase firing with increases in b.p.
  - Initiate reflexes to reduce arterial b.p. by decreasing cardiac output (both HR and SV) and peripheral vascular resistance





Arterial Chemoreceptors

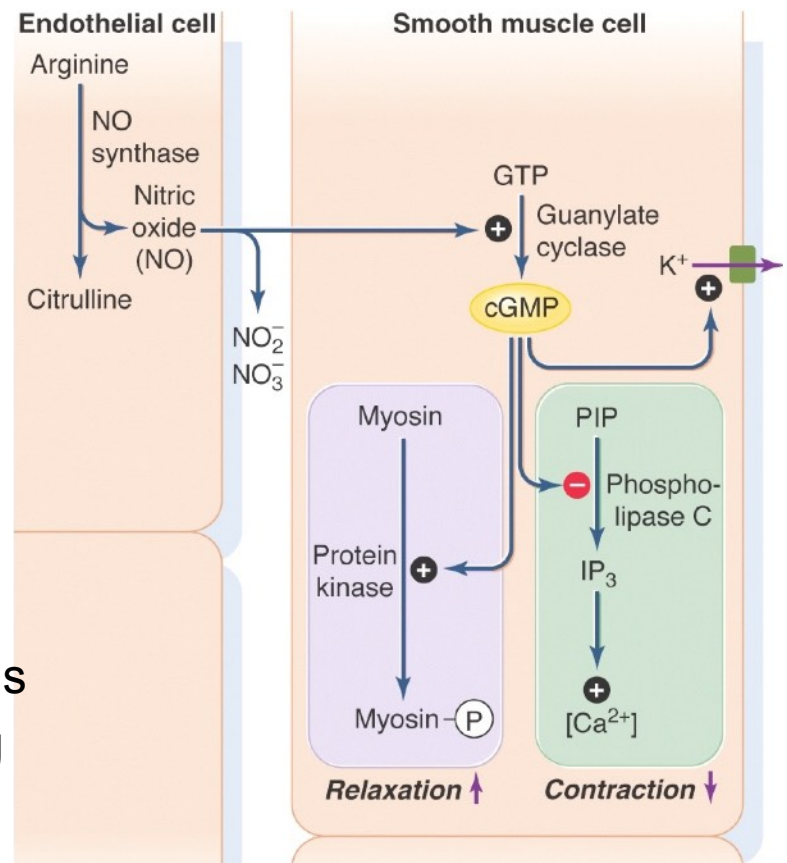
- Chemoreceptors in carotid and aortic body
  - Sense CO_2, pH, O_2
    - Ventilation Regulation
  - Increases in these chemoreceptor impulses also
    - Reduces Heart Rate
    - Increases Peripheral Vasoconstriction
      - Increases Blood Pressure
  - Important in control of dive response

Cardaic Sensory Systems

- Atrial Mechanoreceptor fibers:
  - A-fiber: sense changes in heart beat rate
    - Signals sent to Medullary Cardiovascular Center
  - B-fiber: sense changes in rate of filling of atria
    - Increased venous pressure stimulates B-fibers, which increase HR through innervation of SA node
    - Increase diuresis (urine prod.) which reduces blood volume + pressure
      - Mediated by decreased antidiuretic hormone (ADH) in blood
  - C-fibers: sense stretch at junction of veins and atria
    - Stimulation maintains HR
- Atrial Stretch-sensitive secretory cells:
  - Produce atrial natriuretic peptide (ANP)
    - Increases Na+ excretion (natriuresis) and urine production
      - Reduces blood volume + pressure
    - ANP also inhibits pathways to resorb Na and increase blood volume
- Ventricular mechanoreceptors:
  - Low coronary blood flow stimulates and increases cardiac output
  - High stimulation causes stomach relaxation and produces vomiting

Capillary blood flow control

- Hyperemia/Ischemia control (too much/too little blood)
  - Increase/decrease
- Neuronal control
  - Norepinephrine (sympathetic): vasoconstriction, flow reduction, incr. b.p.
  - Acetylcholine (parasympathetic): vasodilation, flow increase, decr. B.p.
- Local control by Nitric Oxide (NO)
  - Produced in vascular endothelial cells
  - Diffuses into vascular smooth muscle
  - Binds to receptors at metal ion or S
  - Activates guanulate cyclase which produces second messenger cGMP
    - like adenylate cyclase
  - cGMP relaxes muscles by affecting multiple pathways
- NO synthases are activated by Ca^{2+}
  - Ca^{2+} enters through stretch-receptive channels
  - Potentially NO synthases are activated during every pulse



Just say NO: molecule of the year in 1992

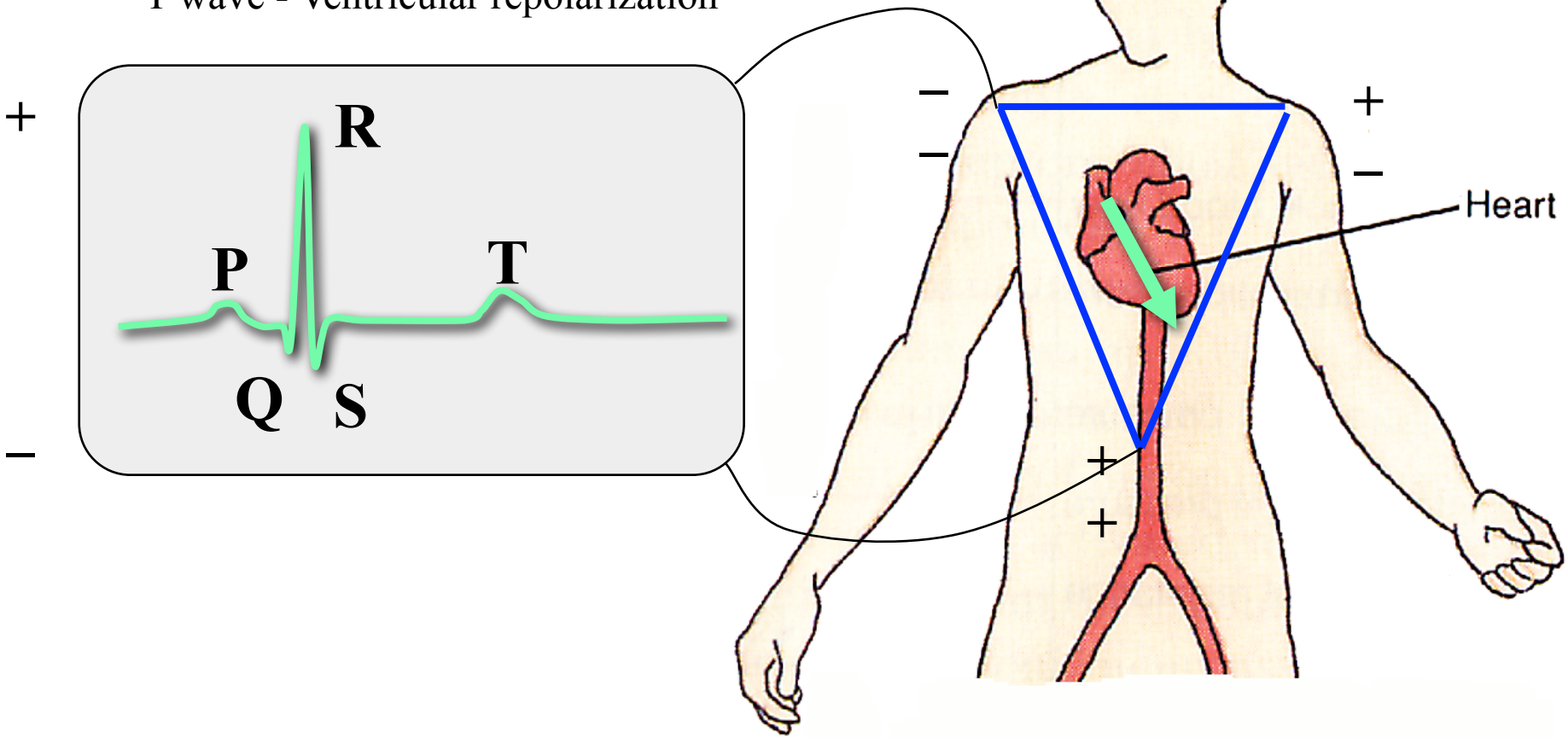
- Nitric Oxide is an important diffusible messenger in many physiological processes, and has many important applications
  - Smooth Muscle Relaxation
    - Vasodilation:
      - Viagra, Levitra, Cialis enhance NO effects by inhibiting the enzyme that degrades cGMP
      - Nitroglycerine releases NO when it dissolves
    - Gastrointestinal peristalsis
    - Genito-urinary tract - birth
  - Kidney function
  - Inflammation and immune responses
  - Hormonal secretion
  - Nervous system function
    - Neurotransmitter
    - Ventilation control (complexed with Hemoglobin)
  - Reproductive physiology - egg fertilization
  - Firefly flashing
  - Plant pathogen defenses, reproduction

Electrocardiogram (EKG)

P wave - atrial depolarization

QRS complex - Ventricular depolarization

T wave - Ventricular repolarization



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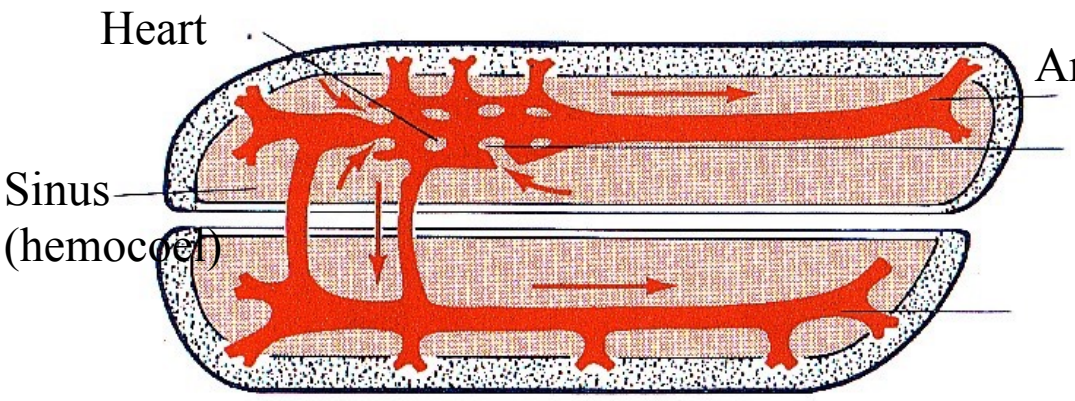
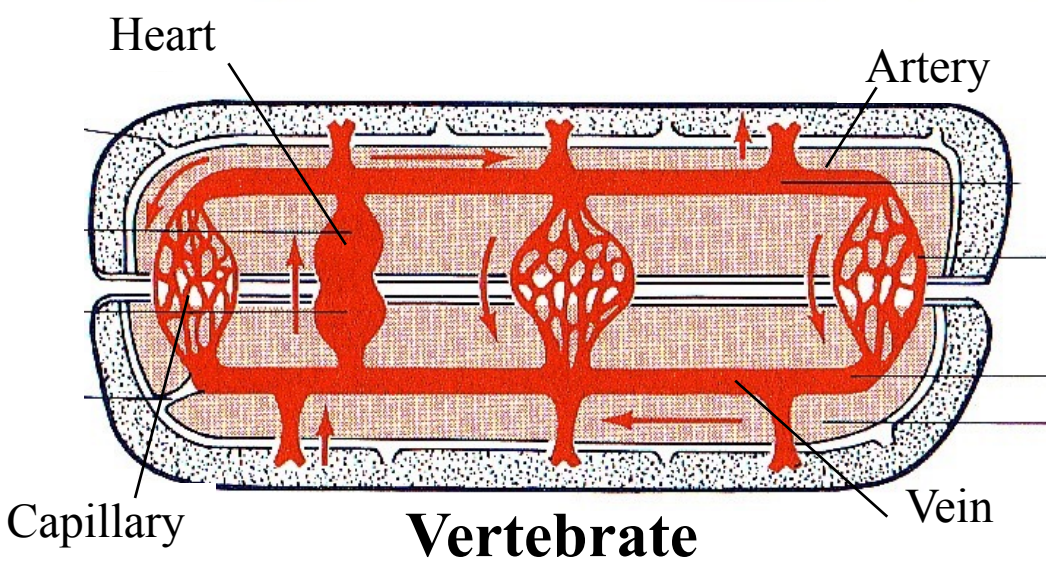
Types of Circulatory Systems



Arthropod

Open circulatory system

- **eg arthropods and mollusks**
- **body fluid leaves the heart by a series of tubes called arteries**
- **blood (*hemolymph*) from the arterial system enters sinuses called the *hemocoel***
- **where it bathes the cells directly**

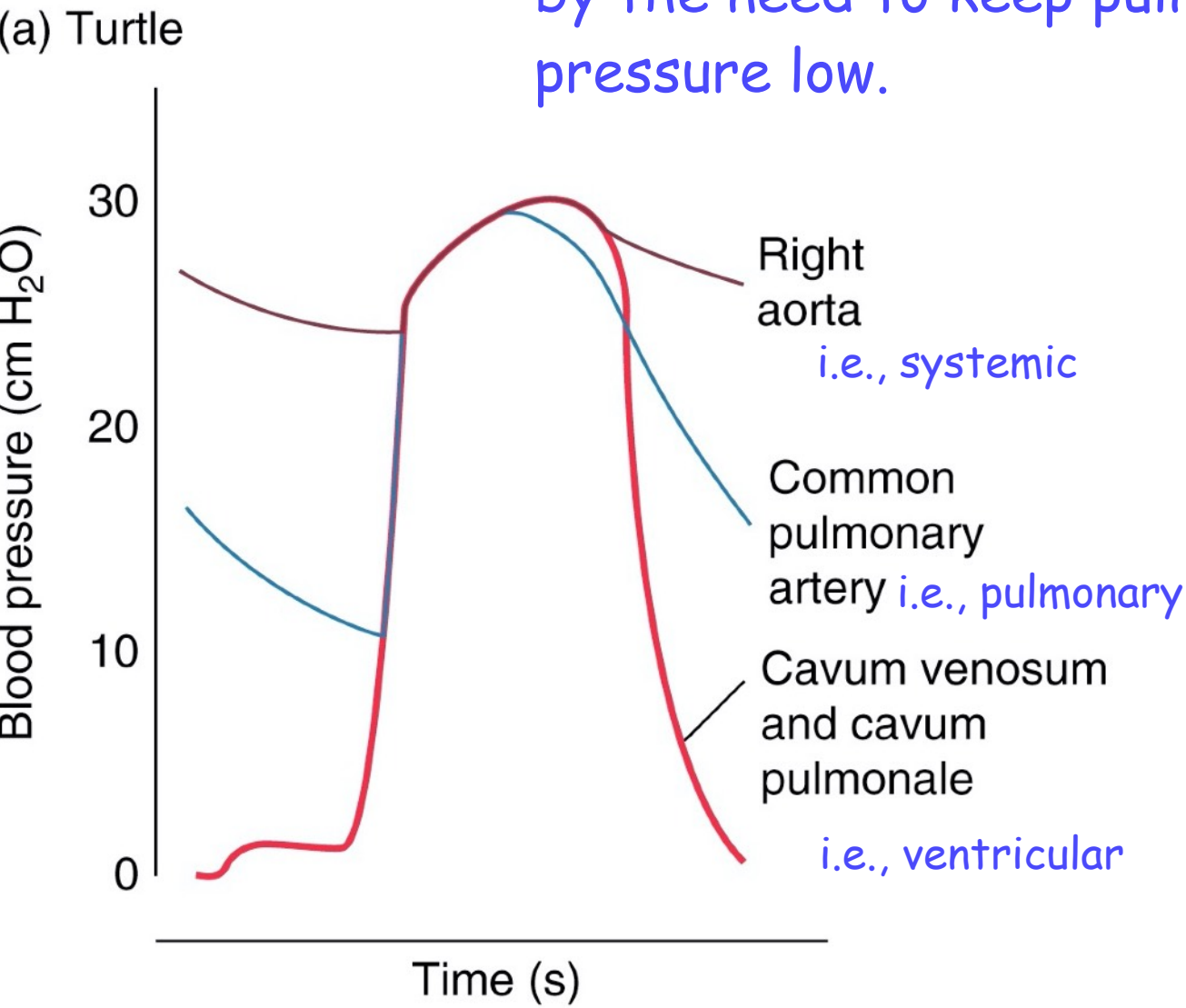


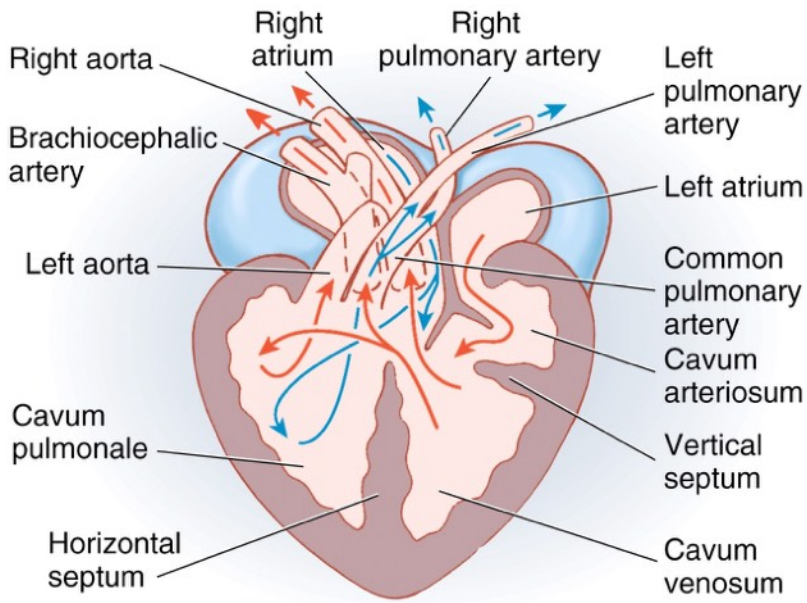
Vertebrate

Closed circulatory system

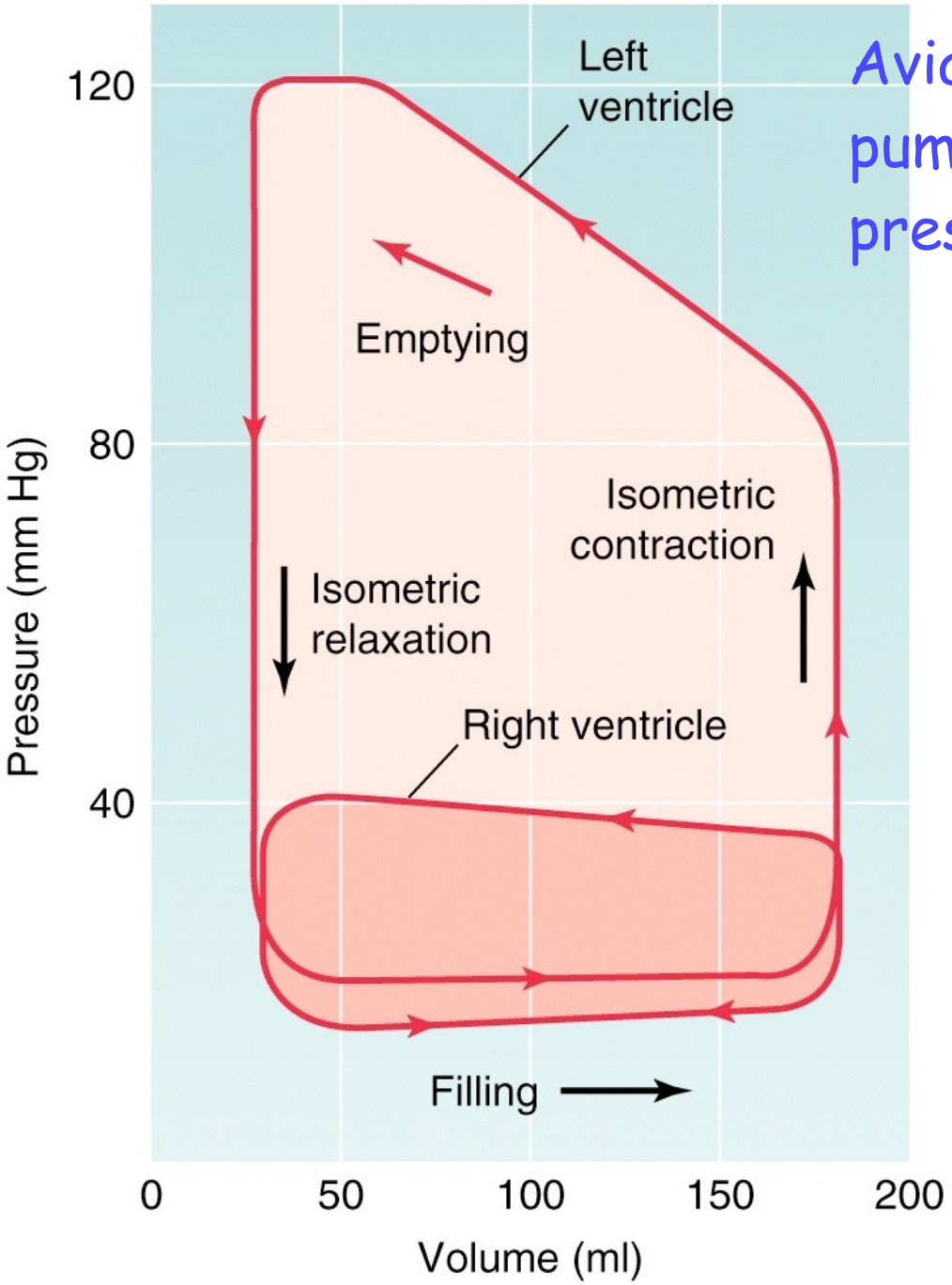
- **eg annelids and vertebrates**
- **heart to arteries to capillaries to venules to veins**
- **Blood stays in tubes for entire trip around body**

Systemic pressure is limited by the need to keep pulmonary pressure low.

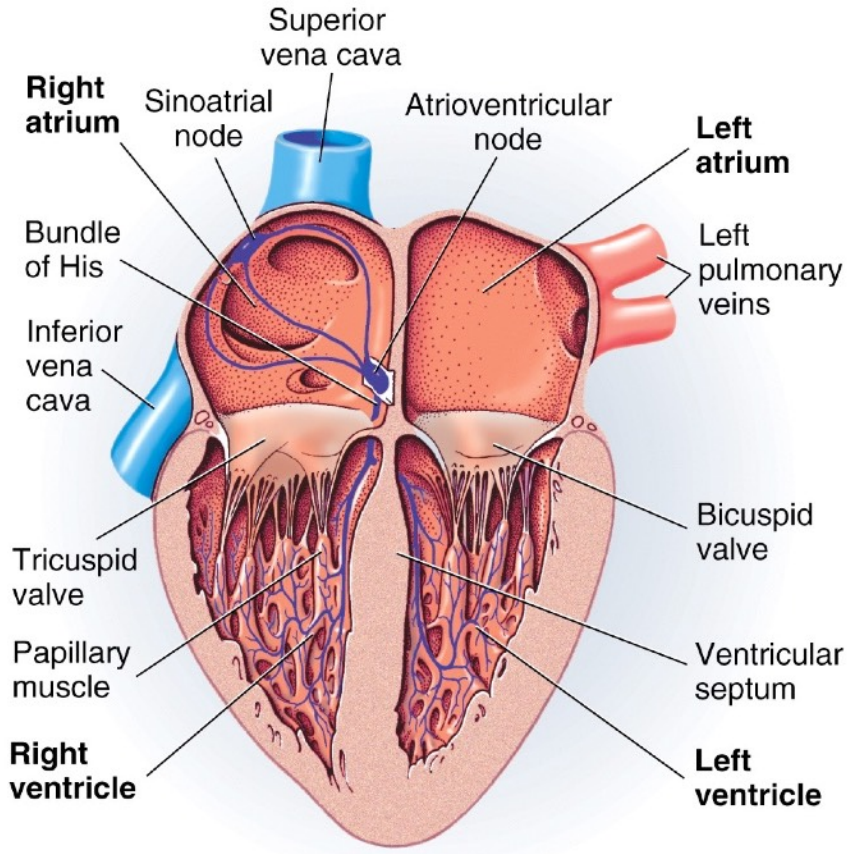




Reptile heart



Avian and mammalian double pump allows high systemic pressure.



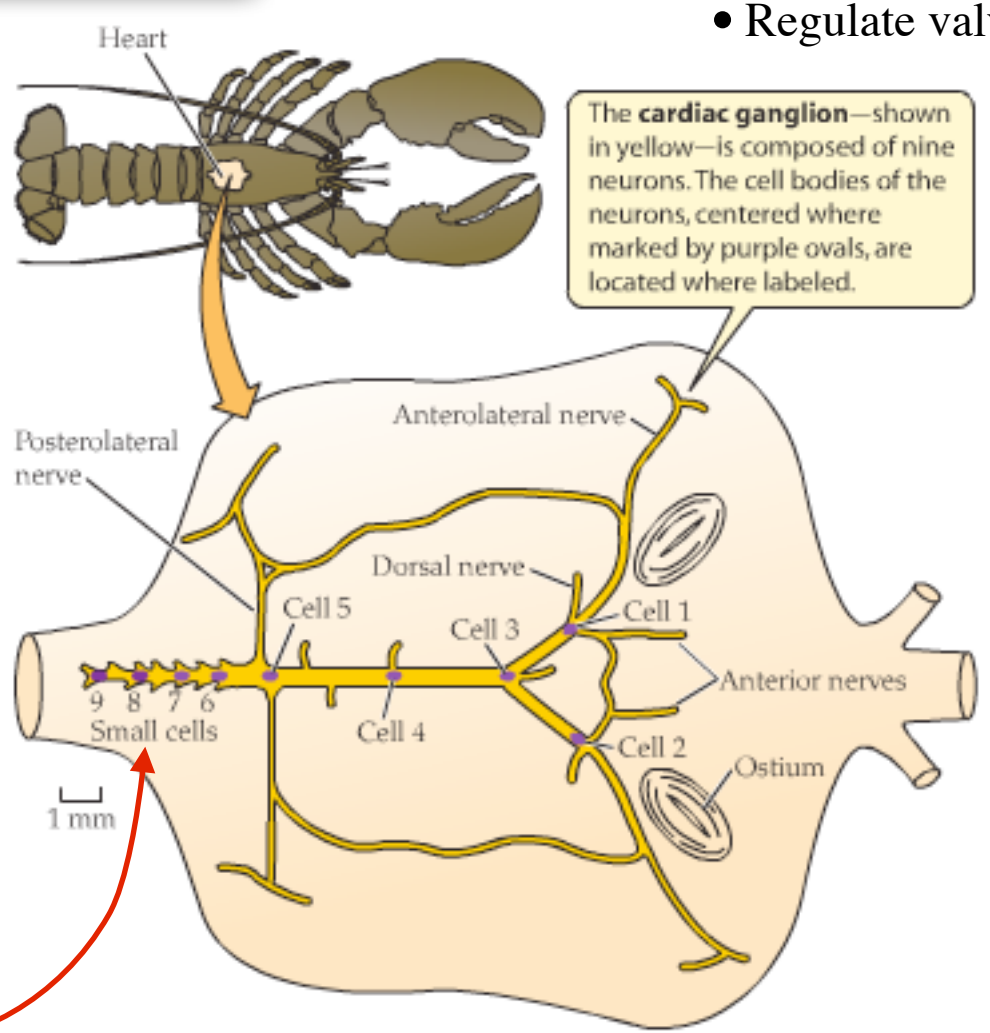
A four chambered heart results in the right side receiving only venous blood.

How is the right side supplied with oxygen?

Lobster Cardiac Ganglion

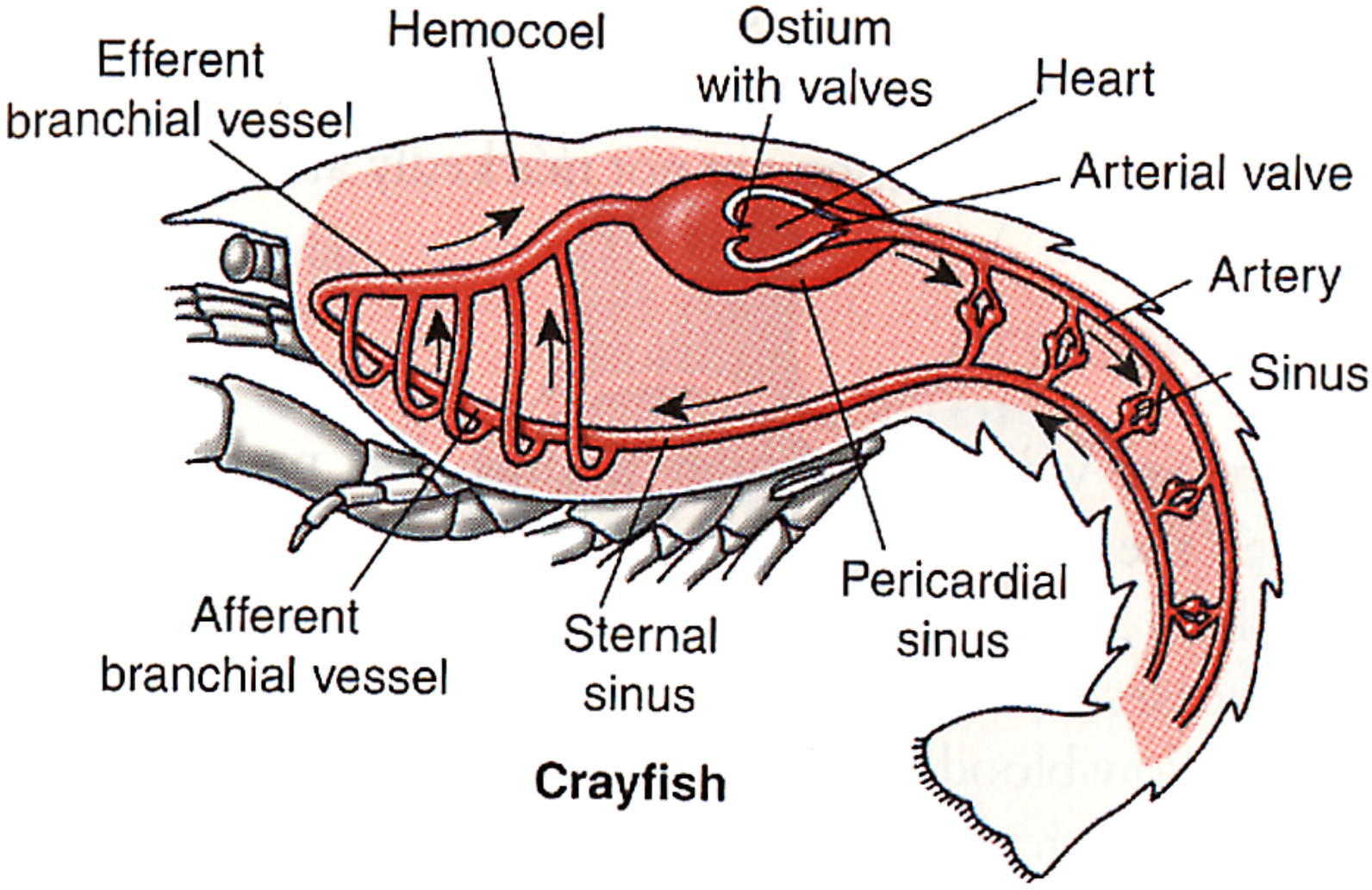
- 9 neurons in CG
- Simple pattern generation system
- Attached inside dorsal wall of heart

- 5 anterior neurons have axons that innervate the heart muscle
- impulses from anterior neurons produce heart contraction in unison
- Regulate valves in arteries and ostia



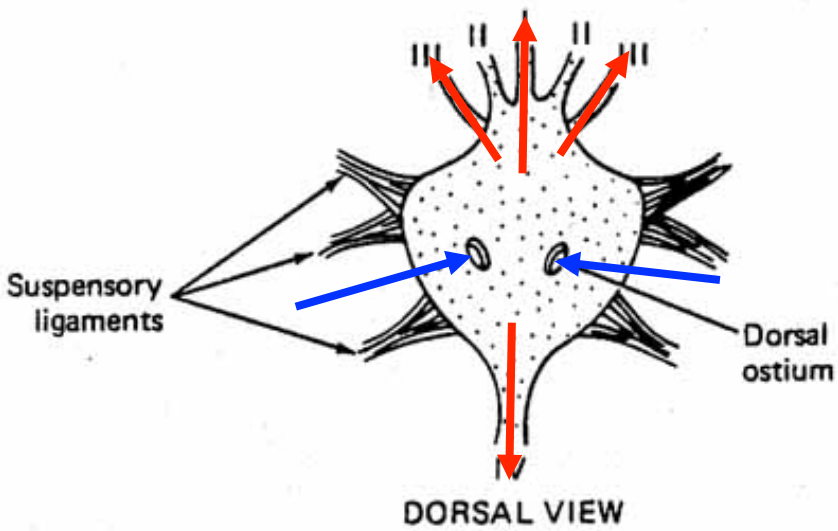
- 4 dorsal neurons synapse with 5 anterior neurons
- one serves as the "pacemaker" or cellular oscillator (central pattern generator)
- spontaneously excites other dorsal neurons with train of impulses
- dorsal neuron impulses activate 5 anterior neurons

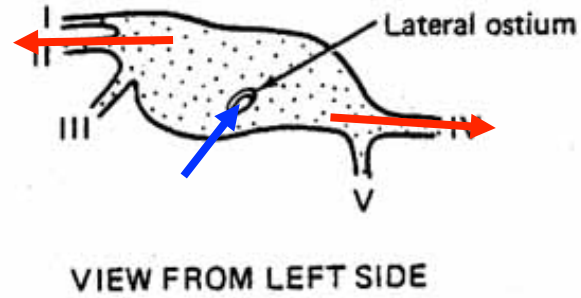
Tubular Heart - Open System



3

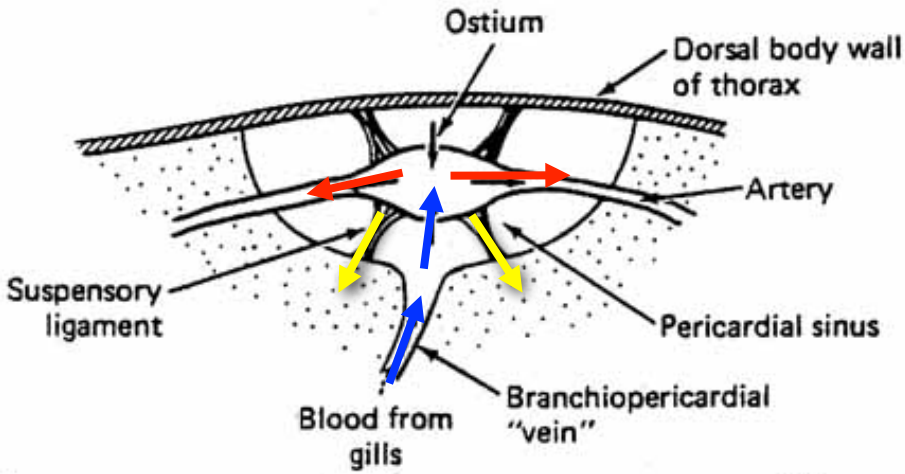
Simple Tubular Hearts

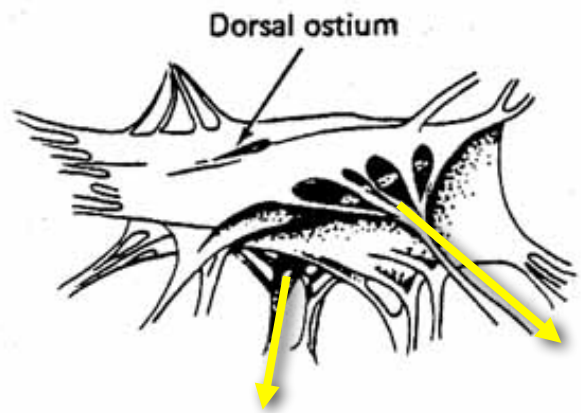




Systole - heart contraction

Diastole - heart relaxation

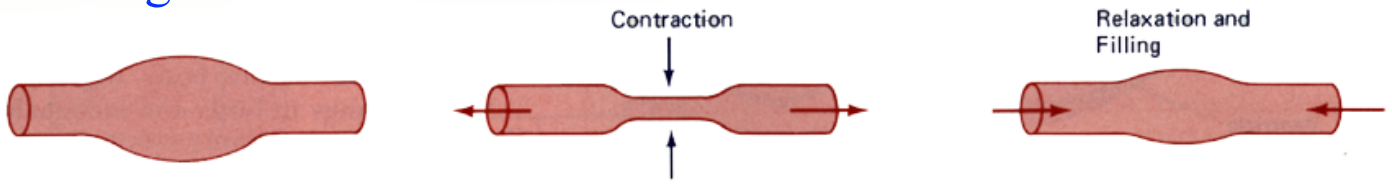




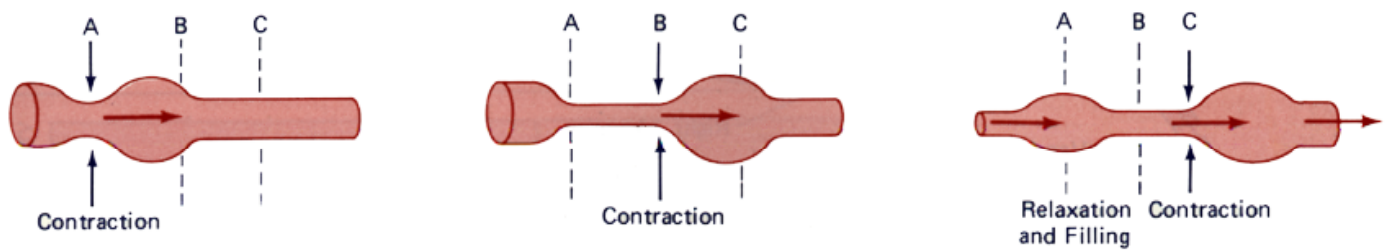
4

Types of Pumps

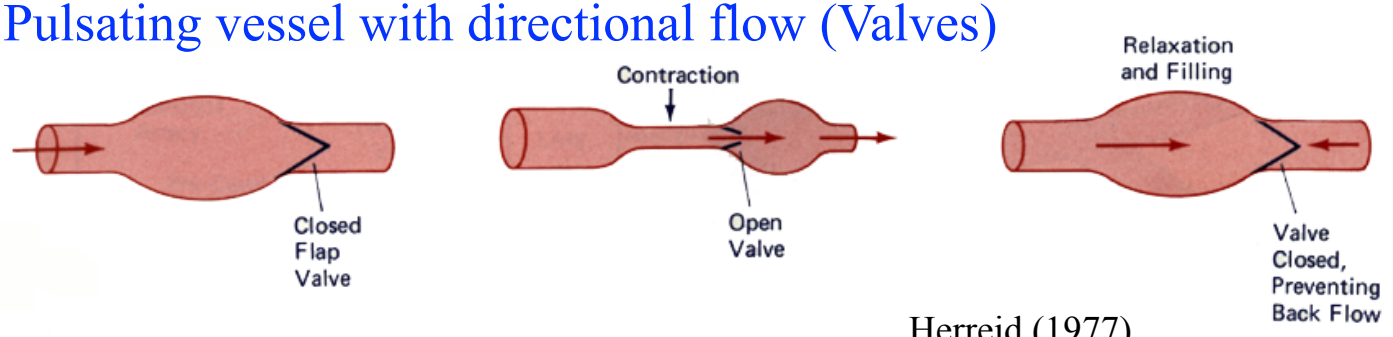
Pulsating vessel without directional flow



Pulsating vessel with directional flow (Peristaltic waves)



Pulsating vessel with directional flow (Valves)



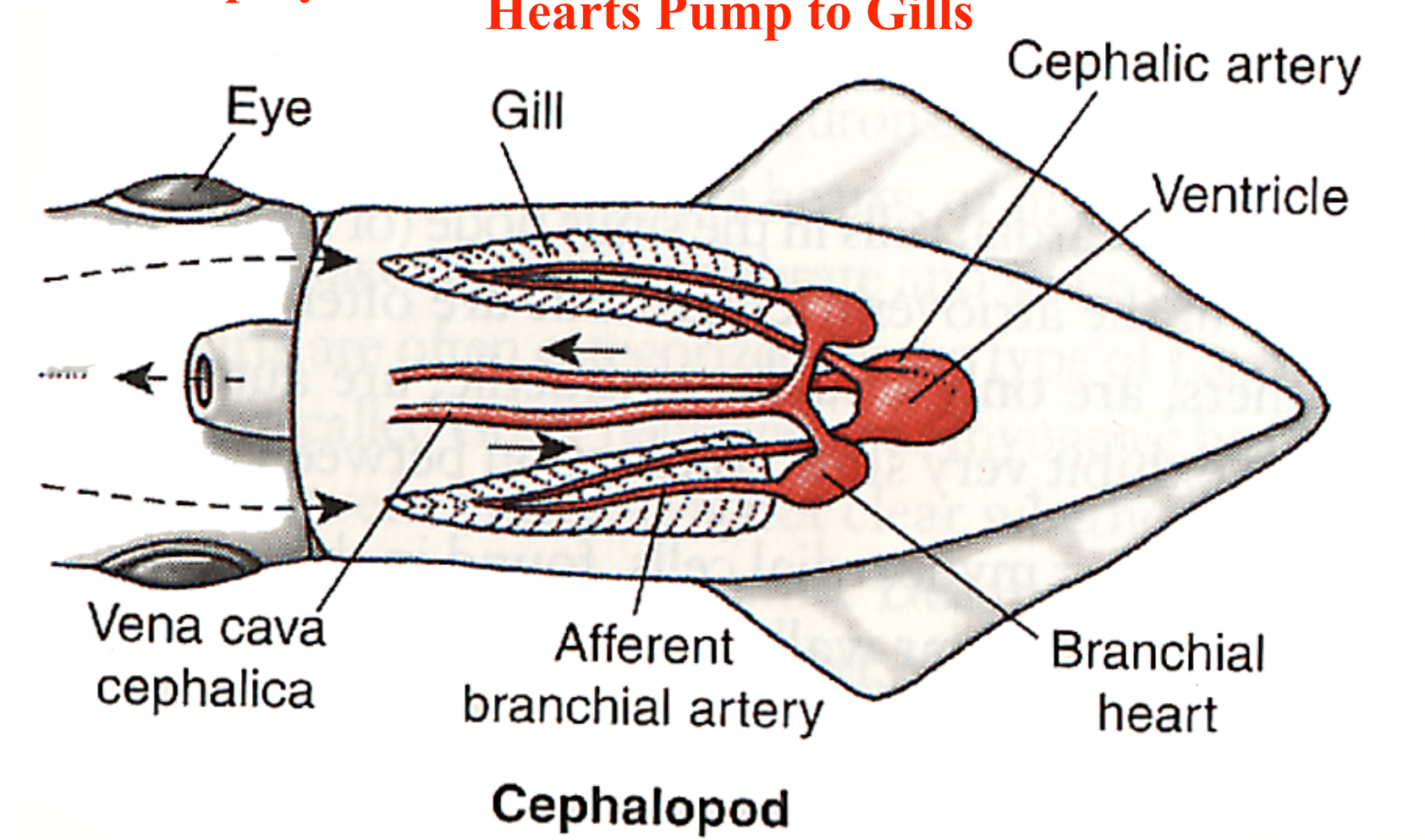
Herreid (1977)

2

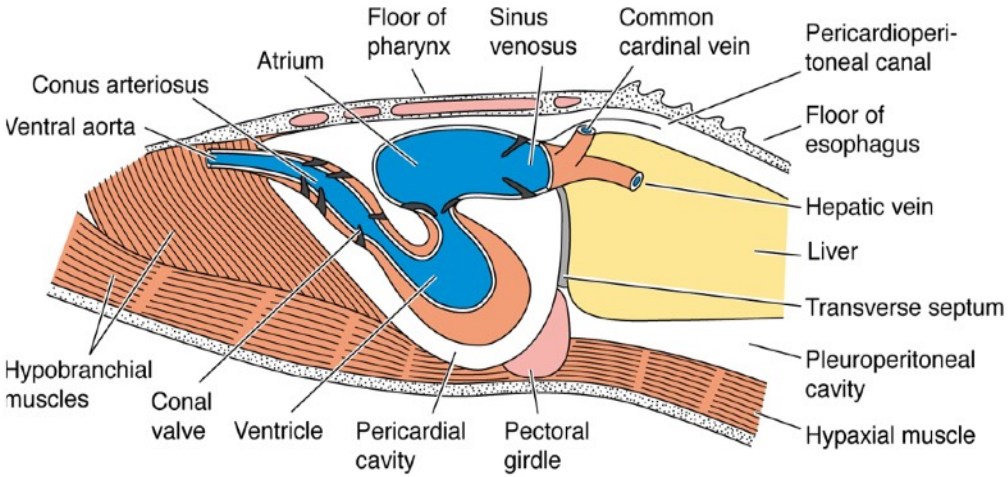
Cephalopod Circuit

Double Pump System

Heart Pumps to Body
Hearts Pump to Gills

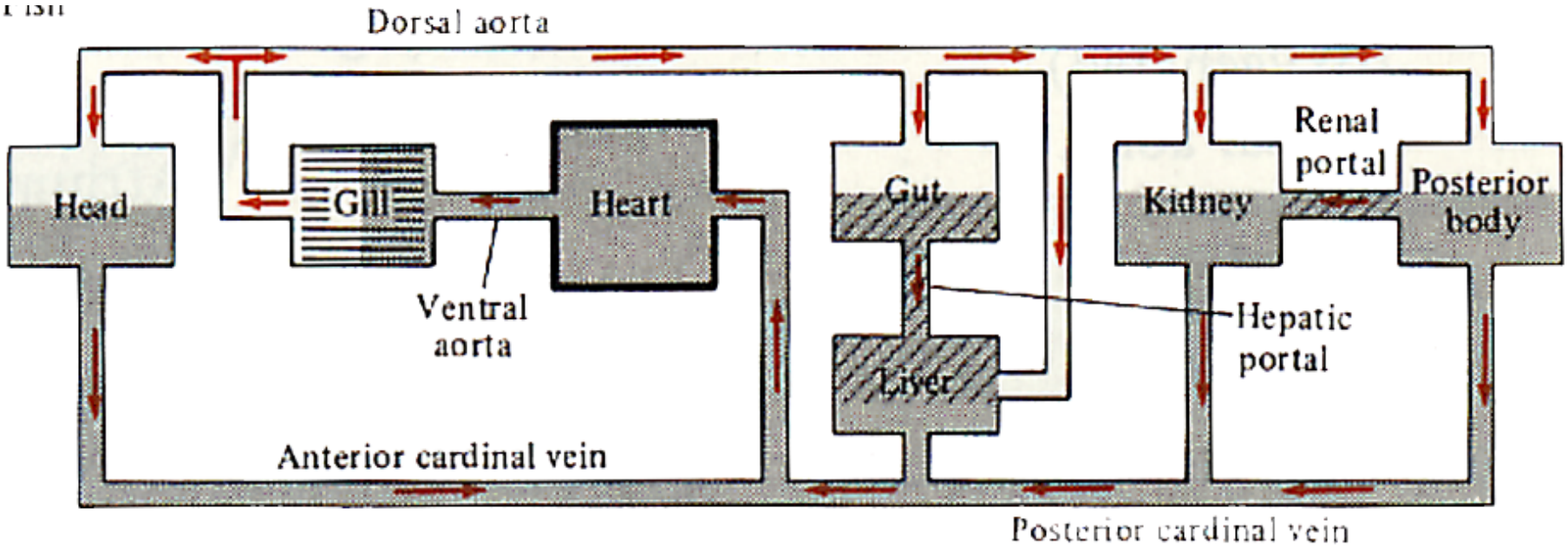


Chambered Heart - Fish



Four chambers in series

Unidirectional flow maintained by valves



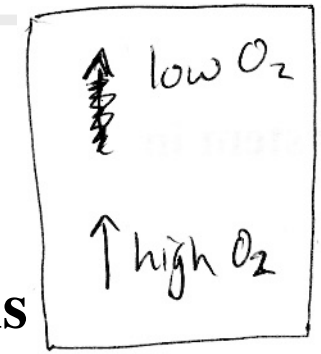
Heart pumps through two resistances

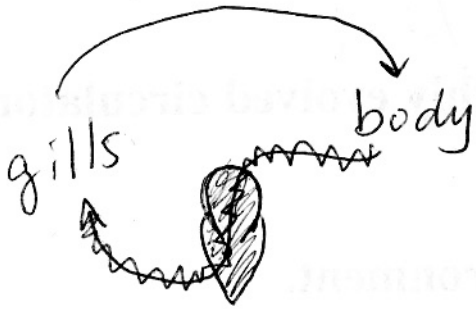
5

Pumps and Circuits - General Plan

Fishes

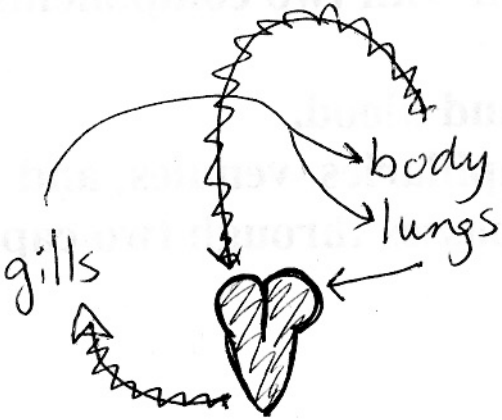
<u>Single-circuit pump</u>





Gill-breathing amphibians

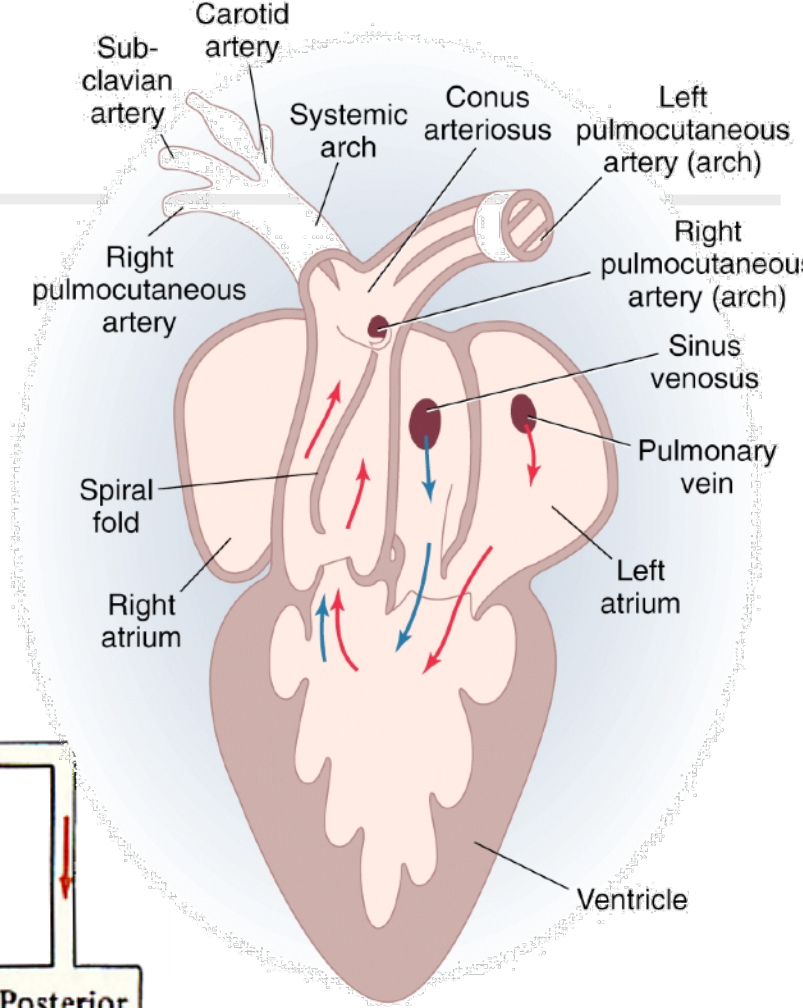
<u>Intermediate</u>



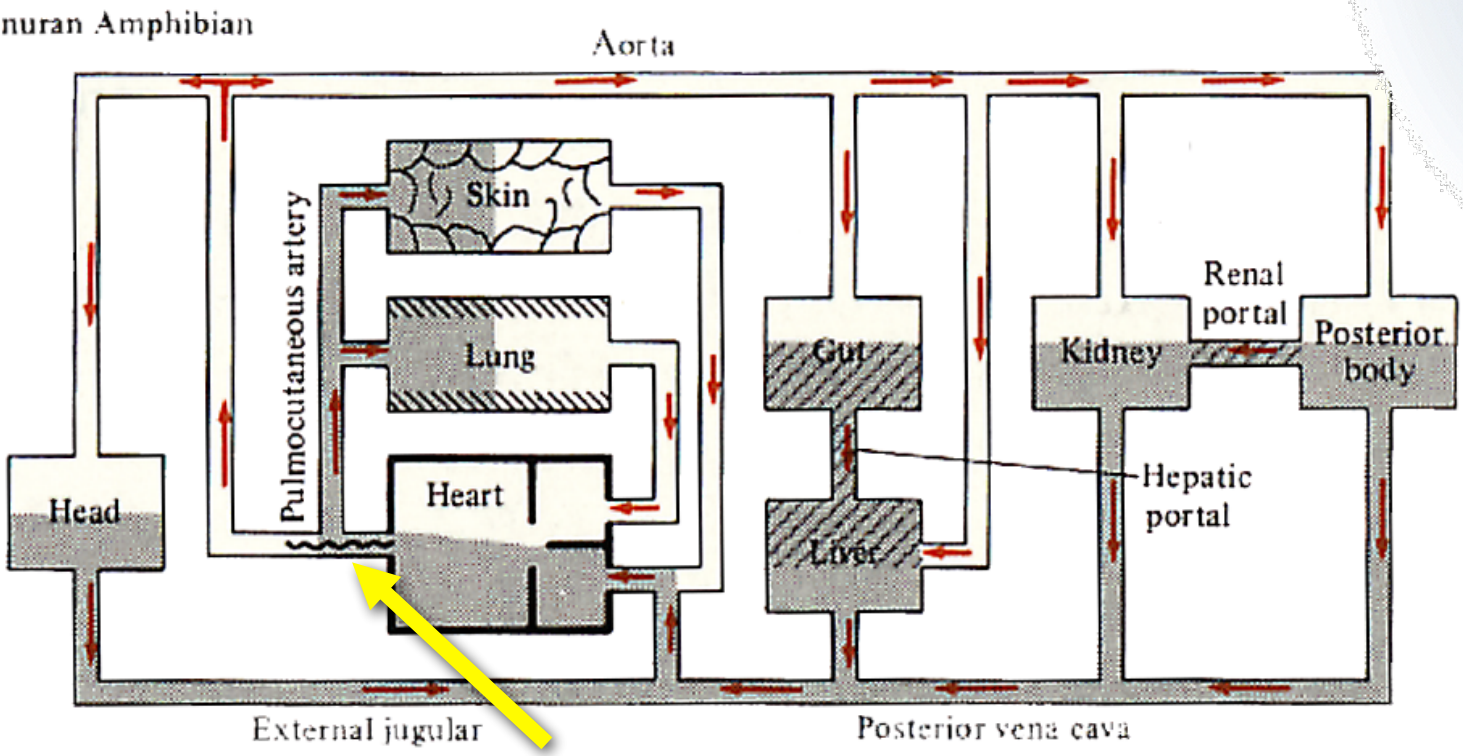
partial double circuit, some mixing of low O2, high CO2 blood.

But some separation of blood streams via timing and direction to right/left atrium.

Frog Heart



Atria completely subdivided with a single ventricle



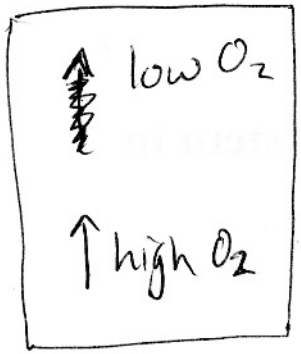
Spiral fold, partial separation via timing

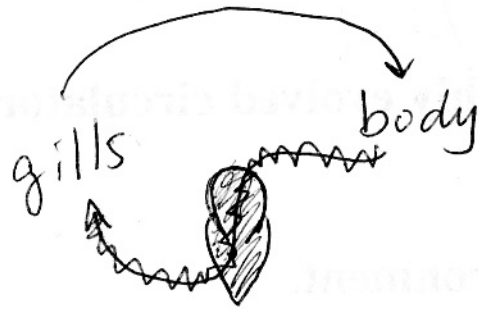
6

Pumps and Circuits - General Plan

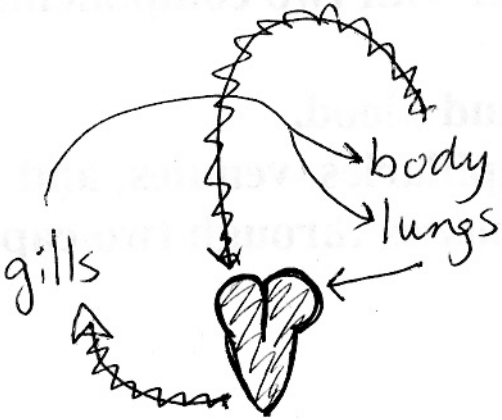
Fishes

<u>Single-circuit pump</u>





Gill-breathing amphibians

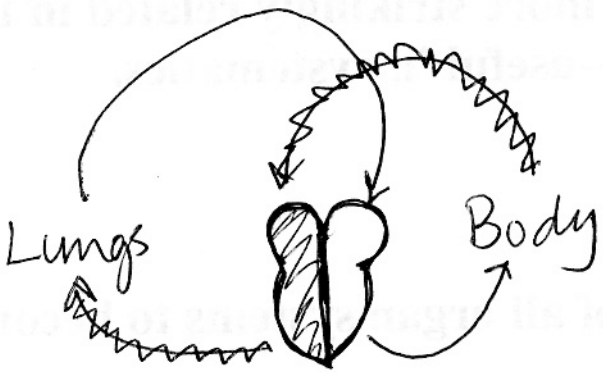


<u>Intermediate</u>

partial double circuit, some mixing of low O2, high CO2 blood.

But some separation of blood streams via timing and direction to right/left atrium.

Amniotes



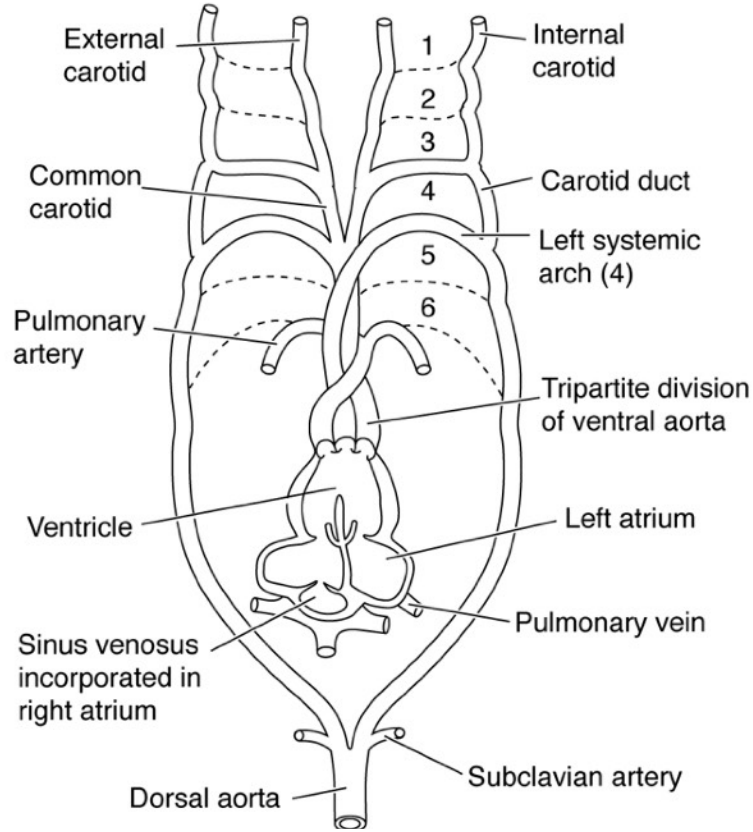
<u>Double-circuit pump</u>

lizards and turtles intermediate, but more separation of blood flow than amphibians

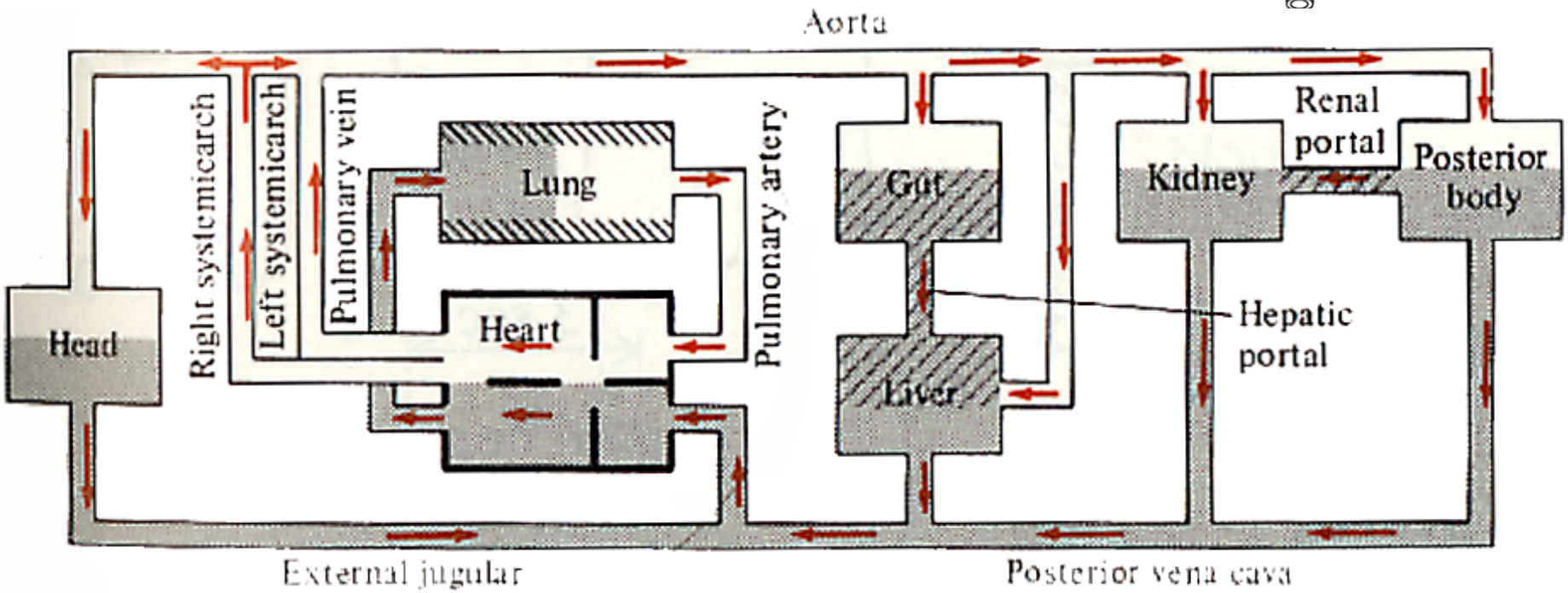
crocodiles - complete separation but have shunting (also lizards, turtles and amphibians)

mammals and birds -- complete separation, fully double circuit, no shunting

Lizard Heart

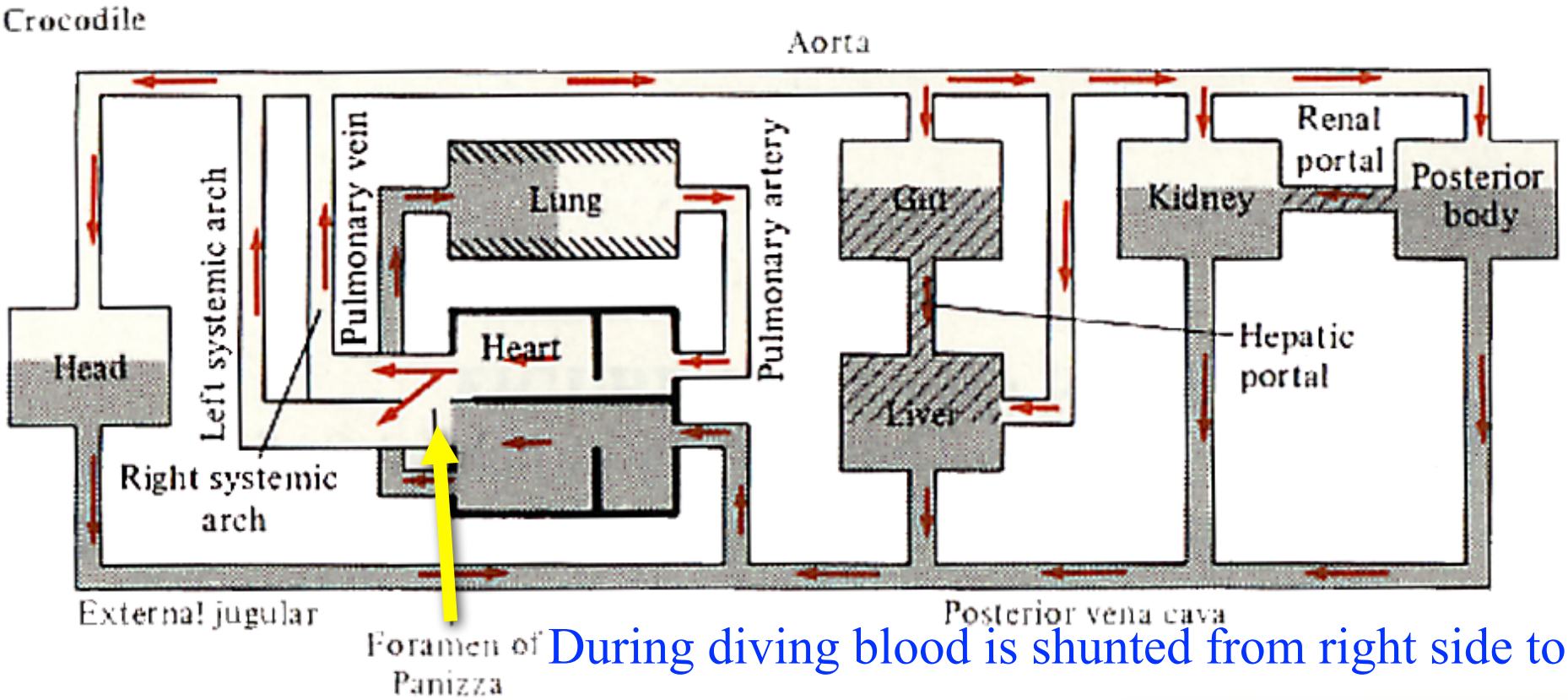


Partially divided ventricle



Crocodile Heart

Completely divided ventricle

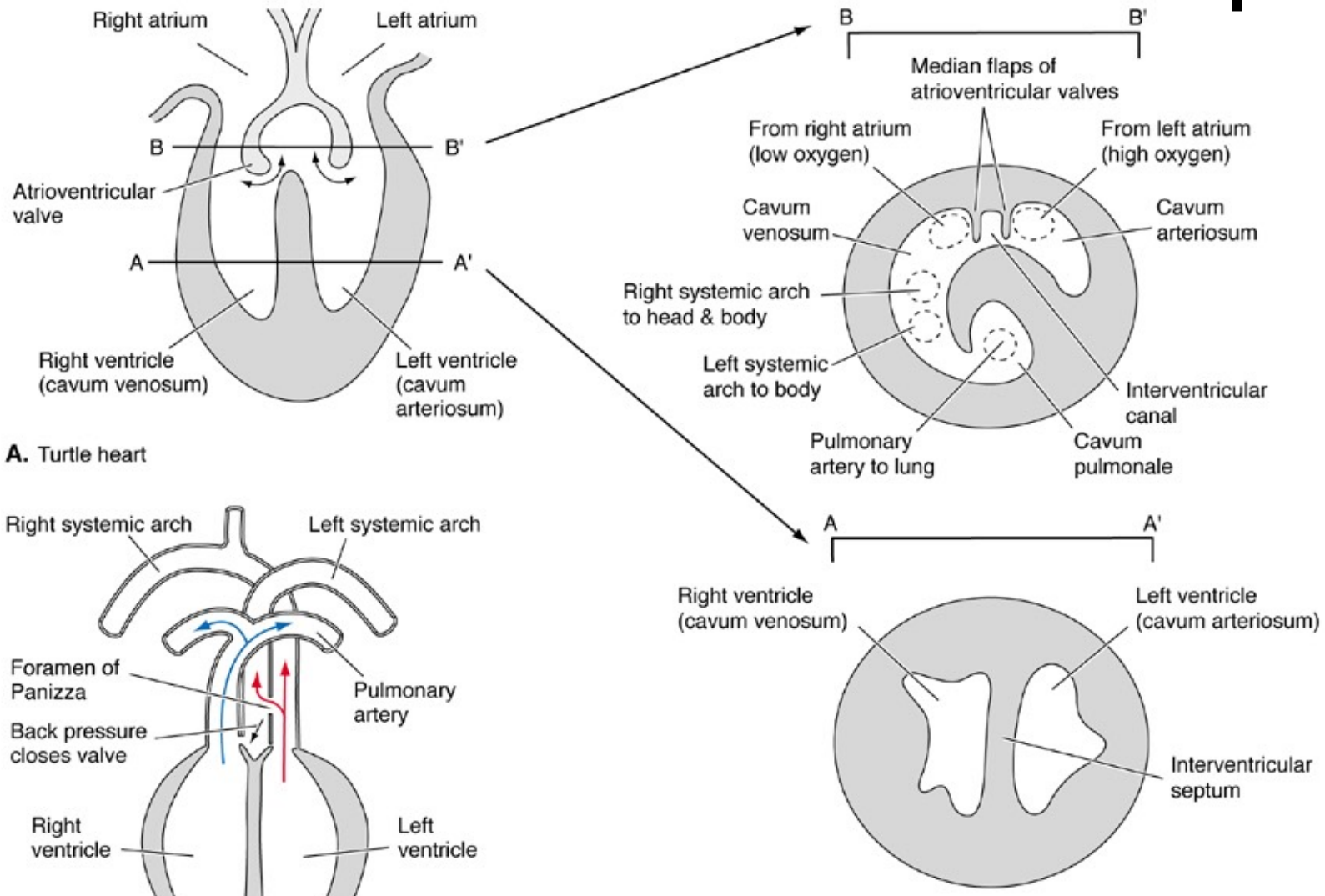


During diving blood is shunted from right side to left

Deoxygenated blood doesn't return to lungs, keeps circulating and getting lower in pO_2, and more acidified

8

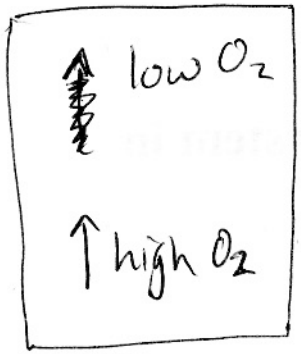
Turtle and Crocodile Hearts Compared

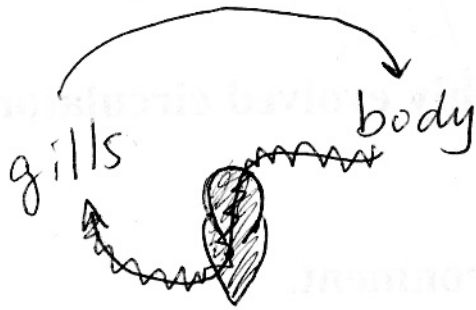


Pumps and Circuits - General Plan

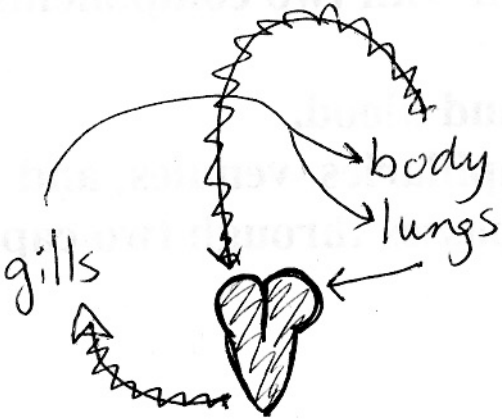
Fishes

<u>Single-circuit pump</u>





Gill-breathing amphibians



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partial double circuit, some mixing of low O2, high CO2 blood.

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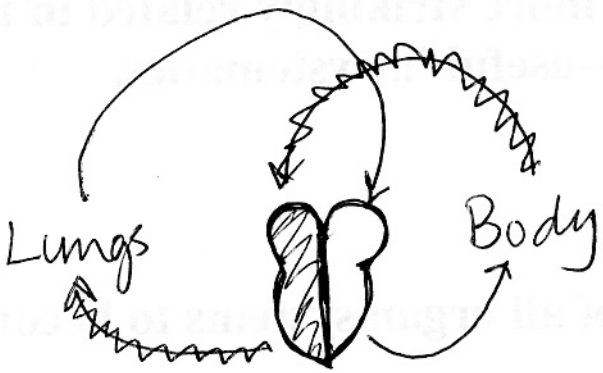
Amniotes



<u>Double-circuit pump</u>

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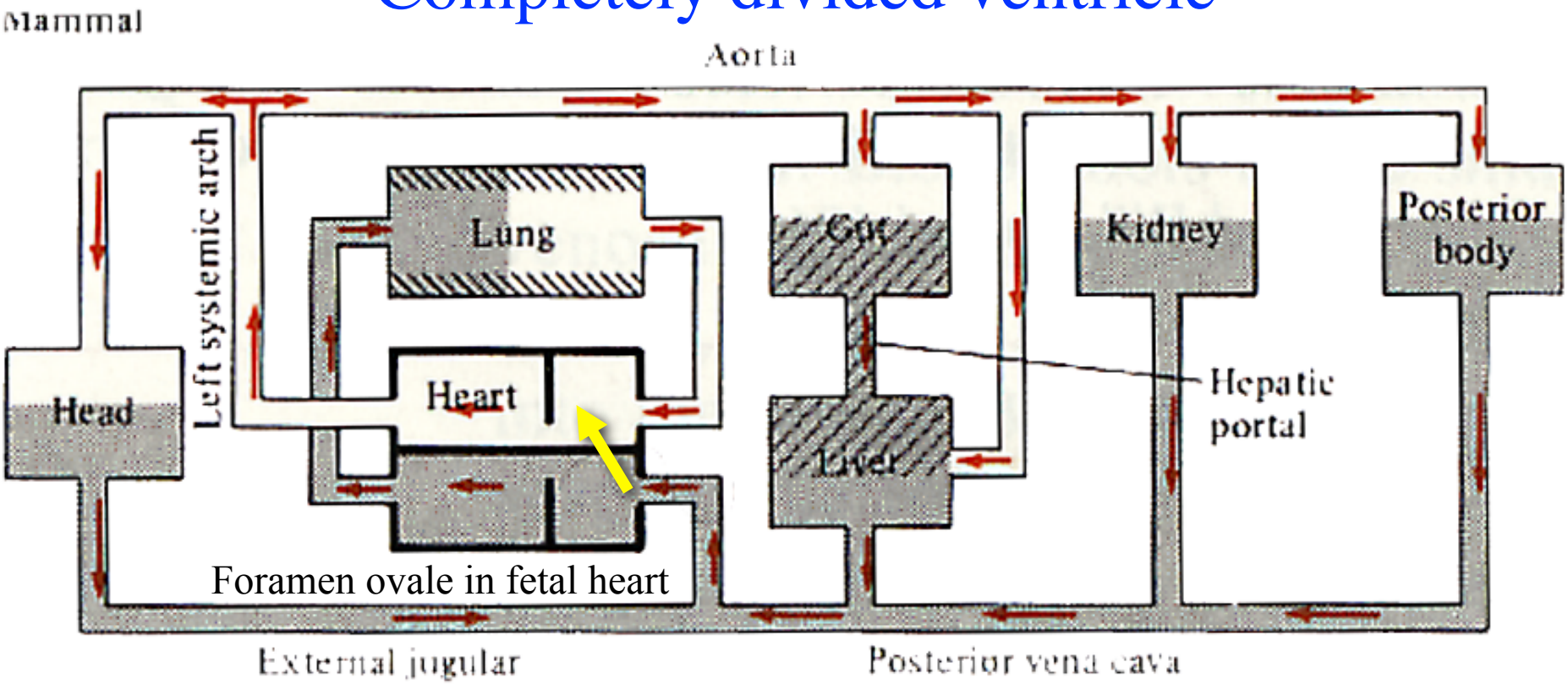
Mammalian Heart

Completely divided ventricle

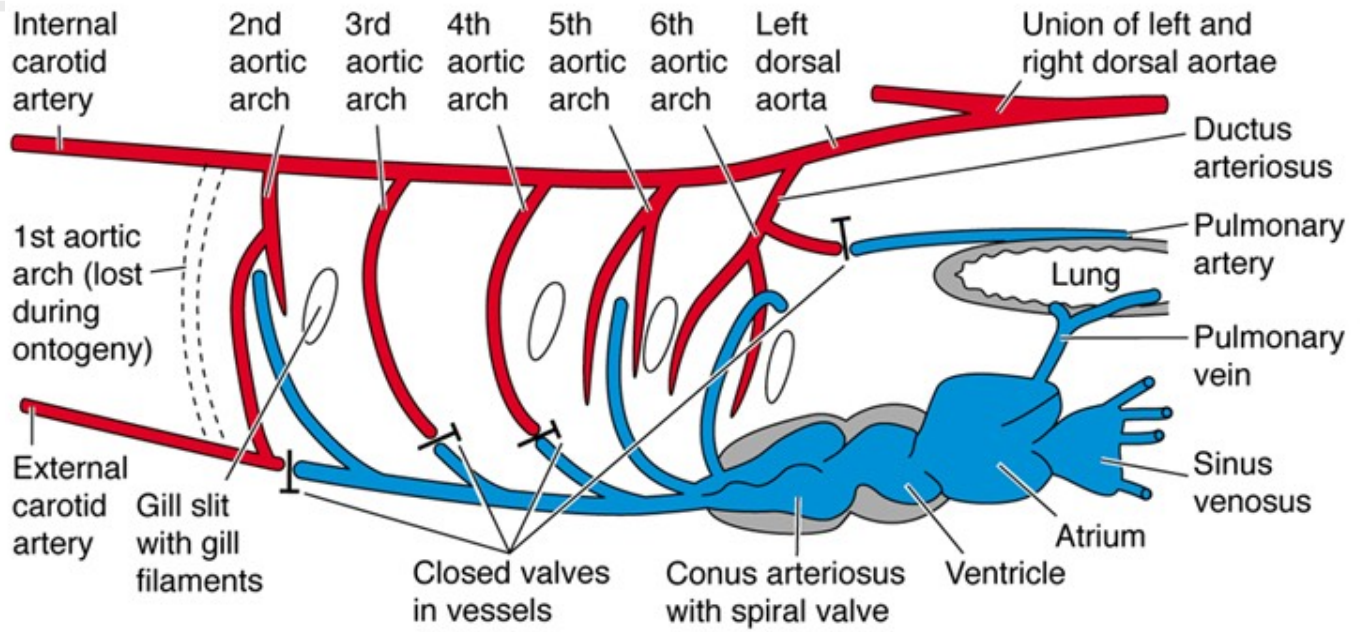


Double pump system - systemic (body) and pulmonary (lung)

African Lungfish Gill & Lung Breathing

Aquatic Breathing

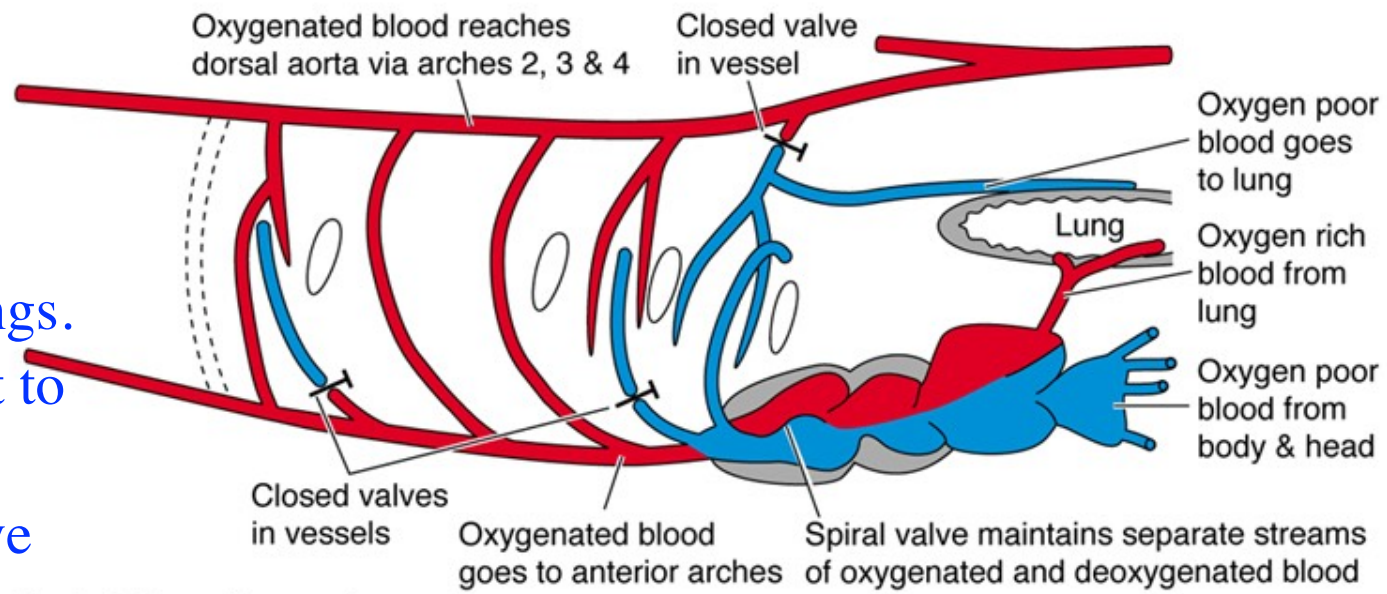
valves to lungs, arch 1,3,4 shut -- blood forced through gills



A. Aquatic breathing mode

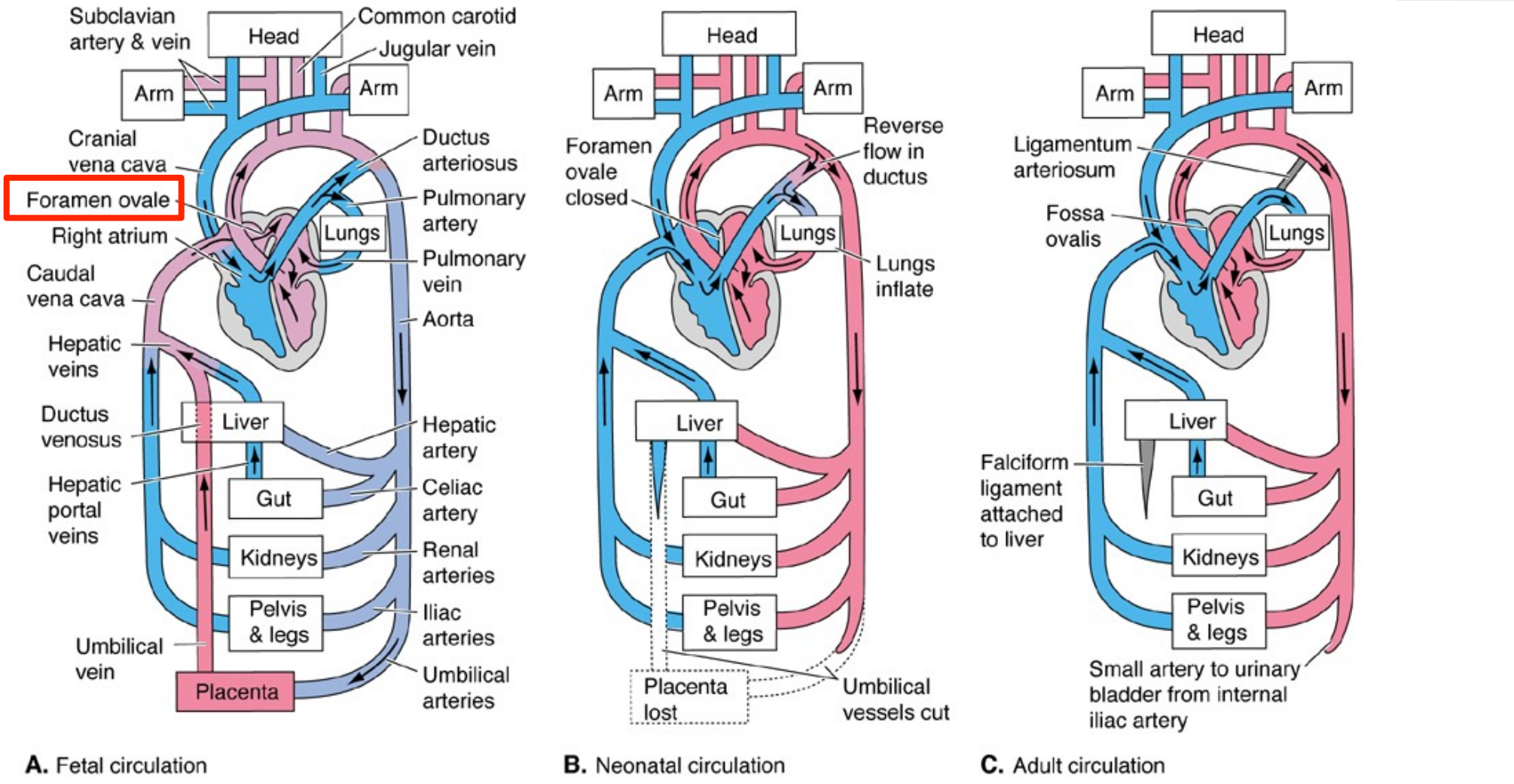
Terrestrial Breathing

valves to aortic arch 2,5 shut directing de-oxygenated blood to lungs. Returns to hear and sent to rest of body. Blood separated via spiral valve



B. Aerial breathing mode

Changes in mammalian circulation at birth.



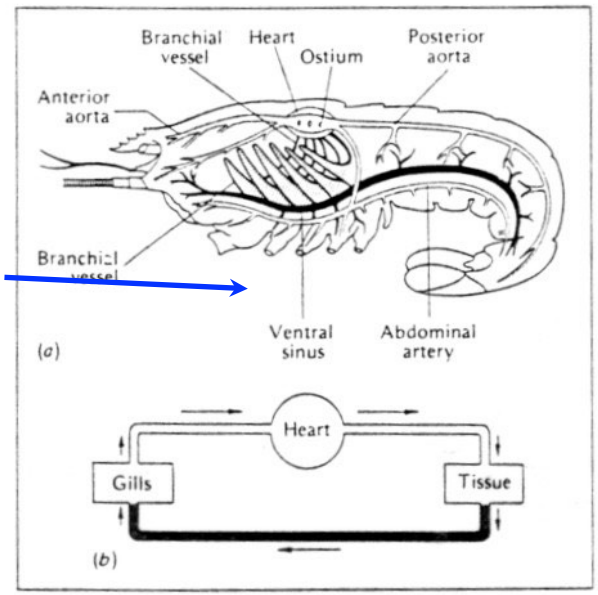
Fetal: O2 from mom, lungs not functional. Foramen ovale is open, blood mixes.

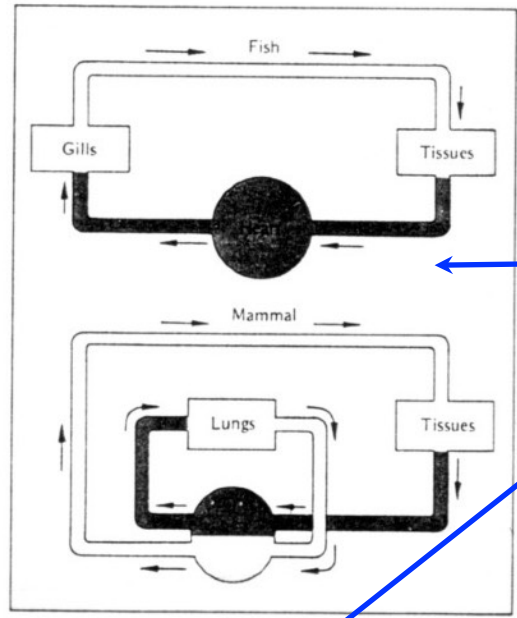
Neonatal: foramen ovale closed, blood directed through lungs, but some reverse flow (mixing) through ductus arteriosus.

Adult: shortly thereafter, ductus arteriosus closes, circulation fully unidirectional through lungs

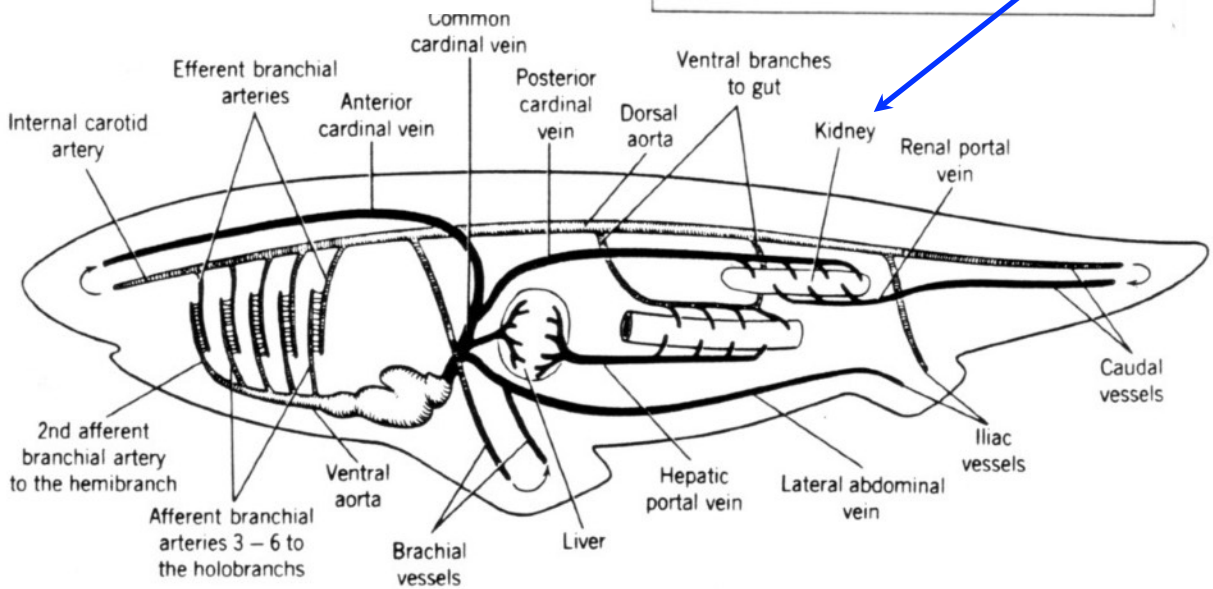
Odd consequences of Design

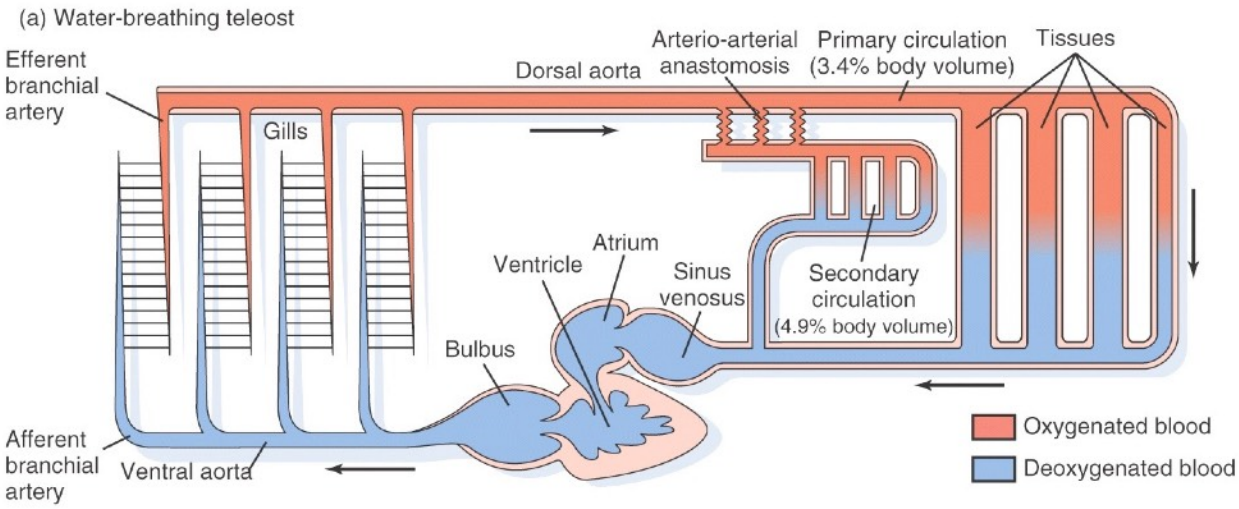
Good design

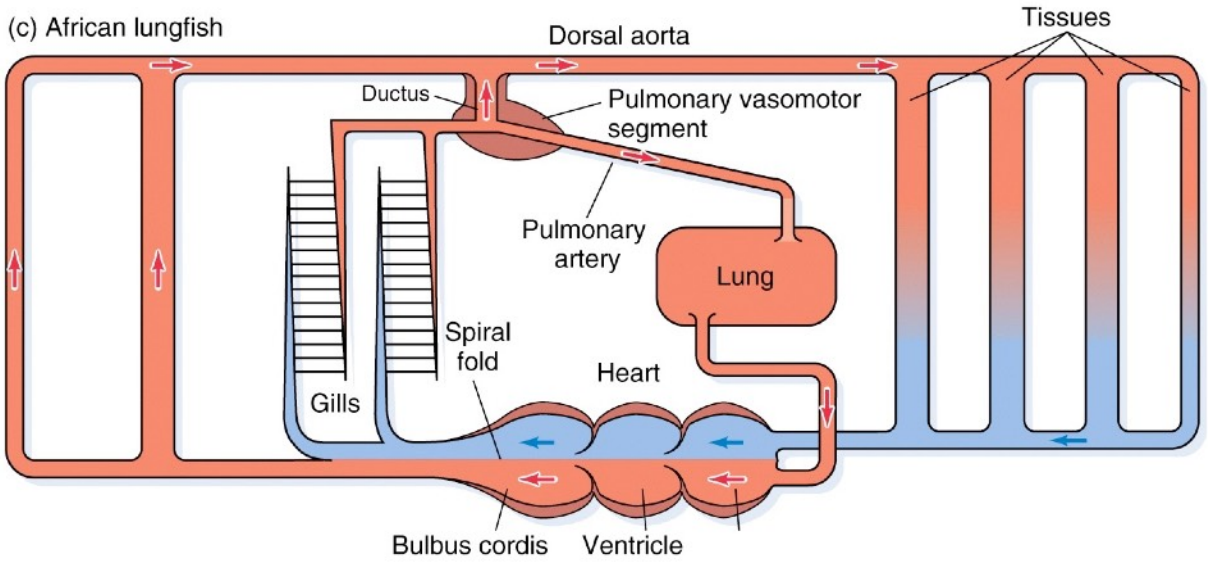




Remarkably bad design







Controversy -

Did lungs evolve so fish could live in hypoxic water?

or

Did lungs evolve to provide O_2 to the heart, allowing increased activity metabolism?

Coronary circulation is most highly developed in birds and mammals.