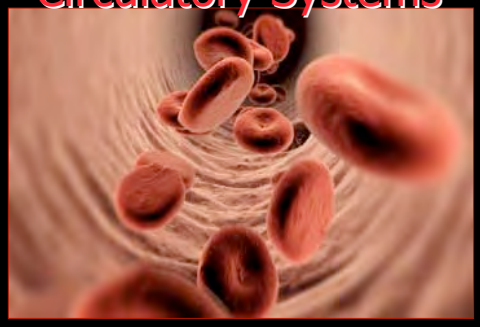
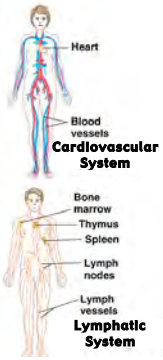
Circulatory Systems



Circulatory Systems

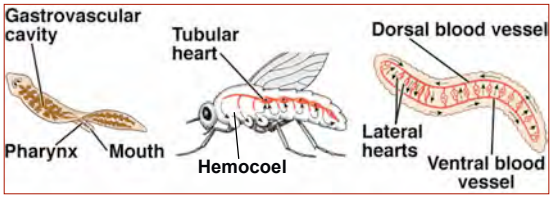
Functions:

- Transportation
  - Water & electrolytes (salts)
  - Dissolved gases— O_2 & CO_2
  - Nutrients
  - Wastes
  - Chemical messengers (hormones)
  - Defense (immune) systems
  - Repair (clotting) factors
- Thermoregulation
- Hydraulics



Circulatory Systems

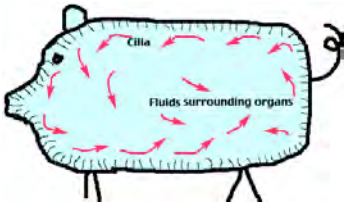
- Ciliated Body Cavity
- Open Circulatory System
- Closed Circulatory System



Size & System Development

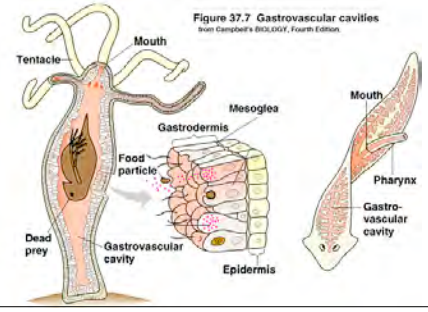
- Diffusion is sufficient for small organisms w/ low volumes & metabolic demands (e.g. protozoans and micrometazoans).

Ciliated Body Cavity



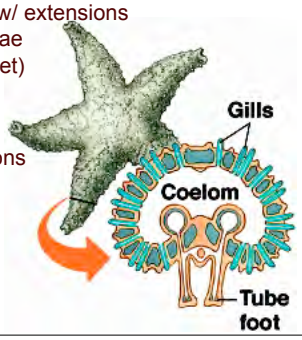
Cnidarians & Platyhelmintheans

- **gastrovascular system**
  - ciliated digestive cavity w/ branching extensions.



Echinoderms

- **water vascular system**
  - ciliated coelom w/ extensions (dermal branchae & tube feet) for respiration.
  - Important hydraulic functions

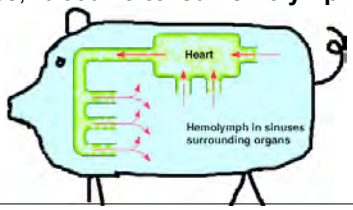


Vascular System Components

- Four components are
  - –1) circulatory fluids
  - –2) vessels
  - –3) pump
  - –4) valves
- Vasculature (vessels) may form **open** or **closed** circulatory system

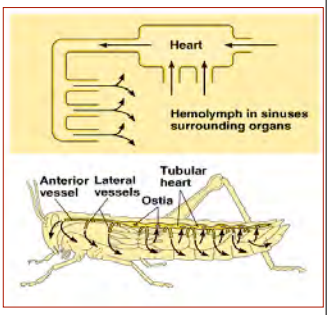
Open Circulatory Systems

- In arthropods & most molluscs.
- 4-part system - *what are those parts?*
- circulatory fluids mix w/ interstial fluids of body cavity.
- Hence, "blood" is called **hemolymph**.



Open Circulatory Systems

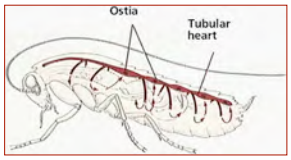
- **Dorsal heart** pumps **hemolymph** out vessels into body cavity (= **hemocoel**)
- Hemocoel partially compartmentalized into sinuses
- Hemolymph returns to heart via **ostia** or veins.

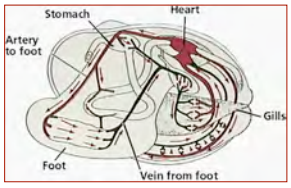


Open Circulatory Systems

Dorsal Vessel as Pump

- Whole dorsal vessel may act as a tubular heart
  - Insects
- Specific region specialized into a heart
  - Crustaceans & Molluscs
  - Hemolymph pulled from hemocoel by veins to gills to heart to arteries to hemocoel



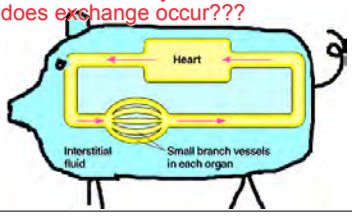


Limitations of Open Systems

- Difficult to regulate different perfusion of different tissues.
- Great for small body plans; not so great for big bodies with variable metabolic activities.
- *How can it be enhanced for large bodies?*

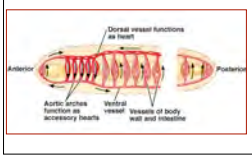
Closed Circulatory Systems

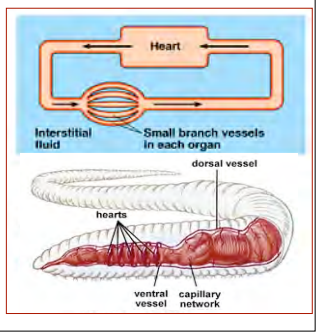
- Complete circuit between heart, arteries & veins with capillaries.
- Better circulation + better regional control
  - higher activity levels.
- **Problem**: if circulatory fluid is confined to vessels, how does exchange occur???



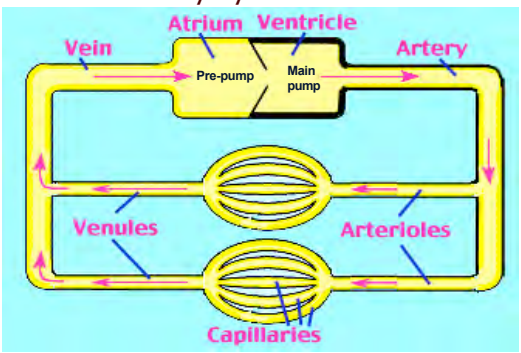
Closed Circulatory Systems

- Cephalopod molluscs have 3 hearts — one to each gill and one for the body.
- Annelid worms use dorsal vessel plus anterior lateral branches as heart.





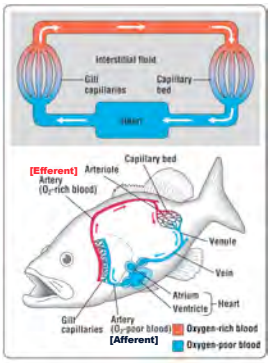
Closed Circulatory Systems in **Vertebrates**



- **Cardiovascular system**

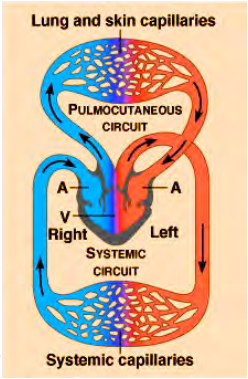
Closed Circulatory Systems in **Vertebrates**

- Heart is from *ventral* vessel, not dorsal vessel.
- **Fish**
  - **2-chambered heart**
  - **Single circuit**: blood flows from heart to gills, and then to systemic vessels
  - Blood pressure drops when flowing through the gill capillary beds.
  - Muscle contraction during swimming accelerates blood flow in the vessels.



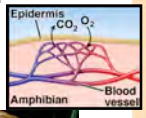
Closed Circulatory Systems in **Vertebrates**

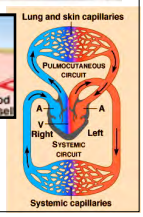
- **Amphibians & (Most) Reptiles**
  - **3-chambered heart**
    - 2 atria/1 ventricle
  - **Double circuit**:
    - 1a. (amphibians) Pulmocutaneous circuit: blood flows from heart to lungs & skin
    - 1b. (reptiles) Pulmonary circuit: blood flows from heart to lungs only
    - 2. Systemic circuit: repressurized blood flows from heart to systemic vessels
  - ~10% mixing of deoxygenated + oxygenated blood in single ventricle



Closed Circulatory Systems in **Vertebrates**

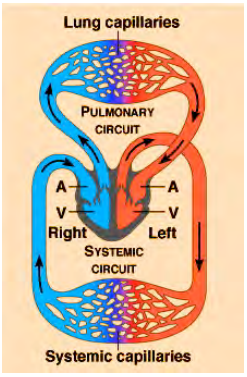
- **Amphibians & (Most) Reptiles**
  - **3-chambered heart**
    - 2 atria/1 ventricle
  - **Double circuit**:
    - Pulmocutaneous circuit: blood flows from heart to lungs & skin
    - **Cutaneous exchange may include skin, throat, and/or gills (in larvae & neotenes)**
    - **Pulmonary flow may be diverted to cutaneous while underwater**





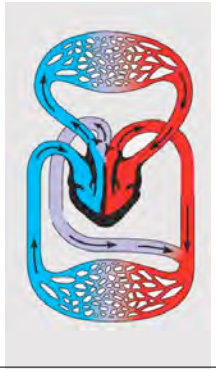
Closed Circulatory Systems in **Vertebrates**

- **Crocodilians, Birds & Mammals**
  - **4-chambered heart**
    - 2 atria/2 ventricles
  - **Double circuit**:
    - 1. Pulmonary circuit: blood flows from heart to lungs only
    - 2. Systemic circuit: repressurized blood flows from heart to systemic vessels
  - No mixing of deoxygenated + oxygenated blood
  - Pulmonary & systemic circuits are pressurized differently
  - >10x more efficient systemic oxygenation

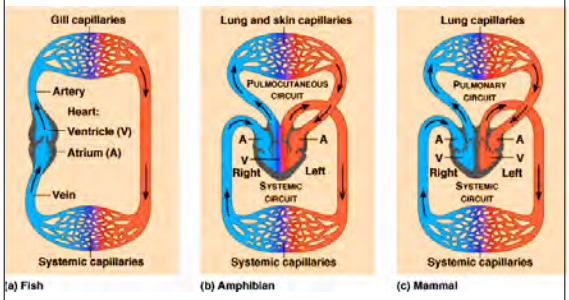


Closed Circulatory Systems in **Vertebrates**

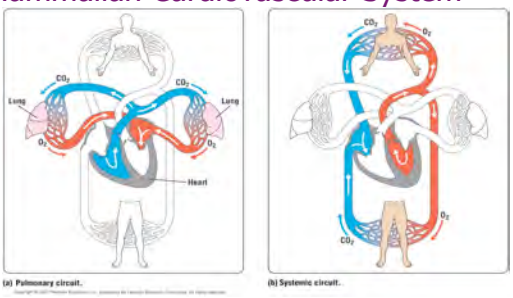
- **Crocodilians**
  - **4-chambered heart**
    - 2 atria/2 ventricles
  - **Double circuit**:
    - 1. Pulmonary circuit: blood flows from heart to lungs only
    - 2. Systemic circuit: repressurized blood flows from heart to systemic vessels
  - Shunt to divert pulmonary to systemic flow when underwater



Review of Designs

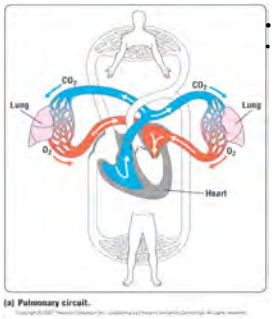


Mammalian Cardiovascular System



- **Two circuits, each with its own 2-chamber pump**
  - **Different pressure**
  - **Same flow rate**

Mammalian Cardiovascular System



- **Pulmonary circuit:**
- **Right pump → lungs → left pump**
  - Deoxygenated systemic blood fills right A&V
  - Right A&V contract pushing deoxygenated blood through pulmonary artery to lungs
    - Release CO_2
    - Take up O_2
  - Oxygenated blood from lungs flows through pulmonary veins to left atrium

Mammalian Cardiovascular System

- **Systemic circuit:**
- **Left pump → body → right pump**
  - Oxygenated pulmonary blood fills left A&V
  - Left A&V contract pushing oxygenated blood through aorta to branching major arteries to all other body organs
    - Release O_2
    - Take up CO_2
  - Deoxygenated blood from body tissues flows through branches of veins converging on vena cava to right atrium

The Pump

- For any pump to function, it needs two components:

1. Constriction (stroke) chamber

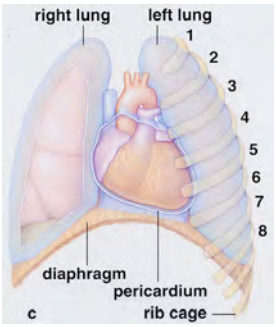
chamber volume ↑pressure
move fluid

2. Valves

direct fluid flow direction

Human Heart Anatomy

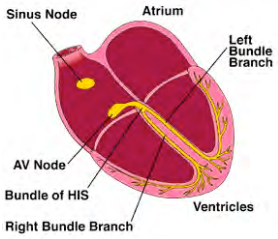
- Diagrams show heart from front
  - Viewer's "right" is heart's "left"
- Enclosed in fluid-filled sac behind sternum



Human heart in chest cavity

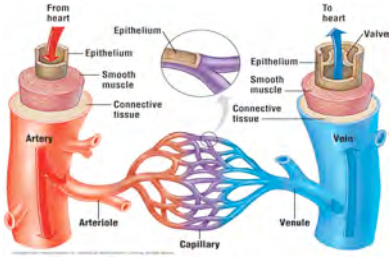
Cardiac Contractions

1. Sinus node (pacemaker) fires
2. Signal spreads across atria
3. Cardiac muscle in atria contract
4. Signal reaches AV node; travels down Bundle of HIS to apex of heart
5. Signal spreads across venticles
6. Cardiac muscle in venticles contract



The Vessels

- **Arteries** – carry blood away from the heart
- **Arterioles** – smaller branches of arteries
- **Capillaries** – thin, microscopic, with porous walls
- **Venules** – smaller branches that converge into veins
- **Veins** – carry blood back to heart



Vessel Structure & Function

- **Arteries:** blood away from heart
  - Thick-walled and elastic to withstand higher pressure
  - Smooth muscle in **arteriole** walls regulate selective blood flow
- **Veins:** blood toward heart
  - Thin, compliant walls
  - Internal valves prevent backflow
- **Capillaries:** thin-walled and highly branched
  - **Only vessels exchanging with tissue fluids!**
  - Walls only 1 cell thick to maximize diffusion rates
  - Not permeable to blood cells & proteins; permeable to water and other solutes

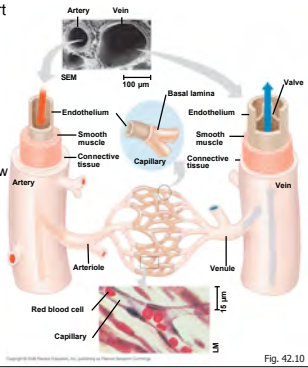


Fig. 42.10

Poisseuille's Law

The Hagen-Poiseuille Equation:

- **Flow rate = $Q = (\Delta P_p)(\pi r^4)/(8L\eta)$**

where

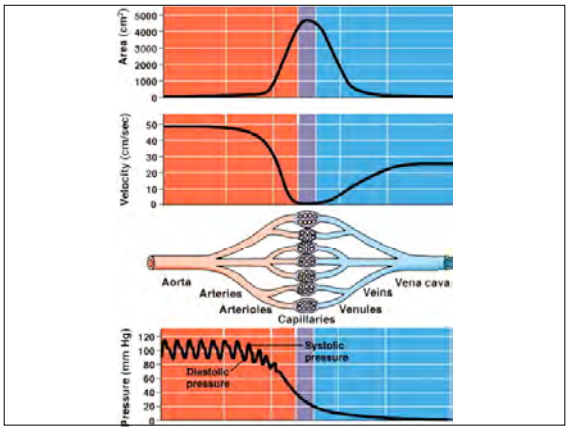
ΔP_p = pressure difference

- r = radius

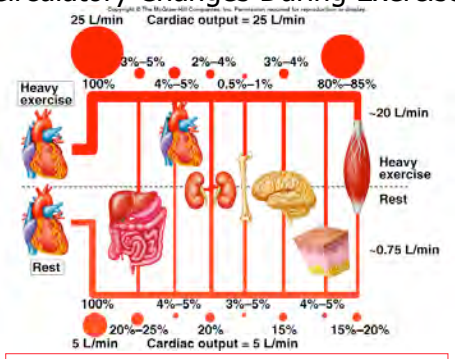
η = fluid viscosity

L = length of tube

- NOTE: Q proportional with r^4 !



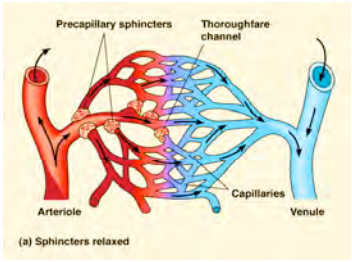
Circulatory Changes During Exercise



Selective flow regulated by dilating & constricting specific arterioles

Capillary beds — the sites for exchange

- In addition to regulation by vasodilation/vasoconstriction of arterioles, localized perfusion regulated by pre-capillary sphincters
- Only 5–10% of capillaries open at a given time



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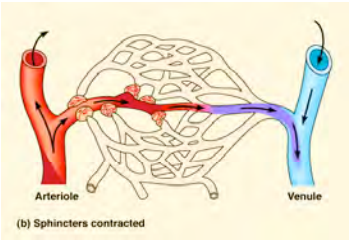
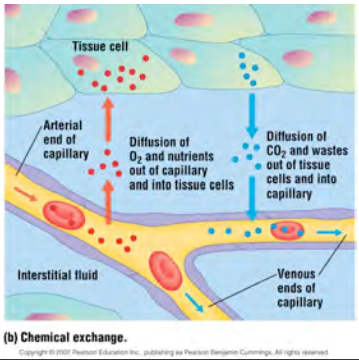


Capillary beds — the sites for exchange

Capillary filtration

- Walls only 1 cell thick to maximize diffusion rates
- Not permeable to blood cells & proteins
- Permeable to water and other solutes

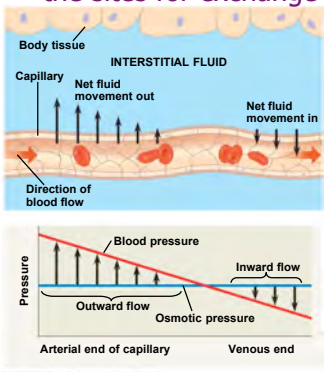


(b) Chemical exchange.

Capillary beds — the sites for exchange

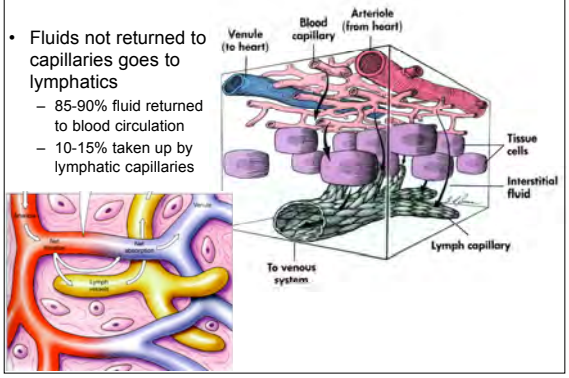
Capillary filtration

- Blood pressure (P_B) pushes fluid out
- Osmotic pressure (P_{Osm}) pulls fluid in
- At arteriole end of capillary: (P_B) > (P_{Osm})
- At venule end of capillary: (P_{Osm}) > (P_B)



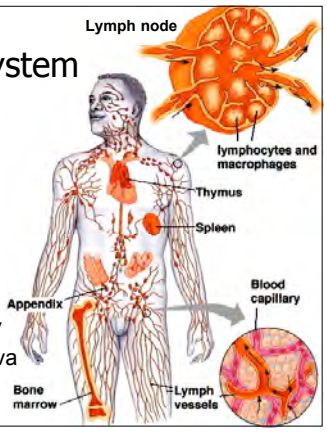
Capillary exchange

- Fluids not returned to capillaries goes to lymphatics
  - 85-90% fluid returned to blood circulation
  - 10-15% taken up by lymphatic capillaries



Lymphatic System

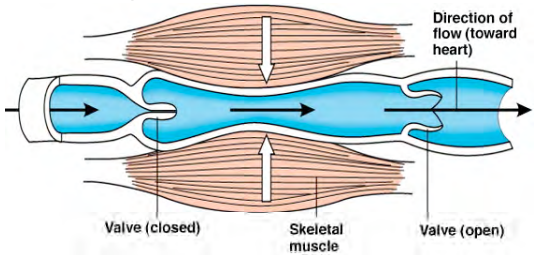
- Recaptures lost fluids & proteins
- Interstitial fluids filtered through lymphoid tissues and monitored by immune system
- Fluids return to CV system in vena cava



Fluid Flow in Veins

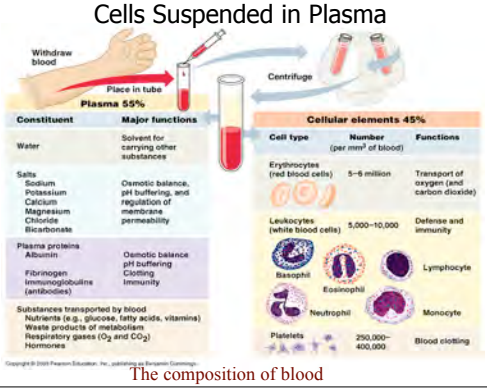
— both Cardiovascular & Lymphatic Systems

- Fluids pumped by "skeletal muscle pumps"
- Valves prevent backflow



Blood: Liquid Tissue

Cells Suspended in Plasma



The composition of blood

Blood Structure and Function

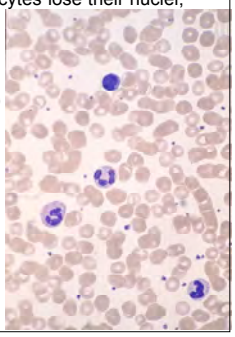
"Formed Elements" — cells and cell-derivatives

Since erythrocytes and thrombocytes lose their nuclei, they are no longer truly cells.

- Erythrocytes (red blood cells)
  - Carry oxygen
- Leukocytes (white blood cells)
  - Defense/clean up
- Thrombocytes (platelets)
  - Blood clotting

Plasma

- 90% H_2O
- 7–9% protein



Human blood smear

Clotting