Chapter 9

GAS EXCHANGE & CIRCULATION

MECHANISMS OF GAS EXCHANGE

Respiration

Taking up O_2 and giving up CO_2

MECHANISMS OF GAS EXCHANGE

- **Three phases of gas exchange**
  - **Breathing**
  - **Transport of oxygen and carbon dioxide in blood**
  - **Body tissues take up oxygen and release carbon dioxide in the process of Cellular respiration**
- **Cellular respiration (Glucose + $O_2 \rightarrow CO_2 + H_2O$) requires a continuous supply of oxygen and the disposal of carbon dioxide**

Animals exchange O_2 and CO_2 across respiratory surfaces

Respiratory Surface = the site of gas exchange

- **Respiratory surfaces must be thin and moist for diffusion of O_2 and CO_2**
- **Earthworms and other animals use their skin for gas exchange**
- **Most animals have specialized body parts that promote gas exchange called Respiratory Surface = the site of gas exchange include:**

1) **Skin Sponges, jellies and flatworms rely on the skin as their only respiratory surface**
2) **Gills in fish and amphibians**
3) **Tracheal systems in arthropods**
4) **Lungs in tetrapods that live on land, amphibians, reptiles, birds and mammals**

Lungs

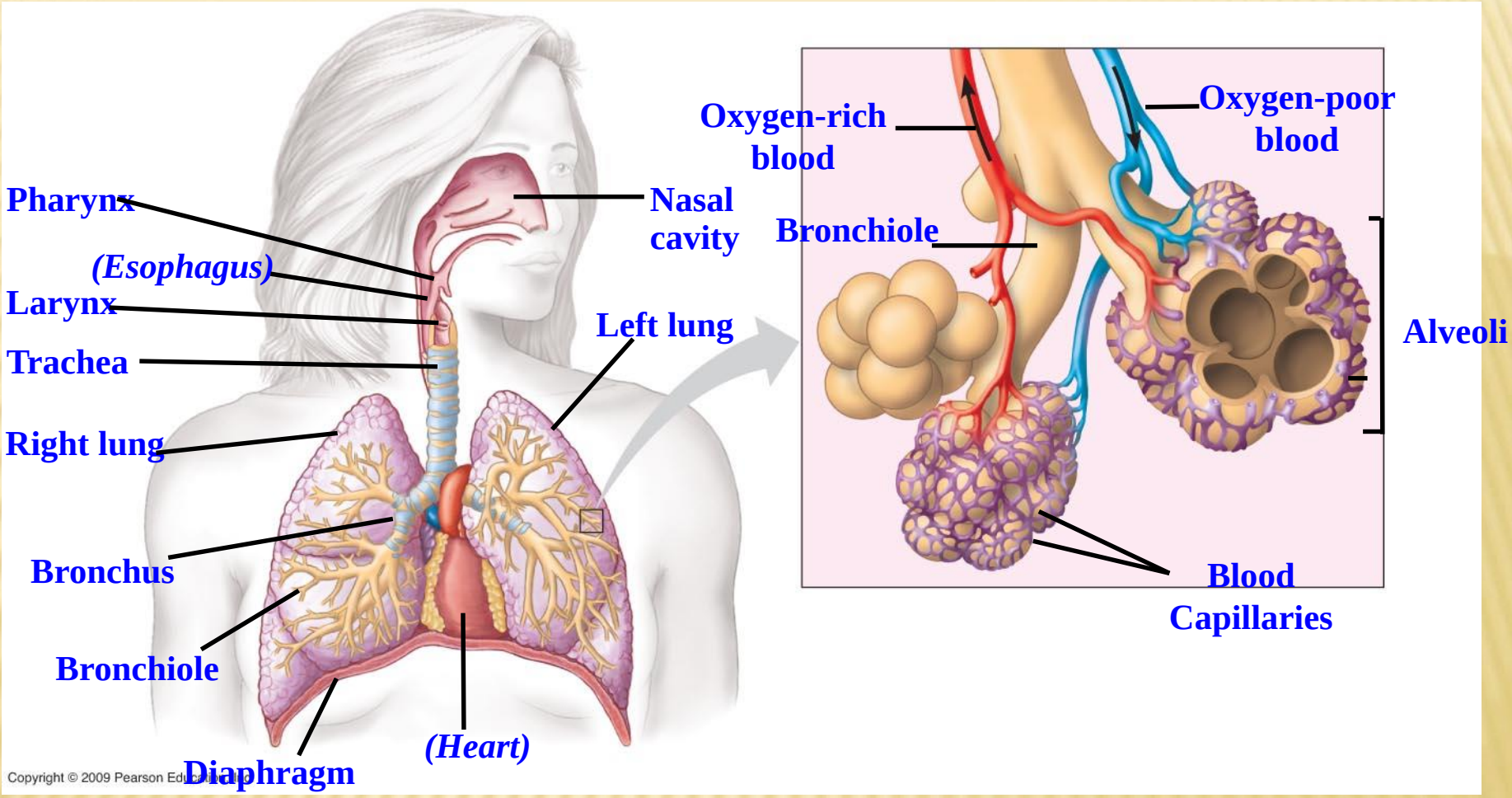
- **Tetrapods seem to have evolved in shallow water**
- **The first tetrapods on land diverged into three major lineages**
  - **Amphibians use small lungs and their body surfaces**
  - **Nonbird reptiles have lower metabolic rates and simpler lungs**
  - **Birds and mammals have higher metabolic rates and more complex lungs**

In the human respiratory system, branching tubes convey air to lungs located in the chest cavity

- **In mammals, air is inhaled through the nostrils into the nasal cavity**
  - **Air is filtered by hairs and mucus surfaces**
  - **Air is warmed and moisturized**
  - **Air is sampled for odors**

In the human respiratory system, branching tubes convey air to lungs located in the chest cavity

- **From the nasal cavity, air next passes**
  - **To the pharynx**
  - **Then larynx, past the vocal cords**
  - **Into the trachea (held open by cartilage crescent rings)**
  - **Into the paired bronchi**
  - **Into bronchioles**
  - **Bronchioles ends in a cluster of "bubbles" – the alveoli, grapelike clusters of air sacs, where gas exchange occurs**



The anatomy of the human respiratory system (left) and details of the structure of alveoli (right)

How alveoli are adapted for gas exchange ?

- **Alveoli are well adapted for gas exchange**
  - **Alveoli are surrounded by capillaries**
  - **This is the actual site of gas exchange**
  - **Huge surface area (100 m^2 in humans)**
- **In alveoli**
  - **O_2 diffuses into the blood**
  - **CO_2 diffuses out of the blood**

Mechanics of Breathing

Breathing is the alternate inhalation and exhalation of air (ventilation)

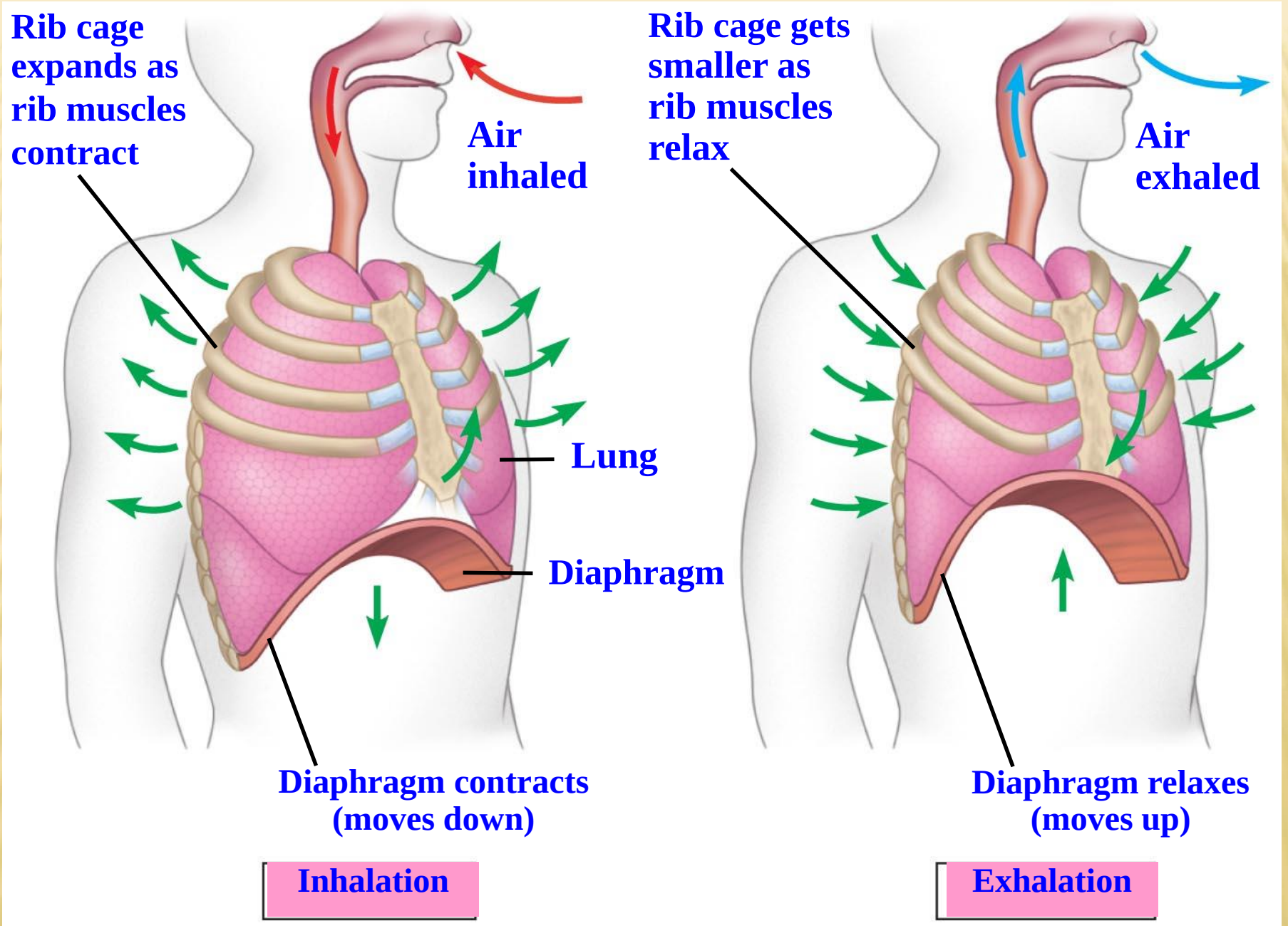
1) Inhalation occurs when

- **The rib cage expands (muscles between ribs contract and rib cage rises)**
- **The diaphragm moves downward**
- **The volume of the chest cavity increases, lowering the air pressure around lungs.**
- **Air rushes into lungs to equalize the pressure difference**
-

22.8 Negative pressure breathing ventilates our lungs

2) Exhalation occurs when

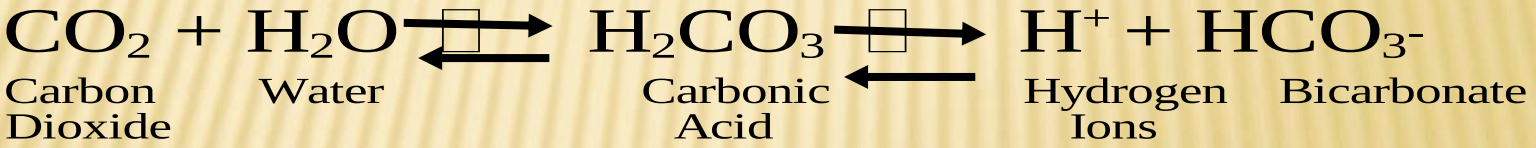
- The rib cage contracts
- The diaphragm moves upward
- The pressure around the lungs increases
- And air is forced out of the respiratory tract



Negative pressure breathing draws air into the lungs

Breathing is automatically controlled

- **Breathing is usually under automatic control.**
- **It is controlled by two centers at the base of the brain the pons and medulla oblongata**
- **Breathing control centers in the brain sense and respond to CO_2 levels in the blood**
- **A decrease in blood pH increases the rate and depth of breathing**



- **Aorta and carotid arteries have O_2 sensors which signal the brain to increase breathing**

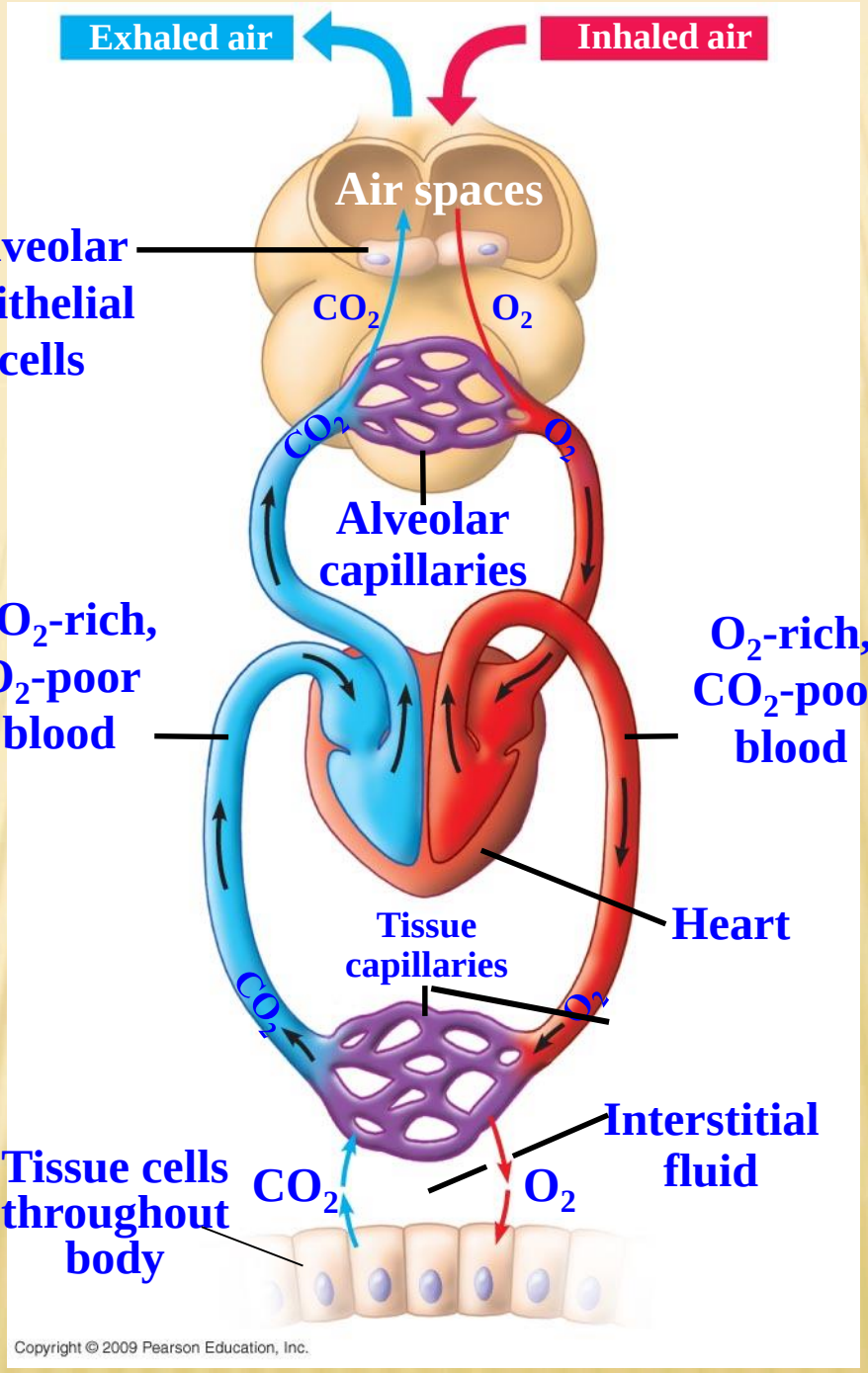
TRANSPORT OF GASES IN THE HUMAN BODY

Blood transports of respiratory gases

- In the lungs, blood picks up O_2 and drops off CO_2
- In the body tissues, blood drops off O_2 and picks up CO_2
- The heart pumps blood to two regions
  - The right side pumps oxygen-poor blood to the lungs
  - The left side pumps oxygen-rich blood to the body

Coordination of circulation and gas exchange

Gas transport and exchange in the body.



Blood transport of gases

- **Gases move from areas of higher concentration to areas of lower concentration**

Gases exchange between alveoli and blood

- **Gases in the alveoli have more O_2 and less CO_2 than gases the blood**
- **O_2 moves from the alveoli of the lungs into the blood**
- **CO_2 moves from the blood into the alveoli of the lungs**

Gases exchange between blood and tissues

- **The tissues have more CO2 and less O2 than in the blood**
- **CO2 moves from the tissues into the blood**
- **O2 moves from the blood into the tissues**

Blood transport of gases

1. Once the oxygen reaches the body cells, it is taken up by the mitochondria.

2. The mitochondria use oxygen to breakdown glucose into ATP. This is called cellular respiration

Oxygen transport

- Oxygen is not very soluble in water (blood)
- Oxygen transport and delivery are enhanced by binding of O_2 to respiratory pigments (hemoglobin in vertebrates)
- Binding is reversible

Respiratory pigments

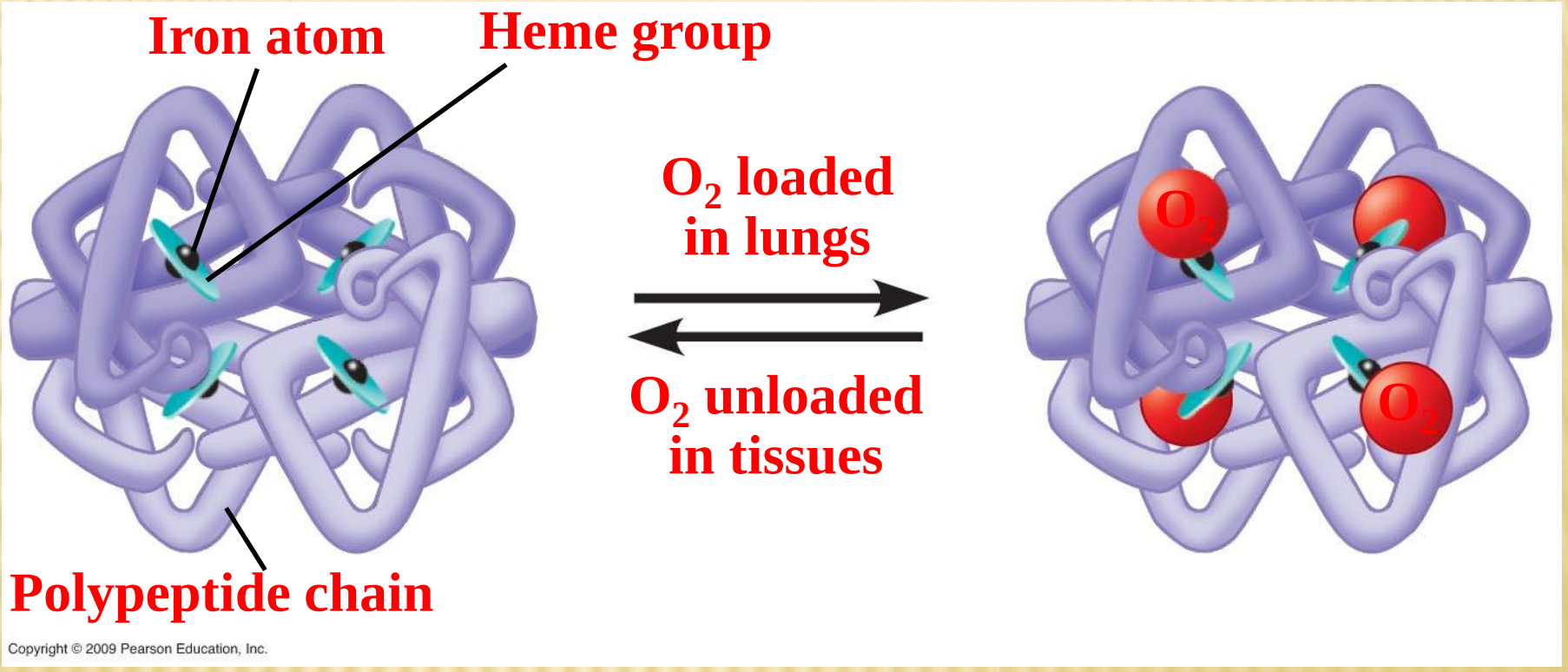
- **Most animals transport O_2 bound to proteins called respiratory pigments**

1) Copper-containing pigment (hemocyanin)

in Mollusca and Arthropods

2) Iron-containing pigment (hemoglobin)

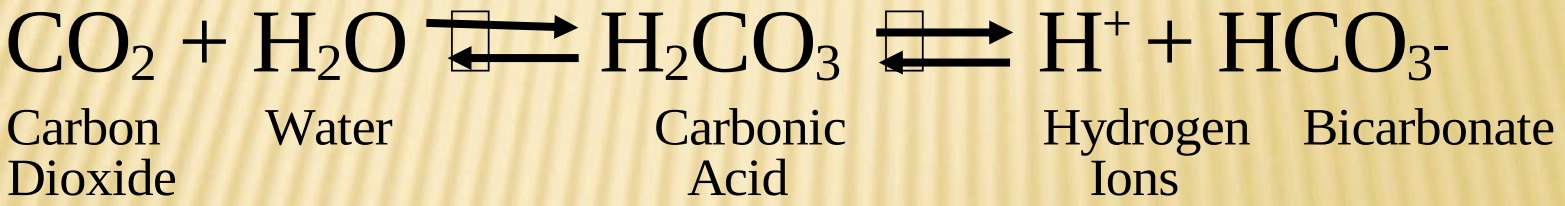
in almost all vertebrates and many invertebrates transports oxygen, buffers blood, and transports CO_2



Hemoglobin loading and unloading of O_2

Carbon dioxide transport

- **Most CO_2 in the blood is transported as bicarbonate ions in the plasma**



Circulation

3 Major Parts of the Circulatory system

- **Circulatory system in most animals consists of Blood, Heart and Blood vessels**
- **Blood Vessels - networks of hollow tubes that transport blood throughout the entire body.**
- **Heart – pumps blood through body**
- **Blood – carries oxygen, food, & waste ..etc through body.**

MECHANISMS OF INTERNAL TRANSPORT

- **An internal transport system assists diffusion by moving materials between**
  - **Surfaces of the body**
  - **Internal tissues**

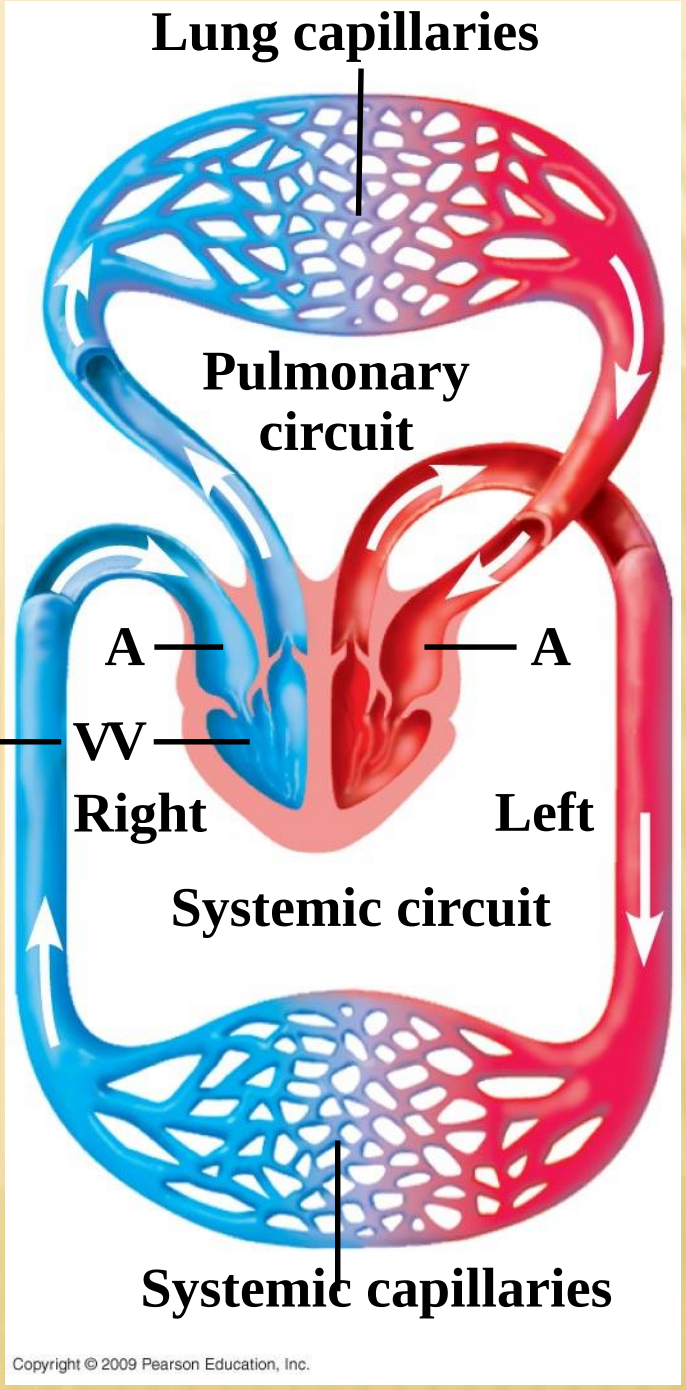
Circulatory systems facilitate exchange with all body tissues

- **All cells need**
  - **Nutrients**
  - **Gas exchange**
  - **Removal of wastes**

Four-chambered hearts: Two atria and two ventricles

- Four-chambered hearts Two atria and two ventricles
  - Two circuits that do not mix
    - Right side pumps blood from body to lungs
    - Left side pumps blood from lungs to body
- Oxygen rich blood is completely separated from oxygen poor blood
- No mixing → much more efficient gas transport
- Birds, mammals Crocodilians have four-chambered hearts
- Needed in endothermic animals

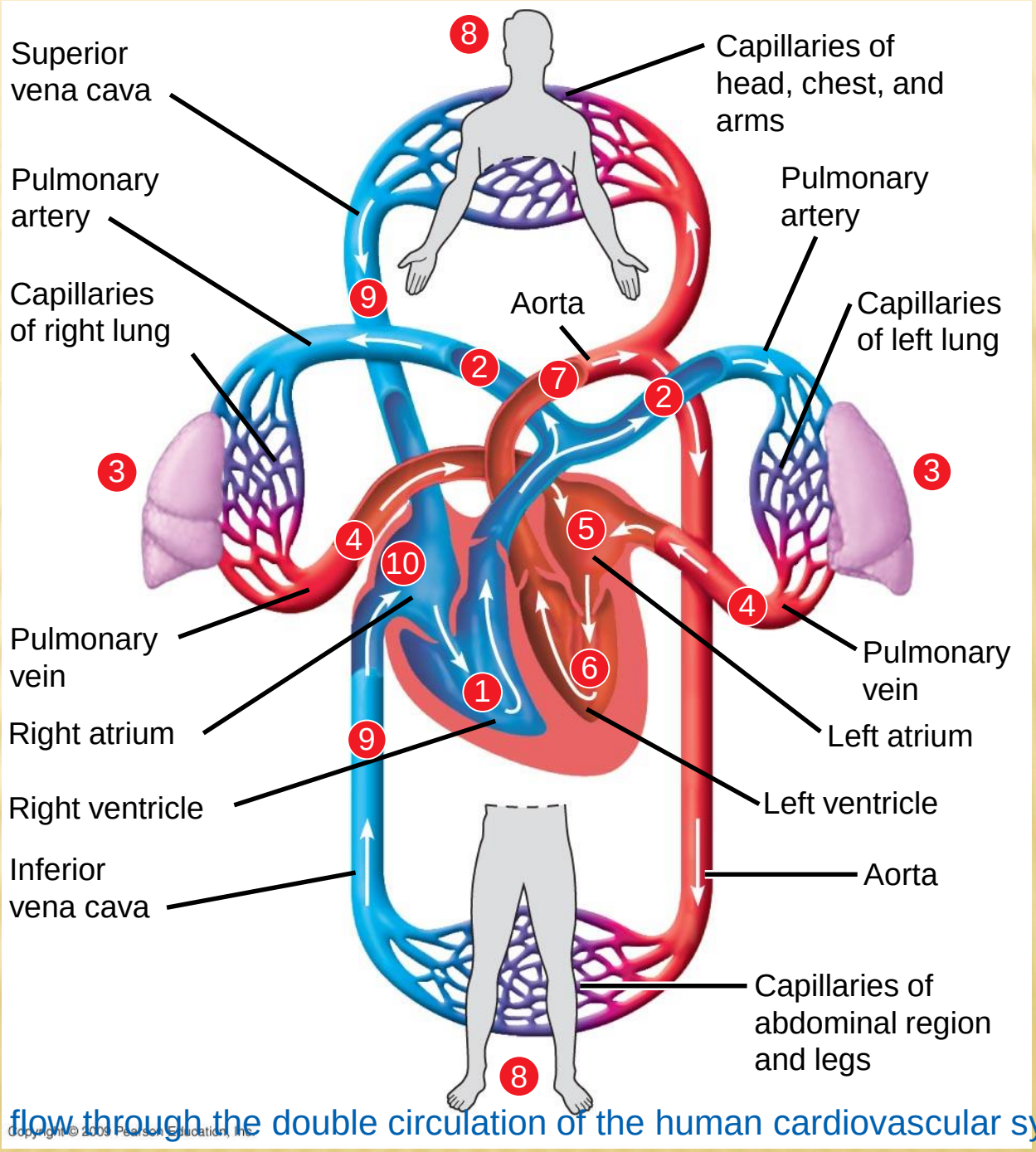
The double circulation and four-chambered heart of a bird or mammal



THE HUMAN CARDIOVASCULAR SYSTEM

The human cardiovascular system illustrates the double circulation of mammals

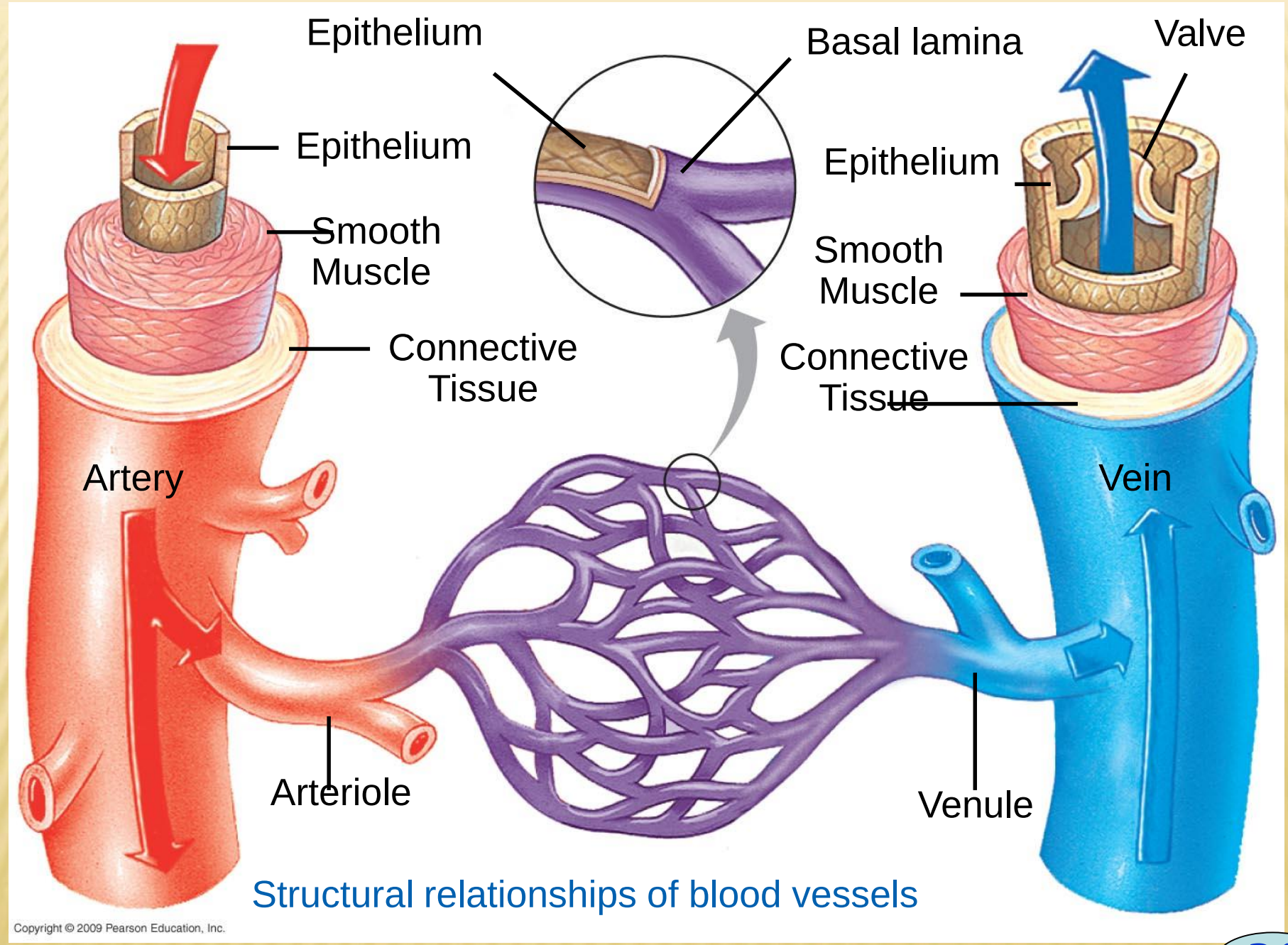
- **Blood flow through the double circulatory system of humans**
- **The mammalian heart consists of**
  - **Two thin-walled atria that move blood to ventricles**
  - **Thick-walled ventricles that Pump blood to lungs and all other body regions**



Blood flow through the double circulation of the human cardiovascular system

The structure of blood vessels fits their functions

- **Arteries and veins**
  - **Arteries have thicker walls than veins**
  - **Arteries are under more pressure than veins**
  - **Veins have one-way valves that restrict backward flow and force blood back to right heart atrium**

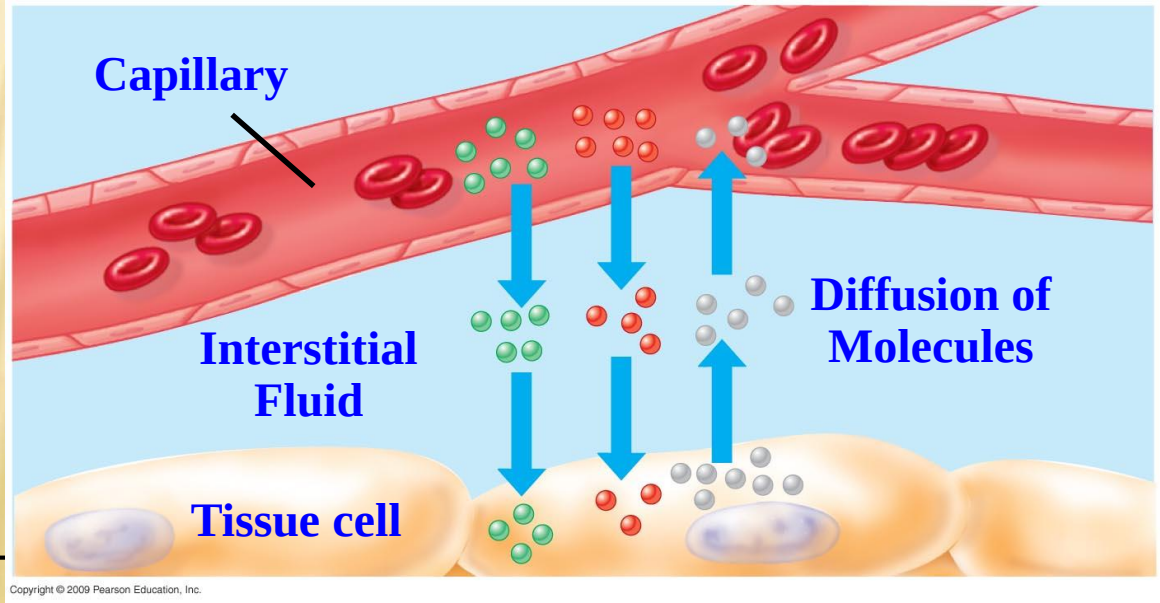


Structural relationships of blood vessels

Capillaries are the exchange surface

- **Capillaries**
  - **Thin walls: a single layer of epithelial cells**
  - **Narrow: blood cells flow in a single file**
  - **Increase surface area for gas and fluid exchange**
  - **Gas exchange and other transfers occur in the capillary beds**
  - **Endocytosis → exocytosis across membrane. Diffusion based on electrochemical gradients**

Diffusion between blood and tissue cells



The heart contracts and relaxes rhythmically

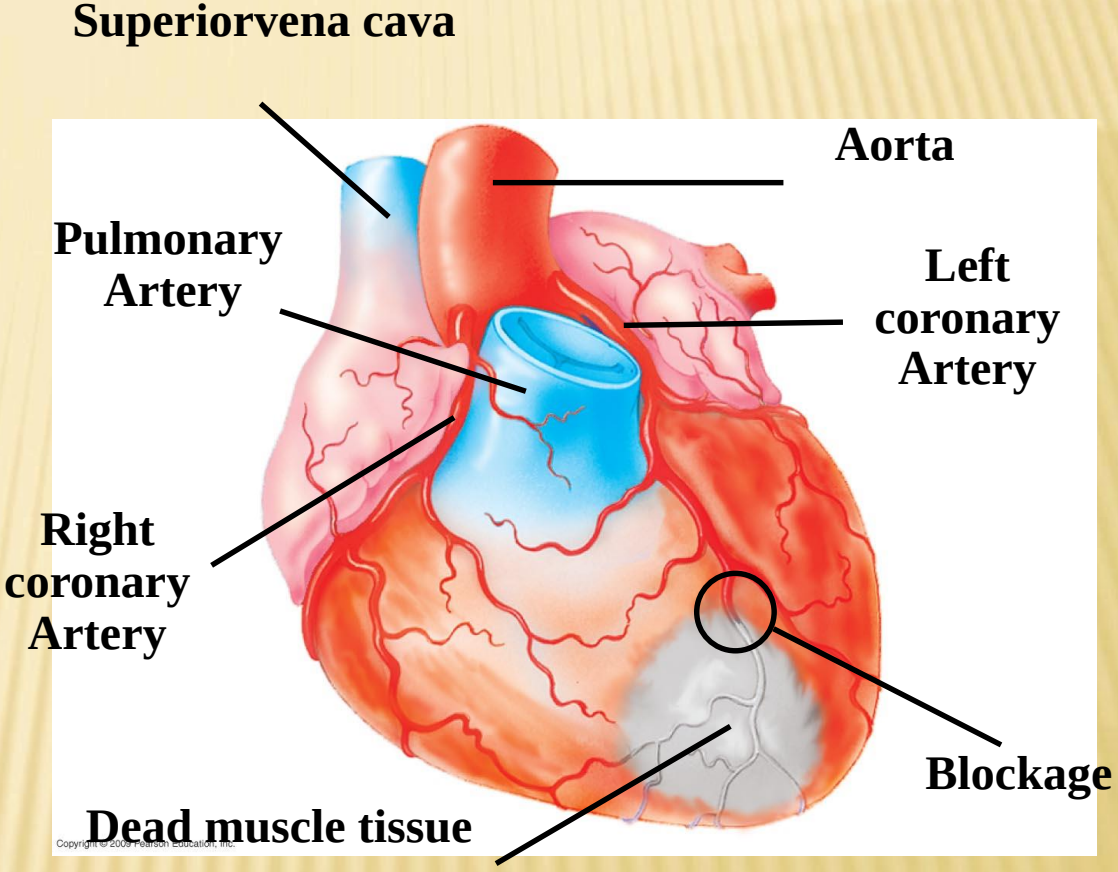
- **Cardiac output**: Amount of blood/minute pumped into systemic circuit
- **Heart rate**: Number of beats/minute
- **Heart valves**: Prevent the backflow of blood
- **Heart murmur**: A defect in one or more heart valves

The pacemaker sets the tempo of the heartbeat

- **The pacemaker (SA node)**
  - **Sets the rate of heart contractions**
  - **Generates electrical signals in atria**
- **The AV node**
  - **Relays these signals to the ventricles**

CONNECTION: What is a heart attack

- **A heart attack is damage to cardiac muscle typically from a blocked coronary artery**
- **Stroke Death of brain tissue from blocked arteries in the head**

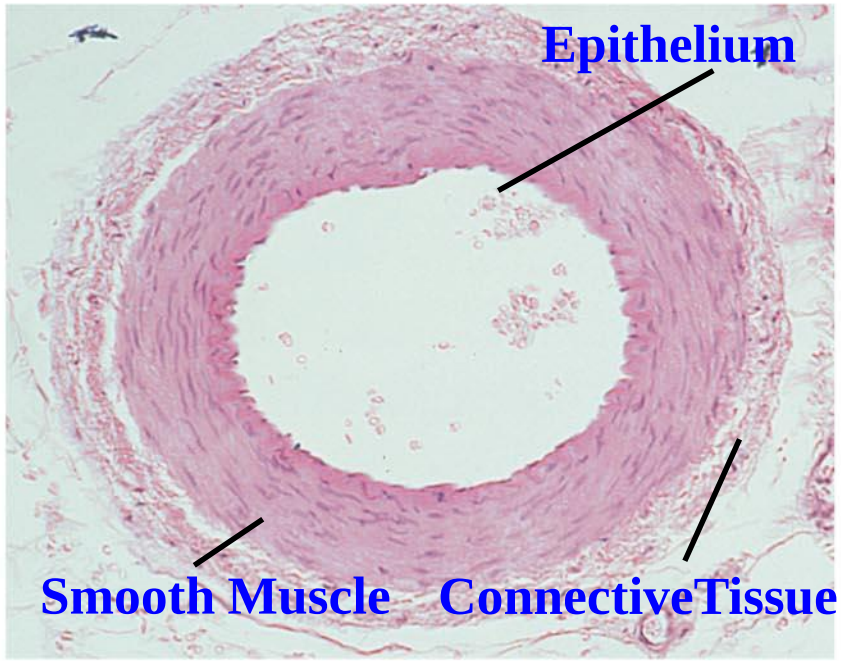


Blockage of a coronary artery, resulting in a heart attack

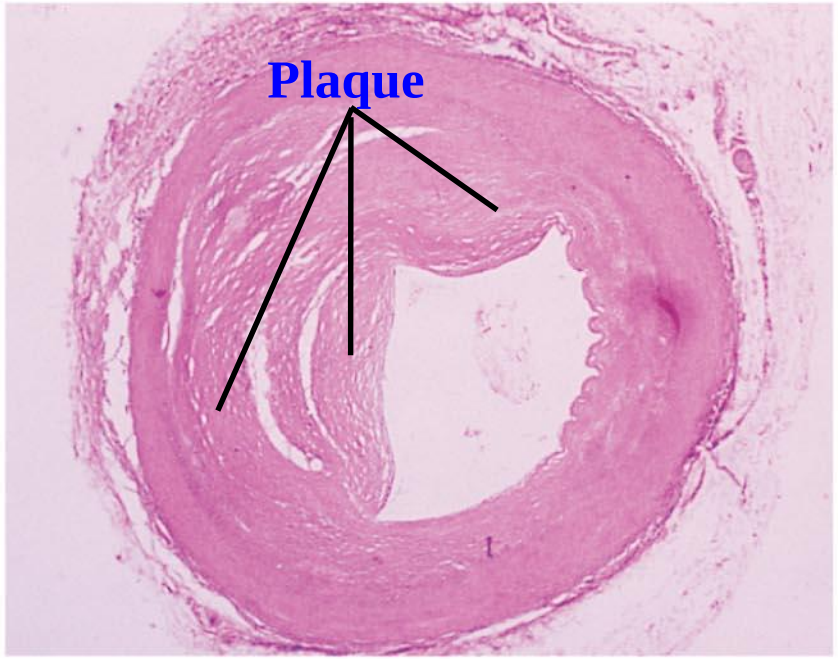
CONNECTION: What is a heart attack?

- **Atherosclerosis**
  - **Plaques develop inside inner walls of blood vessels**
  - **Plaques narrow blood vessels**
  - **Blood flow is reduced**

A normal artery



Atherosclerosis: an artery partially closed by plaque



Blood pressure and velocity reflect the structure and arrangement of blood vessels

- **Blood pressure: The force blood exerts on vessel walls**
  - Depends on cardiac output and resistance of vessels
  - Decreases as blood moves away from heart
  - Highest in arteries & lowest in veins
  - It is measured as
    - **Systolic pressure:** caused by ventricular contraction
    - **Diastolic pressure:** low pressure between contractions

BLOOD STRUCTURE AND FUNCTION

- **Blood consists of:**
  1. **Cellular elements (red and white blood cells and platelets) suspended in plasma.**
  2. **Plasma which is about 90% water and contains**
     - **Various inorganic ions**
     - **Proteins, nutrients**
     - **Wastes, gases**
     - **Hormones**

Blood Cellular Elements

1) Red blood cells (erythrocytes)

   Transport O_2 bound to hemoglobin

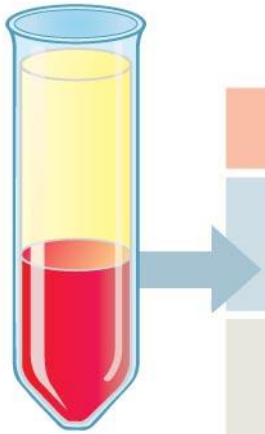
2) White blood cells (leukocytes)

   Function inside and outside the circulatory system

   Fight infections and cancer

3) Platelets: Small fragments of cells promote clotting

Centrifuged blood Sample



Cellular elements (45%)		
Cell type	Number العدد per µL (mm^3) of blood	Functions
Erythrocytes (red blood cells)	5–6 million	Transport of oxygen (and carbon dioxide)
Leukocytes (white blood cells)	5,000–10,000	Defense and Immunity
Basophil		
Eosinophil		Lymphocyte
Neutrophil		Monocyte
Platelets	250,000–400,000	Blood clotting

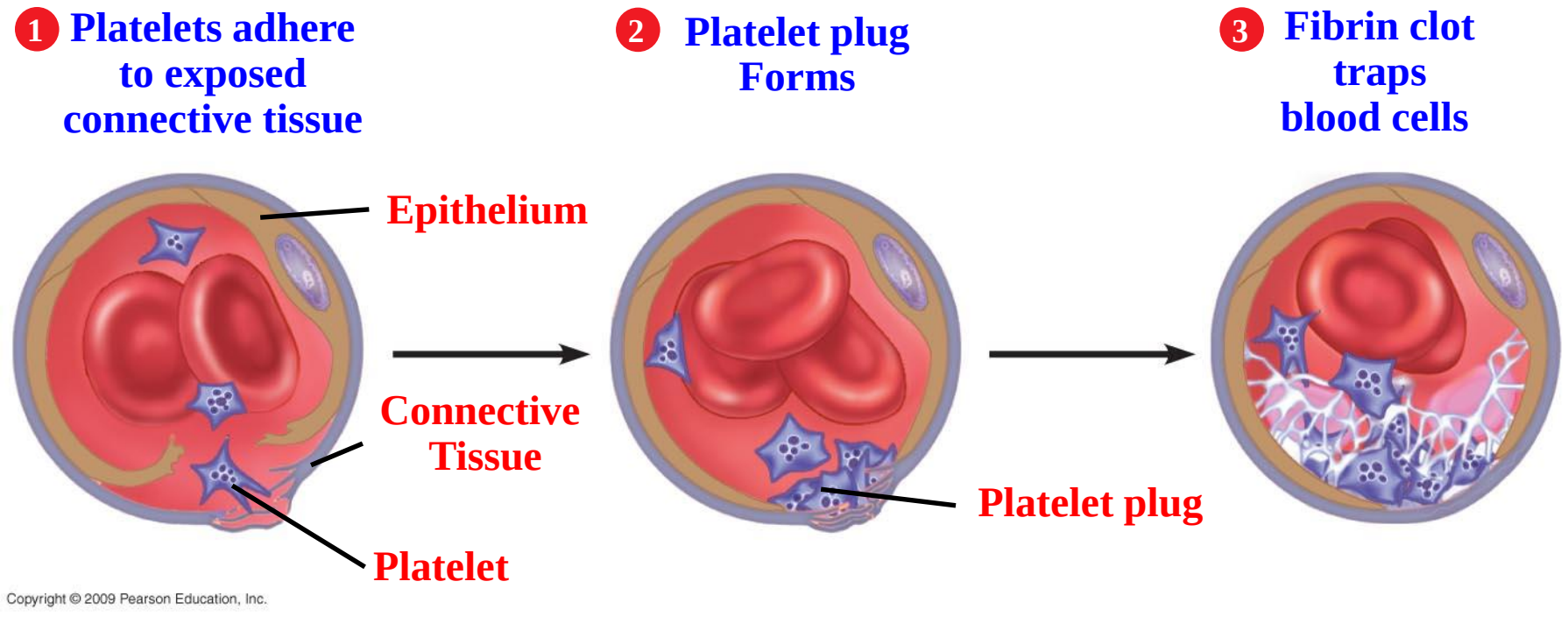
CONNECTION: Too few or too many red blood cells can be unhealthy

- **Anemia**
  - Abnormally low amounts of hemoglobin or red blood cells
  - Causes fatigue due to lack of oxygen in tissues
- **Erythropoietin hormone (EPO) Regulates red blood cell production**
- **Some athletes artificially increase red blood cell production by injecting erythropoietin which can lead to Clotting , Stroke, Heart failure, Death**

The Clotting Process

Blood clots plug leaks when blood vessels are injured

- **When a blood vessel is damaged**
  - **Platelets help trigger the conversion of fibrinogen (plasma protein) → fibrin (fiber) which makes knit that forms a clot and plugs the leak**
- **The blood-clotting process**
  - **Platelets adhere to exposed connective tissue**
  - **Platelets form a plug**
  - **A fibrin clot traps blood cells**



The blood-clotting process

A fibrin clot