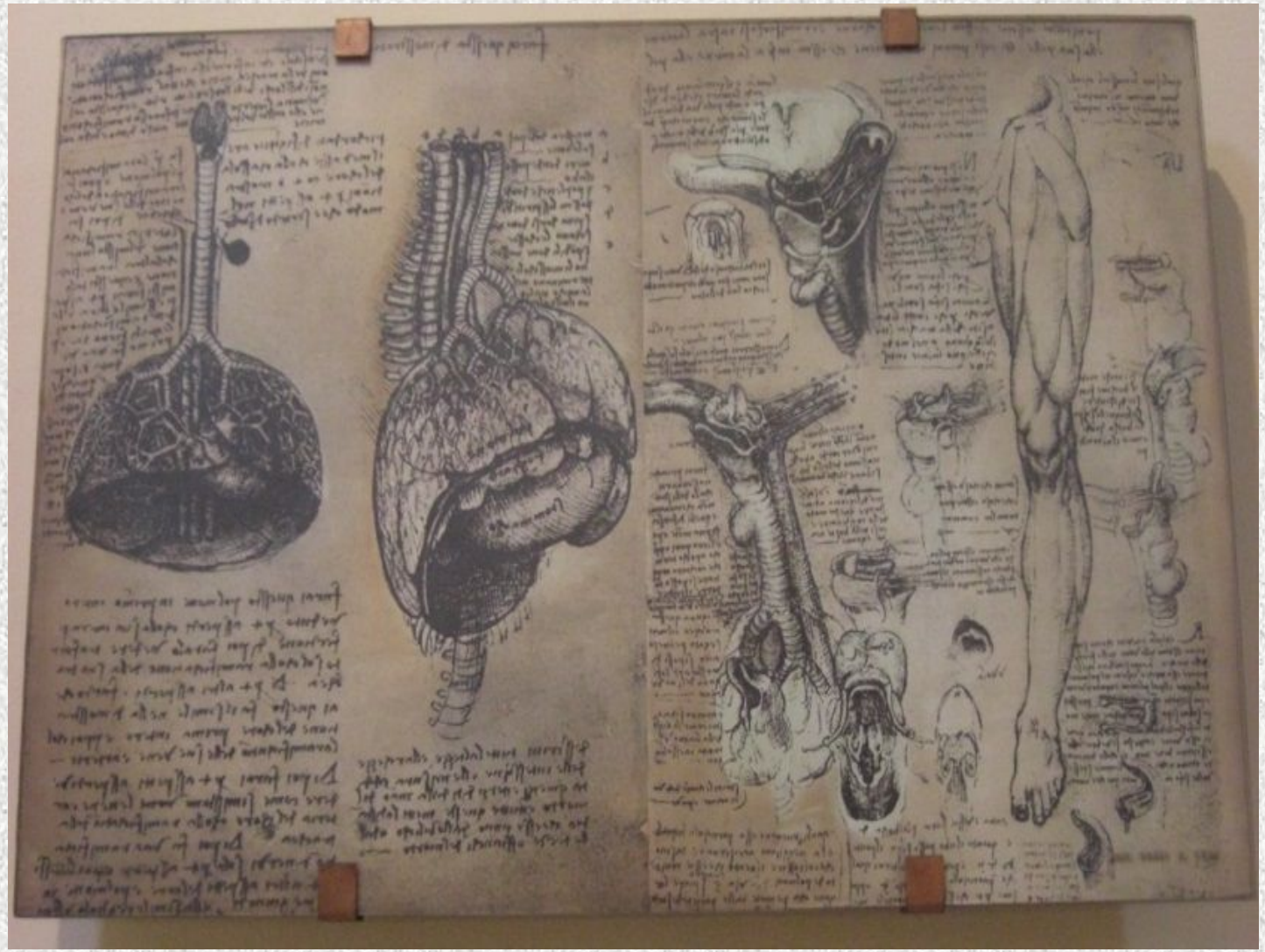
LKS Faculty of Medicine
School of Biomedical Sciences
香港大學生物醫學學院

Gas Uptake and Exchange

Enrichment Course in Biology

Dr Denny CW Ma

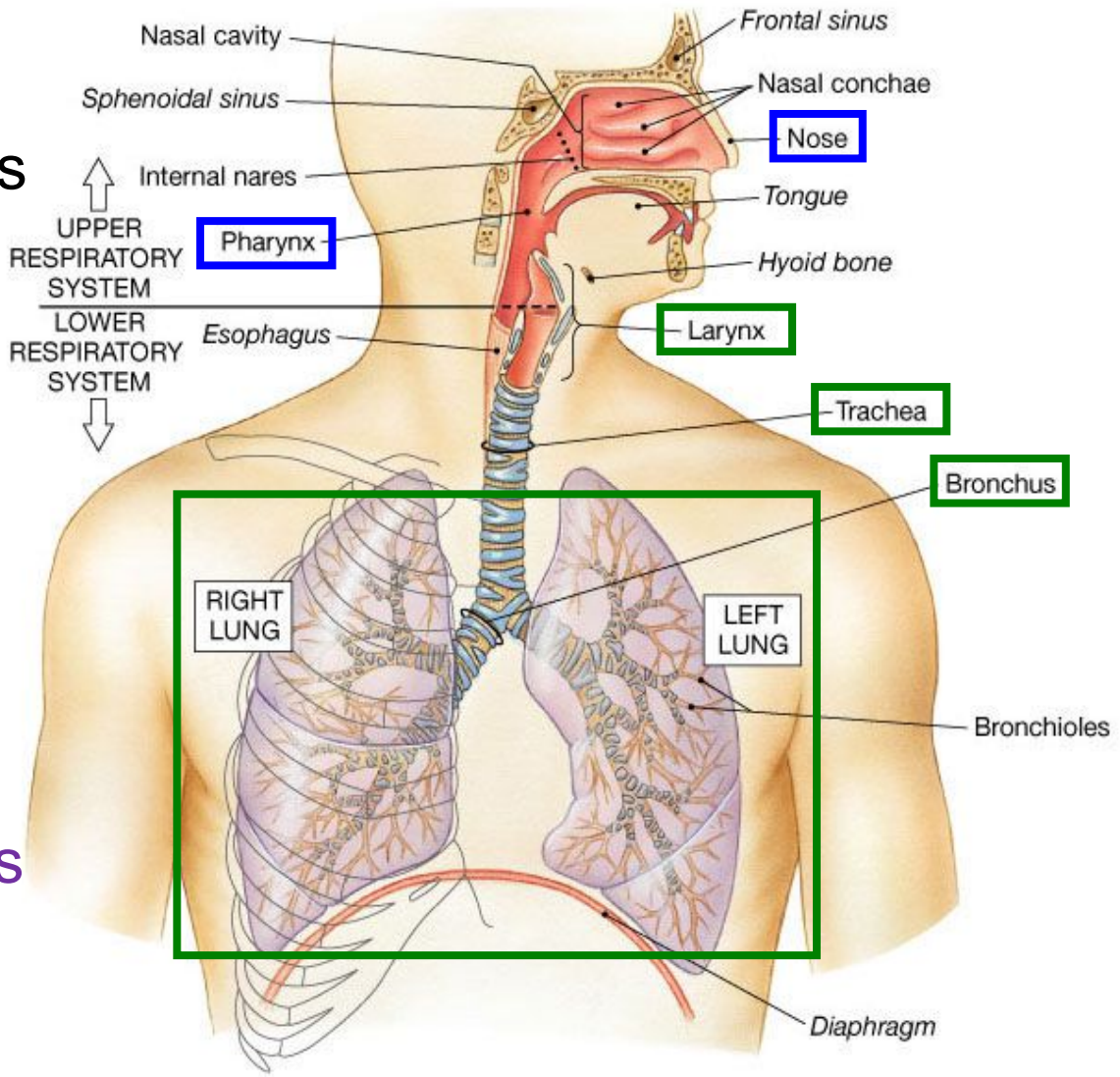


Leonardo da Vinci
(1452 – 1519)

Respiratory System

Components of the Respiratory System

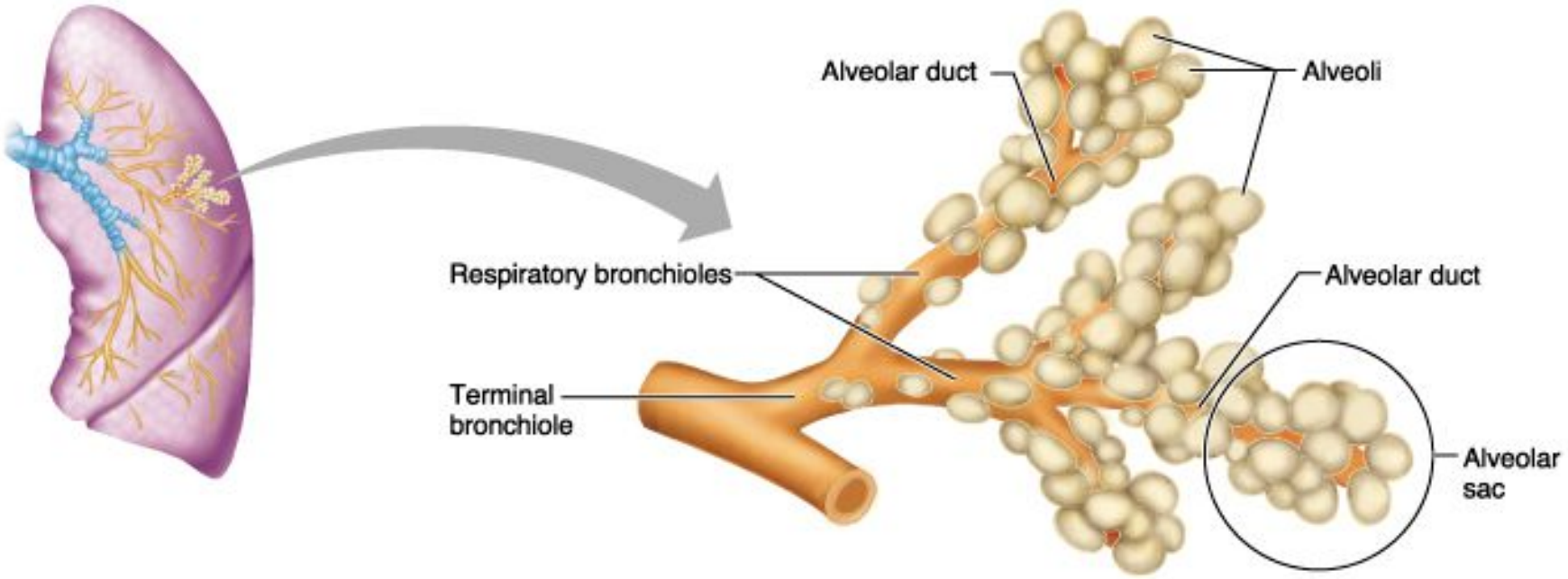
- Upper Tract
  - Nose, pharynx & associated structures
  - Filter & humidify incoming air
- Lower Tract
  - Larynx, trachea, bronchi & lungs
  - Include delicate conduction passages & gas exchange surfaces (alveoli)



Respiratory System

- Composed of respiratory & conducting zones

- **Respiratory zone**
  - Site of gas exchange
  - Consists of bronchioles, alveolar ducts & alveoli



Respiratory System

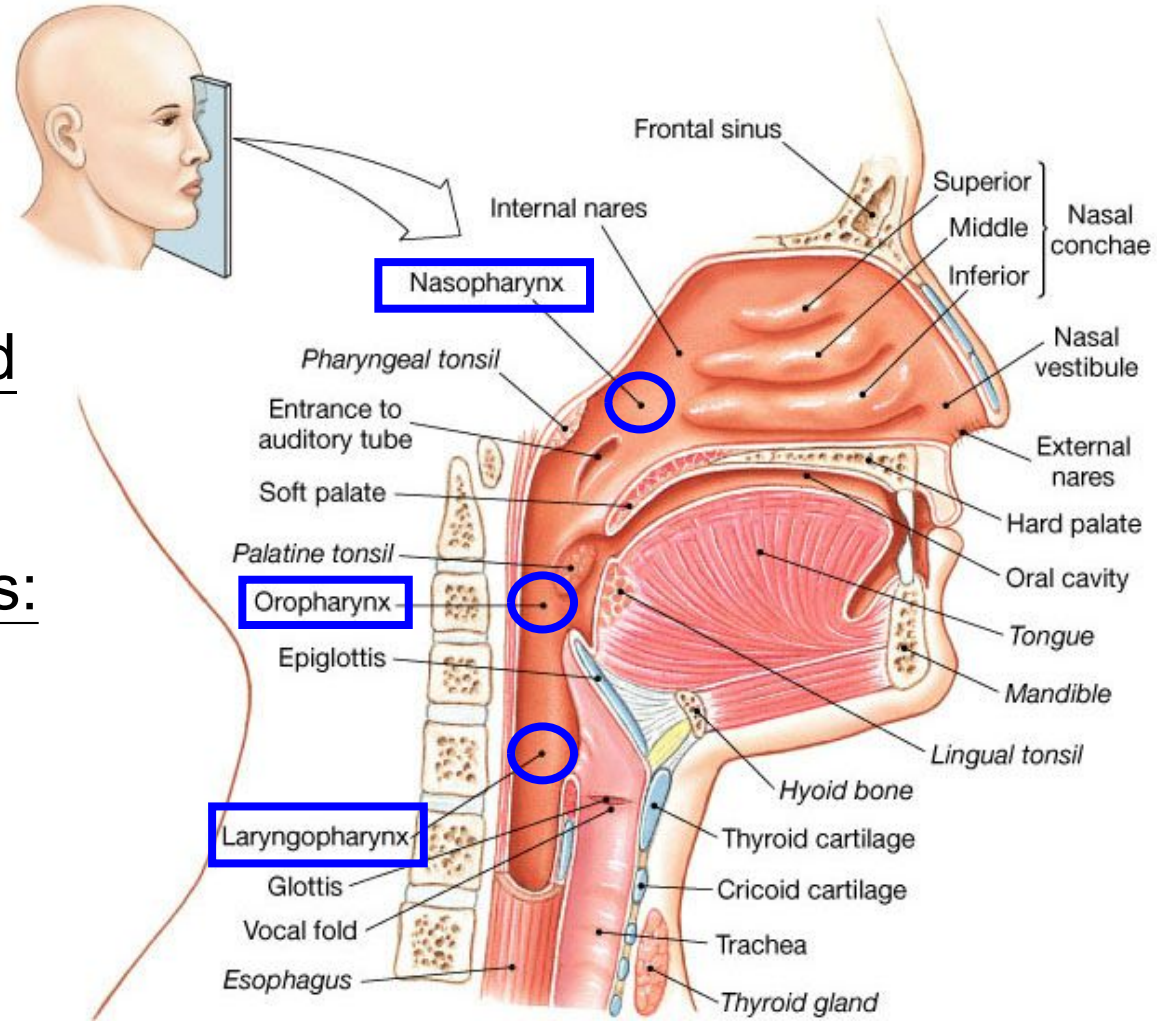
- **Conducting zone**
  - Includes all other respiratory structures (e.g. nose, nasal cavity, pharynx, trachea)
  - Provides rigid conduits for air to reach the sites of gas exchange

- **Respiratory muscles**
  - Diaphragm & other muscles that promote ventilation

Pharynx [Conducting Zone]

- Commonly called throat.
- Serves as a common pathway for air & food

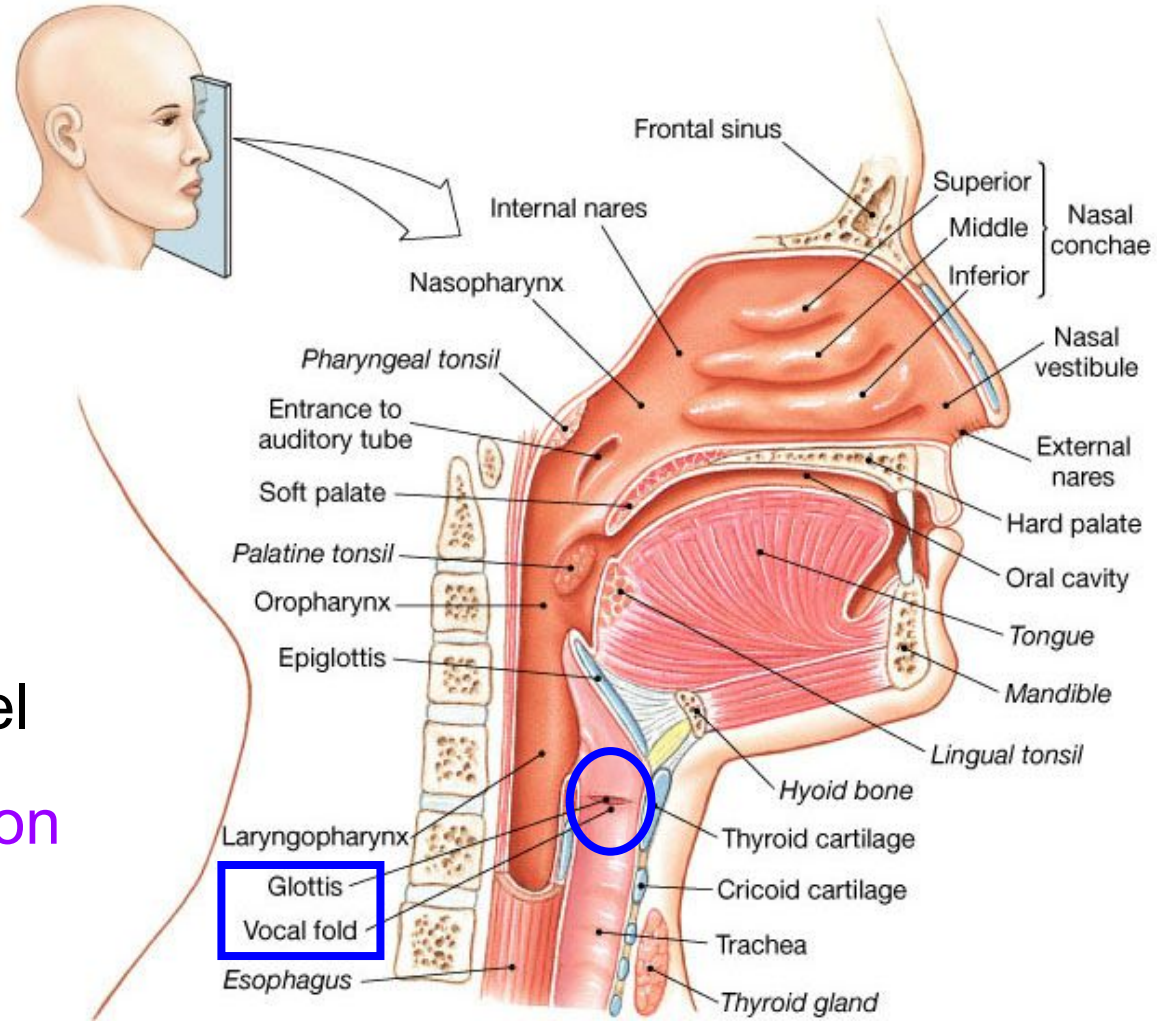
- 3 anatomical divisions:
  - Nasopharynx
  - Oropharynx
  - Laryngopharynx



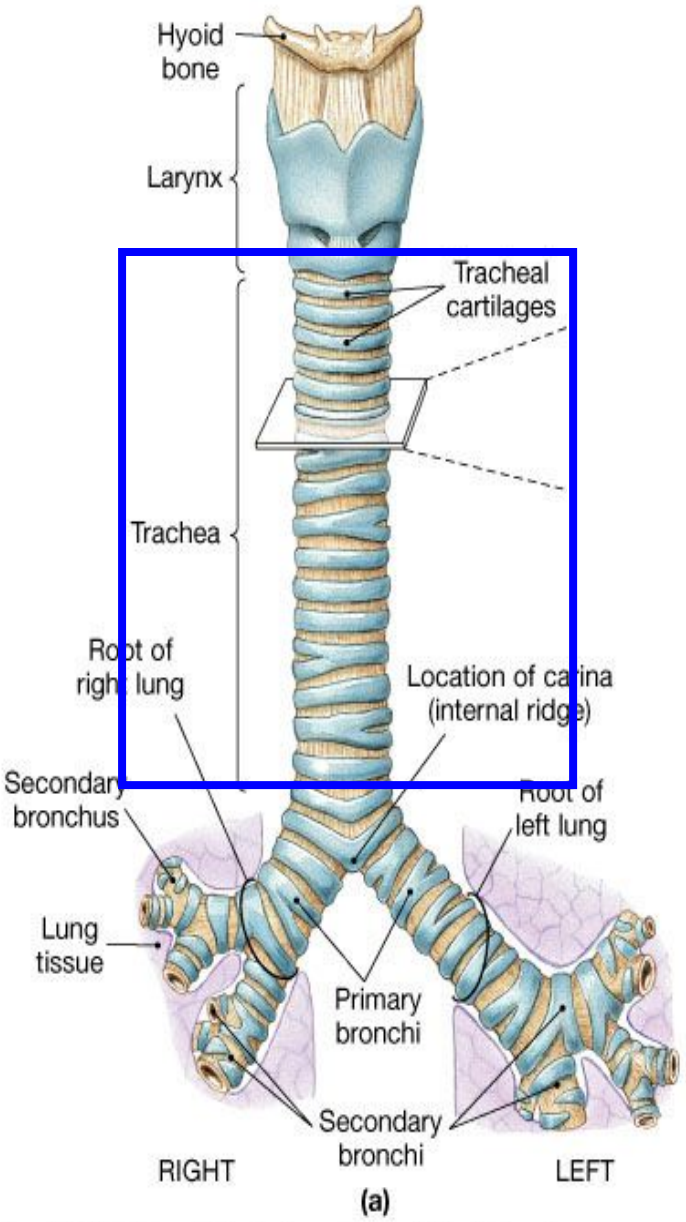
Larynx [Conducting Zone]

- Voice box

- 3 important functions:
  - To provide open airway
  - To route air & food into proper channel
  - For voice production



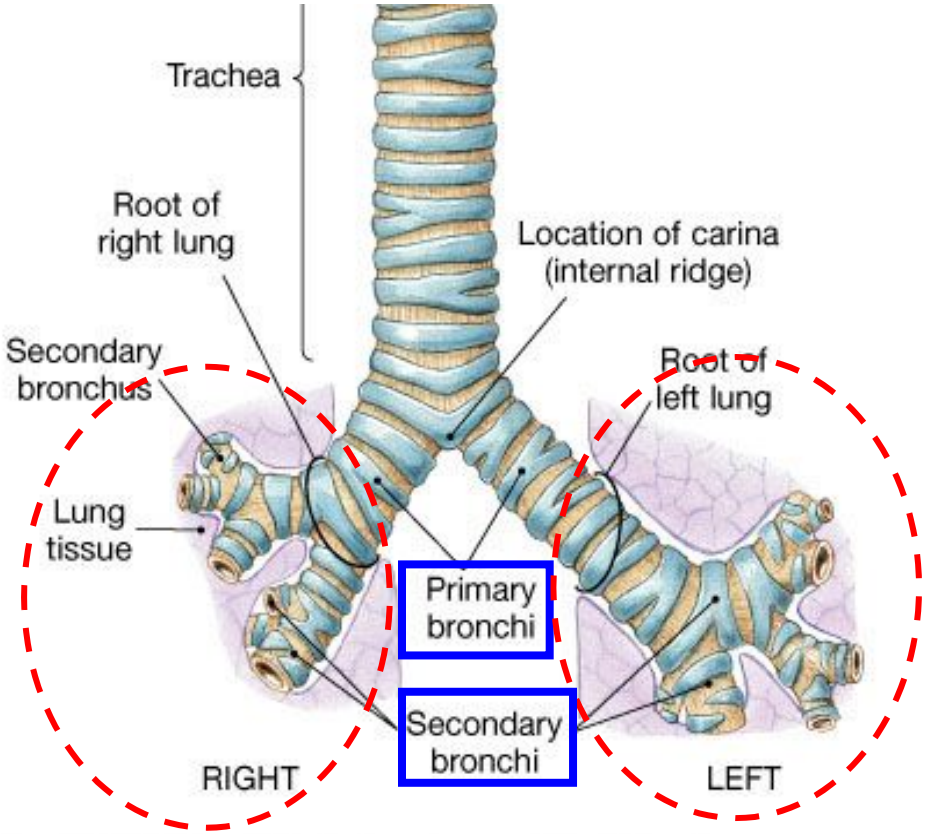
Trachea [Conducting Zone]



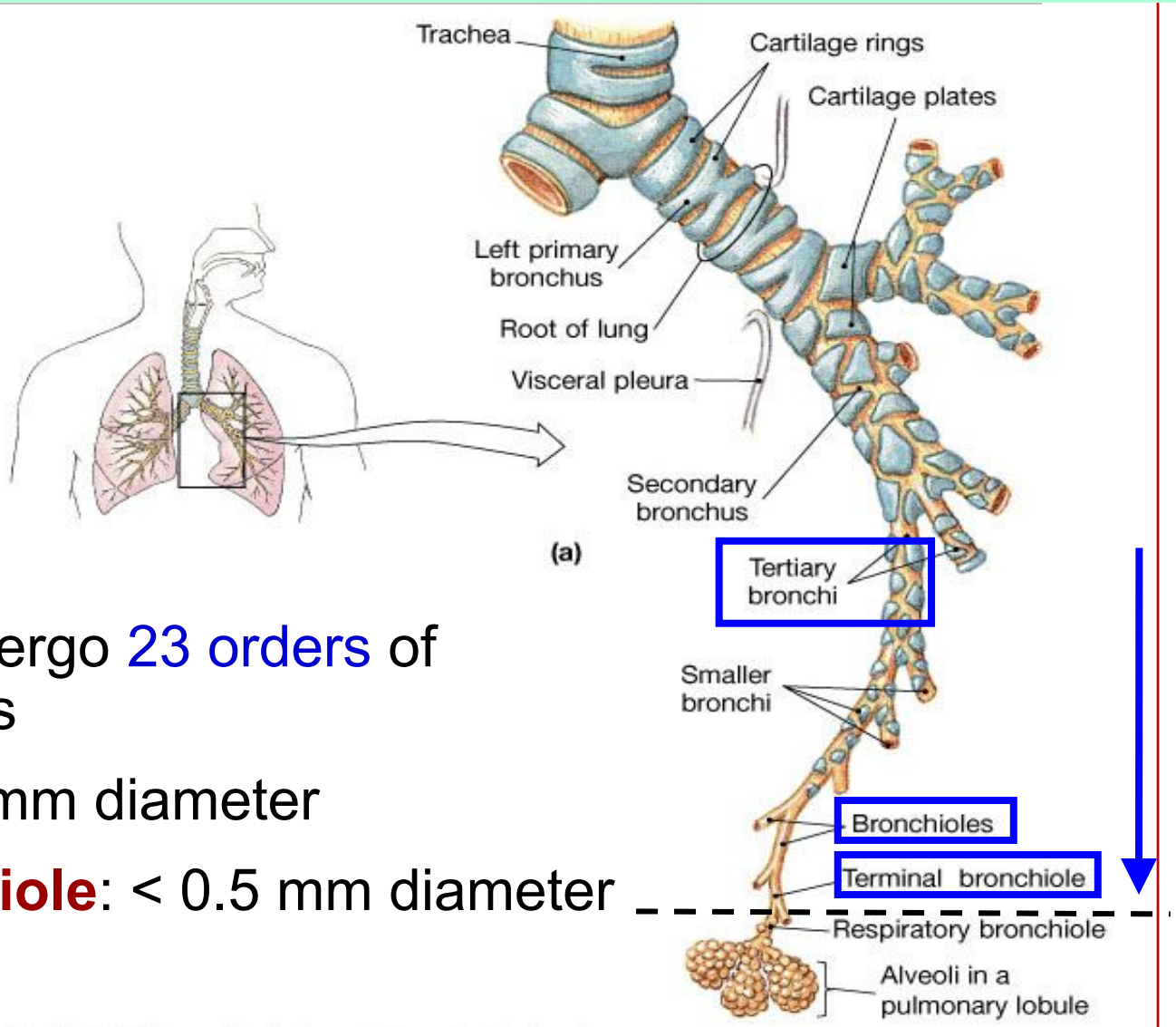
- A tough, flexible tube running from larynx to bronchi
- Clean, warm & moisten incoming air

Bronchi [Conducting Zone]

- Trachea divides at its lower end into **2 primary bronchi**
- Once inside lungs, **primary bronchi** subdivide into **secondary bronchi**, each supplying a lobe of lungs
- Secondary bronchi branch into third-order **tertiary bronchi**, which in turn divide repeatedly into smaller & smaller bronchi



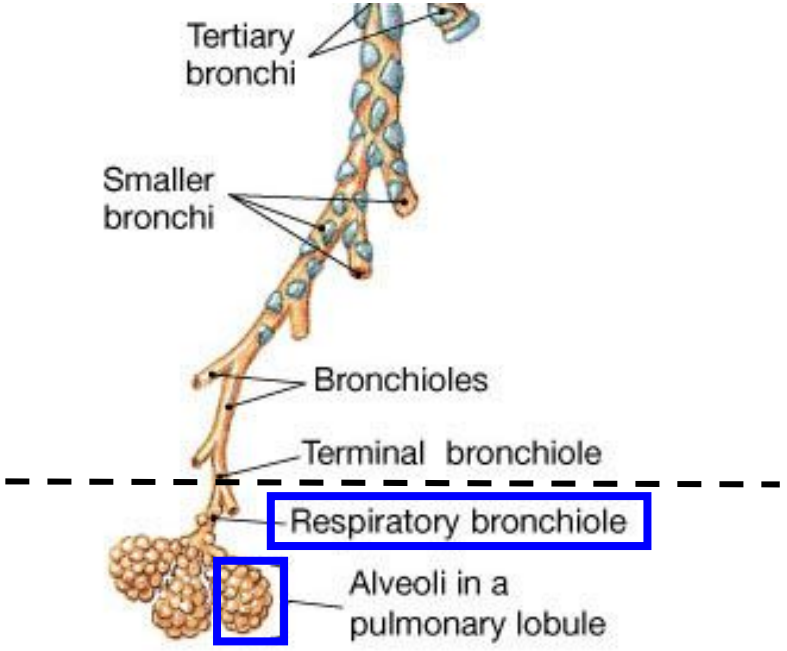
Bronchial Tree [Conducting Zone → Respiratory Zone]



- Air passages undergo 23 orders of branching in lungs
- **Bronchiole**: < 1 mm diameter
- **Terminal bronchiole**: < 0.5 mm diameter

Bronchioles [Respiratory Zone]

- Terminal bronchiole → **respiratory bronchioles**
- Delivers air to a single **pulmonary lobule**

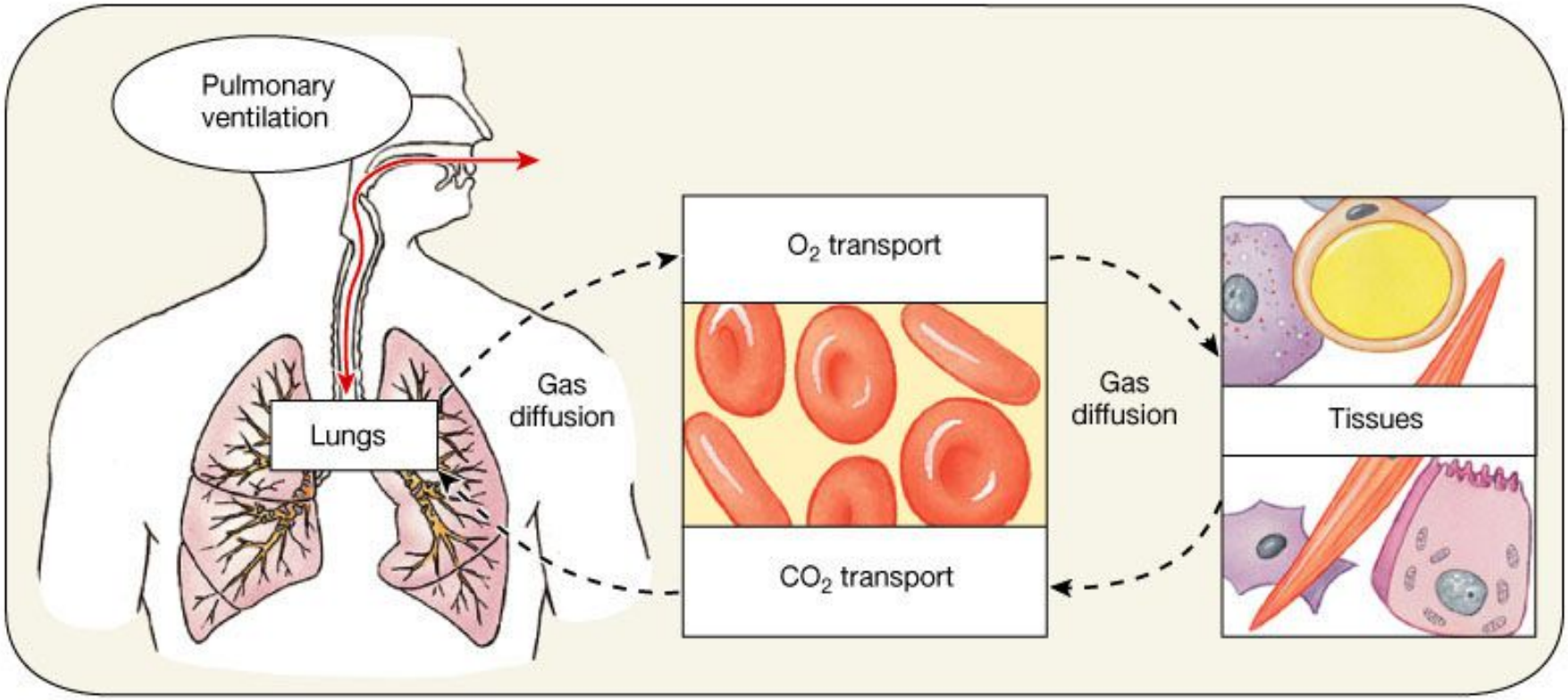


Processes in Respiration

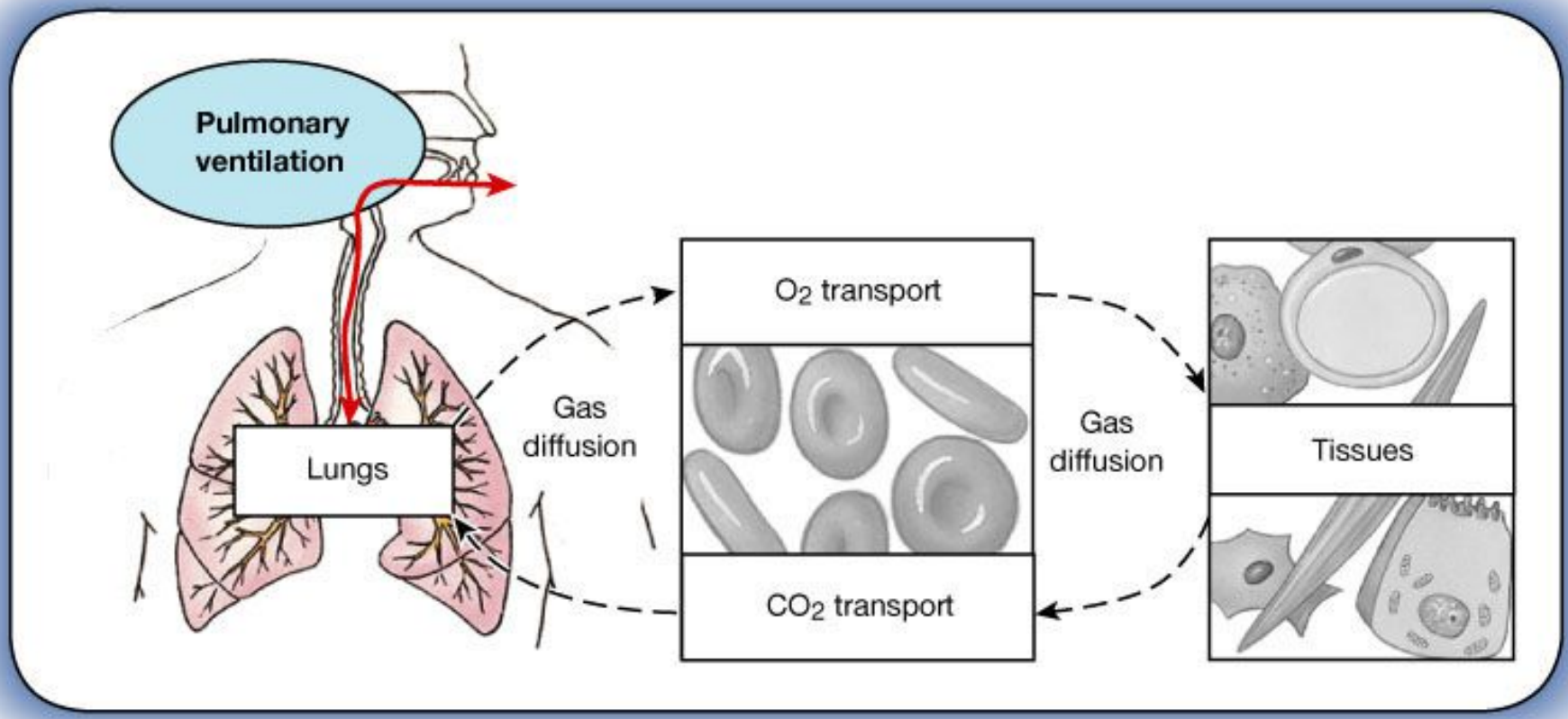
- To supply the body with oxygen & dispose of carbon dioxide

- Respiration involves 4 distinct processes:
  - **Pulmonary ventilation** – movement of air into & out of **lungs**
  - **External respiration** – gas exchange between **lungs** & **blood**
  - **Transport** – transport of O_2 & CO_2 between **lungs** & **tissues**
  - **Internal respiration** – gas exchange between systemic **blood** vessels & **tissues**

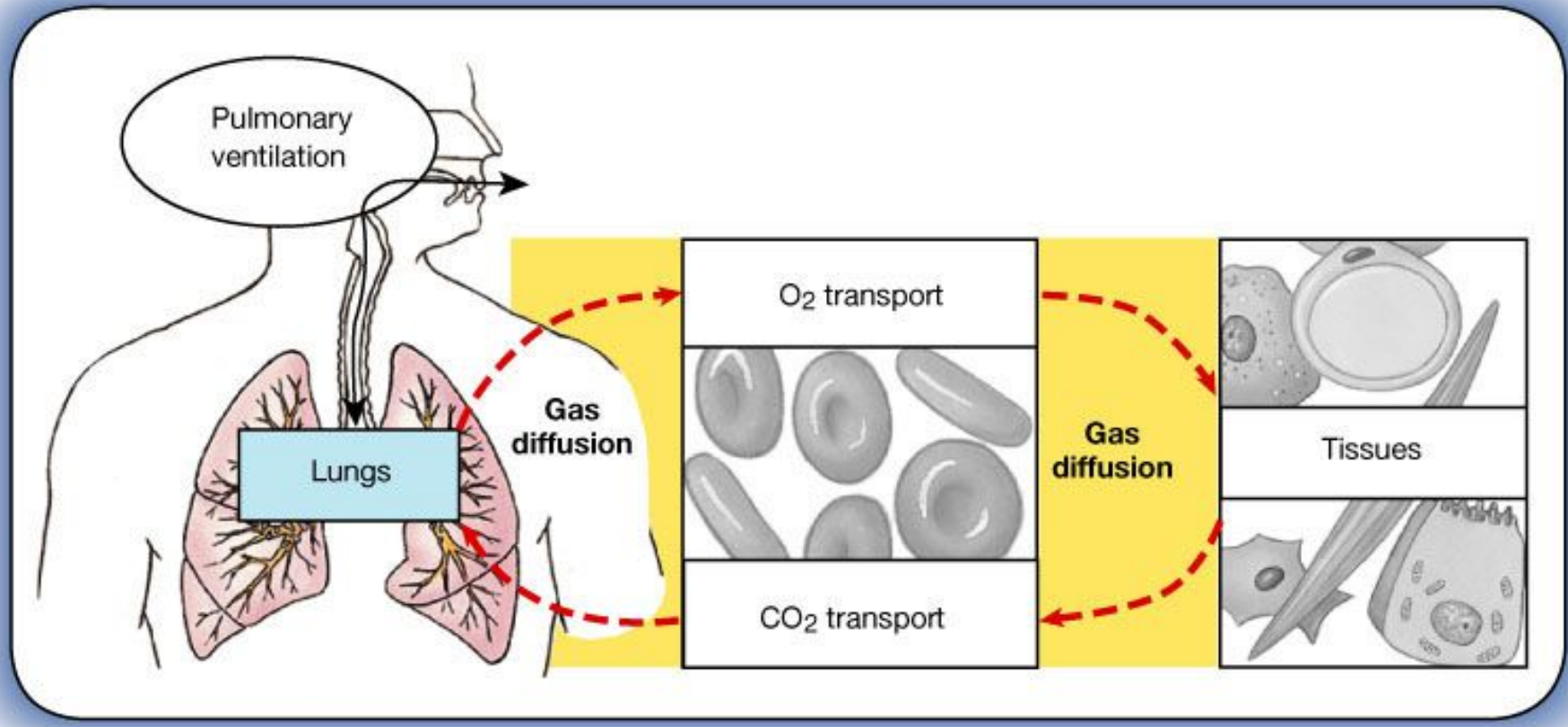
Processes in Respiration



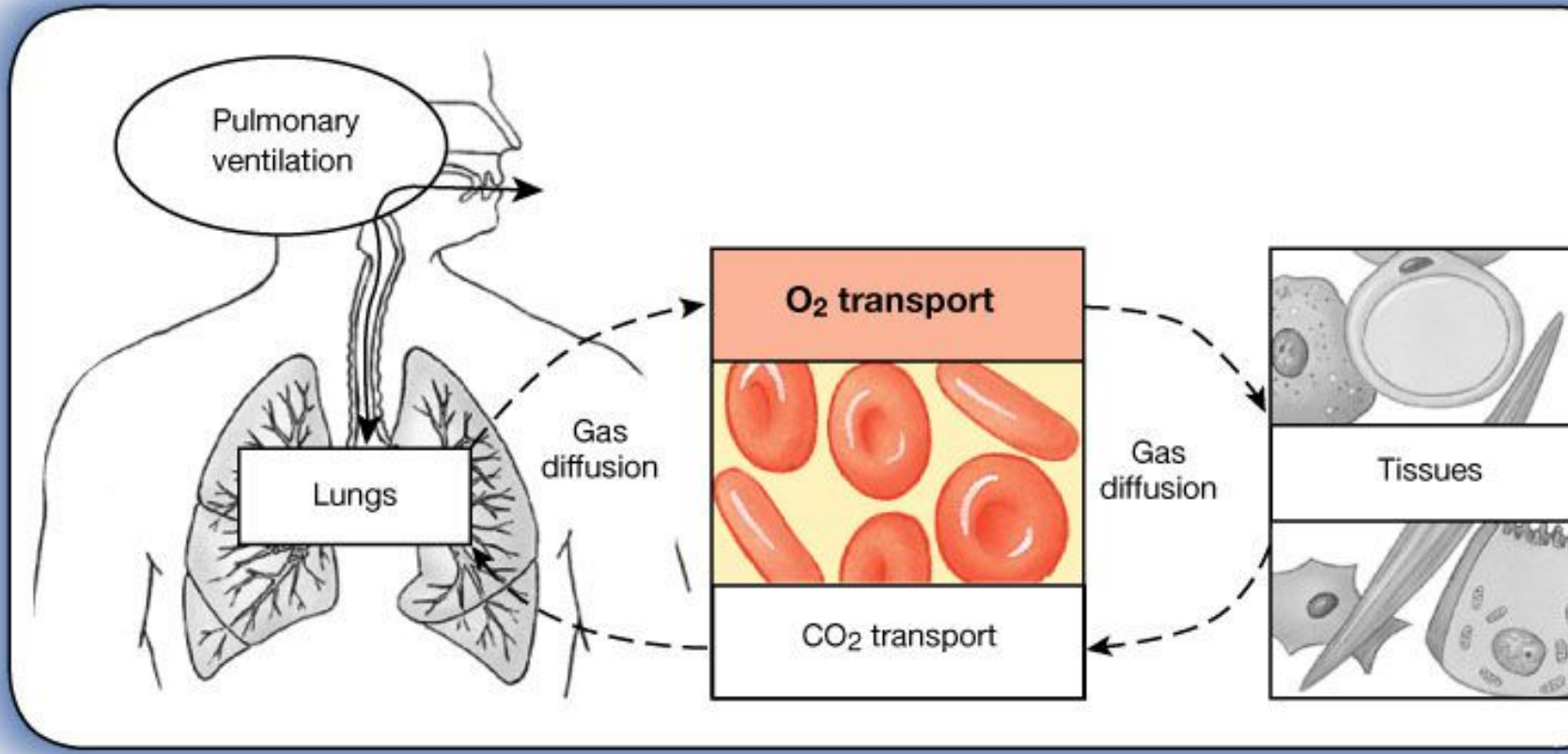
1. Pulmonary Ventilation



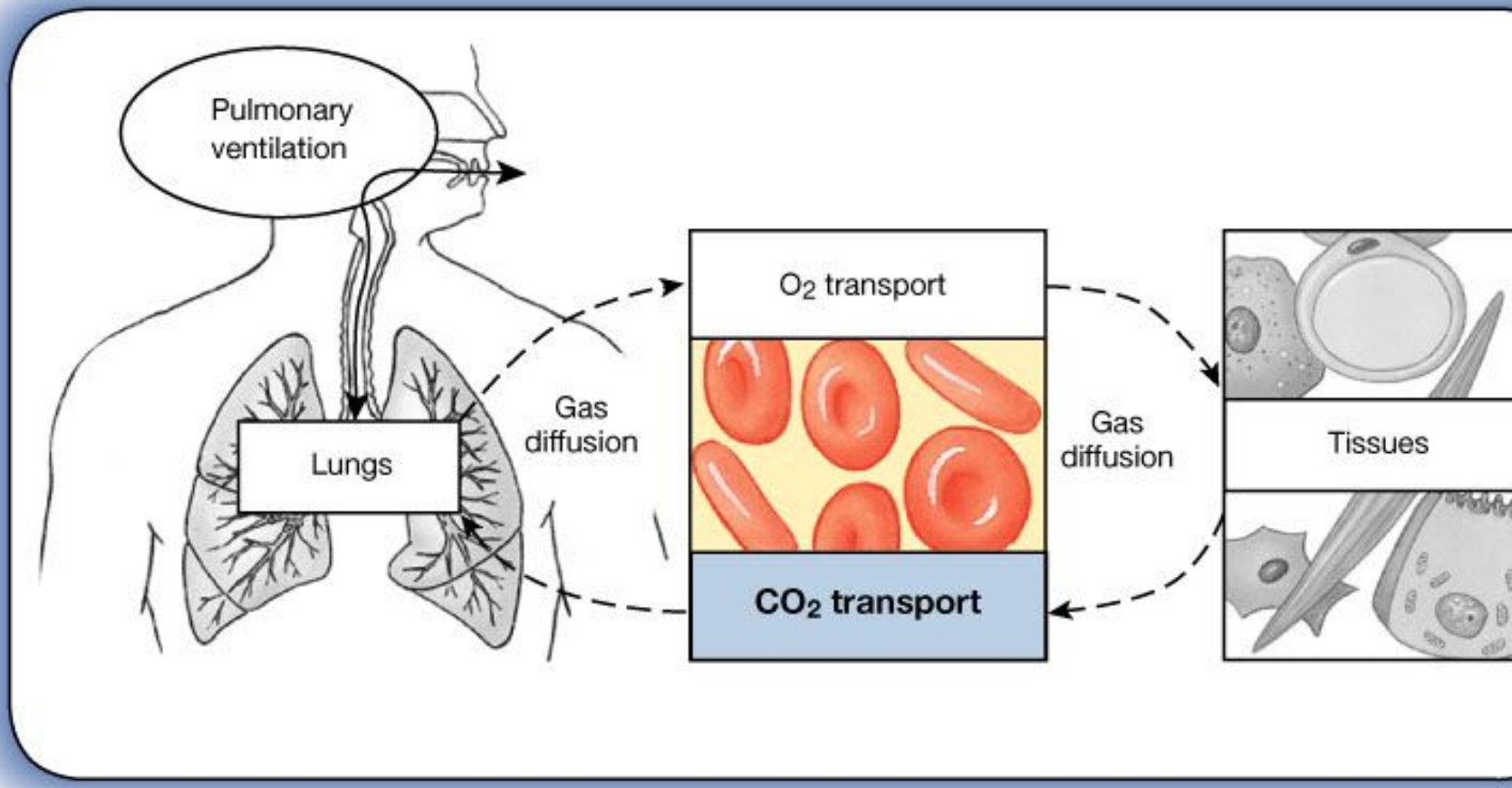
2. External Respiration & Internal Respiration



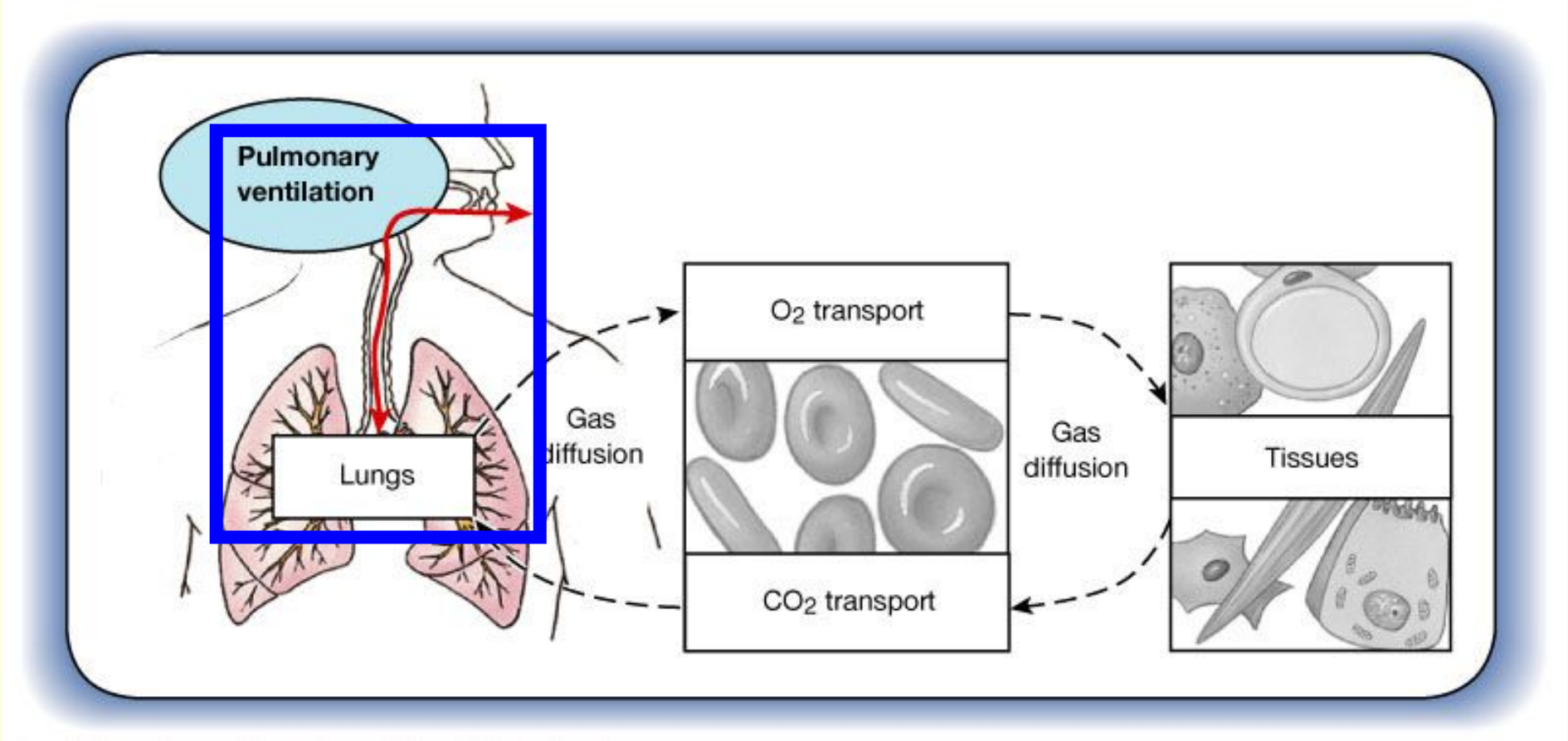
3. Transport (Oxygen)



4. Transport (Carbon Dioxide)



1. Pulmonary Ventilation



Mechanism of Pulmonary Ventilation

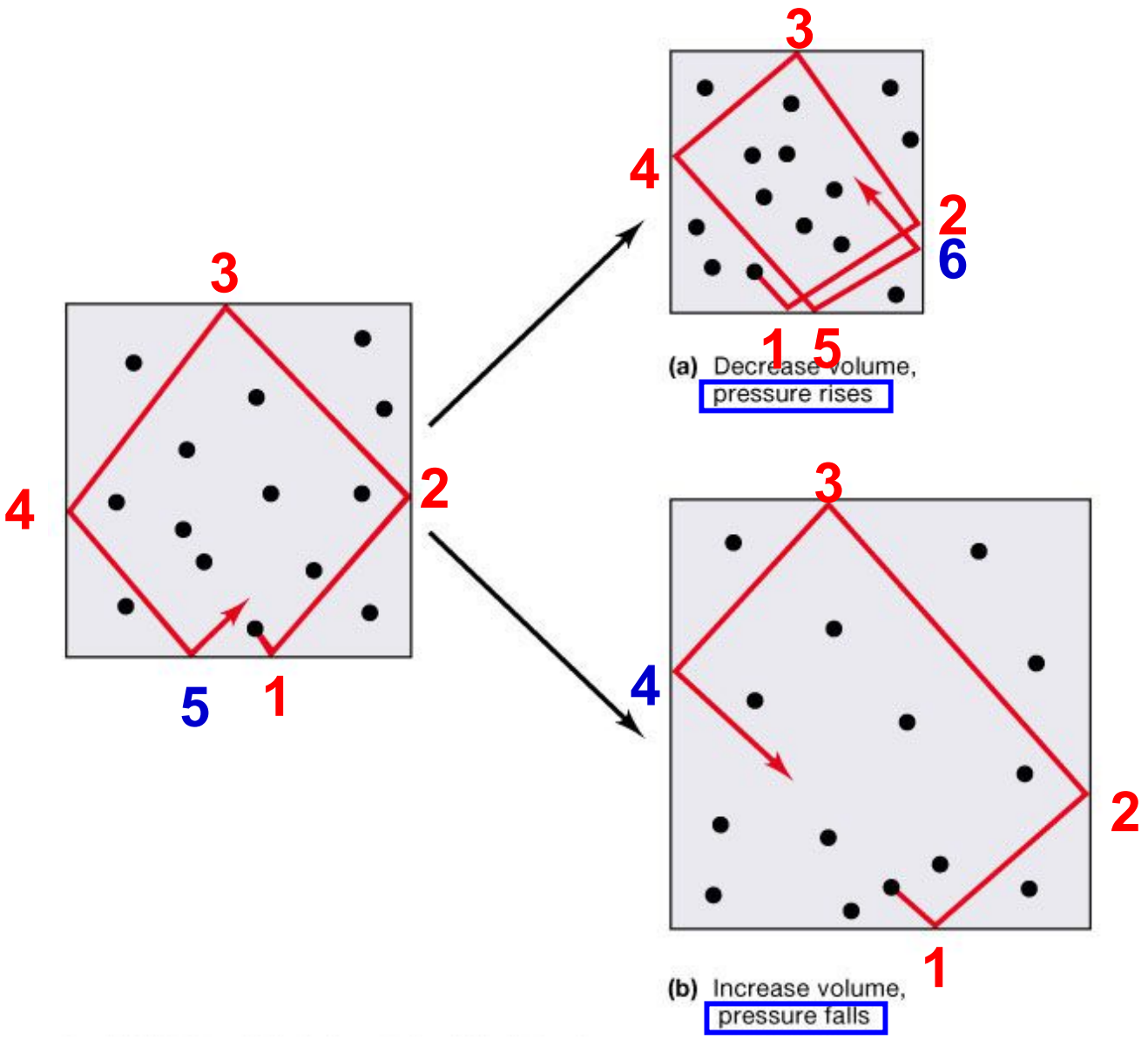
- Breathing (pulmonary ventilation) consists of 2 phases:
  - Inspiration – air flows into lungs
  - Expiration – gases exit lungs

- Mechanical process that depends on volume changes in the thoracic cavity
- Volume changes lead to pressure changes, which lead to the flow of gases (to equalize pressure):

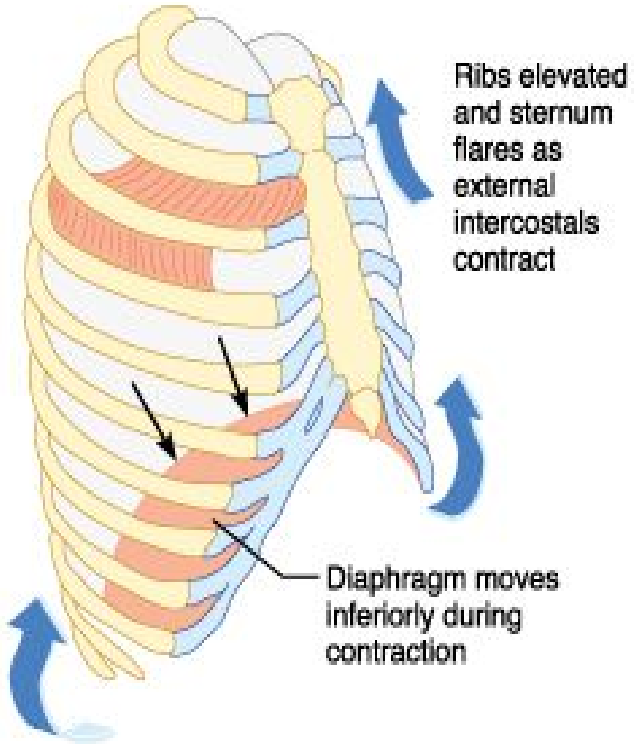
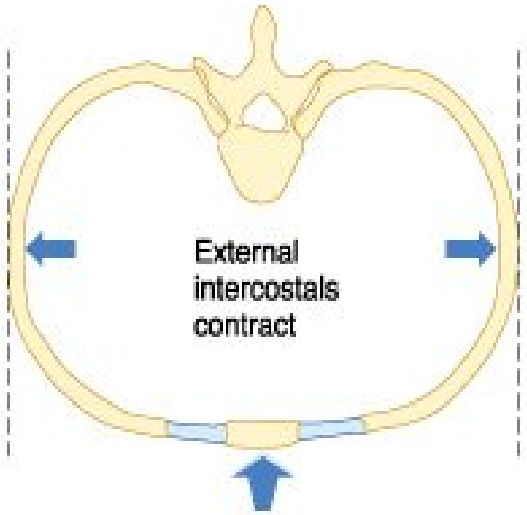
$$\Delta V \rightarrow \Delta P \rightarrow F \text{ (flow of gases)}$$

- **Boyle's law**
  - When temperature (T) is constant, the pressure (P) of a gas **varies inversely** with its volume (V)
  - Volume depends on movement of diaphragm & ribs

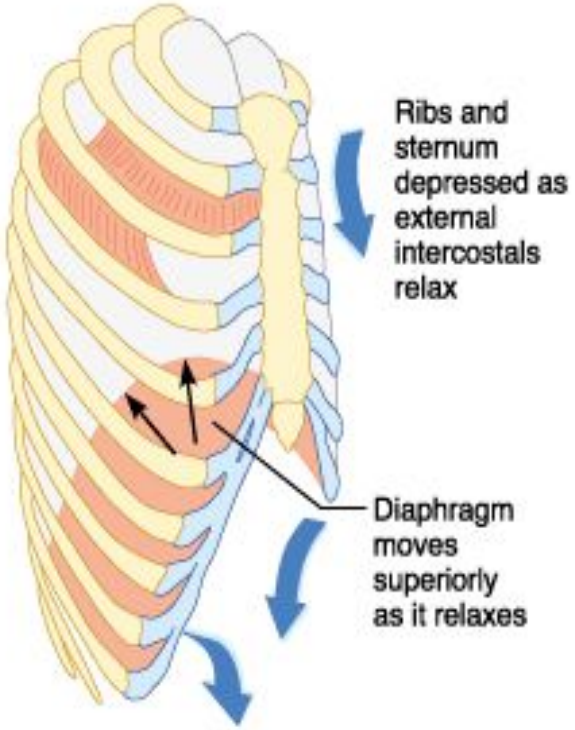
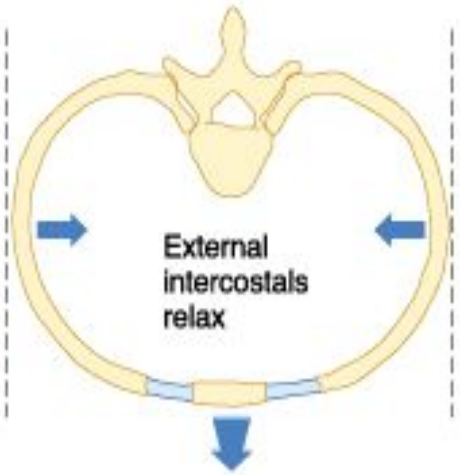
Pressure-Volume Relationships



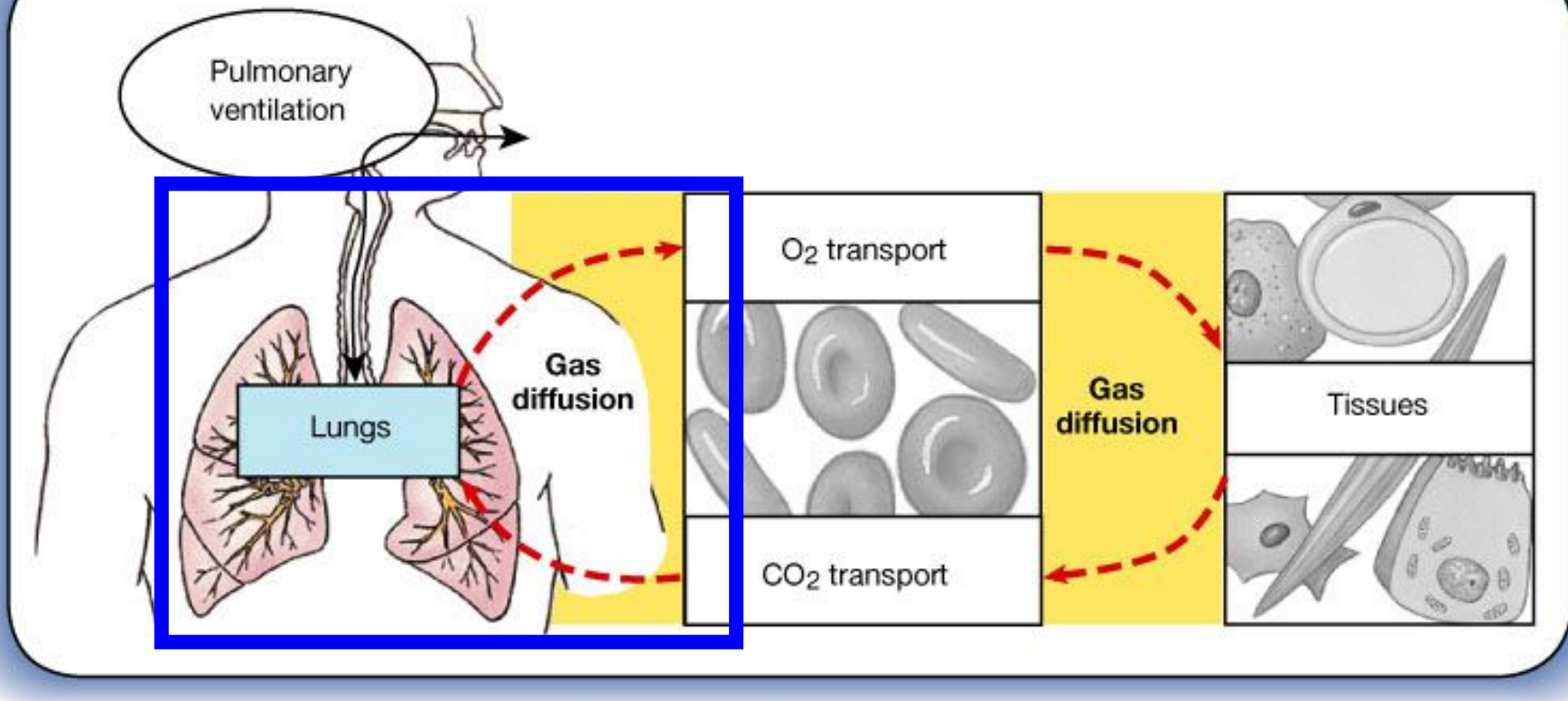
Inspiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Inspiration	① Inspiratory muscles contract (diaphragm descends; rib cage rises) ↓ ② Thoracic cavity volume increases ↓ ③ Lungs stretched; intrapulmonary volume increases ↓ ④ Intrapulmonary pressure drops (to −1 mm Hg) ↓ ⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure)		

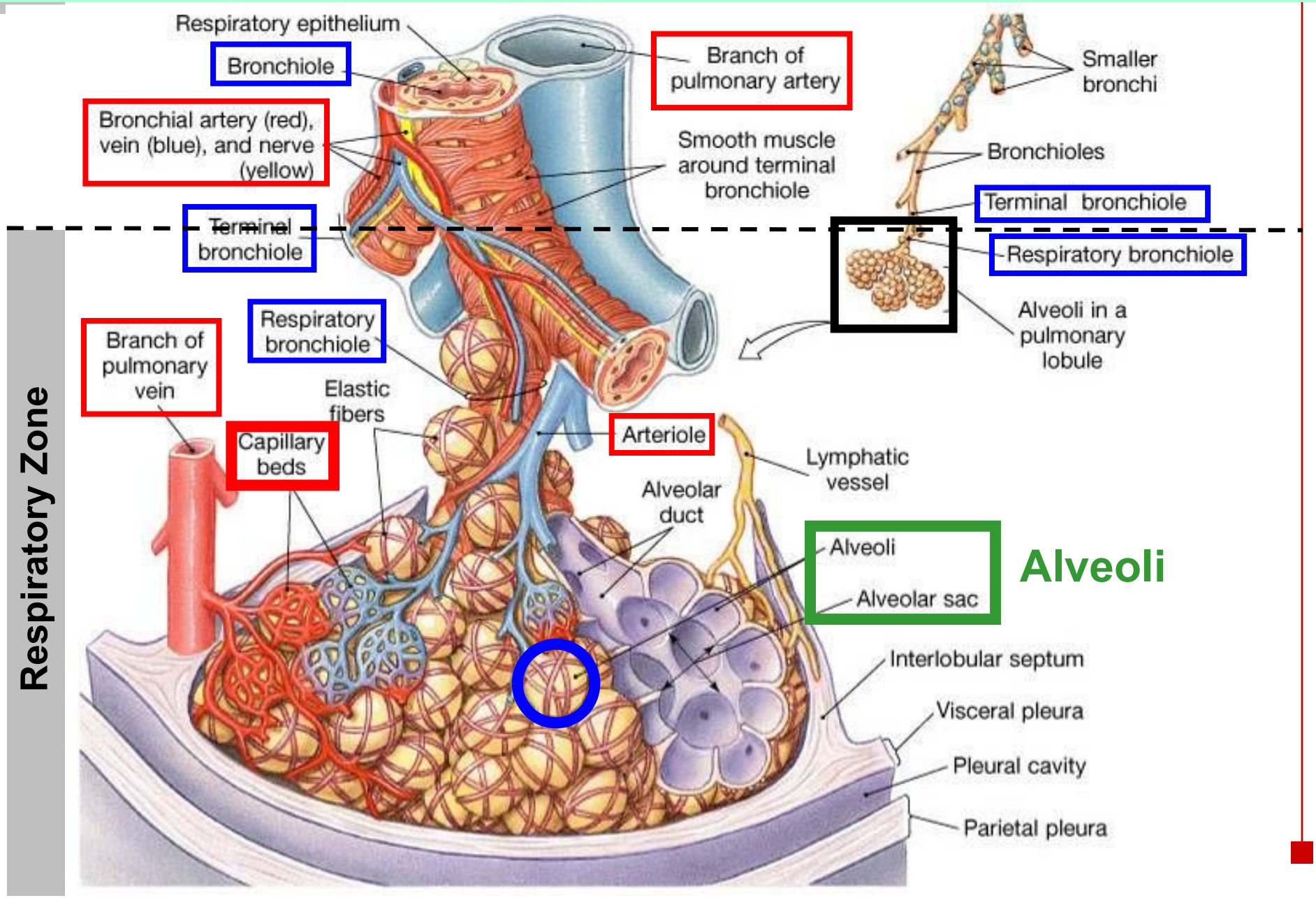
Expiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Expiration	① Inspiratory muscles relax (diaphragm rises; rib cage descends due to gravity) ↓ ② Thoracic cavity volume decreases ↓ ③ Elastic lungs recoil passively; intrapulmonary volume decreases ↓ ④ Intrapulmonary pressure rises (to +1 mm Hg) ↓ ⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0		

2a. External Respiration



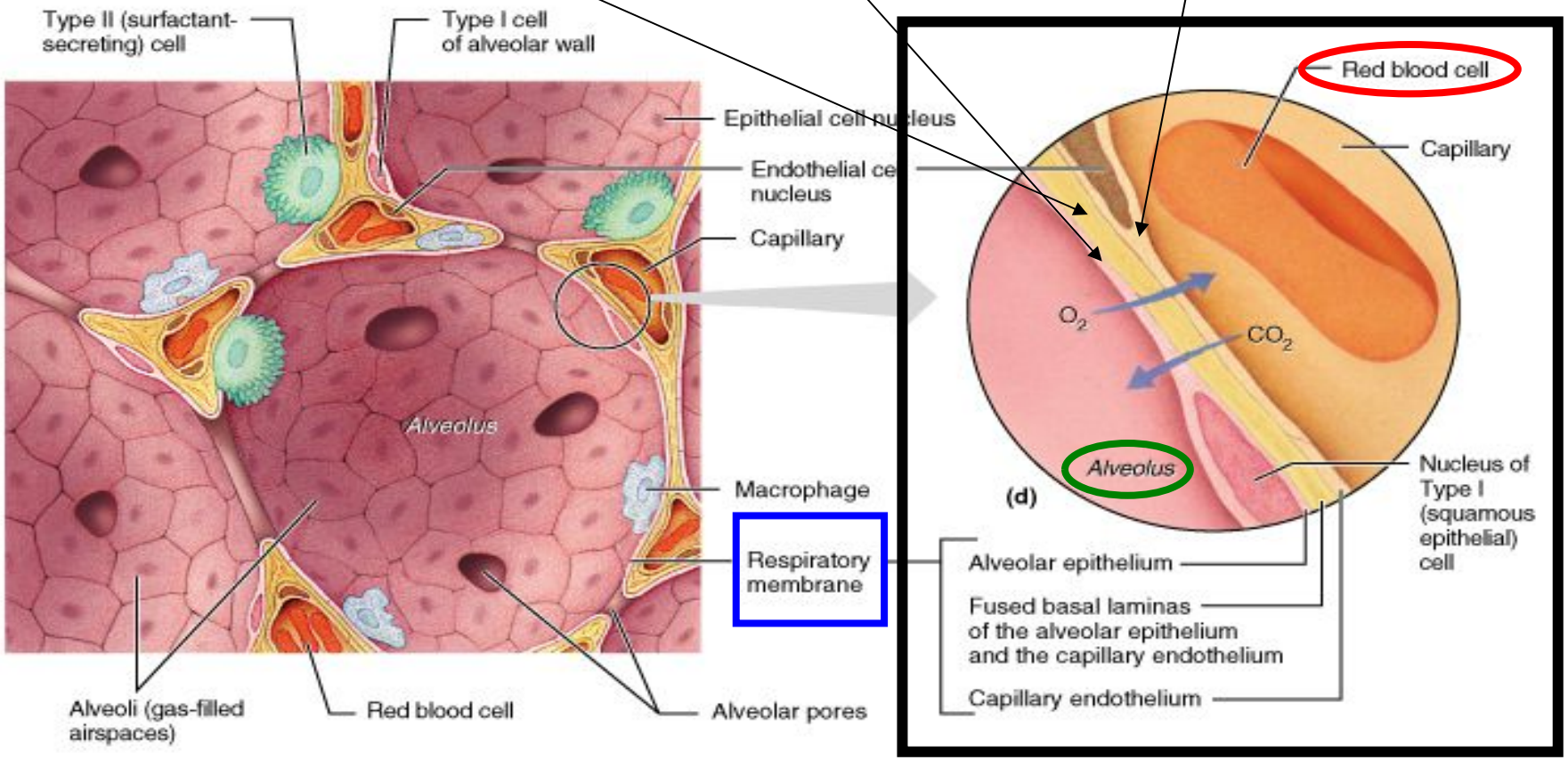
Respiratory Zone



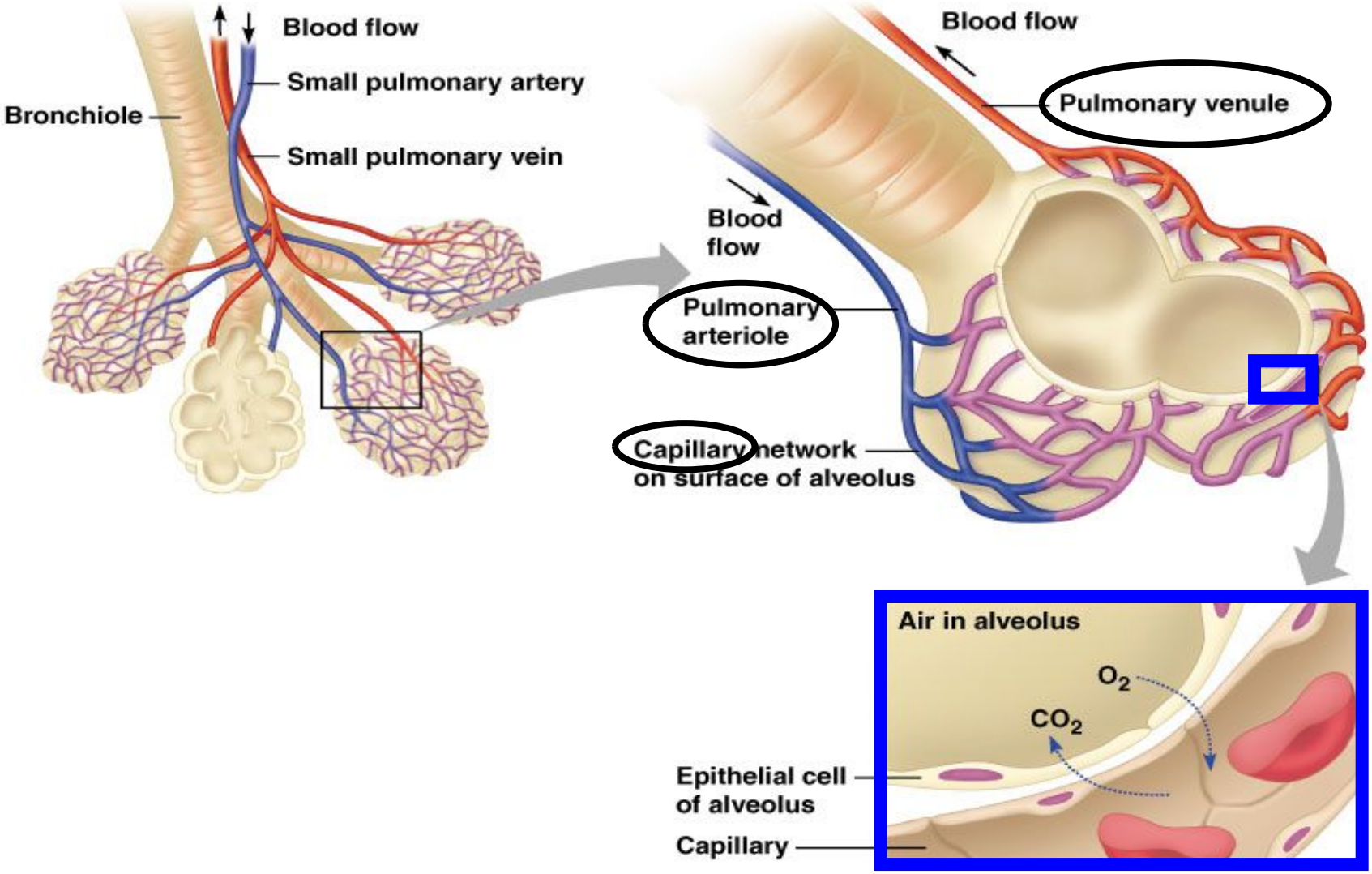
Respiratory Zone

Respiratory Membrane

- **Respiratory membrane:** barrier across which gases are exchanged between alveolar air & blood
- Consists of **alveolar epithelium**, **capillary endothelium** & their joined **basement membranes.**

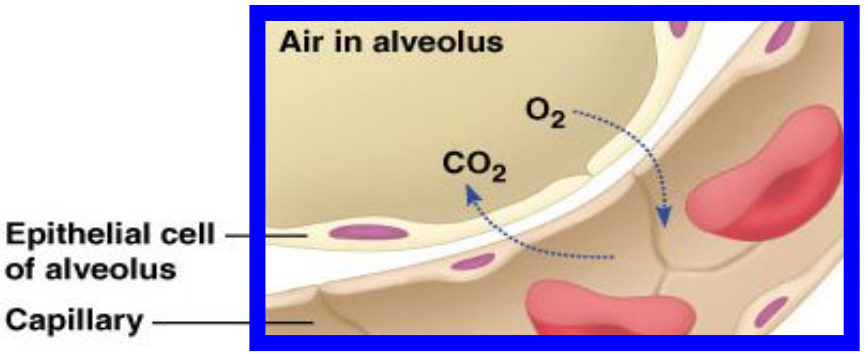


Pulmonary Gas Exchange

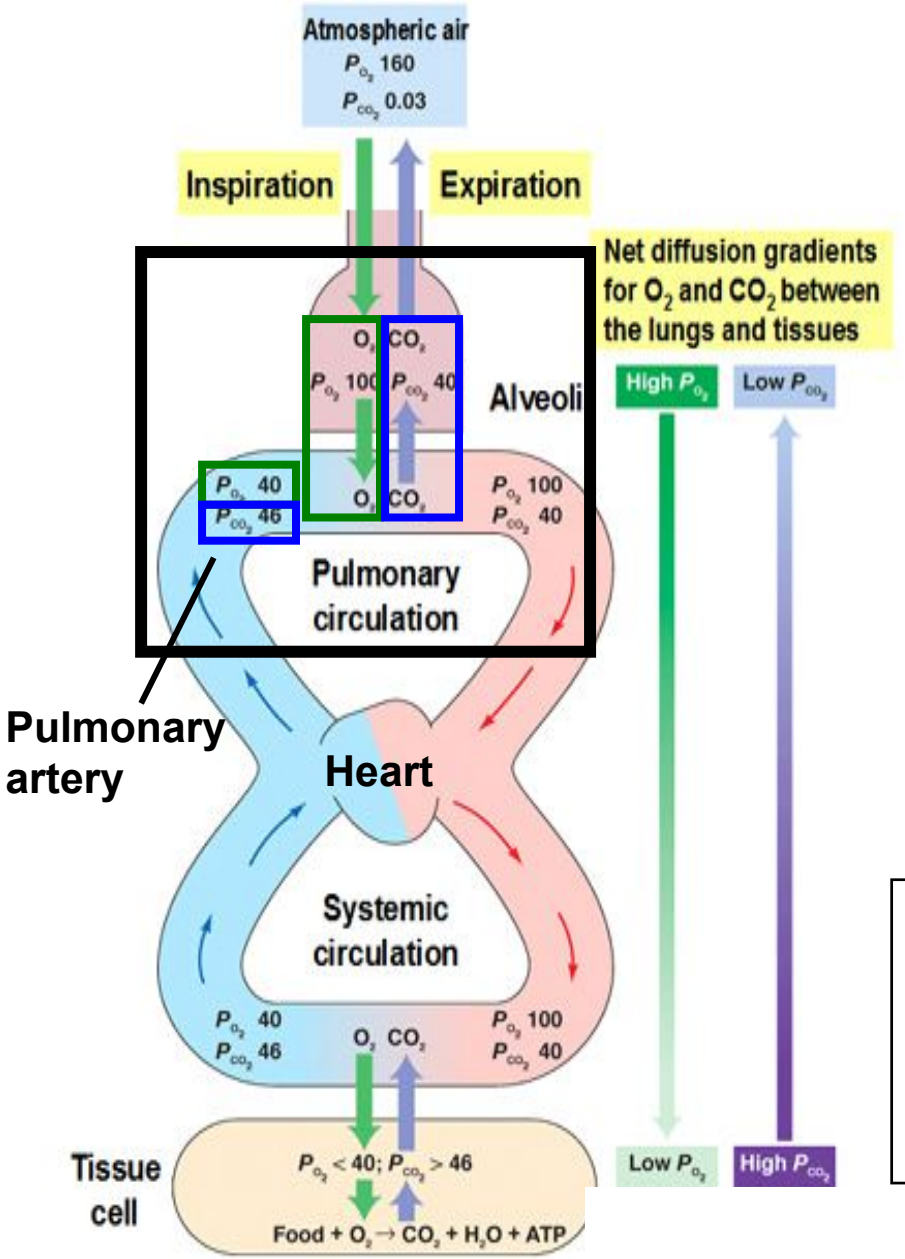


Factors Affecting Gas Movement Across Respiratory Membrane

- Partial pressure gradients & gas solubilities
- Structural characteristics of respiratory membrane (~1 μm-thick)
- Matching of alveolar ventilation & pulmonary blood perfusion:
  - At alveoli with maximal ventilation, the pulmonary arterioles dilate, increasing blood flow into associated pulmonary capillaries.
  - At alveoli with inadequate ventilation, the pulmonary arterioles constrict, blood is redirected to other respiratory areas.



Partial Pressure Gradient



Steep **O_2** partial pressure gradient

P_{O_2} in **alveoli** (100 mmHg)

vs

P_{O_2} in **pulmonary artery** (40 mmHg)

Less steep **CO_2** partial pressure gradient

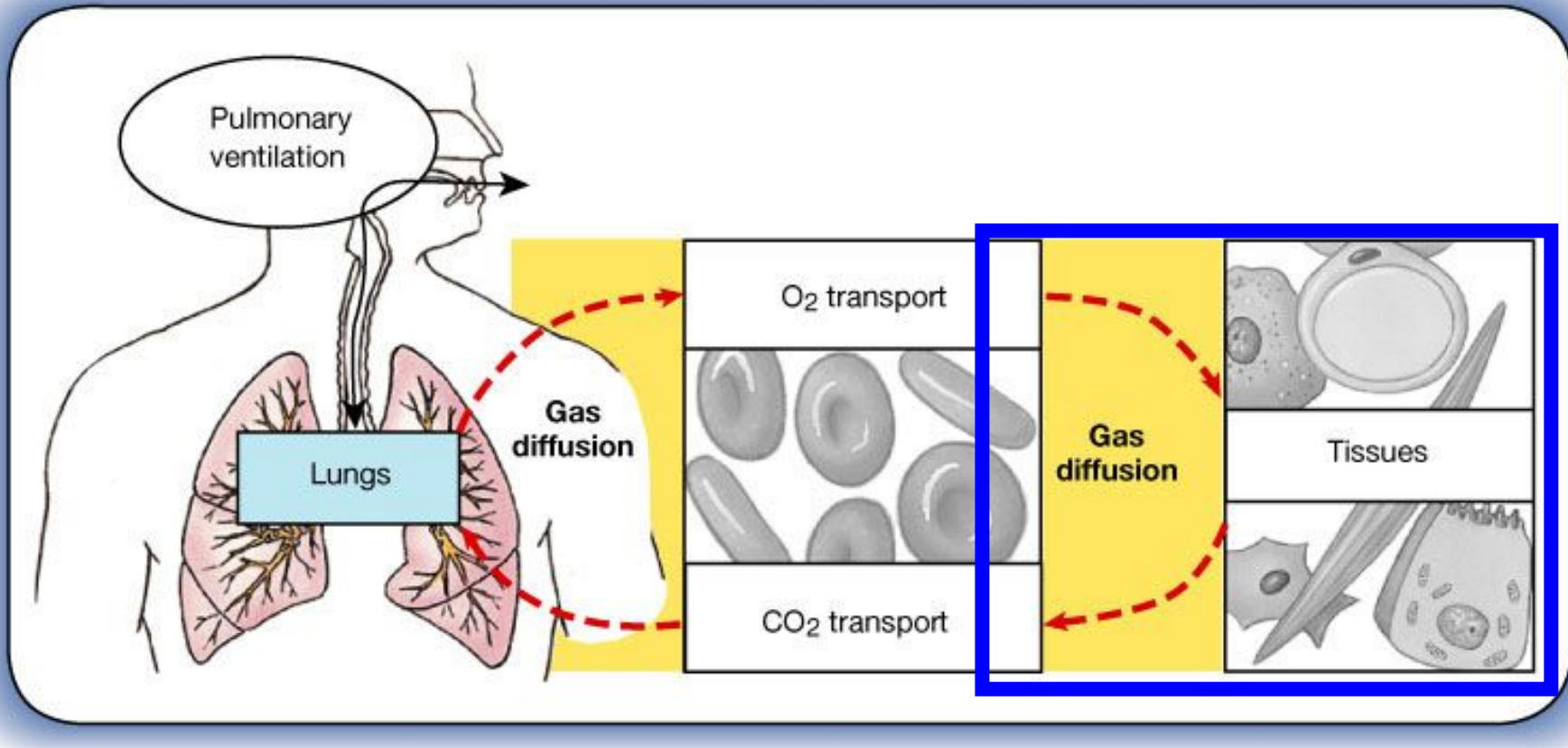
P_{CO_2} in **alveoli** (40 mmHg)

vs

P_{CO_2} in **pulmonary artery** (46 mmHg)

External respiration:
Gradients promote oxygen & carbon dioxide exchanges across respiratory membrane in lungs

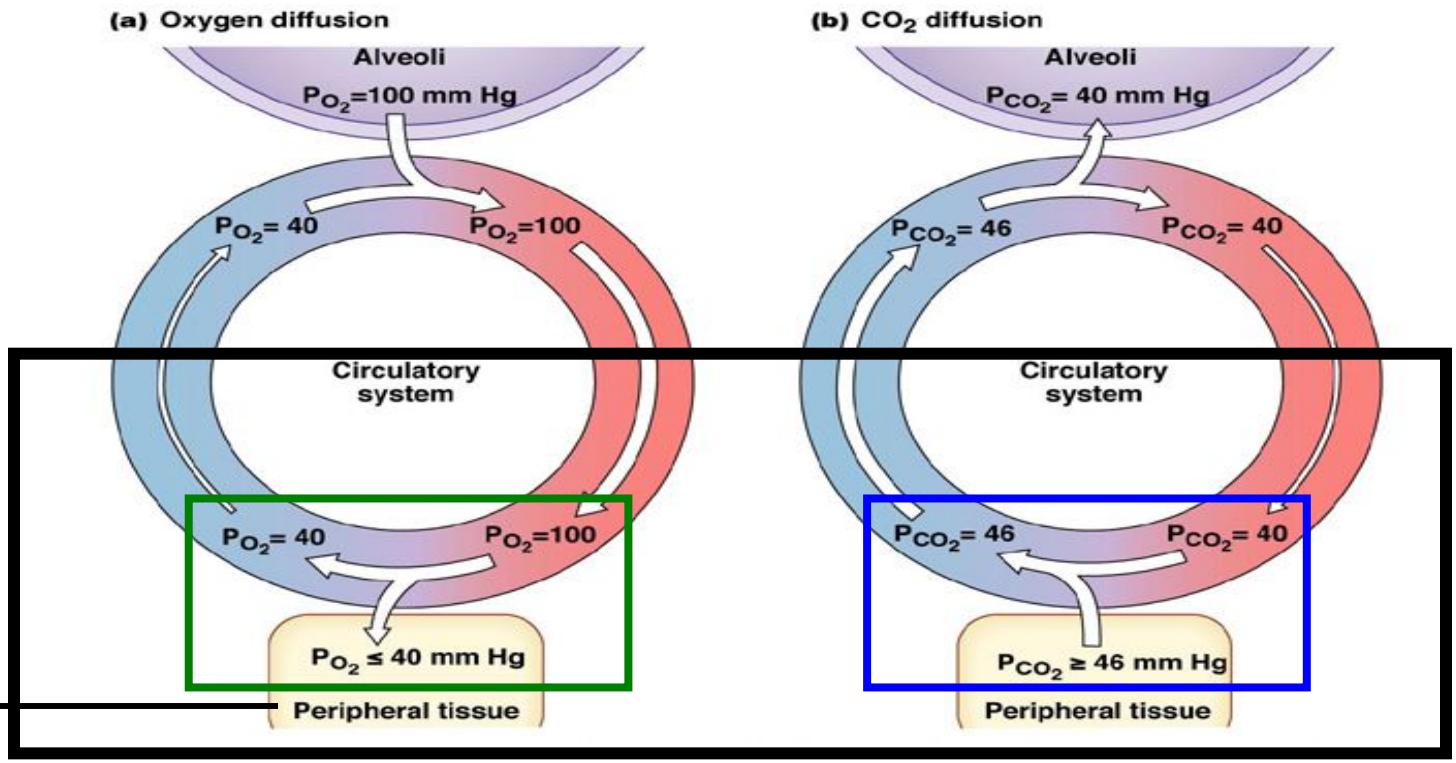
2b. Internal Respiration



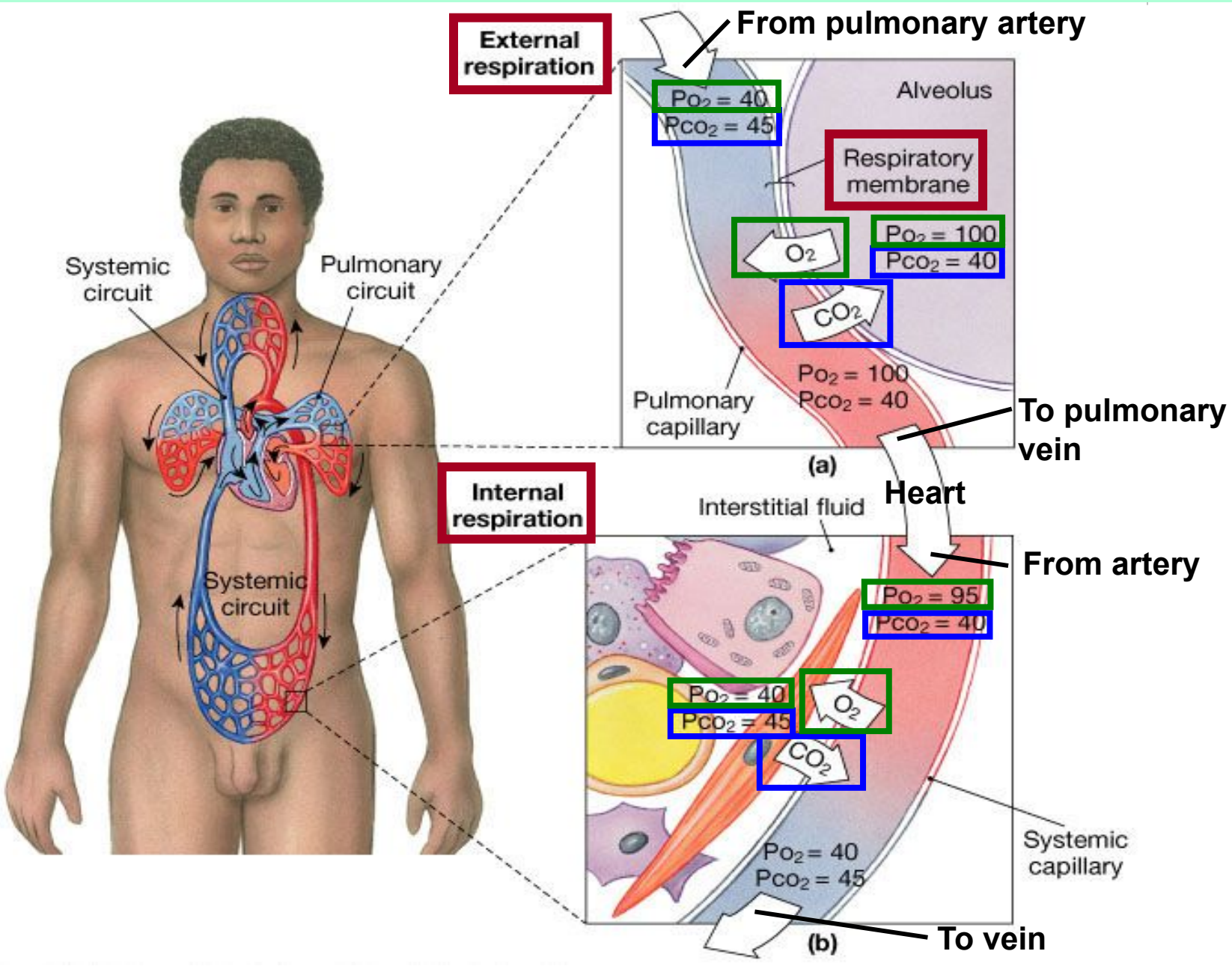
Partial Pressure Gradient

Internal respiration: Gradients promote gas movements across systemic capillary membranes in body tissues

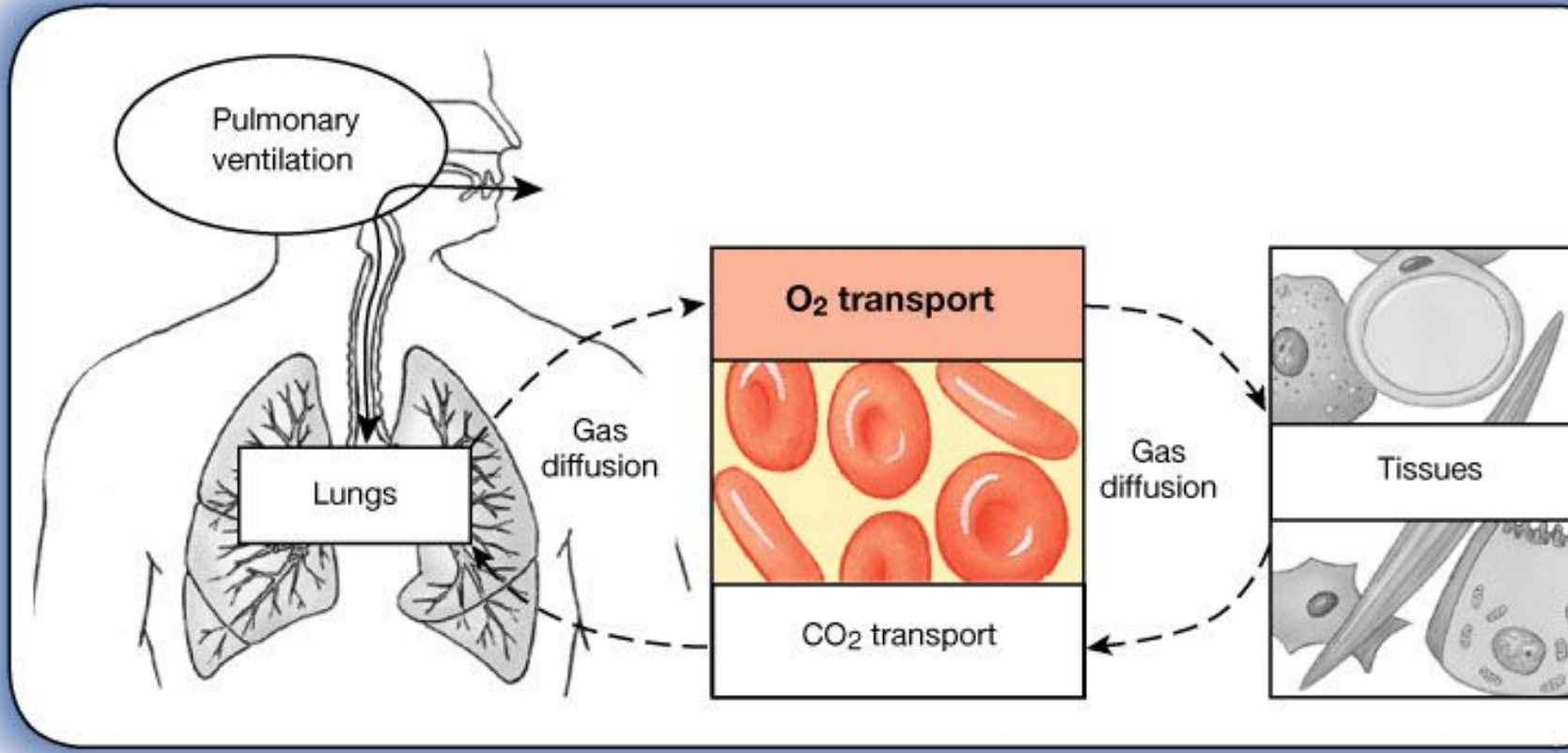
- P_{O_2} in tissue is always **lower** than in systemic arterial blood
- In venous blood draining tissues, P_{O_2} of is 40 mm Hg & P_{CO_2} is 46 mm Hg



External Respiration & Internal Respiration



3. Oxygen Transport

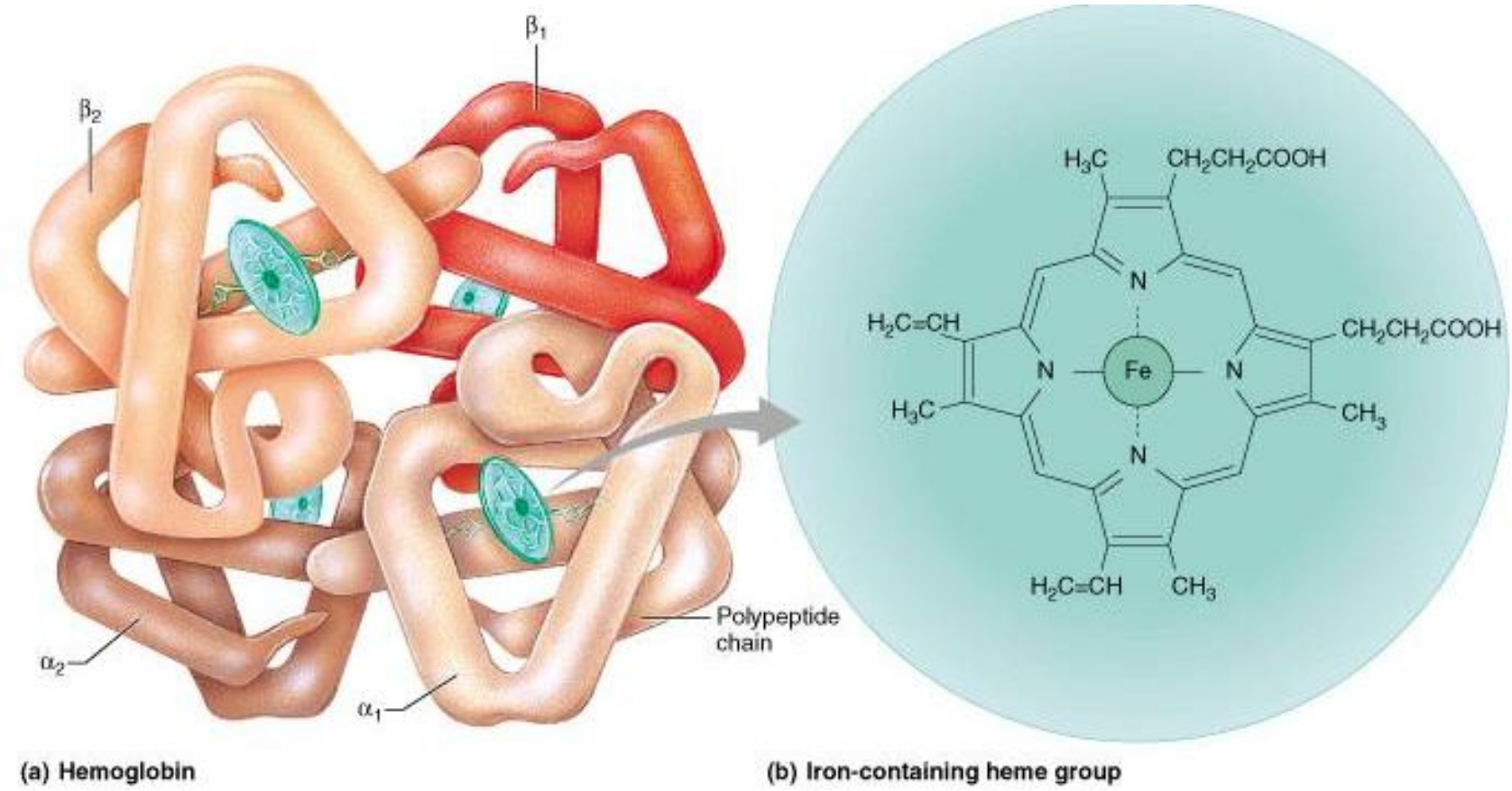


Ways of Oxygen Transport

Oxygen molecules are carried in blood in 2 ways:

(1) Dissolved in plasma

(2) Bound to hemoglobin (Hb) within RBCs



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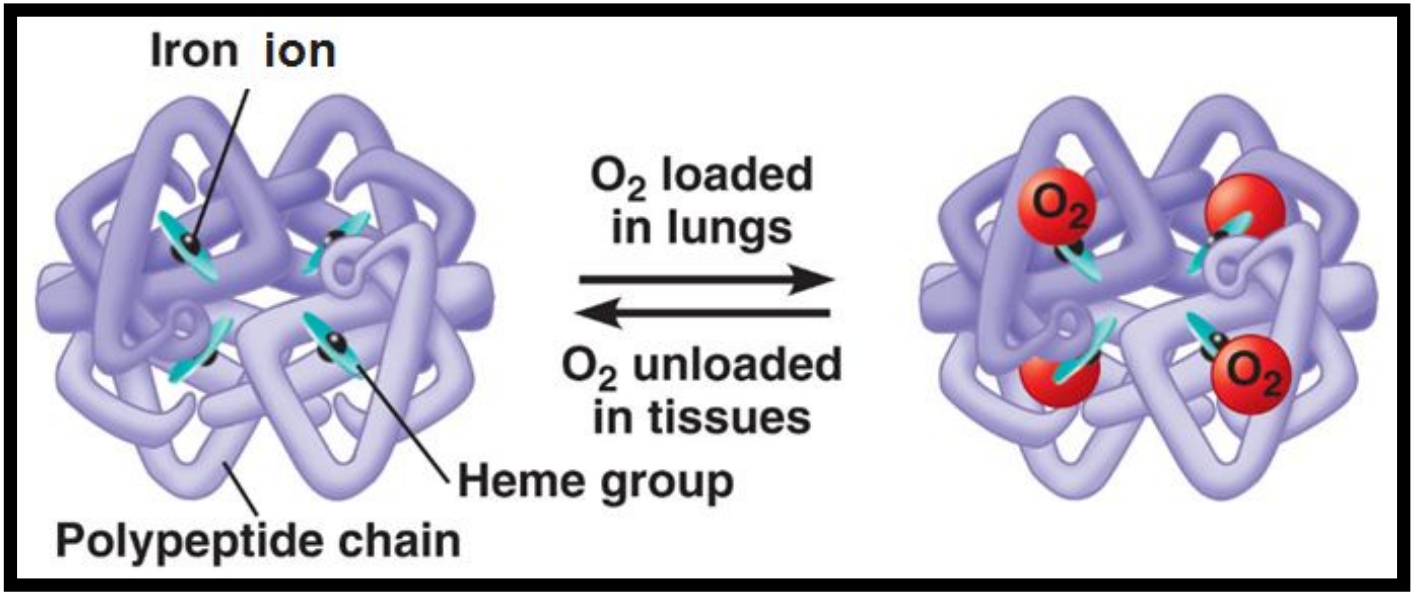


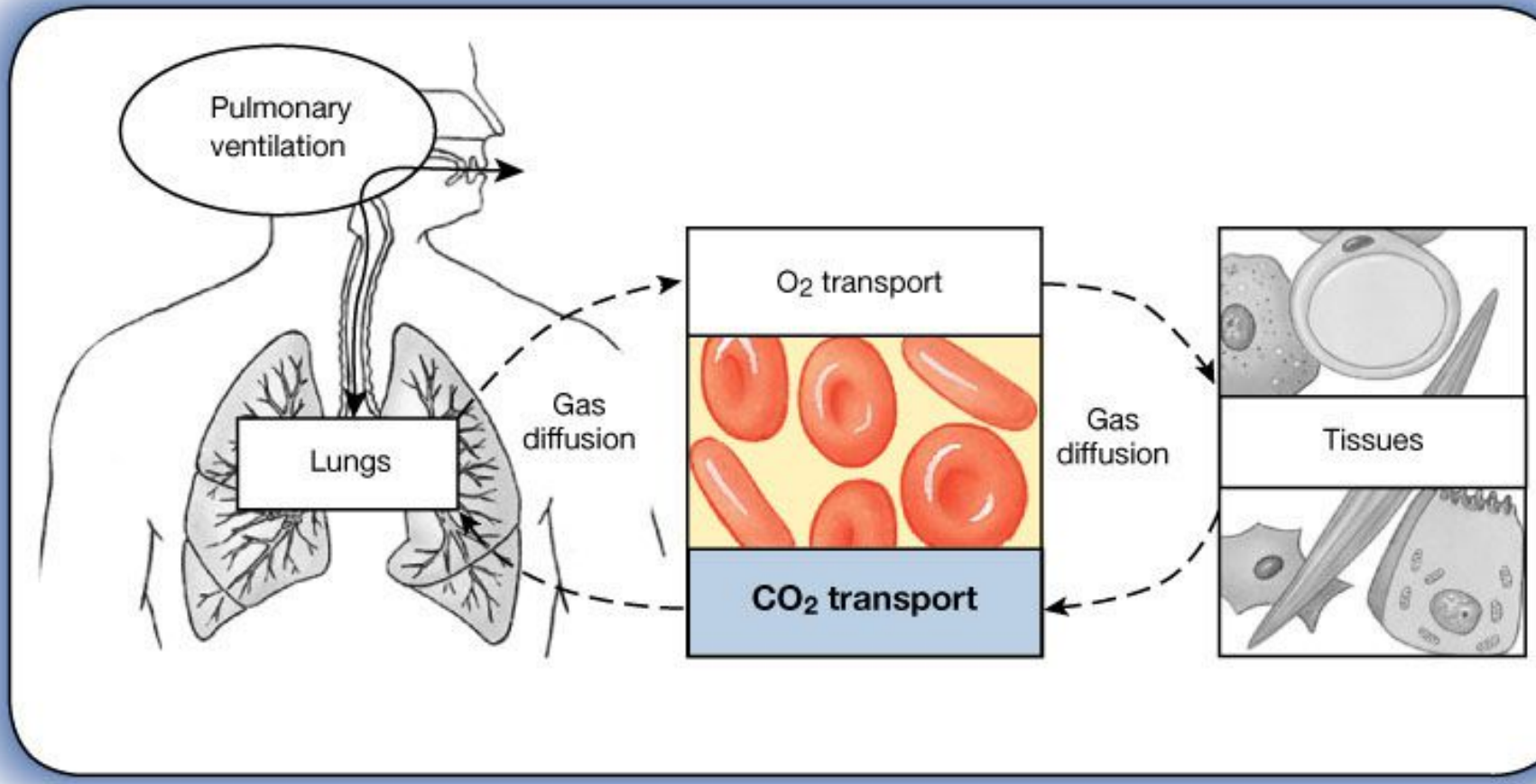
- Each hemoglobin molecule binds 4 oxygen molecules in a rapid & reversible process
- **Oxyhemoglobin (HbO_2):** Hemoglobin-oxygen combination
- **Deoxyhemoglobin:** Hemoglobin that has released oxygen

Hemoglobin (Hb)

- Fully saturated hemoglobin – when all 4 hemes are bound to oxygen
- Partially saturated hemoglobin – when 1 to 3 hemes are bound to oxygen

- Rate at which hemoglobin binds & releases oxygen is regulated by:
  - PO_2
  - PCO_2
  - Temperature
  - Blood pH

4. Carbon Dioxide Transport



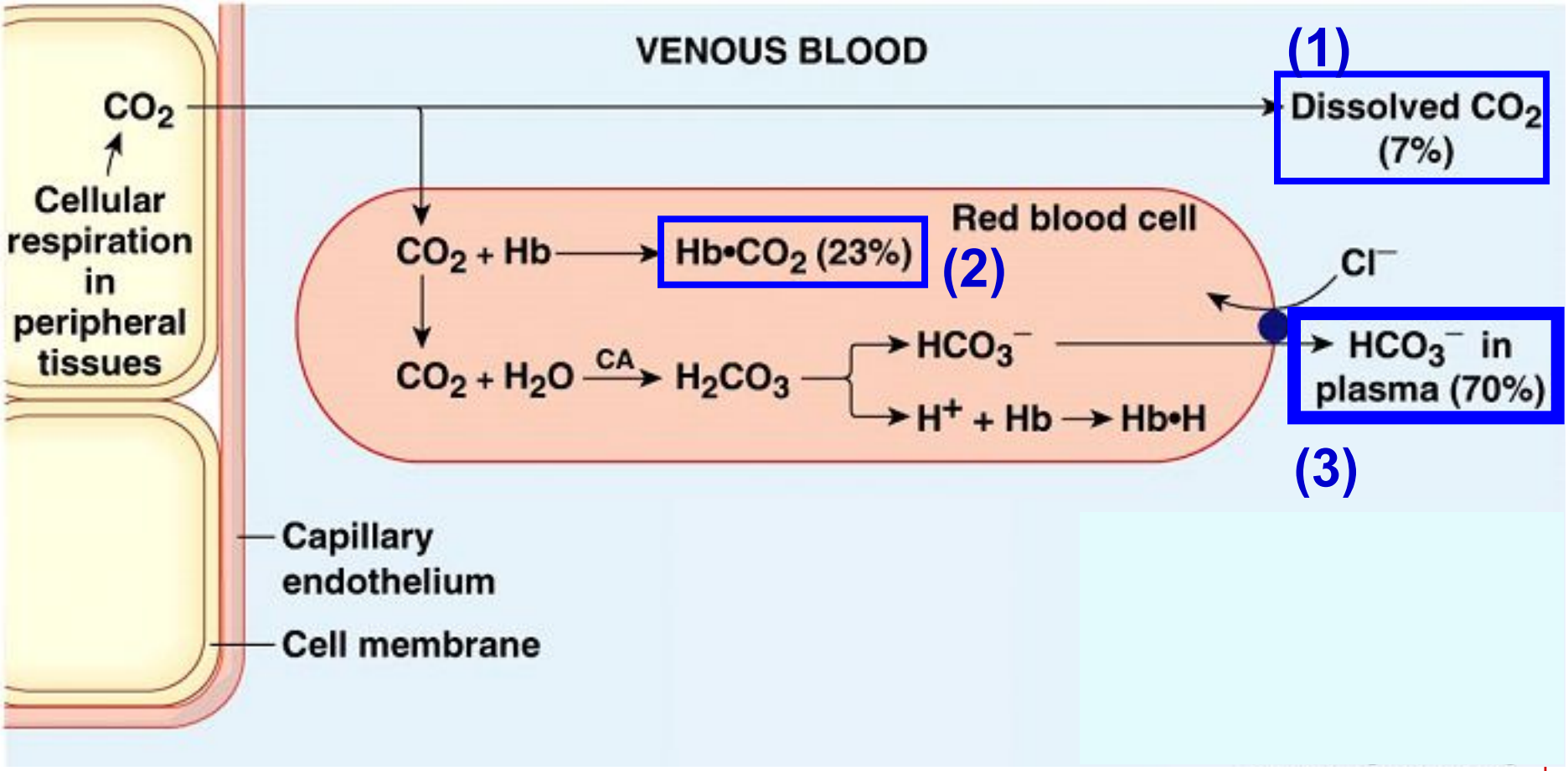
Ways of Carbon Dioxide Transport

Carbon dioxide is transported in blood in 3 forms:

(1) Dissolved in plasma	7% – 10%
(2) Bound to hemoglobin chemically	20% is carried in RBCs as carbaminohemoglobin
(3) Bicarbonate ion in plasma	70% is transported as bicarbonate (HCO_3^-)

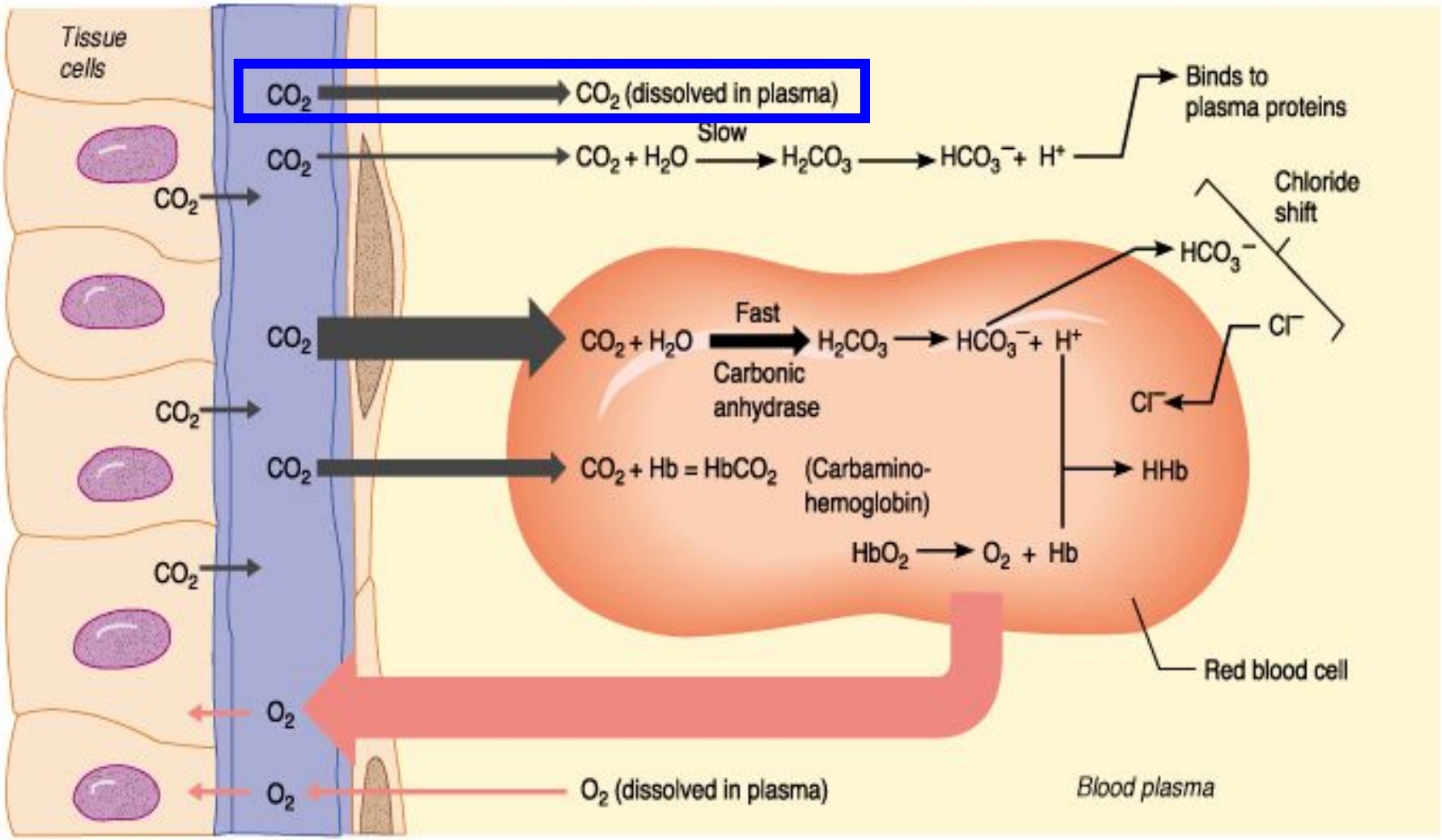
Ways of Carbon Dioxide Transport

Carbon dioxide is transported in blood in 3 forms:



Carbon Dioxide Dissolved in Plasma

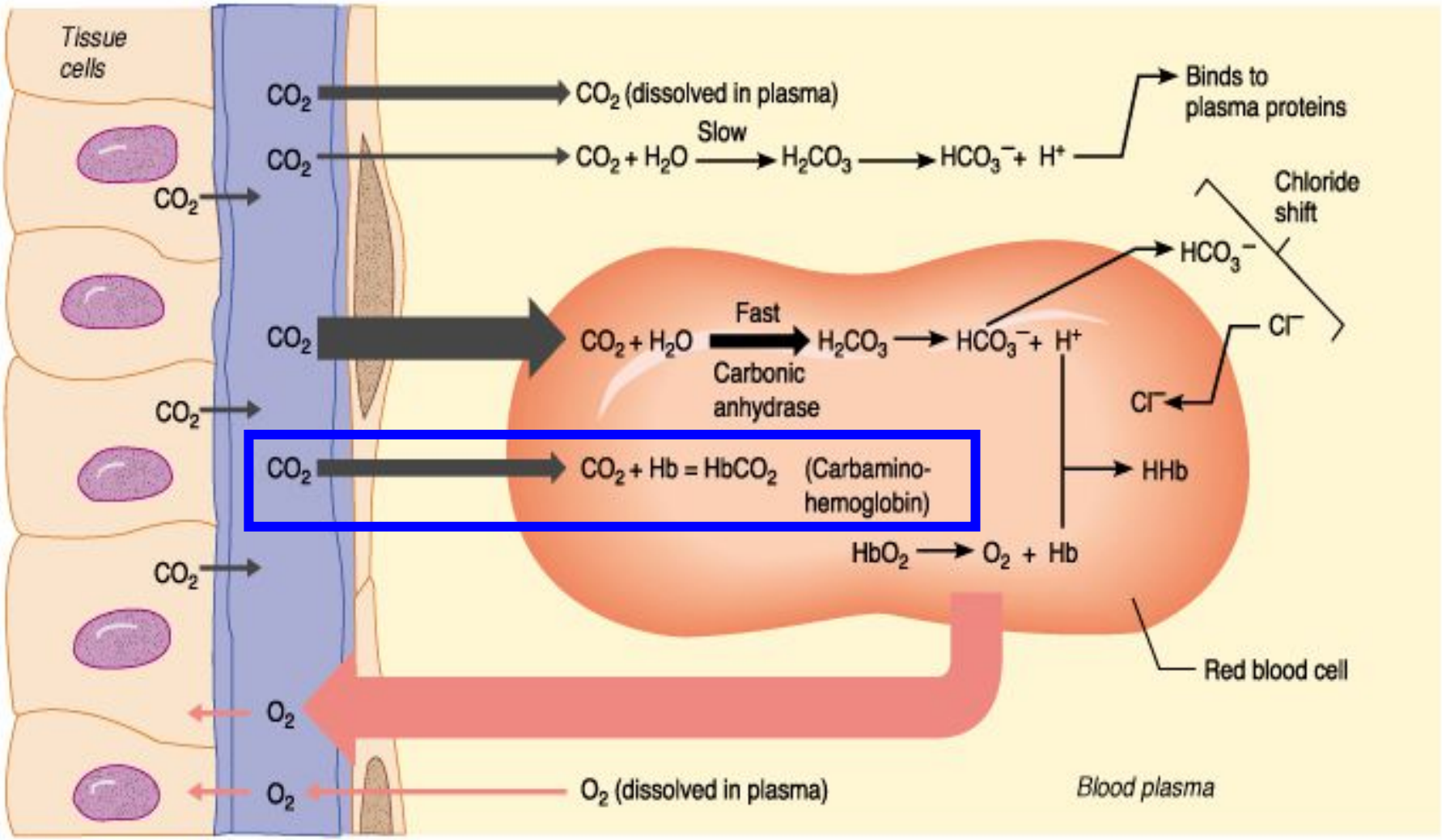
(1) CO_2 is dissolved in plasma



(a) Oxygen release and carbon dioxide pickup at the tissues

Carbon Dioxide Bound to Hemoglobin in RBC

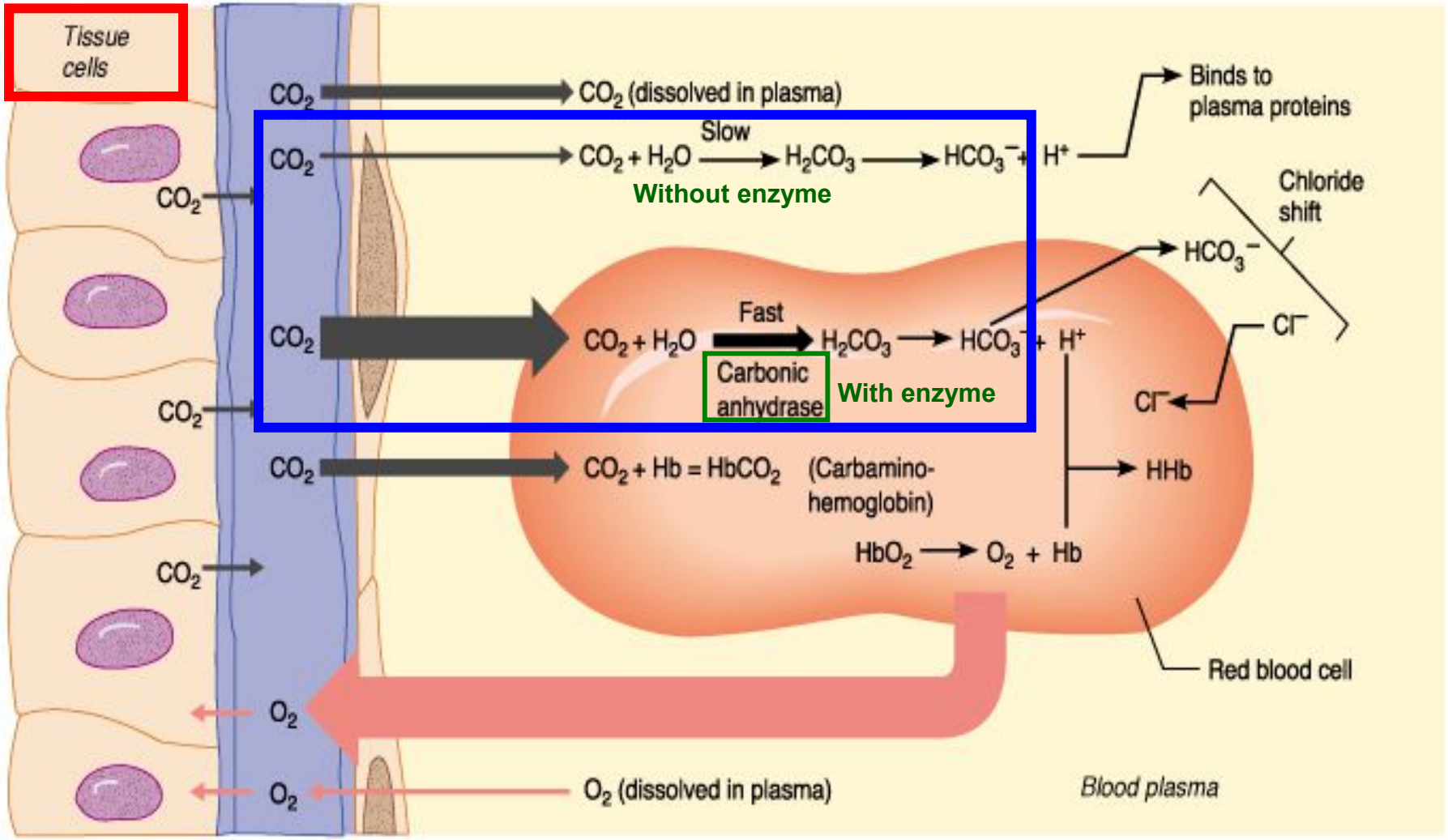
(2) CO_2 is carried within RBCs as carbaminohemoglobin



(a) Oxygen release and carbon dioxide pickup at the tissues

Carbon Dioxide As Bicarbonate Ions in Plasma

(3) CO_2 is transported as bicarbonate ions

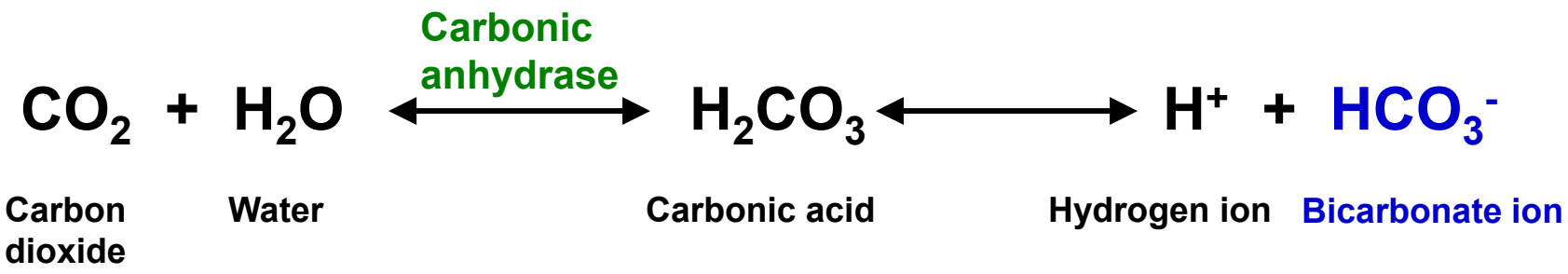


(a) Oxygen release and carbon dioxide pickup at the tissues

Carbon Dioxide As Bicarbonate Ions in Plasma

At tissues:

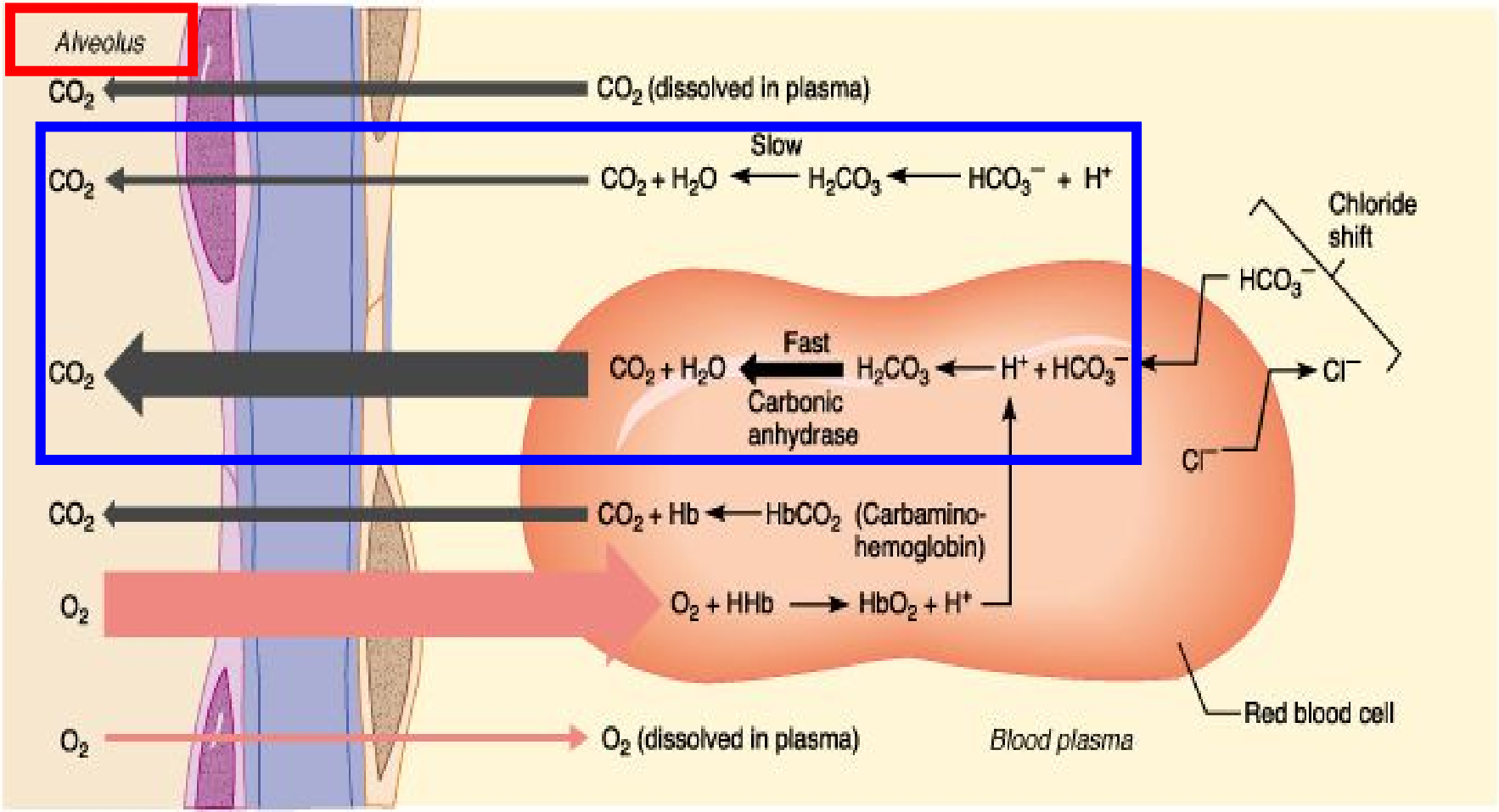
- CO_2 diffuses into RBCs & combines with water to form carbonic acid (H_2CO_3)
- H_2CO_3 quickly dissociates into hydrogen ions & **bicarbonate ions (HCO_3^-)**



- **HCO_3^-** diffuses from **RBCs** into **plasma**

Carbon Dioxide As Bicarbonate Ions in Plasma

At lungs:



(b) Oxygen pickup and carbon dioxide release in the lungs

Carbon Dioxide As Bicarbonate Ions in Plasma

At lungs:

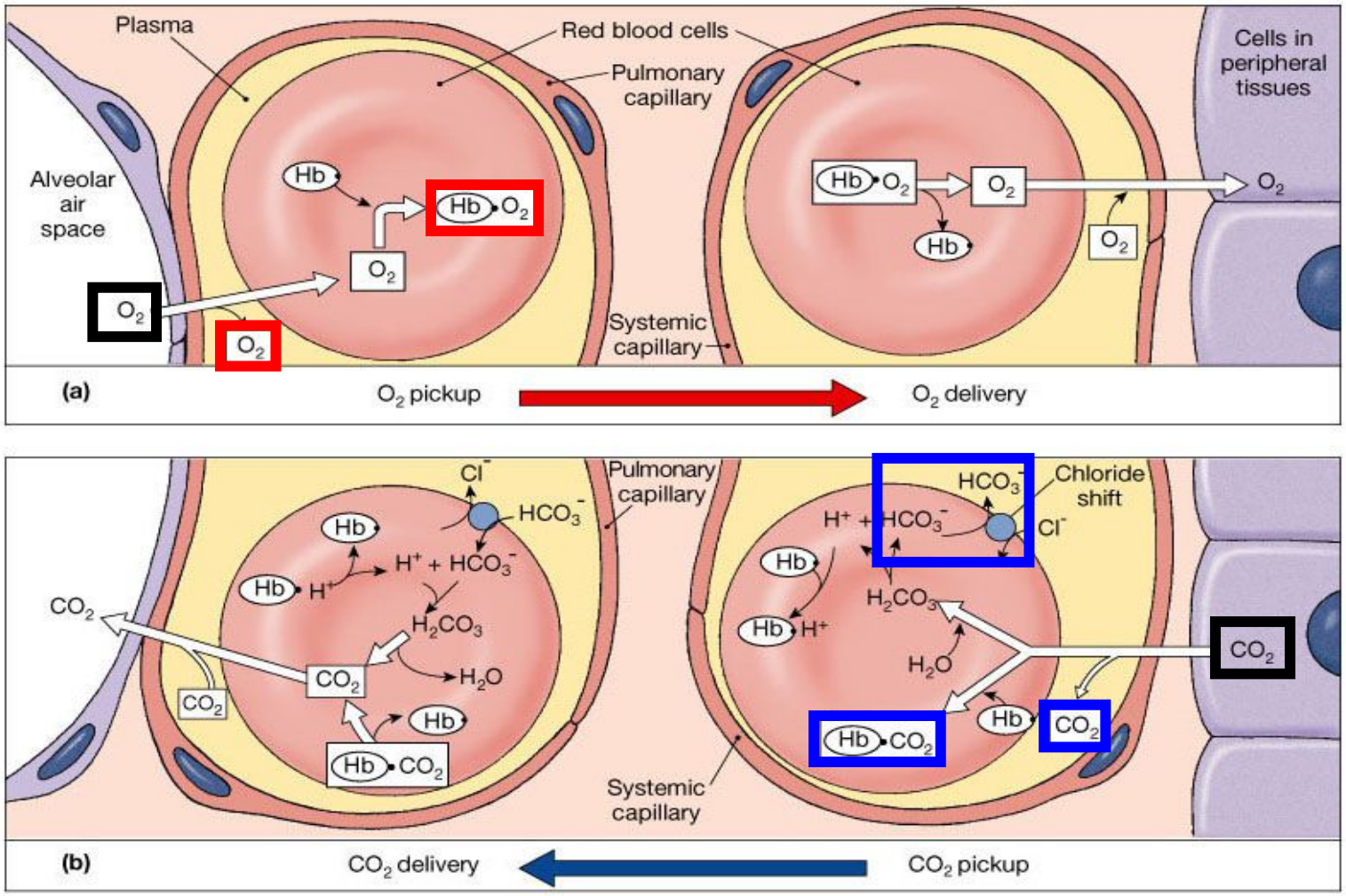
Processes are reversed:

- Bicarbonate ions move into RBCs & combine with hydrogen ions to form carbonic acid
- Carbonic acid is then split by carbonic anhydrase to release CO_2 & water
- CO_2 diffuses from **blood** into **alveoli**

Gas Exchange & Transport (Overall)

- Driven by differences in partial pressure
- Oxygen enters blood at lungs & leaves at tissues
- Carbon dioxide enters blood at tissues & leaves at lungs

Lung



Tissue

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