Gas Exchange & Transport

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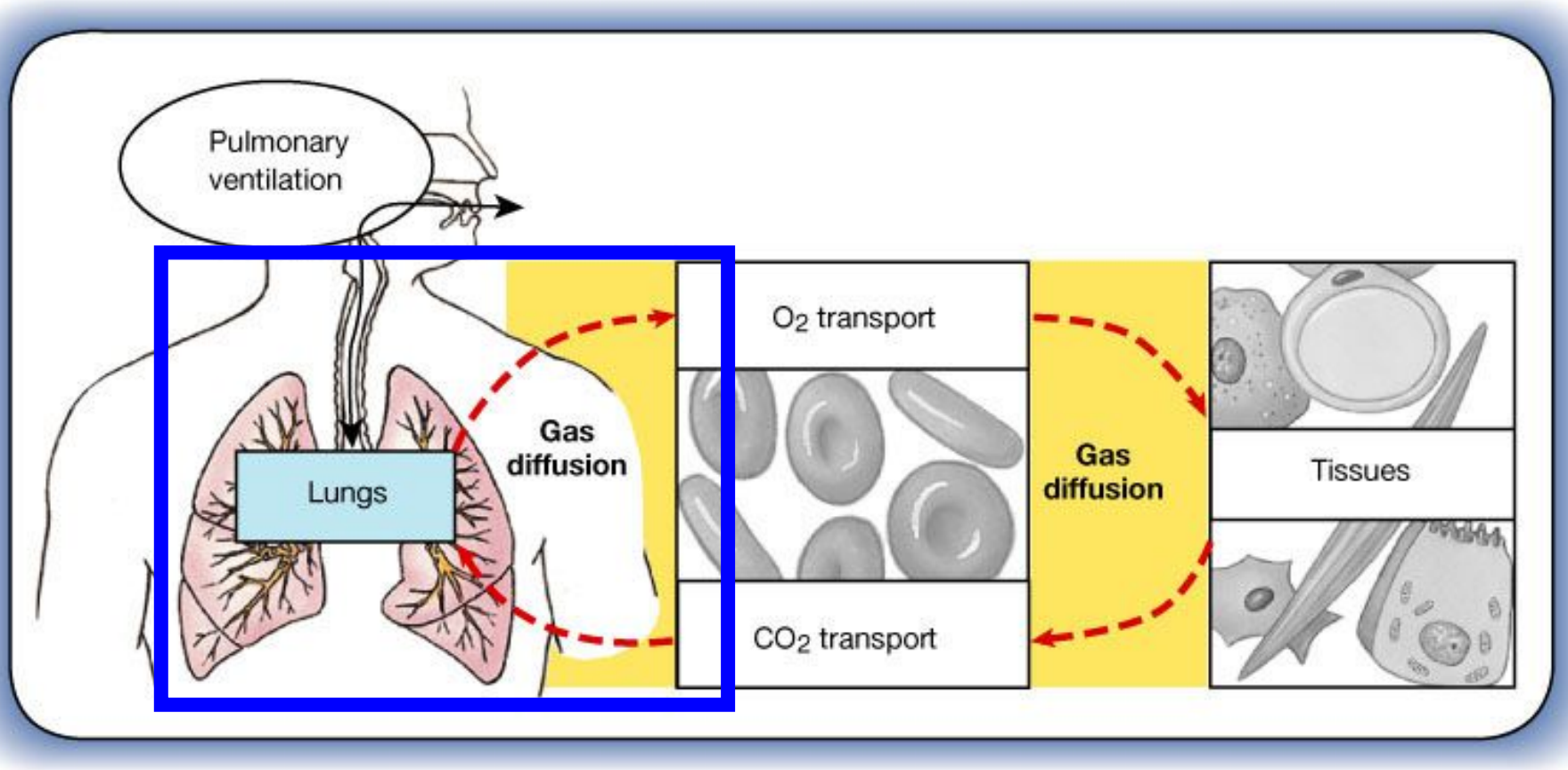
Processes in Respiration

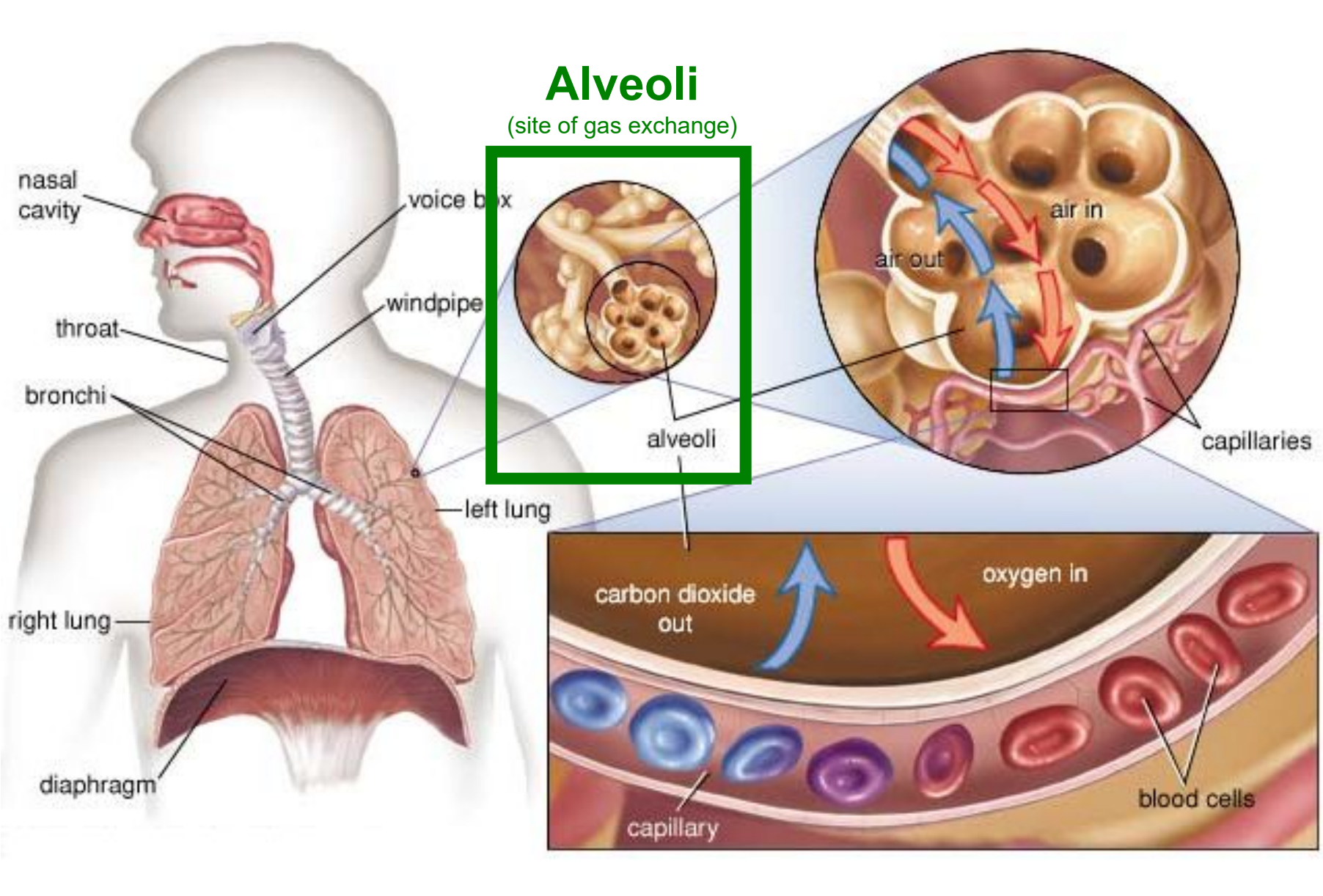
- To supply the body with oxygen & dispose of carbon dioxide

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

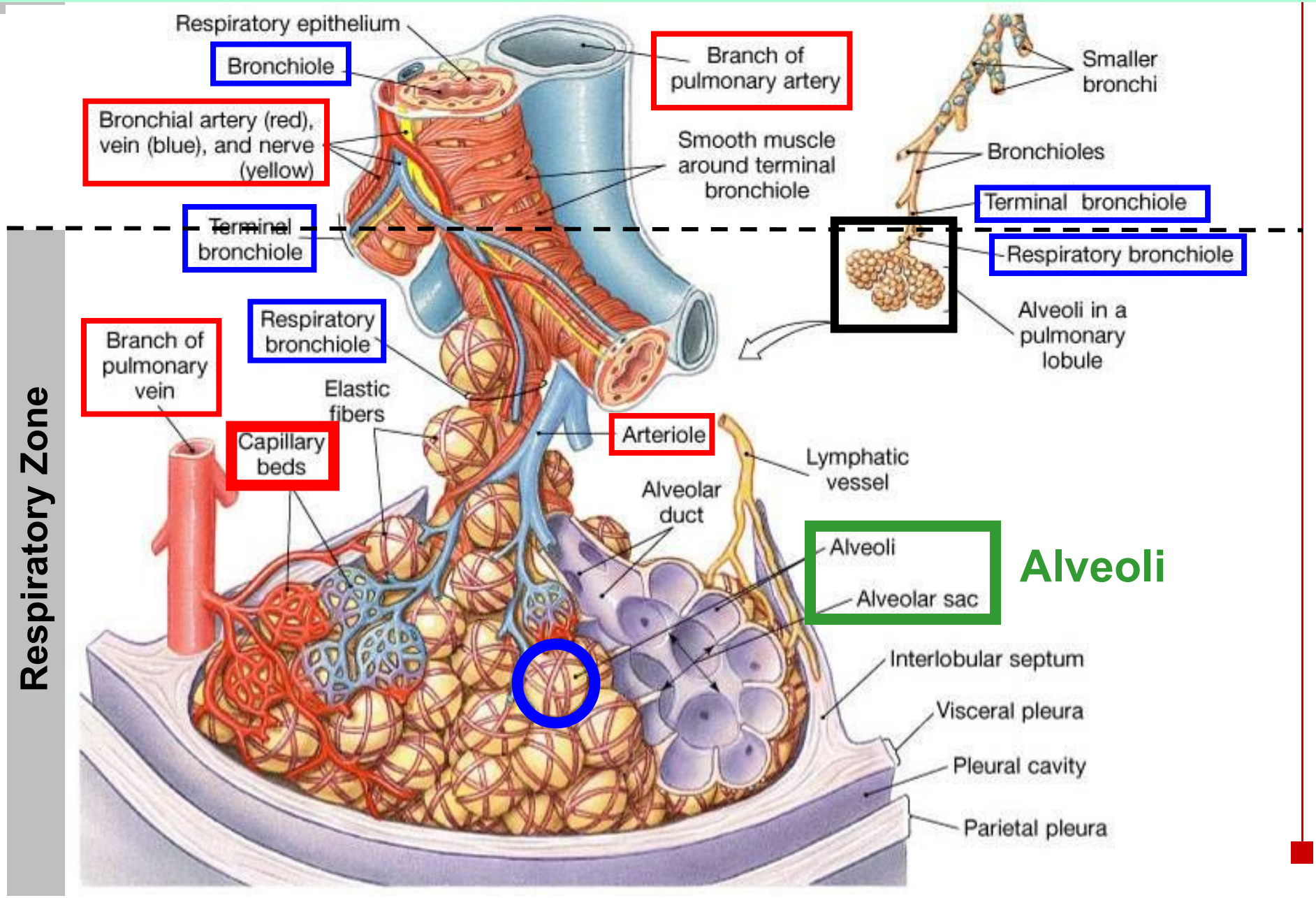
External Respiration



Respiratory Zone



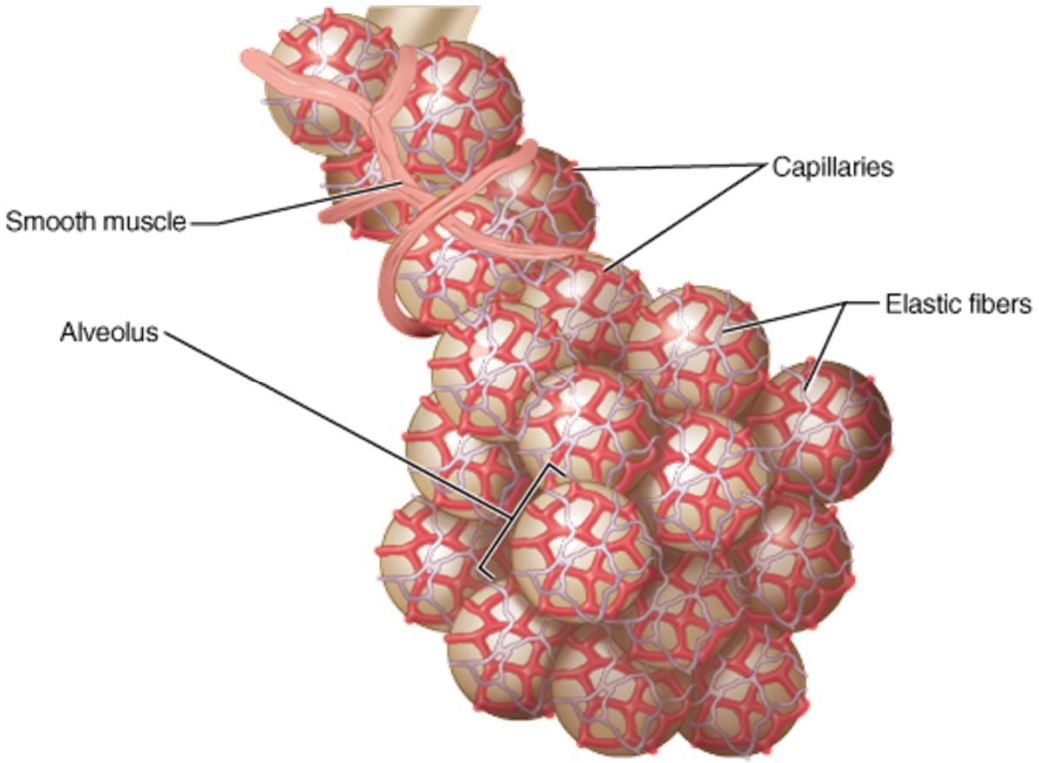
Respiratory Zone



Respiratory Zone

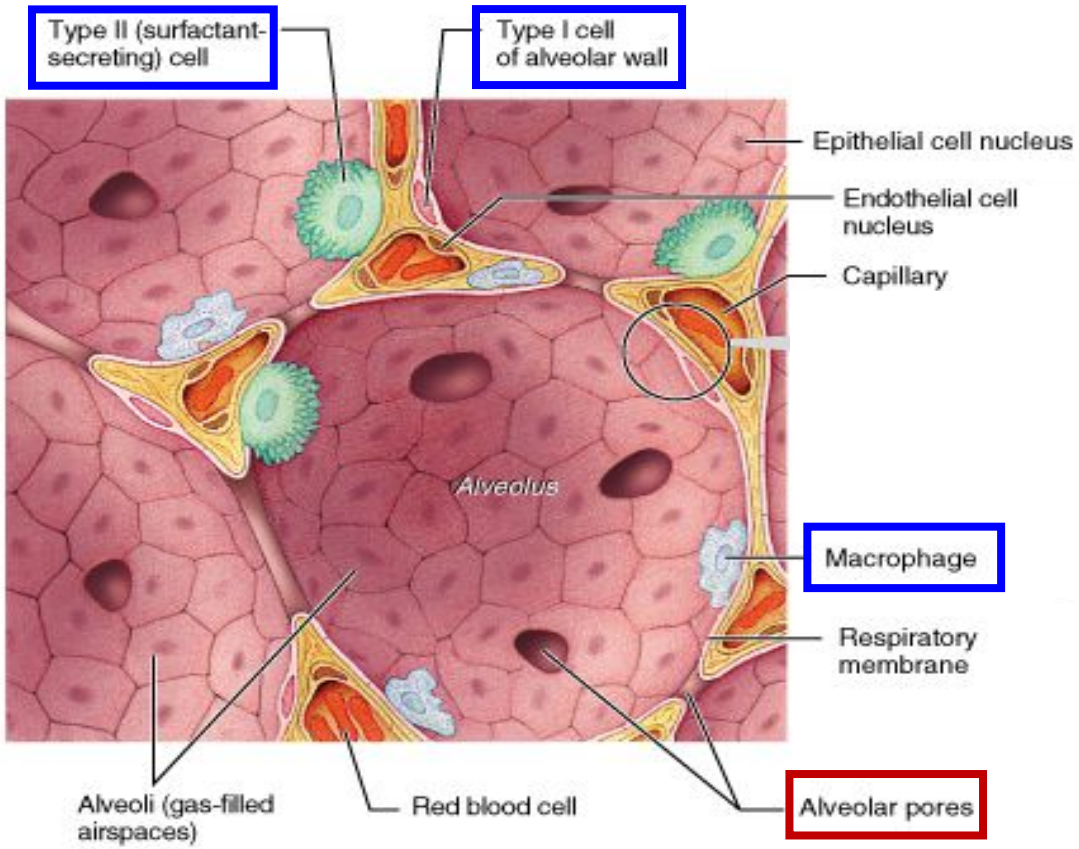
Alveoli

- ~ 600 million **alveoli** (both lungs)
- Account for most of lungs volume
- Provide tremendous surface area for gas exchange (~50 m^2)
- Surrounded by fine elastic fibers
- Densely covered with a cobweb of pulmonary capillaries



Alveoli

- **Type I cells:** Single layer of squamous epithelial cells that form alveolar wall
- **Type II cells:** Secrete **surfactant** that coats the alveolar surfaces exposed to gas
- **Macrophages:** Keep alveolar surfaces sterile



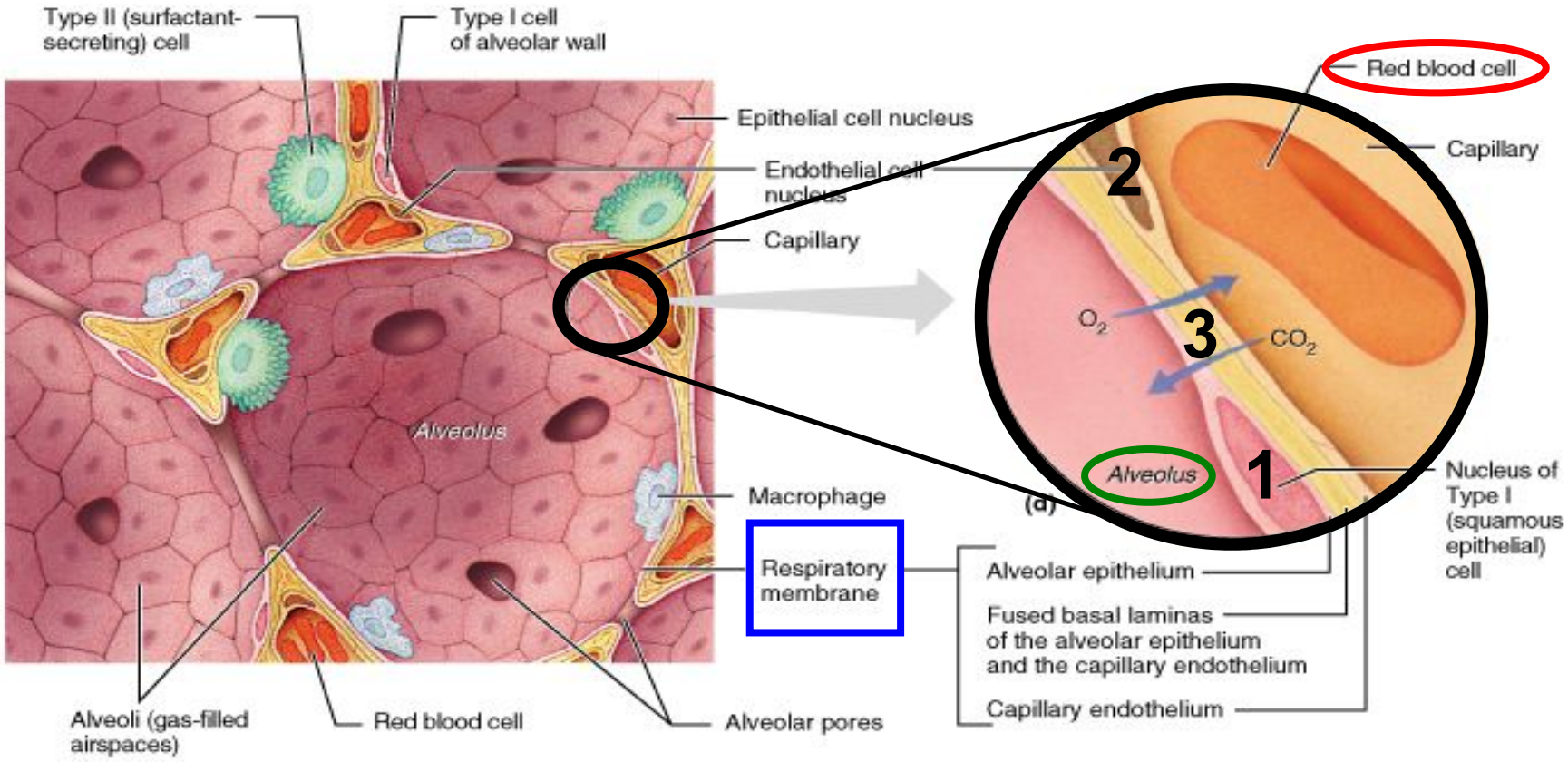
Alveolar pores:

- Connect adjacent alveoli
- Equalize air pressure throughout the lung

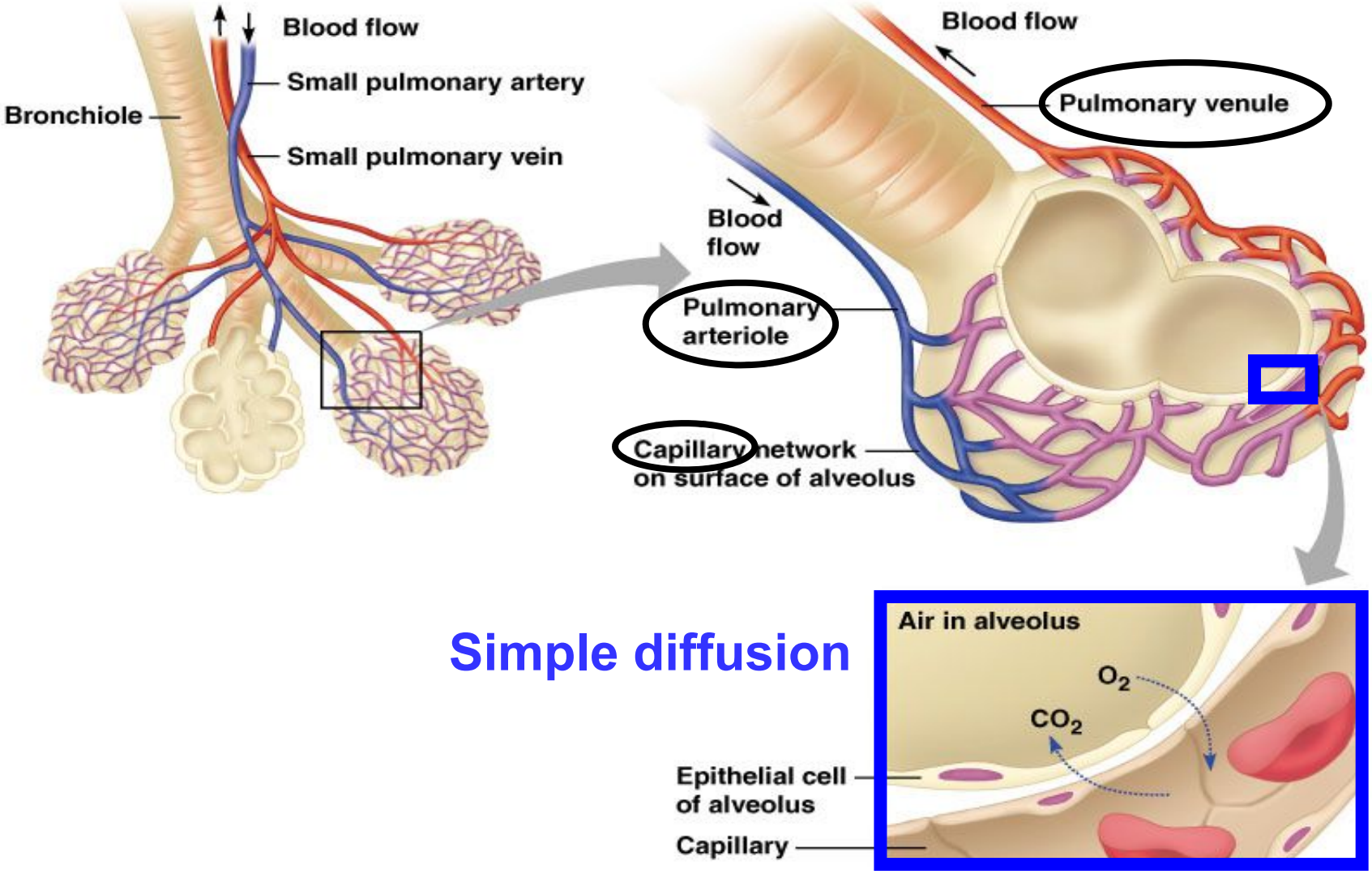
Respiratory Membrane

Respiratory membrane:

- Barrier across which gases are exchanged between alveolar air & blood
- Consists of (1) **alveolar epithelium**, (2) **capillary endothelium** & (3) their joined **basement membranes**



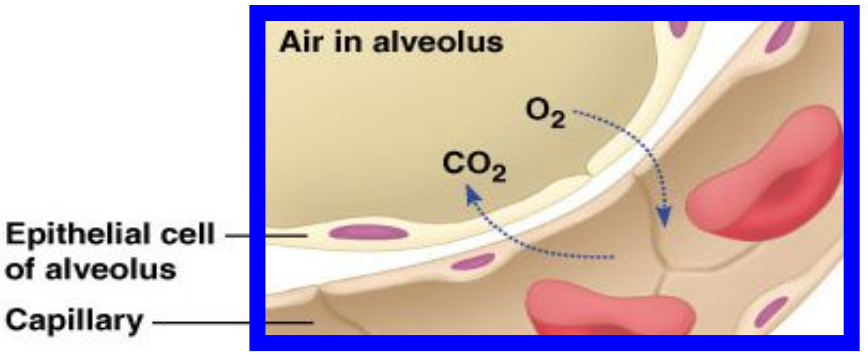
Pulmonary Gas Exchange



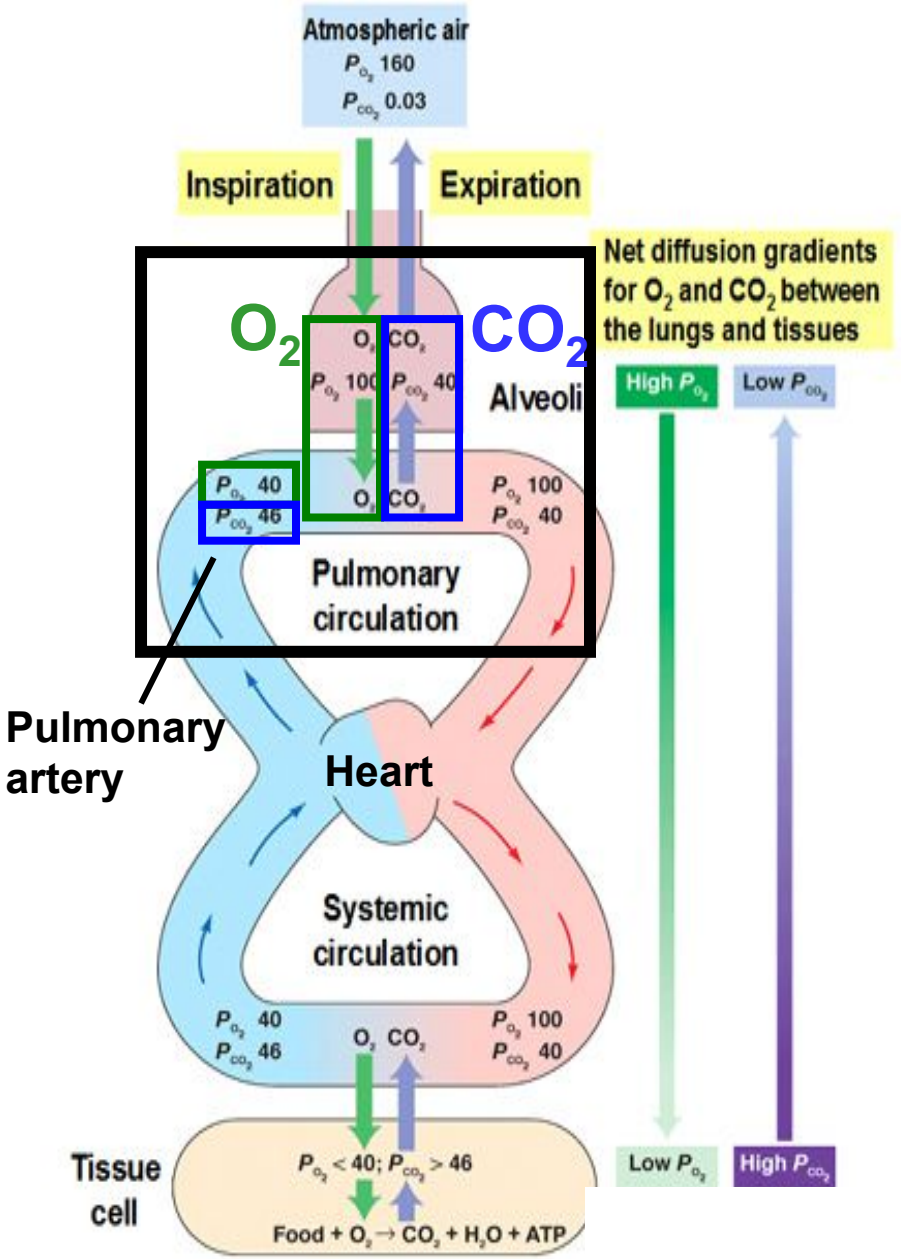
Pulmonary Gas Exchange

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, redirecting blood to other respiratory areas.



External Respiration



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

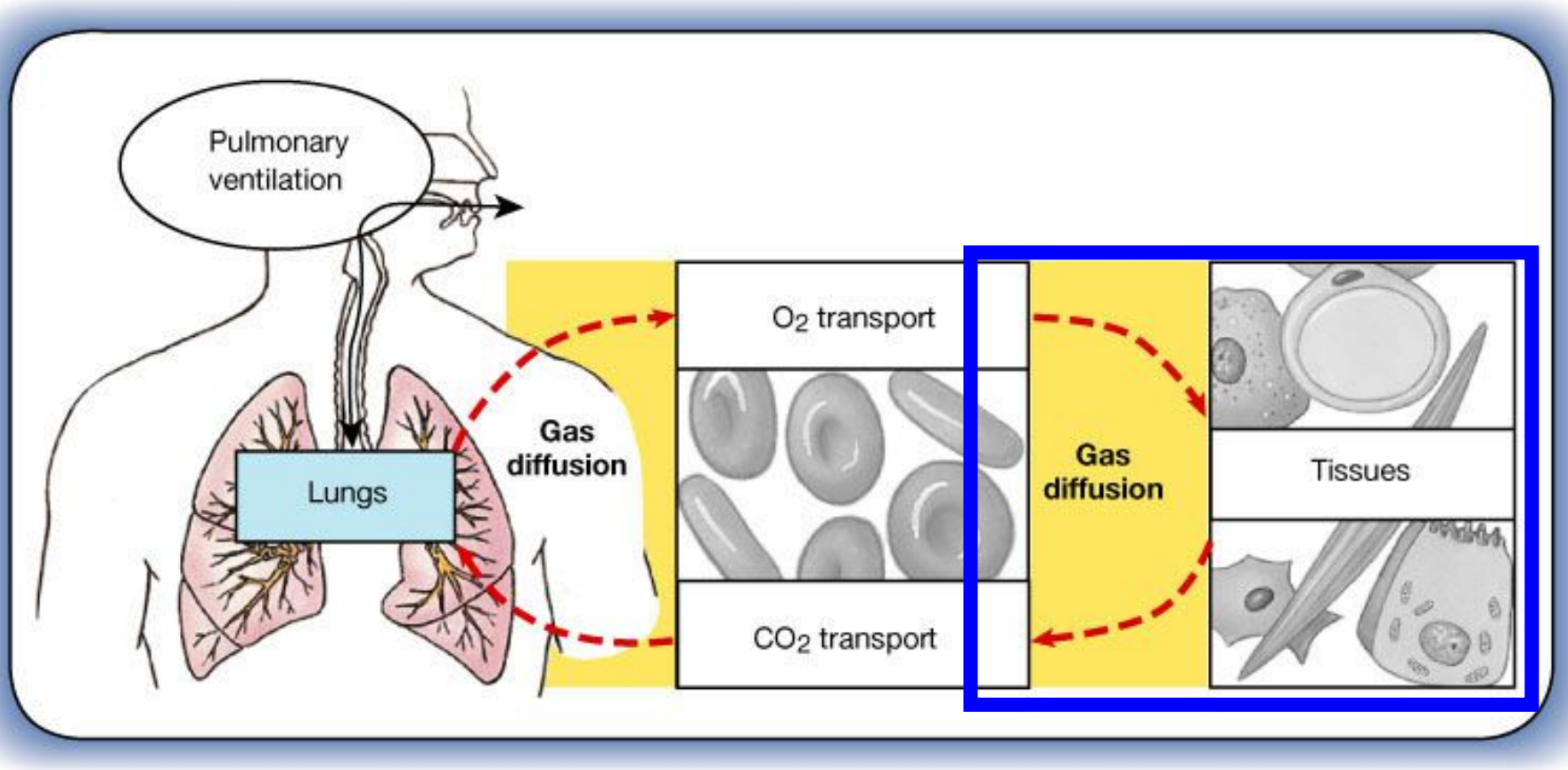
P_{CO_2} in **pulmonary artery** (46 mmHg)

vs

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

Gradients promote O_2 & CO_2 exchange across respiratory membrane in lungs

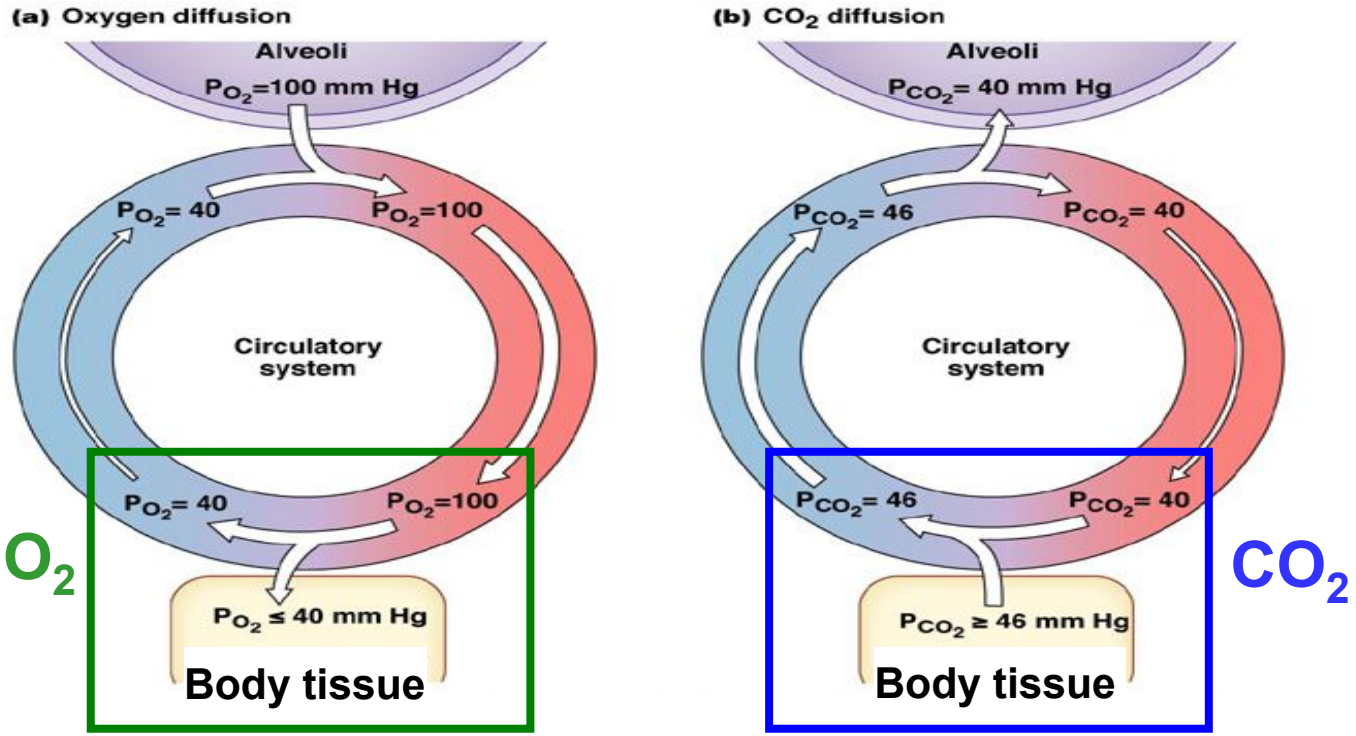
Internal Respiration



Internal Respiration

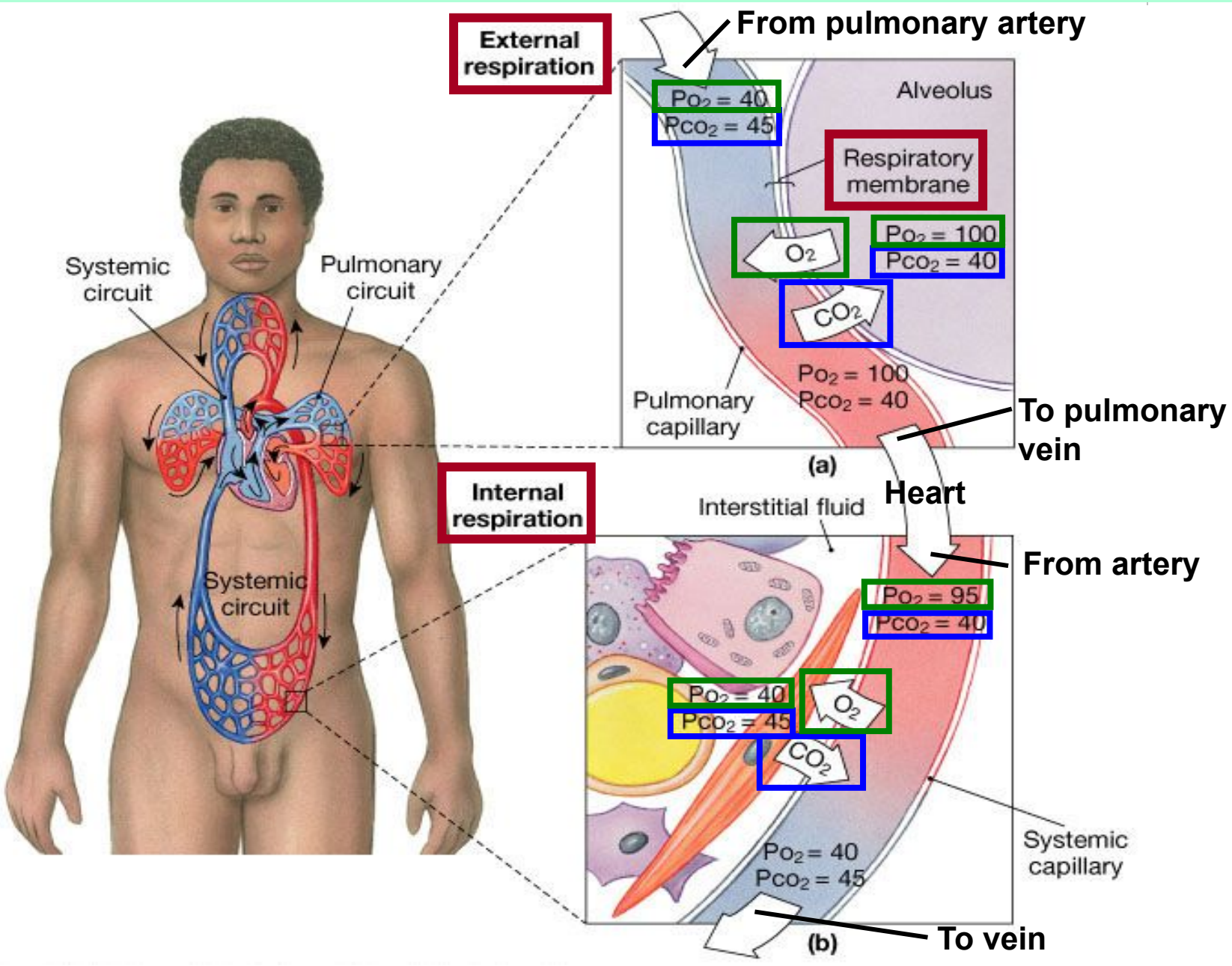
- P_{O_2} in tissue is always **lower** than in systemic arterial blood
- In venous blood draining tissues:

P_{O_2} of is 40 mm Hg & P_{CO_2} is 46 mm Hg

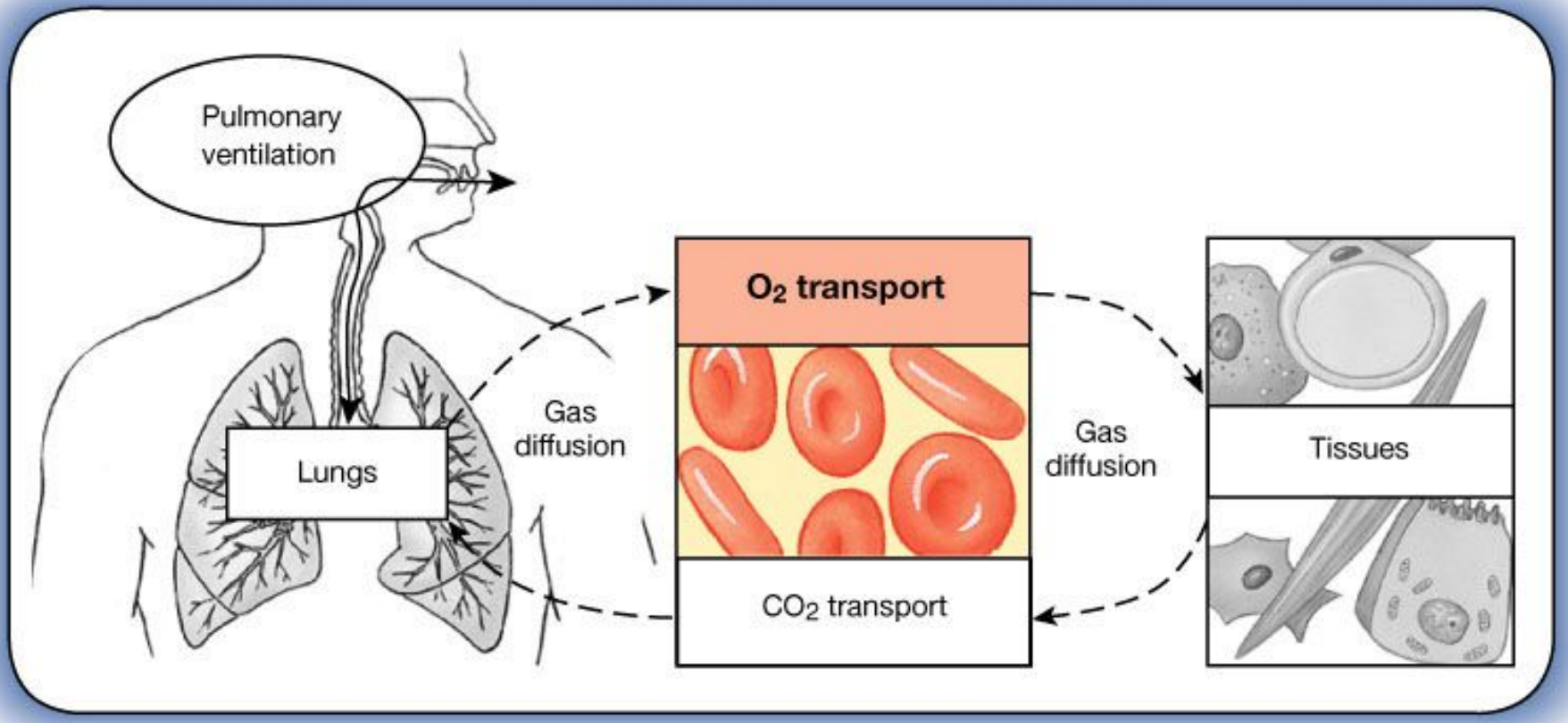


Gradients promote O_2 & CO_2 exchange across systemic capillary membranes in body tissues

External Respiration & Internal Respiration



Oxygen Transport

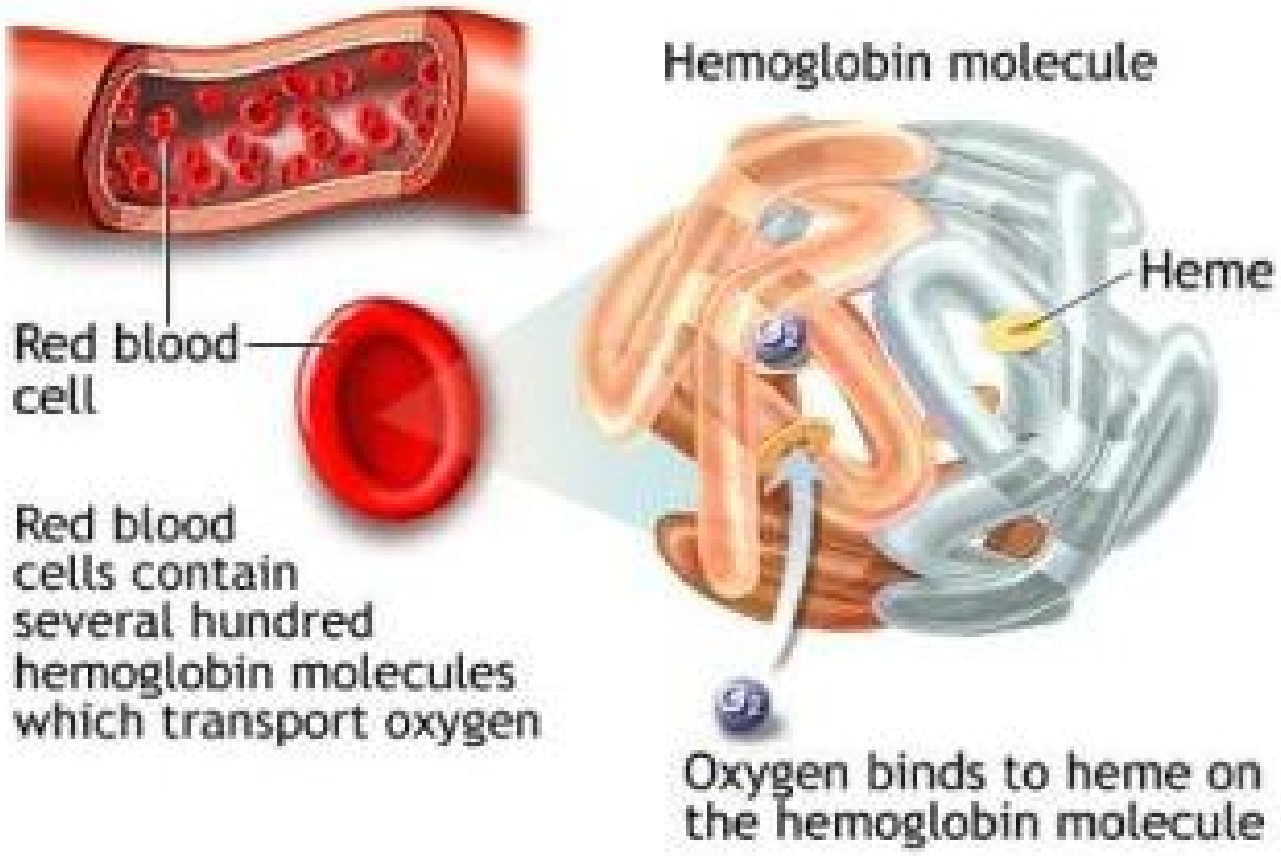


Ways of Oxygen Transport

Oxygen molecules are carried in blood in 2 ways:

(1) Dissolved in plasma

(2) Bound to hemoglobin (Hb) within RBCs



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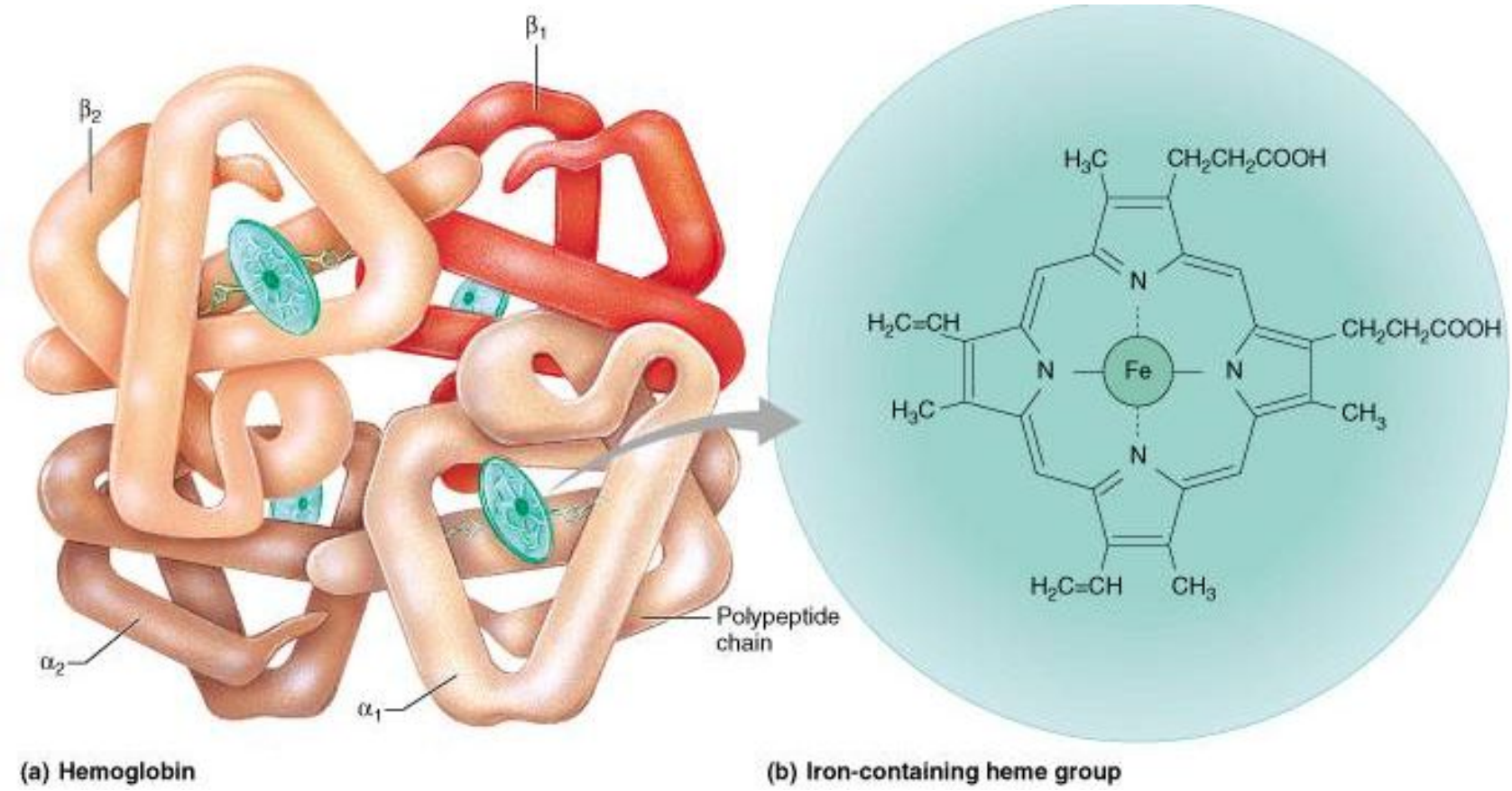

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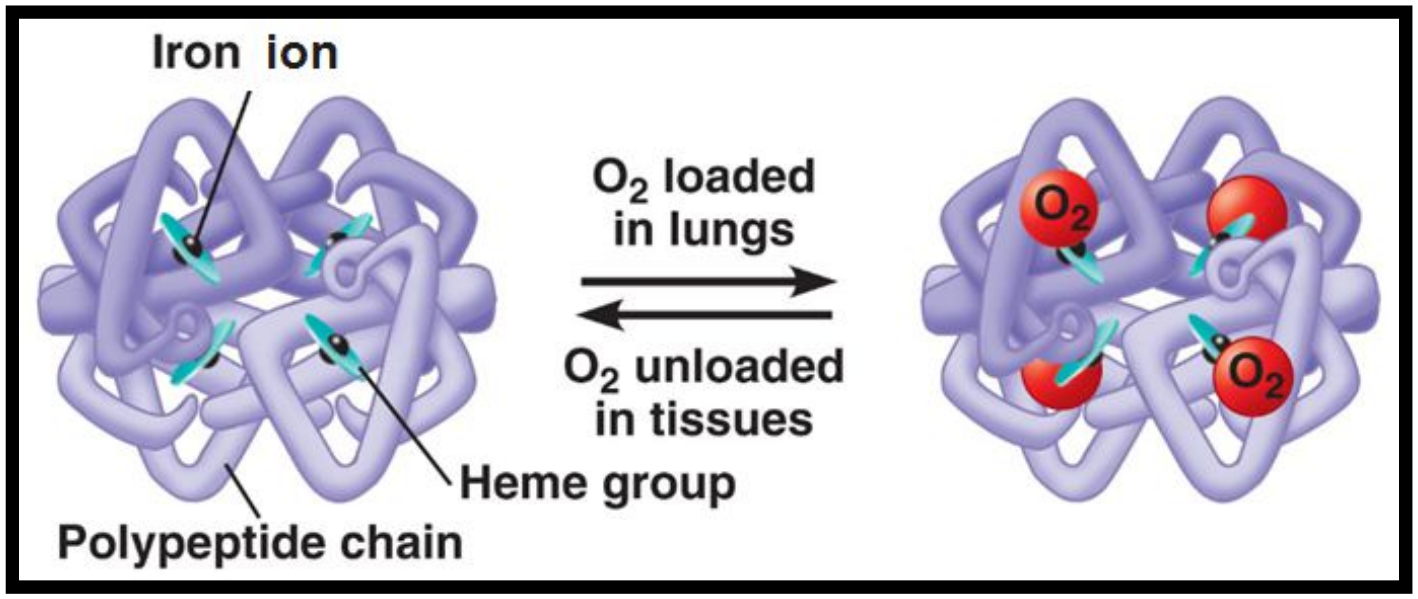


- Each hemoglobin molecule binds 4 oxygen molecules in a rapid & reversible process
- **Oxyhemoglobin (HbO_2):** Hemoglobin-oxygen combination
- **Deoxyhemoglobin:** Hemoglobin that has released oxygen

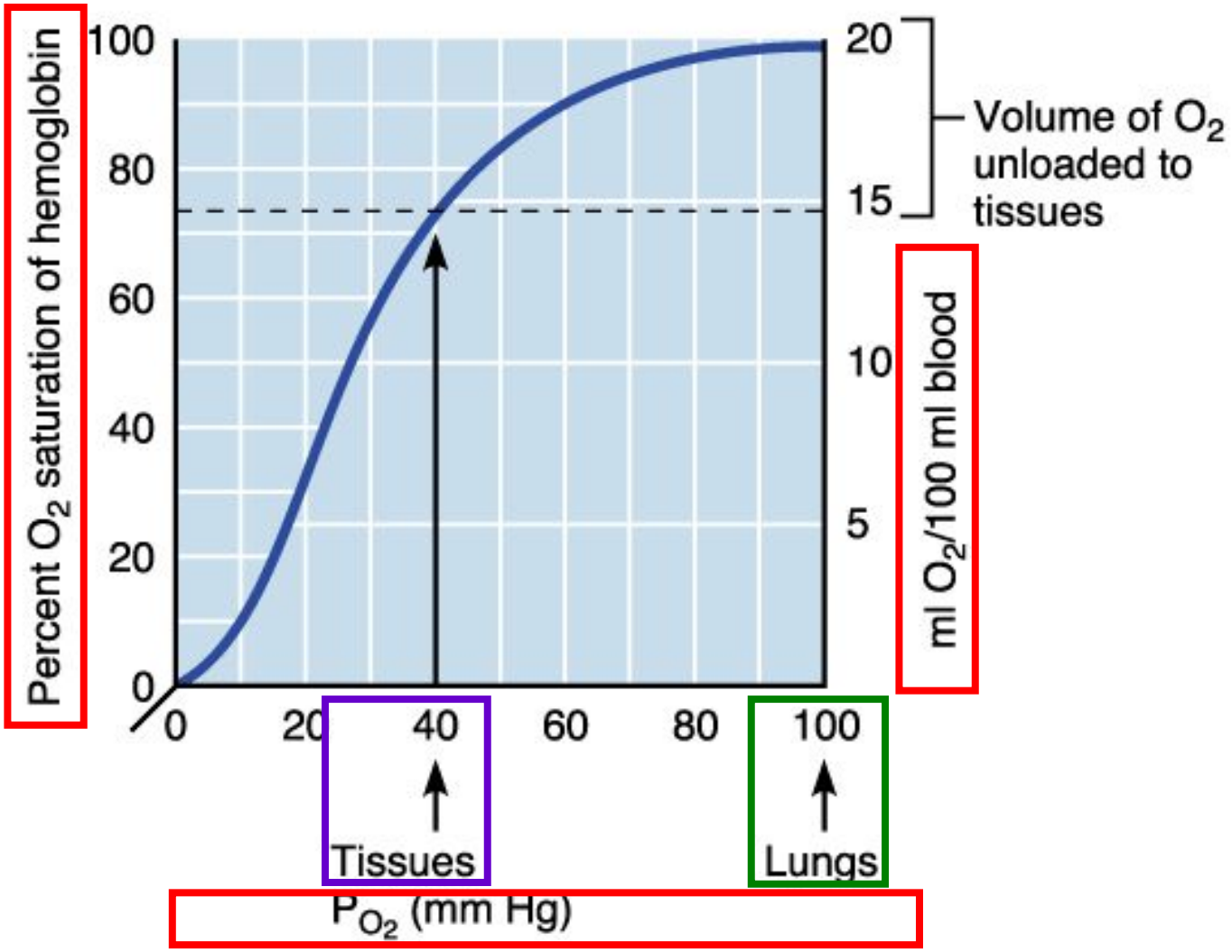
Hemoglobin (Hb)

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

- Rate at which hemoglobin binds & releases oxygen is <u>regulated</u> by:
  - P_{O_2}
  - P_{CO_2}
  - Temperature
  - Blood pH
  - Concentration of 2,3-bisphosphoglycerate (BPG)

Influence of P_{O_2} on Hemoglobin Saturation

Oxygen-hemoglobin dissociation curve



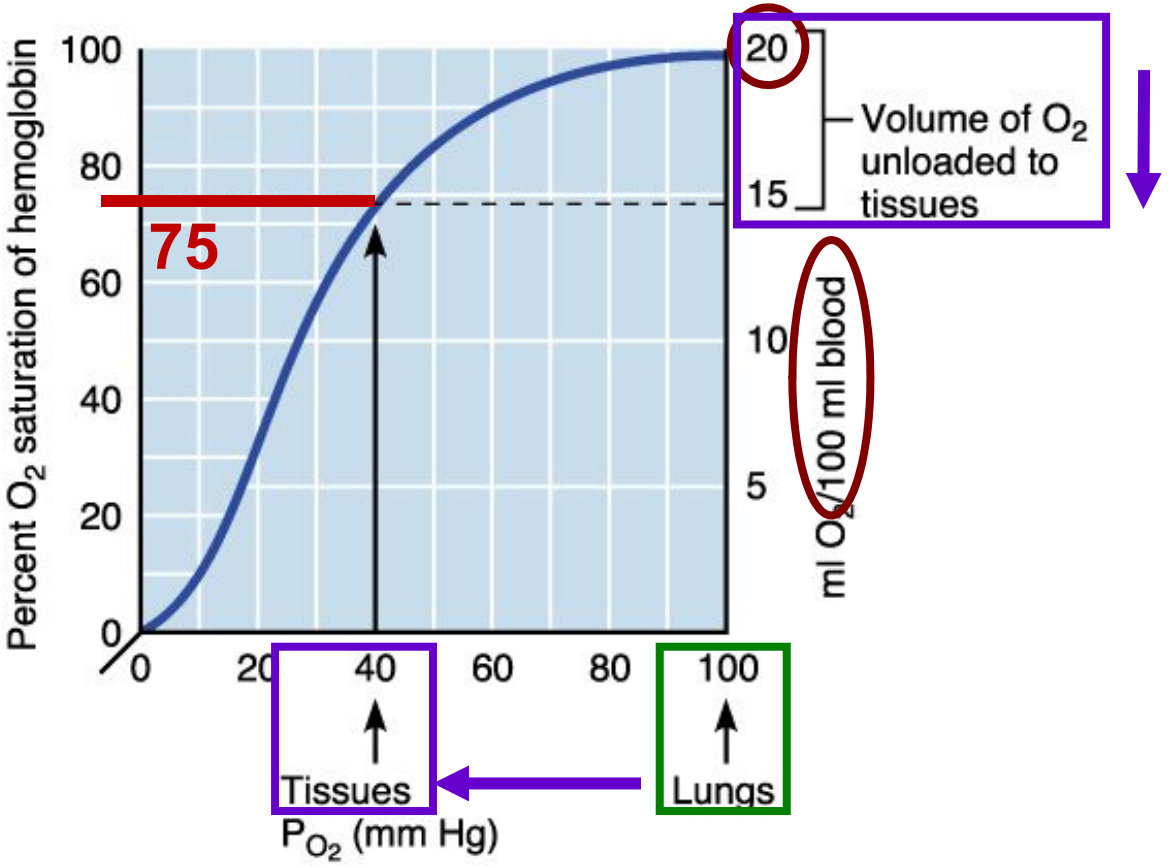
Influence of P_{O_2} on Hemoglobin Saturation

In lungs, P_{O_2} is 100 mmHg

- 100 mL of arterial blood contains ~ 20 mL of O_2

As arterial blood flows through capillaries, P_{O_2} decreases to 40 mmHg

- ~ 5 mL O_2 per 100 mL of blood is released to tissues
- 100 mL of arterial blood only contains ~ 15 mL of O_2 (75% saturation of hemoglobin)



Other Factors Influencing Hemoglobin Saturation

Pco_2, H^+, Temperature & BPG:

- Influence hemoglobin saturation by modifying structure of hemoglobin (conformational change)

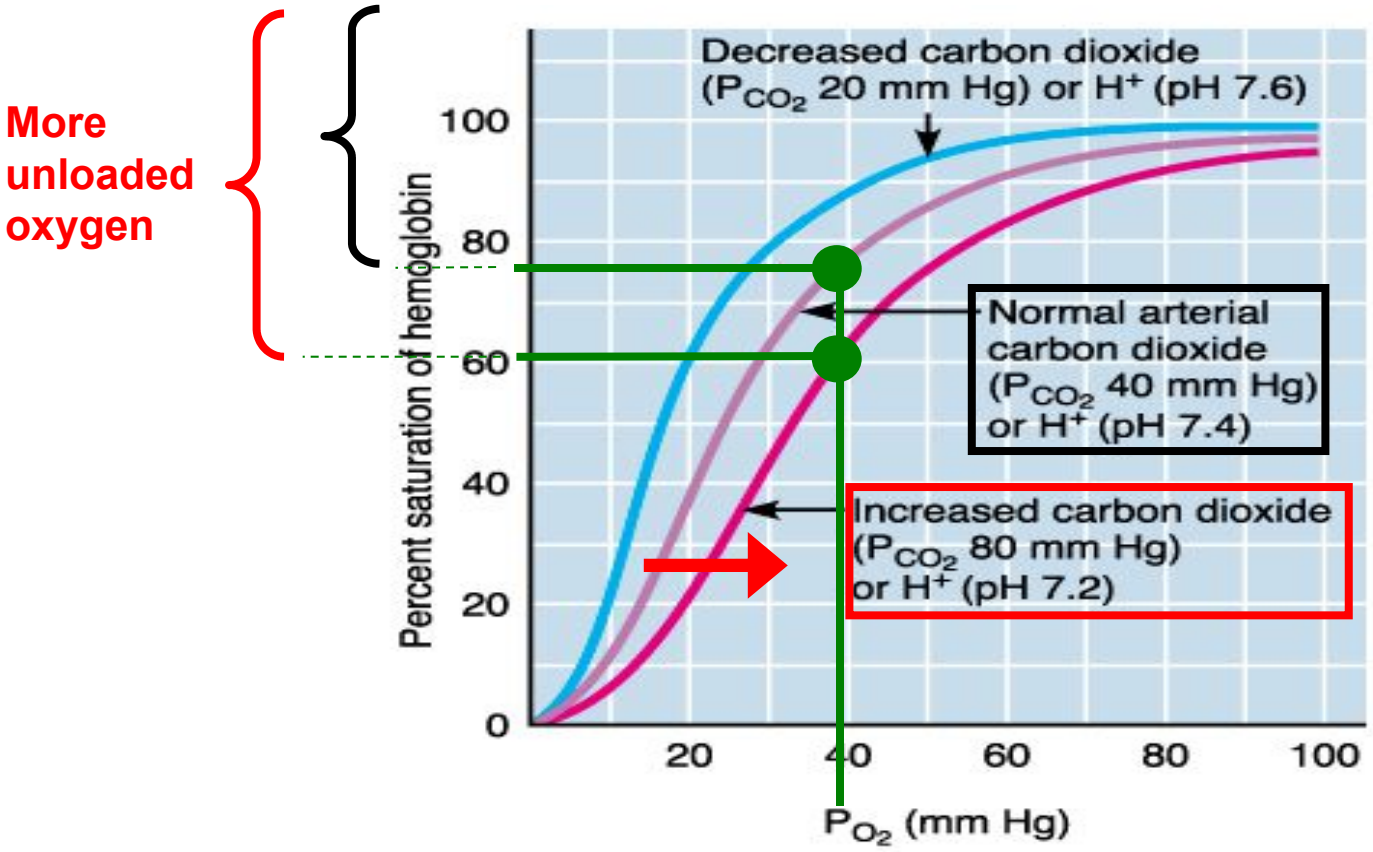
- Increase in level of these factors
  - → Decrease hemoglobin's affinity for oxygen
  - → **Increase release of oxygen** by hemoglobin (to tissue cells)

- Decrease in level of these factors:
  - → Increase hemoglobin's affinity for oxygen
  - → **Decrease release of oxygen** by hemoglobin (to tissue cells)

Other Factors Influencing Hemoglobin Saturation

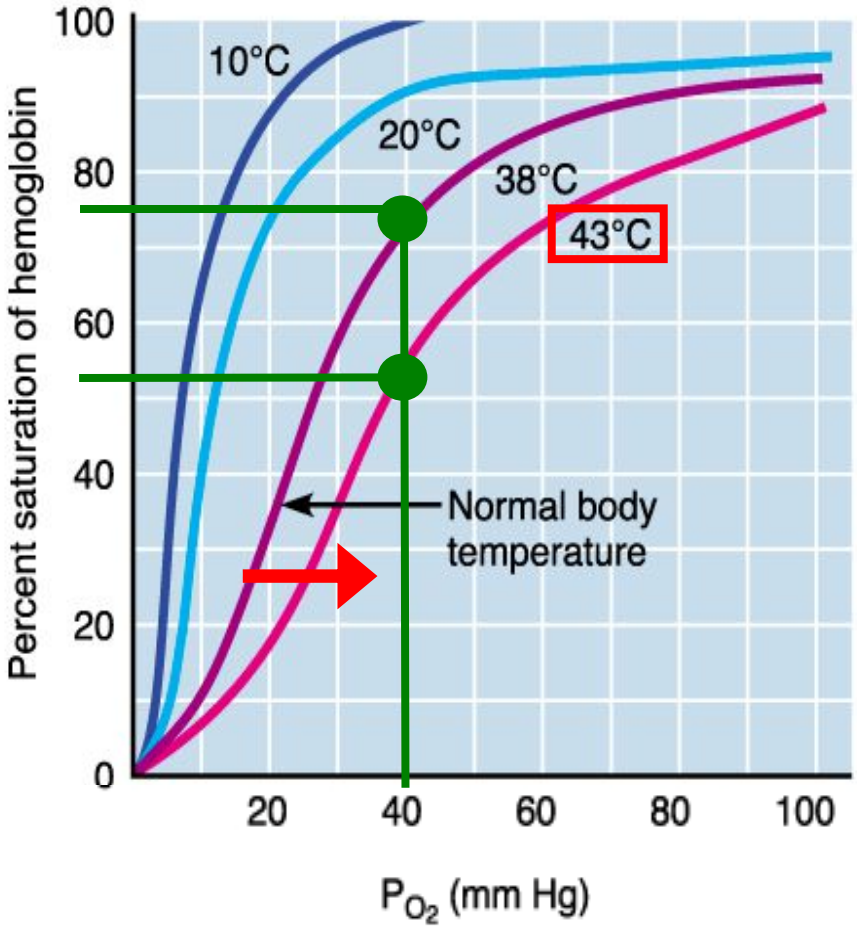
Bohr effect:

Blood pH declines → Weaken hemoglobin-oxygen bond → **Oxygen unloading** is accelerated

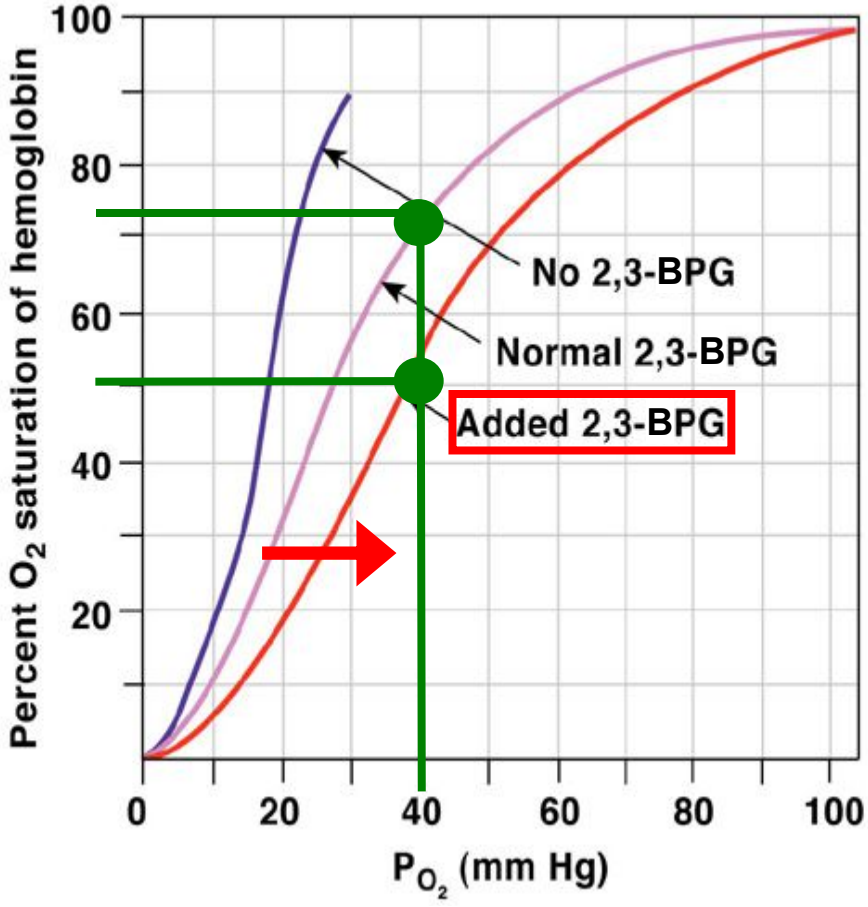


Other Factors Influencing Hemoglobin Saturation

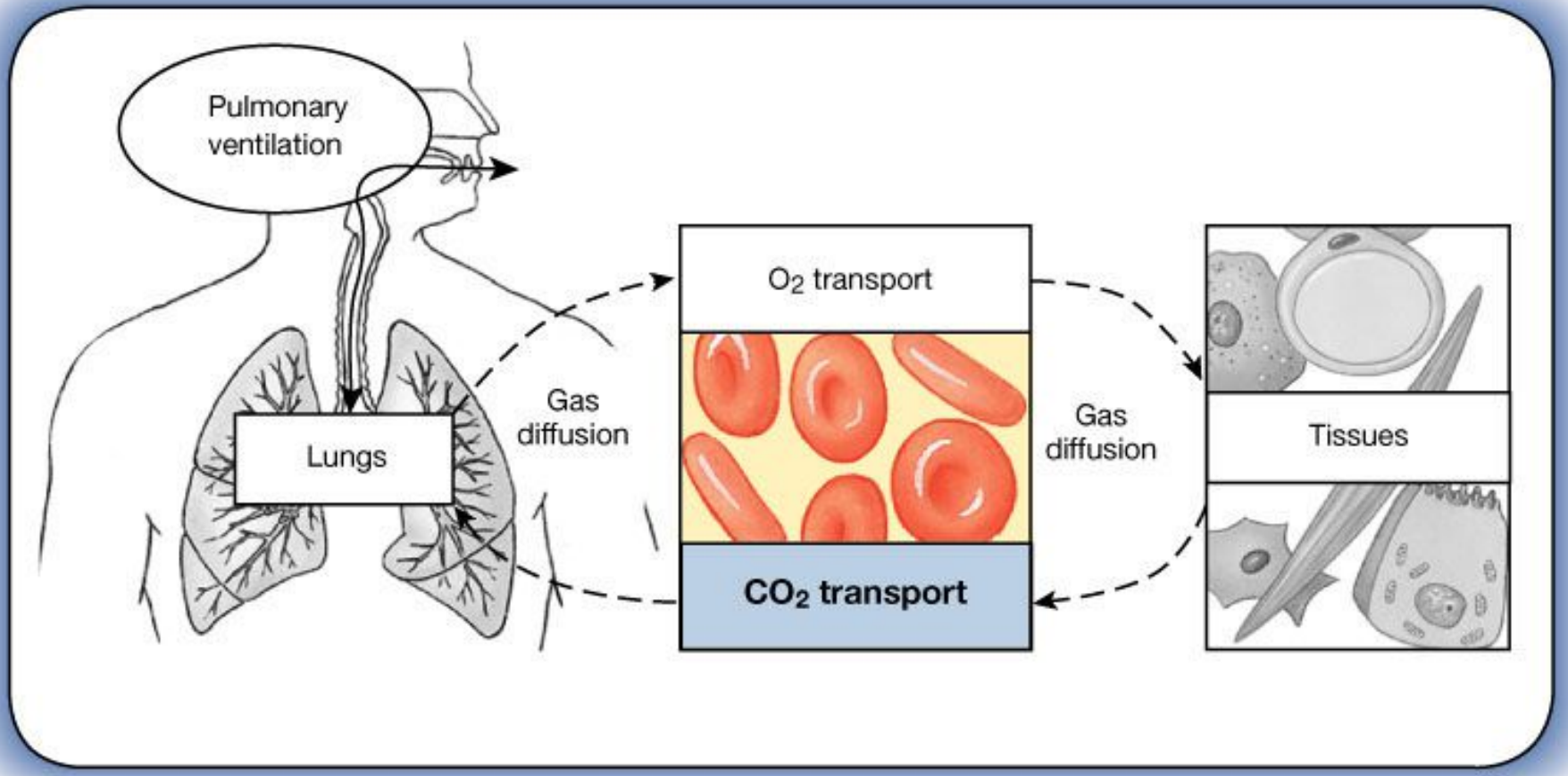
Temperature



BPG



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

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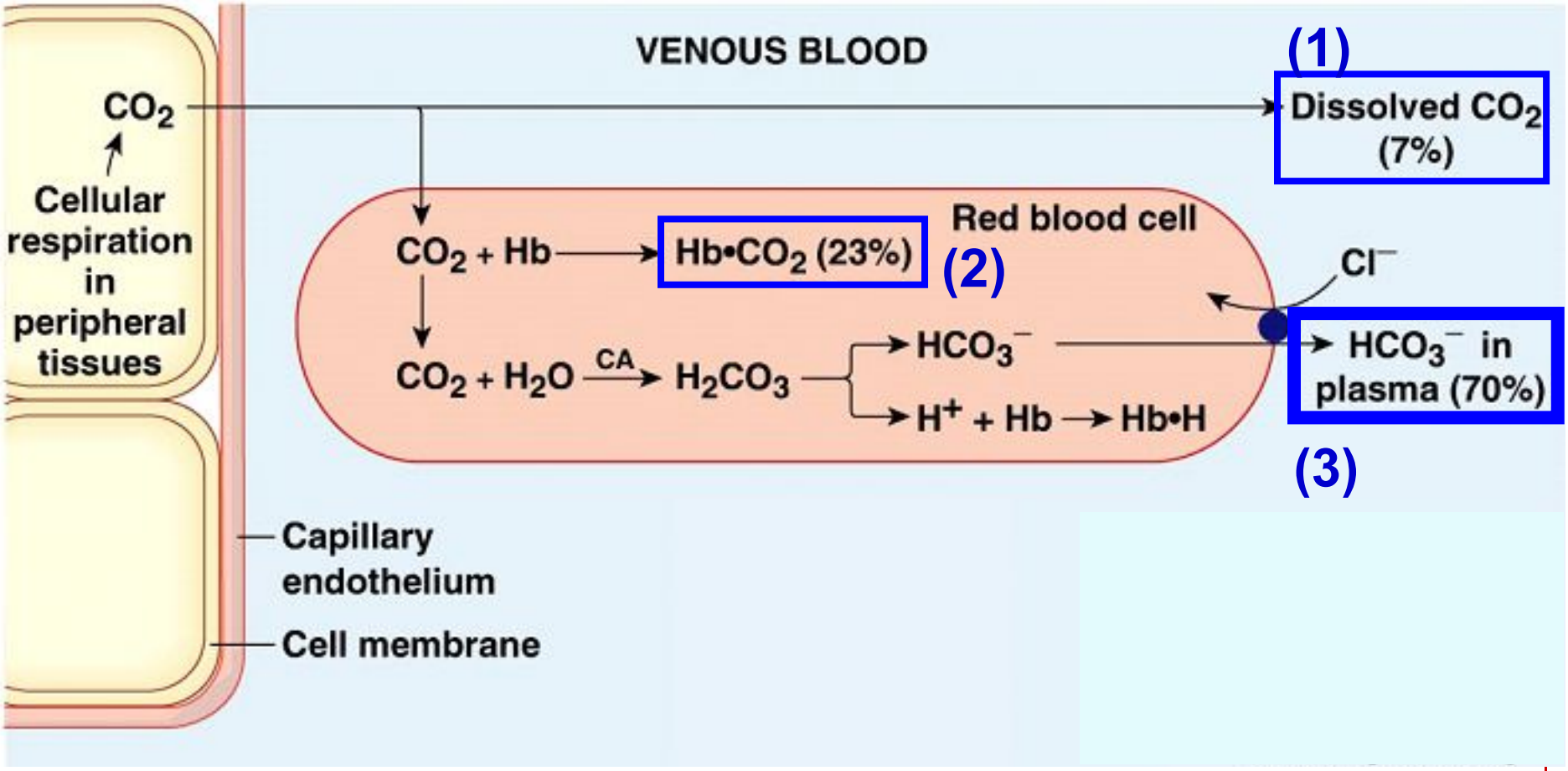
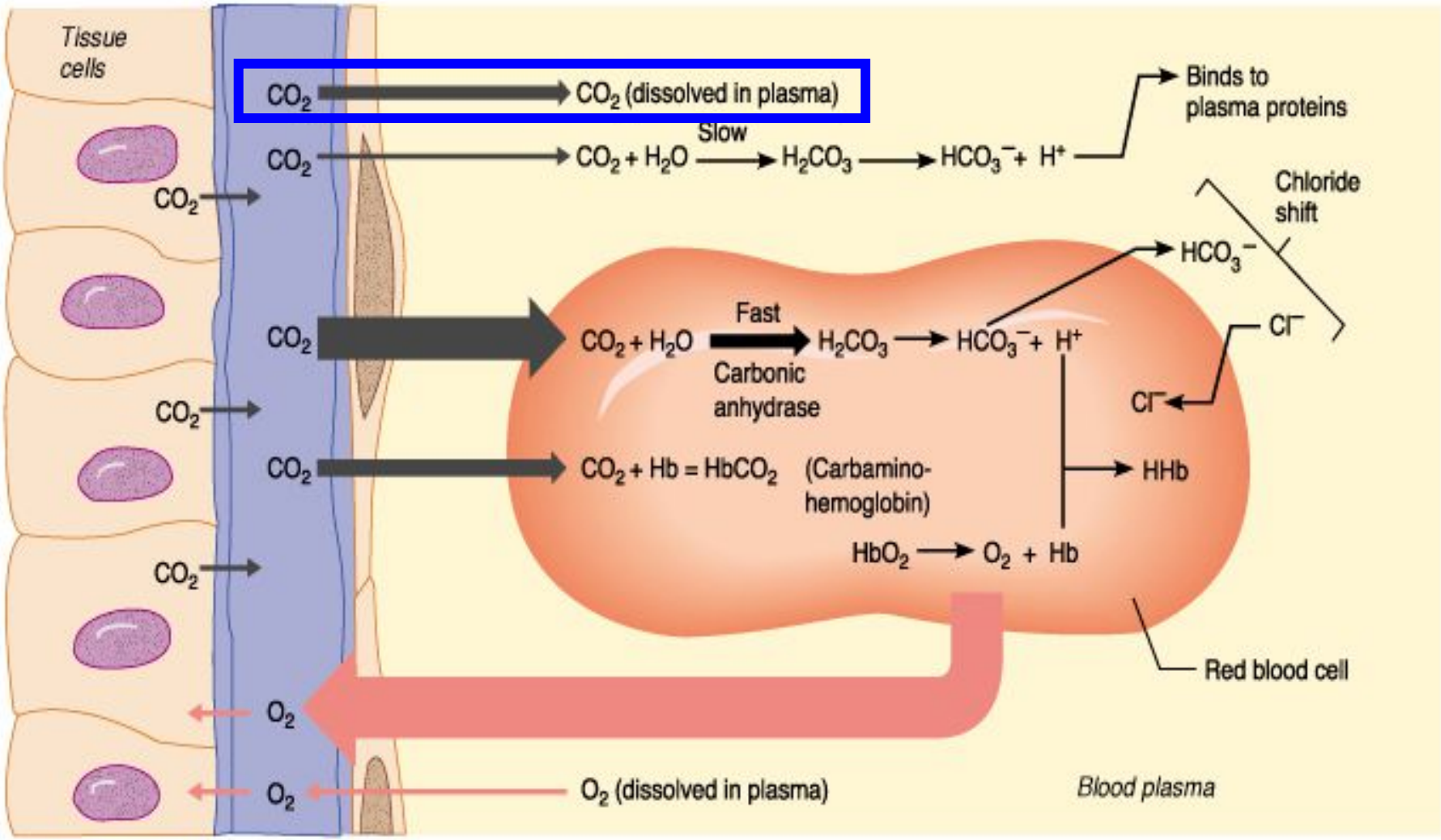


Carbon Dioxide Dissolved in Plasma

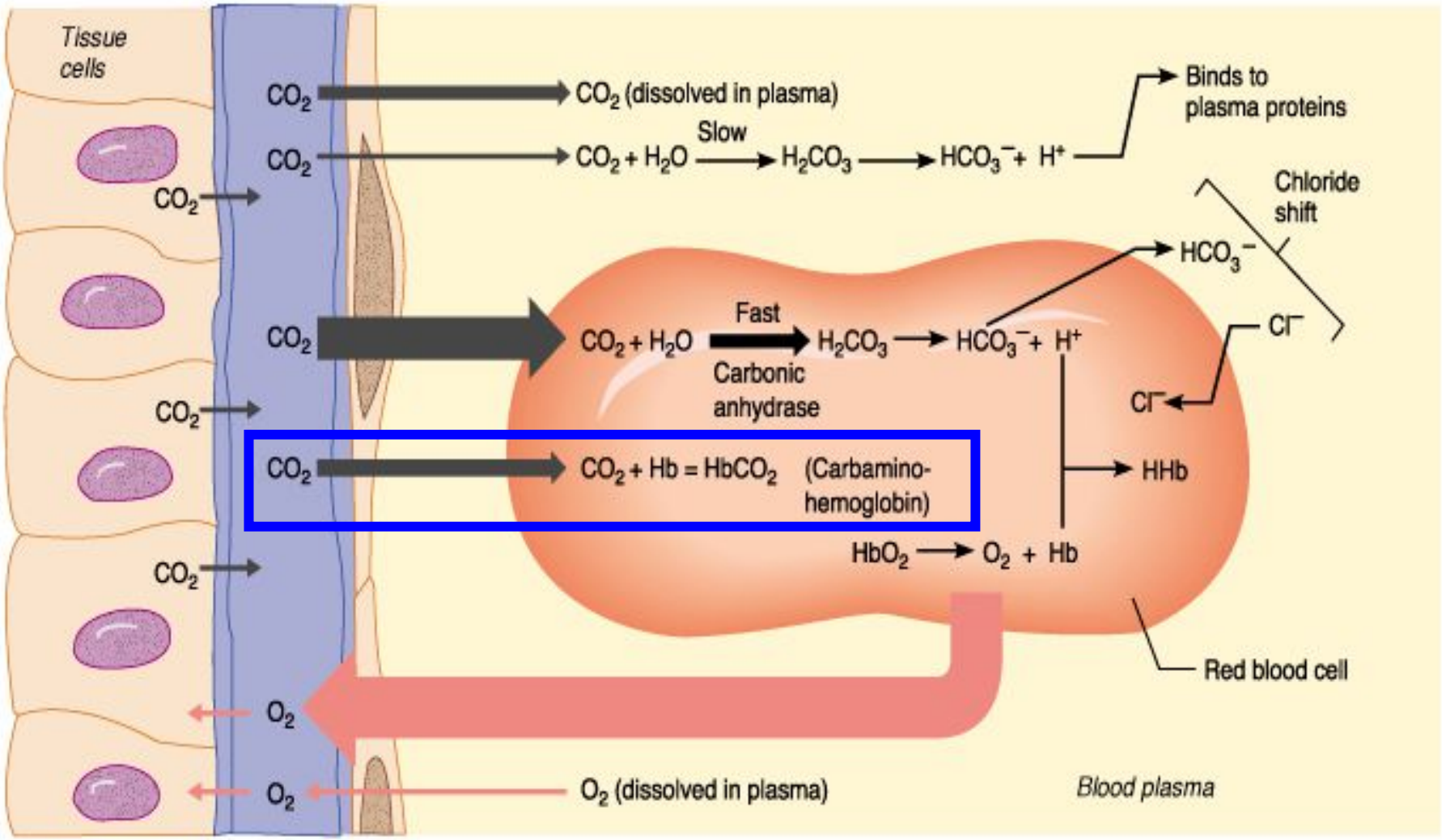
(1) CO_2 is dissolved in plasma



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

Carbon Dioxide Bound to Hemoglobin in RBC

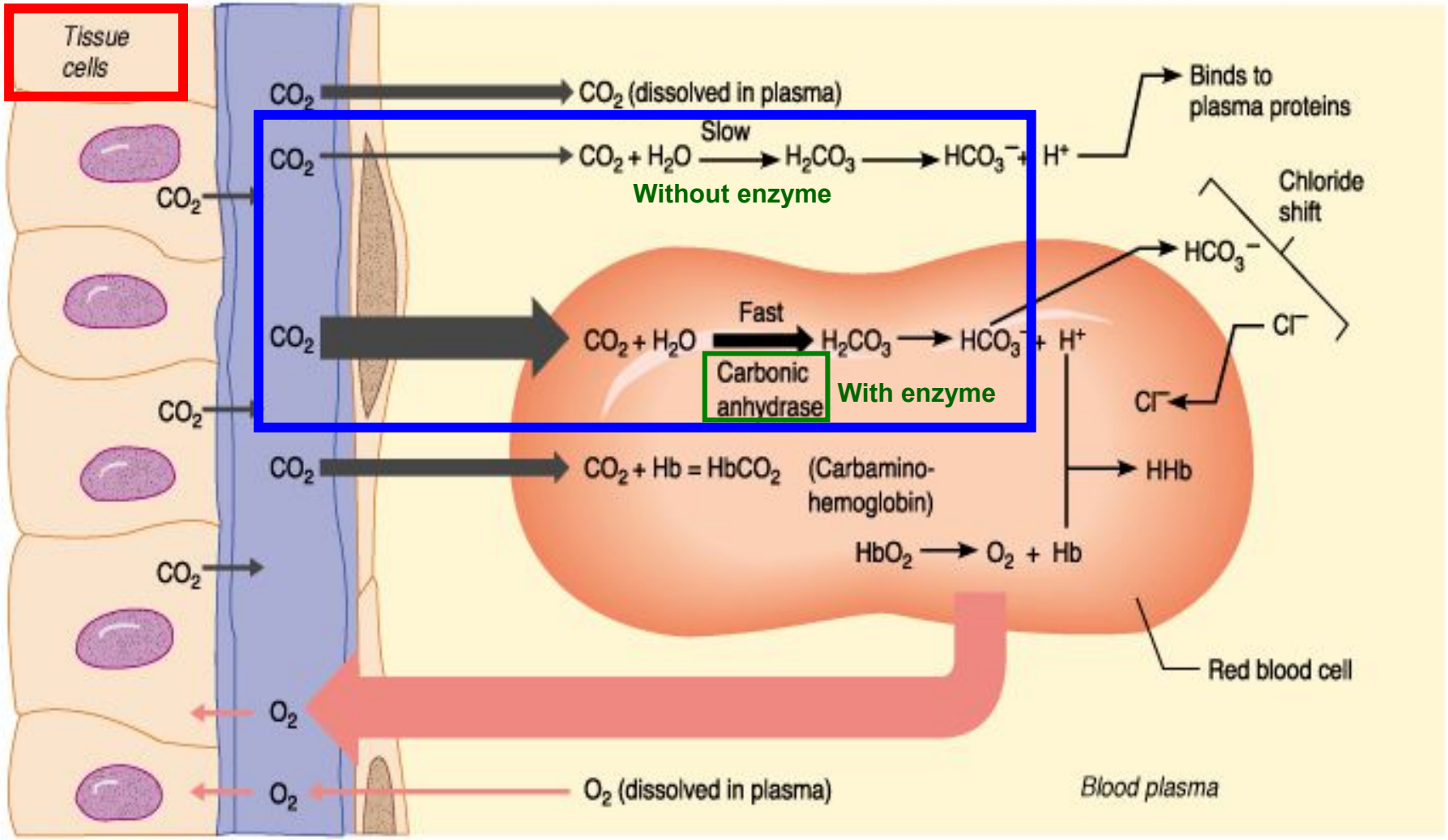
(2) CO_2 is carried within RBCs as carbaminohemoglobin



(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

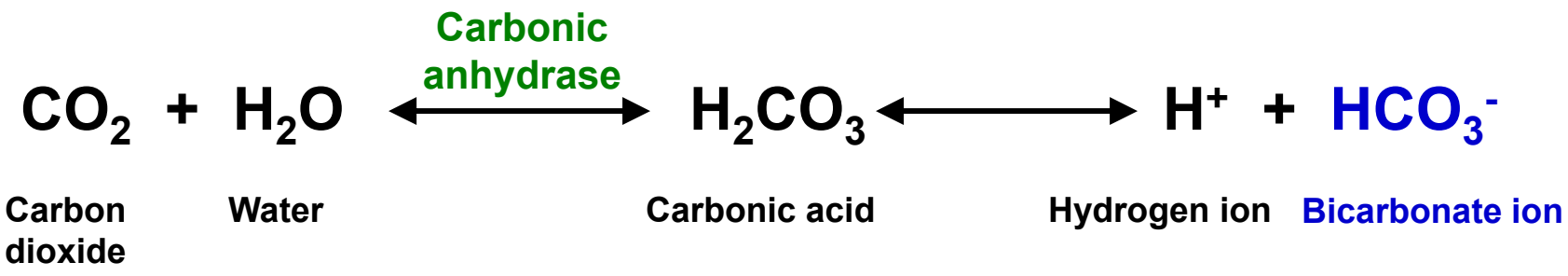


(a) Oxygen release and carbon dioxide pickup at the tissues

Carbon Dioxide As Bicarbonate Ions in Plasma

At tissues:

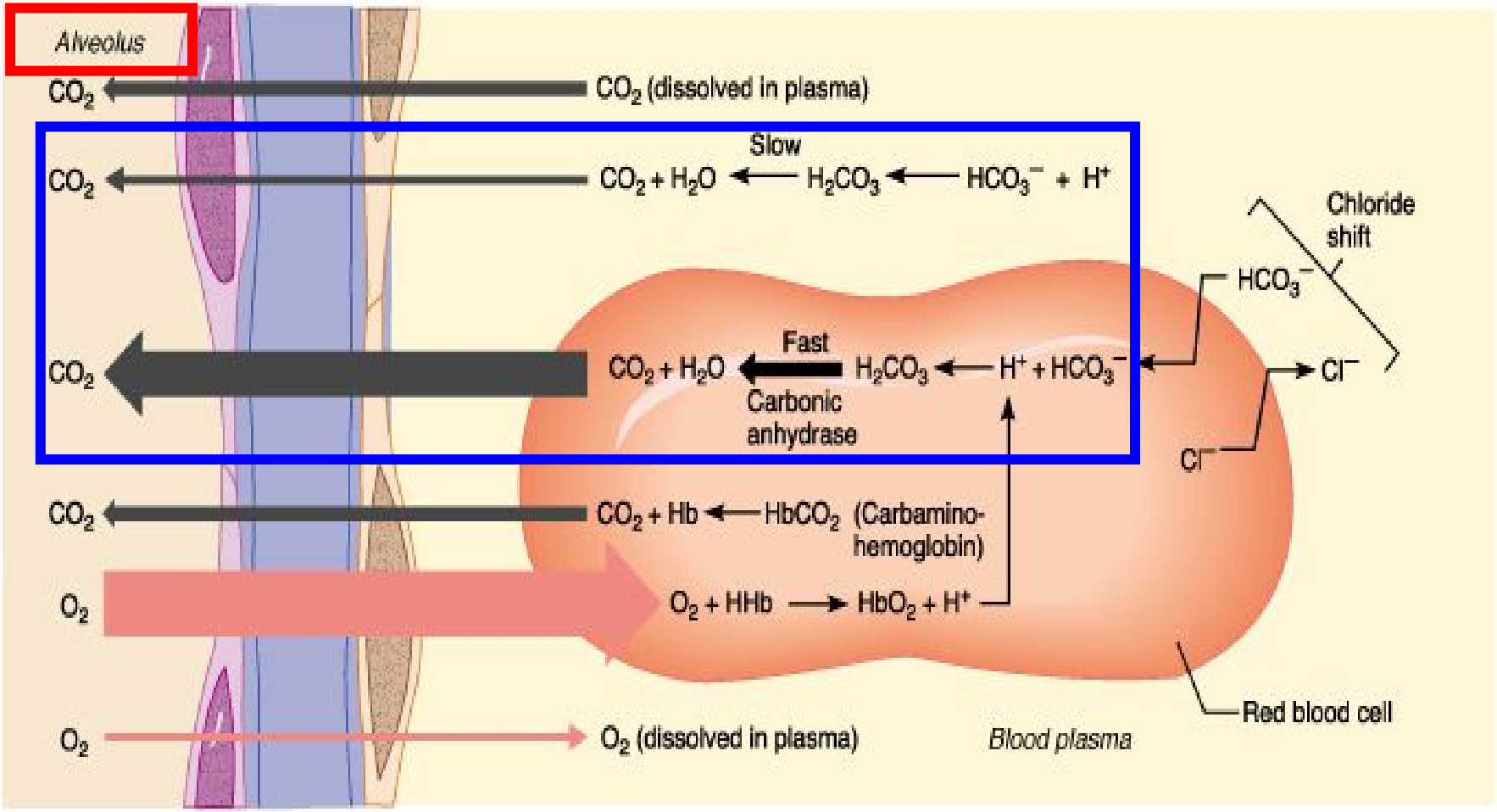
- CO_2 diffuses into RBCs & combines with water to form carbonic acid (H_2CO_3)
- H_2CO_3 quickly dissociates into hydrogen ions & **bicarbonate ions (HCO_3^-)**



- **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:

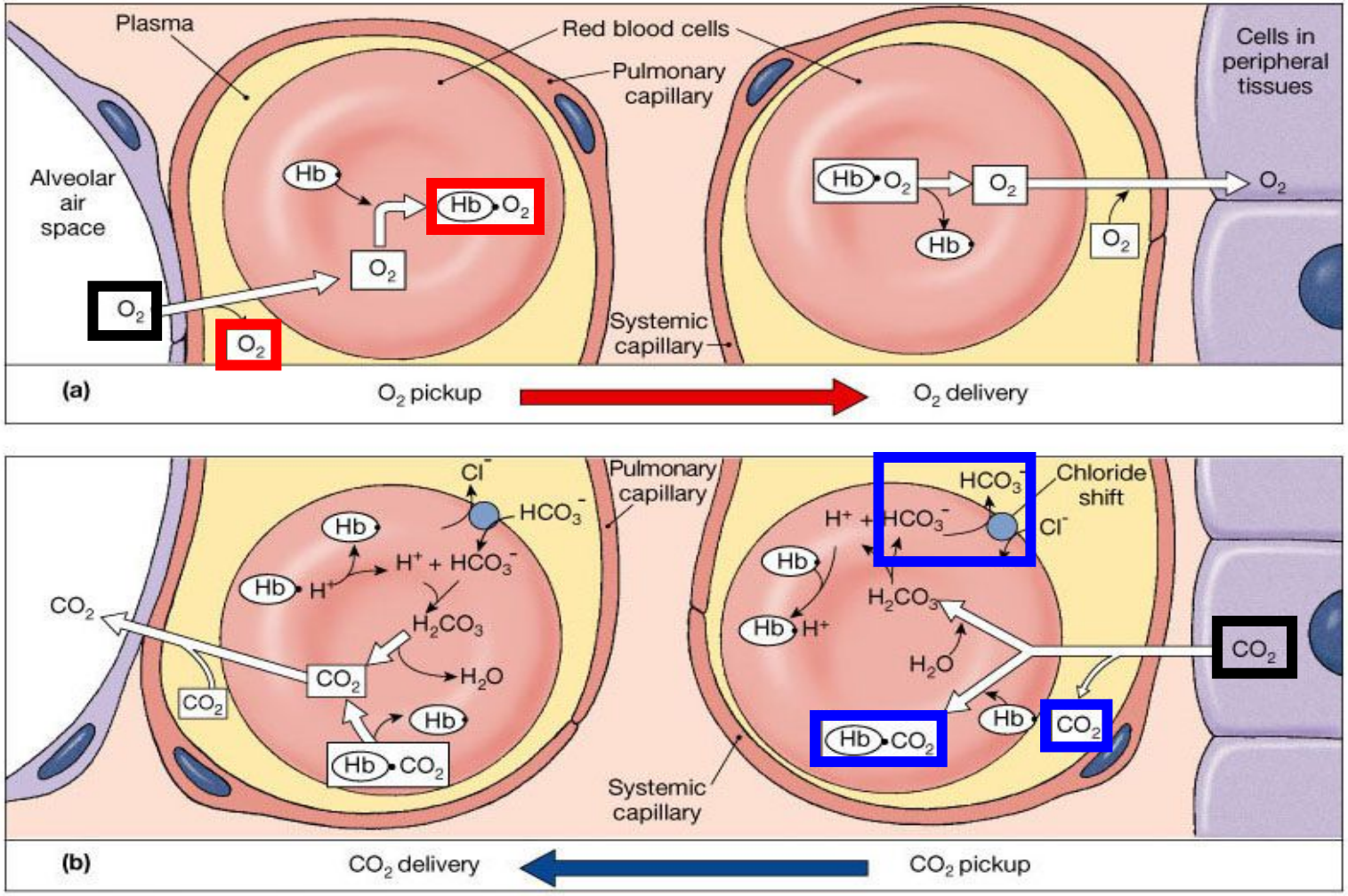
Processes are reversed:

- 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

Key Points

External respiration (Site: alveoli)

- Gas exchange across respiratory membrane in lungs
  - P_{O_2} in alveoli > P_{O_2} in pulmonary artery
  - P_{CO_2} in pulmonary artery > P_{CO_2} in alveoli

Internal respiration

- Gas exchange across systemic capillary membranes in body tissues
  - P_{O_2} in systemic arterial blood > P_{O_2} in tissue
  - P_{CO_2} in tissue > P_{CO_2} in systemic arterial blood

Oxygen transport

(1) Dissolved in plasma

(2) Bound to hemoglobin in RBCs

- Factors influencing affinity between hemoglobin & oxygen molecules
  - P_{O_2}, P_{CO_2}, blood pH, temperature, BPG concentration

Carbon dioxide transport

(1) Dissolved in plasma

(2) Bound to hemoglobin in RBCs (carbaminohemoglobin)

(3) Bicarbonate ions in plasma (70%)