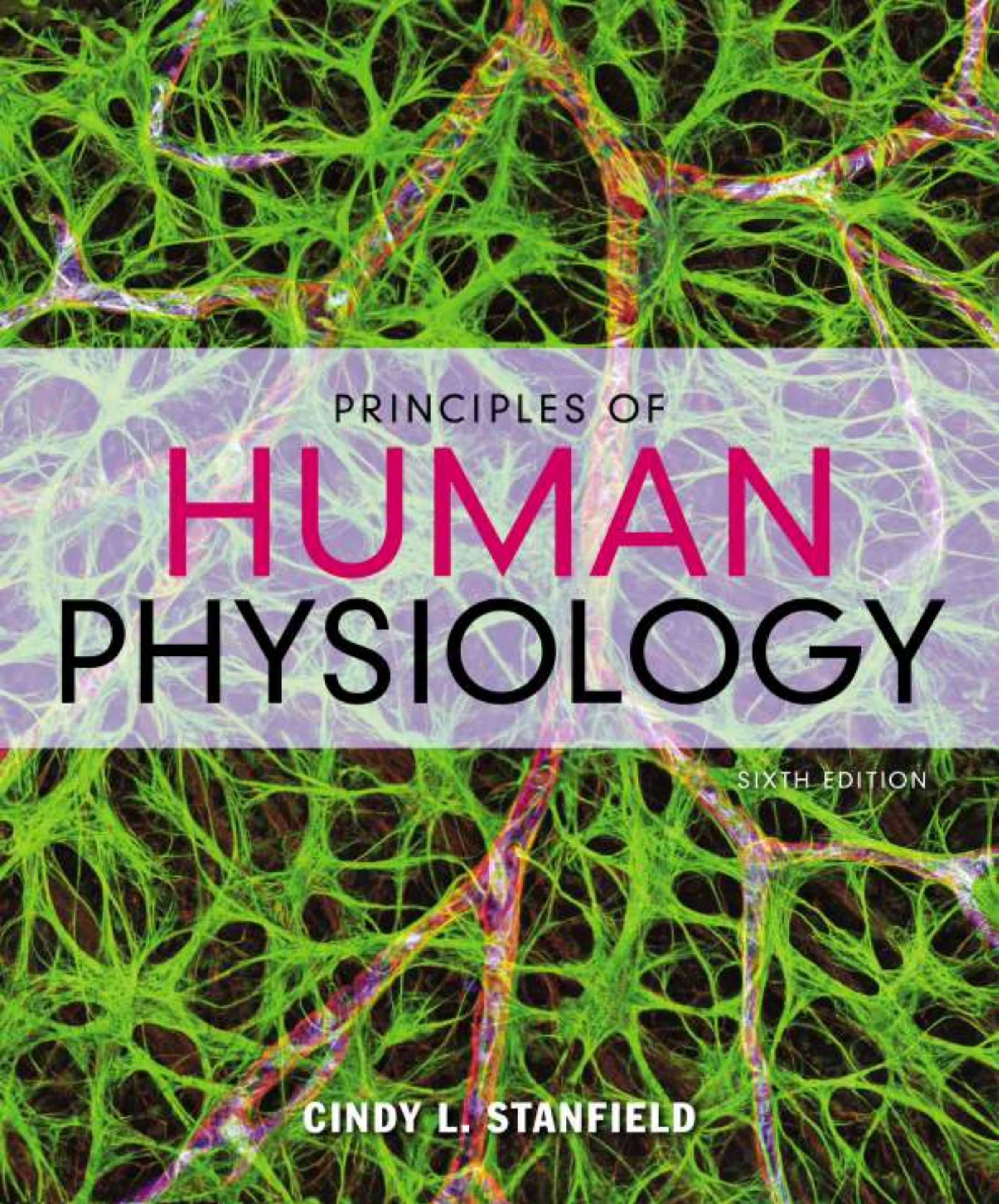


PowerPoint® Lecture Presentation

CHAPTER 17

The Respiratory System: Gas Exchange and Regulation of Breathing

Chapter Opener

17.1 Overview of Pulmonary Circulation

17.2 Diffusion of Gases

17.3 Exchange of Oxygen and Carbon Dioxide

17.4 Transport of Gases in the Blood

17.5 Central Regulation of Ventilation

17.6 Control of Ventilation by Chemoreceptors

17.7 Local Regulation of Ventilation and Perfusion

17.8 Respiratory System in Acid-Base Homeostasis

17.1 Overview of Pulmonary Circulation

- Arterial blood O_2 and CO_2 levels remain relatively constant
  - O_2 moves from alveoli to blood at the same rate it is consumed by cells
  - CO_2 moves from blood to alveoli at the same rate it is produced by cells

Figure 17.1 Movements of oxygen and carbon dioxide in pulmonary and systemic tissues during rest.

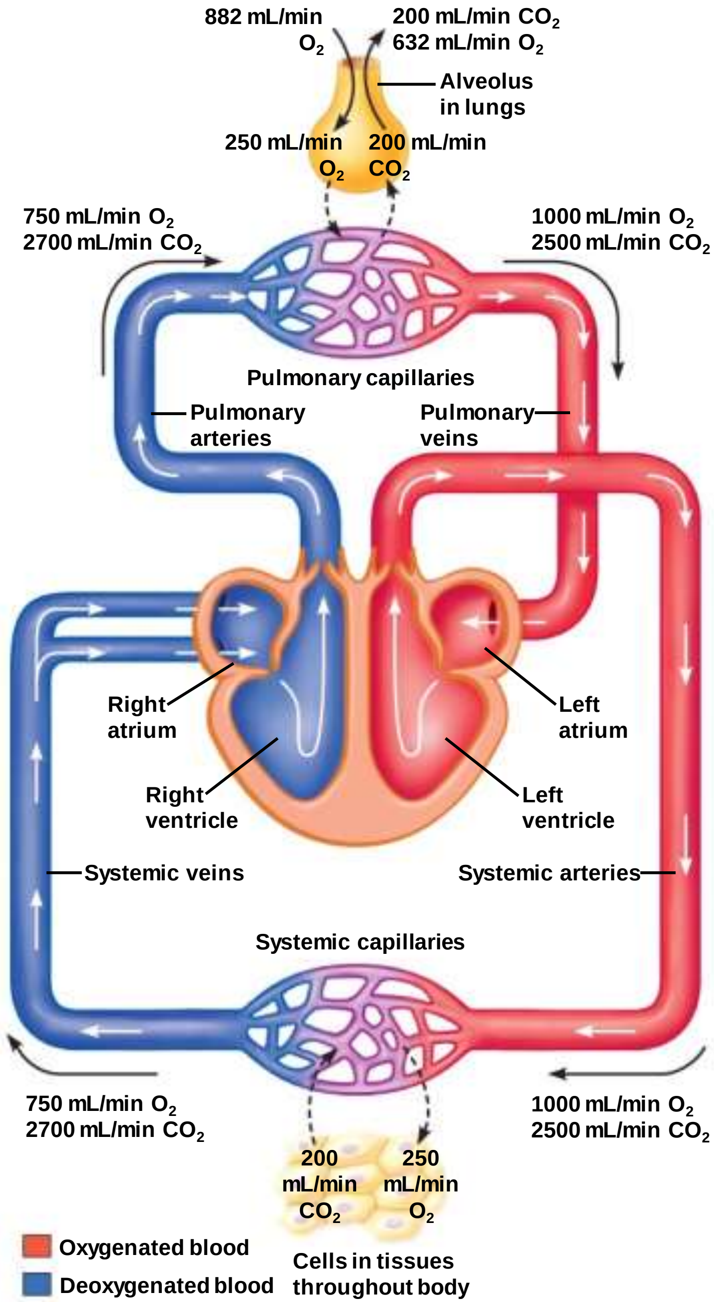
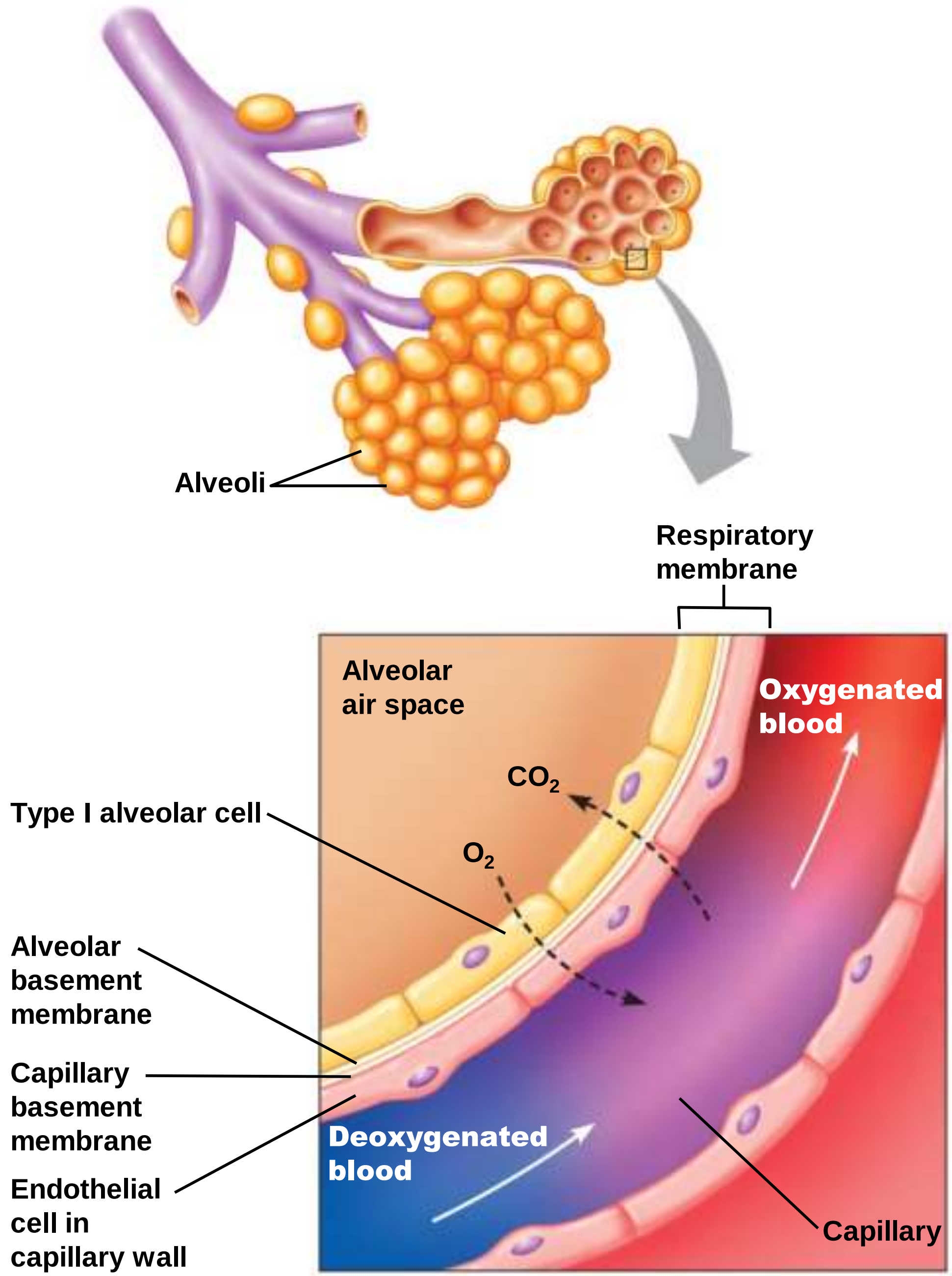


Figure 17.2 The respiratory membrane.



17.2 Diffusion of Gases

- Partial pressures of gases
- Solubility of gases in liquids

Partial Pressure of Gases

- Ideal gas law
  - Pressure of a gas depends on the temperature, number of gas molecules, and volume
  - $PV = nRT$
  - $P = nRT/V$

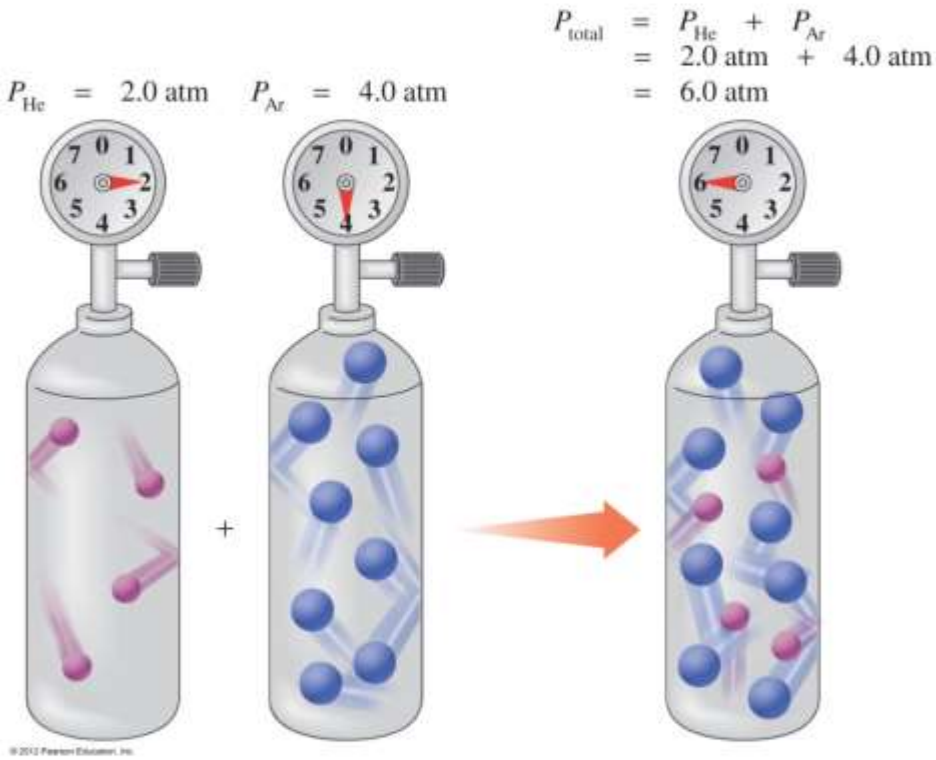
Partial Pressure of Gases

- Gas mixtures
  - Many gases are mixtures of different molecules
  - Partial pressure of a gas = proportion of pressure of entire gas that is due to presence of the individual gas
  - $P_{\text{total}} = P_1 + P_2 + P_3 + \ldots P_n$
  - Partial pressure of a gas depends on fractional concentration of the gas
  - Total pressure of gas mixture

$$P_{\text{gas}} = \%_{\text{gas}} \times P_{\text{total}}$$

Partial Pressure

The **partial pressure** of a gas is the pressure that each gas in a mixture would exert if it were by itself in the container.



Dalton's Law of Partial Pressures

Dalton's law of partial pressures indicates that

- pressure depends on the total number of gas particles, not on the types of particles
- the total pressure exerted by gases in a mixture is the sum of the partial pressures of those gases

$$P_T = P_1 + P_2 + P_3 + \ldots.$$

Partial Pressure of Gases

- Gas mixtures
  - Many gases are mixtures of different molecules
  - Partial pressure of a gas = proportion of pressure of entire gas that is due to presence of the individual gas
  - $P_{\text{total}} = P_1 + P_2 + P_3 + \ldots P_n$
  - Partial pressure of a gas depends on fractional concentration of the gas
  - Total pressure of gas mixture

$$P_{\text{gas}} = \%_{\text{gas}} \times P_{\text{total}}$$

Partial Pressure of Gases

- Composition of air
  - 79% nitrogen
  - 21% oxygen
  - Trace amounts of carbon dioxide, helium, argon, and other gases
  - Water can be a factor depending on humidity
- P_{air} = 760 mm Hg = $P_{N_2} + P_{O_2}$
  - P_{N_2} = 0.79 × 760 mm Hg = 600 mm Hg
  - P_{O_2} = 0.21 × 760 mm Hg = 160 mm Hg
  - Air is only 0.03% carbon dioxide
    - P_{CO_2} = 0.0003 × 760 mm Hg = 0.23 mm Hg

Partial Pressure of Gases

- Composition of air at 100% humidity
- P_{air} = 760 mm Hg = $P_{N_2} + P_{O_2} + P_{H_2O}$
  - P_{N_2} = 0.741 × 760 mm Hg = 563 mm Hg
  - P_{O_2} = 0.196 × 760 mm Hg = 149 mm Hg
  - P_{H_2O} = 0.062 × 760 mm Hg = 47 mm Hg
  - P_{CO_2} = 0.00027 × 760 mm Hg = 0.21 mm Hg

Solubility of Gases in Liquids

- Gas molecules can exist in gas form or dissolved in a liquid
- Ability to dissolve depends on properties of the gas and properties of the liquid
- Both vaporized and dissolved gases exert partial pressures
- The partial pressure of a gas affects the amount of gas that goes into solution
  - Partial pressures of vaporized and dissolved gases will be equal at equilibrium

Solubility of Gases in Liquids

- Henry's law
  - $c = kP$
  - c = molar concentration of dissolved gas
  - k = Henry's law constant
  - P = partial pressure of gas in atmospheres

Solubility of Gases in Liquids

- Oxygen and carbon dioxide solubility
  - At 100 mm Hg partial pressure in water
    - $[O_2]$ in water = 0.15 mmole/L
    - $[CO_2]$ in water = 3.0 mmole/L
  - CO_2 is more soluble than O_2 in water (and blood).

Figure 17.3a Solubilities of oxygen and carbon dioxide in water.

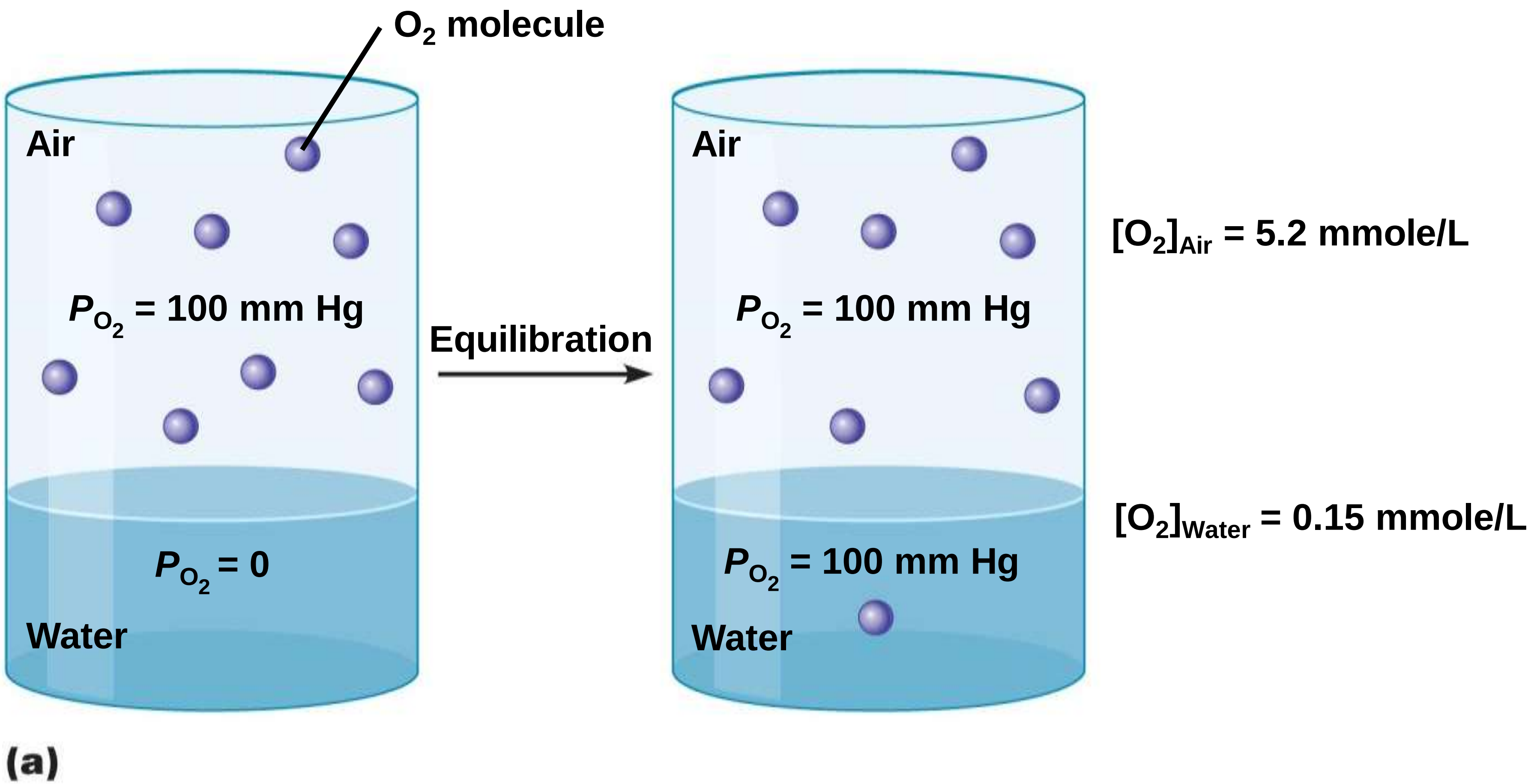
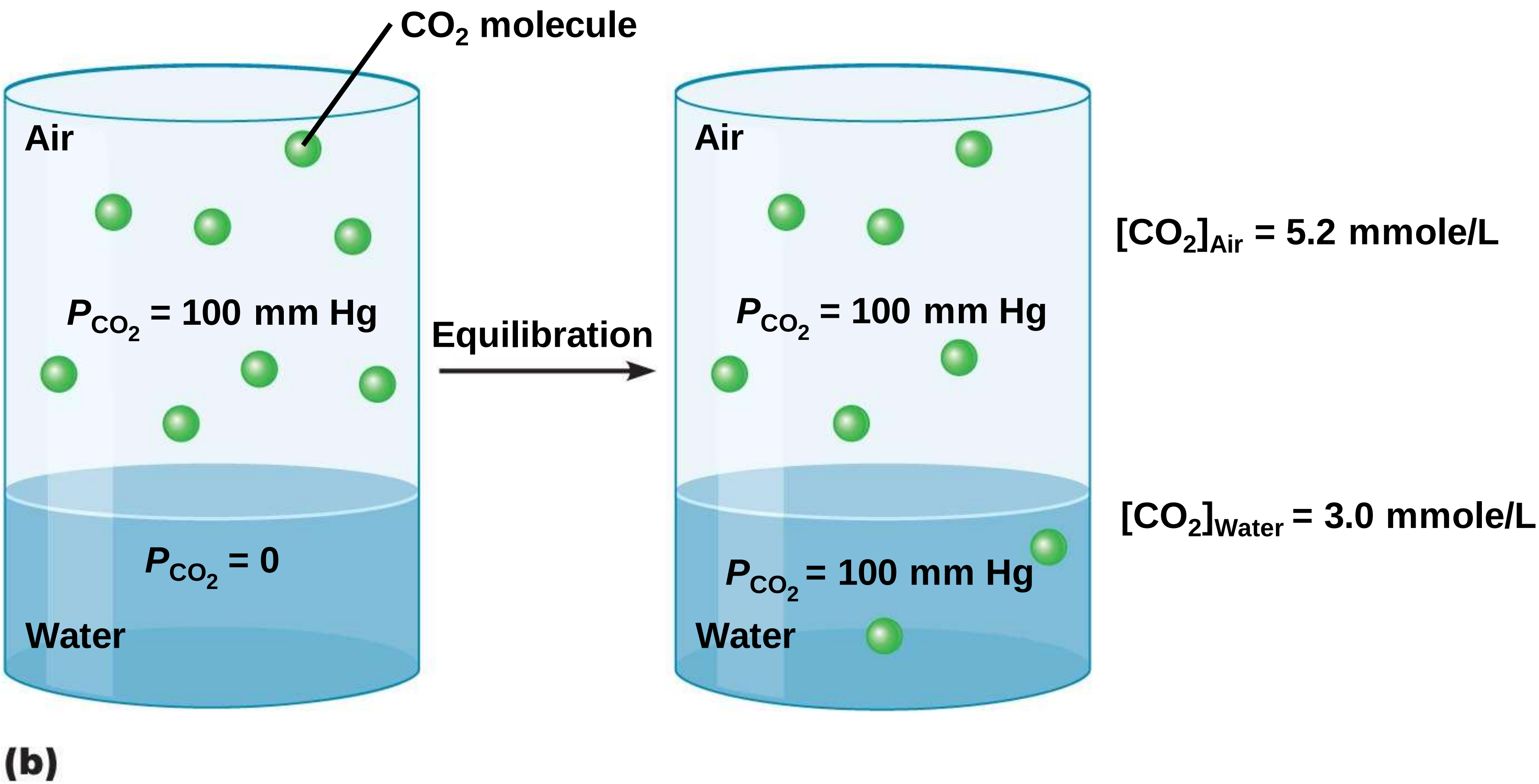


Figure 17.3b Solubilities of oxygen and carbon dioxide in water.



17.3 Exchange of Oxygen and Carbon Dioxide

- Gas exchange in the lungs
- Gas exchange in respiring tissue
- Determinants of alveolar P_{O_2} and P_{CO_2}

Gas Exchange in the Lungs

- Diffusion of gases
  - Gases diffuse down pressure gradients
    - High pressure → low pressure
  - In gas mixtures, gases diffuse down partial pressure gradients
    - High partial pressure → low partial pressure
  - A particular gas diffuses down its own partial pressure gradient
    - Presence of other gases is irrelevant

TABLE 17.1 Typical Partial Pressures of Oxygen and Carbon Dioxide in Atmospheric Air and at Various Sites in the Body

	Oxygen	Carbon dioxide
Atmospheric air	160 mm Hg	0.3 mm Hg
Alveolar air	100 mm Hg	40 mm Hg
Pulmonary veins	100 mm Hg	40 mm Hg
Systemic arteries	100 mm Hg	40 mm Hg
Cells	≤40 mm Hg	≥46 mm Hg
Systemic veins	40 mm Hg	46 mm Hg
Pulmonary arteries	40 mm Hg	46 mm Hg

Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.

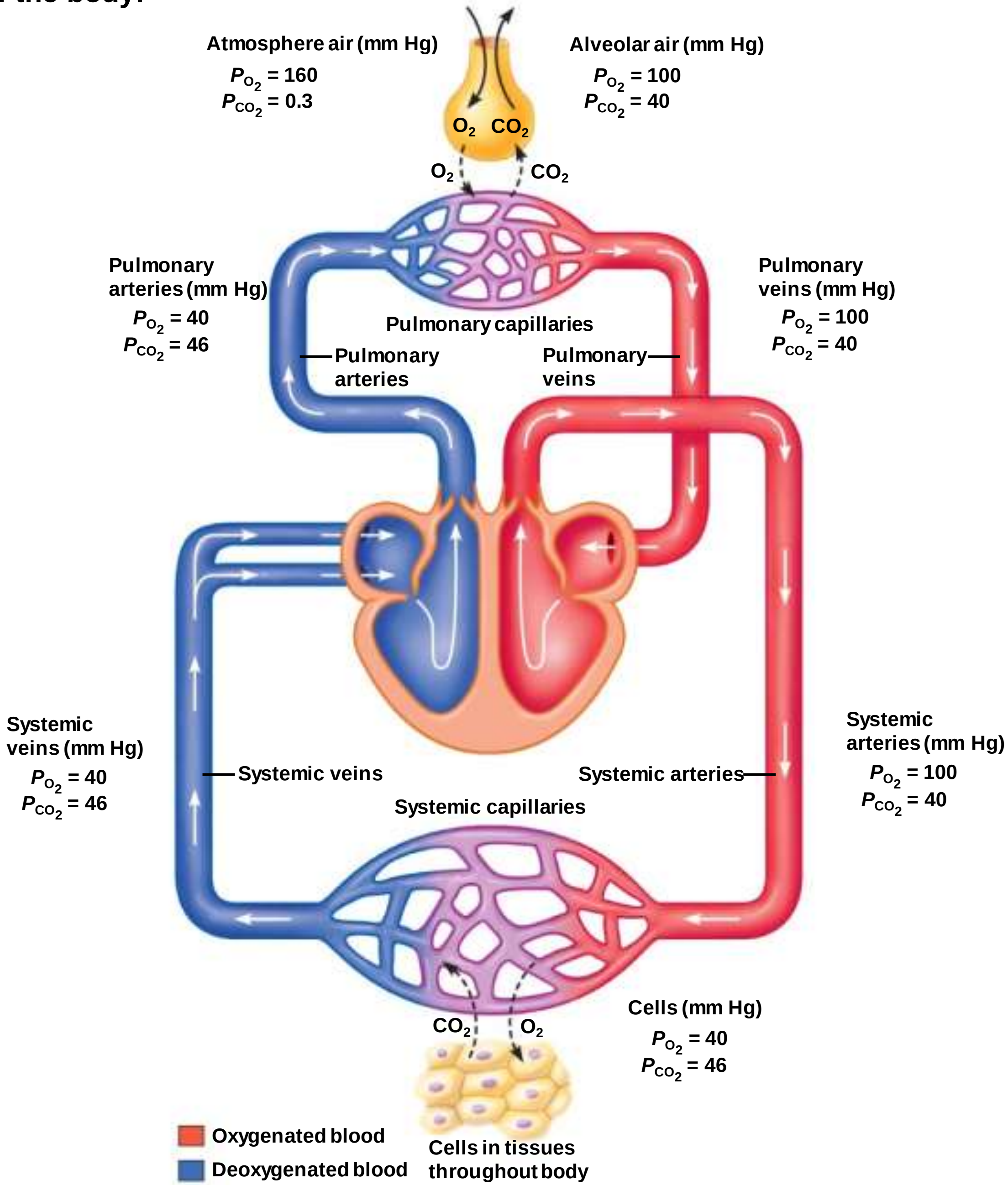


Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.

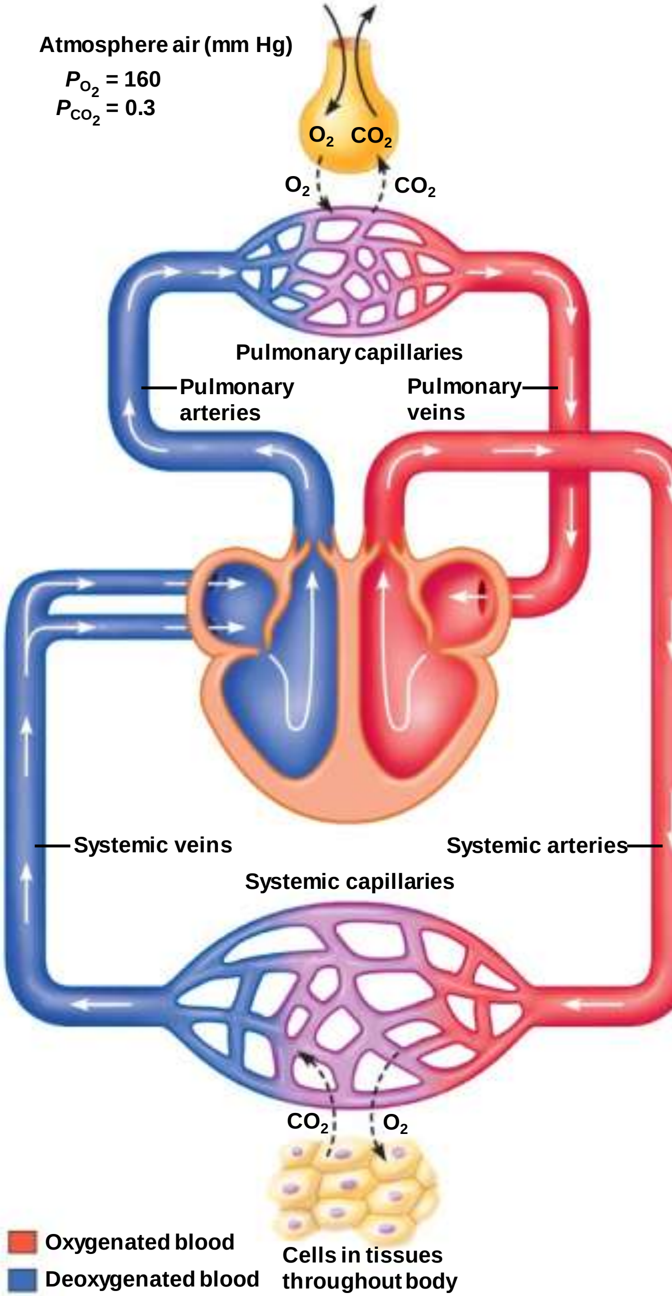


Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.

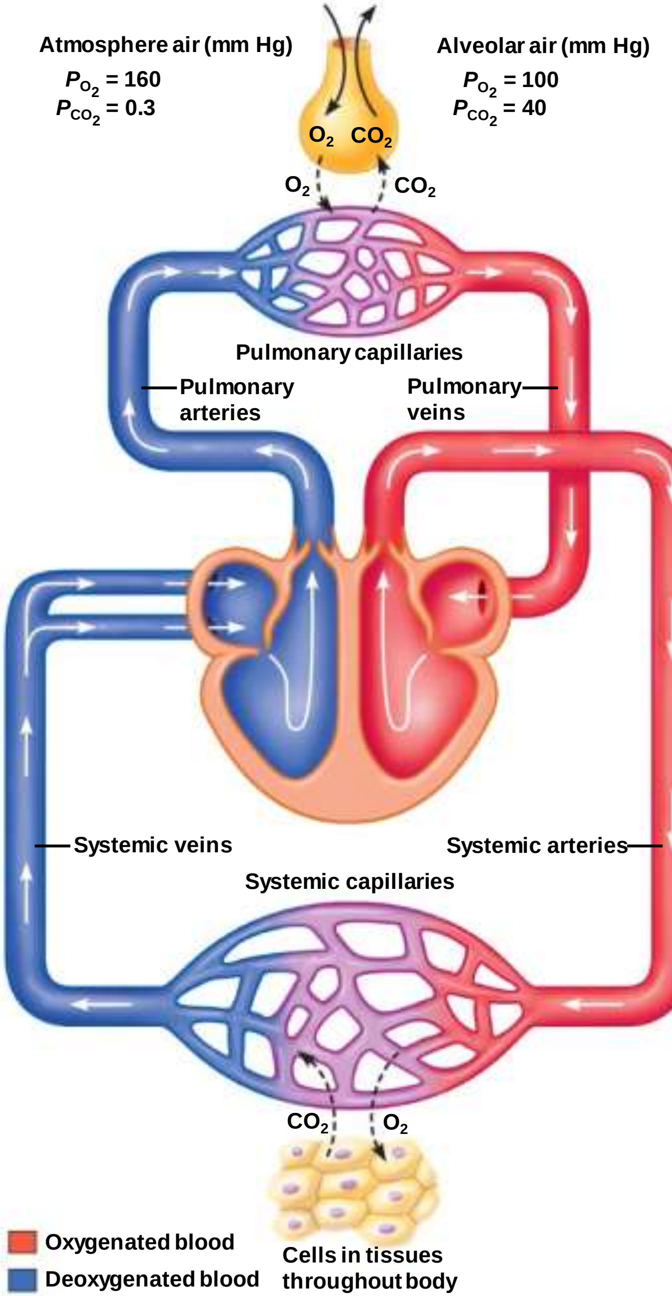


Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.

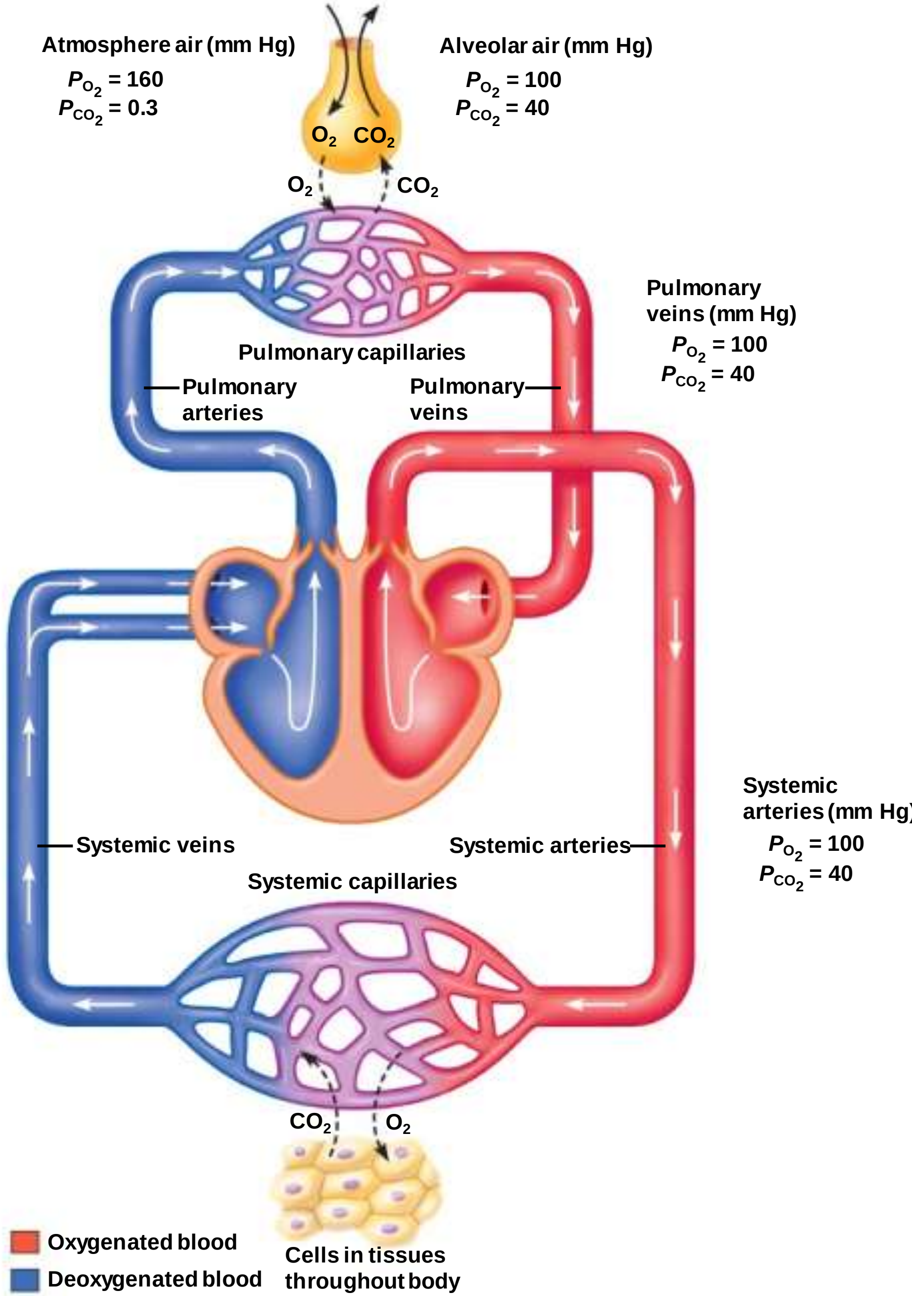


Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.

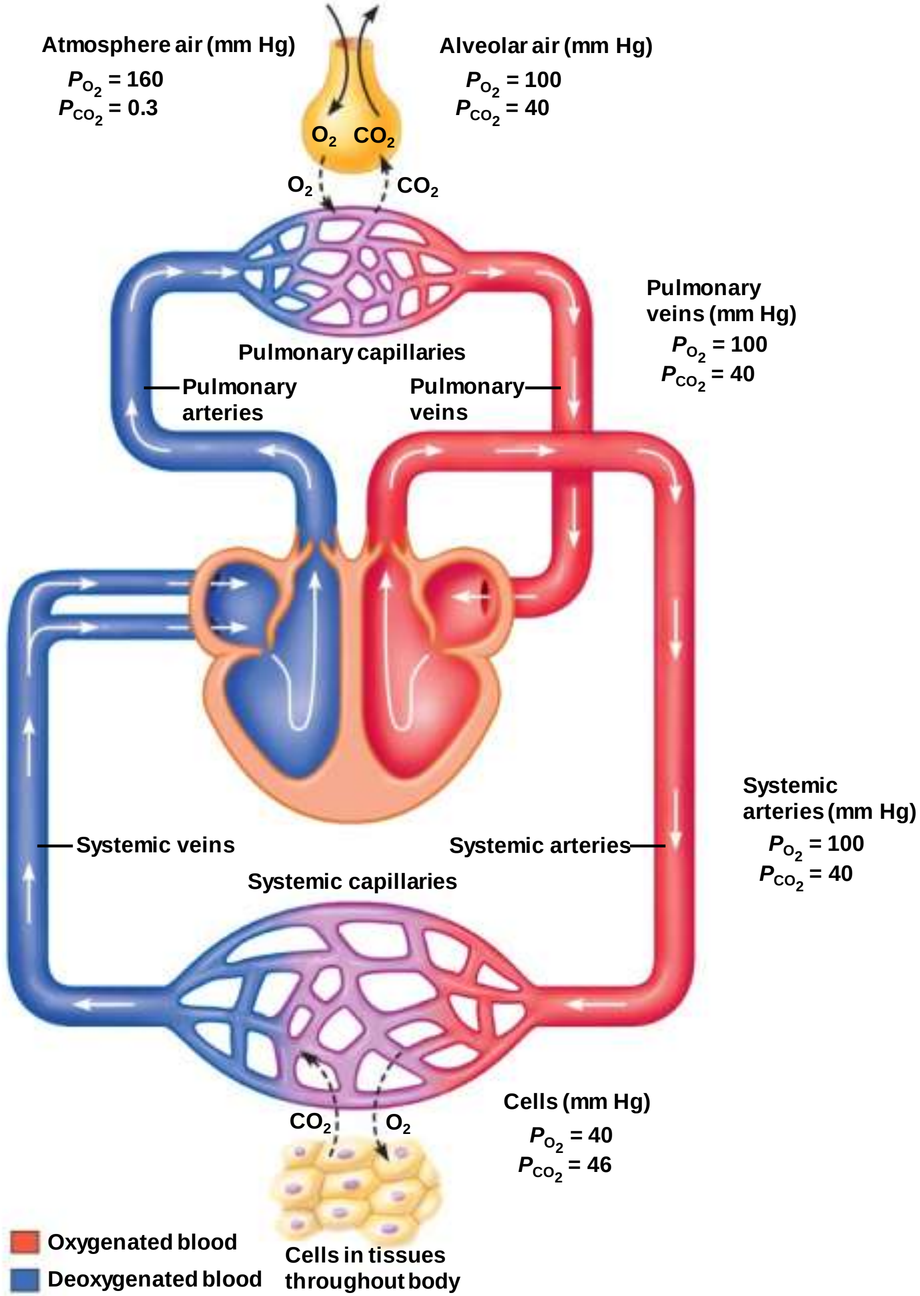
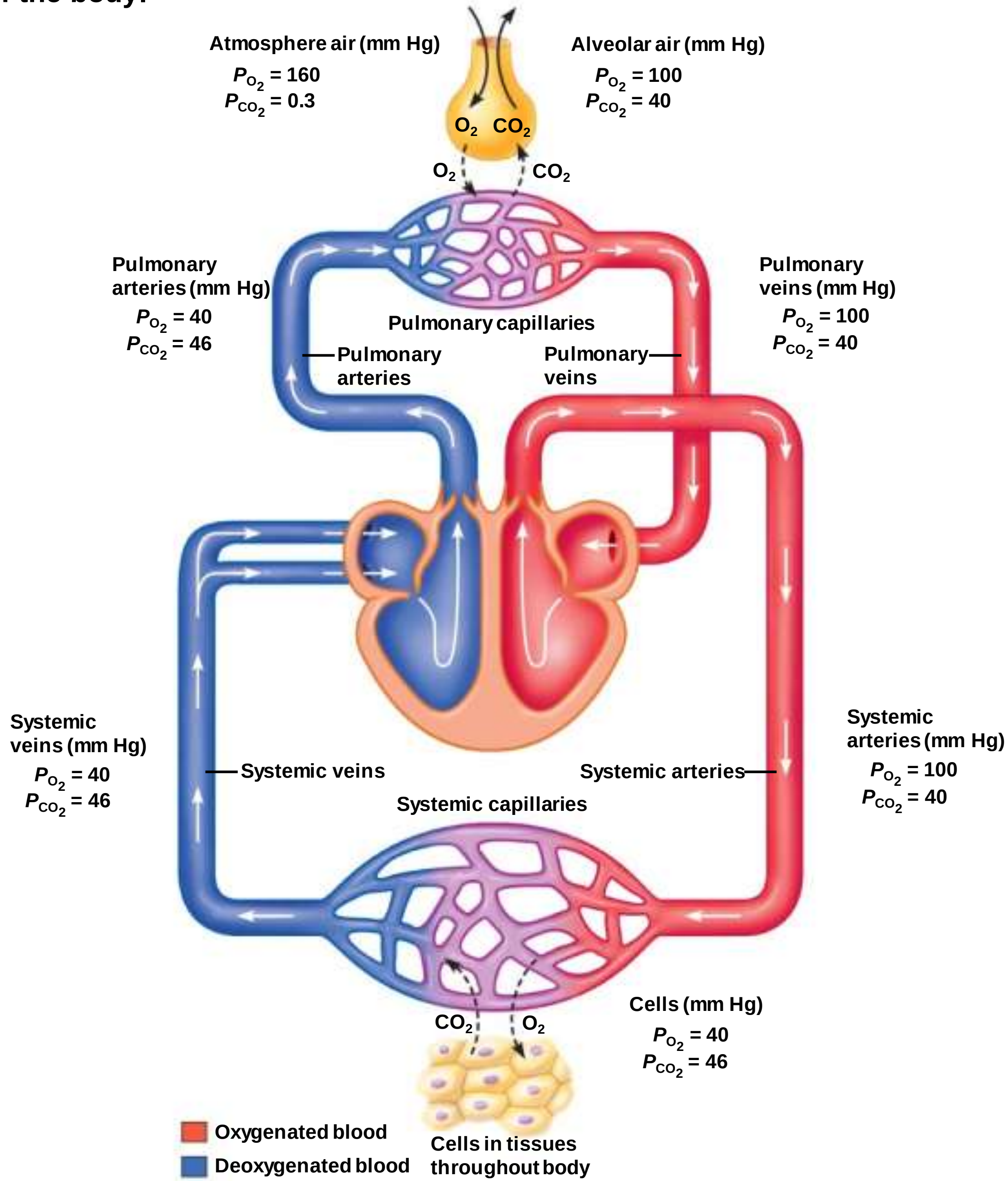


Figure 17.4 Partial pressures of oxygen and carbon dioxide in atmospheric air, in alveolar air, and at various sites in the body.



Gas Exchange in the Lungs

- Diffusion between alveoli and blood is rapid
  - Small diffusion barrier
  - Large surface area

Figure 17.5a Gas exchange as a function of pulmonary capillary length.

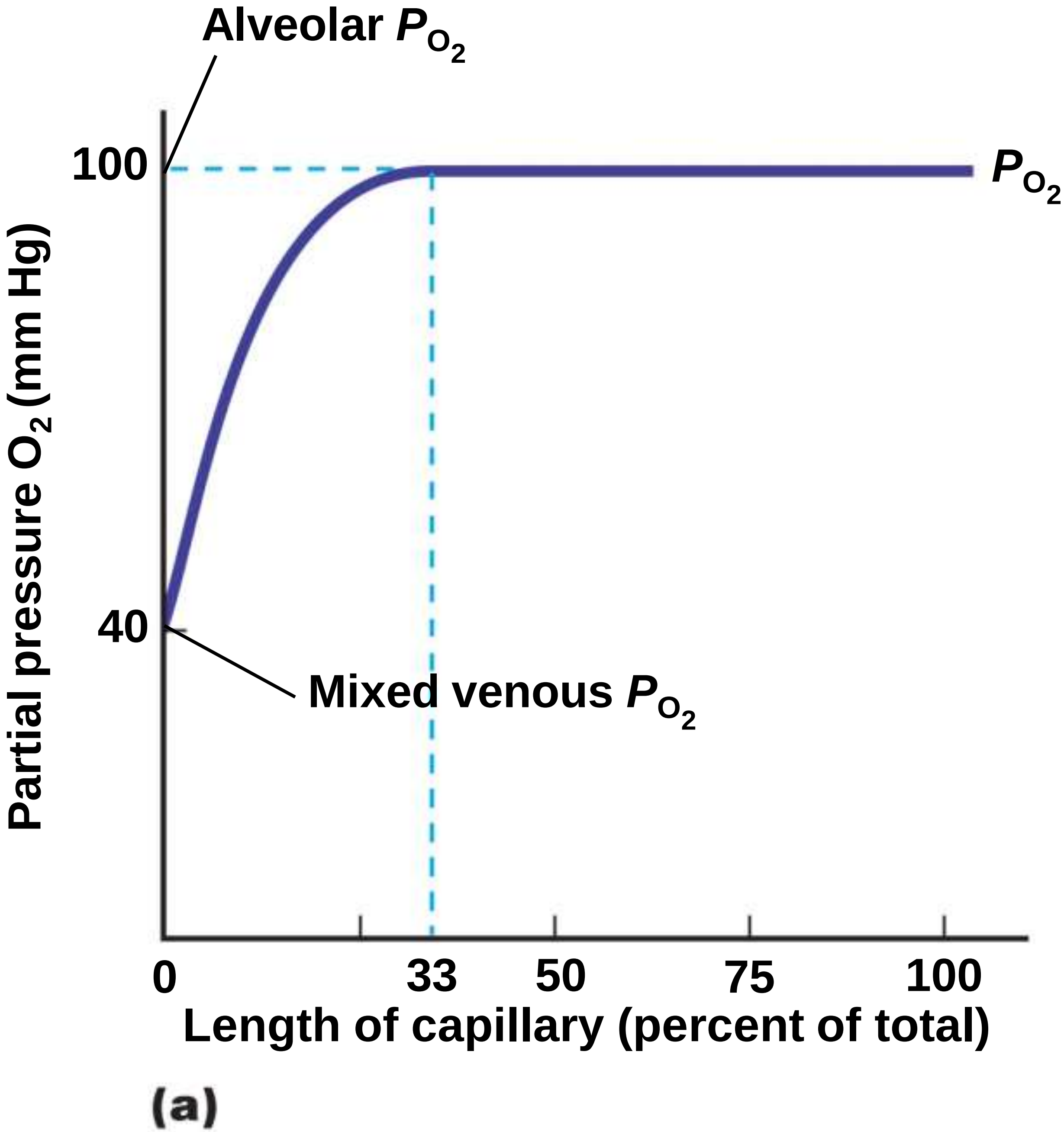
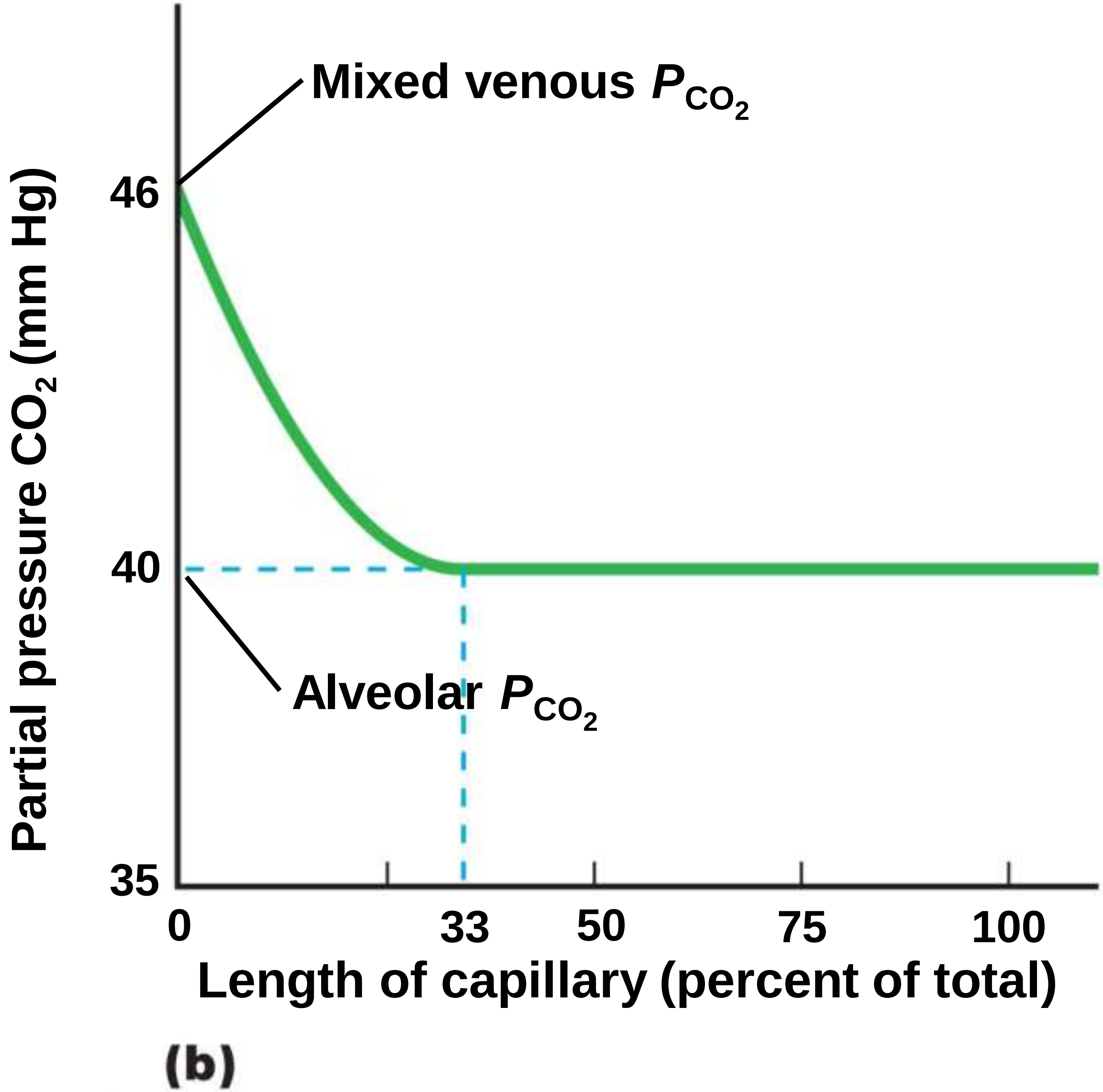


Figure 17.5b Gas exchange as a function of pulmonary capillary length.



Gas Exchange in Respiring Tissue

- Gases diffuse down partial pressure gradients
- P_{O_2} cells ≤ 40 mm Hg; P_{O_2} systemic arteries = 100 mm Hg
  - Oxygen diffuses from blood to cells
  - P_{O_2} systemic veins = 40 mm Hg
- P_{CO_2} cells ≥ 46 mm Hg; P_{CO_2} systemic arteries = 40 mm Hg
  - Carbon dioxide diffuses from cells to blood
  - P_{CO_2} systemic veins = 46 mm Hg

Gas Exchange in Respiring Tissue

- Mixed venous blood
  - Amount of O_2 and CO_2 that is exchanged in a vascular bed depends on metabolic activity of the tissue
    - Greater rate of metabolism → greater exchange
  - P_{O_2} and P_{CO_2} in different systemic veins vary
  - All systemic venous blood returns to the right atrium and is pumped out of the right ventricle and into the pulmonary artery
  - Blood in pulmonary artery = mixed venous blood
    - P_{O_2} = 40 mm Hg
    - P_{CO_2} = 46 mm Hg

Determinants of Alveolar P_{O_2} and P_{CO_2}

- Factors affecting alveolar partial pressures
  - P_{O_2} and P_{CO_2} of inspired air
  - Minute alveolar ventilation
  - Rates at which respiring tissues use O_2 and produce CO_2
- Most critical is the rate of alveolar ventilation relative to the rate of O_2 use and CO_2 production

Determinants of Alveolar P_{O_2} and P_{CO_2}

- Hyperpnea: increased ventilation due to increased demand
  - Minimal changes in arterial P_{O_2} and P_{CO_2}
- Hypoventilation: ventilation does not meet demands
  - Arterial P_{O_2} decreases
  - Arterial P_{CO_2} increases
- Hyperventilation: ventilation exceeds demands
  - Arterial P_{O_2} increases
  - Arterial P_{CO_2} decreases

TABLE 17.2 Some Terms Used in Respiratory Physiology

Term	Definition
Hyperpnea	An increase in ventilation to meet an increase in the metabolic demands of the body
Dyspnea	Labored or difficult breathing
Apnea	Temporary cessation of breathing
Tachypnea	Rapid, shallow breathing
Hyperventilation	A condition in which ventilation exceeds the metabolic demands of the body
Hypoventilation	A condition in which ventilation is insufficient to meet the metabolic demands of the body
Hypoxia	A deficiency of oxygen in the tissues
Hypoxemia	A deficiency of oxygen in the blood
Hypercapnia	An excess of carbon dioxide in the blood
Hypocapnia	A deficiency of carbon dioxide in the blood

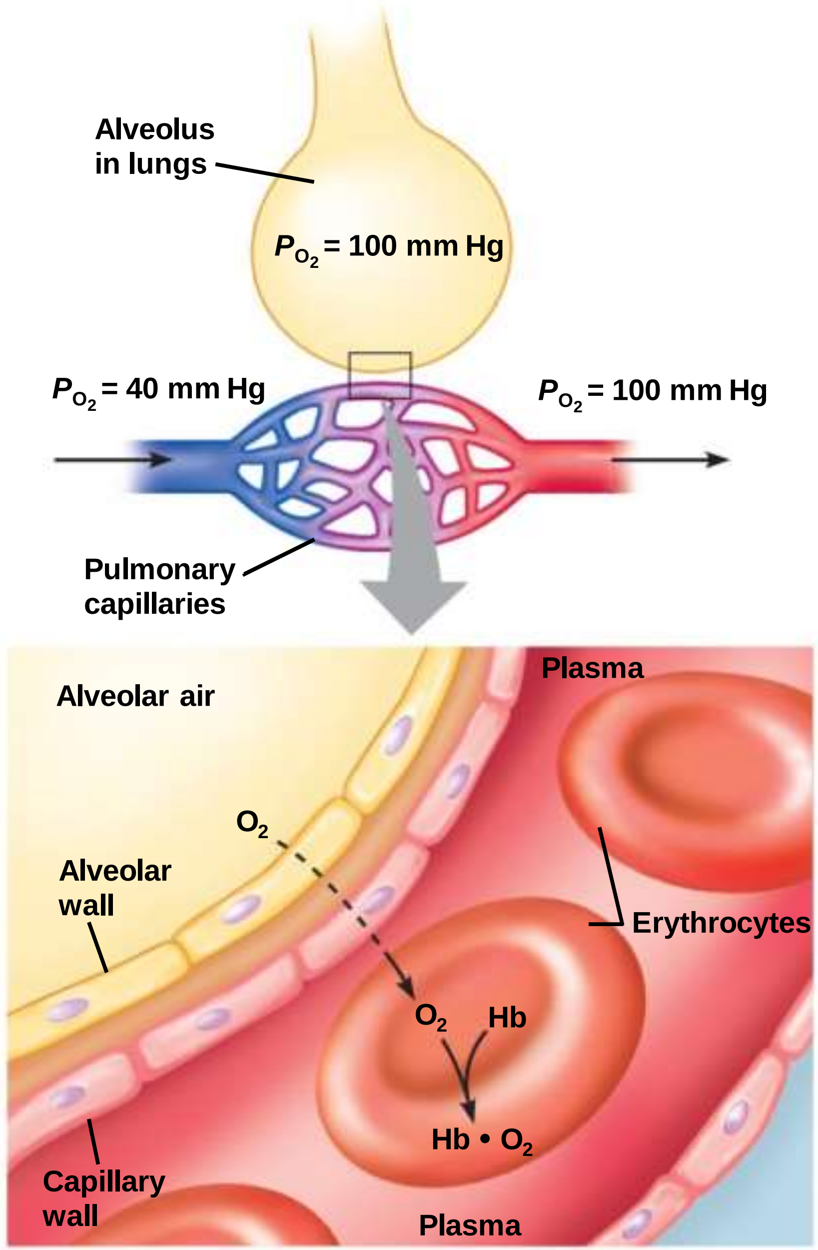
17.4 Transport of Gases in the Blood

- Oxygen transport in blood
- Carbon dioxide transport in blood

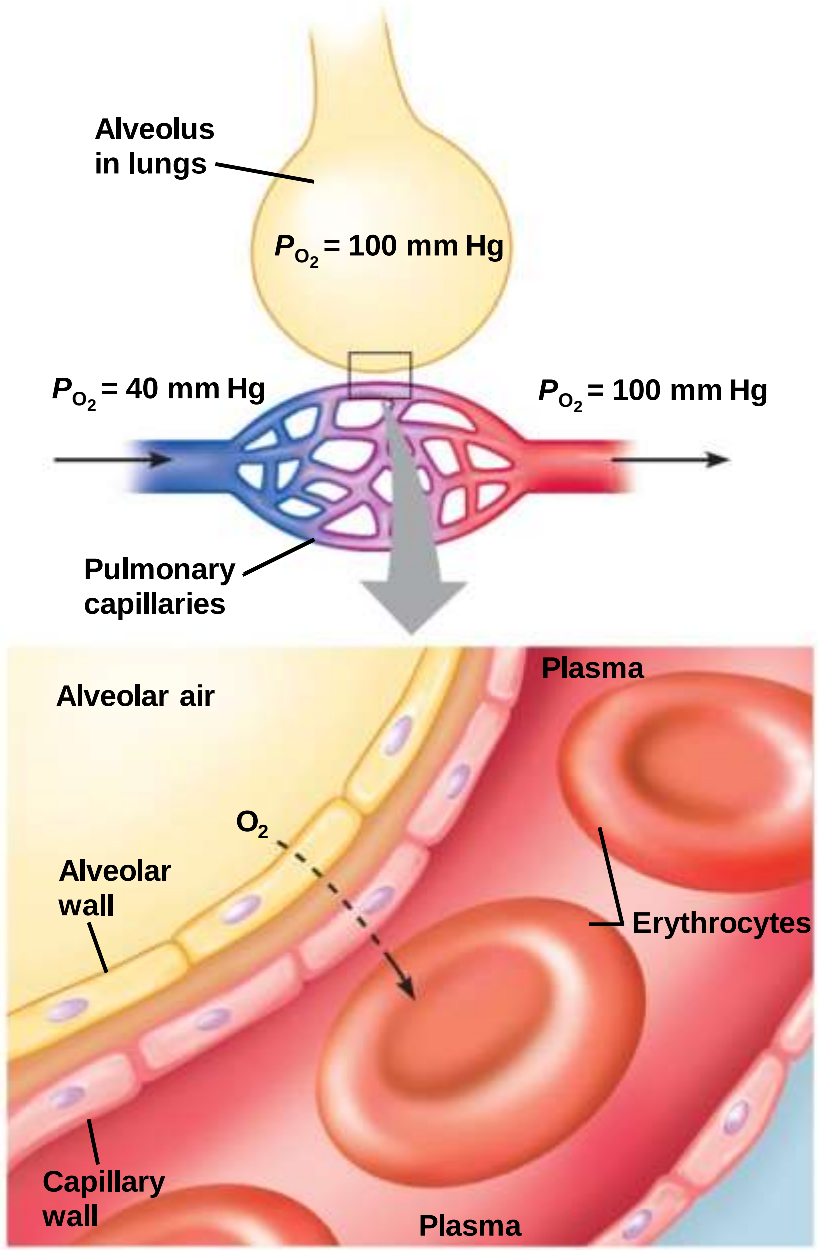
Oxygen Transport in the Blood

- Oxygen transport by hemoglobin
  - O_2 is not very soluble in plasma
  - Only 3.0 mL of every 200 mL of arterial blood O_2 is dissolved in plasma (1.5%)
  - The other 197 mL of arterial blood O_2 is transported by hemoglobin
- Oxygen binding to hemoglobin
  - $Hb + O_2 \rightleftharpoons Hb \bullet O_2$
  - Hb = deoxyhemoglobin
  - $Hb \bullet O_2$ = oxyhemoglobin

Figure 17.6a Transport of oxygen by hemoglobin.



(a)


Alveolus
in lungs
P_{O_2} = 100 mm Hg
P_{O_2} = 40 mm Hg
P_{O_2} = 100 mm Hg
Pulmonary
capillaries
Alveolar air
Plasma
O_2
Alveolar
wall
Erythrocytes
Capillary
wall
Plasma

(a)

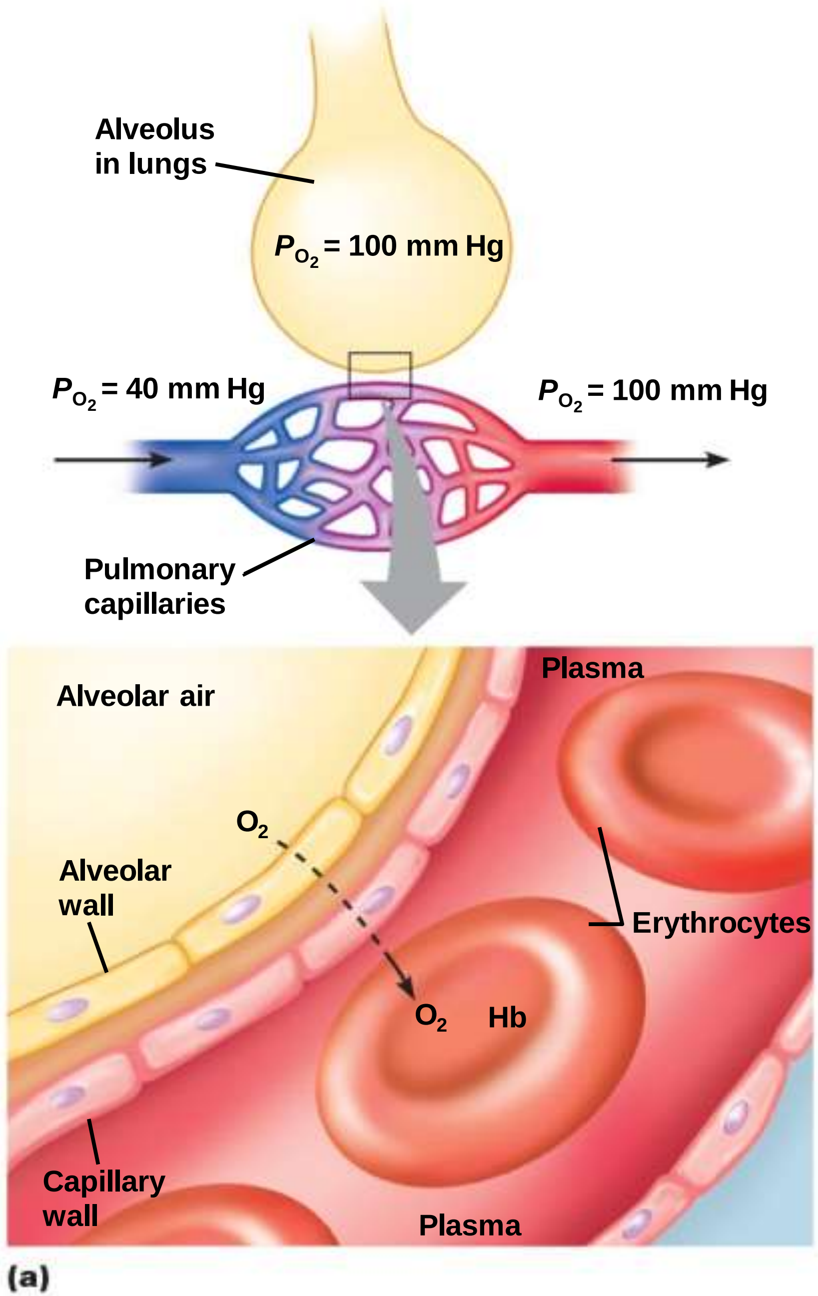
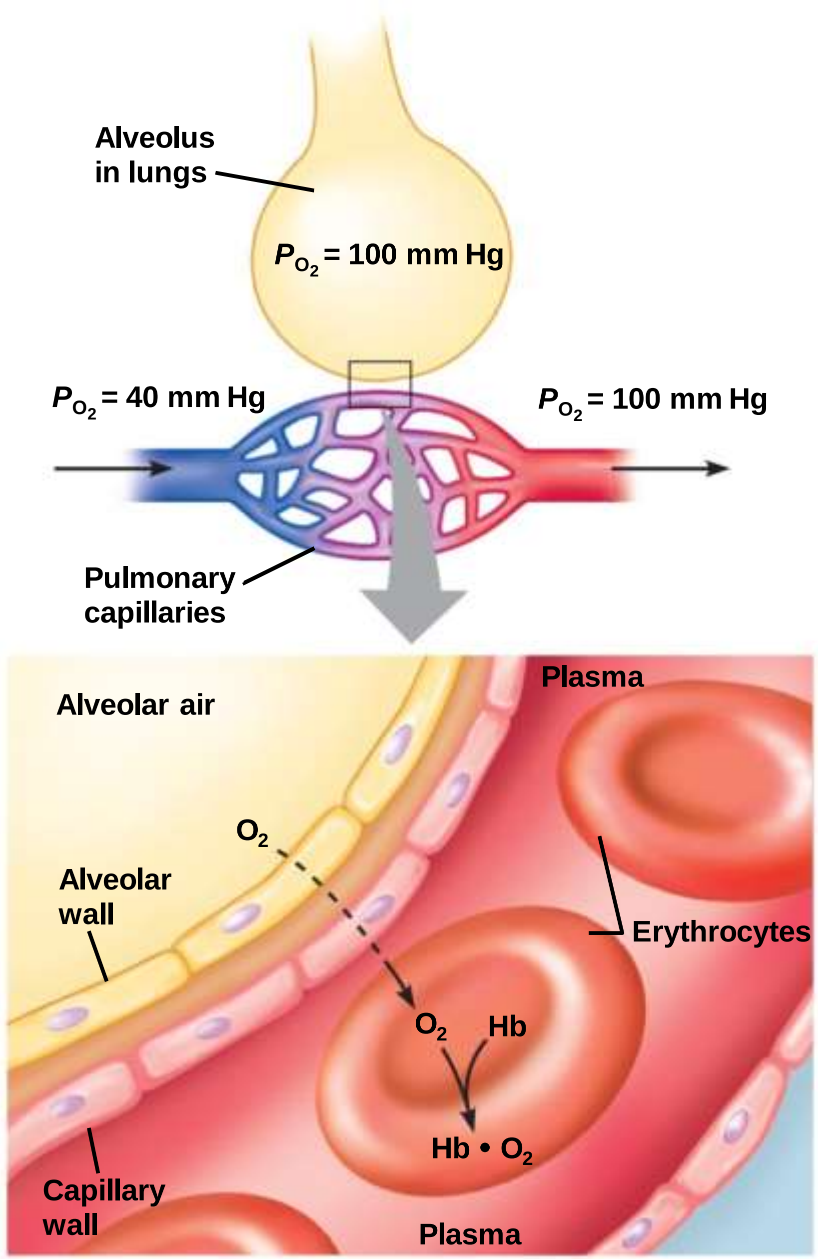
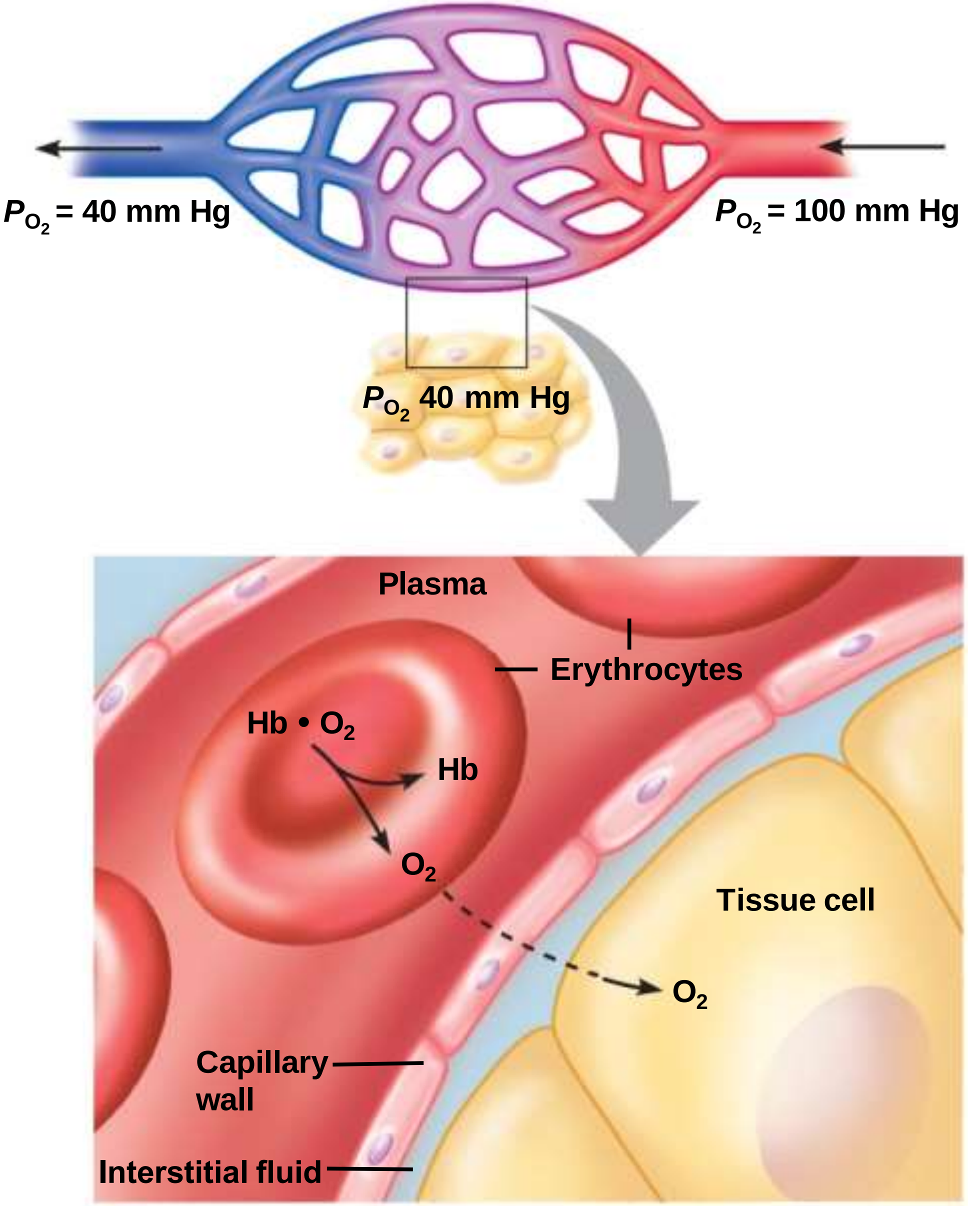

Alveolus
in lungs
P_{O_2} = 100 mm Hg
P_{O_2} = 40 mm Hg
P_{O_2} = 100 mm Hg
Pulmonary
capillaries
Alveolar air
Plasma
O_2
Alveolar
wall
Erythrocytes
O_2 Hb
Capillary
wall
Plasma
(a)

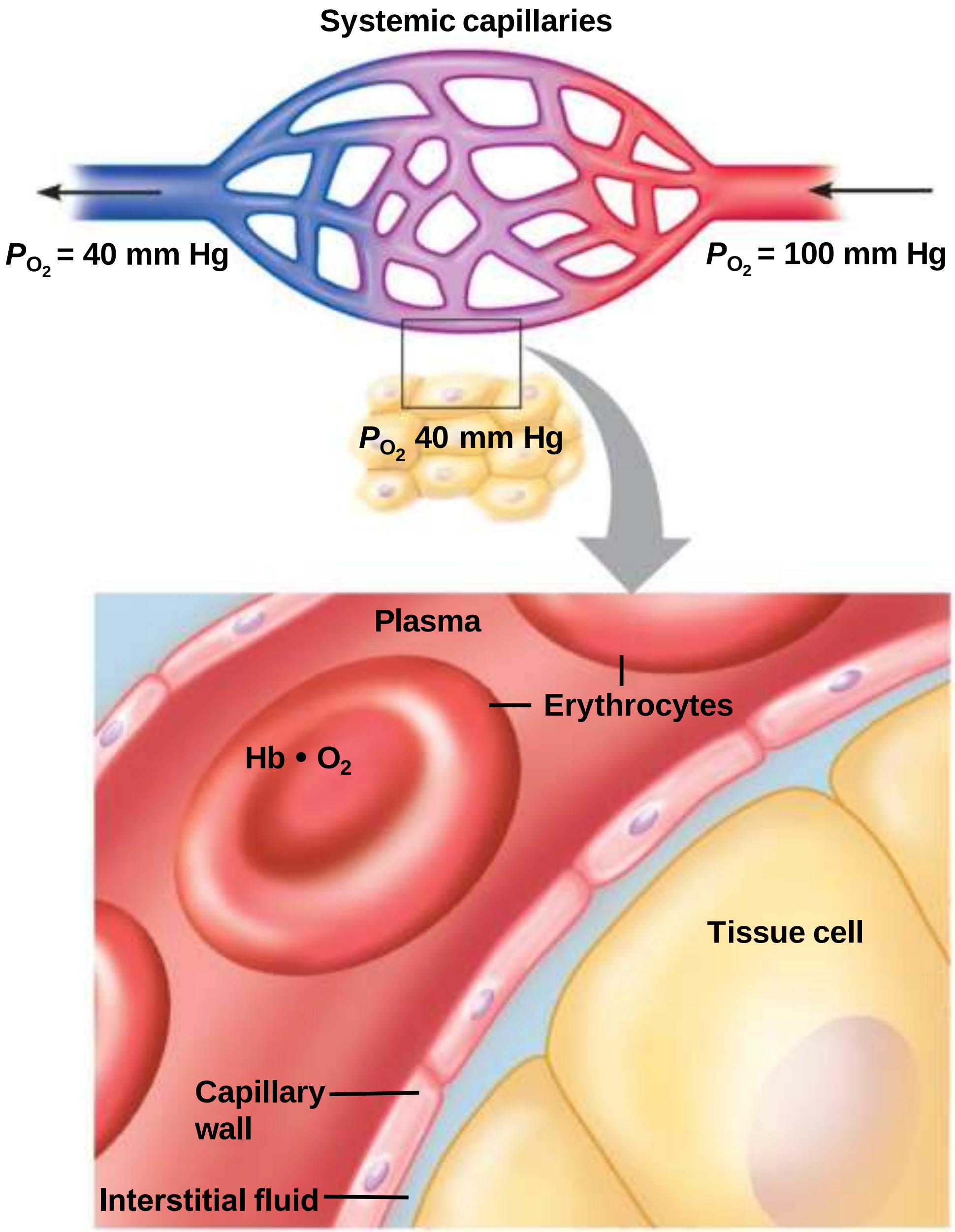
Figure 17.6a Transport of oxygen by hemoglobin.



(a)


Systemic capillaries
P_{O_2} = 40 mm Hg
P_{O_2} = 100 mm Hg
P_{O_2} 40 mm Hg
Plasma
Erythrocytes
Hb • O_2
Hb
O_2
Tissue cell
O_2
Capillary wall
Interstitial fluid

(b)


Systemic capillaries
P_{O_2} = 40 mm Hg
P_{O_2} = 100 mm Hg
P_{O_2} 40 mm Hg
Plasma
Erythrocytes
Hb • O_2
Tissue cell
Capillary wall
Interstitial fluid

(b)

Figure 17.6b Transport of oxygen by hemoglobin.

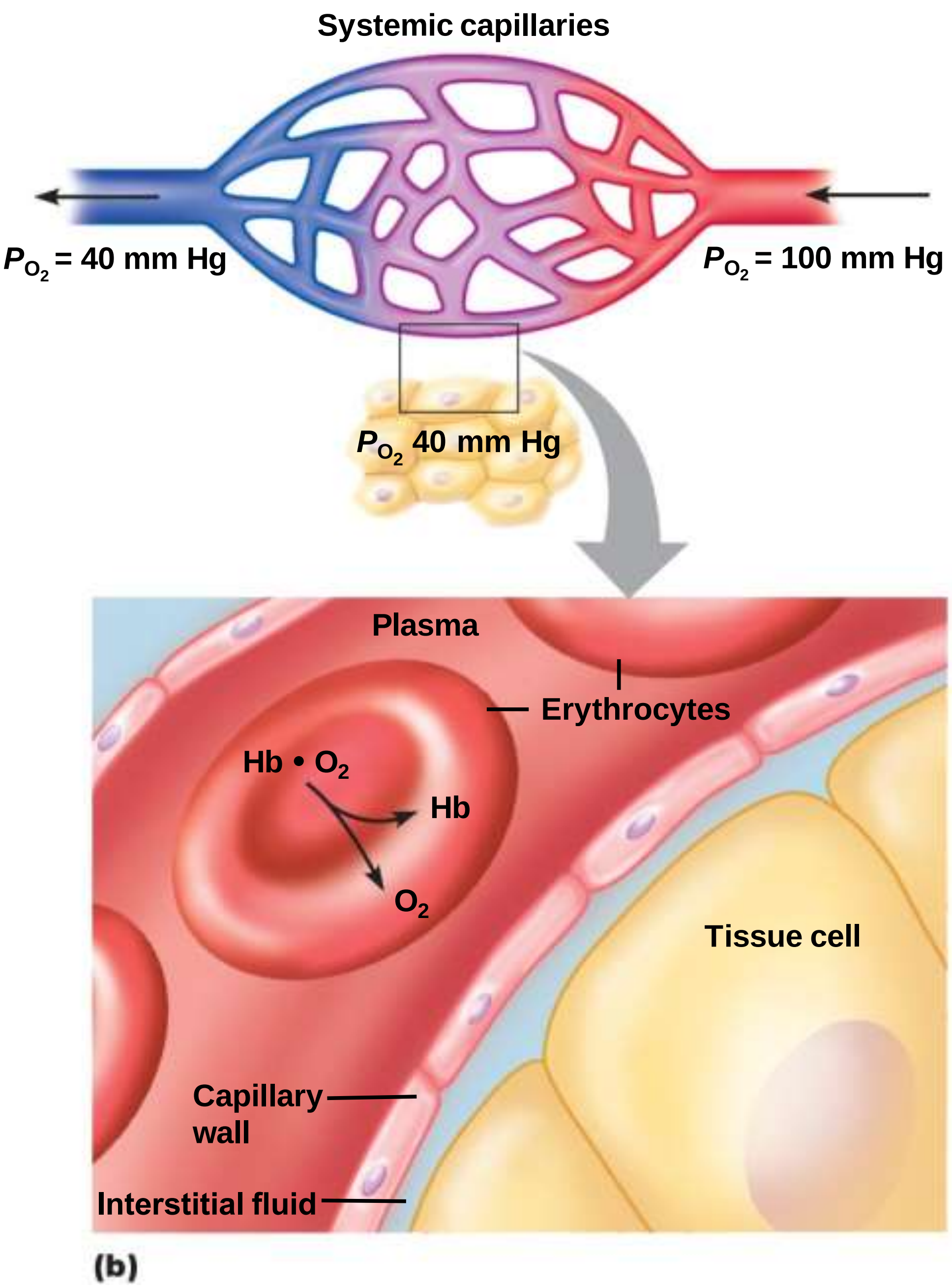
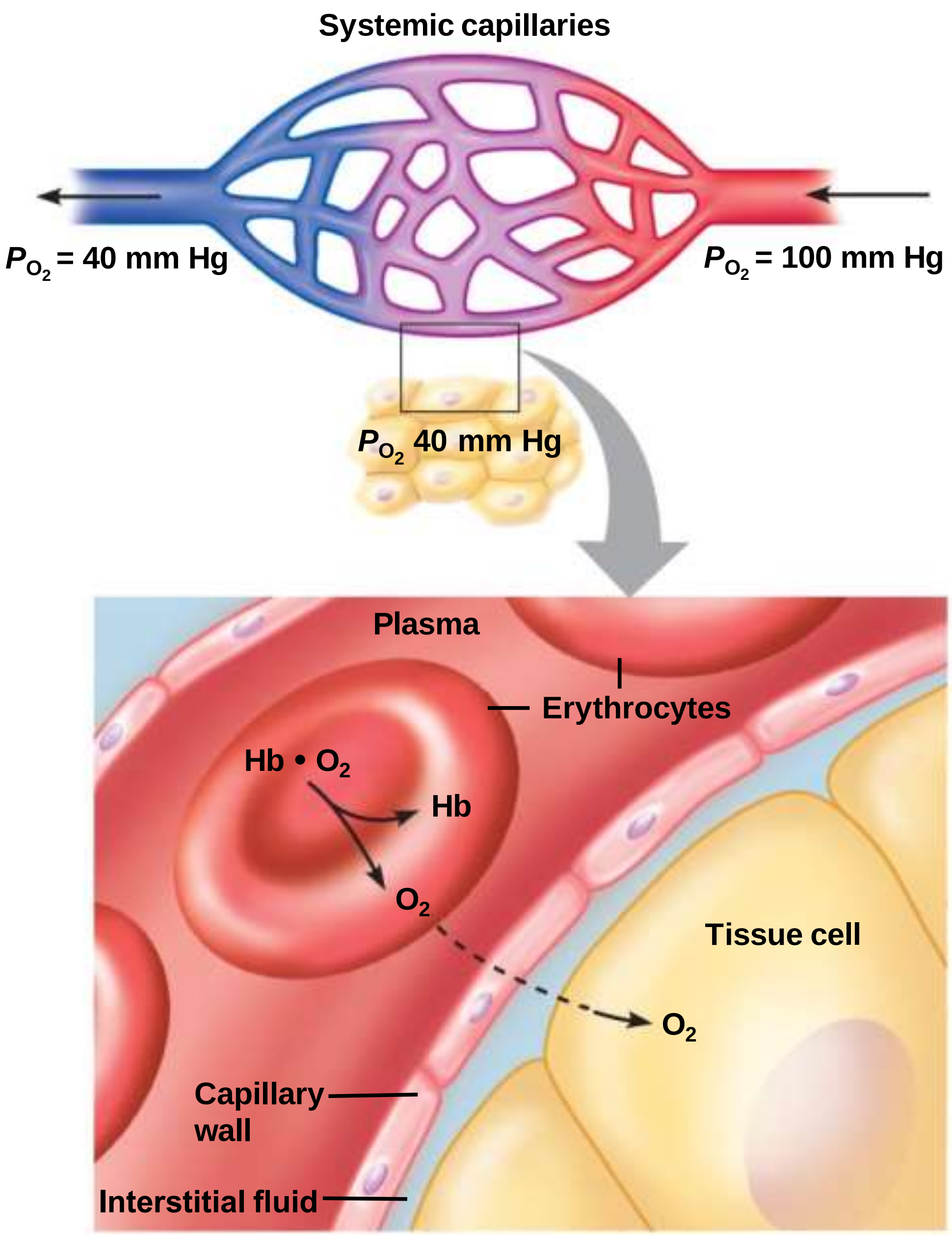


Figure 17.6b Transport of oxygen by hemoglobin.



(b)

Oxygen Transport in the Blood

- Saturation of hemoglobin
  - Hemoglobin can bind up to four oxygen molecules
  - Binding of oxygen to hemoglobin follows the law of mass action
    - More oxygen → more binds to hemoglobin
    - Nonlinear relationship: positive cooperativity
  - Saturation of hemoglobin is a measure of how much oxygen is bound to hemoglobin
    - 100% saturation → all four binding sites on hemoglobin have oxygen bound to them

Oxygen Transport in the Blood

- O_2-carrying capacity of blood
  - When 100% saturated, 1 g hemoglobin carries 1.34 mL O_2
  - Normal blood hemoglobin levels
    - 2–17 g/dL
  - O_2-carrying capacity of hemoglobin in blood
    - 200 mL O_2 per 1 L blood
- Arterial blood
  - Hemoglobin is 98.5% saturated
- Venous blood
  - Hemoglobin is 75% saturated

Figure 17.7a Saturation of hemoglobin.

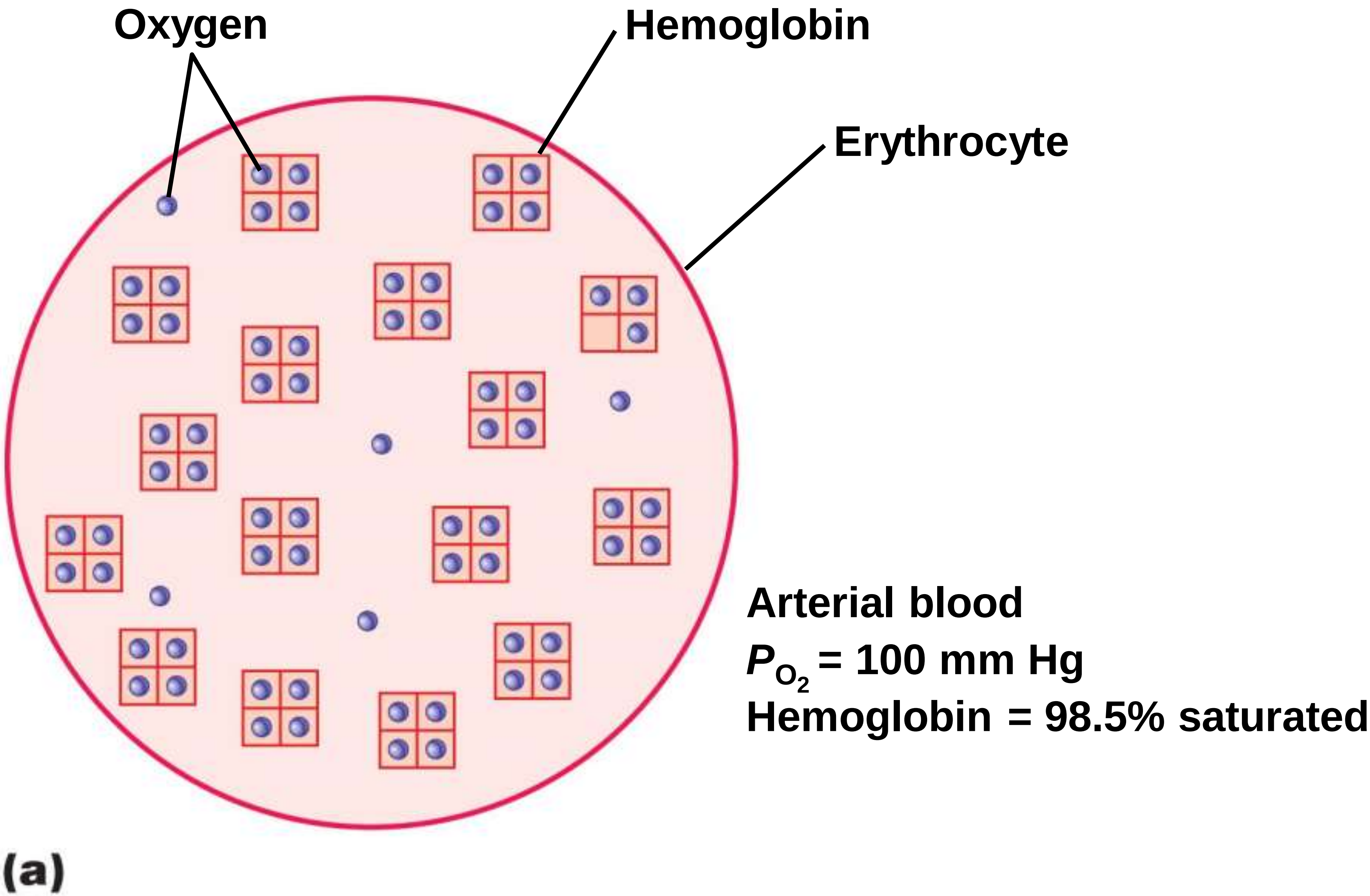
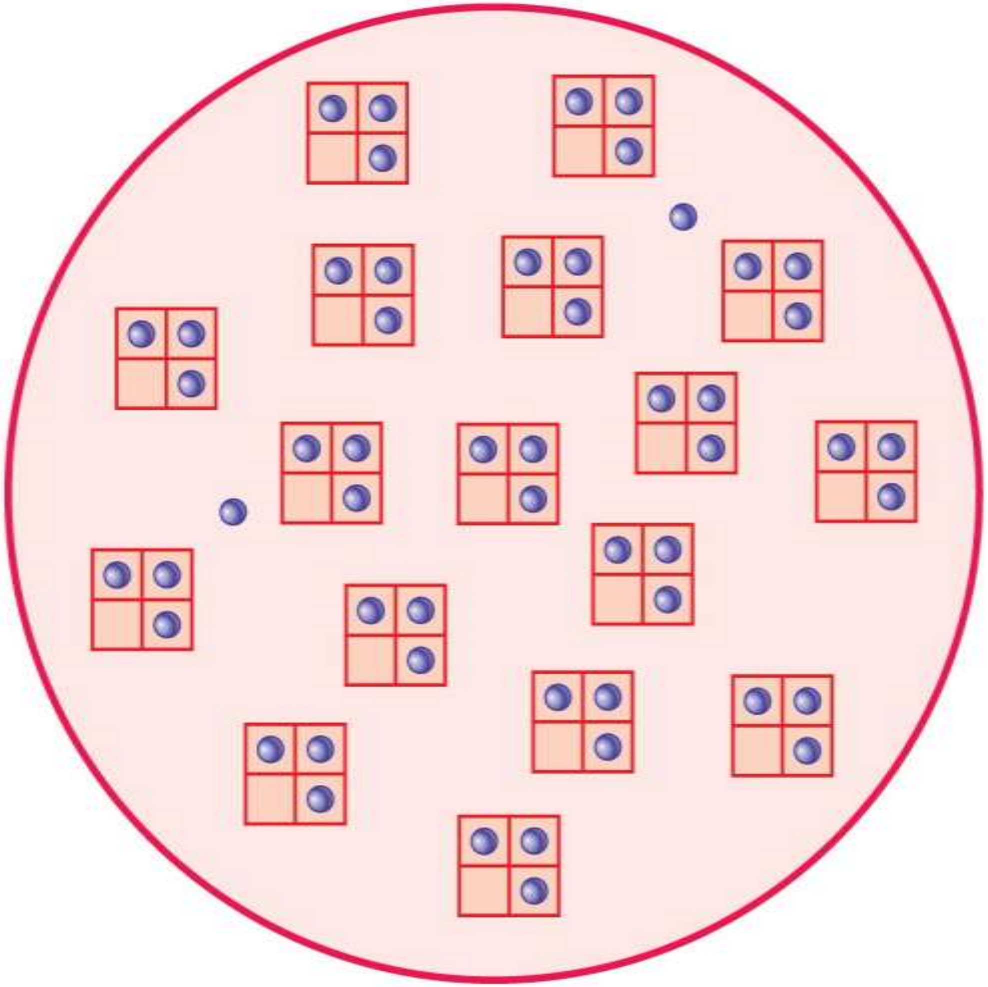


Figure 17.7b Saturation of hemoglobin.



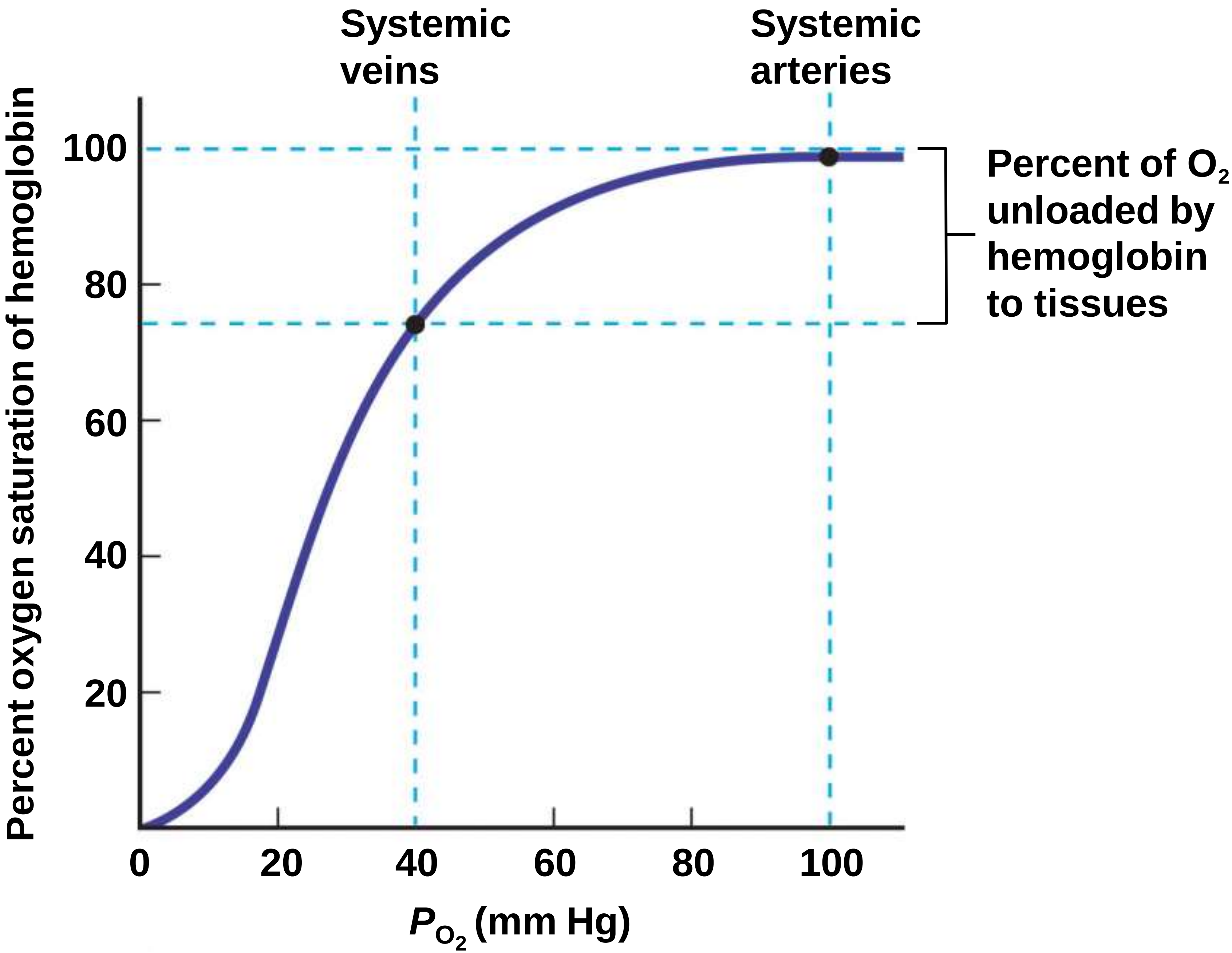
Mixed venous blood

P_{O_2} = 40 mm Hg

Hemoglobin = 75% saturated

(b)

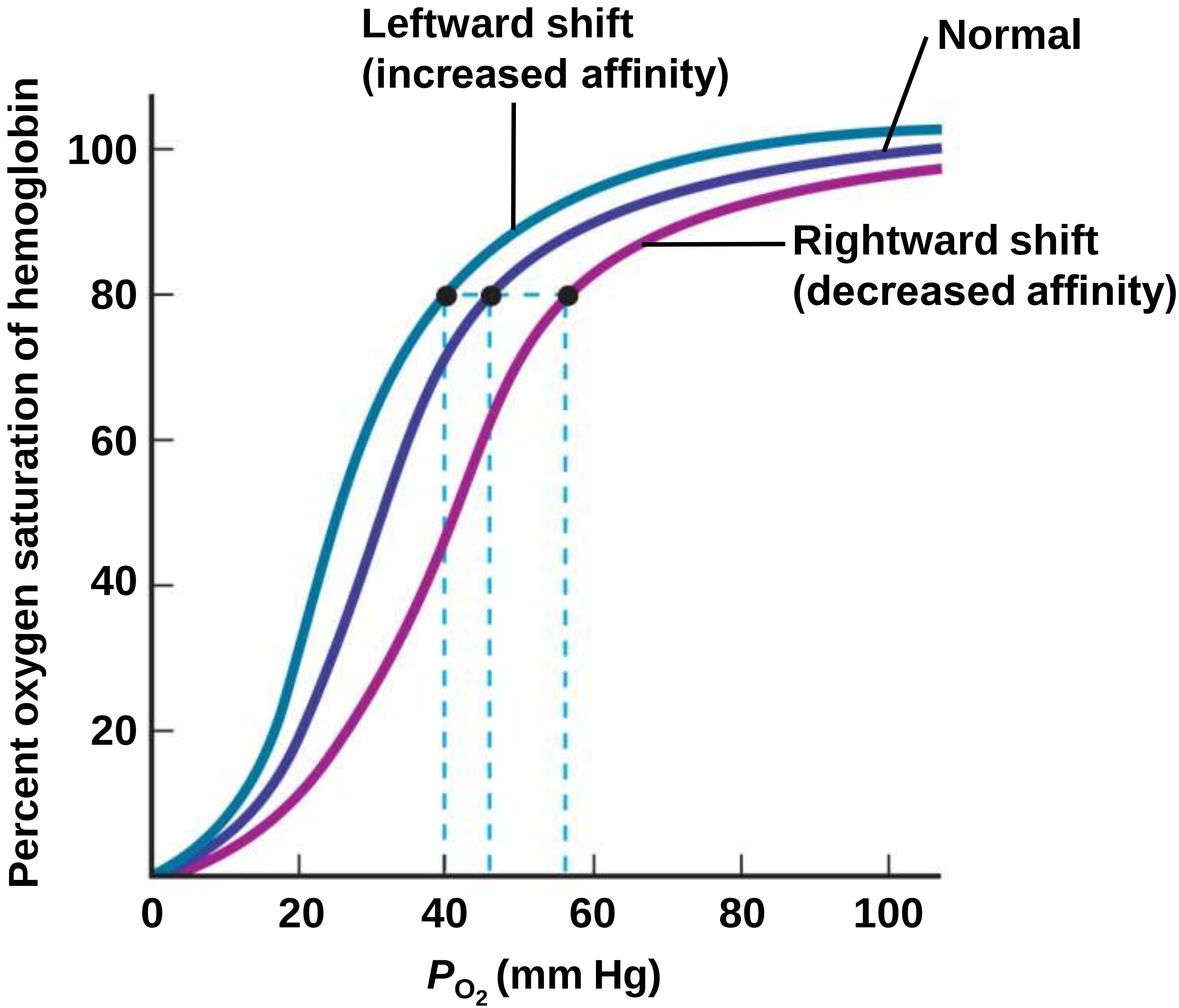
Figure 17.8 Hemoglobin-oxygen dissociation curve.



Oxygen Transport in the Blood

- Effects of O_2 affinity changes on Hb•O_2 dissociation curve
  - Shift right
    - Less loading of O_2 and less unloading
  - Shift left
    - More loading of O_2 and less unloading

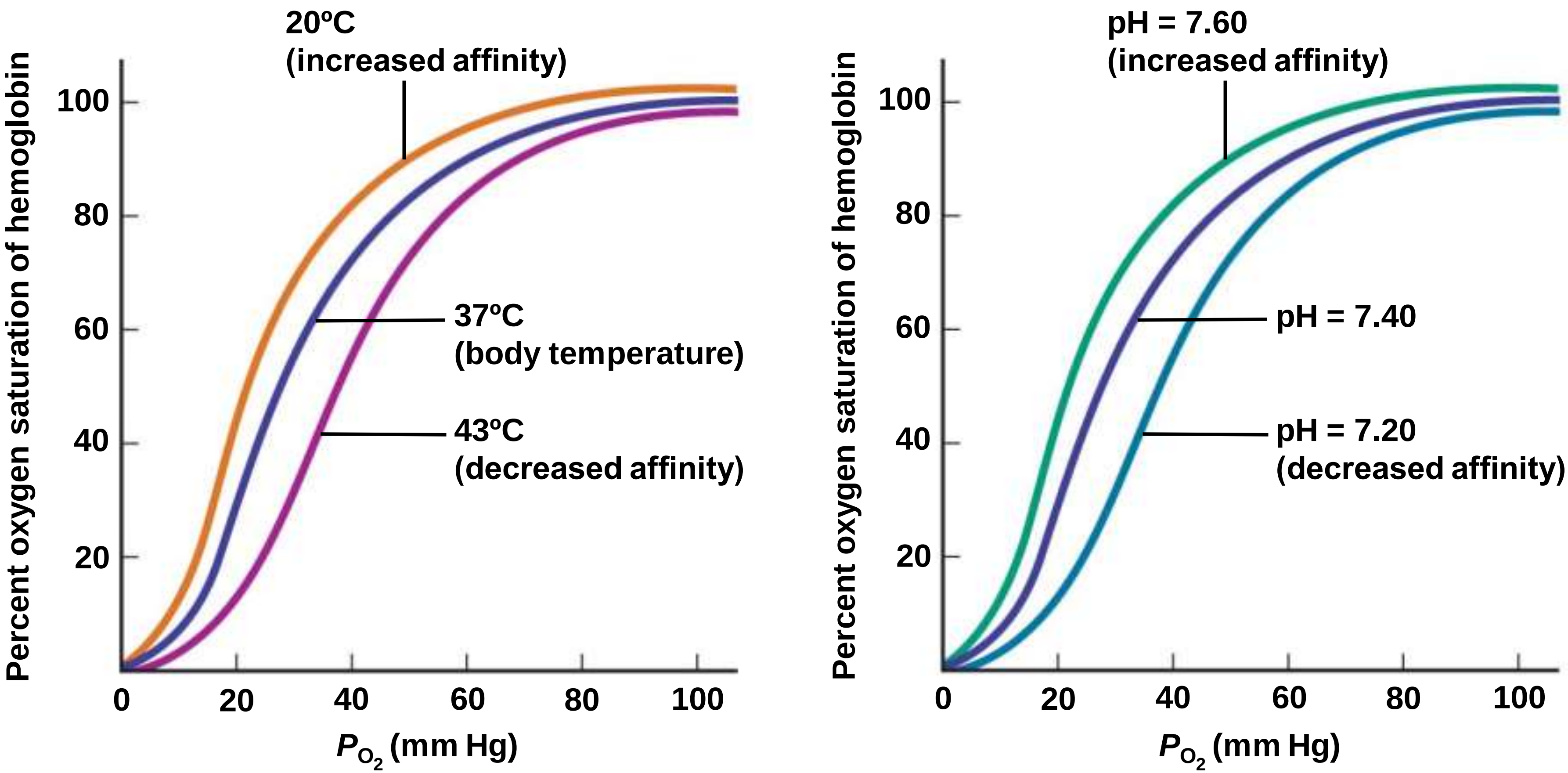
Figure 17.9 Effects of changes in the affinity of hemoglobin for oxygen on the hemoglobin-oxygen dissociation curve.



Oxygen Transport in the Blood

- Effects of temperature on Hb•O_2 dissociation curve
- Higher temperature
  - Active tissues
  - Shift right
  - More O_2 unloading in tissues
  - More O_2 delivery to tissues

Figure 17.10 Effects of temperature and pH on the hemoglobin-oxygen dissociation curve.



(a) Effects of temperature

(b) Effects of pH

Oxygen Transport in the Blood

- Effects of pH on Hb•O_2 dissociation curve
- Bohr effect
  - Lower pH increases O_2 unloading
- Active tissues
  - Produce more acid; pH decreases in tissues
  - Decreased pH causes shift right in saturation curve
  - More O_2 is unloaded to tissues

Oxygen Transport in the Blood

- Effects of CO_2–carbamino effect
  - CO_2 reacts with hemoglobin to form *carbaminohemoglobin*
    - $Hb + CO_2 \rightleftharpoons HbCO_2$
  - $HbCO_2$ has lower affinity for oxygen than Hb
  - Increased metabolic activity → increases CO_2
  - Increased oxygen unloading in active tissue

Oxygen Transport in the Blood

- Effect of 2,3-DPG
  - 2,3-DPG = 2,3-diphosphoglycerate
  - Produced in red blood cells under conditions of low O_2 such as anemia and high altitude
  - Synthesis inhibited by oxyhemoglobin
  - 2,3-DPG decreases affinity of hemoglobin for O_2, enhancing O_2 unloading
- Effect of carbon monoxide
  - Hemoglobin has greater affinity for carbon monoxide (CO) than for O_2
  - Prevents O_2 from binding to hemoglobin

Carbon Dioxide Transport in Blood

- Role of carbonic anyhdrase in carbon dioxide transport
  - Carbon dioxide exchange and transport in systemic capillaries and veins
  - Carbon dioxide exchange and transport in pulmonary capillaries and veins
- Effect of oxygen on carbon dioxide transport

TABLE 17.3 Carbon Dioxide Transport in Blood

Form	Systemic Arterial Blood		Systemic Venous Blood	
	CO_2 volume (mL/liter of blood)	% of total CO_2 in blood	CO_2 volume (mL/liter of blood)	% of total CO_2 in blood
Dissolved in blood	27	5.5	31	5.8
Dissolved as bicarbonate	439	89.6	470	87.0
Bound to hemoglobin	24	4.9	39	7.2
Total	490	100.0	540	100.0

Carbon Dioxide Transport in Blood

- CO_2 is more soluble in plasma than O_2, but still not very soluble
  - 5–6% transported dissolved in plasma
- CO_2 can bind to hemoglobin to form carbaminohemoglobin
  - 5–8% transported bound to hemoglobin
- CO_2 can be converted to bicarbonate by erythrocytes, then transported in plasma
  - 86–90% of transported CO_2 dissolved in the plasma as bicarbonate

Carbon Dioxide Transport in Blood

- Carbonic anhydrase
  - Enzyme that converts carbon dioxide and water to carbonic acid
  - *Law of mass action*: an increase in CO_2 causes an increase in bicarbonate and hydrogen ions

$$CO_2 + H_2O \xrightleftharpoons{\text{carbonic anhydrase}} H_2CO_3$$

Figure 17.11 Carbon dioxide exchange and transport in blood.

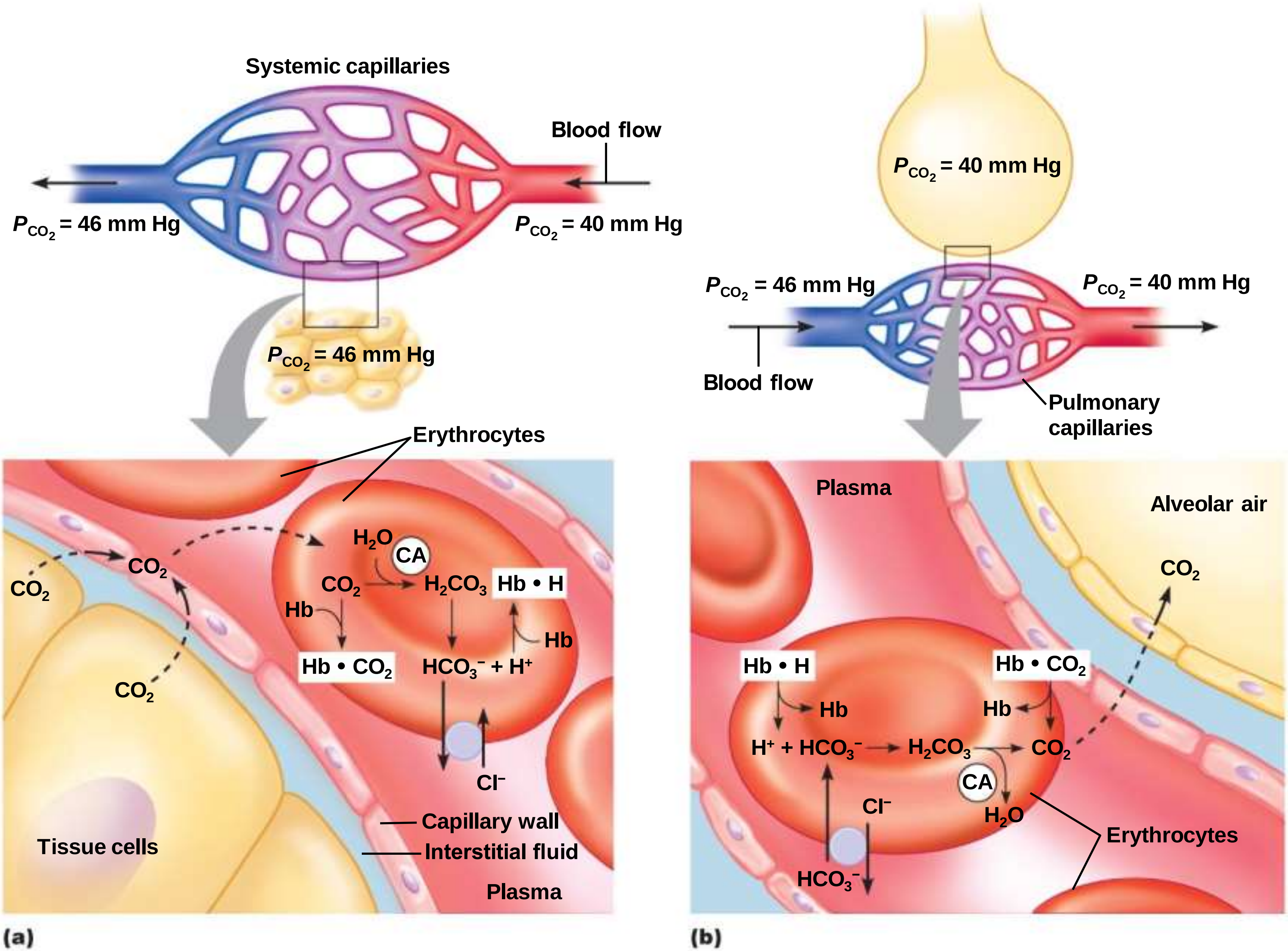


Figure 17.12 Effect of P_{O_2} on carbon dioxide transport.

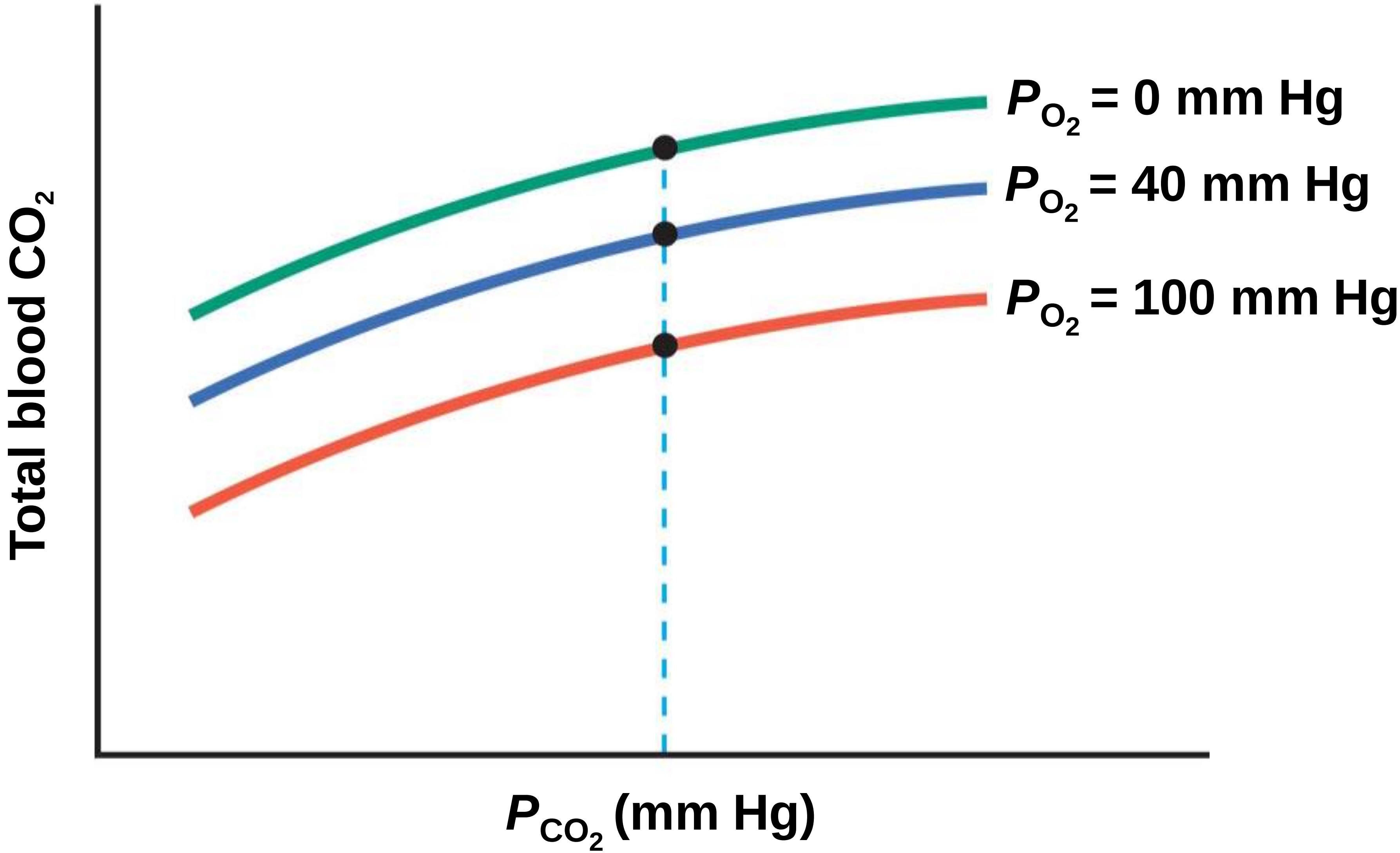
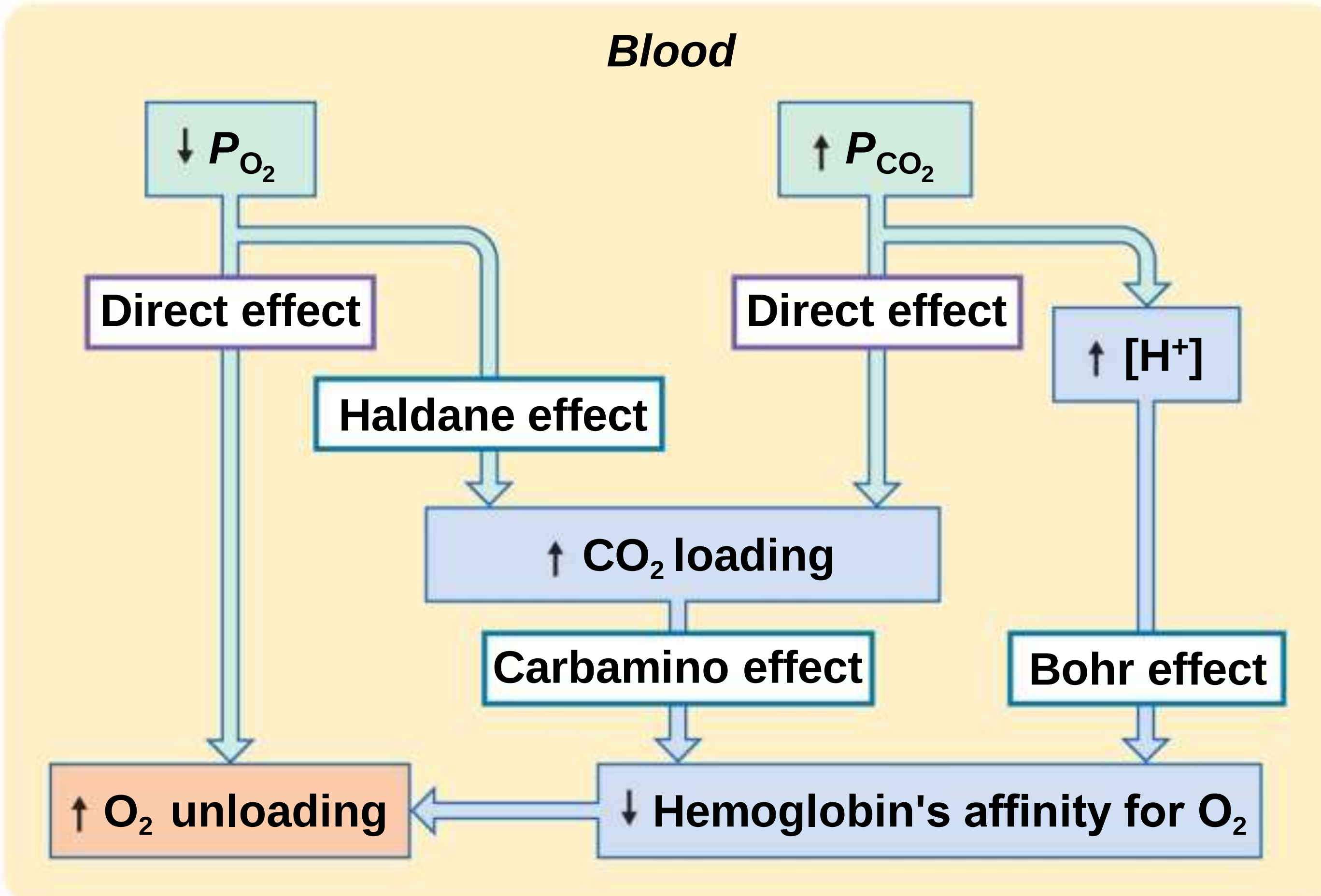
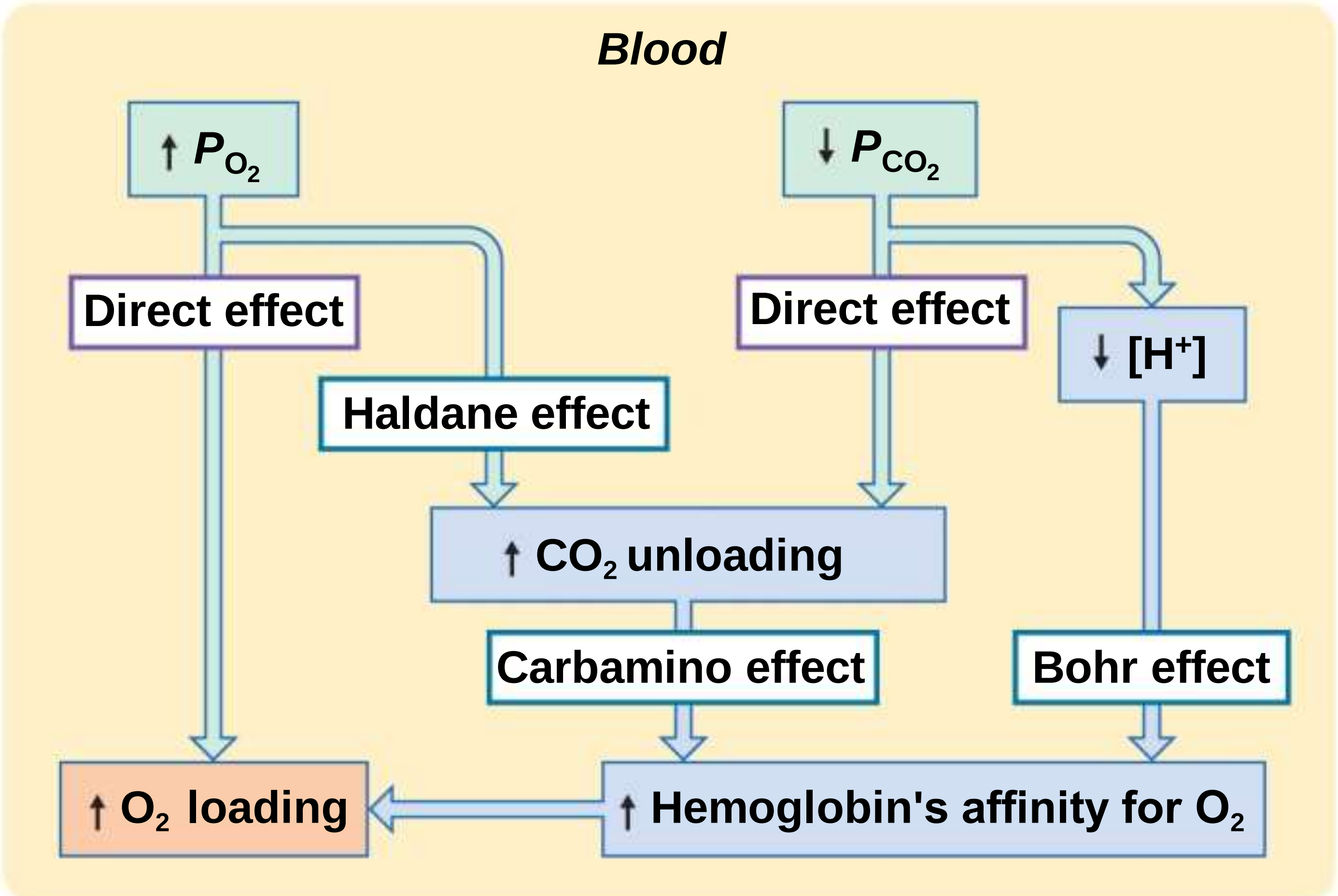


Figure 17.13a Effects of P_{O_2} and P_{CO_2} on carbon dioxide and oxygen loading and unloading.



(a) CO_2 loading and O_2 unloading of hemoglobin in respiring tissue

Figure 17.13b Effects of P_{O_2} and P_{CO_2} on carbon dioxide and oxygen loading and unloading.



(b) CO_2 unloading and O_2 loading of hemoglobin in lungs

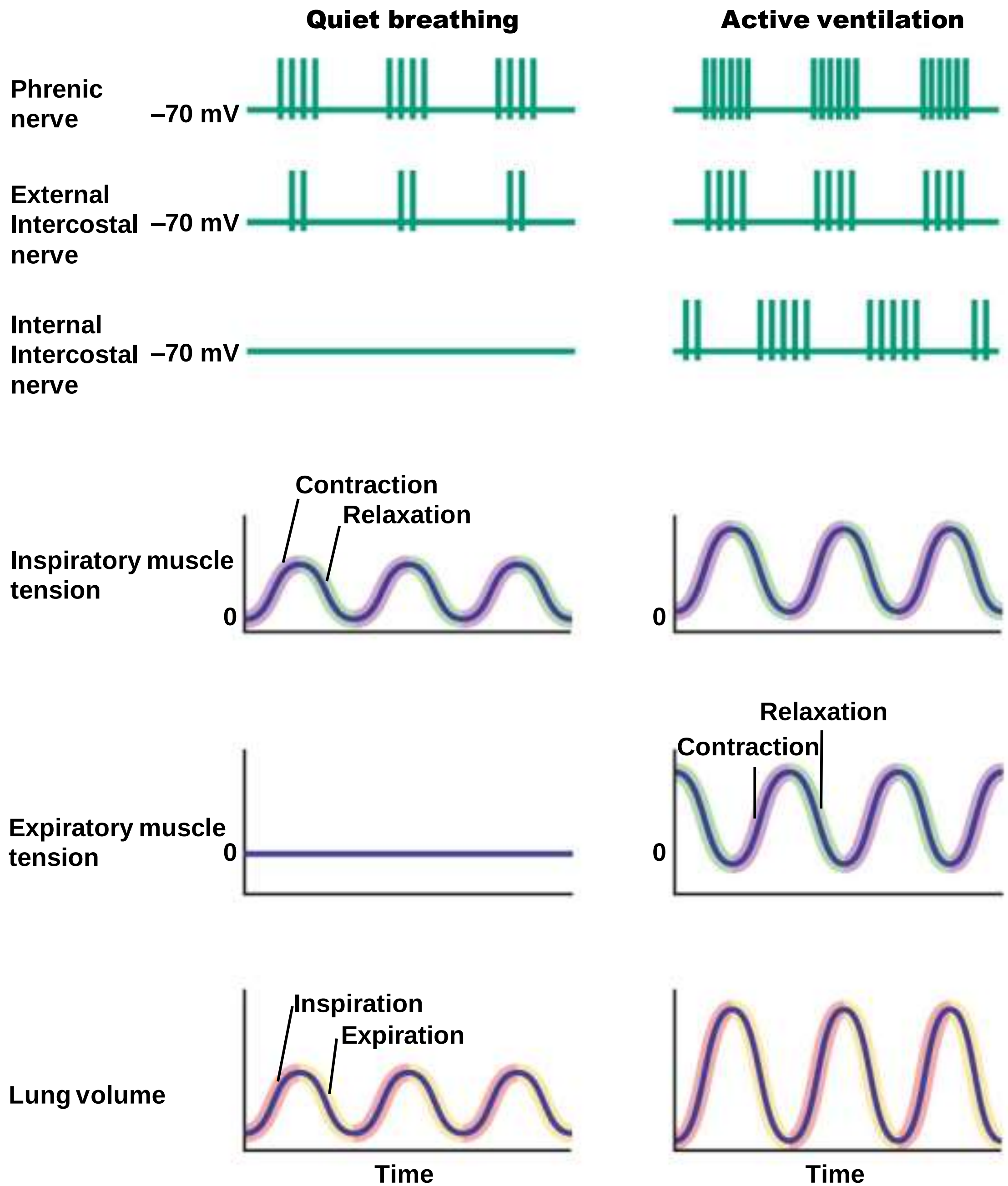
17.5 Central Regulation of Ventilation

- Neural control of breathing by motor neurons
- Generation of breathing rhythm in the brainstem
- Peripheral input to respiratory centers

Neural Control of Breathing by Motor Neurons

- Respiratory muscles = skeletal muscles
- Controlled by motor neurons
- Inspiration
  - Phrenic nerve → diaphragm
  - External intercostal nerve → external intercostal muscles
- Expiration
  - Internal intercostal nerve → internal intercostal muscles

Figure 17.14 A comparison of quiet breathing and active ventilation.



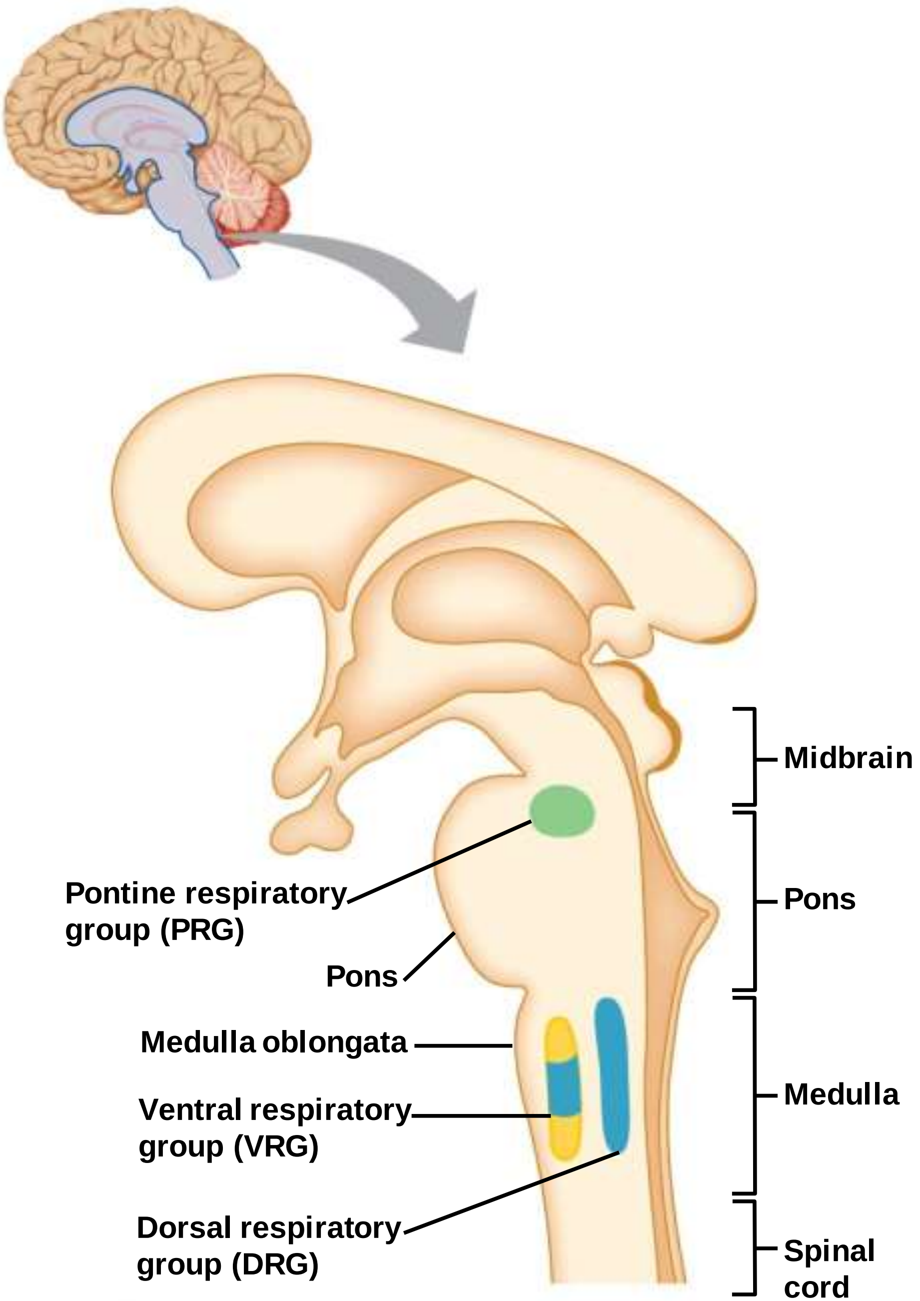
Neural Control of Breathing by Motor Neurons

- Components that generate the breathing rhythm
  - Phrenic nerve
  - Internal and external intercostal nerves
  - Inspiratory and expiratory neurons
  - Respiratory control centers of medulla
  - Respiratory control centers of pons
  - Central pattern generator

Generation of the Breathing Rhythm in the Brainstem

- Brainstem respiratory centers
  - Inspiratory neurons
    - Depolarize during inspiration
  - Expiratory neurons
    - Depolarize during expiration
  - Mixed neurons
    - Have properties of both inspiratory and expiratory neurons

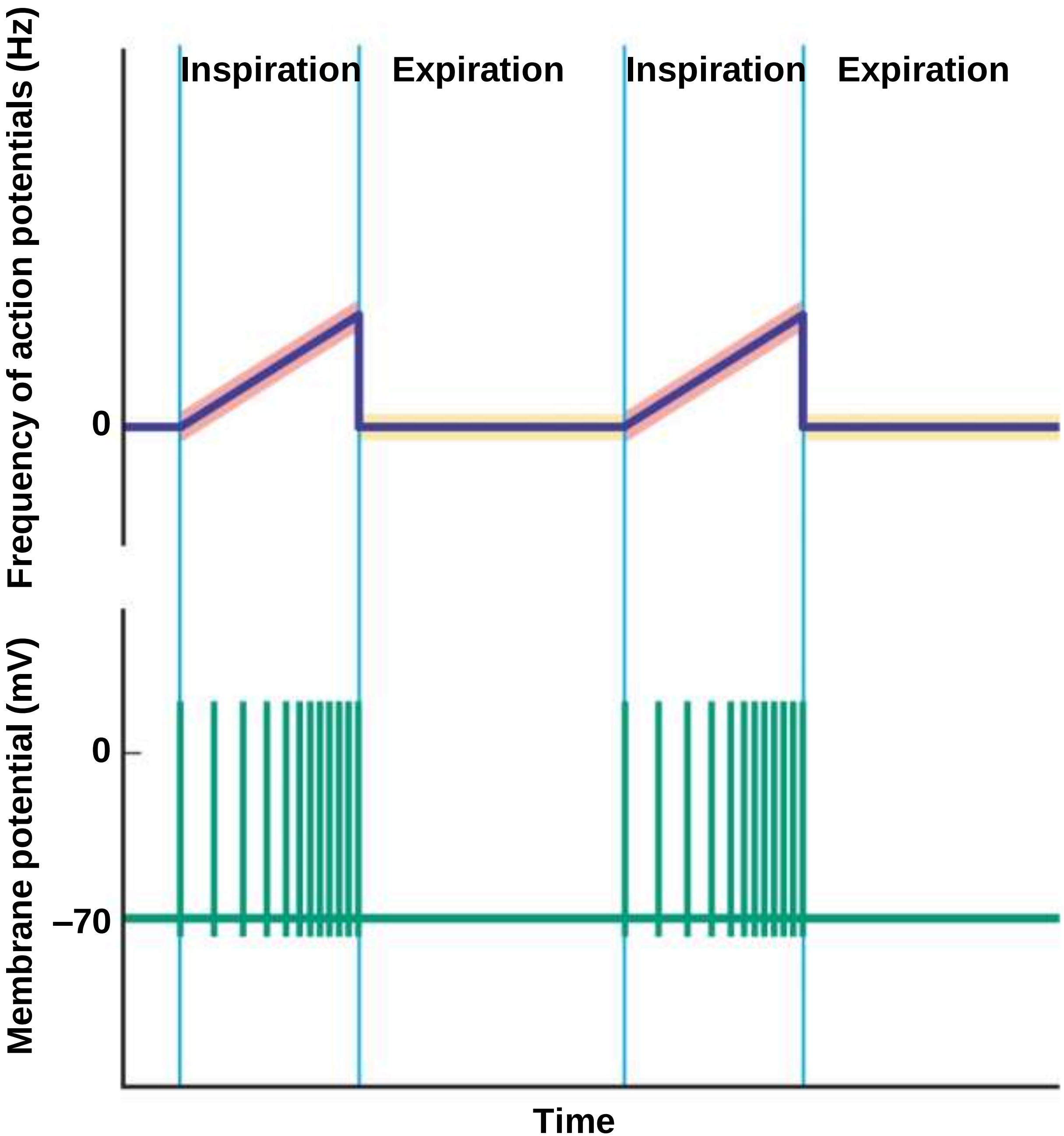
Figure 17.15 Brainstem centers of respiratory control.



Generation of the Breathing Rhythm in the Brainstem

- In medulla
  - Two respiratory control centers located on each side of the medulla
    - Ventral respiratory group (VRG): nucleus ambiguus
    - Dorsal respiratory group (DRG): nucleus tractus solitarius
  - Inspiratory neurons are hypothesized to control motor neurons to inspiratory muscles
  - Expiratory neurons are hypothesized to control motor neurons to expiratory muscles and/or inhibit inspiratory neurons

Figure 17.16 Activity of inspiratory neurons.



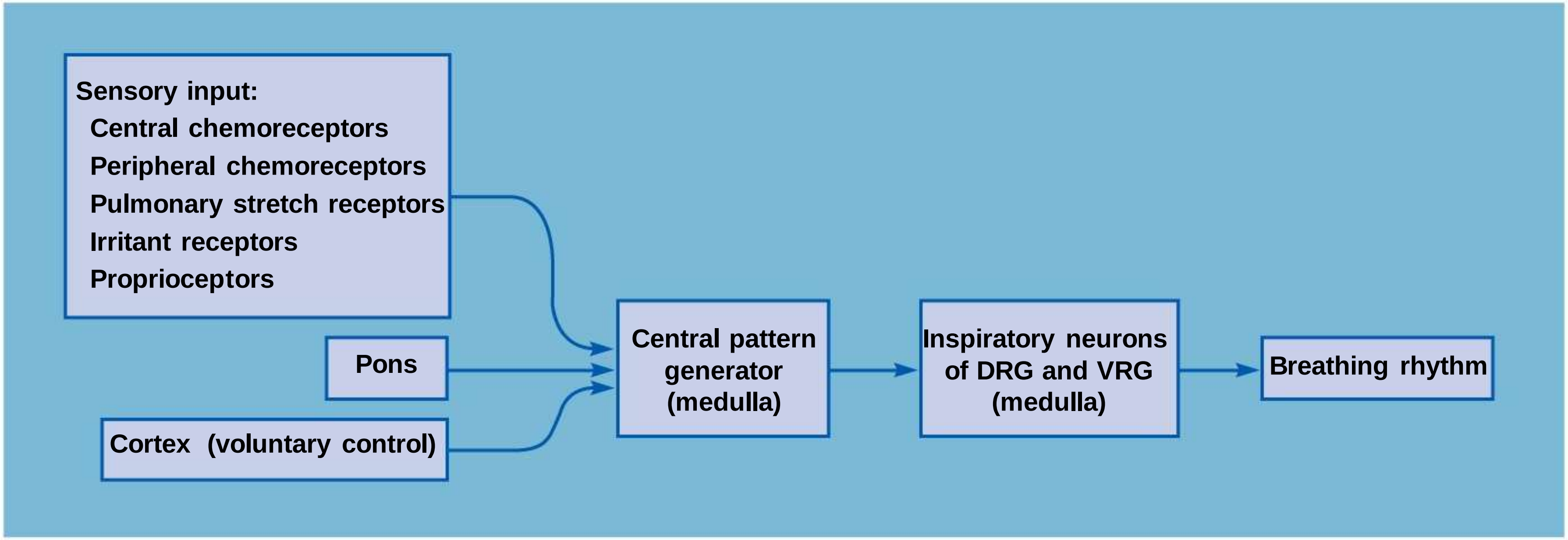
Generation of the Breathing Rhythm in the Brainstem

- Pontine respiratory group
  - Contains inspiratory, expiratory, and mixed neurons
  - May regulate transitions between inspiration and expiration

Generation of the Breathing Rhythm in the Brainstem

- Central pattern generator
  - Central pattern generator establishes respiratory cycle
  - Location and mechanism of action are unknown

Figure 17.17 Model of respiratory control during quiet breathing.



Peripheral Input to Respiratory Centers

- Chemoreceptors
- Pulmonary stretch receptors
- Irritant receptors
- Muscle and joint proprioceptors

17.6 Control of Ventilation by Chemoreceptors

- Chemoreceptors
  - Detect blood levels of O_2 and CO_2
  - Two types
    - Peripheral chemoreceptors in carotid bodies
    - Central chemoreceptors in medulla oblongata

Chemoreceptors

- Peripheral chemoreceptors
  - Located in carotid bodies near carotid sinus
  - Direct contact with arterial blood
  - Communicate with afferent neurons via chemical messenger
  - Afferent neurons project to medullary respiratory control areas
  - Respond mainly to changes in blood pH

Figure 17.18 Location of peripheral chemoreceptors in the carotid bodies.

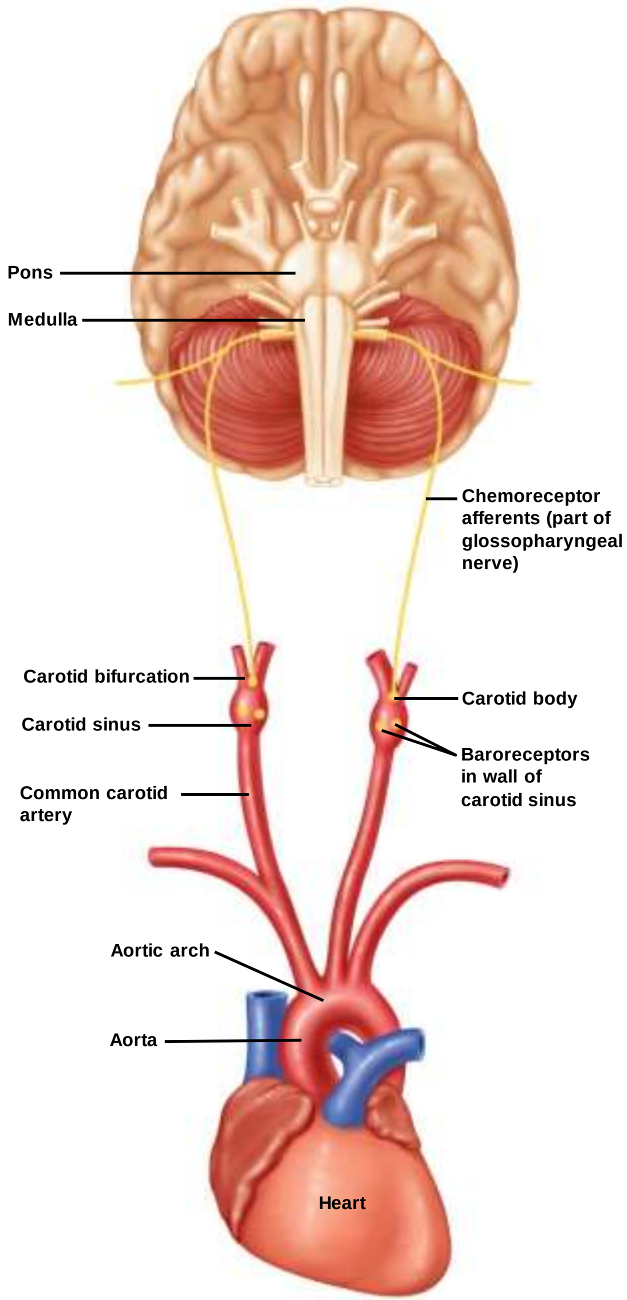
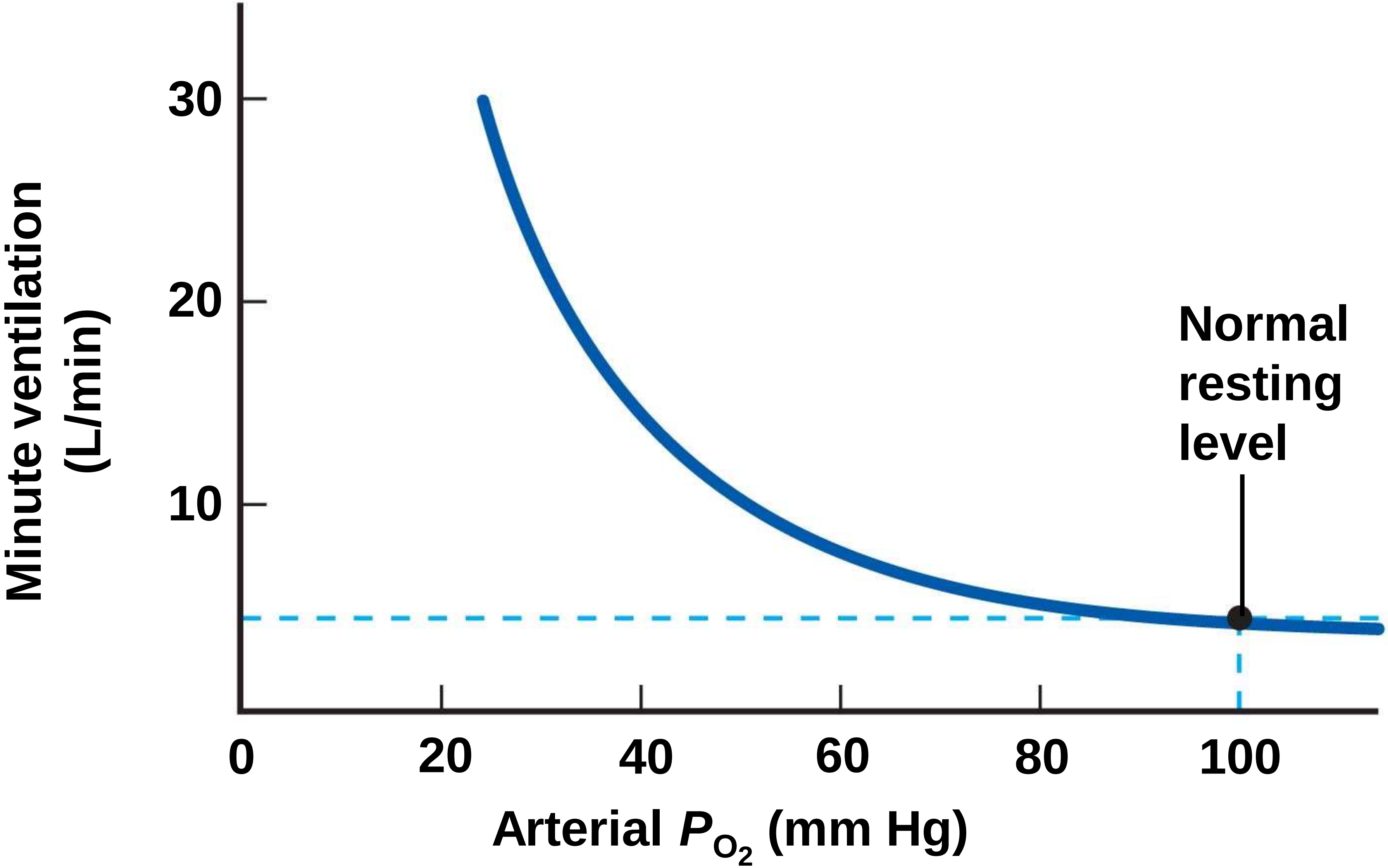
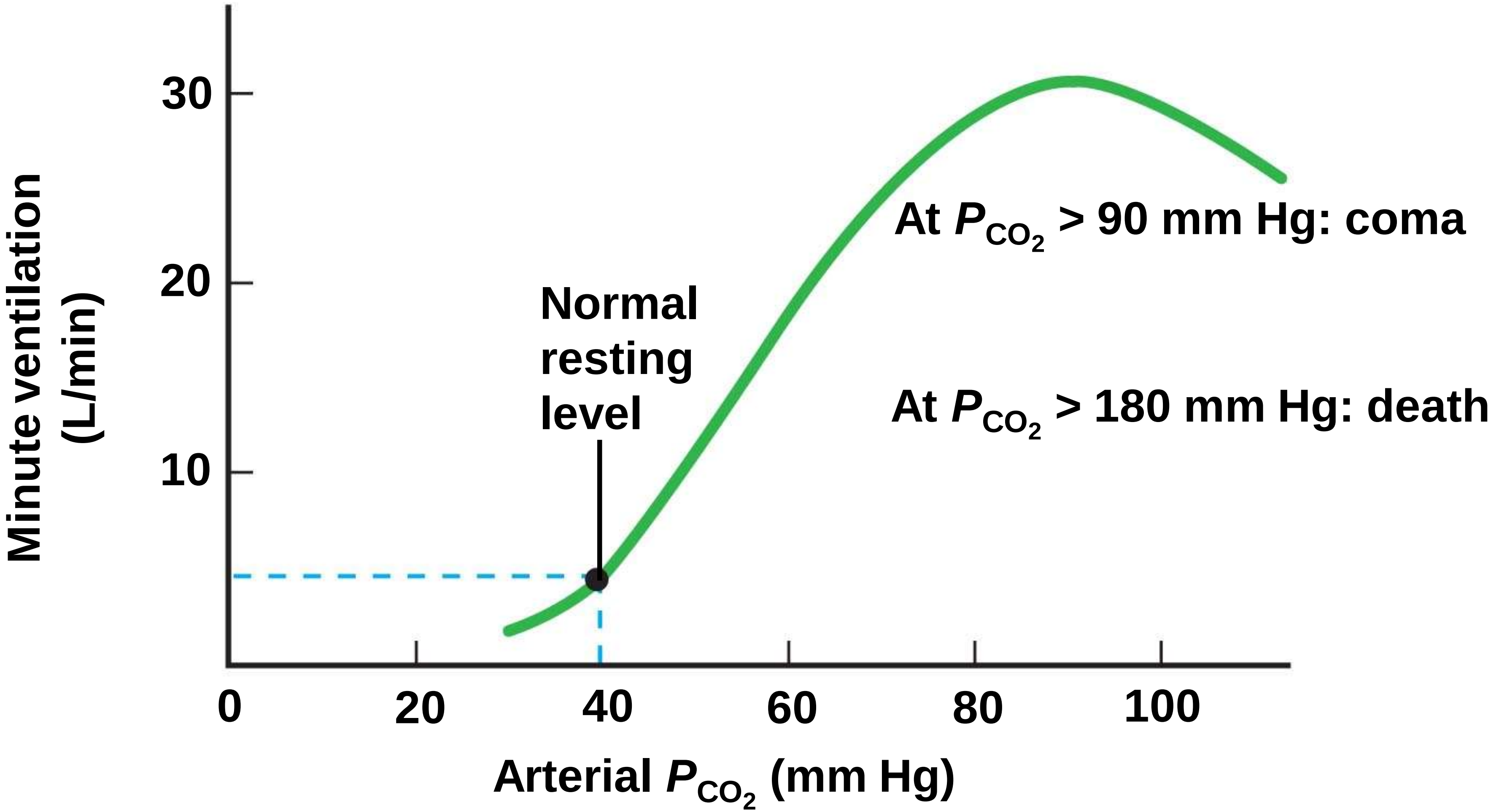


Figure 17.19a Respiratory control by chemoreceptors.



(a) Effects of arterial P_{O_2} on ventilation

Figure 17.19b Respiratory control by chemoreceptors.



(b) Effects of arterial P_{CO_2} on ventilation

Chemoreceptors

- Central chemoreceptors
  - Located on the ventral surface of medulla
  - Respond to changes in pH of the CSF
  - Not directly responsive to CO_2
    - Respond indirectly to CO_2 via pH
    - Increased CO_2 decreases pH
  - Not responsive to changes in $[O_2]$

Figure 17.20 Activation of central chemoreceptors in the medulla oblongata.

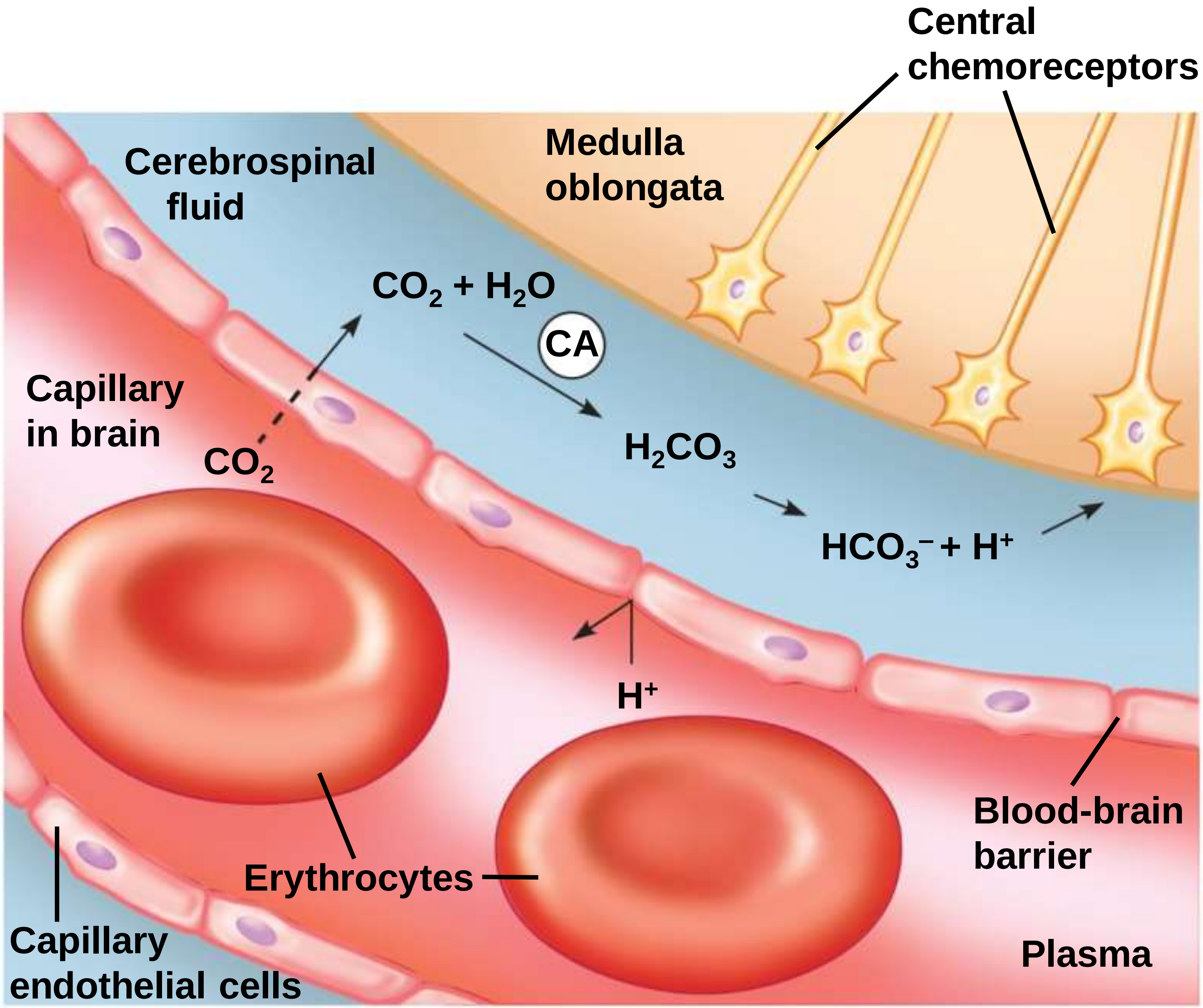


Figure 17.21 Chemoreceptor reflexes: The effects of changes in arterial P_{O_2}, P_{CO_2}, and pH on ventilation.

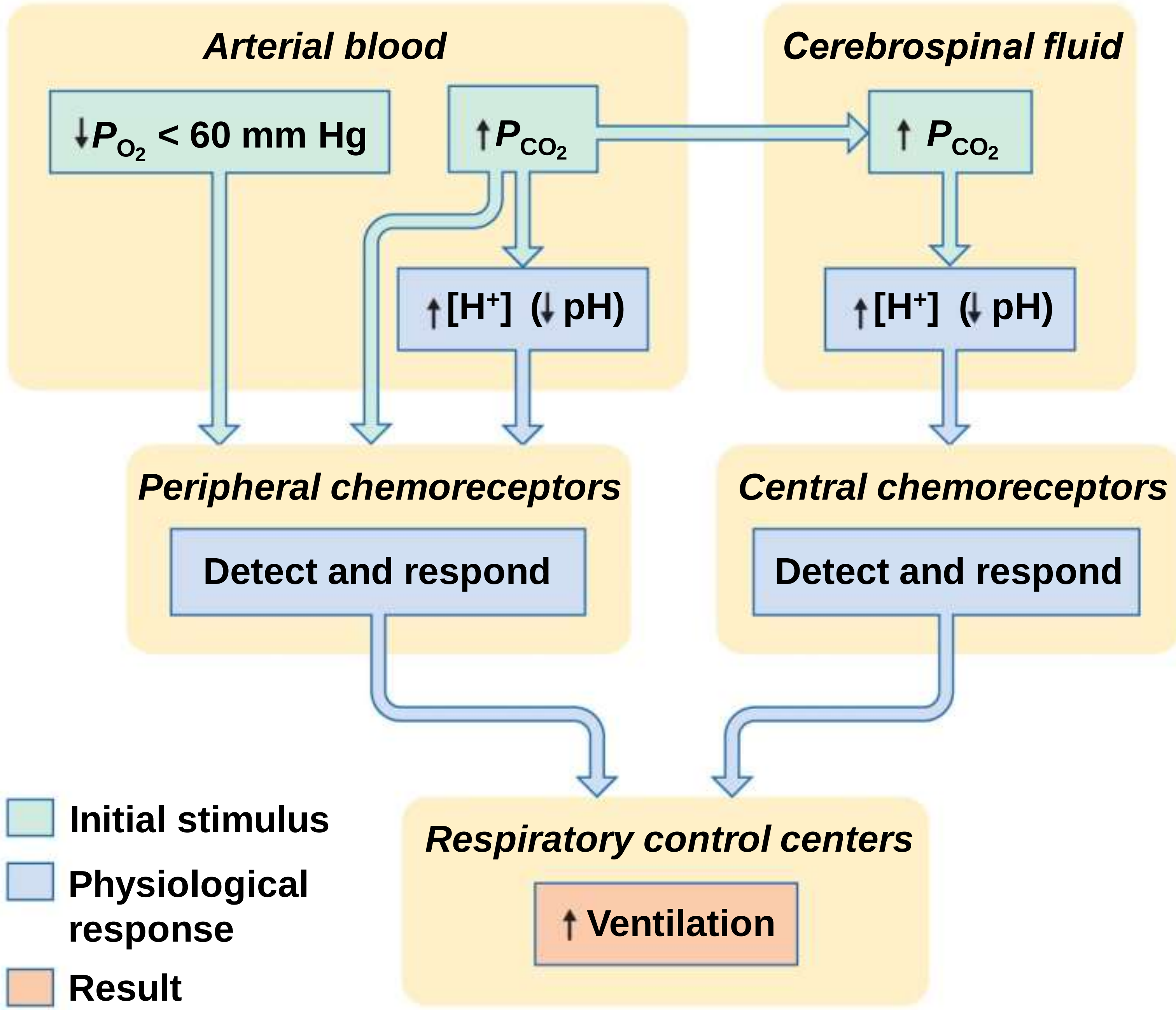


Figure 17.22a The effects of hypoventilation and hyperventilation on minute ventilation.

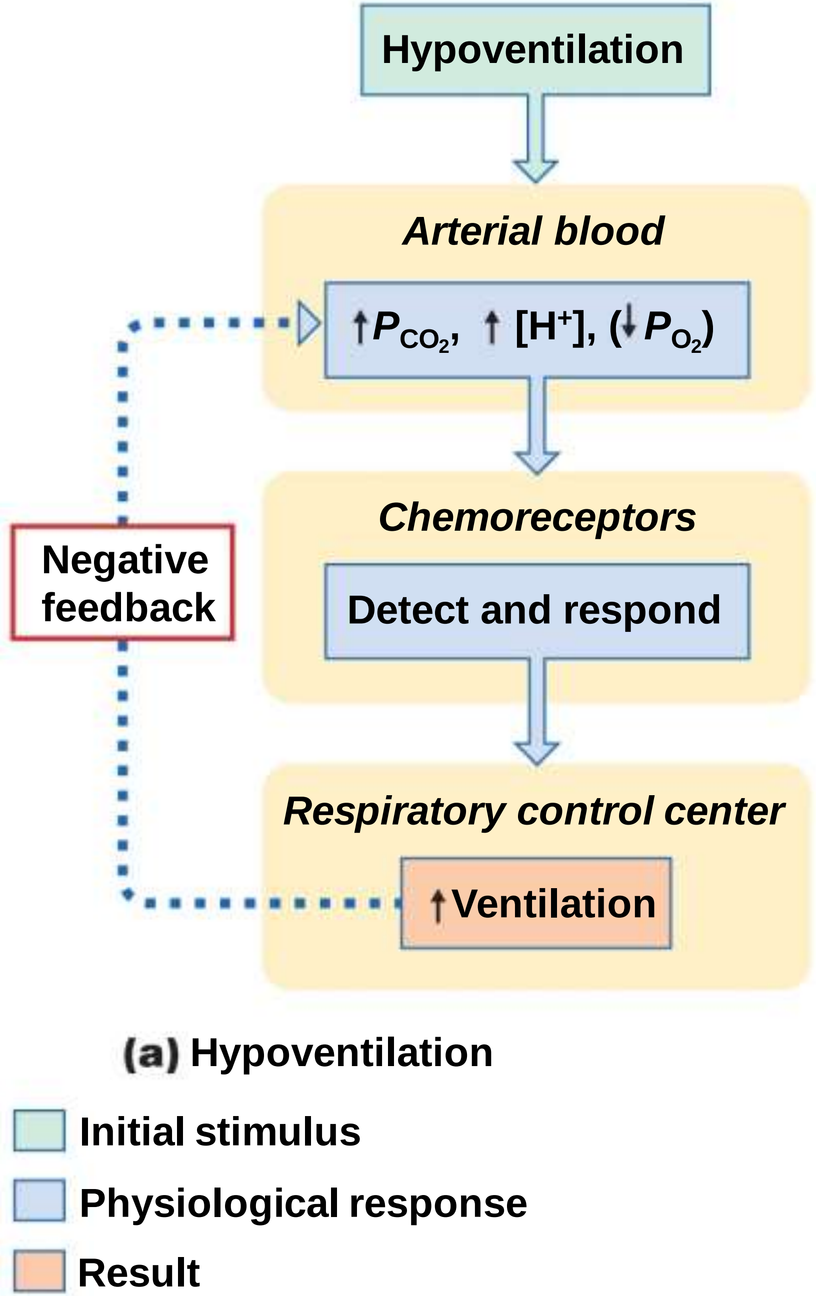
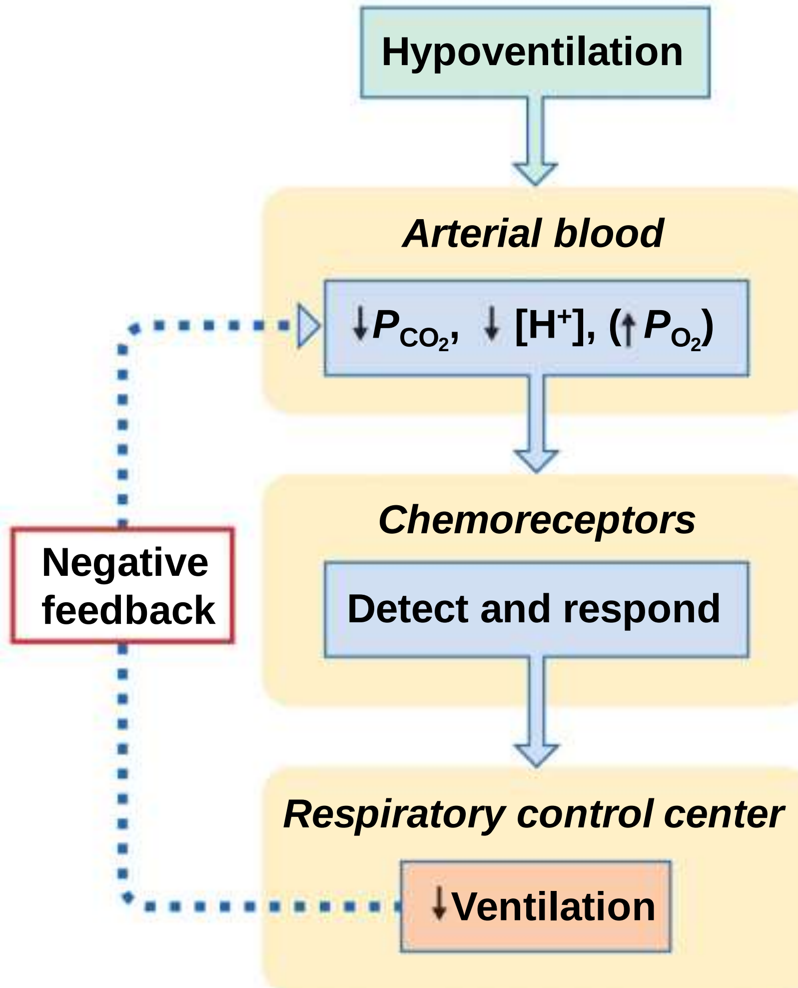


Figure 17.22b The effects of hypoventilation and hyperventilation on minute ventilation.



(b) Hyperventilation

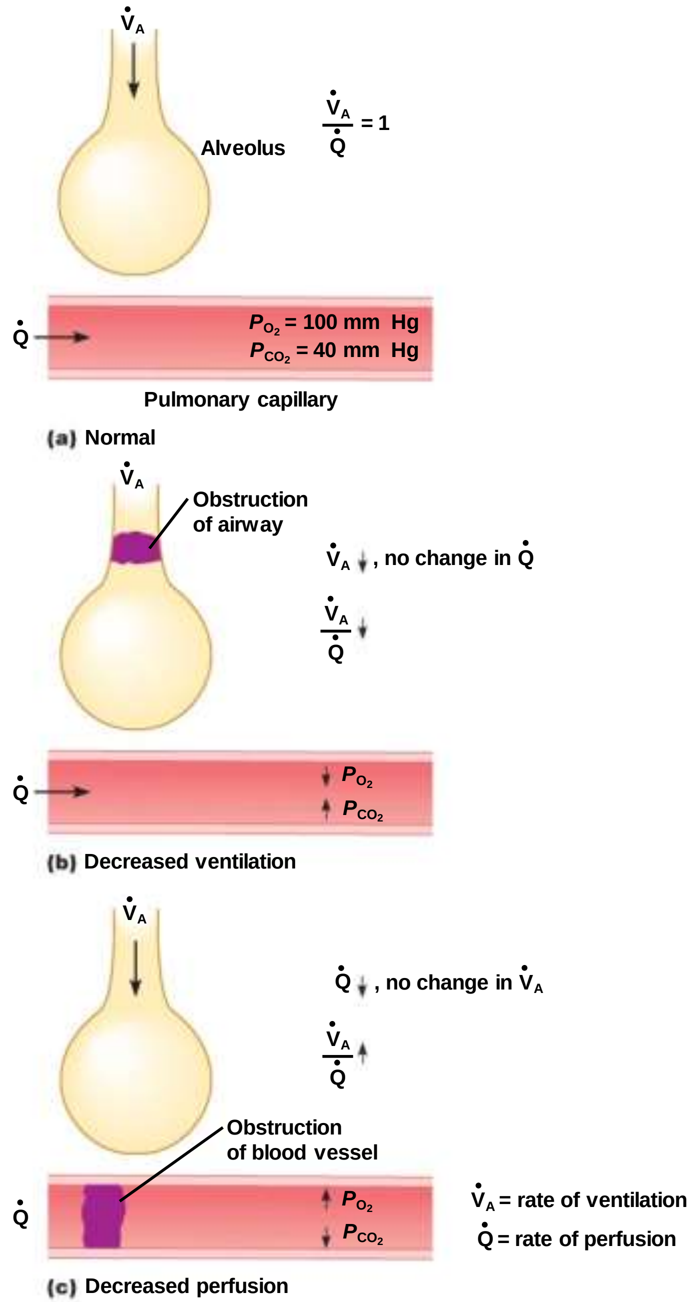
17.7 Local Regulation of Ventilation and Perfusion

- Ventilation-perfusion ratios
- Local control of ventilation and perfusion

Ventilation-Perfusion Ratios

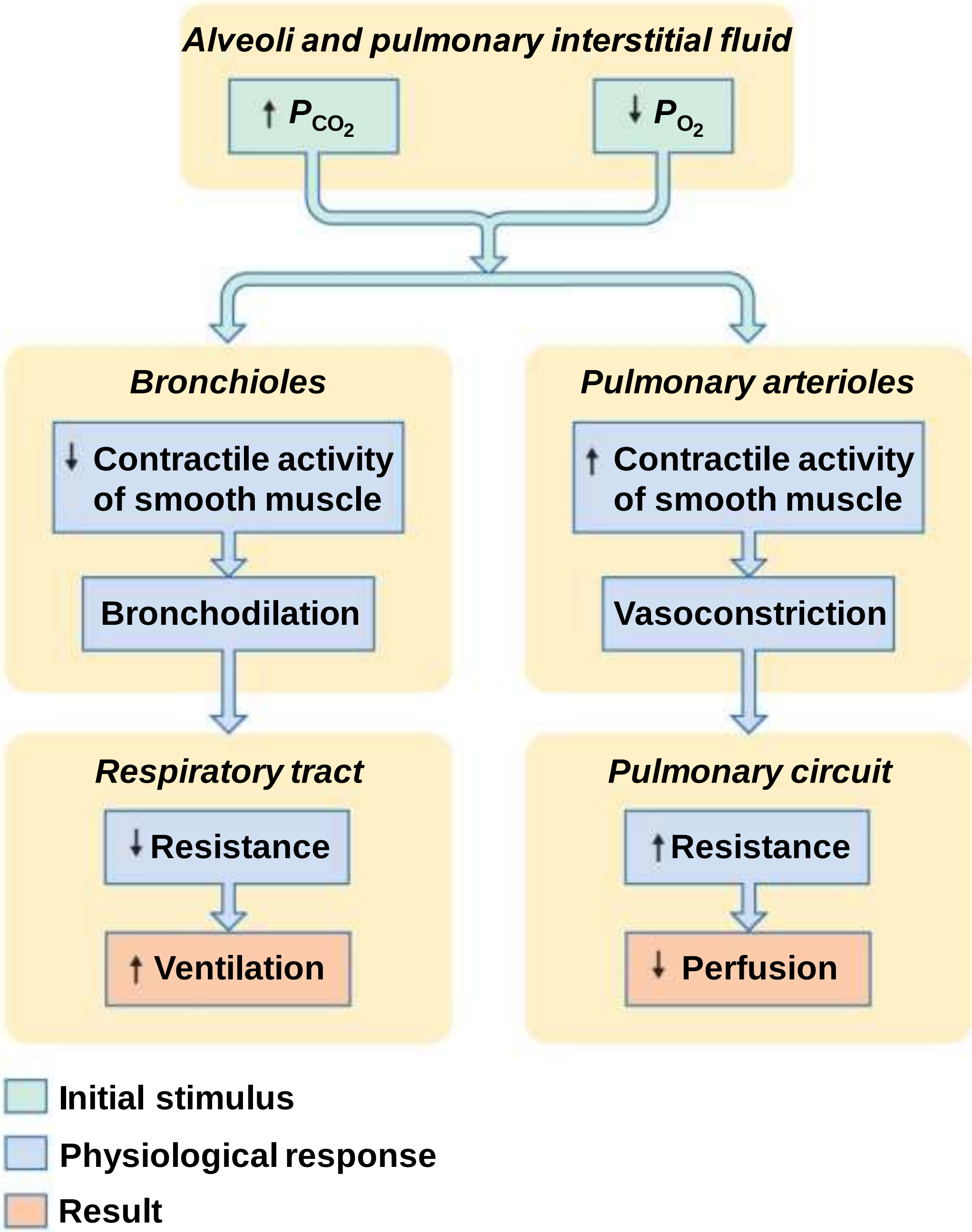
- Matching of ventilation to perfusion
  - Ventilation (V) = rate of air flow
  - Perfusion (Q) = rate of blood flow
  - Local ventilation and perfusion are regulated to match
- VA/Q = ventilation-perfusion ratio

Figure 17.23 Ventilation-perfusion ratios.



Ventilation-Perfusion Ratios

- If ventilation to certain alveoli decreases
  - Increased P_{CO_2} and decreased P_{O_2} in blood and air
  - Increased P_{CO_2} in bronchioles → bronchodilation
  - Decreased P_{O_2} in P. arterioles → vasoconstriction
- If perfusion to certain alveoli decreases
  - Increased P_{O_2} and decreased P_{CO_2} in blood and air
  - Increased P_{O_2} in P. arterioles → vasodilation
  - Decreased P_{CO_2} in bronchioles → bronchoconstriction


Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Pulmonary arterioles
↑ Contractile activity of smooth muscle
Vasoconstriction
Respiratory tract
↓ Resistance
↑ Ventilation
Pulmonary circuit
↑ Resistance
↓ Perfusion
Initial stimulus
Physiological response
Result

Alveoli and pulmonary interstitial fluid

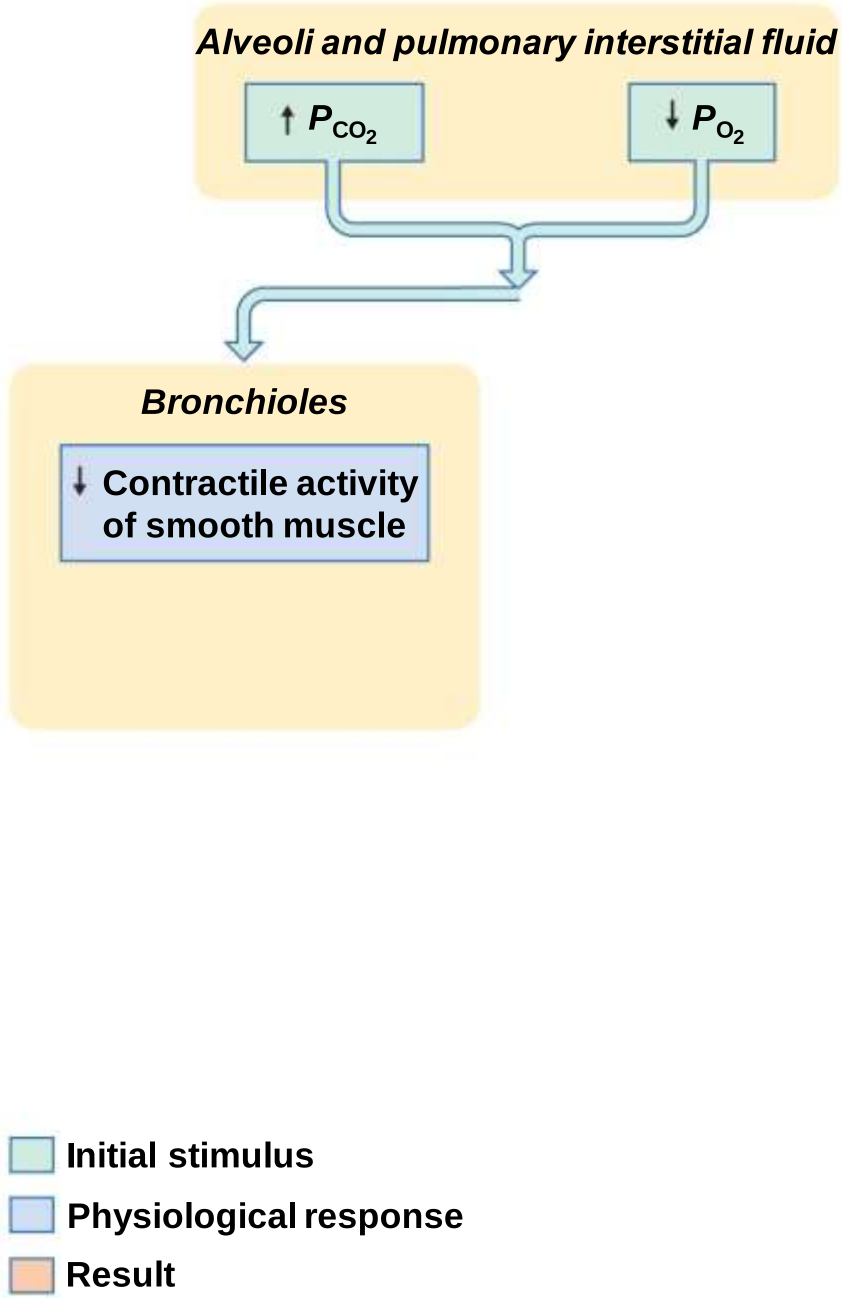
↑ P_{CO_2}

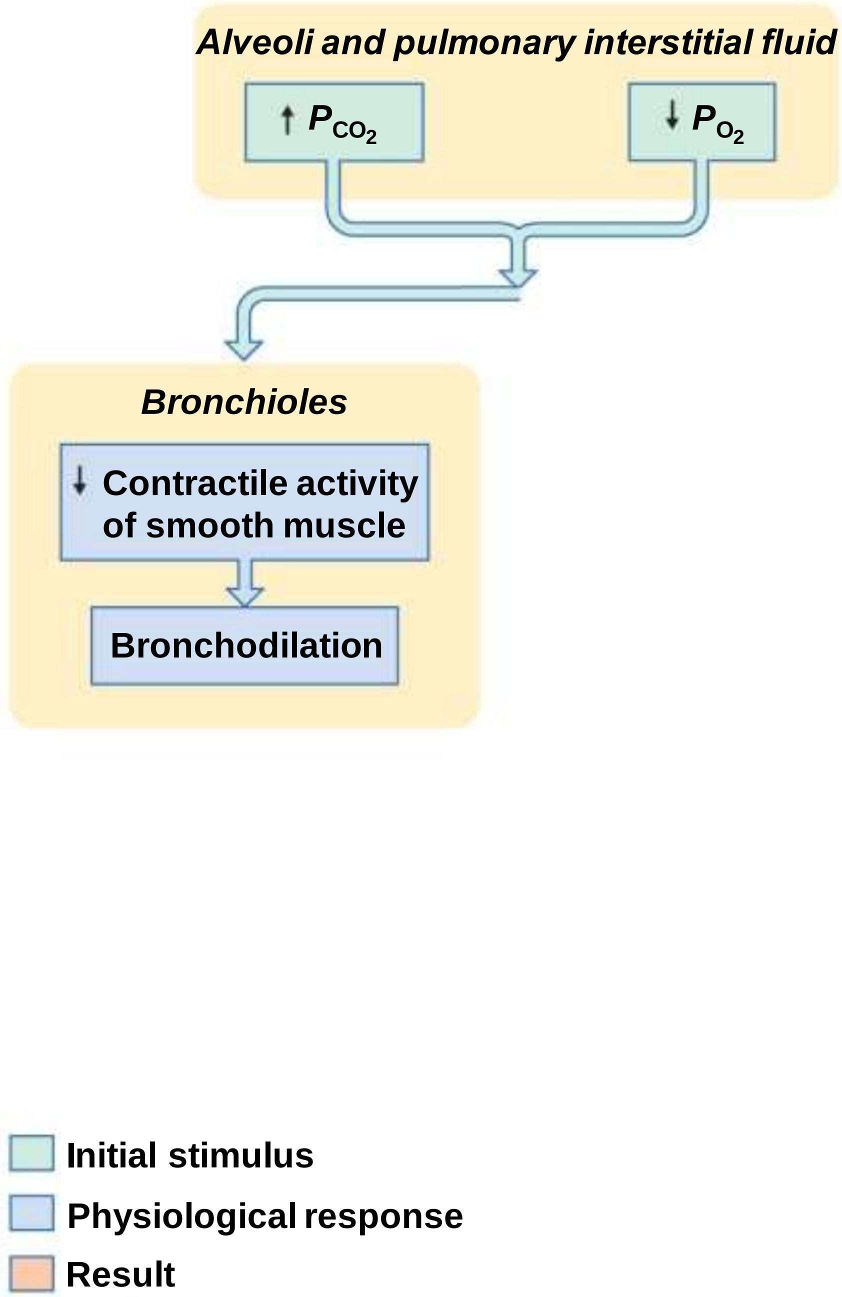
↓ P_{O_2}

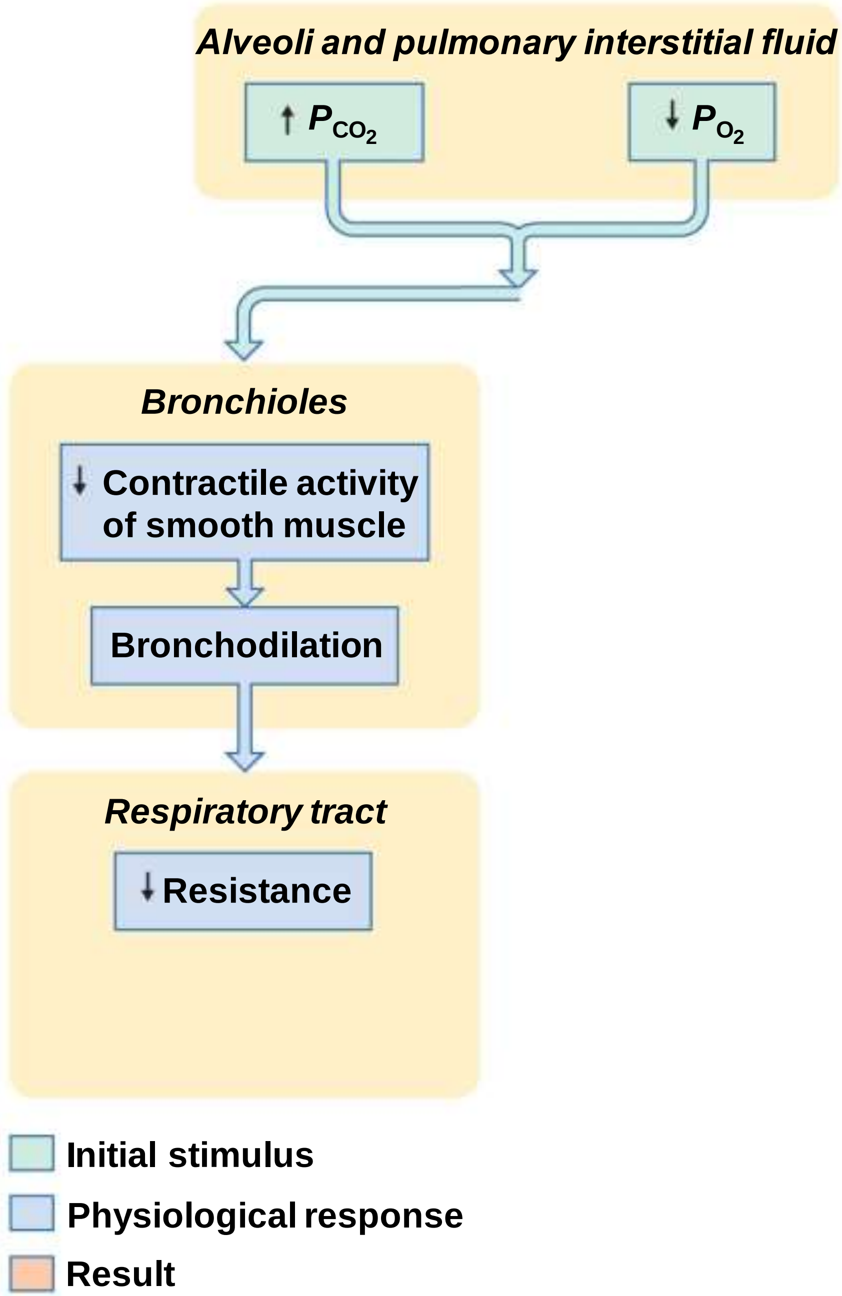
Initial stimulus

Physiological response

Result


Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Initial stimulus
Physiological response
Result


Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Initial stimulus
Physiological response
Result


Alveoli and pulmonary interstitial fluid
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Respiratory tract
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Initial stimulus
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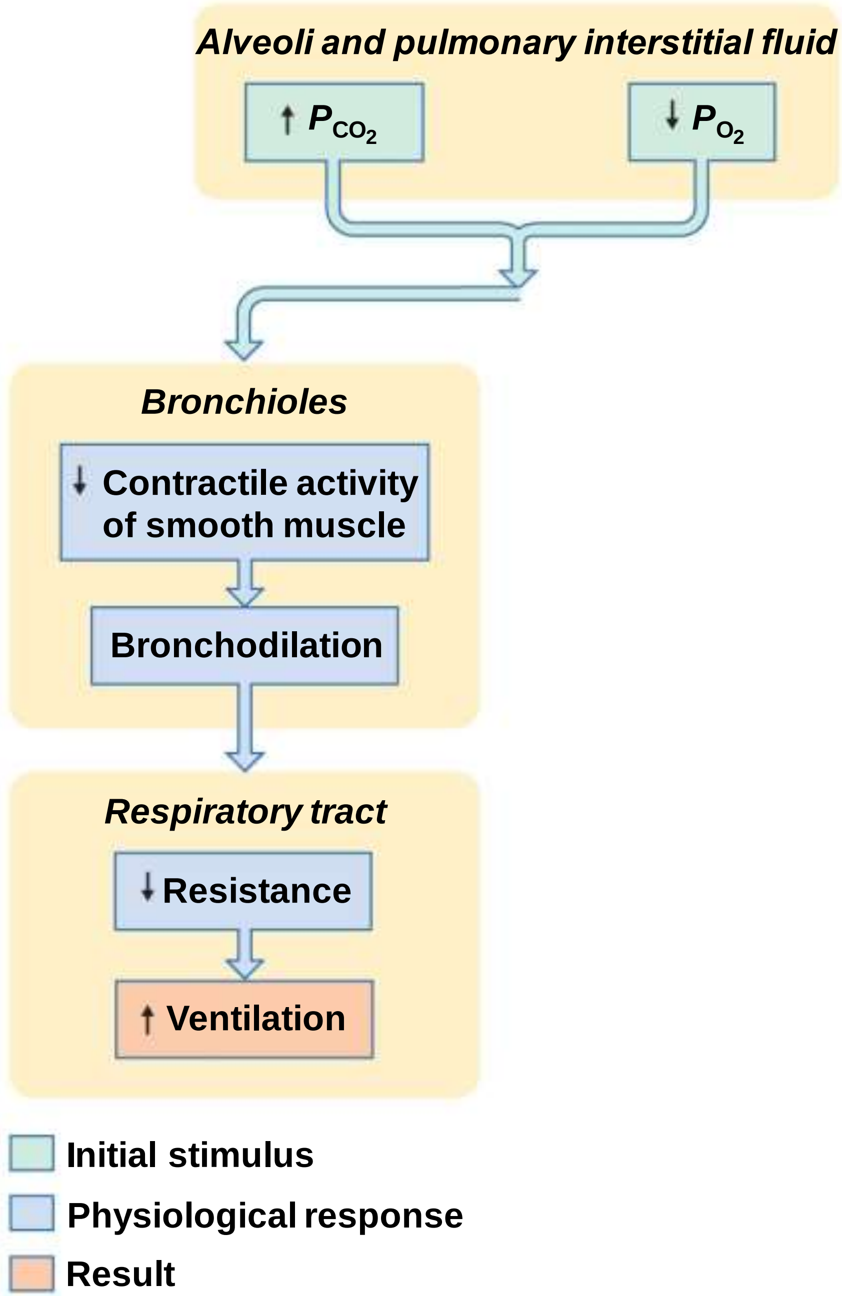
Result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Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Respiratory tract
↓ Resistance
↑ Ventilation
Initial stimulus
Physiological response
Result

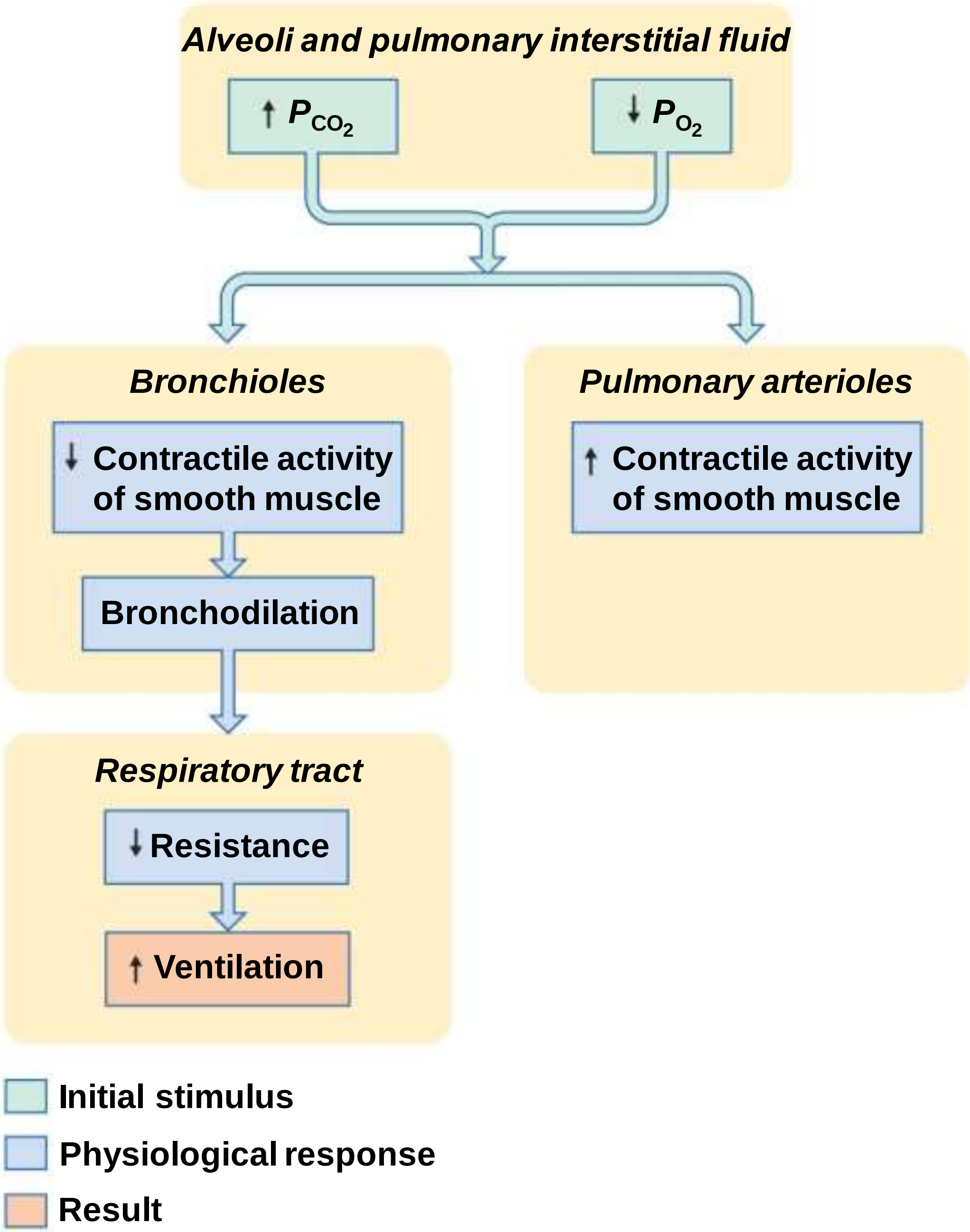
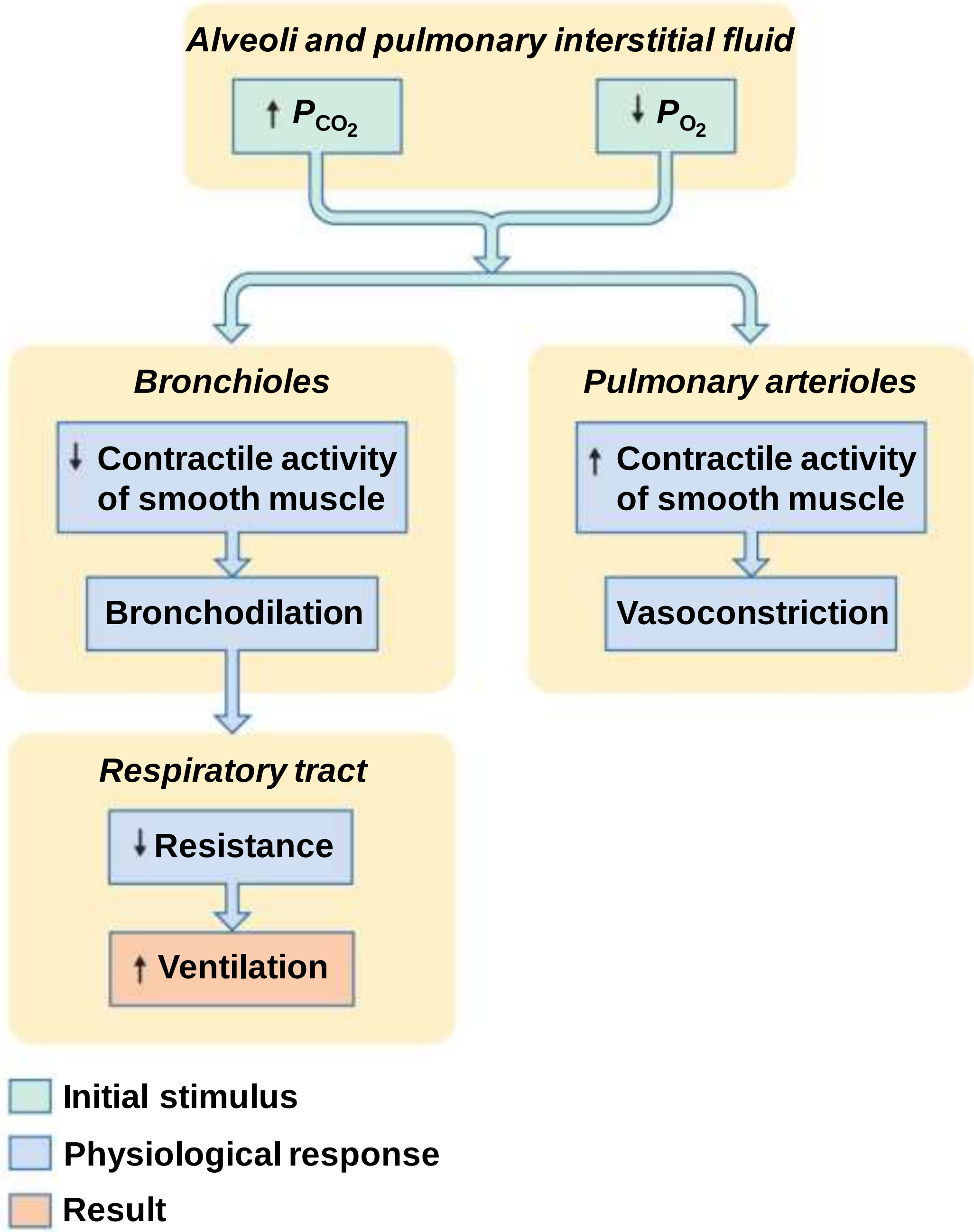
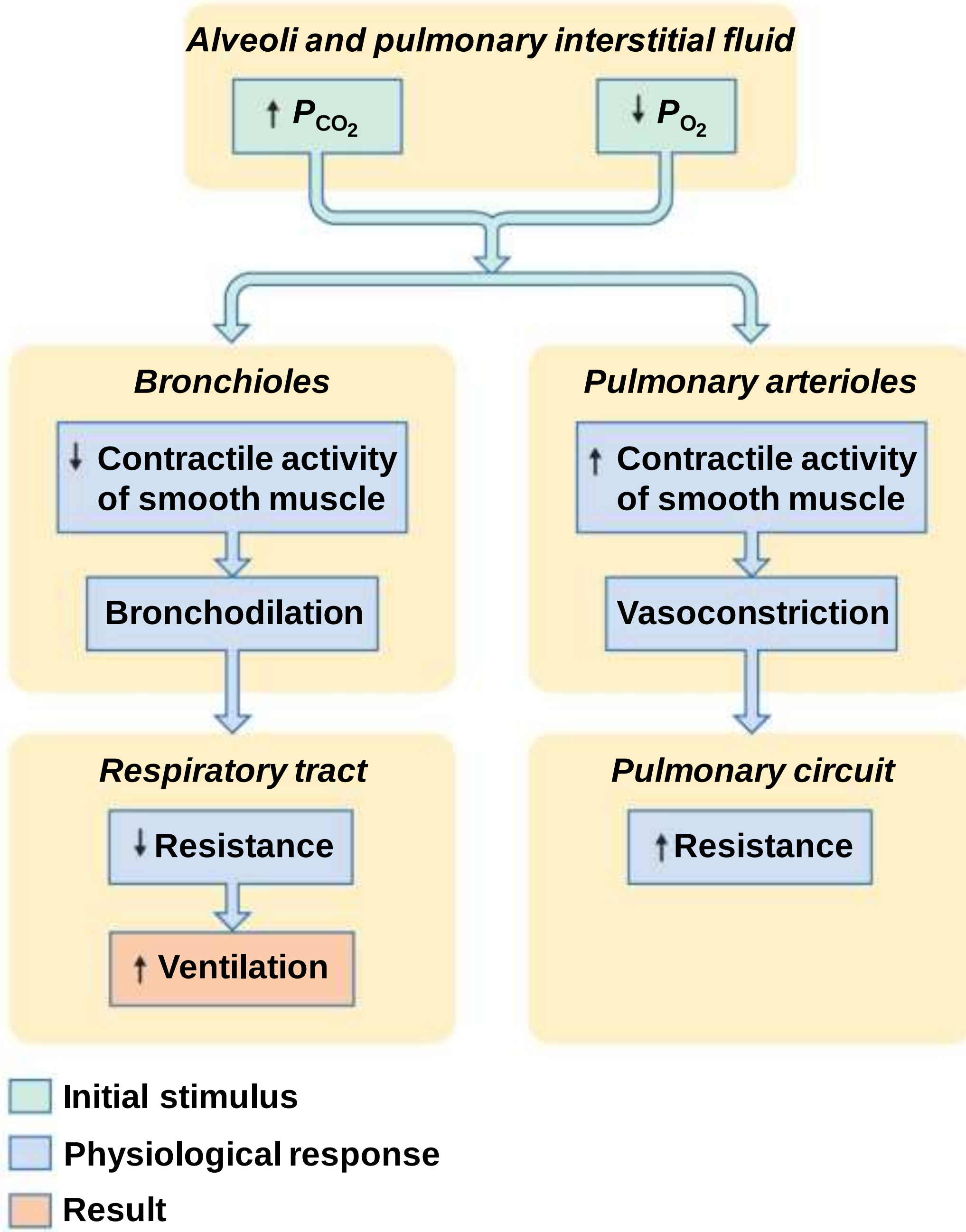
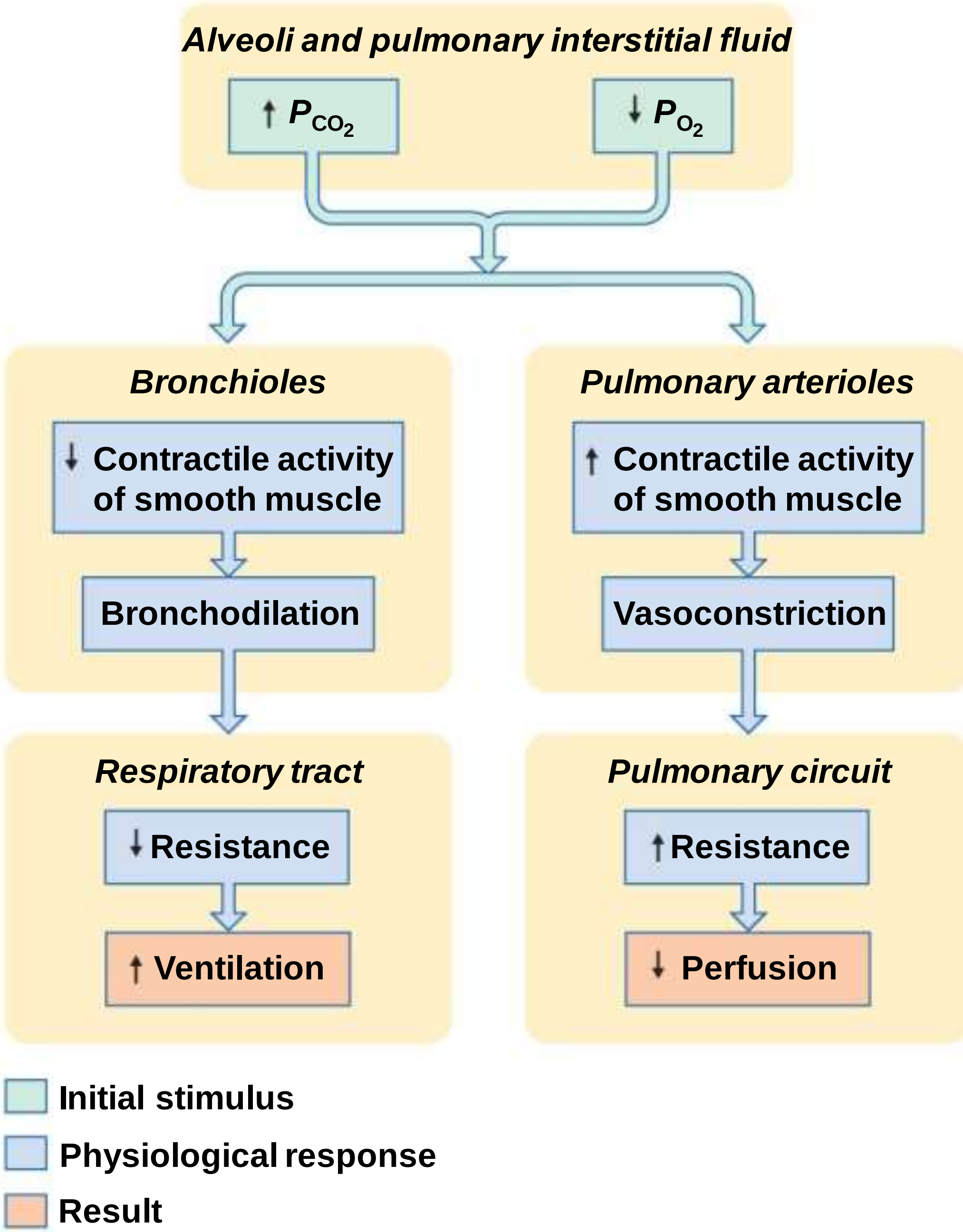

Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Pulmonary arterioles
↑ Contractile activity of smooth muscle
Respiratory tract
↓ Resistance
↑ Ventilation
Initial stimulus
Physiological response
Result

Figure 17.24 Local controls of ventilation and perfusion.




Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Pulmonary arterioles
↑ Contractile activity of smooth muscle
Vasoconstriction
Respiratory tract
↓ Resistance
↑ Ventilation
Pulmonary circuit
↑ Resistance
Initial stimulus
Physiological response
Result



Alveoli and pulmonary interstitial fluid
↑ P_{CO_2}
↓ P_{O_2}
Bronchioles
↓ Contractile activity of smooth muscle
Bronchodilation
Pulmonary arterioles
↑ Contractile activity of smooth muscle
Vasoconstriction
Respiratory tract
↓ Resistance
↑ Ventilation
Pulmonary circuit
↑ Resistance
↓ Perfusion
Initial stimulus
Physiological response
Result

TABLE 17.4 Local Controls of the Radius of Bronchioles and Pulmonary Arterioles

Change in gas composition in lungs	Response of bronchioles	Response of pulmonary arterioles
Increased P_{CO_2}	Dilation (increased $\dot{V}_A$*)	Weak constriction (decreased $\dot{Q}$†)
Decreased P_{CO_2}	Constriction (decreased $\dot{V}_A$)	Weak dilation (increased $\dot{Q}$)
Increased P_{O_2}	Weak constriction (decreased $\dot{V}_A$)	Dilation (increased $\dot{Q}$)
Decreased P_{O_2}	Weak dilation (increased $\dot{V}_A$)	Constriction (decreased $\dot{Q}$)

*$\dot{V}_A$ = ventilation
†$\dot{Q}$ = perfusion

17.8 The Respiratory System in Acid-Base Homeostasis

- Acid-base disturbances in blood
- The role of the respiratory system in acid-base balance

Acid-Base Disturbances in Blood

- Normal blood pH = 7.4 (range 7.3–7.42)
- Respiratory and renal systems regulate blood pH
- Small changes in pH have large physiological effects
  - Alter protein activity
- Acidosis: blood pH < 7.35
  - CNS depression
- Alkalosis: blood pH > 7.45
  - CNS over-excitation

The Role of the Respiratory System in Acid-Base Balance

- Hemoglobin functions as a buffer
  - Deoxyhemoglobin has greater affinity for H^+
  - $Hb + H^+ \rightleftharpoons HbH$
- Bicarbonate ions as a buffer
  - $HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons CO_2 + H_2O$
- Can regulate pH by regulating CO_2 levels

The Role of the Respiratory System in Acid-Base Balance

- Henderson-Hasselbalch equation

$$pH = 6.1 + \log \frac{[HCO_3^-]}{[CO_2]}$$

- To maintain normal arterial pH = 7.4, $[HCO_3^-]$: $[CO_2]$ must be 20:1
- Respiratory system regulates $[CO_2]$
- Kidneys regulate $[HCO_3^-]$

The Role of the Respiratory System in Acid-Base Balance

- Respiratory acid-base disturbances
  - Respiratory acidosis
    - Caused by increased [CO_2]
  - Respiratory alkalosis
    - Caused by decreased [CO_2]