CHAPTER 8

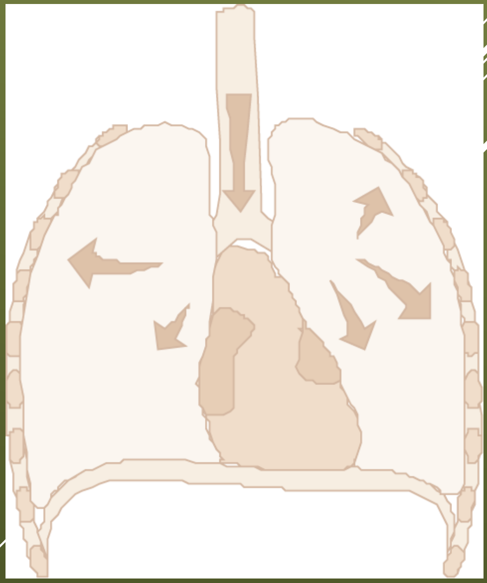
RESPIRATORY REGULATION DURING EXERCISE

Respiration

Respiration—delivery of oxygen to and removal of carbon dioxide from the tissue

External respiration—ventilation and exchange of gases in the lung

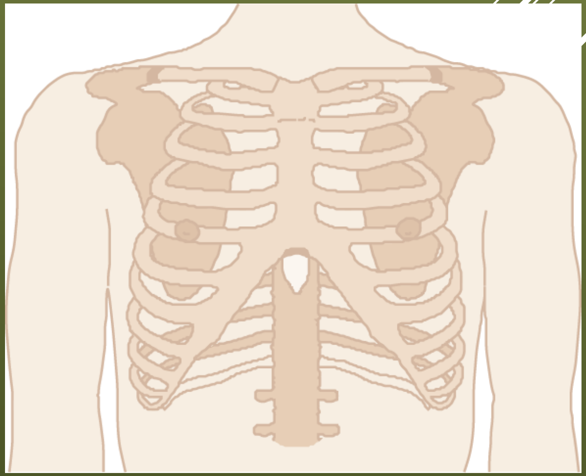
Internal respiration—exchange of gases at the tissue level (between blood and tissues)



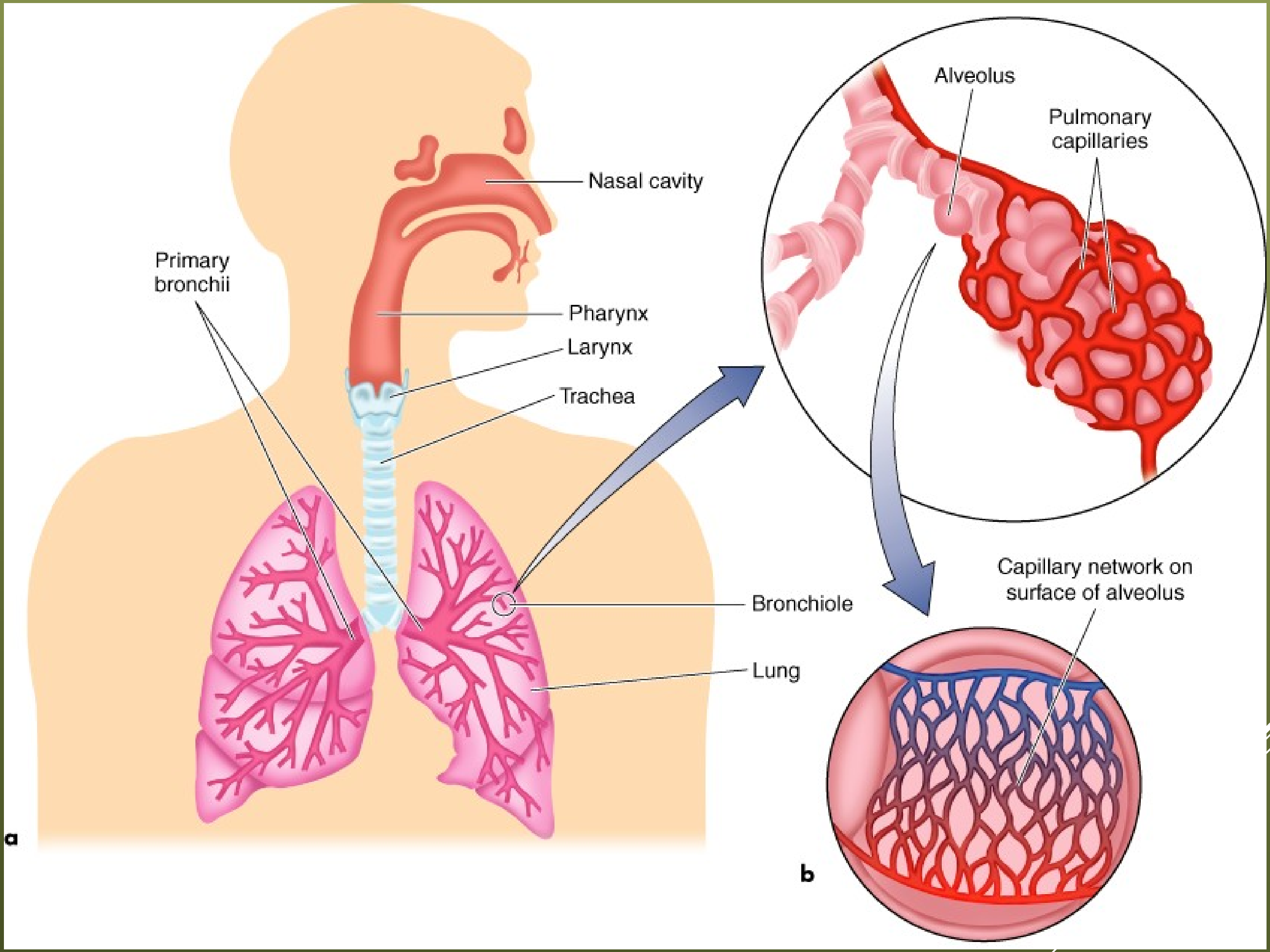
External Respiration

Pulmonary ventilation—movement of air into and out of the lungs—inspiration and expiration

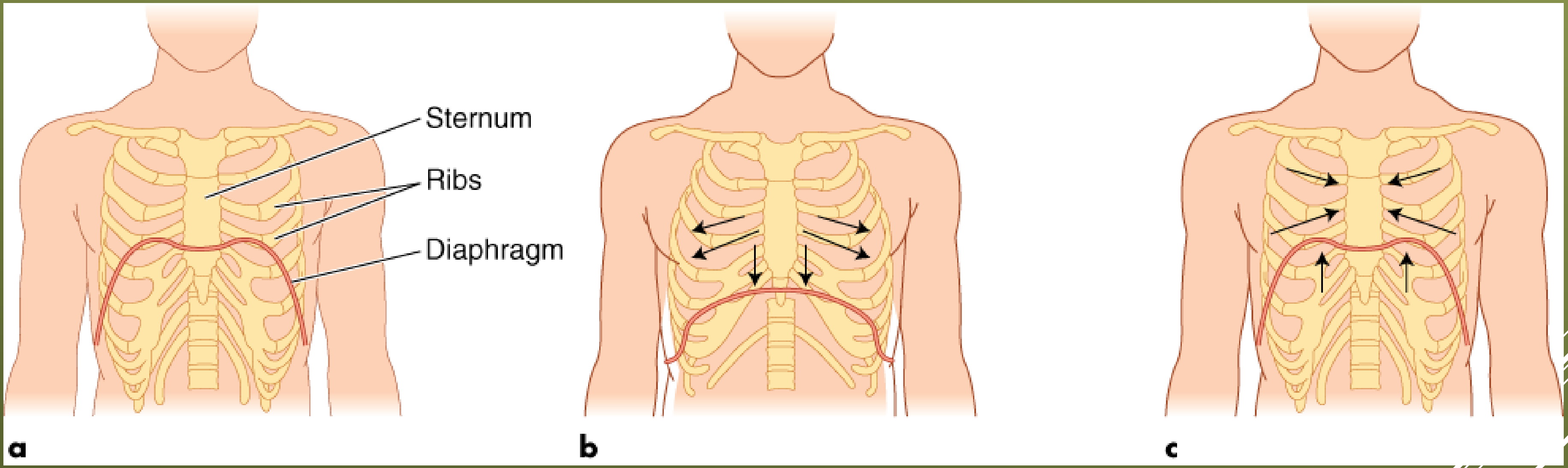
Pulmonary diffusion—exchange of oxygen and carbon dioxide between the lungs and blood



RESPIRATORY SYSTEM



INSPIRATION AND EXPIRATION

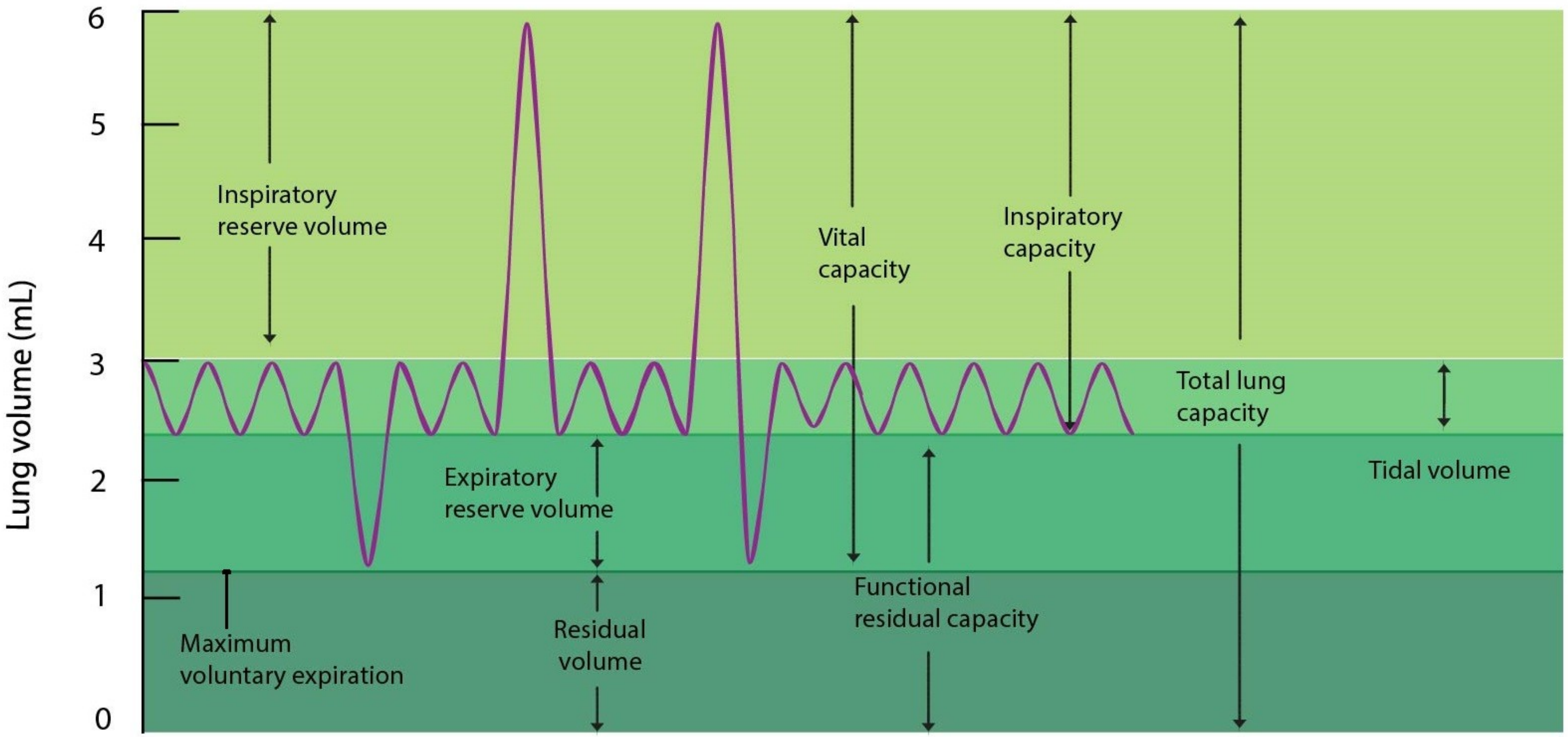


Rest

Inspiration

Expiration

Lung Volumes



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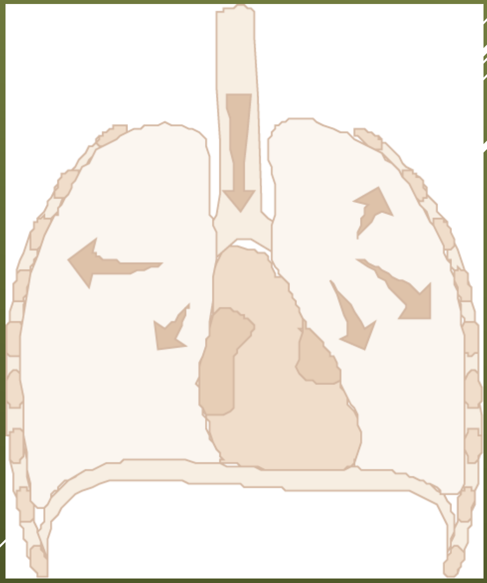
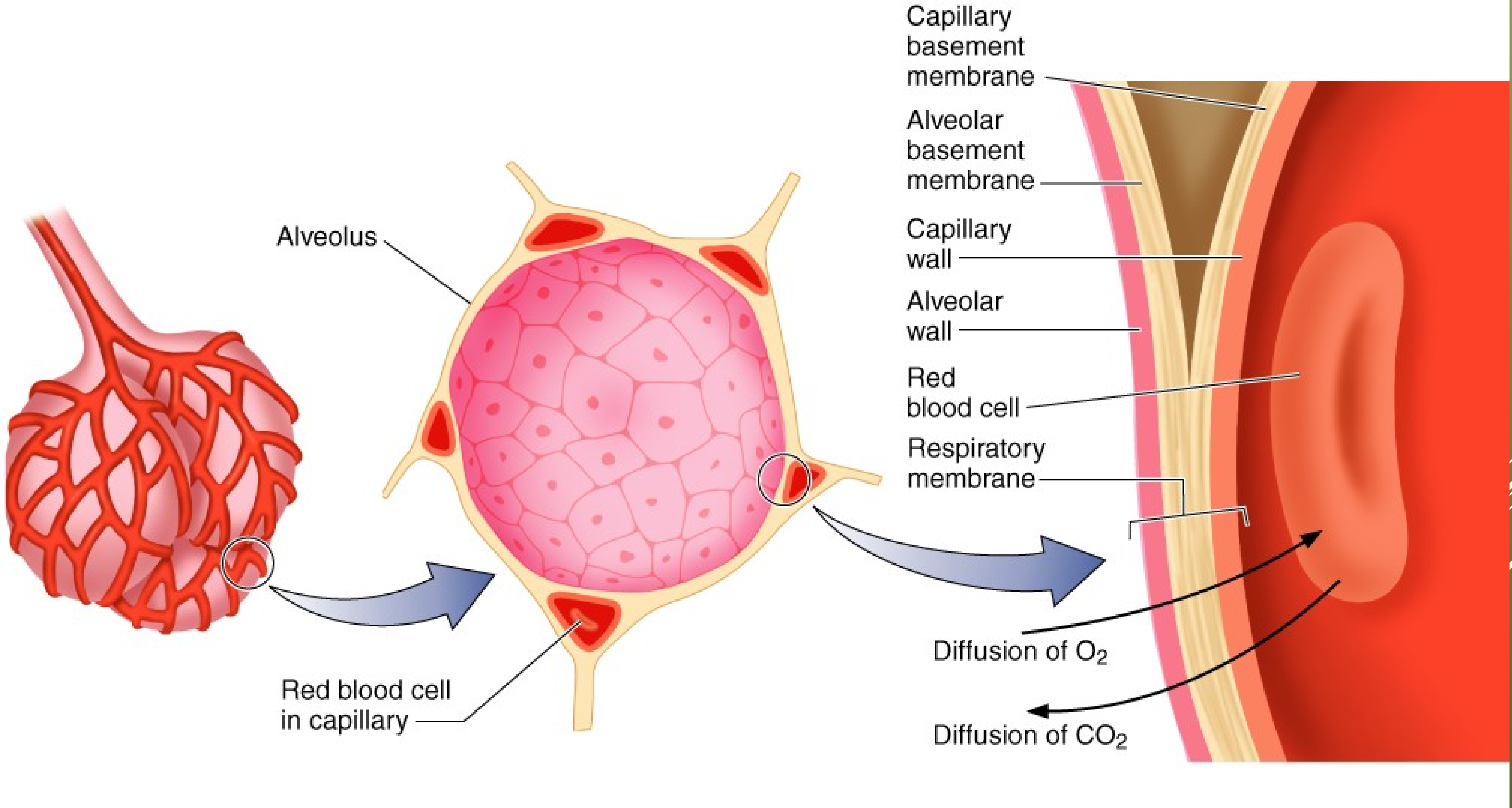
Pulmonary Diffusion

- Replenishes blood's oxygen supply that has been depleted for oxidative energy production
- Removes carbon dioxide from returning venous blood
- Occurs across the thin respiratory membrane



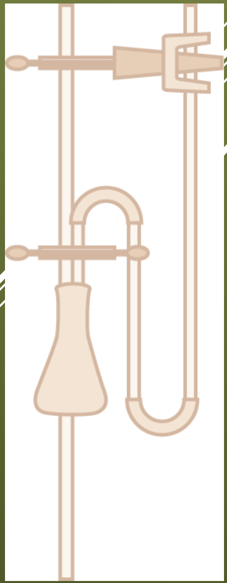
RESPIRATORY MEMBRANE



Laws of Gases

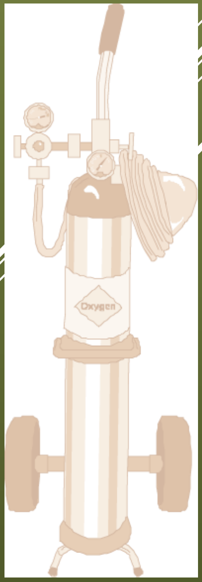
Dalton's Law: The total pressure of a mixture of gases equals the sum of the partial pressures of the individual gases in the mixture.

Henry's Law: Gases dissolve in liquids in proportion to their partial pressures, depending on their solubilities in the specific fluids and depending on the temperature.



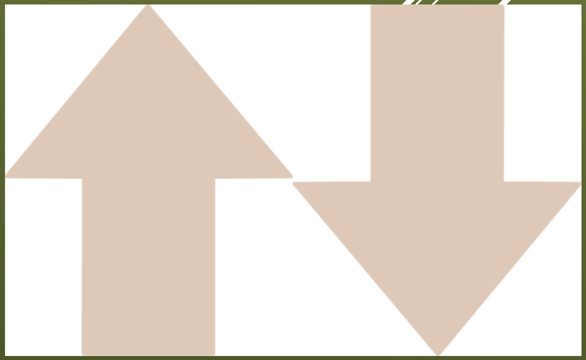
Partial Pressures of Air

- Standard atmospheric pressure (at sea level) = 760 mmHg (= Torr)
- Nitrogen (N_2) is 79.04% of air; the partial pressure of nitrogen (PN_2) = 600.7 mmHg
- Oxygen (O_2) is 20.93% of air; PO_2 = 159.1 mmHg
- Carbon dioxide (CO_2) is 0.03%; PCO_2 = 0.2 mmHg



Did You Know…?

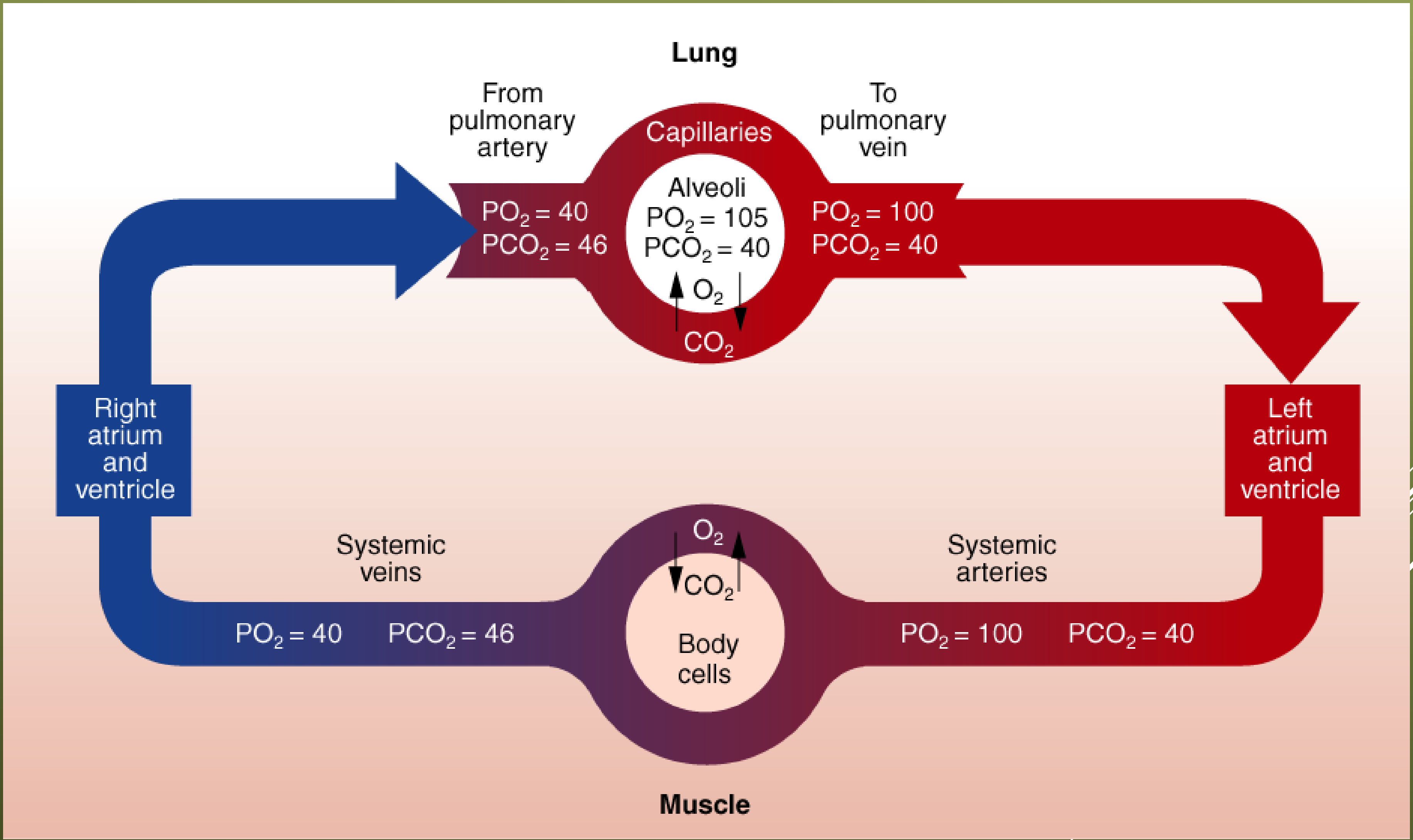
Differences in the partial pressures of gases in the aveoli and in the blood create a pressure gradient across the respiratory membrane. This difference in pressures leads to diffusion of gases across the respiratory membrane. The greater the pressure gradient, the more rapidly oxygen diffuses across it.



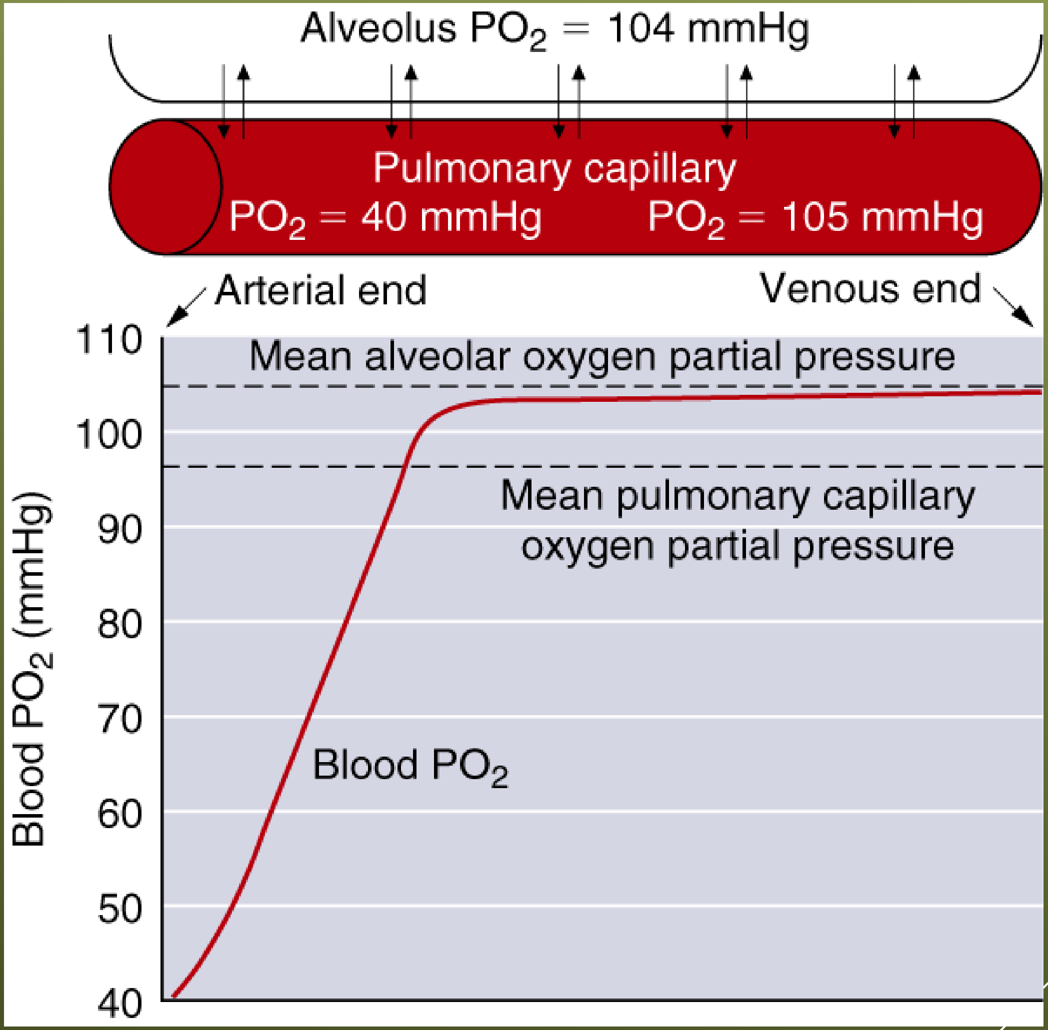
Partial Pressures of Respiratory Gases at Sea Level

Gas	% in dry air	Partial pressure (mmHg) Dry air	Alveolar air	Arterial blood	Venous blood	Diffusion gradient
Total	100.00	760.0	760	760	706	0
H_2O	0.00	0.0	47	47	47	0
O_2	20.93	159.1	105	100	40	60
CO_2	0.03	0.2	40	40	46	6
N_2	79.04	600.7	568	573	573	0

PO_2 AND PCO_2 IN BLOOD

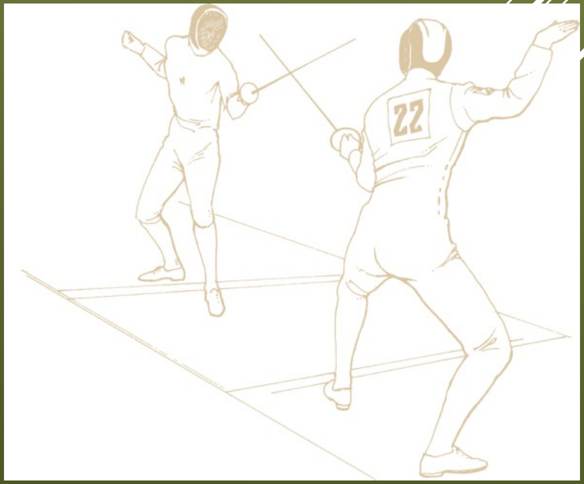


UPTAKE OF OXYGEN INTO PULMONARY CAPILLARY

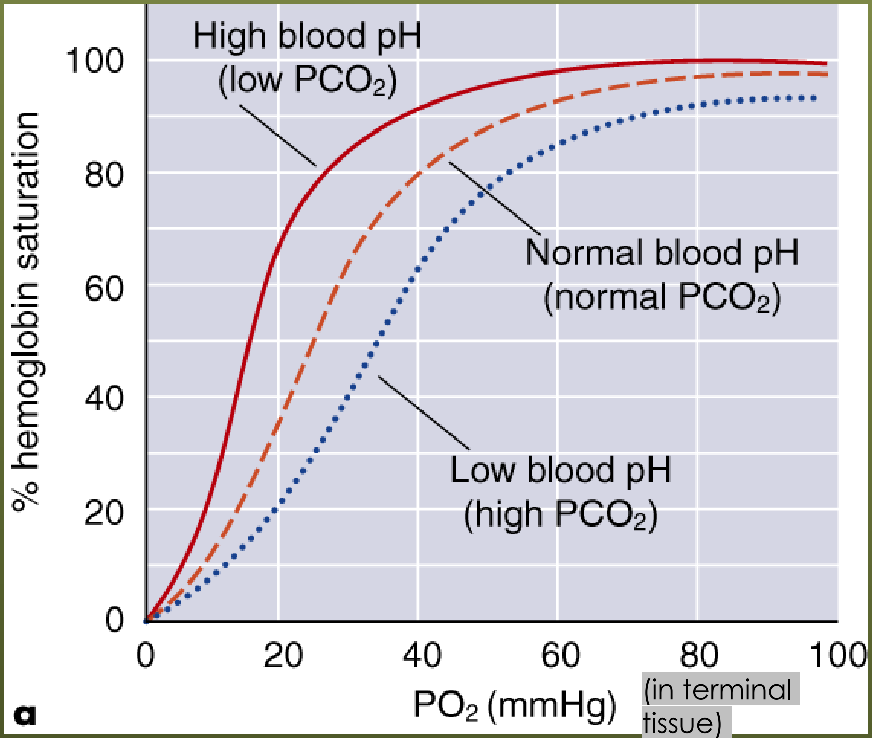


Oxygen Transport

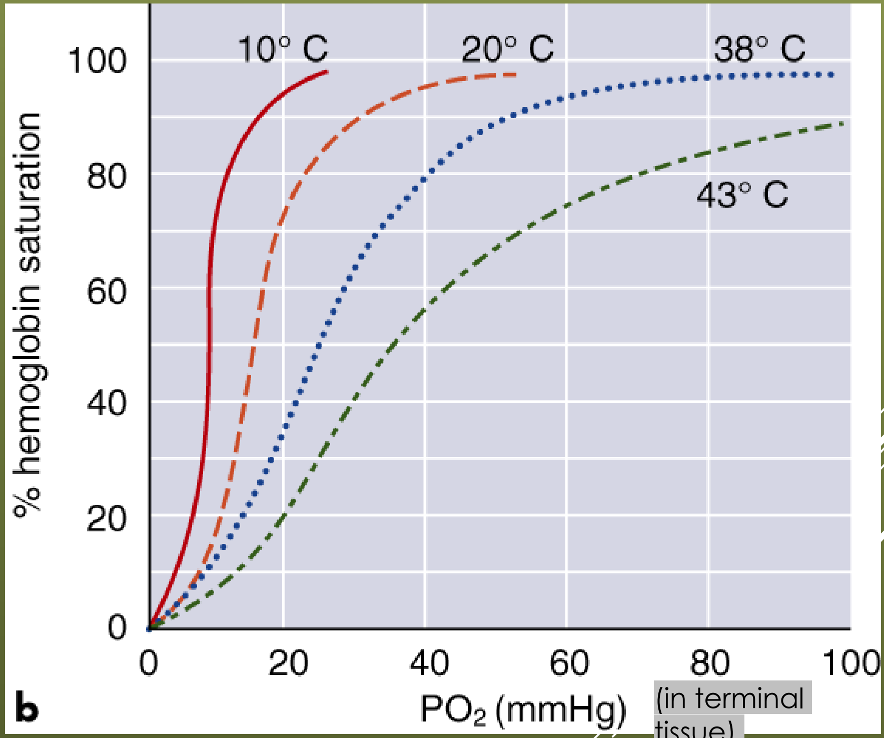
- Hemoglobin concentration largely determines the oxygen-carrying capacity of blood (>98% of oxygen transported).
- Increased H^+ (acidity) and temperature of a muscle allows more oxygen to be unloaded there.
- Training affects oxygen transport in muscle.



OXYGEN-HEMOGLOBIN DISSOCIATION CURVE



(in terminal tissue)



(in terminal tissue)

Carbon Dioxide Transport

- Dissolved in blood plasma (7% to 10%)
- As bicarbonate ions resulting from the dissociation of carbonic acid (60% to 70%)
- Bound to hemoglobin (carbaminohemoglobin) (20% to 33%)

The a-$\bar{v}O_2$ diff—Arterial O_2 Content

- Indication of how much oxygen is removed from the blood in capillaries.
- Hemoglobin (Hb)—1 molecule of Hb carries 4 molecules of O_2, and 100 ml of blood contains ~14–18 g of Hb in men and ~12–14 in women.
- (1 g of Hb combines with 1.34 ml of oxygen.)
- There are ~20.1 ml of O_2 per 100 ml of arterial blood in men and ~17.4 ml of O_2 per 100 ml of arterial blood in women.
- Low iron leads to iron-deficiency anemia, reducing the body's capacity to transport oxygen—this is more of a problem in women than men.

Did You Know…?

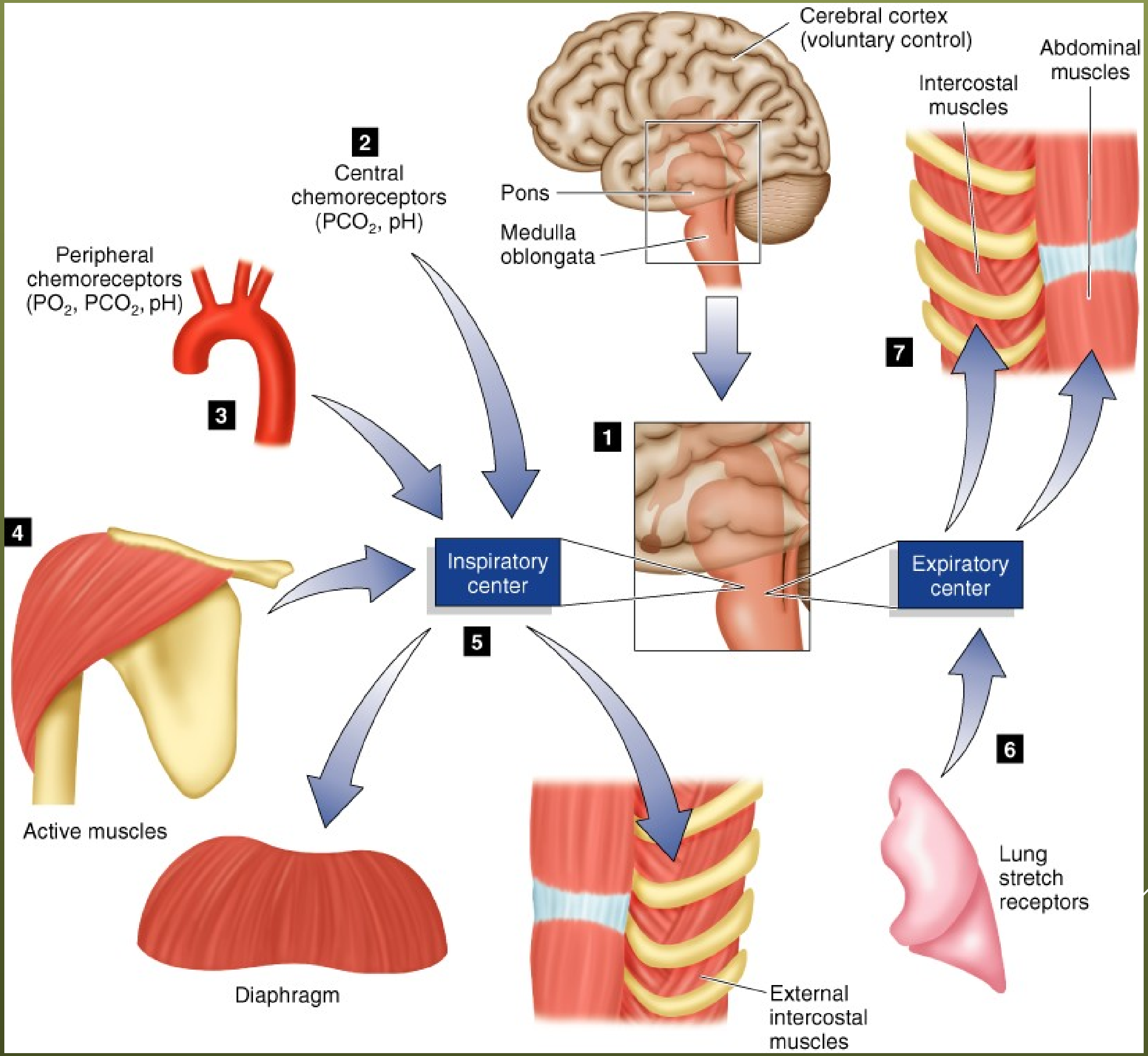
The increase in a-$\bar{v}O_2$ diff (difference between arterious and venous vO_2) during strenuous exercise reflects increased oxygen use by muscle cells. This use increases oxygen removal from arterial blood, resulting in a decreased venous oxygen concentration.

Regulators of Pulmonary Ventilation at Rest

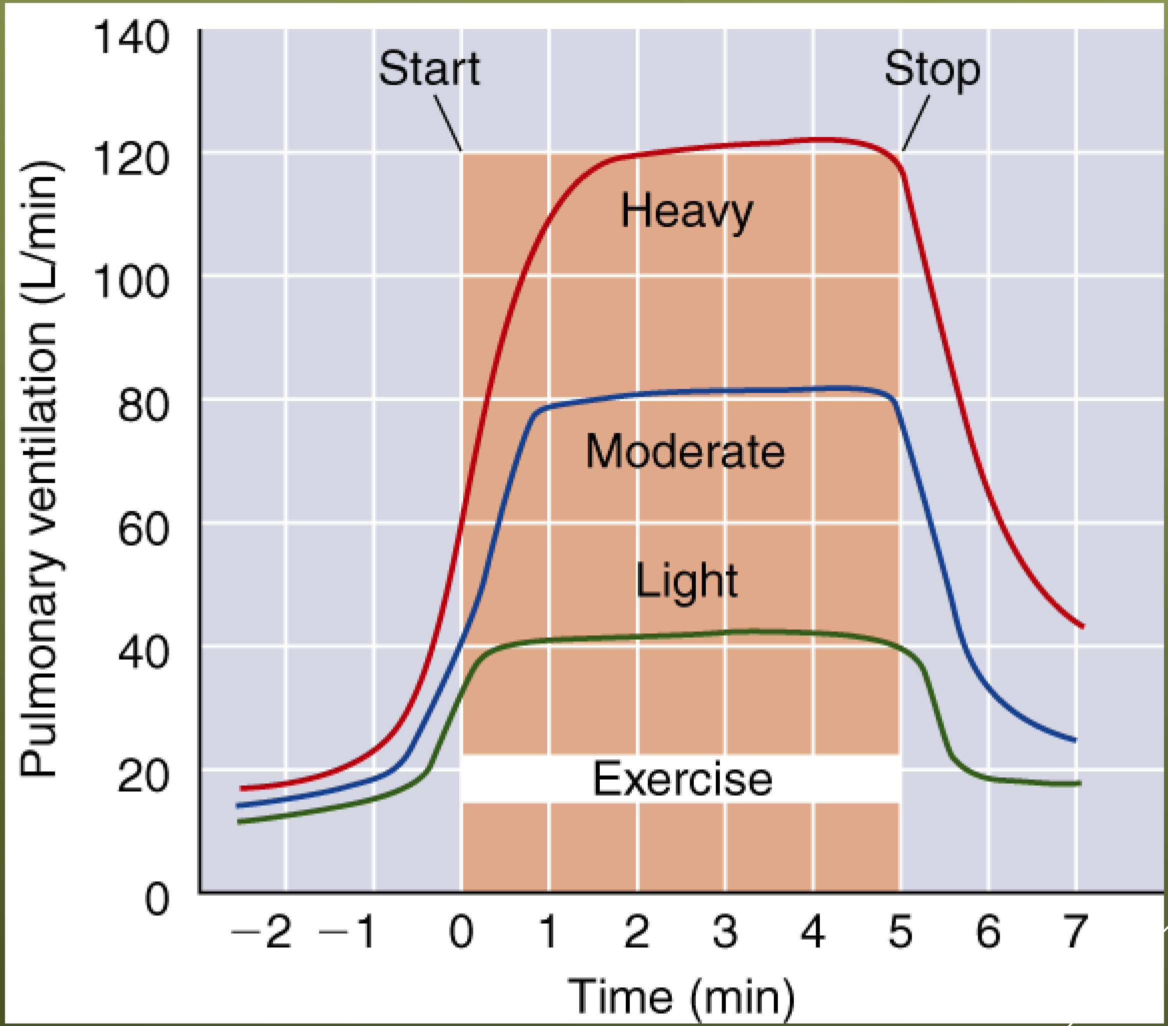
- Higher brain centers
- Chemical changes within the body
- Chemoreceptors
- Muscle mechanoreceptors
- Hypothalamic input
- Conscious control

- Generally – increased PCO_2 and/or decreased pH simulates ventilation

RESPIRATORY REGULATION



VENTILATORY RESPONSE TO EXERCISE



Breathing Terminology

Dyspnea—shortness of breath.

Hyperventilation—increase in ventilation that exceeds the metabolic need for oxygen. (Voluntary hyperventilation, as is often done before underwater swimming, removes CO_2 and thus increases blood pH.)

Valsalva maneuver—a breathing technique to trap and pressurize air in the lungs to allow the exertion of greater force; if held for an extended period, it can reduce HR (by vagal tone). This technique is often used during heavy lifts.

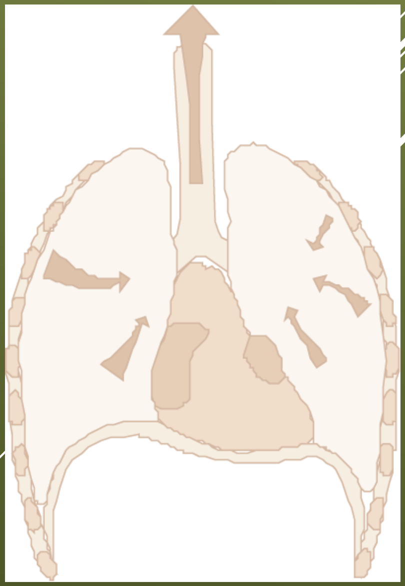
Pulmonary Ventilation

Ventilation ($\dot{V}_E$) is the product of tidal volume (TV) and breathing frequency (f):

$\dot{V}_E$ = TV

Ventilatory Equivalent for Oxygen

- The ratio between V_E (air) and VO_2 (oxygen) in a given time frame
- Indicates breathing economy
- At rest—$\dot{V}_E/\dot{V}O_2$ = 23 to 28 L of air breathed per L $\dot{V}O_2$ per minute
- At max exercise—$\dot{V}_E/\dot{V}O_2$ = 30 L of air per L $\dot{V}O_2$ per minute
- Generally $\dot{V}_E/\dot{V}O_2$ remains relatively constant over a wide range of exercise levels

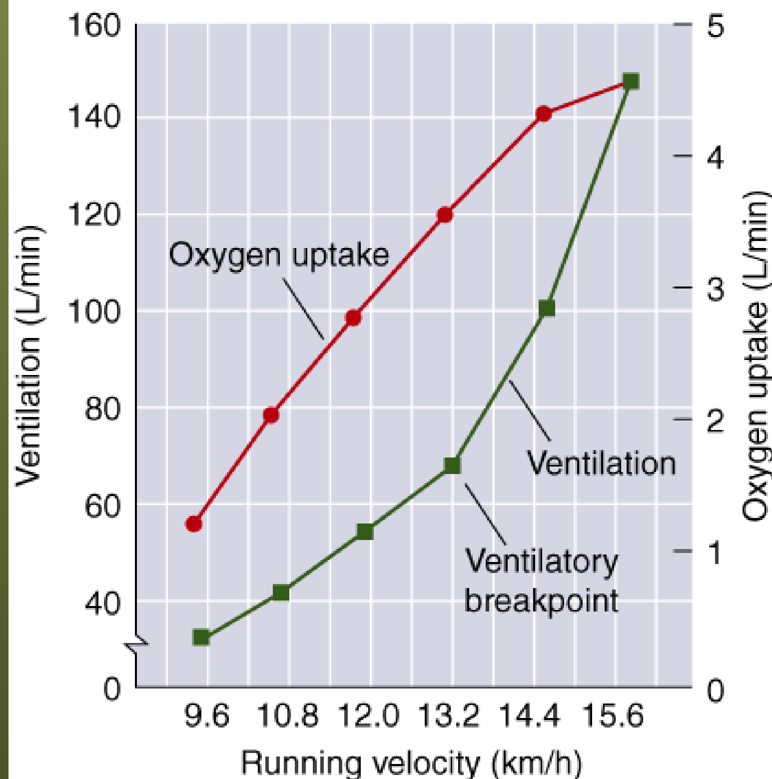


Ventilatory Breakpoint

- The point during intense exercise at which ventilation increases disproportionately to the oxygen consumption.
- When work rate exceeds 55% to 70% $\dot{V}O_2max$, oxygen delivery can no longer match the energy requirements so energy must be derived from anaerobic glycolysis.
- Anaerobic glycolysis increases lactate level, which decreases pH and and simulates ventilation.

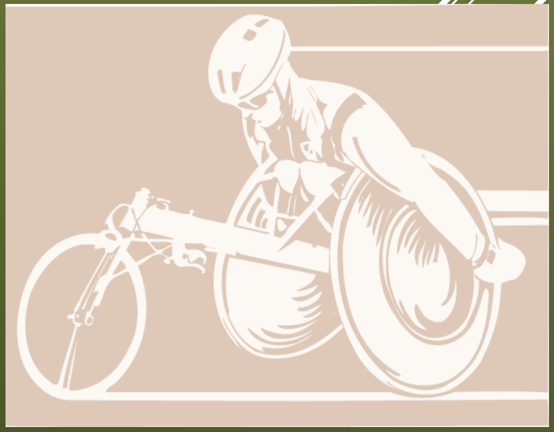
$\dot{V}_E$ AND $\dot{V}O_2$ DURING EXERCISE

Running speed (km/h)	$\dot{V}_E/\dot{V}O_2$
9.6	21.5
10.8	20.0
12.0	20.4
13.2	20.3
14.4	24.9
15.6	33.3

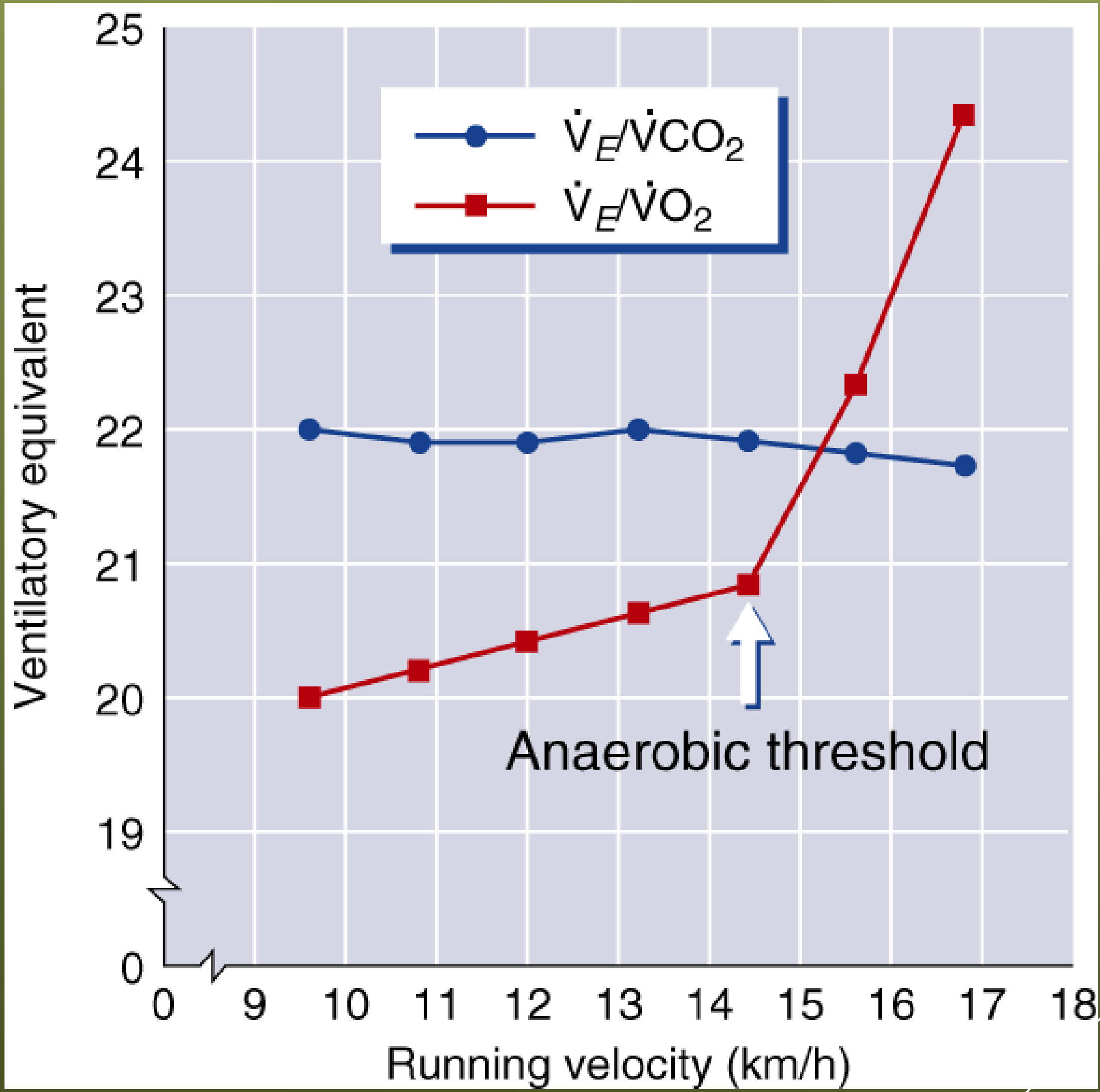


Anaerobic Threshold

- Point during intense exercise at which metabolism becomes increasingly more anaerobic
- Reflects the lactate threshold under most conditions, though the relationship is not always exact
- Identified by noting an increase in $\dot{V}_E/\dot{V}O_2$ without a concomitant increase in the ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$)



$\dot{V}_E/\dot{V}CO_2$ AND $\dot{V}_E/\dot{V}O_2$



ARTERIAL BLOOD AND MUSCLE pH