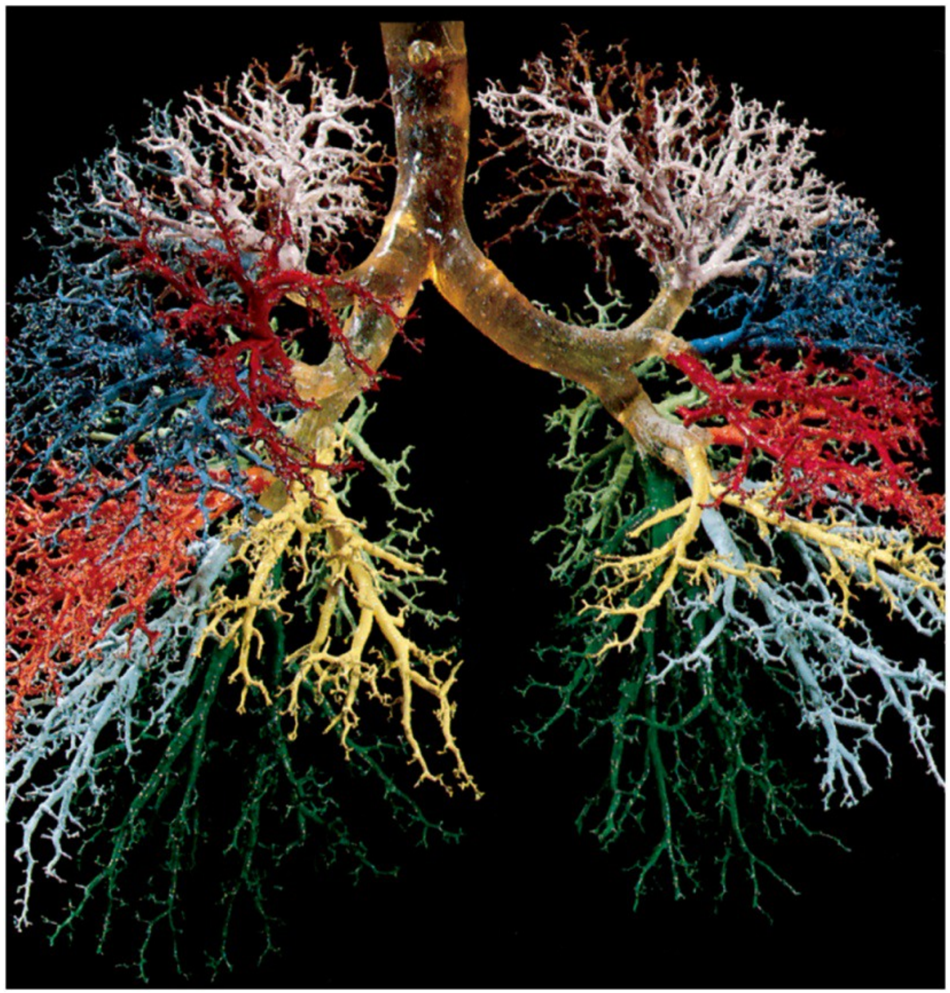
Chapter 22.1

Respiratory System Learning Objectives



Principal Organs of Respiratory System

- upper respiratory tract
  - located in head and neck
  - nose through laryngopharynx

- lower respiratory tract
  - organs of the thorax
  - larynx through alveoli

Conducting Division VS Respiratory Division

conducting division of the respiratory system

those passages that serve only for airflow

no gas exchange

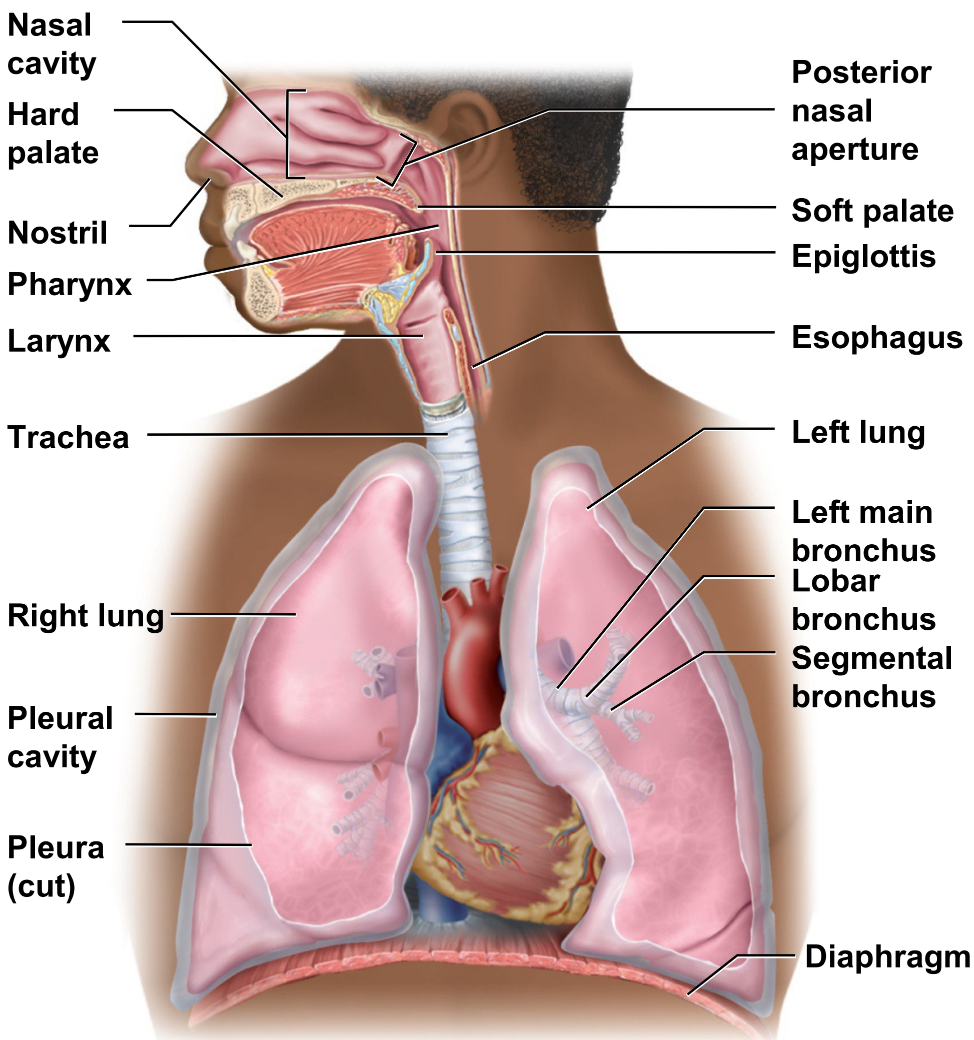
nostrils through major bronchioles

respiratory division of the respiratory system

consists of alveoli and other gas exchange regions

- respiratory membrane is space between alveoli and capillary
- incoming air stops at the alveoli of the lungs
- 300 millions alveoli (150 million per lung)
- gases inside alveoli are exchanged with the gases in the bloodstream
- gas molecules diffuse “down” concentration gradients
- 70 and 80 square meters of surface area

Organs of Respiratory System



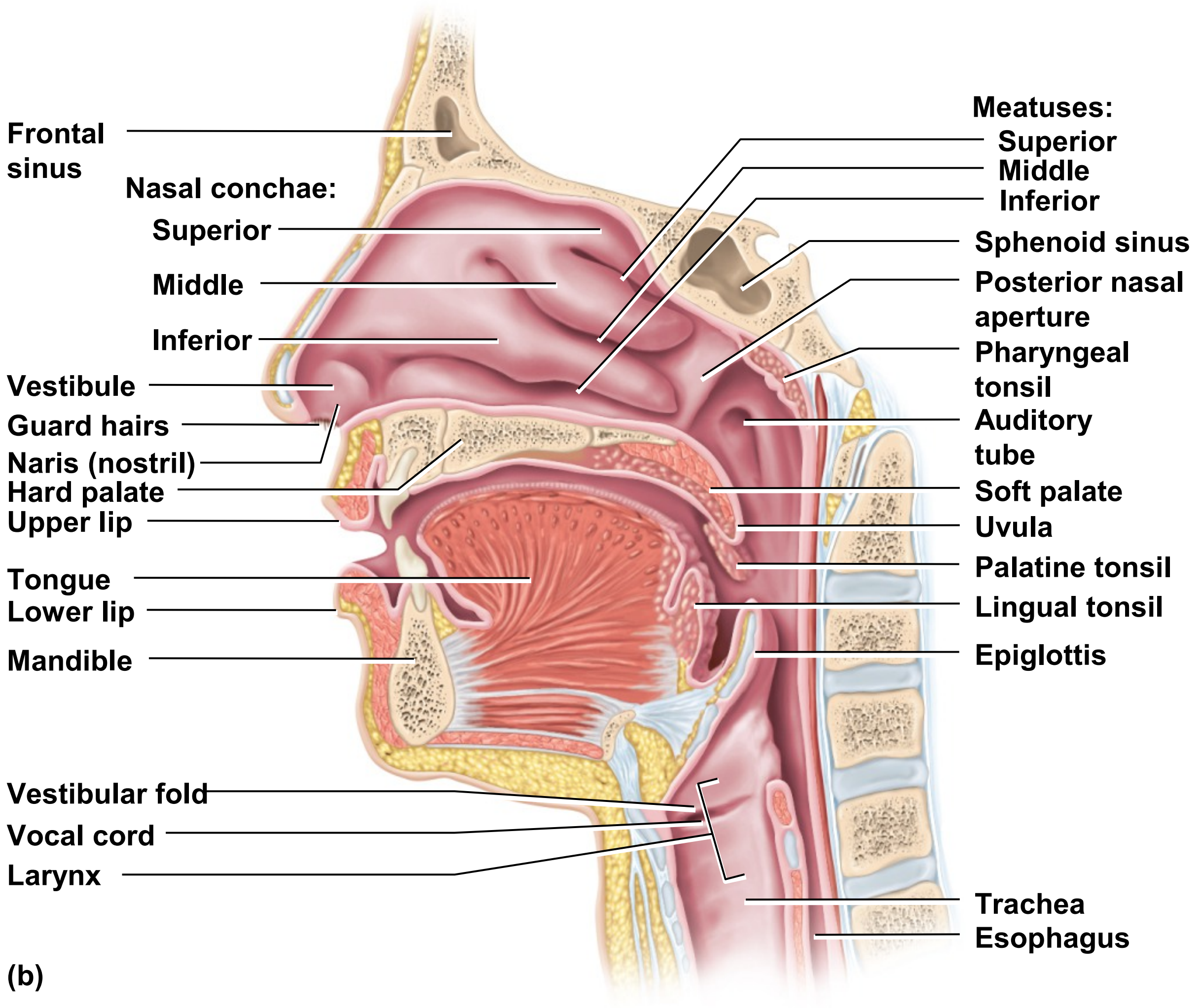
- nose, pharynx, larynx, trachea, bronchi, lungs

Nasal Cavity

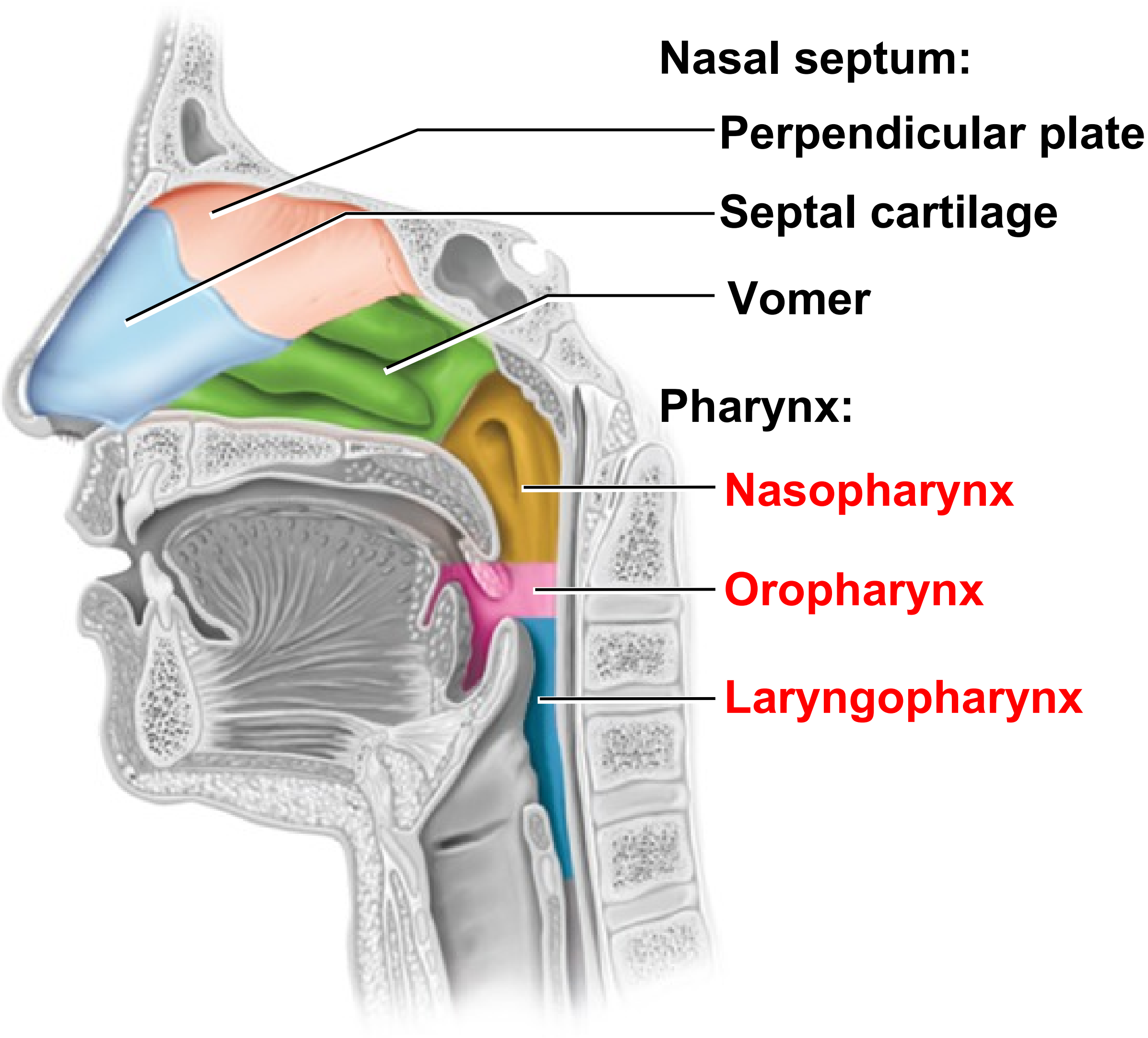
- **nasal conchae**
  - nasal cavity occupied by three folds of tissue
  - **superior, middle, and inferior nasal conchae** (turbinates)
    - project from lateral walls toward septum
    - **meatus** – narrow air passage beneath each concha
    - narrowness and turbulence insure that most air contacts mucous membranes
    - cleans, warms, and moistens the air

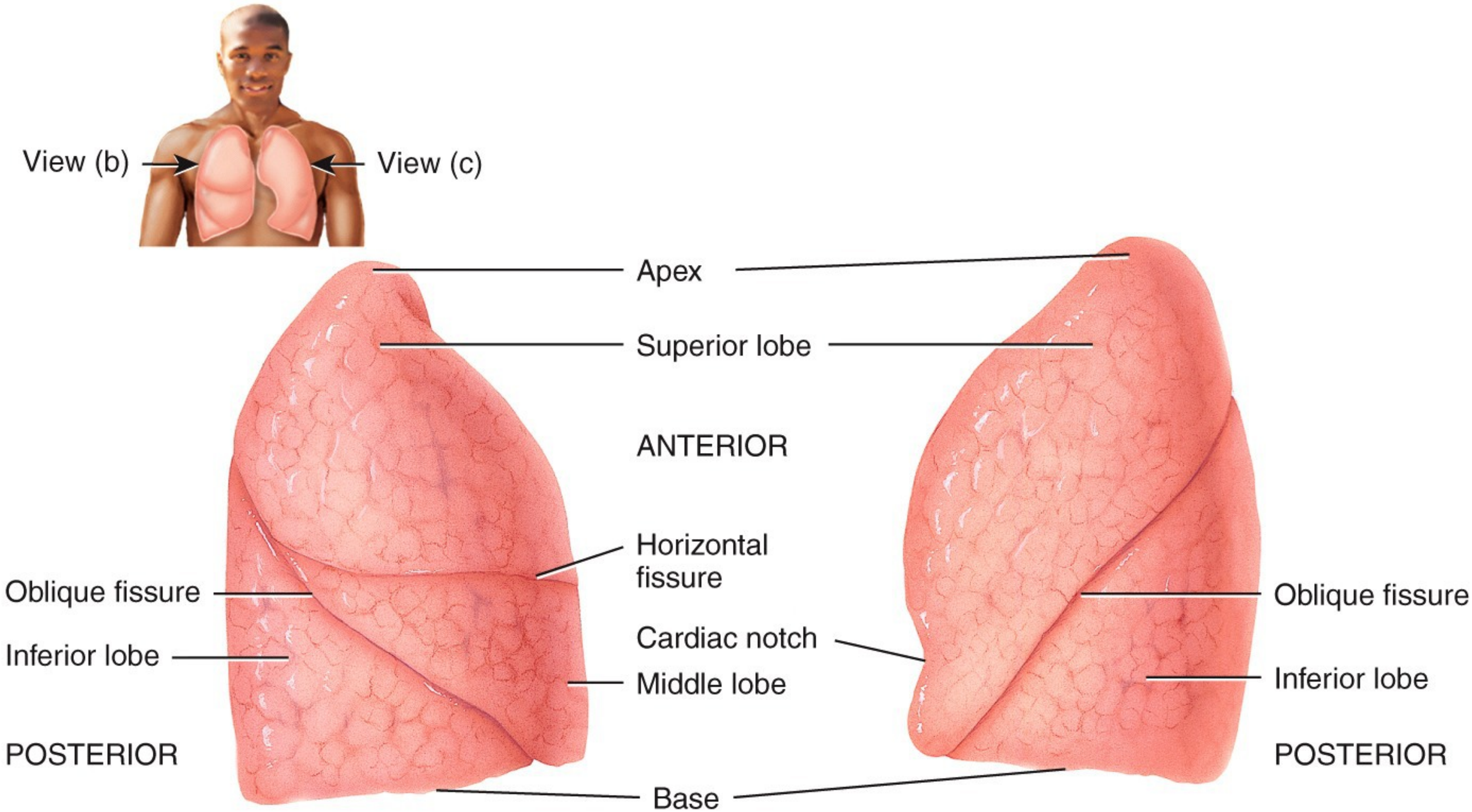
Upper Respiratory Tract

(respiratory organs in the head and neck / stop at entrance to larynx)



Regions of Pharynx

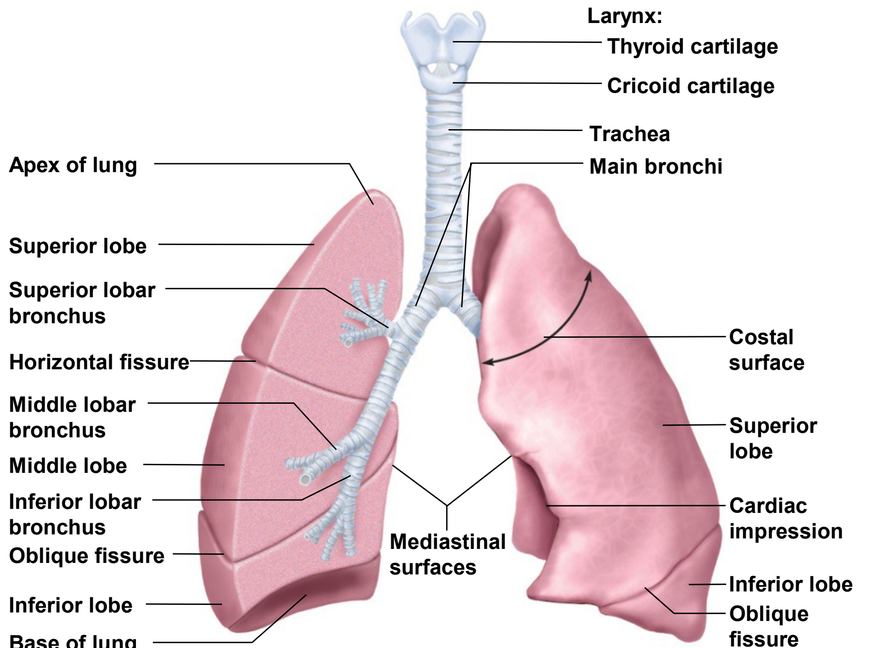




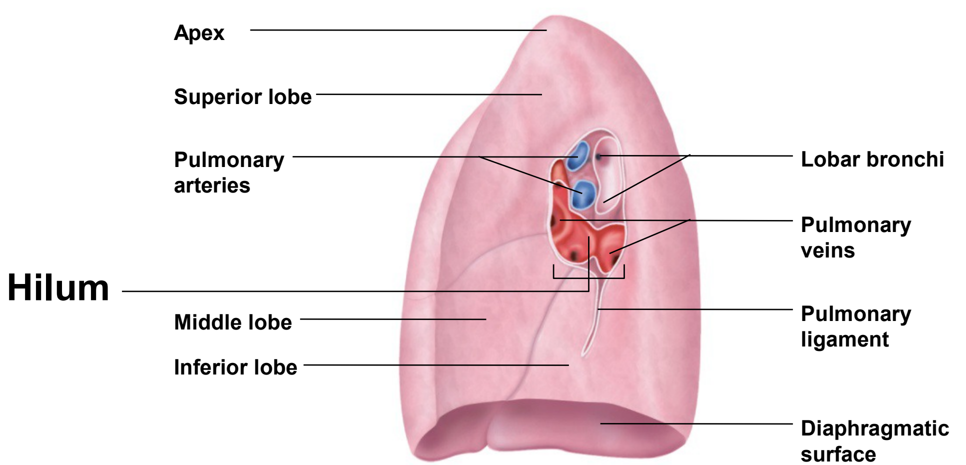
(b) Lateral view of right lung

(c) Lateral view of left lung

Lungs - Surface Anatomy



(a) Anterior view



(b) Mediastinal surface, right lung

Path of Air Flow

Conducting Division

- nasal cavity
- pharynx
- larynx
- trachea
- main bronchus
- lobar bronchus
- segmental bronchus
- Bronchiole
- Terminal bronchiole

Respiratory Division

- respiratory bronchiole
- alveolar duct
- atrium
- alveolus

Nares

↓

Mucous + Cilia — **Nasal cavity**

↓

Mucous + Cilia — **Nasopharynx**

↓

Oropharynx

↓

Laryngopharynx

↓

Transition Between Upper/Lower Respiratory Tract

Larynx

↓

Start of Mucous + Cilia — **Trachea**

↓

Primary bronchi

→

Secondary bronchi

↓

Tertiary bronchi

↓

Multiple branches of bronchi

↓

Last Segment both with Mucous + Cilia — **Bronchioles** — No supporting cartilage but thick smooth muscle walls keep bronchioles open

↓

Cilia — **Terminal bronchioles**

↓

Transition Between Conducting / Respiratory Division

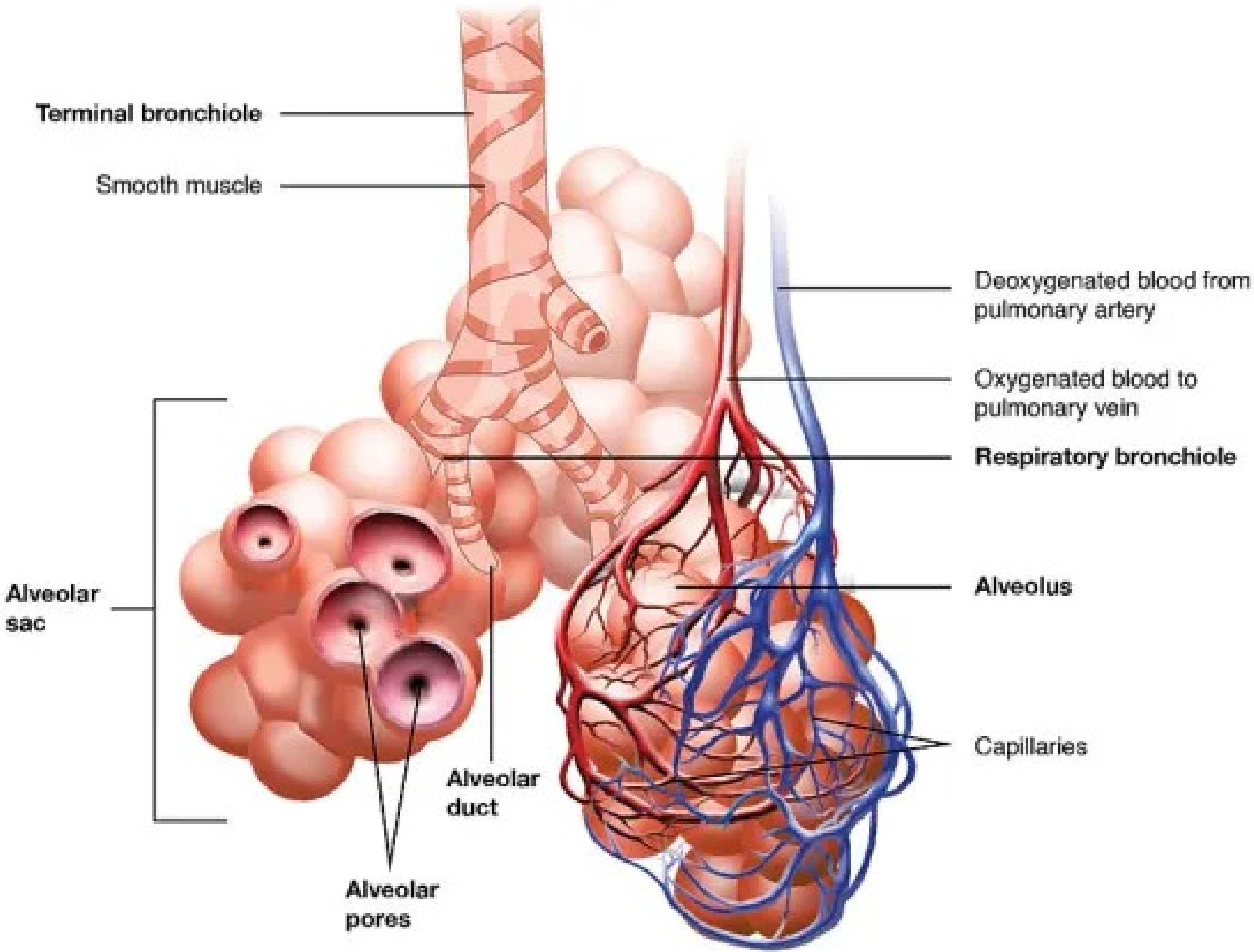
Neither — **Respiratory bronchioles**

↓

Alveolar ducts

↓

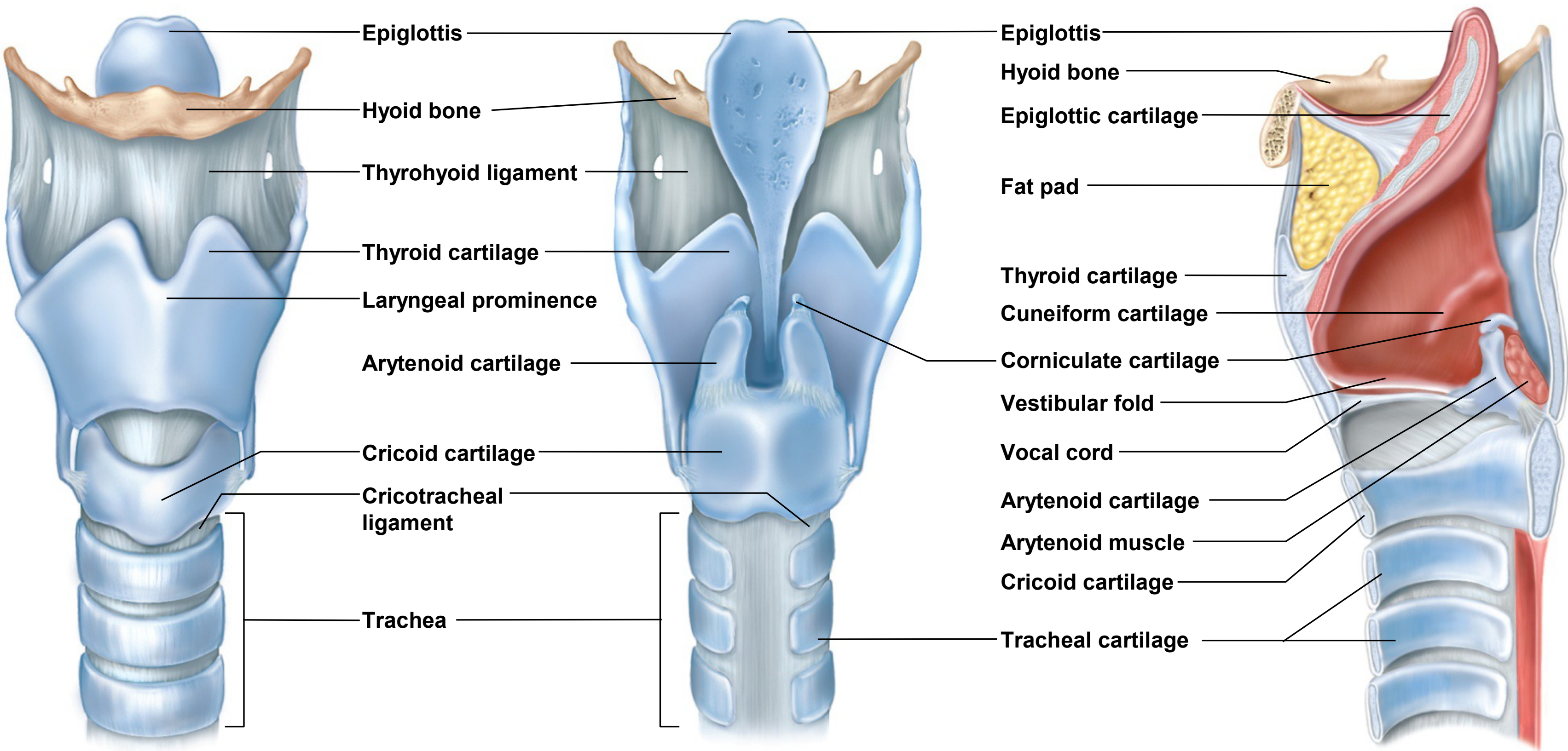
Alveolar sacs


Terminal bronchiole
Smooth muscle
Deoxygenated blood from pulmonary artery
Oxygenated blood to pulmonary vein
Respiratory bronchiole
Alveolus
Alveolar sac
Capillaries
Alveolar duct
Alveolar pores

Larynx

- larynx (voice box) – cartilaginous chamber about 4 cm (1.5 in.)
- primary function is to keep food and drink out of the airway
- has evolved additional role – phonation – production of sound
- epiglottis – flap of tissue that guards the superior opening of the larynx
  - at rest, stands almost vertically
  - during swallowing, extrinsic muscles of larynx pull larynx upward
  - tongue pushes epiglottis down to meet it
  - closes airway and directs food to the esophagus behind it
  - vestibular folds of the larynx play greater role in keeping food and drink out of the airway VS vestibular ligaments (also called vocal cords)

Views of Larynx

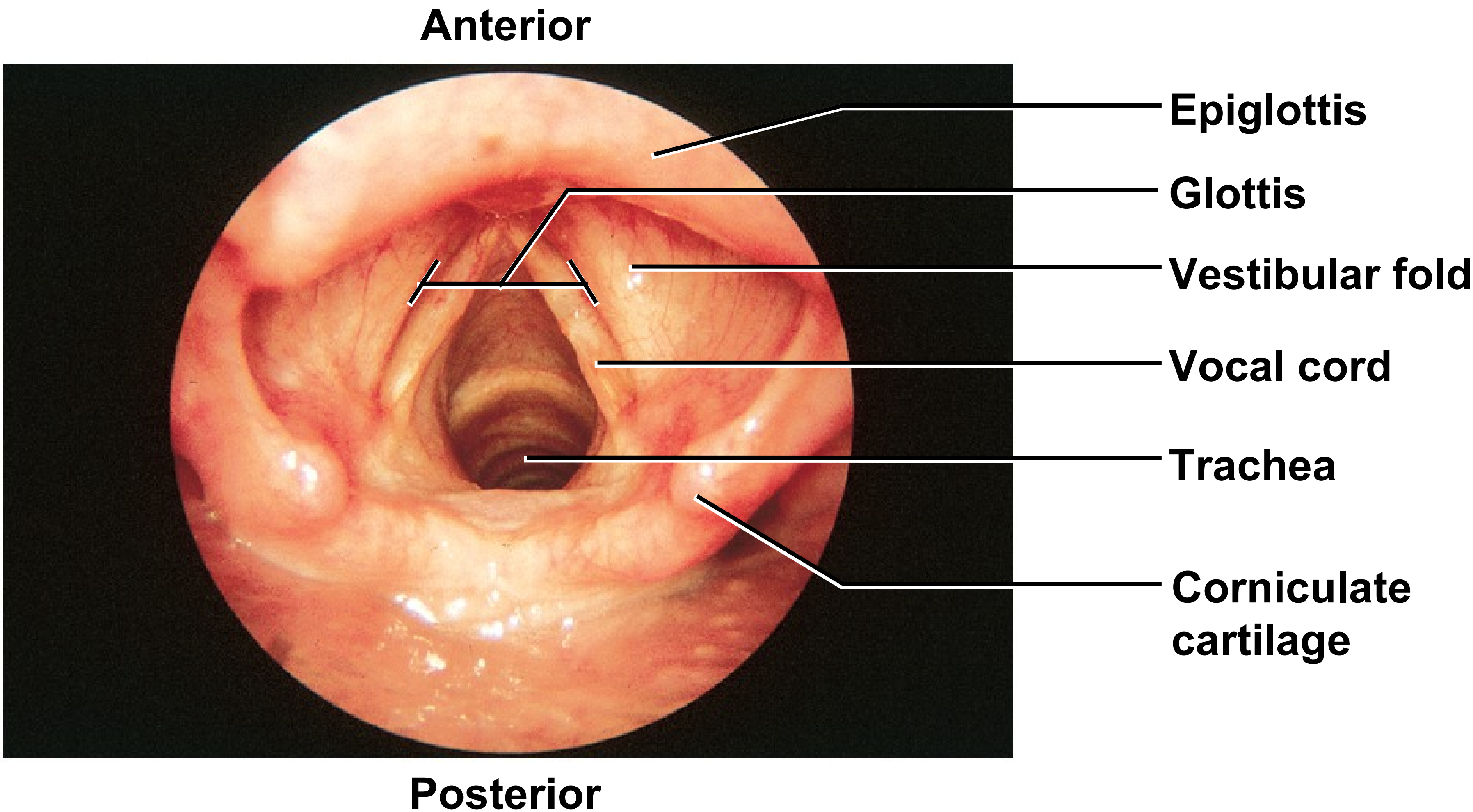


(a) Anterior

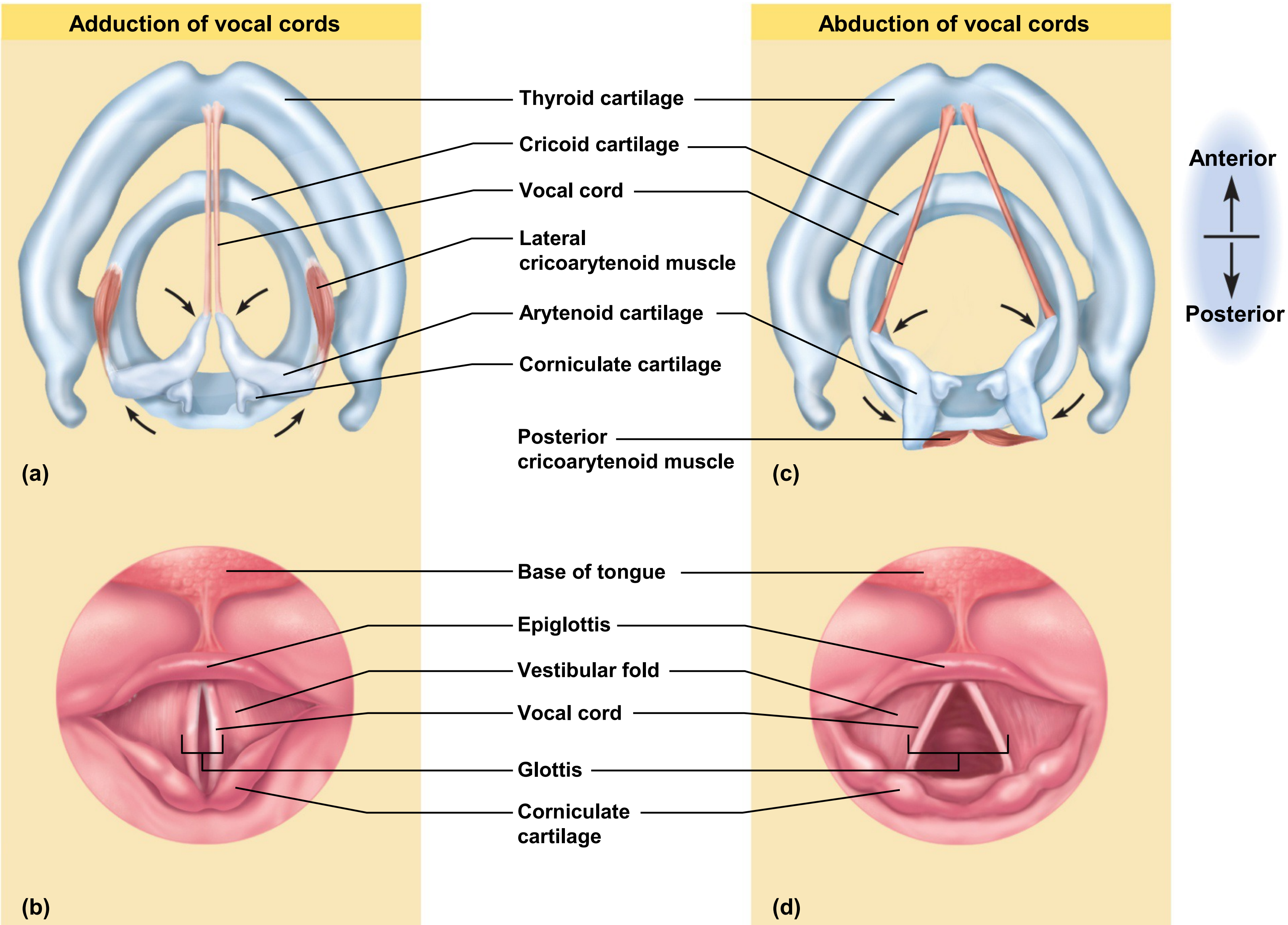
(b) Posterior

(c) Median

Endoscopic View of the Larynx



Action of Vocal Cords



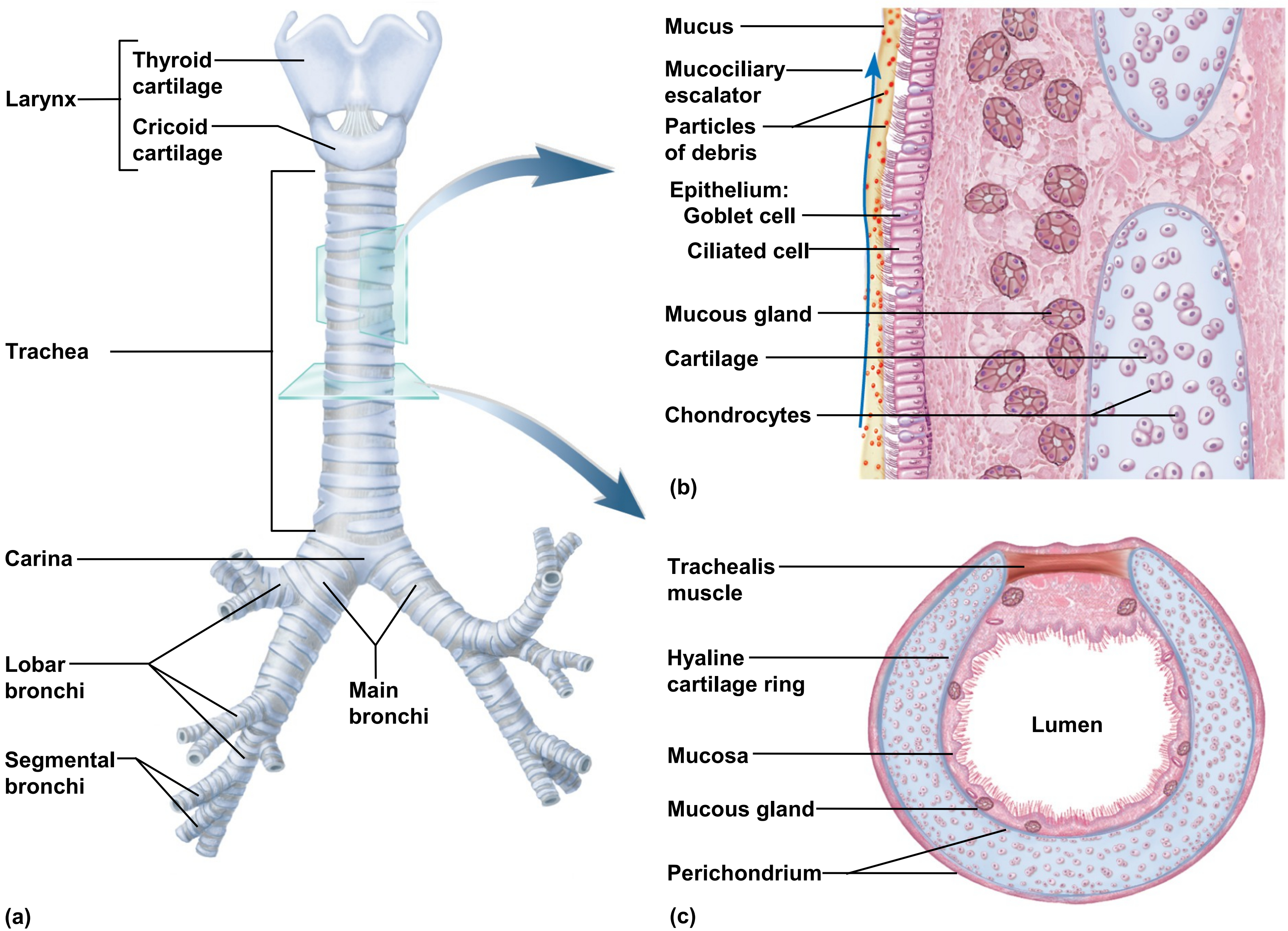
Trachea (1 of 2)

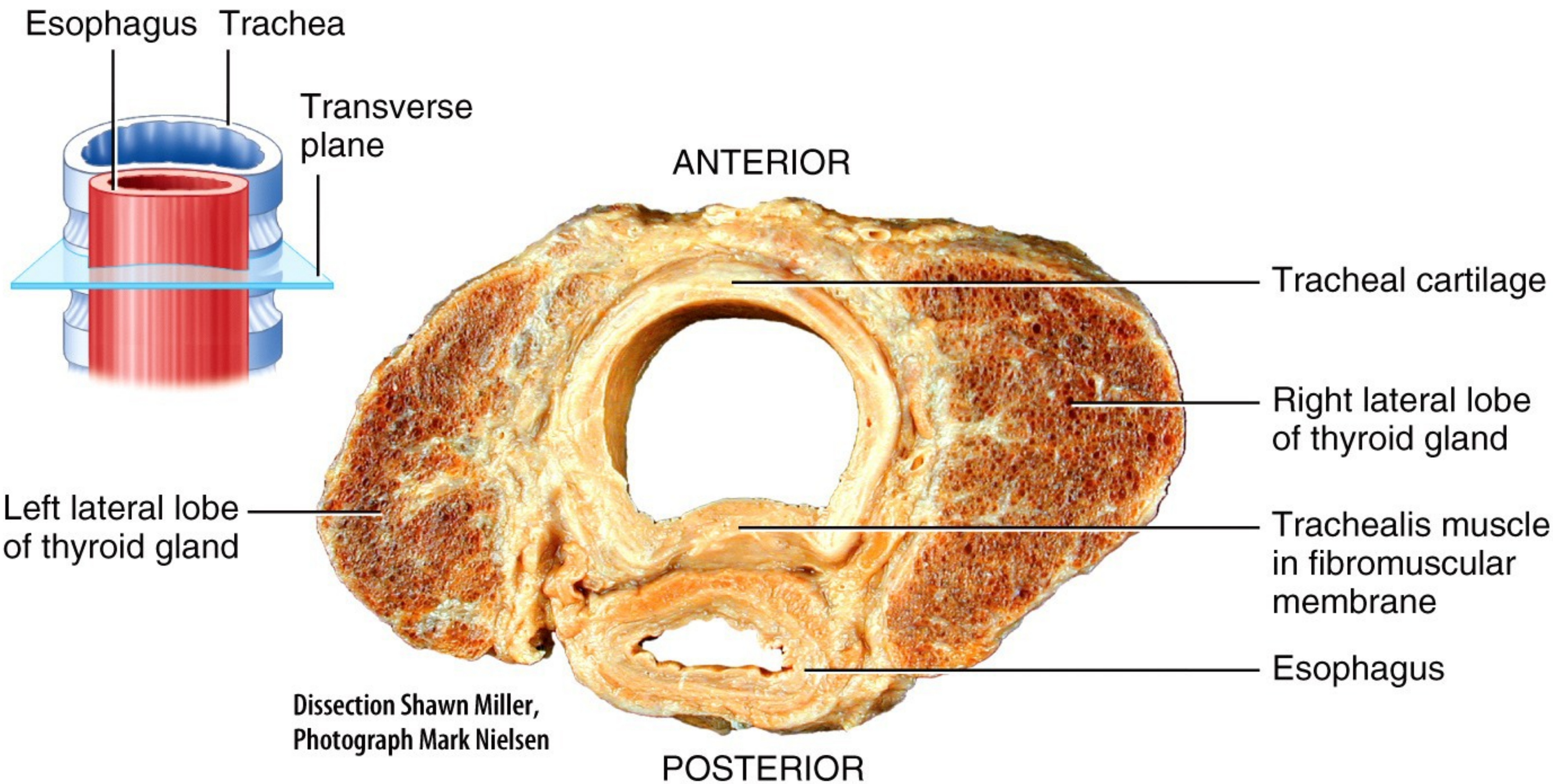
- **trachea** (windpipe) – a rigid tube about 12 cm (4.5 in.) long and 2.5 cm (1 in.) in diameter
  - found anterior to esophagus
  - supported by 16 to 20 **C-shaped** rings of **hyaline cartilage**
  - reinforces the trachea and keeps it from collapsing when you inhale
  - opening in rings faces posteriorly towards esophagus
  - **trachealis muscle** spans opening in rings
    - gap in C allows room for the esophagus to expand as swallowed food passes by
    - contracts or relaxes to adjust air flow

Trachea (2 of 2)

- inner lining of trachea is a ciliated pseudostratified columnar epithelium
  - composed mainly of mucus-secreting cells, ciliated cells, and stem cells
  - mucociliary escalator – mechanism for debris removal
    - mucus traps inhaled particles
    - upward beating cilia drives mucus toward pharynx where it is swallowed
- right and left main bronchi
  - trachea forks at level of sternal angle /// carina – internal medial ridge in the lowermost tracheal cartilage
    - directs the airflow to the right and left

Lower Respiratory Tract





Superior view of transverse section of thyroid gland, trachea, and esophagus

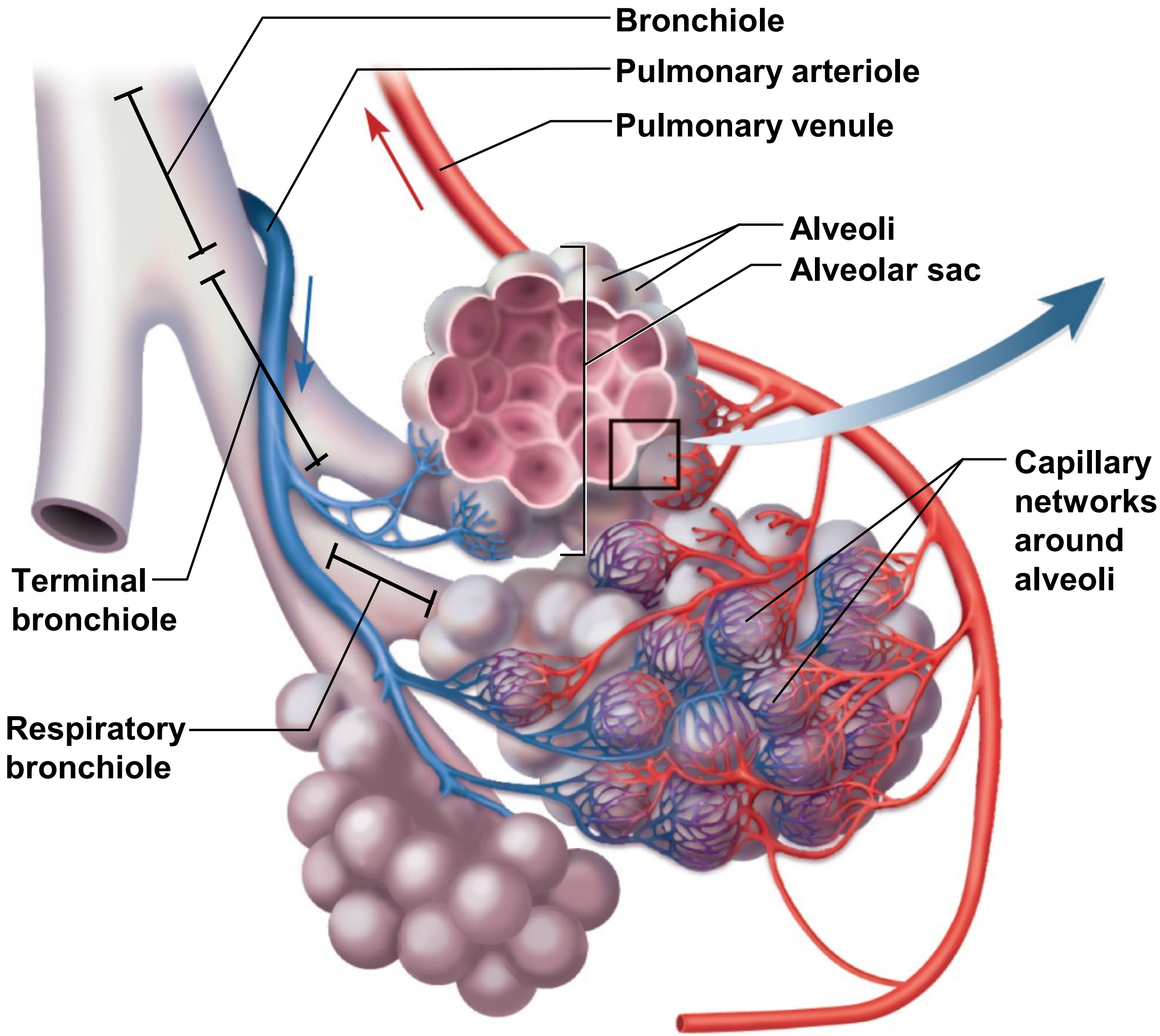
Tracheal Epithelium

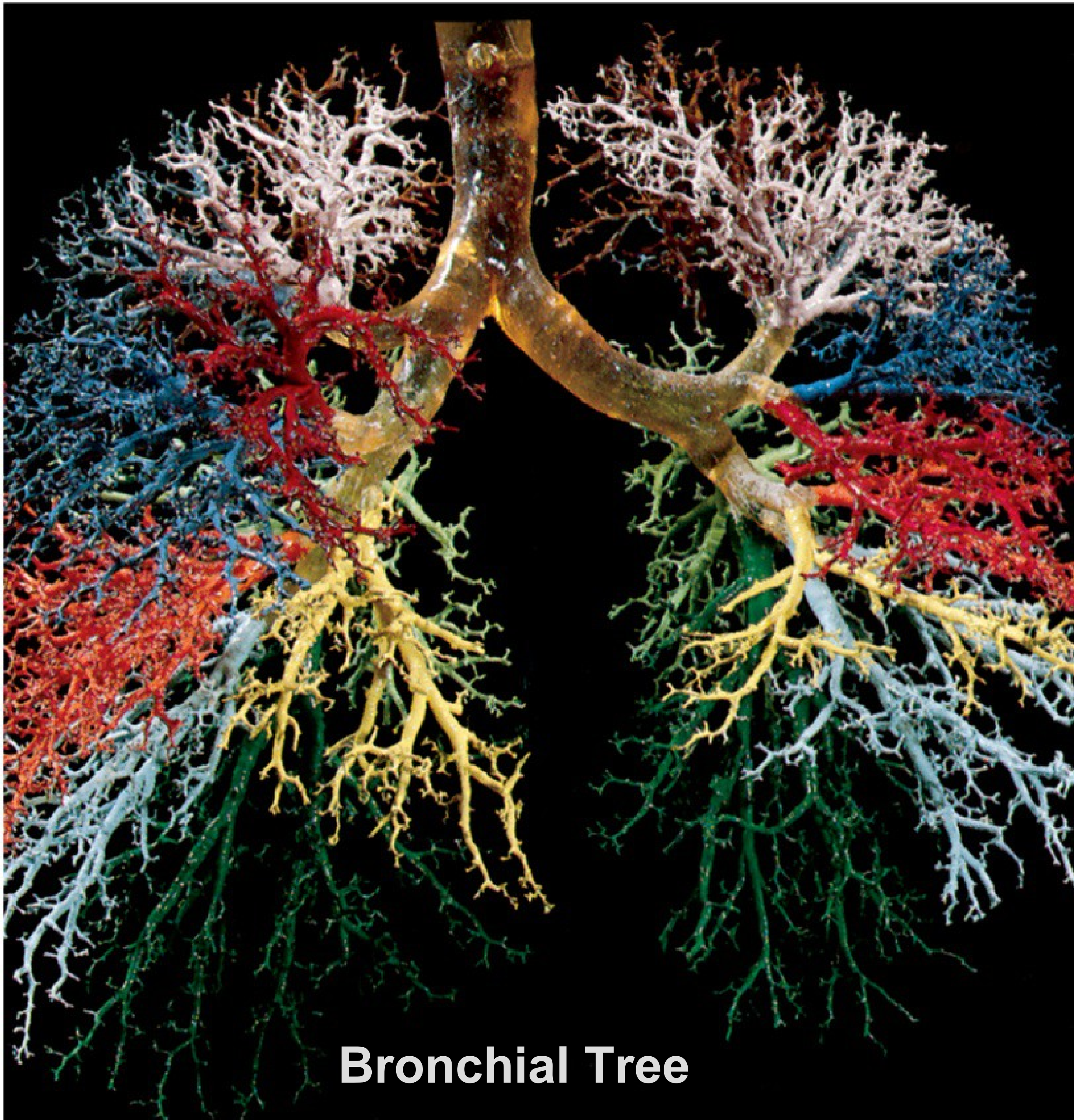
Blood Vessels Associated with the Lungs

pulmonary arteries & veins These blood vessels closely follow the **bronchial tree** (air passage ways) as they make their way to the alveoli /// pulmonary circuit = blood flow from right ventricle to left atria

bronchial arteries & veins – branch of thoracic aorta /// delivers oxygen and removes waste products from lung tissues /// part of the systemic circuit

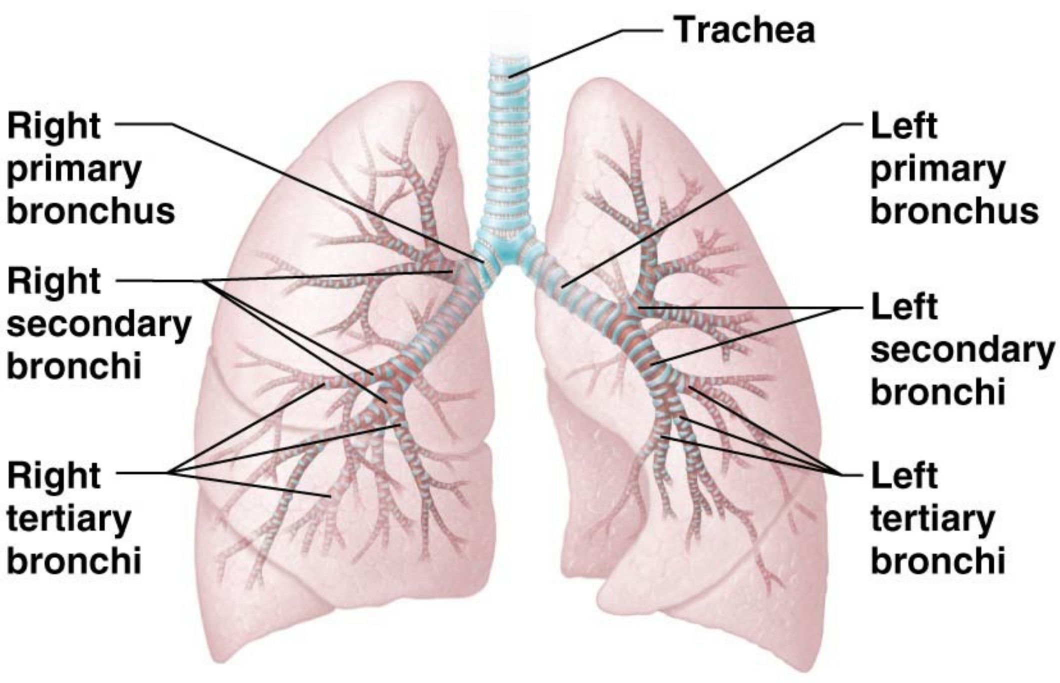
Blood Supply to the Alveolar Sacs





Bronchial Tree

Branching pattern of the bronchial tree.



(a) Conducting zone passages and bronchial tree

(b) Cast of bronchial tree

Main Brochi = Primary Bronchi // Secondary = Lobar // Tertiary = Segmental

Bronchial Tree
(Main Bronchi / Lobar Bronchi / Segmental Bronchi)

- Bronchial tree – a branching system of air tubes located in each lung /// from one main bronchus extends 65,000 terminal bronchioles

- Main (primary) bronchi – supported by c-shaped hyaline cartilage rings /// rt. main bronchus is a 2-3 cm branch arising from fork of trachea
  - right bronchus slightly wider and more vertical than left
  - aspirated (inhaled) foreign objects lodge right bronchus more often the left
  - lt. main bronchus is about 5 cm long /// slightly narrower and more horizontal than the right

Bronchial Tree
(Main Bronchi / Lobar Bronchi / Segmental Bronchi)

- Lobar (secondary) bronchi – supported by crescent shaped cartilage plates
  - three right lobar bronchi – superior, middle, and inferior /// one to each lobe of the right lung
  - two left lobar bronchi - superior and inferior /// one to each lobe of the left lung
- Segmental (tertiary) bronchi - supported by crescent shaped cartilage plates
  - 10 on right, and 8 on left
  - bronchopulmonary segment –functionally independent unit of the lung tissue

Bronchial Tree

(Main Bronchi / Lobar Bronchi / Segmental Bronchi)

- All distal segments of the bronchial tree down to the “ bronchioles” are lined with a mucous secreting mucosa lined with ciliated pseudostratified columnar epithelial cells
  - lamina propria = connective tissue /// has an abundance of mucous glands and lymphocyte nodules
  - bronchus-associated lymphoid tissue = BALT /// immediately deep to epithelium
  - all divisions of bronchial tree have a large amount of elastic connective tissue /// contributes to the recoil that expels air from lungs
  - the mucosa also has a well-developed layer of smooth muscle /// muscularis mucosae which contracts or relaxes to constrict or dilate the airway, regulating air flow

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

- **Bronchioles**
  - **lack cartilage // thick smooth muscle walls prevent bronchioles from collapsing from negative pressure // only 1mm diameter**
  - **pulmonary lobule** - portion of lung ventilated by one bronchiole
  - Bronchioles have ciliated cuboidal epithelium and mucous glands
  - Terminal bronchioles have cilia but no mucus glands
  - Respiratory bronchioles do not have cilia and no mucous glands
  - Why does this make sense?

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

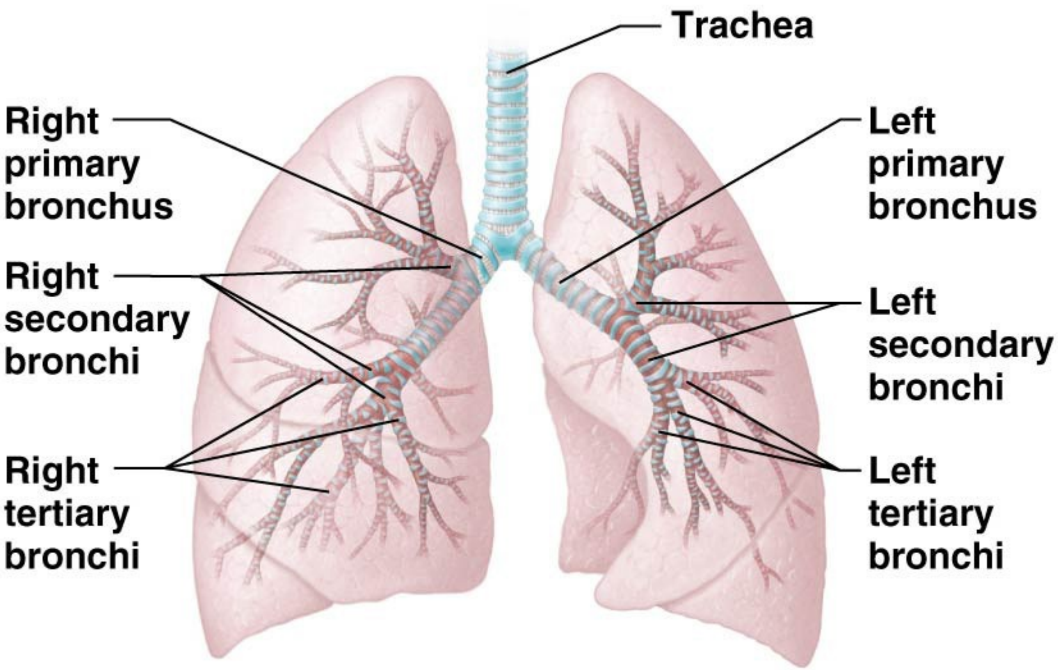
- **Terminal bronchioles**
  - divides into 50 - 80 branches
  - final branches of conducting division
  - measure 0.5 mm or less in diameter
  - **no mucous glands** or goblet cells
  - **but still have cilia** // move mucus draining into them from bronchioles towards larynx by mucociliary escalator (last segment with cilia)
  - each terminal bronchiole gives off two or more smaller respiratory bronchioles

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

- **Respiratory bronchioles**
  - **no cilia and no mucous glands**
  - have alveoli budding from their walls
  - considered the **beginning of the respiratory division** since alveoli participate in gas exchange
  - divide into 2-10 **alveolar ducts**
  - end in **alveolar sacs** – grape-like clusters of alveoli arrayed around a central space called the **atrium**

Branching pattern of the bronchial tree.

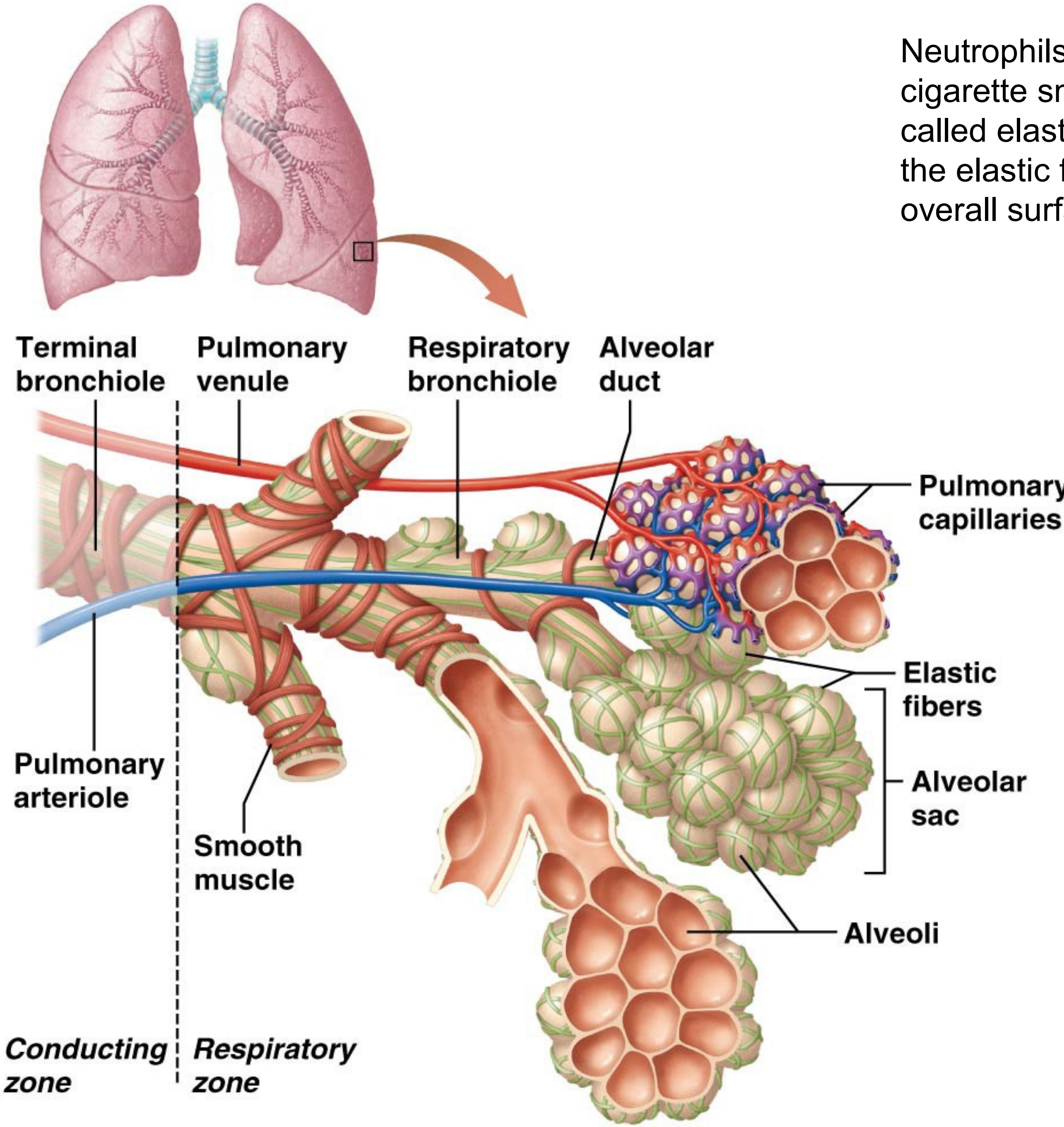


(a) Conducting zone passages and bronchial tree

(b) Cast of bronchial tree

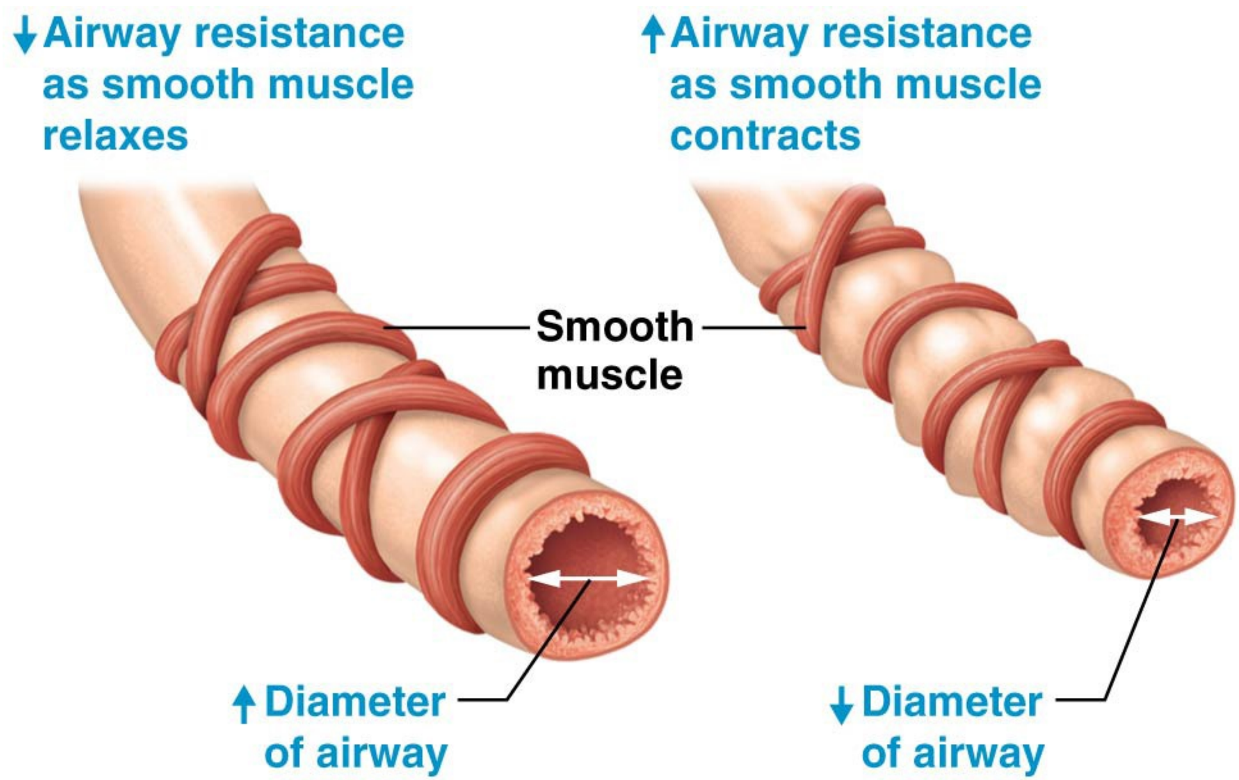
Main Brochi = Primary Bronchi // Secondary = Lobar // Tertiary = Segmental

Neutrophils move into the are due to cigarette smoke and release an enzyme called elastase. The enzyme degrades the elastic fibers. This reduces both overall surface, gas exchange.



(a) Structures of the respiratory zone

Relationship between airway resistance and airway diameter.



Histamine constricts bronchioles /// Epinephrine dilates bronchioles

What occurs when histamine is in the systemic tissues?

Three Cell Types of the Alveoli (1 of 3)

- 150 million alveoli in each lung
- Providing about 70 m^2 of surface for gas exchange
- Three cell type in the alveolus (type I / type II / dust cells)
- Squamous alveolar cells (type I)
    - thin, broad cells that allow for rapid gas diffusion between alveolus and bloodstream
    - cover 95% of alveolus surface area

Three Cell Types of the Alveoli (2 of 3)

Great alveolar cells (type II)

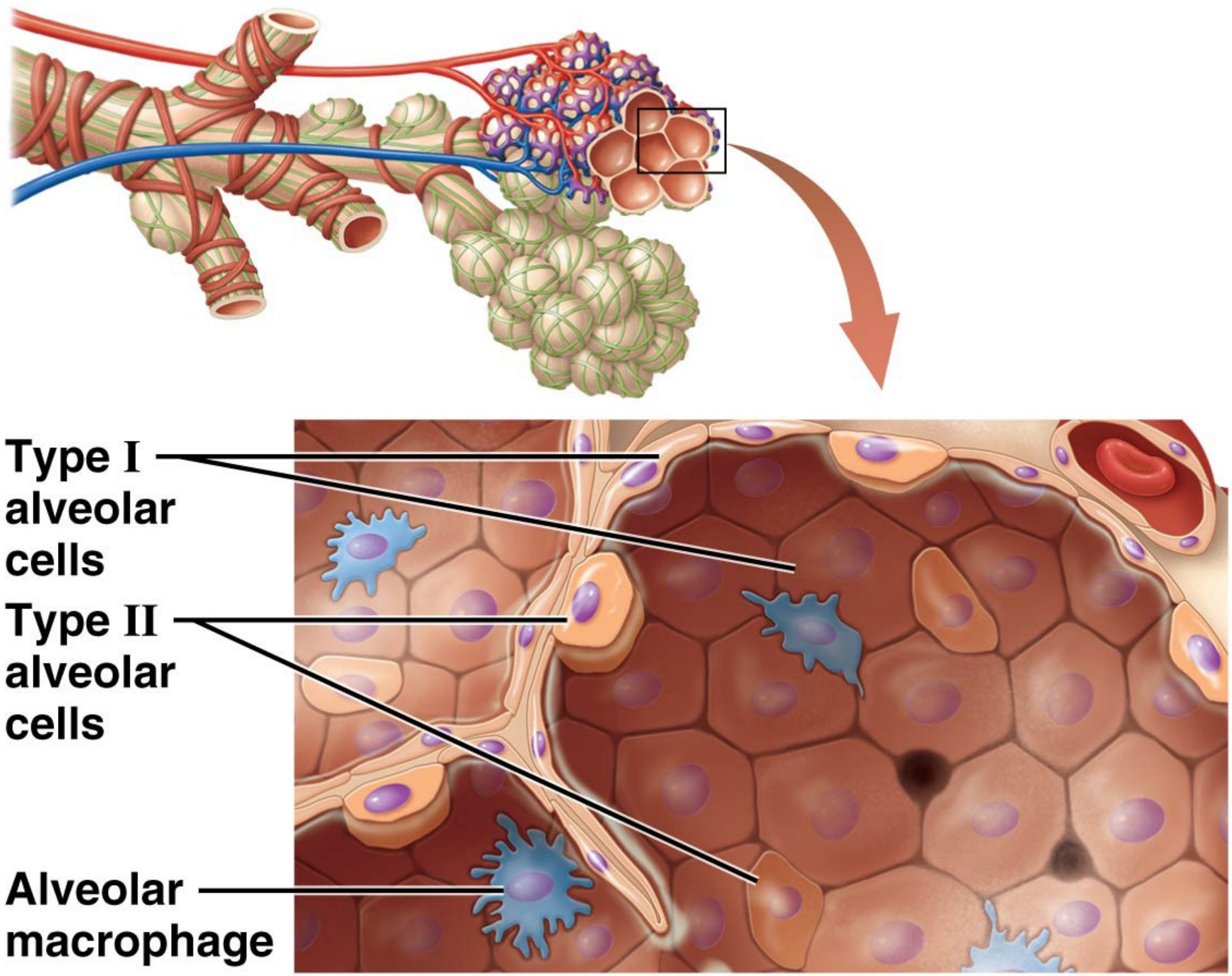
- round to cuboidal cells that cover the remaining 5% of alveolar surface
- repair the alveolar epithelium when the squamous (type I) cells are damaged
- secrete pulmonary surfactant
  - a mixture of phospholipids and proteins that coats the alveoli and prevents them from collapsing when we exhale

Three Cells of the Alveoli (3 of 3)

- Alveolar macrophages (dust cells)
  - most numerous of all cells in the lung
  - wander the lumen and the connective tissue between alveoli
  - keep alveoli free from debris by phagocytizing dust particles
  - 100 million dust cells perish each day as they ride up the mucociliary escalator to be swallowed and digested with their load of debris

Three Alveolar Cell Types

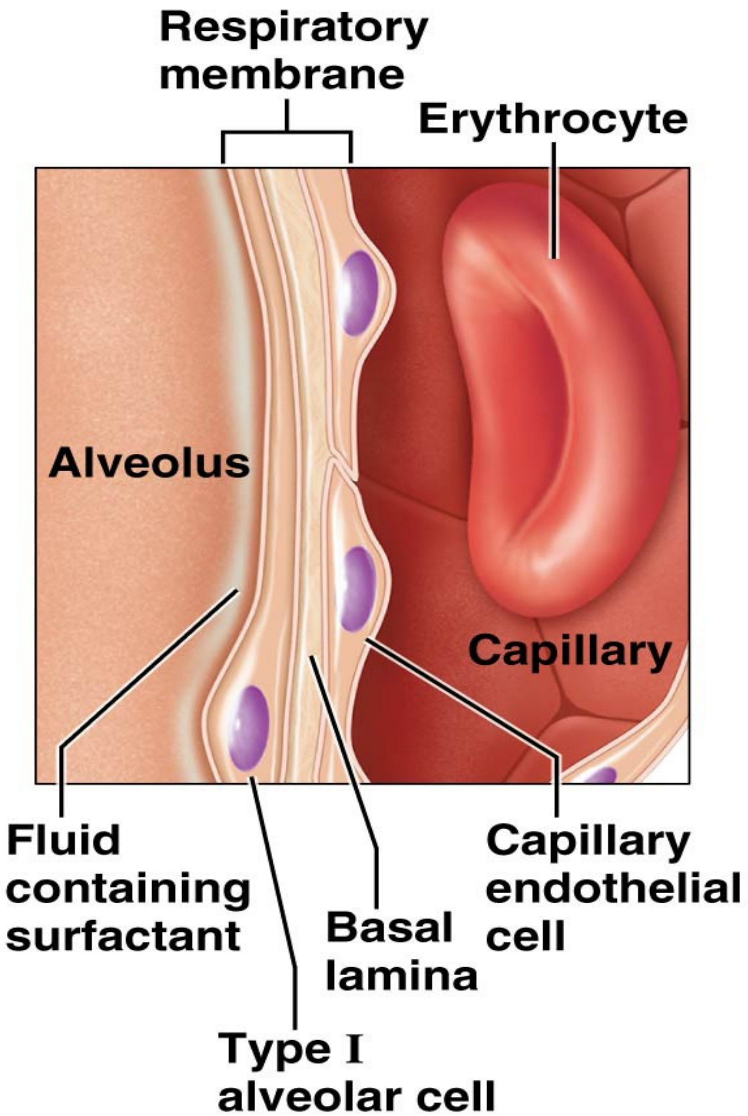
Know the function of each cell type.



Respiratory Membrane

- each alveolus surrounded by a basket like capillary bed // network supplied with blood from pulmonary artery
- respiratory membrane – the barrier between the air inside the alveoli and and the blood inside the pulmonary capillary
- respiratory membrane consists of
  - squamous alveolar cells
  - shared basement membrane
  - endothelial cells of blood capillary
- The shared basement membrane under certain conditions may swell due to edema.
- Anything that increases distance across the respiratory membrane makes the diffusion on gasses slower
- Anything that reduces the overall surface area of the respiratory membrane makes the diffusion of gasses slower

Structures of the respiratory membrane.



(b) Respiratory membrane

How Does a Layer of Water on the Inner Surface of Alveoli Influences Inspiration and Experation?

Pulmonary surfactant produced by the great alveolar cells

decreases surface tension by disrupting the hydrogen bonding in water

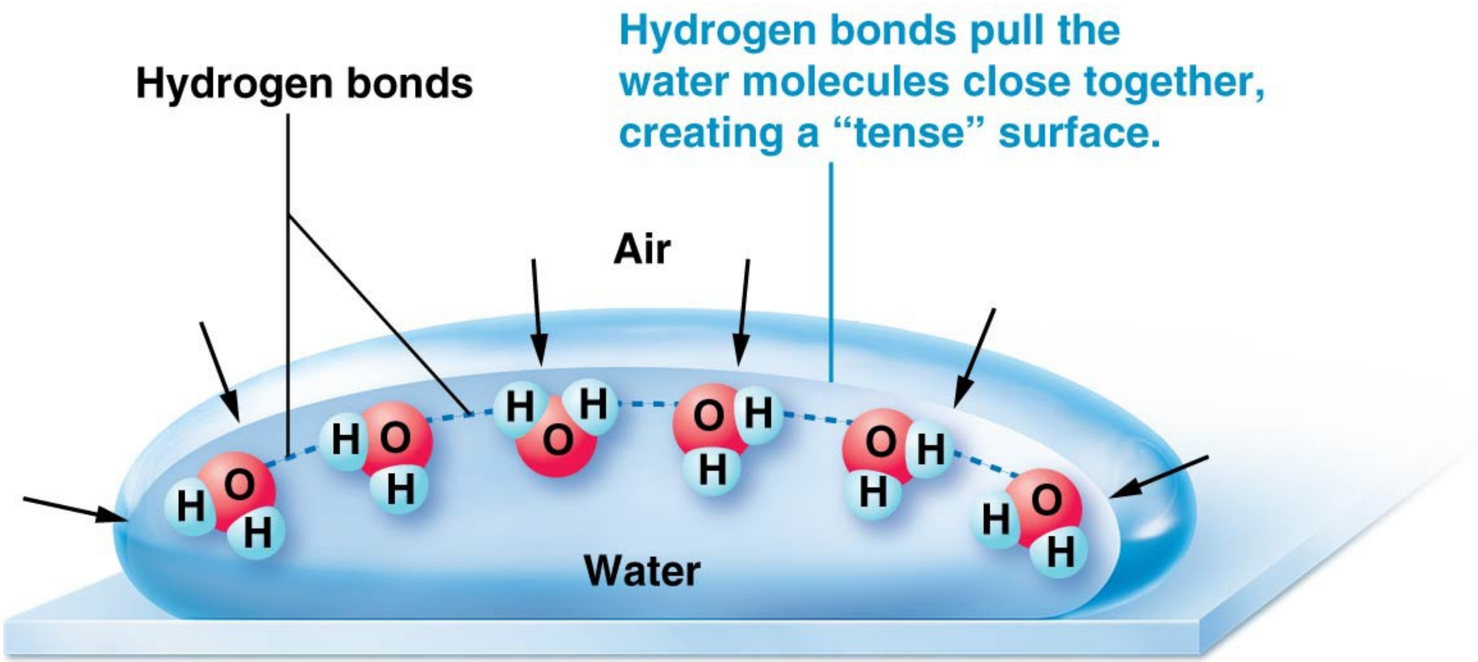
As lungs collapse, thickness of water on inner face of alveoli thickens /// more layers of water molecules stack on top of each other to form 3D lattice of water molecules interconnected by Hydrogen Bonds. /// Surfactant disrupts Hydrogen Bonds so it is easier to inflate lungs!!!

Premature infants that lack surfactant suffer from infant respiratory distress syndrome (IRDS)

great difficulty in breathing

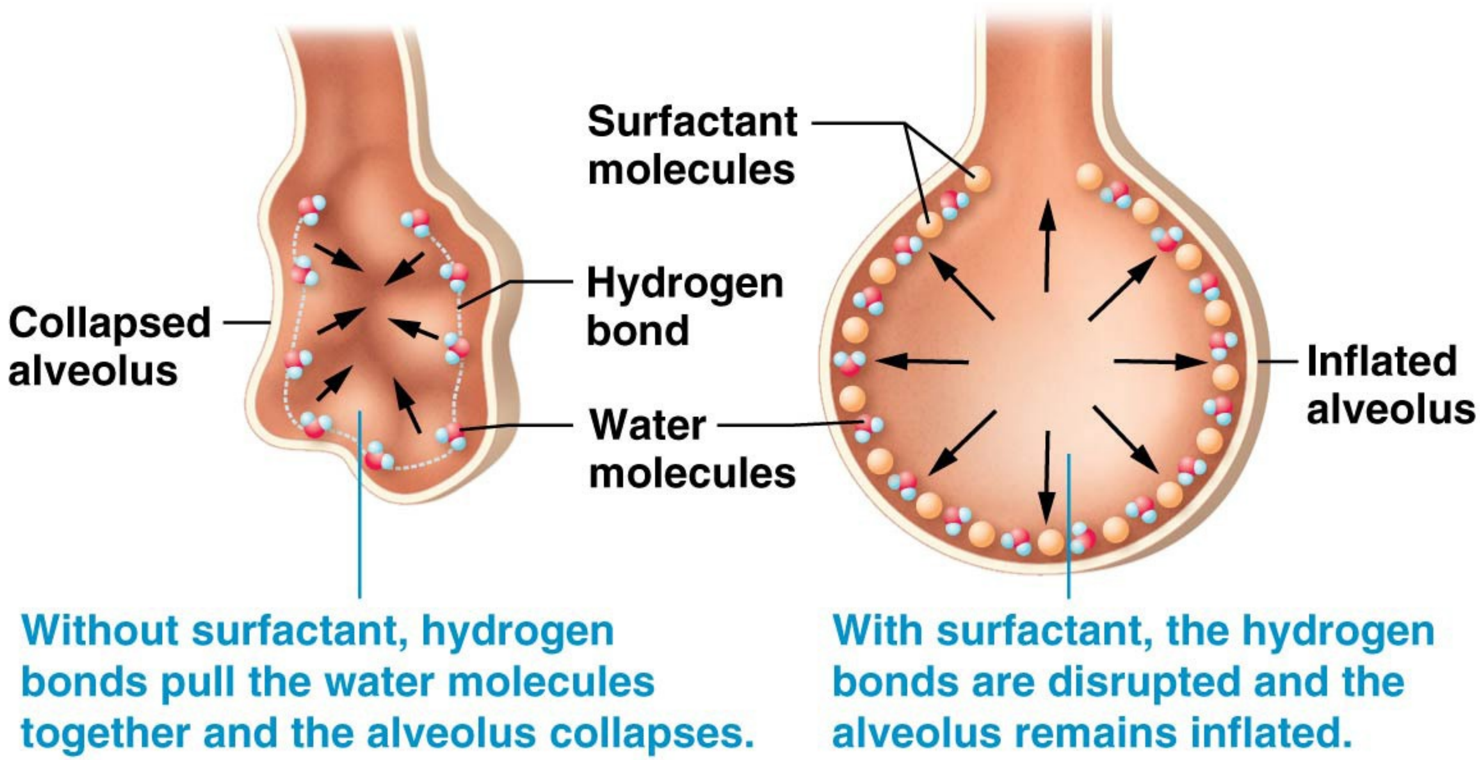
treated with artificial surfactant until lungs can produce own

Water is a polar covalent molecule.



It takes energy to separate water molecules

Effect of surfactant on alveolar surface tension.



(a) Without surfactant **(b) With surfactant**

Without surfactant it will take more energy to inflate alveoli.

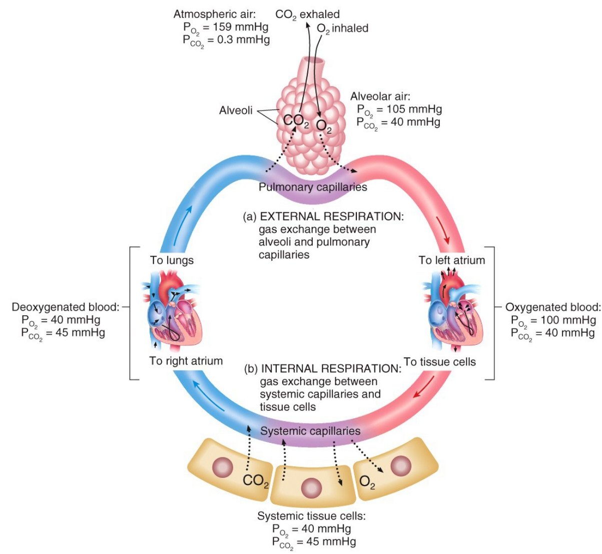
TABLE 22.4 Composition of Inspired (Atmospheric) and Alveolar Air

Gas	Inspired Air*		Alveolar Air	
N_2	78.6%	597 mm Hg	74.9%	569 mm Hg
O_2	20.9%	159 mm Hg	13.7%	104 mm Hg
H_2O	0.5%	3.7 mm Hg	6.2%	47 mm Hg
CO_2	0.04%	0.3 mm Hg	5.3%	40 mm Hg
Total	100%	760 mm Hg	100%	760 mm Hg

*Typical values for a cool clear day; values vary with temperature and humidity. Other gases present in small amounts are disregarded.

We are most concerned with oxygen and carbon dioxide.

How does the concentration of O2 and CO2 change between the atmosphere and systemic tissues?

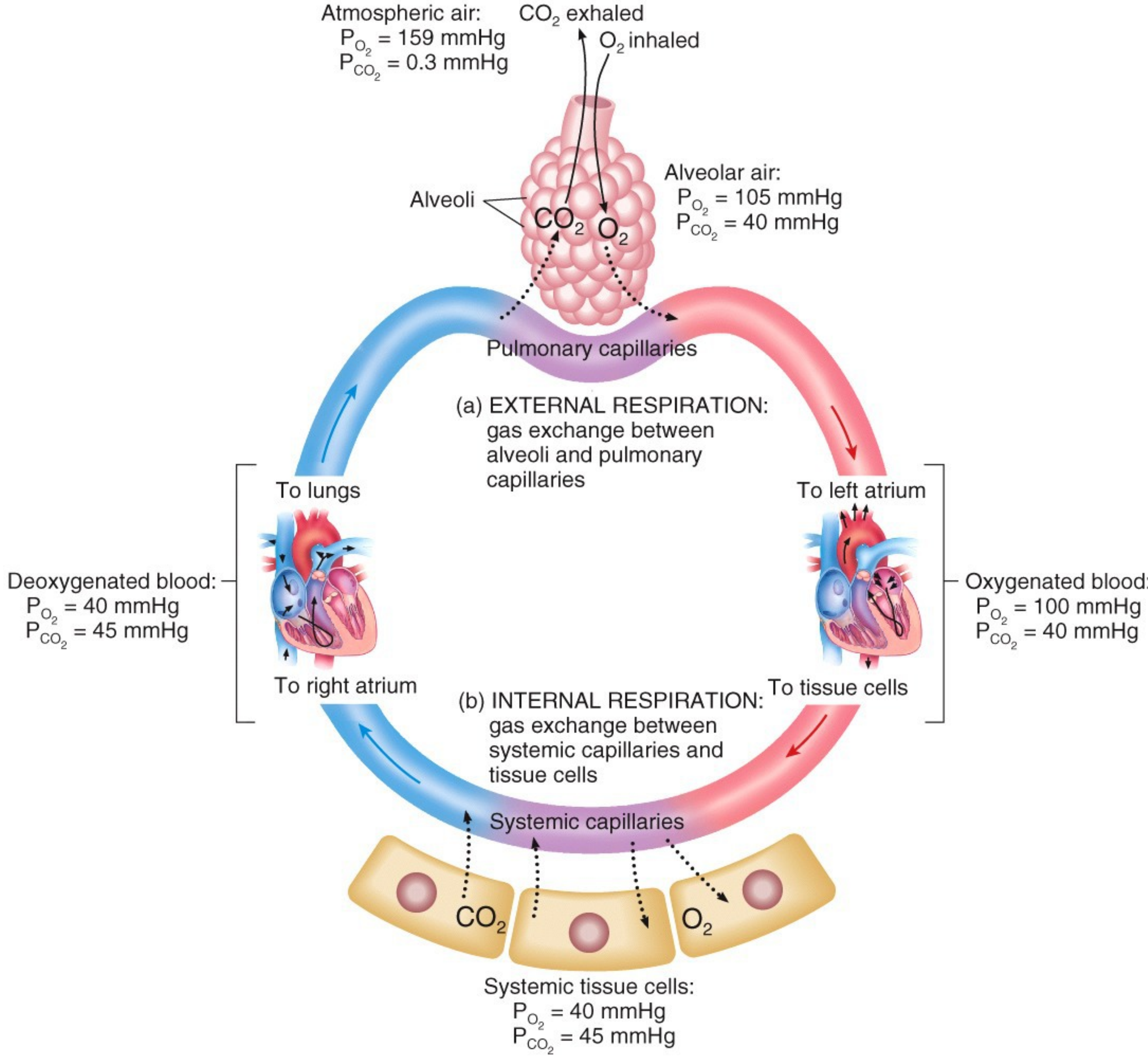


Oxygen

159 mmHg - atmosphere
105 mmHg - alveolar
100 mmHg - blood arterial
040 mm Hg - systemic tissue
040 mmHg - blood venous

Carbon Dioxide

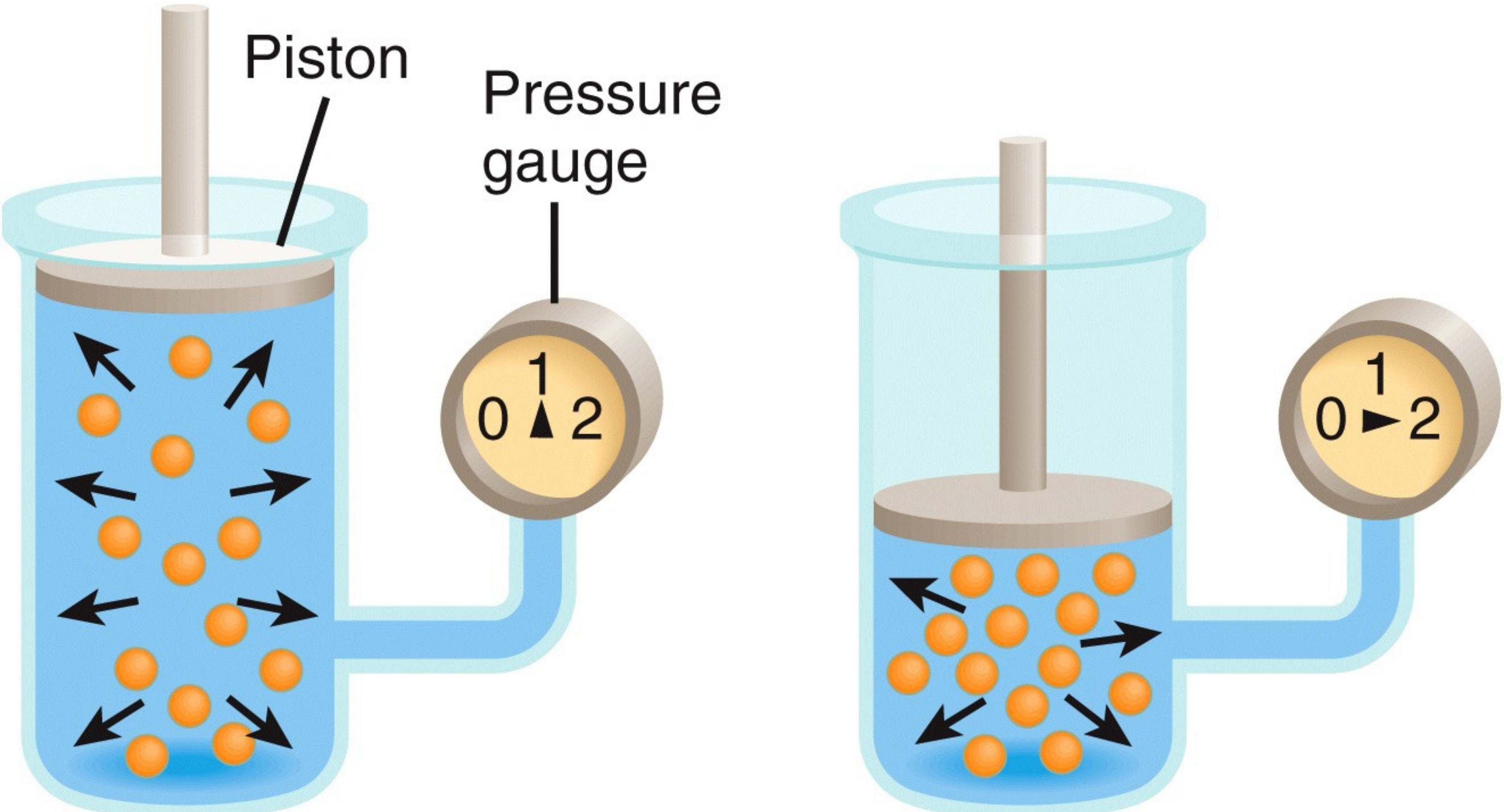
.3 mmHg - atmosphere
40 mmHg - alveolar
40 mmHg - blood arterial
45 mmHg - systemic tissue
45 mmHg - blood venous


Atmospheric air:
P_{O_2} = 159 mmHg
P_{CO_2} = 0.3 mmHg
CO_2 exhaled
O_2 inhaled
Alveoli
CO_2
O_2
Alveolar air:
P_{O_2} = 105 mmHg
P_{CO_2} = 40 mmHg
Pulmonary capillaries
(a) EXTERNAL RESPIRATION:
gas exchange between
alveoli and pulmonary
capillaries
To lungs
To left atrium
Deoxygenated blood:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg
Oxygenated blood:
P_{O_2} = 100 mmHg
P_{CO_2} = 40 mmHg
To right atrium
To tissue cells
(b) INTERNAL RESPIRATION:
gas exchange between
systemic capillaries and
tissue cells
Systemic capillaries
CO_2
O_2
Systemic tissue cells:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg

Pressure Gradients Determine Airflow

- Respiratory airflow is governed by the same principles that regulates the flow of blood: pressure and resistance
  - the flow of a fluid is directly proportional to the pressure difference between two points
  - the flow of a fluid is inversely proportional to the resistance
  - so if we want to ventilate the lungs (move air in and out) then we need to be able to create a transient pressure gradient between the atmosphere and the lung tissue
  - change pressures in pleural cavity to create inspiration (less than atmospheric pressure) or expiration (greater than atmospheric pressure)

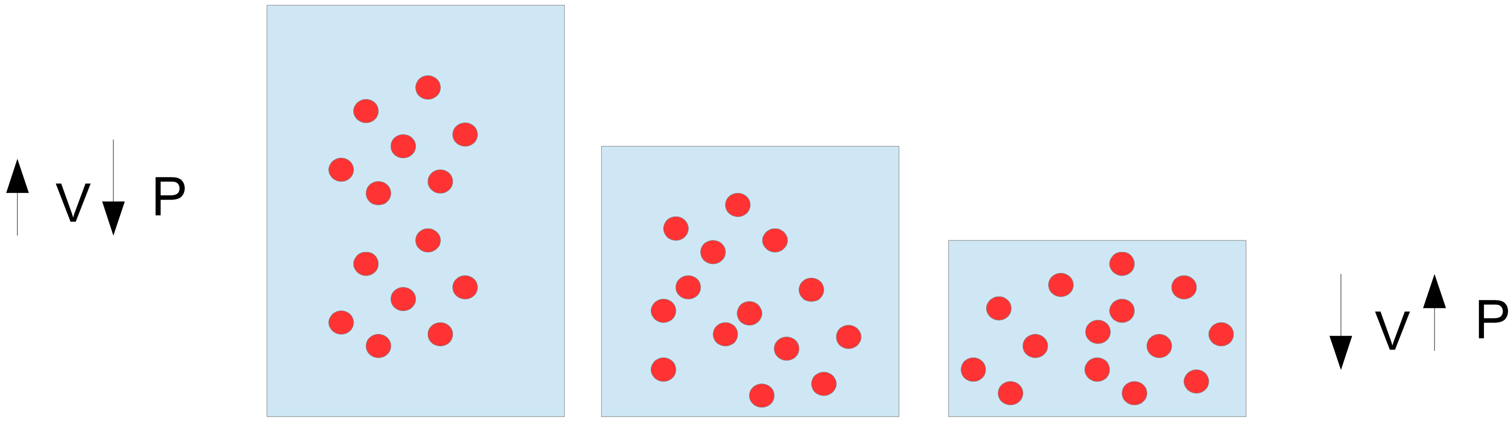
Boyle's Law



Volume = 1 liter
Pressure = 1 atm

Volume = 1/2 liter
Pressure = 2 atm

Boyle's Law



Assume constant temperature

Same number of gas atoms in each container

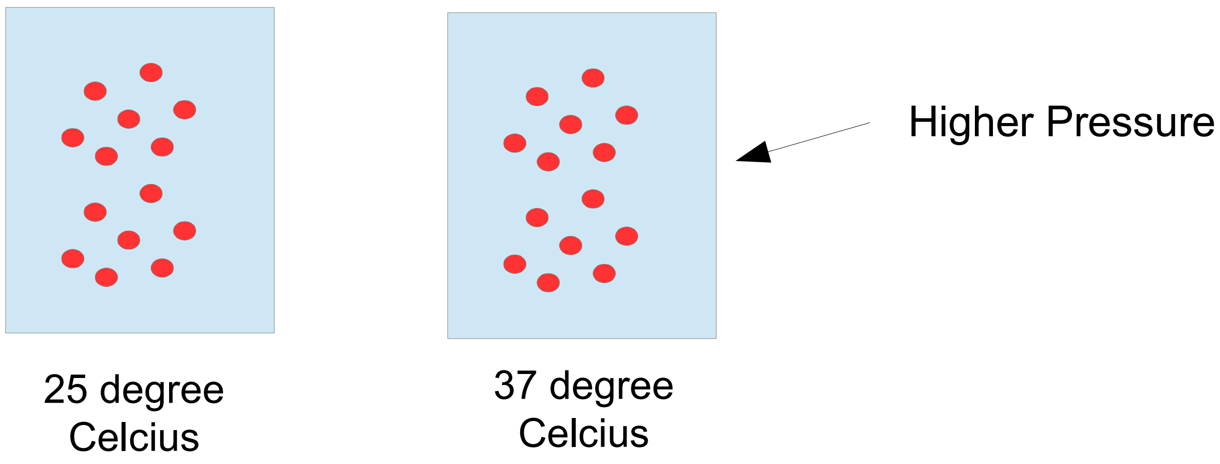
Fewer collisions in larger container (lower pressure)

More collisions in smaller container (higher pressure)

Pressure is inversely proportional to volume.

How does this help respiration? Significance?

Charles' Law



Here the volume is constant but the temperature increases.

Since gas molecules move faster at a higher temperature, there are more gas molecule collisions against the sides of the container which results in an increase in pressure.

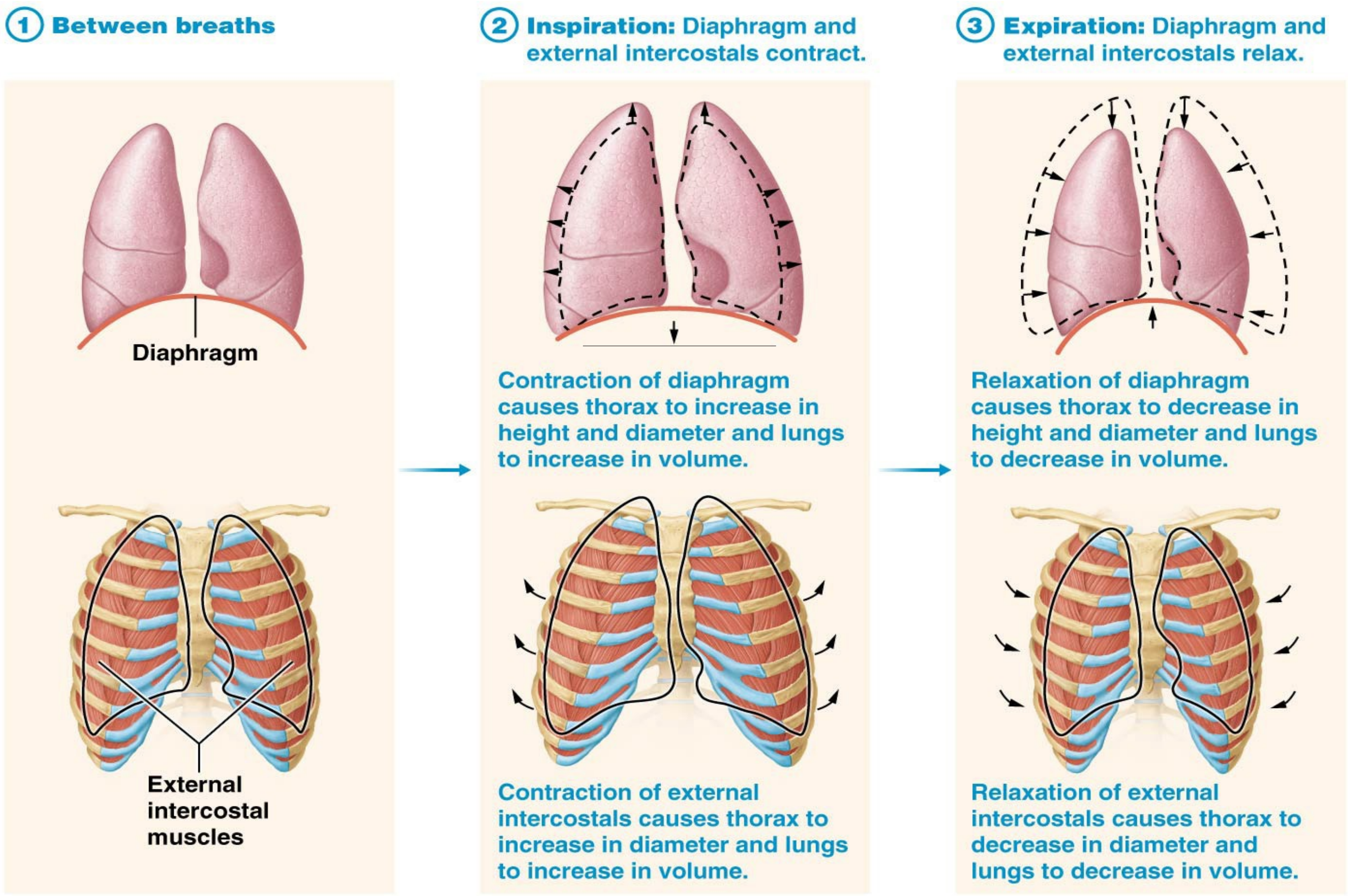
We did not increase the number of molecules, just the number of collisions.

When we breath in air, it is warmed by the mucosa.

How does this help respiration? Significance?

Note: Dalton's Law of Gases and Henry's Law also help to explain respiratory physiology (see reference video for more details)

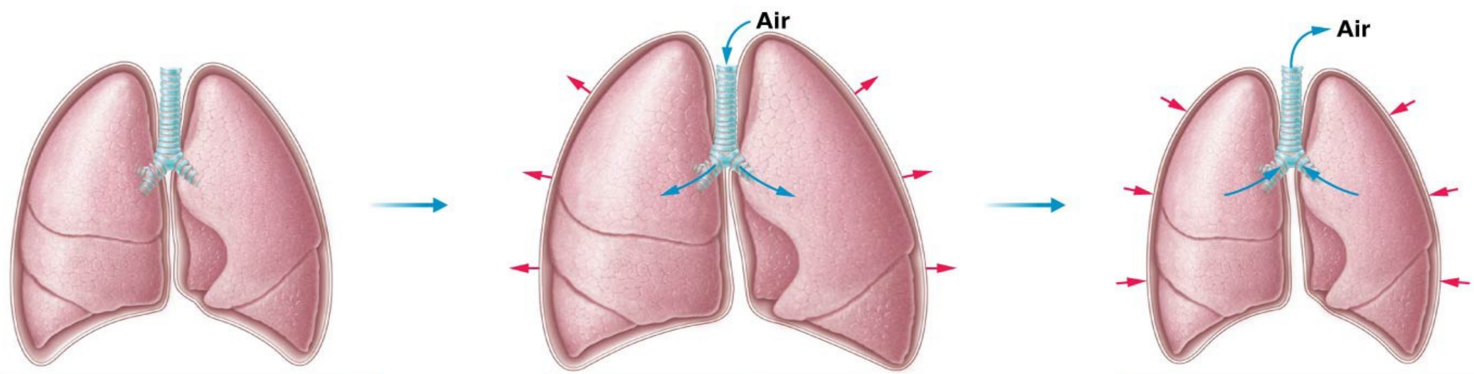
Volume changes in pulmonary ventilation: structure and function of the inspiratory muscles in quiet breathing.



In “quiet breathing” inspiration is active and expiration is passive. Inspiration requires contraction of diaphram and expiration occurs because of the recoil of elastic tissue expanded during inspiration.

Pressure changes in pulmonary ventilation during respiratory cycle.

1. **Between breaths:** Intrapulmonary pressure equals atmospheric pressure.
2. **Inspiration:** Lung volume increases, intrapulmonary pressure decreases, and air rushes into the lungs.
3. **Expiration:** Intrapulmonary pressure increases, lung volume decreases, and air moves out of the lungs.



LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	760
Intrapleural (pleural cavity)	756

LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	↓ 758
Intrapleural (pleural cavity)	↓ 754

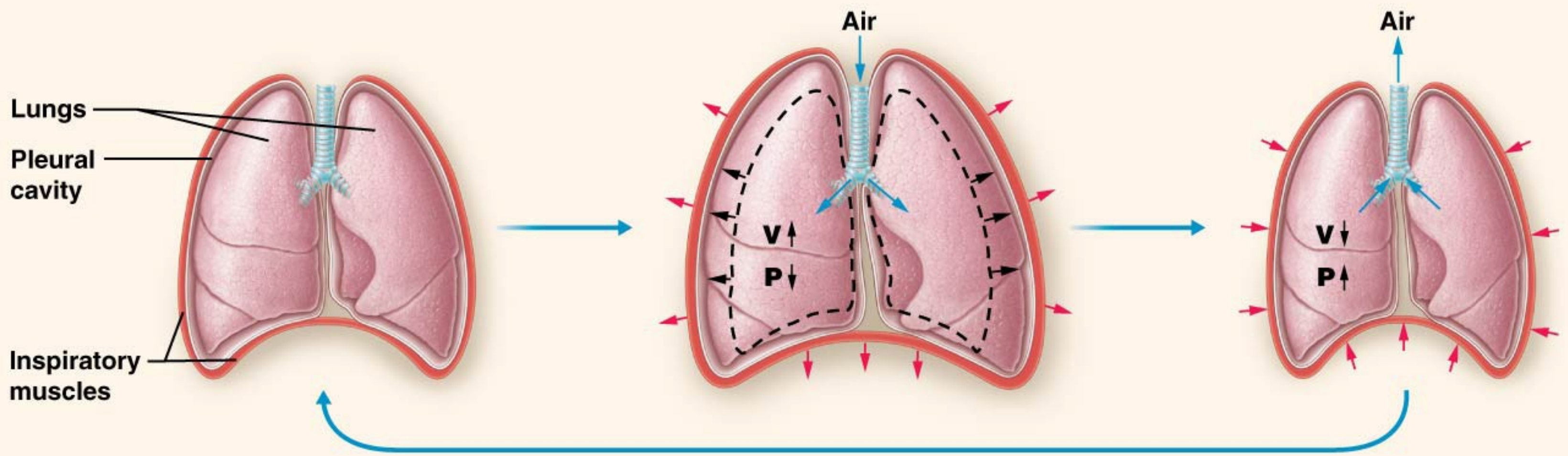
LOCATION	PRESSURE (mm Hg)
Atmospheric (air)	760
Intrapulmonary (alveoli)	↑ 762
Intrapleural (pleural cavity)	↑ 758

Respiratory cycle is five seconds long.

Inspiration occurs for two seconds as diaphragm contracts (active / volume).

Expiration occurs for three seconds as diaphragm relaxes by elastic recoil.

The Big Picture of Pulmonary Ventilation



Between breaths

Intrapulmonary pressure equals atmospheric pressure.

↓

No air movement occurs.

Inspiration

Inspiratory muscles contract.

↓

Thoracic volume increases.

↓

Lung volume increases.

↓

Intrapulmonary pressure decreases to below atmospheric pressure.

↓

Air flows into lungs.

Expiration

Inspiratory muscles relax.

↓

Thoracic volume decreases due to elastic recoil. (Passive)

↓

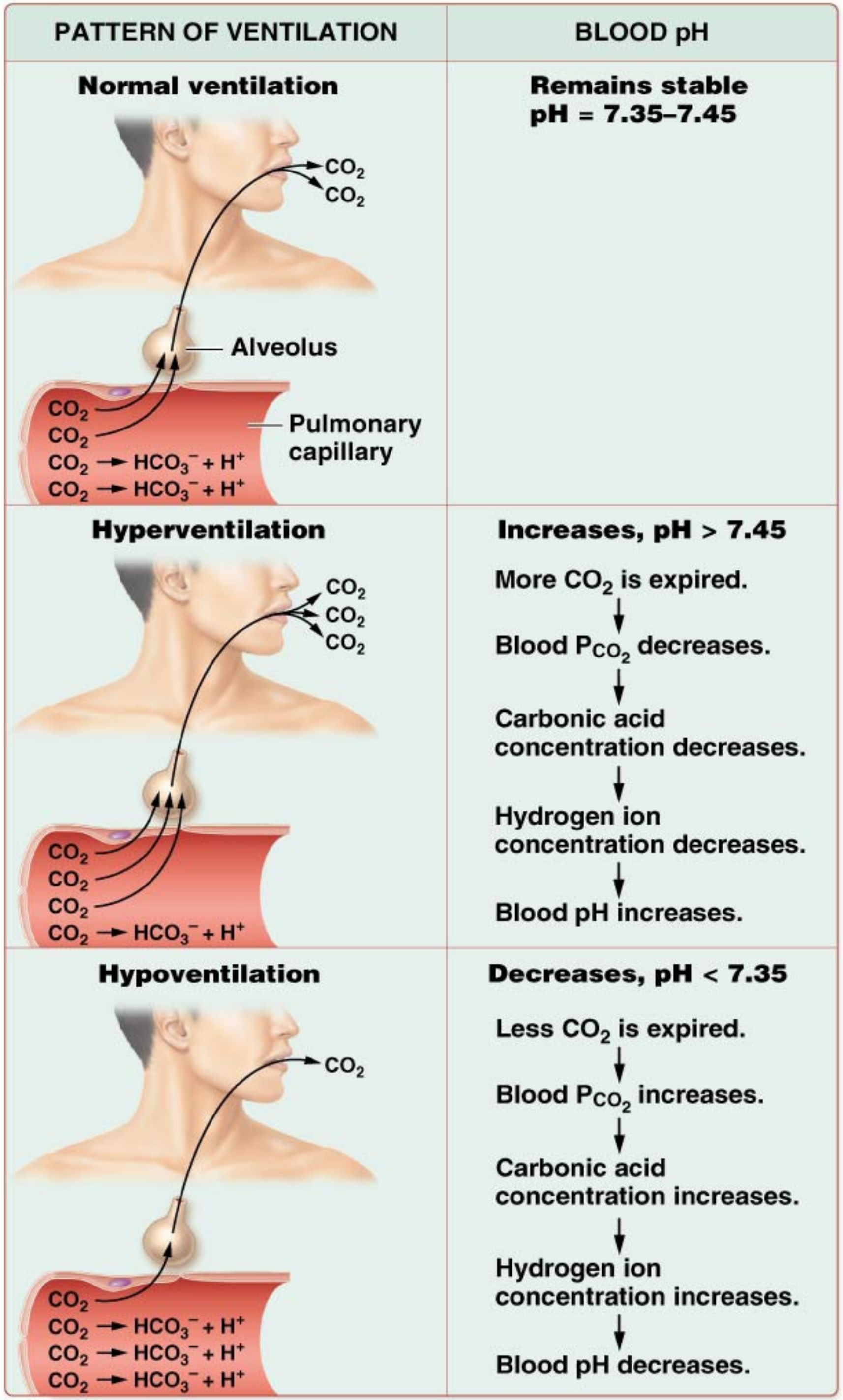
Lung volume decreases.

↓

Intrapulmonary pressure increases to above atmospheric pressure.

↓

Air flows out of lungs.



Effect of blood pH on ventilation patterns

$$\mathrm{CO2 + H2O} \rightleftharpoons \mathrm{CH2O3} \rightleftharpoons \mathrm{H^{+} + CHO3^{-}}$$

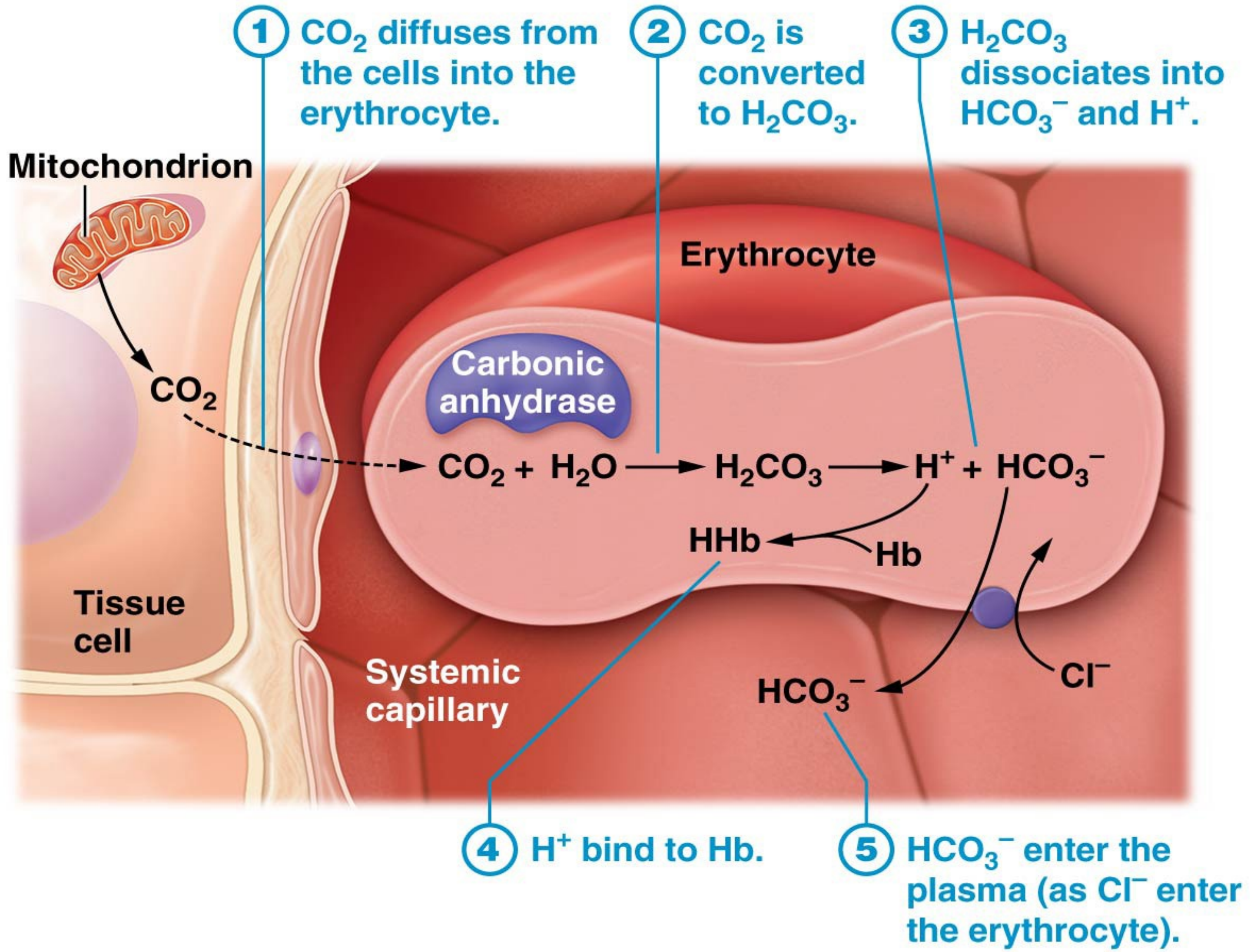
Carbon dioxide plus water makes carbonic acid that then changes into proton plus bicarbonate

Carbonic acid is an acid because it is able to donate a proton

Bicarbonate is a weak base and the proton is an acid

This chemical reaction occurs inside RBC and is catalyzed by carbonic anhydrase (CA)

Transport of carbon dioxide: the conversion of carbon dioxide and water into carbonic acid in erythrocytes.

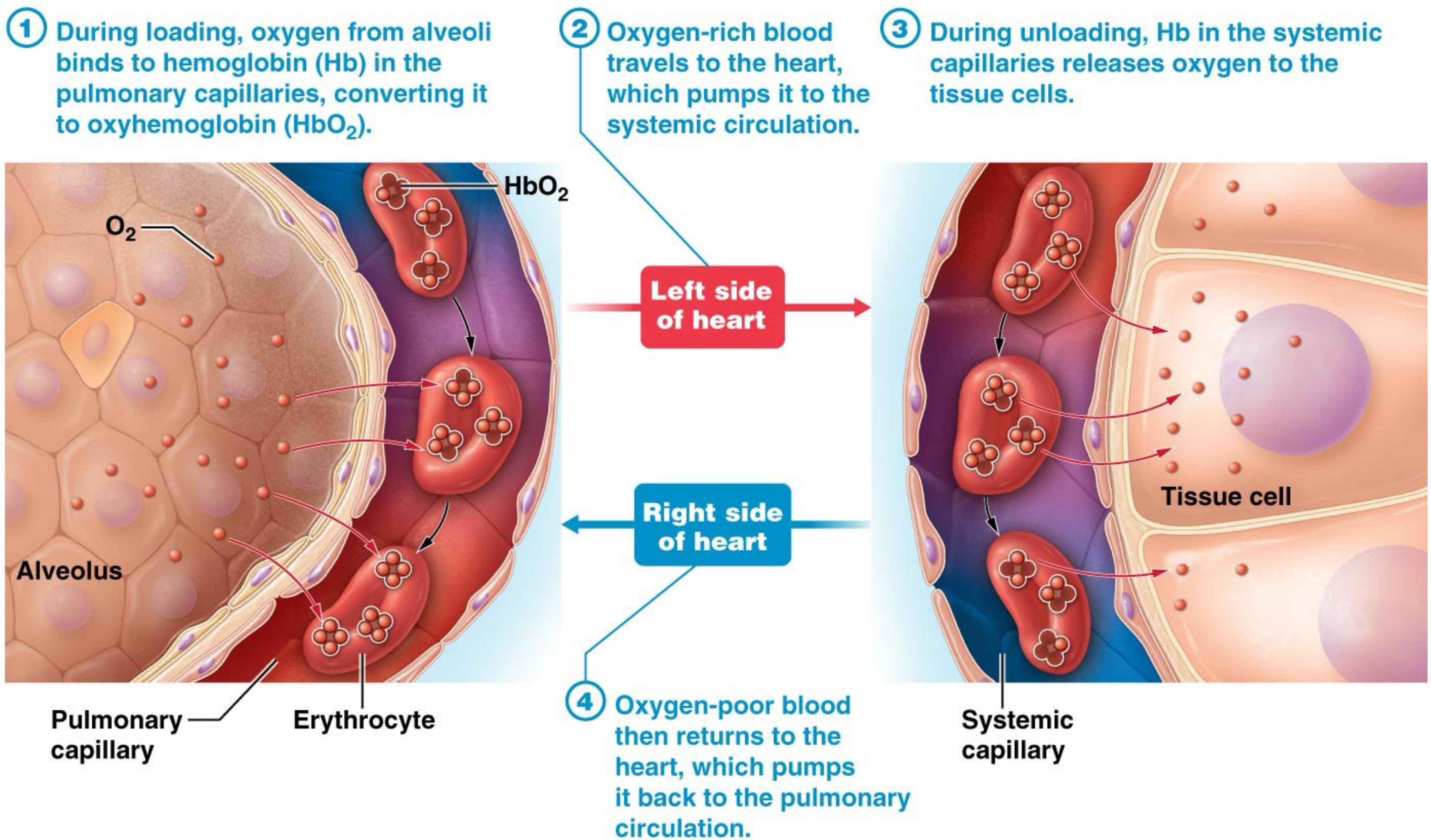


(a) Bicarbonate formation in an erythrocyte in a systemic capillary

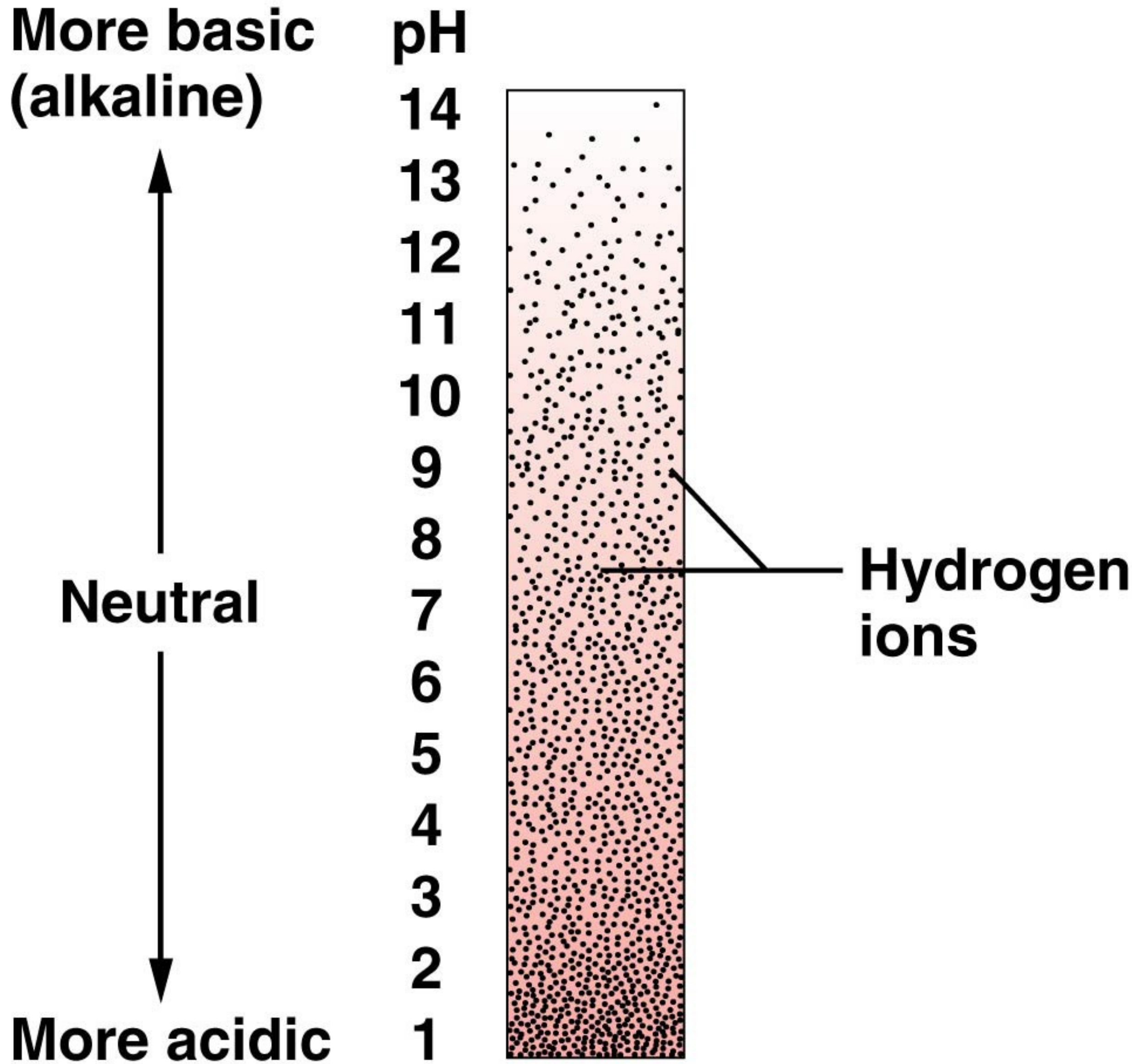
Bicarbonate forms ionic bond with sodium and is transported to lungs as sodium-bicarbonate

Hydrogen ion binds to Hb-O2 and causes oxygen to be released from Hb // oxygen now free to diffuse to mitochondria

Transport of oxygen: loading and unloading of oxygen on hemoglobin in erythrocytes.



pH


More basic
(alkaline)
pH
14
13
12
11
10
9
8
Neutral
7
6
5
4
3
2
More acidic
1
Hydrogen
ions

Primary Control of Ventilation

- The primary control for breathing (ventilation of lungs) are chemoreceptors that respond to carbon dioxide levels in the blood
  - Central chemoreceptors // Located in the medulla
  - Peripheral chemoreceptors // Located in the carotid bodies and aortic arch
  - Both chemoreceptors detect changes in carbon dioxide level & hydrogen ions /// <u>increase CO2 stimulates breathing</u>

Hypercapnia (high PCO2) Main Stimulus for Ventilation

- As carbon dioxide levels in the blood increases // pH lower – blood becomes more acid like.

- Carbon dioxide easily diffuses into cerebral spinal fluid within medula oblongata (respiratory control centers).

  - This lowers pH and stimulates respiratory center

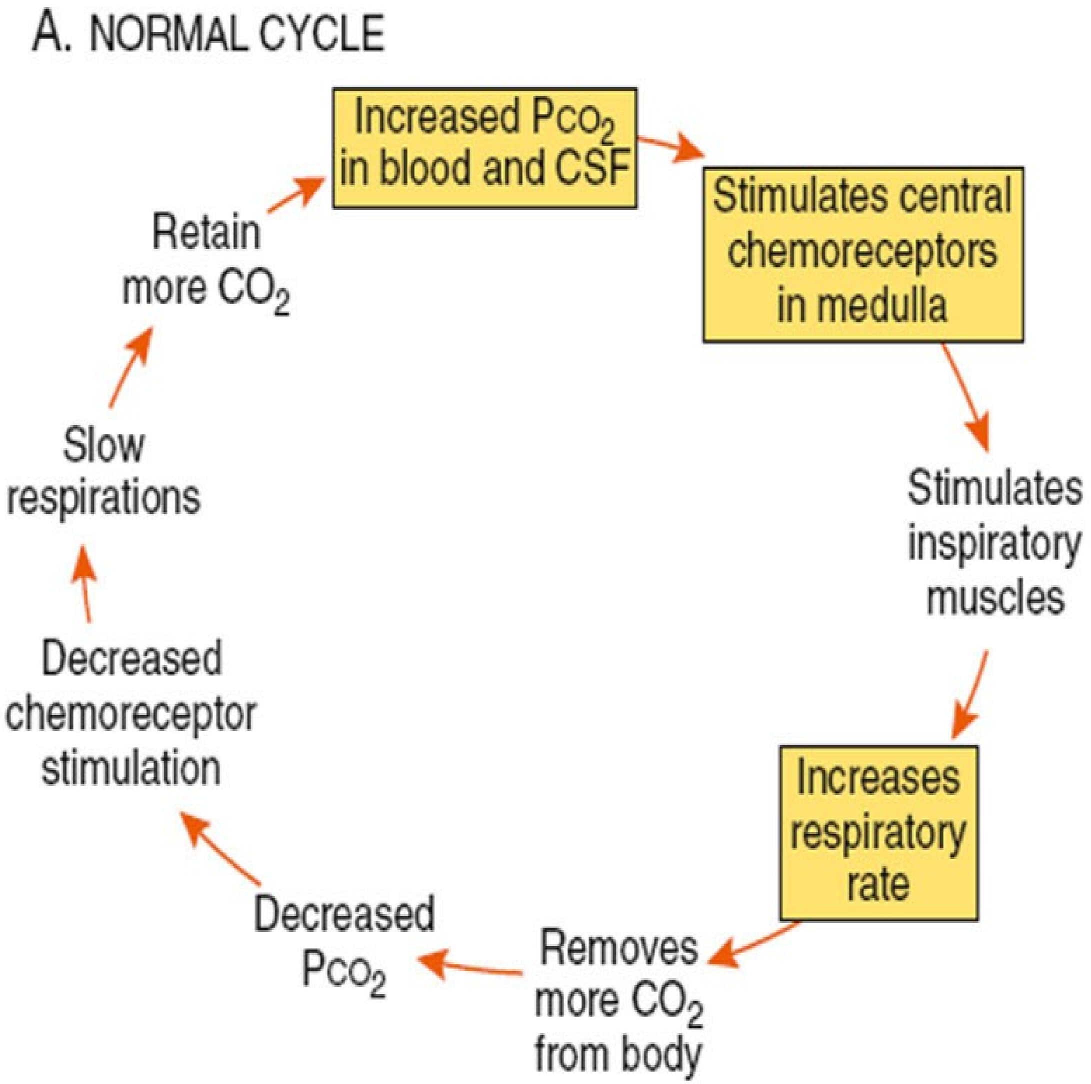
  - Increased rate and depth of respiration

  - Hyperventilation is a condition in which you start to breathe very fast. Healthy breathing occurs with a healthy balance between breathing in oxygen and breathing out carbon dioxide. You upset this balance when you hyperventilate by exhaling more CO_2. This upsets acid-base balance in blood.

  - Hyperventilation causes respiratory alkalosis and this will depress central nervous system.

  - E.g. Swimmers may do this so they can hold breath longer – however, this may cause the swimmer to faint under water. Very dangerous practice!

Normal Respiratory Control



Hydrogen Ions & Pulmonary Ventilation

- Pulmonary ventilation is adjusted to maintain the pH within brain
  - central chemoreceptors in the medulla oblongata produce about 75% of the change in respiration induced by pH shift
  - yet H^+ does not cross the blood-brain barrier very easily
  - CO_2 crosses blood brain barrier rapidly and in CSF reacts with water and produces carbonic acid
    - dissociates into bicarbonate and hydrogen ions /// most H^+ remains free and greatly stimulates the central chemoreceptors
  - hydrogen ions also stimulate peripheral chemoreceptors which produce about 25% of the respiratory response to pH change
  - peripheral chemoreceptors also sensitive to PO2 // play important role in respiration <u>after chronic high PCO2 or very low oxygen concentrations</u>

Primary Control of Ventilation

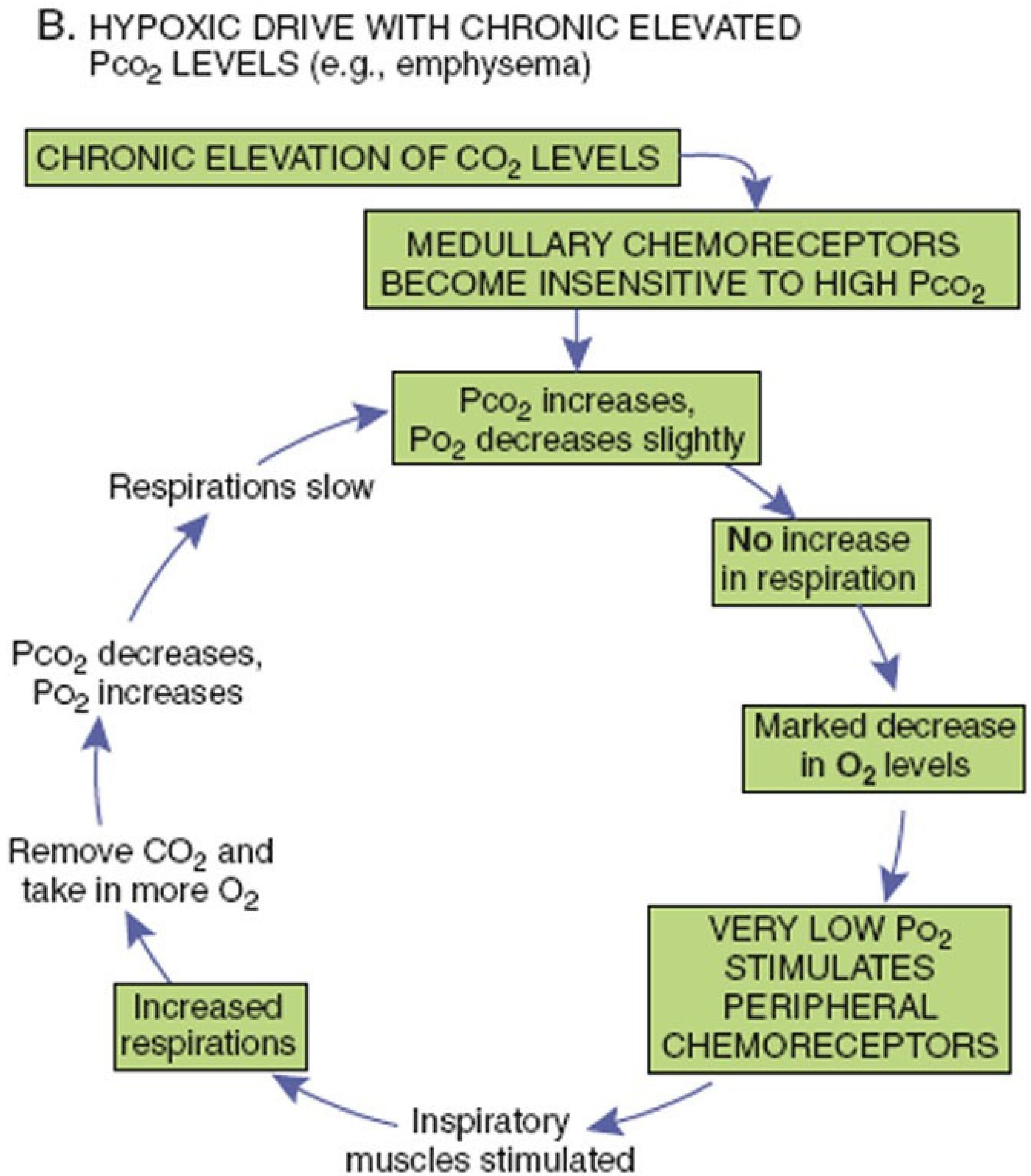
- The peripheral chemoreceptors are stimulated by low oxygen levels (but not the central chemorecptors) // occurs if PO2 falls below normal 100 mmHg and above 50 mmHg // within this range PO2 stimulates breathing rate /// below this range peripheral chemoreceptors do not stimulate inspiration

- Severe PO2 deficiency will depress central chemorecptors // DRG do not respond to any inputs and sends fewer impulses to inhalation muscles // breathing slows – as O2 drops more – **starts positive feedback with fatal results!**

Secondary Control of Ventilation

- Hypoxemia // Marked decrease in oxygen
  - Primary stimulus is under normal physiologic conditions with elevated CO_2 however...........
  - Extended period of high CO_2 will cause chemoreceptors to fatigue and they they will not respond elevated CO_2
  - Peripheral chemoreceptors now may react to low O_2 levels
  - *This is why O_2 becomes most important control mechanism in individuals with chronic lung disease (e.g. emphysema)*
  - This changes respiratory system into hypoxic drive
  - Central control centers no longer responde to CO_2 stimulus, stop working, and now peripheral chemorecptors dominates with PO_2 as "controller"

Hypoxic Drive



Air Flow Into Lung Tissue and Gas Exchange

only air that reaches the alveoli is available for gas exchange

not all inhaled air gets to alveoli

500 mL moved into respiratory system

about 150 mL of tidal volume fills the conducting division of the airway

only 350 mL of air reaches the alveoli

Usable Air Within Lung Tissue

anatomic dead space

- conducting division of airway where there is no gas exchange
- can be altered some slightly by sympathetic and parasympathetic stimulation

pulmonary diseases

- respiratory membrane thickened by edema or fibrosis
- some alveoli may be unable to exchange gases because they lack blood flow (perfusion and ventilation are not matched)
- some diseases reduce amount of respiratory membrane
- These events all add to anatomic dead space to create total dead space

Usable Air Within Lung Tissue

- physiologic dead space (also called total dead space)
  - sum of anatomic dead space and any pathological alveolar dead space caused by disease
- If a person inhales 500 mL of air /// If 150 mL stays in anatomical dead space /// only 350 mL reaches alveoli
- alveolar ventilation rate (AVR)
  - air that ventilates alveoli (350 mL) X respiratory rate (12 bpm) = 4200 mL/min
  - of all the measurements, this one is <u>most directly relevant to the body's ability to get oxygen</u> to the tissues and dispose of carbon dioxide /// disease reduces AVR

Measuring Ventilation Volumes

- spirometer – a device that recaptures expired breath and records such variables such as rate and depth of breathing, speed of expiration, and rate of oxygen consumption (view video)

- respiratory volumes (view video)

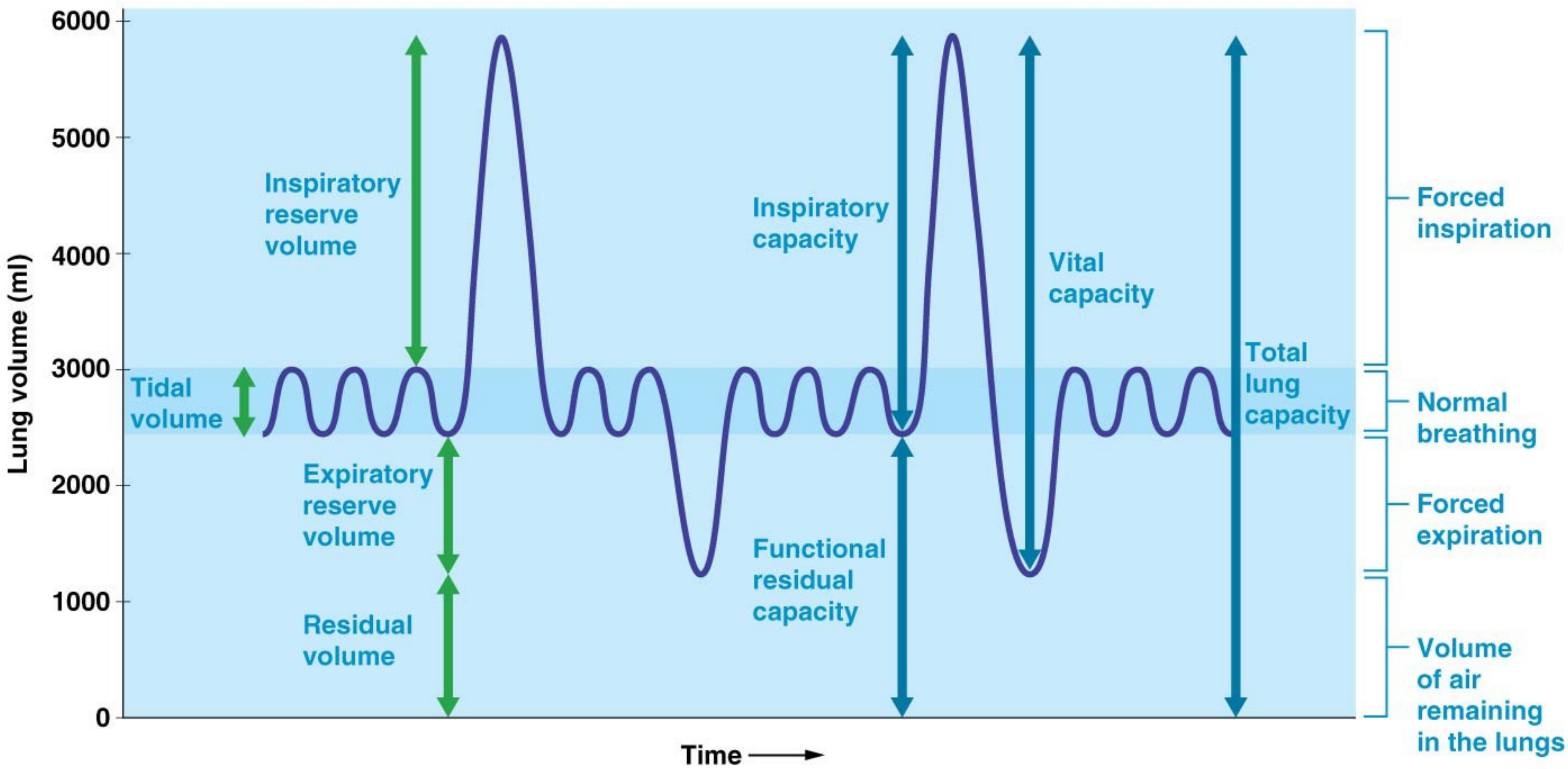
  – tidal volume - volume of air inhaled and exhaled in one cycle during quiet breathing (500 mL)

  – inspiratory reserve volume - air in excess of tidal volume that can be inhaled with maximum effort (3000 mL)

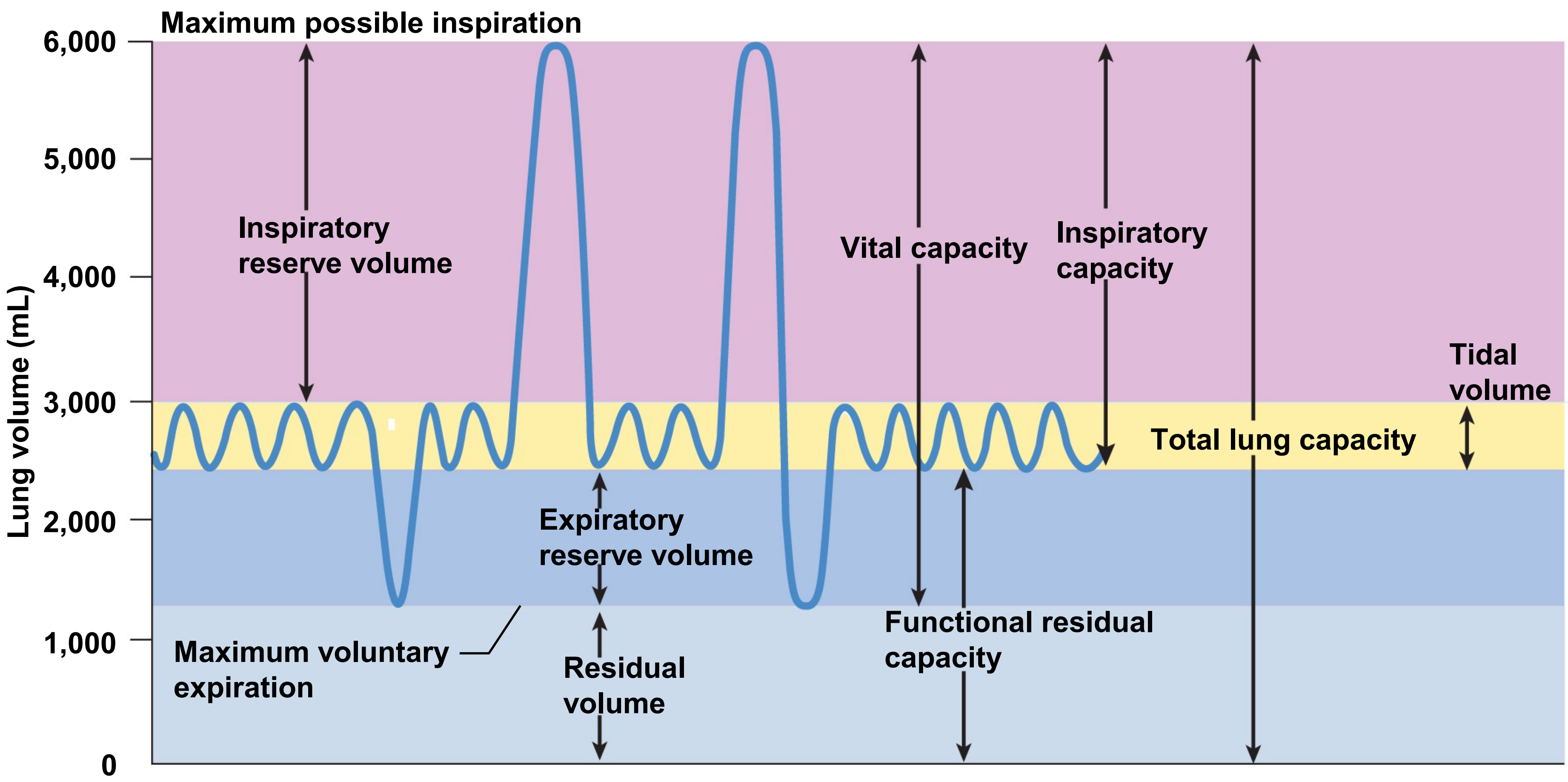
  – expiratory reserve volume - air in excess of tidal volume that can be exhaled with maximum effort (1200 mL)

  – **residual volume** - air remaining in lungs after maximum expiration (1300 mL)

Graph of pulmonary volumes and capacities.



Lung Volumes and Capacities



Factors Affecting Gas Exchange

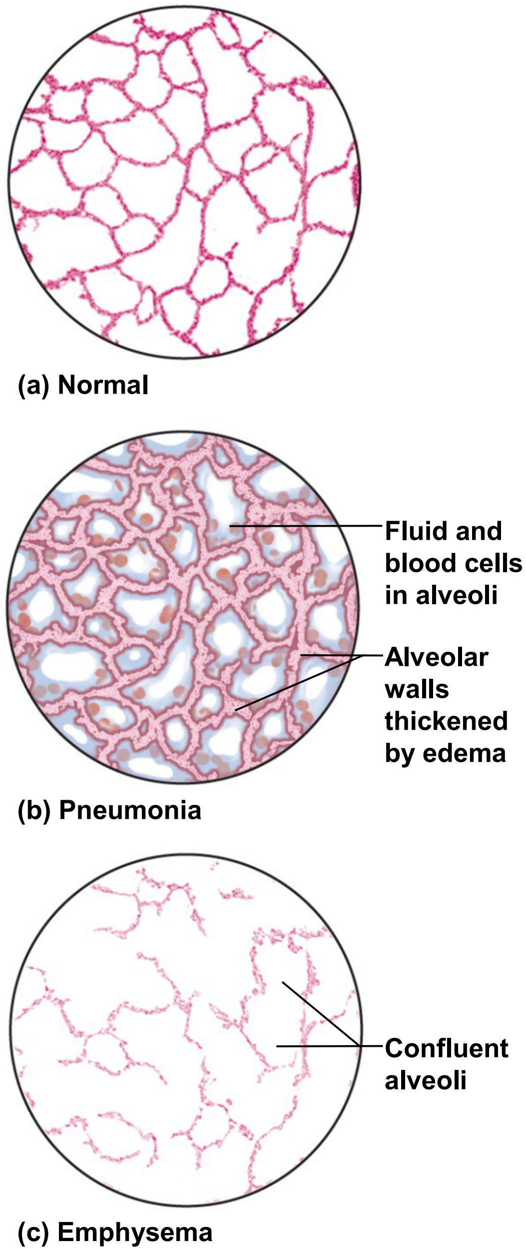
membrane thickness / membrane surface area / ventilation-perfusion coupling

- Respiratory Membrane thickness
  - only 0.5 μm thick
  - presents little obstacle to diffusion
  - pulmonary edema caused by left ventricular failure results in "thickening" of the respiratory membrane
  - pneumonia also causes thickening of respiratory membrane
  - results = greater distance for gases to travel between blood and air
  - cannot equilibrate fast enough to keep up with blood flow

Factors Affecting Gas Exchange

- Membrane surface area
  - 100 ml blood in alveolar capillaries, spread thinly over 70 m^2
  - emphysema, lung cancer, and tuberculosis all decrease surface area for gas exchange
  - these conditions results in hypoxia

Lung Disease Affects Gas Exchange



Abnormally few but large alveoli with total reduction of respiratory membrane.

Autoregulation to Adjust Blood and Air Flows Within Lungs

Ventilation-perfusion coupling

the ability to match ventilation to perfusion (see next two slides)

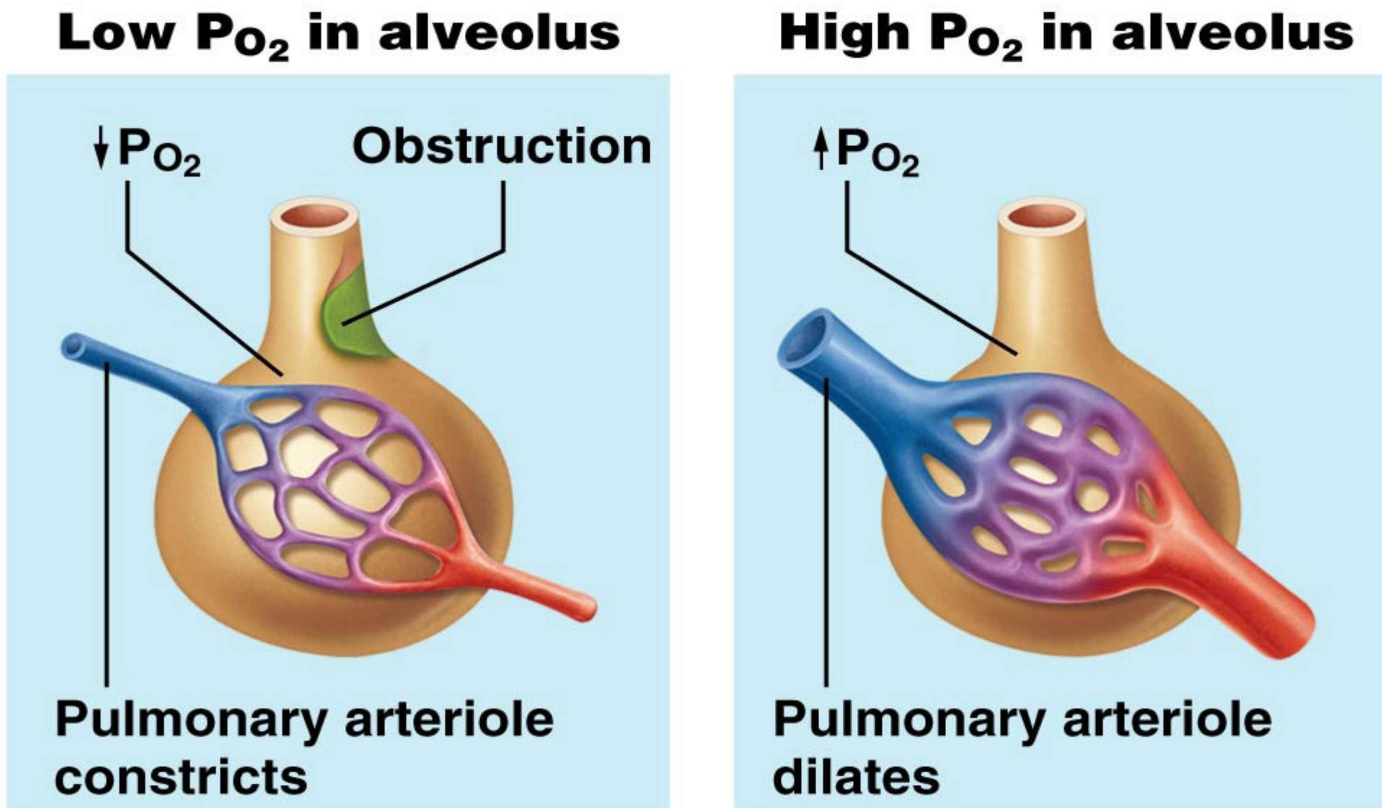
gas exchange requires both good ventilation of alveolus and good perfusion of the capillaries

ventilation-perfusion ratio of 0.8 (a flow of 4.2 L of air and 5.5 L of blood per minute at rest)

- Ventilation is air movement through alveoli /// Perfusion is blood flow through pulmonary capillary
-
- Ventilation and perfusion is matched within the lung tissue by "autoregulation" // smooth muscle in both the brochioles an pulmonary arterioles will selectively open and close to match status of other unit.

Ventilation – Perfusion Coupling

(Oxygen concentration in alveoli regulates smooth muscle in pulmonary arterioles.)

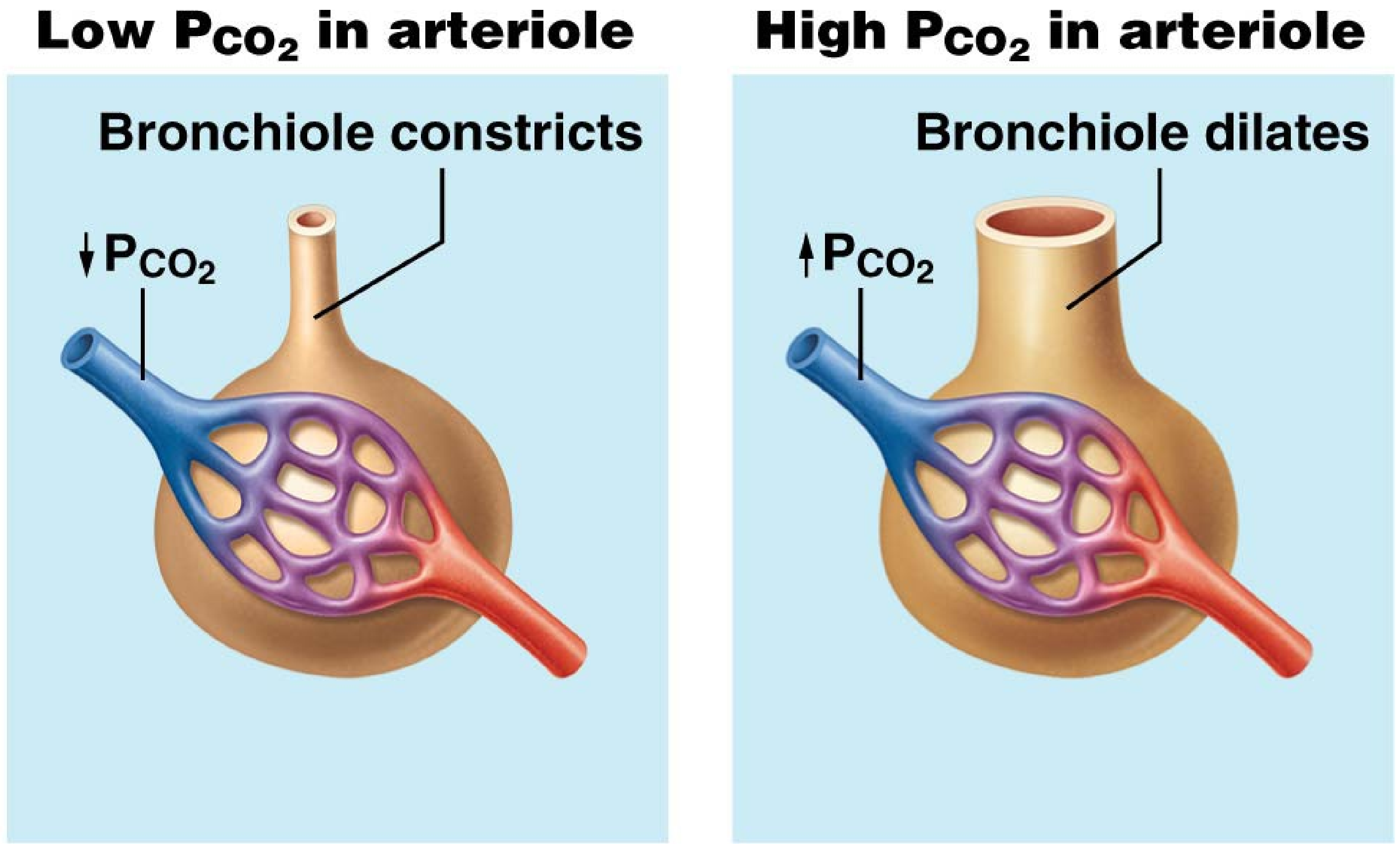


(a) Changes in ventilation (alveolar P_{O_2}) lead to changes in perfusion.

What happens when you change ventilation (bronchioles)?
You change smooth muscle tension in pulmonary arteriole.

Perfusion - Ventilation Coupling

(Carbon dioxide concentration in pulmonary arteriole reglate smooth muscle in bronchioles)



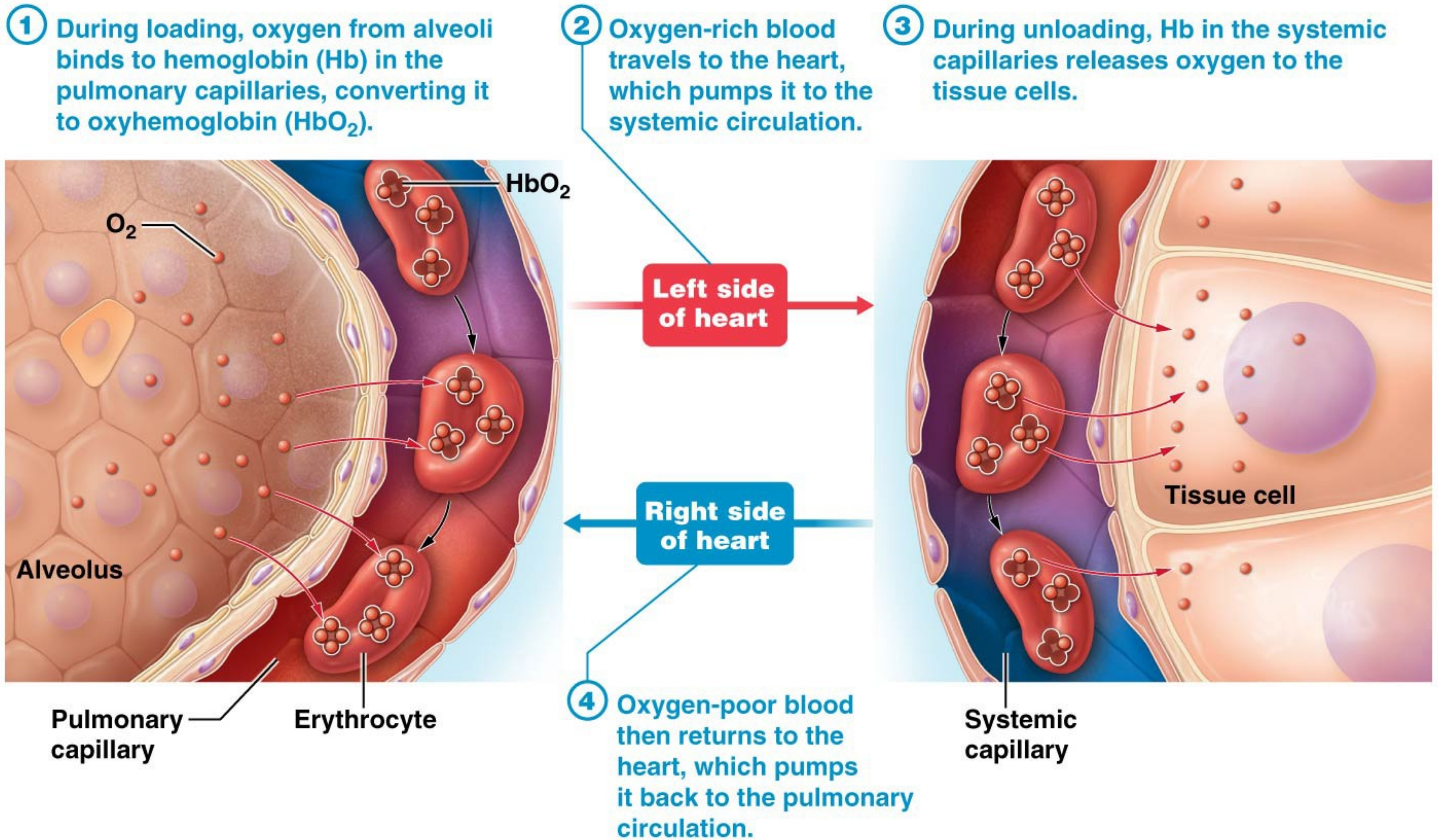
(b) Changes in perfusion (arteriolar P_{CO_2}) lead to changes in ventilation.

What happens when you change perfusion (pulmonary arterioles)?
You change smooth muscle tension in bronchioles.

Gas Transport

- the process of carrying gases
  - from the alveoli to the systemic tissues
  - from the system tissues to the alveoli
- oxygen transport
  - 98.5% bound to hemoglobin
  - 1.5% dissolved in plasma
- carbon dioxide transport
  - 70% as bicarbonate ion
  - 23% bound to hemoglobin (carbamino)
  - 7% dissolved in plasma

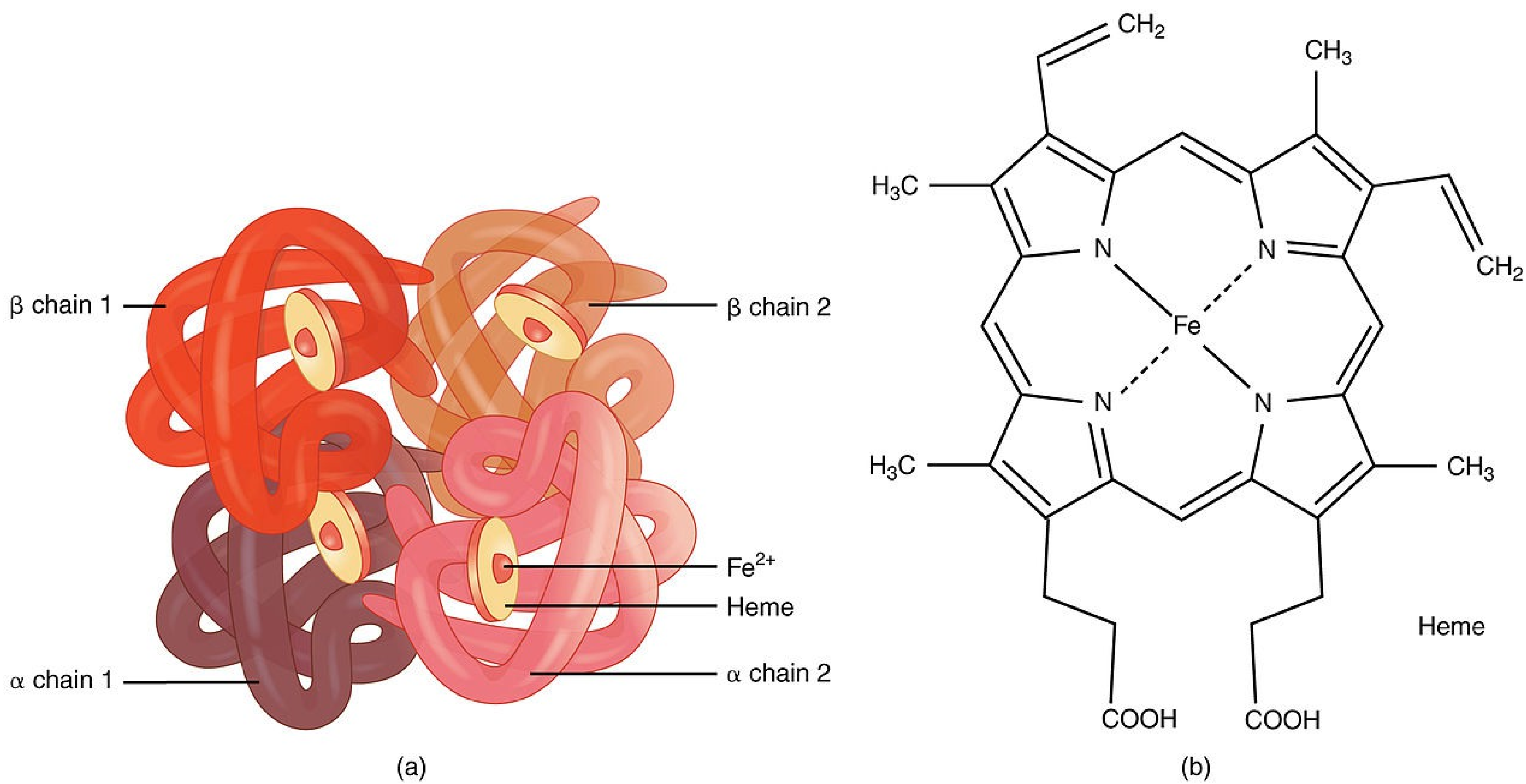
Transport of oxygen: loading and unloading of oxygen on hemoglobin in erythrocytes.



Oxygen Transport

- Hemoglobin (Hb) – molecule specialized in oxygen transport
    - Hb consist of four separate protein molecules (globulin)
    - each globulin molecule has a heme group which binds one O_2 to its ferrous ion (Fe^{2+})
    - therefore, one hemoglobin molecule can carry up to 4 O_2
    - 100% oxyhemoglobin (HbO_2) – 4 O_2 bound to hemoglobin
    - deoxyhemoglobin (HHb) – hemoglobin with no O_2
    - 50% saturation Hb with 2 oxygen molecules

Oxygen Transport



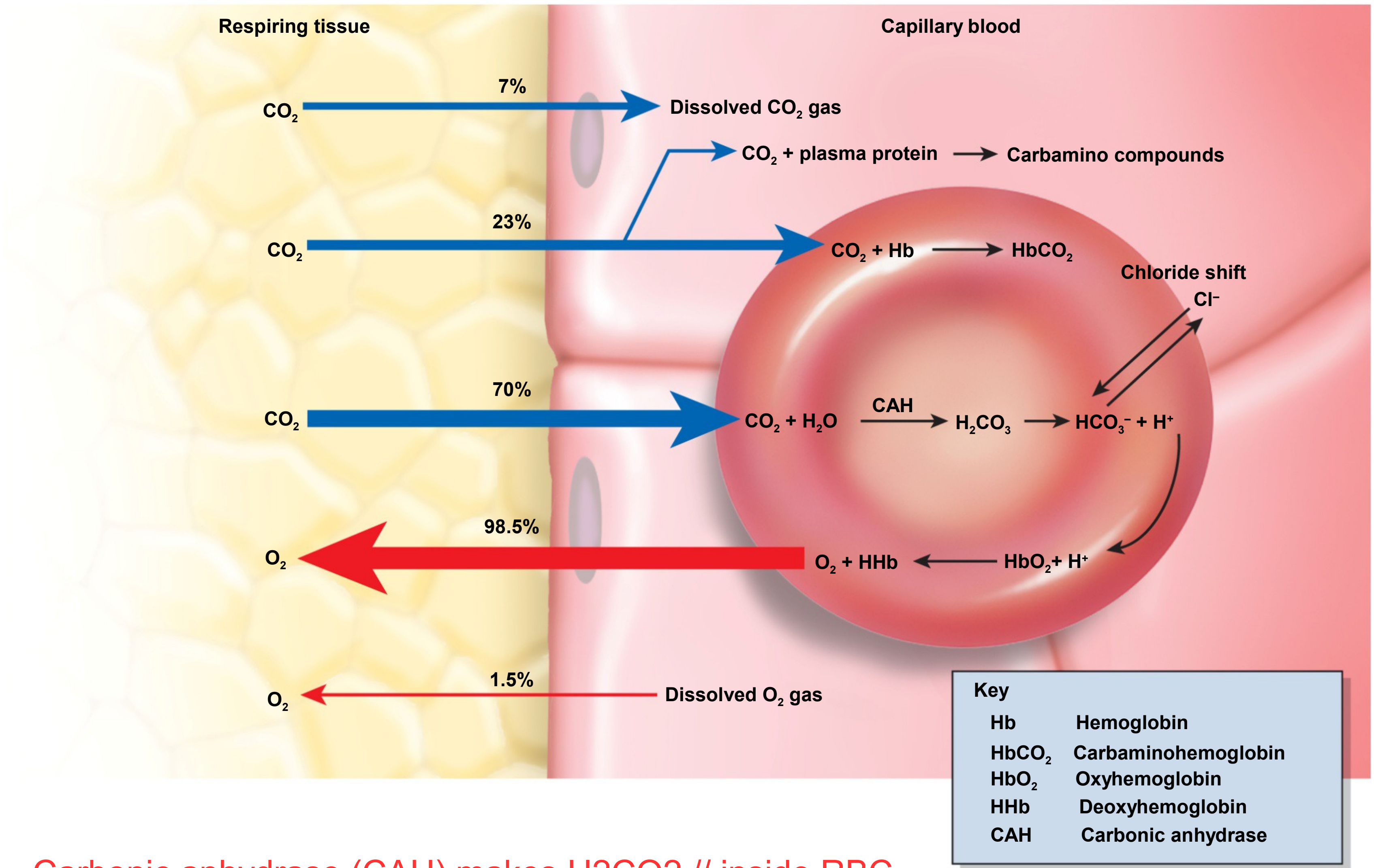
Carbon Dioxide Transport

- Carbon dioxide transported in blood using three forms
  - carbonic acid
  - carbamino compounds
  - dissolved in plasma

How is oxygen and carbon dioxide load and unload during Systemic Gas Exchange?

- Unloading of O_2 /// from blood into tissue
- Loading CO_2 /// from tissue into blood
  - Key event occurs inside RBC // requires *carbonic anhydrase*
    - $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$
  - The "Chloride Shift"
    - keeps reaction proceeding // exchanges HCO_3^- for Cl^-
    - H^+ binds to hemoglobin

Systemic Gas Exchange

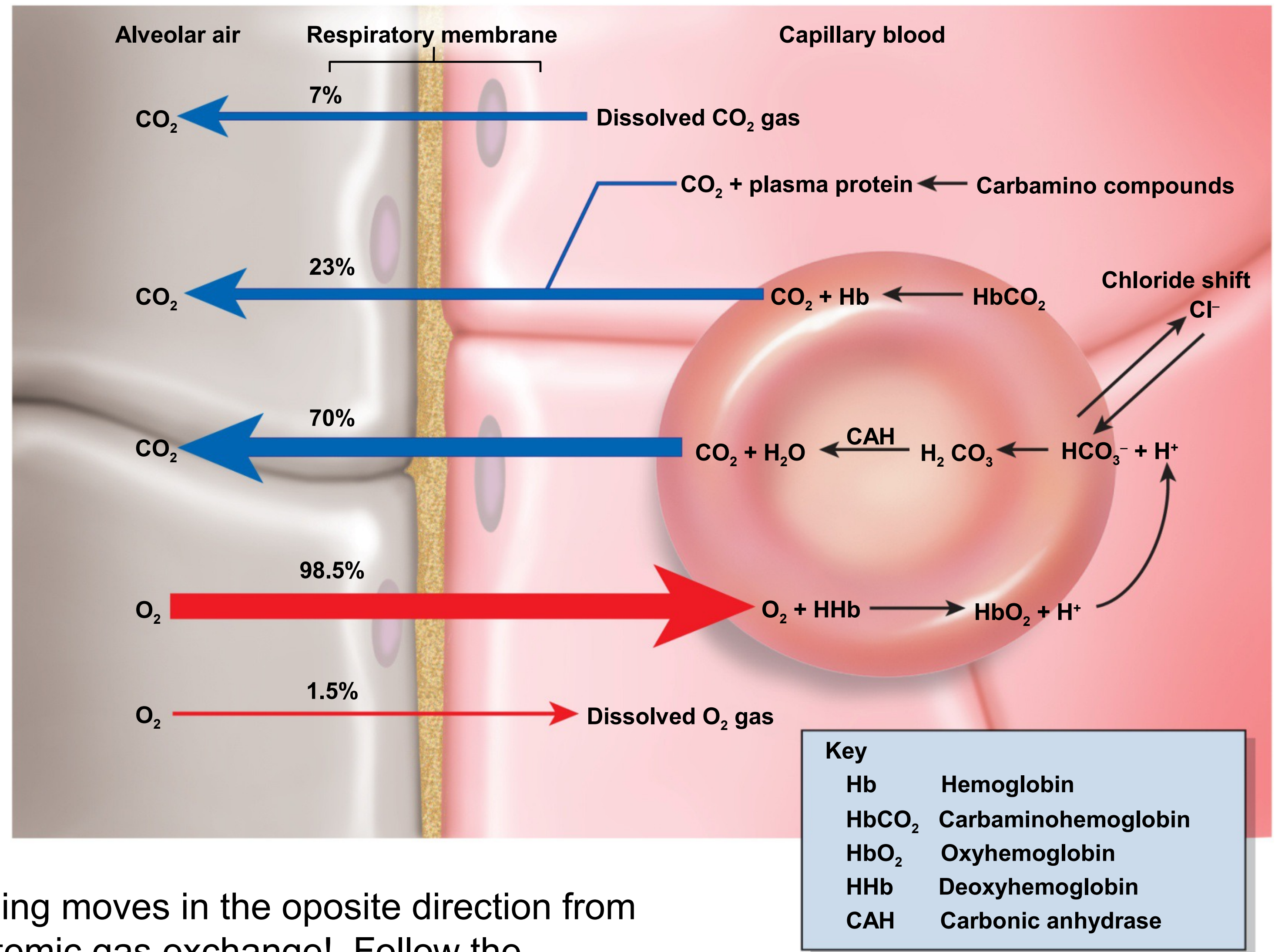


Carbonic anhydrase (CAH) makes H2CO2 // inside RBC

Hydrogen ion (H+) causes the release of O2 from Hb

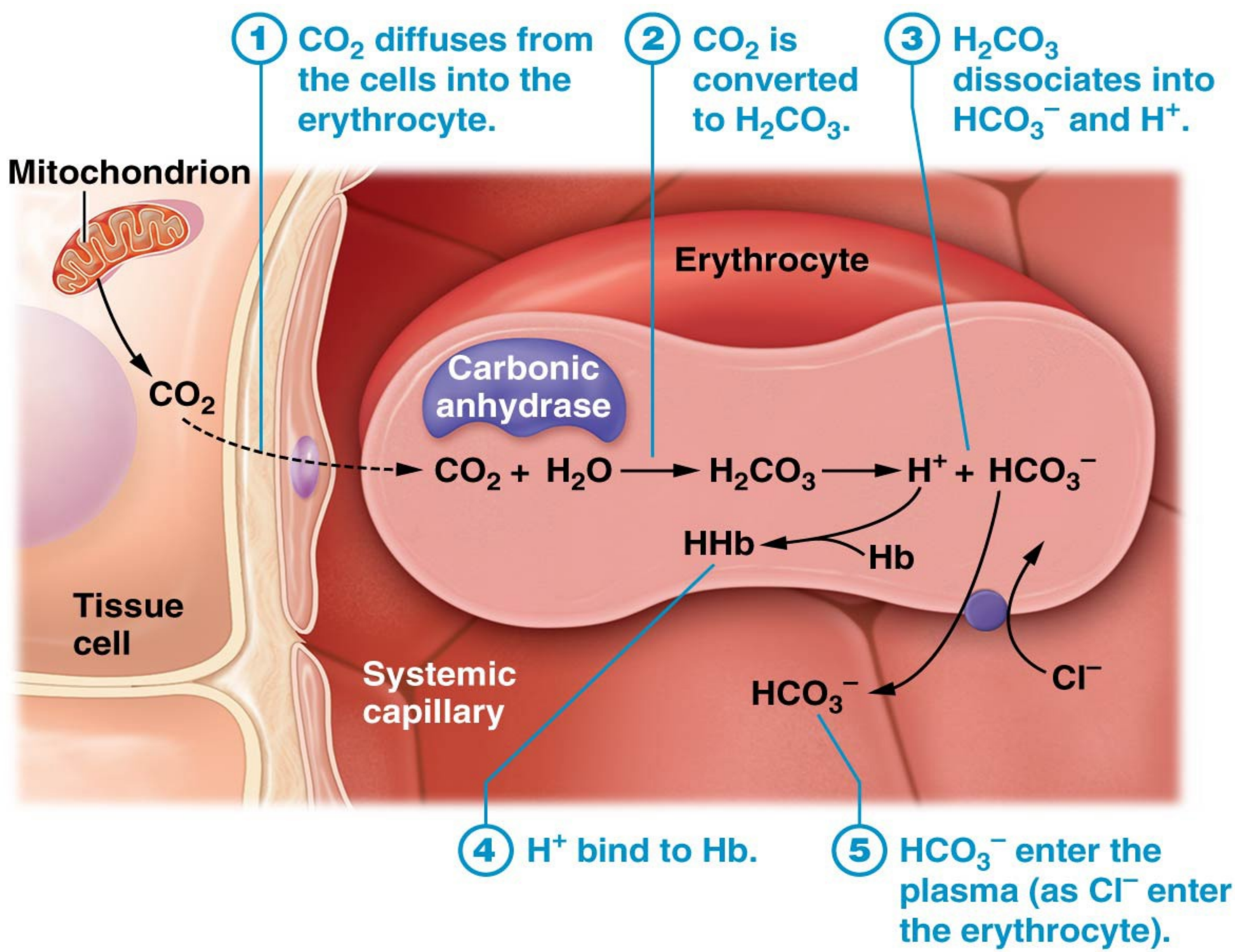
What moves into cell as bicarbonate moves out?

Alveolar Gas Exchange



Everything moves in the oposite direction from the systemic gas exchange! Follow the diffusion of O2 into RBC and see outcome.

Transport of carbon dioxide: the conversion of carbon dioxide and water into carbonic acid in erythrocytes.

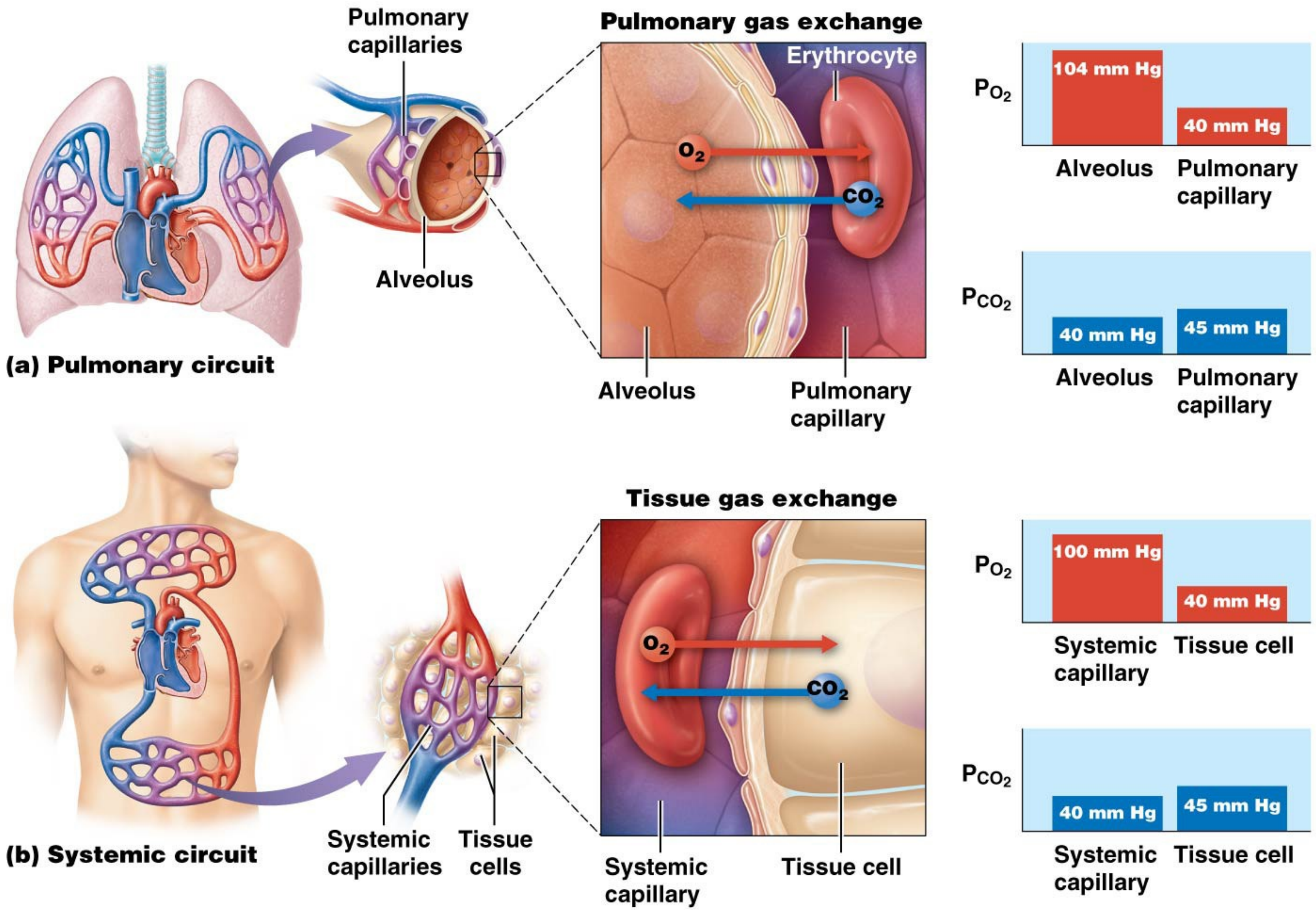


(a) Bicarbonate formation in an erythrocyte in a systemic capillary

Bicarbonate forms ionic bond with sodium and is transported to lungs as sodium-bicarbonate

Hydrogen ion binds to Hb-O2 and causes oxygen to be released from Hb // oxygen now free to diffuse to mitochondria

Gas Transport in Systemic and Pulmonary Circuits



How is oxygen unloaded from RBC in the Systemic Gas Exchange?

O_2 unloading

H^+ binding to HbO_2 reduces its affinity for O_2 /// H^+ responsible for release of O_2 from iron

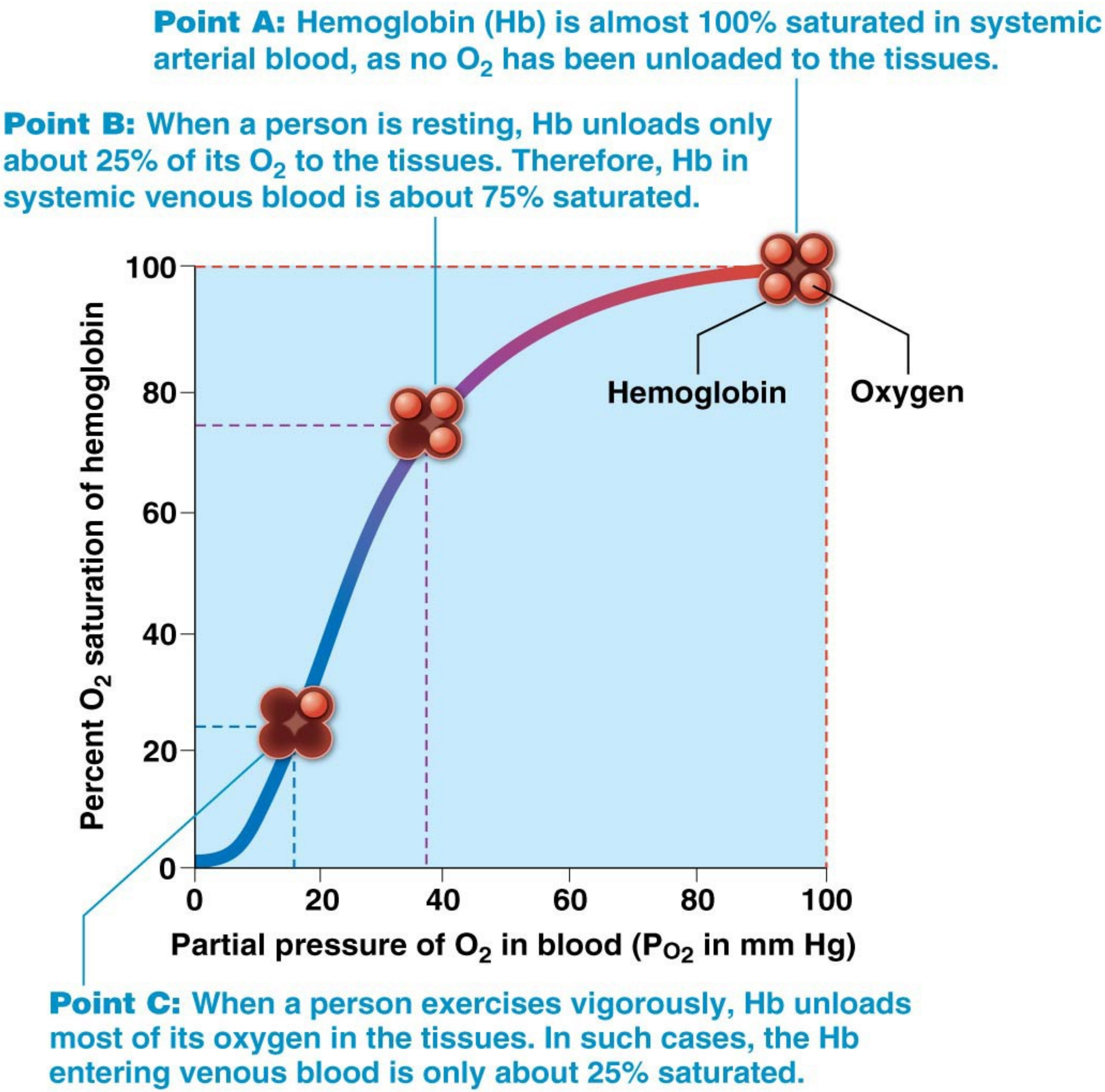
Iron in hemoglobin release oxygen

HbO_2 arrives at systemic capillaries 97% saturated (close to 100%!) /// leaves 75% saturated - unloads 25%

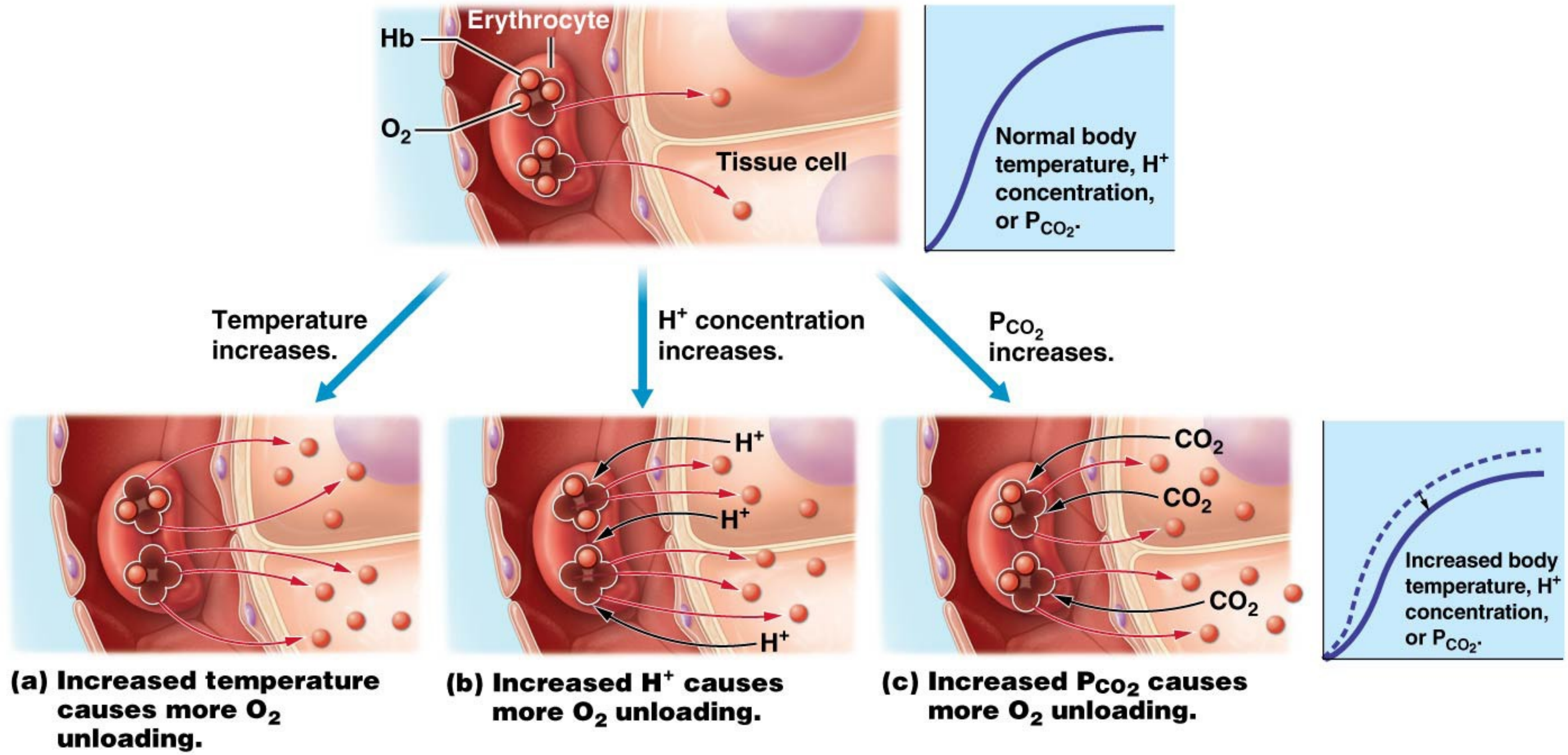
venous reserve – oxygen remaining in the blood after it passes through the capillary beds

utilization coefficient – gives up 22% of its oxygen load

How much oxygen is unloaded during periods of rest or exercise?



Effect of temperature, hydrogen ion concentration, and PCO2 on oxygen unloading from hemoglobin.



These variables all increase when you exercise. This is when we need Hb to release more oxygen so we can deliver more O2 to our mitochondria (organelle that uses reduced coenzymes and oxygen) to make ATP

Another Molecule Used to Unload Oxygen

– Bisphosphoglycerate (BPG) – intermediate in glycolysis // as concentration of BPG increases it indicates high level of anarobic metabolism

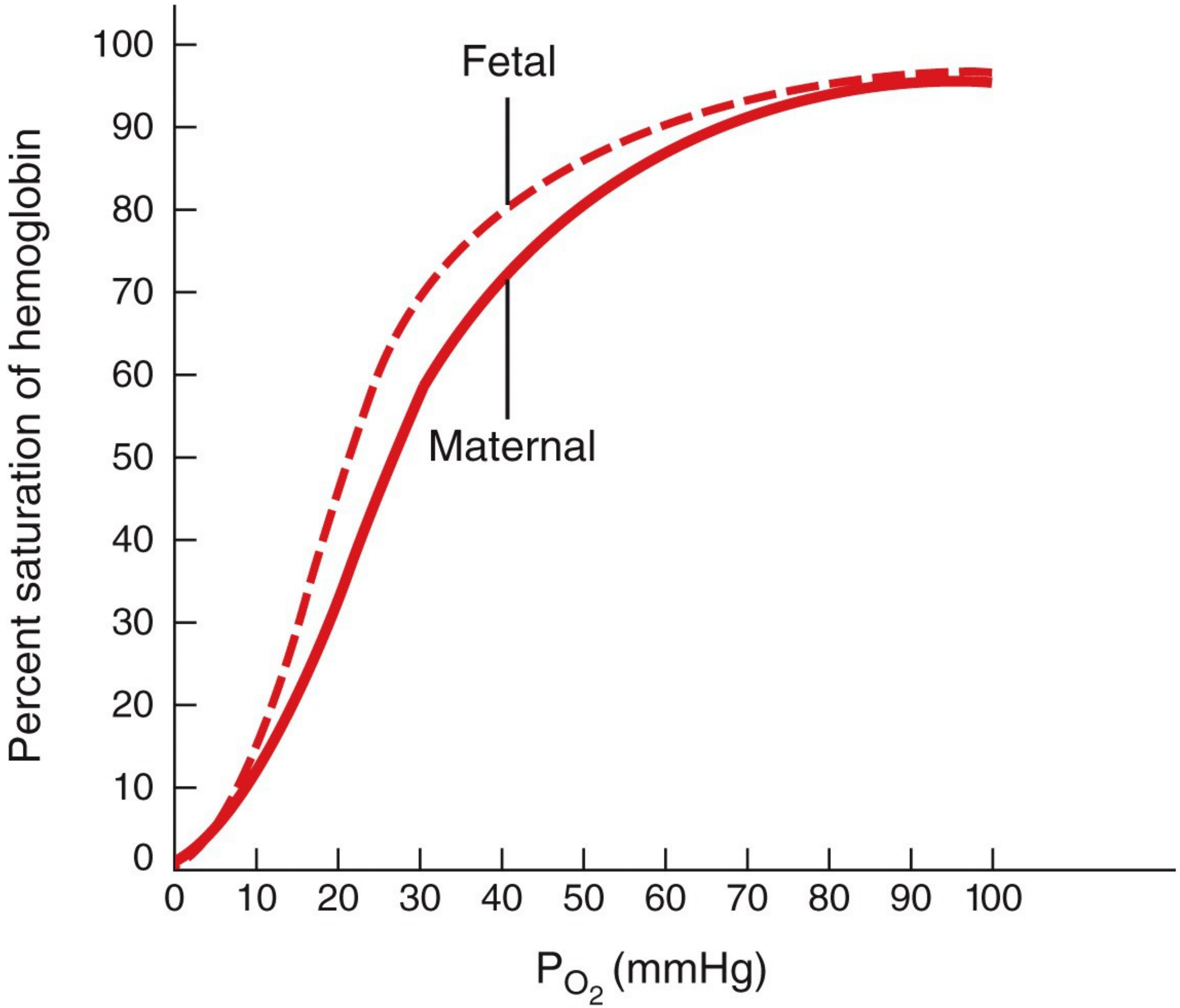
- As RBCs produce more BPG, it binds to Hb and more O_2 is unloaded

- ↑ body temp (fever), thyroxine, growth hormone, testosterone, and epinephrine all raise BPG and cause more O_2 unloading

- ↑ metabolic rate requires ↑ oxygen

- Haldane effect – rate of CO_2 loading is also adjusted to varying needs of the tissues /// low level of oxyhemoglobin enables the blood to transport more CO_2

This Chart Shows Fetal Hb Has a Greater Infinity for O2 Than Maternal Hb



Terminology: Variations in Respiratory Rhythm

- eupnea – relaxed quiet breathing /// characterized by tidal volume 500 mL and the respiratory rate of 12 – 15 bpm
- apnea – temporary cessation of breathing
- dyspnea – labored, gasping breathing; shortness of breath
- hyperpnea – increased rate and depth of breathing in response to exercise, pain, or other conditions
- hyperventilation – increased pulmonary ventilation in excess of metabolic demand
- hypoventilation – reduced pulmonary ventilation
- Kussmaul respiration – deep, rapid breathing often induced by acidosis
- respiratory arrest – permanent cessation of breathing
- tachypnea – accelerated respiration rate
- bradynea – slow respiration rate