Mechanism of breathing; Transport & exchange of gases; Neural and chemical regulation of respiration

By

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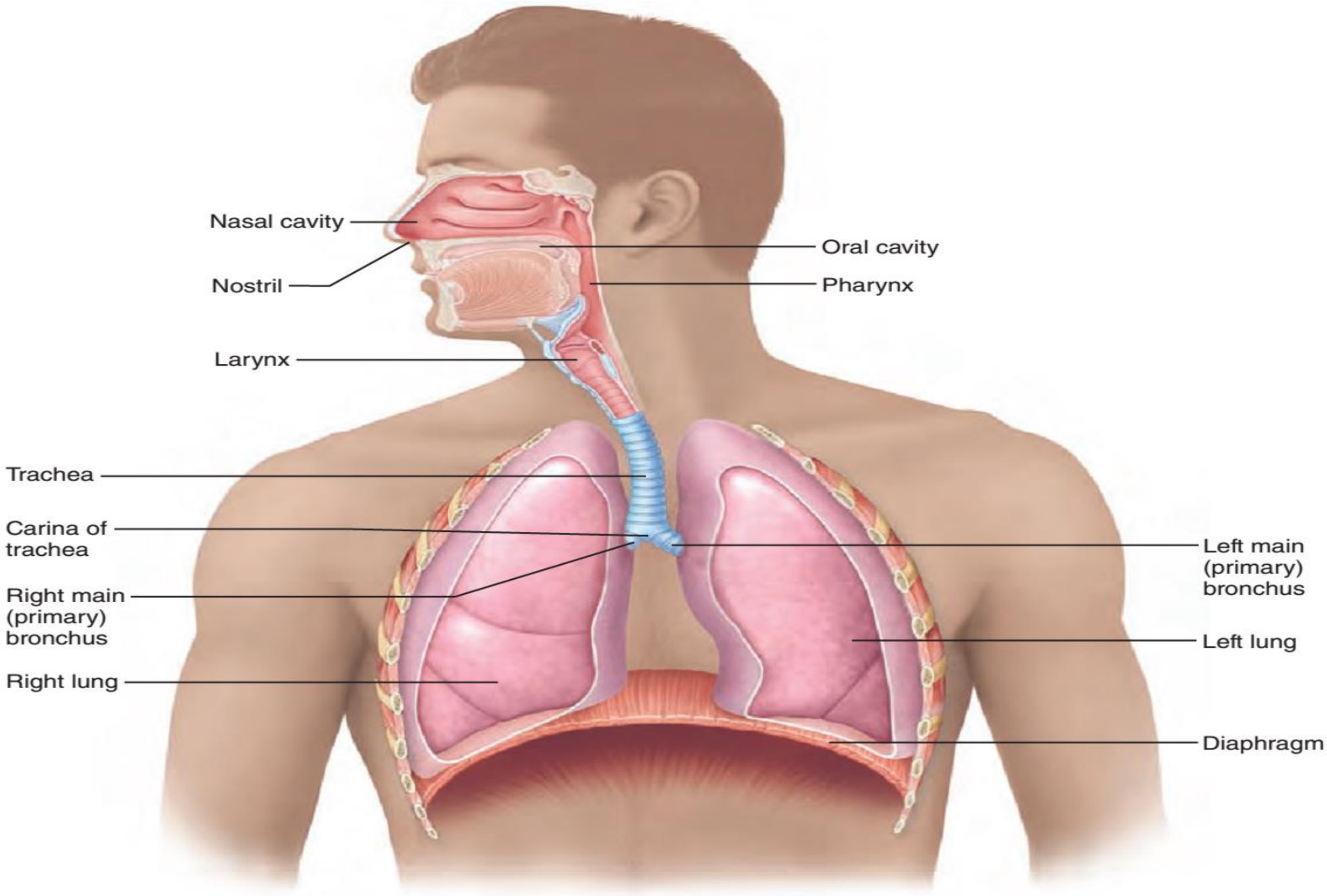
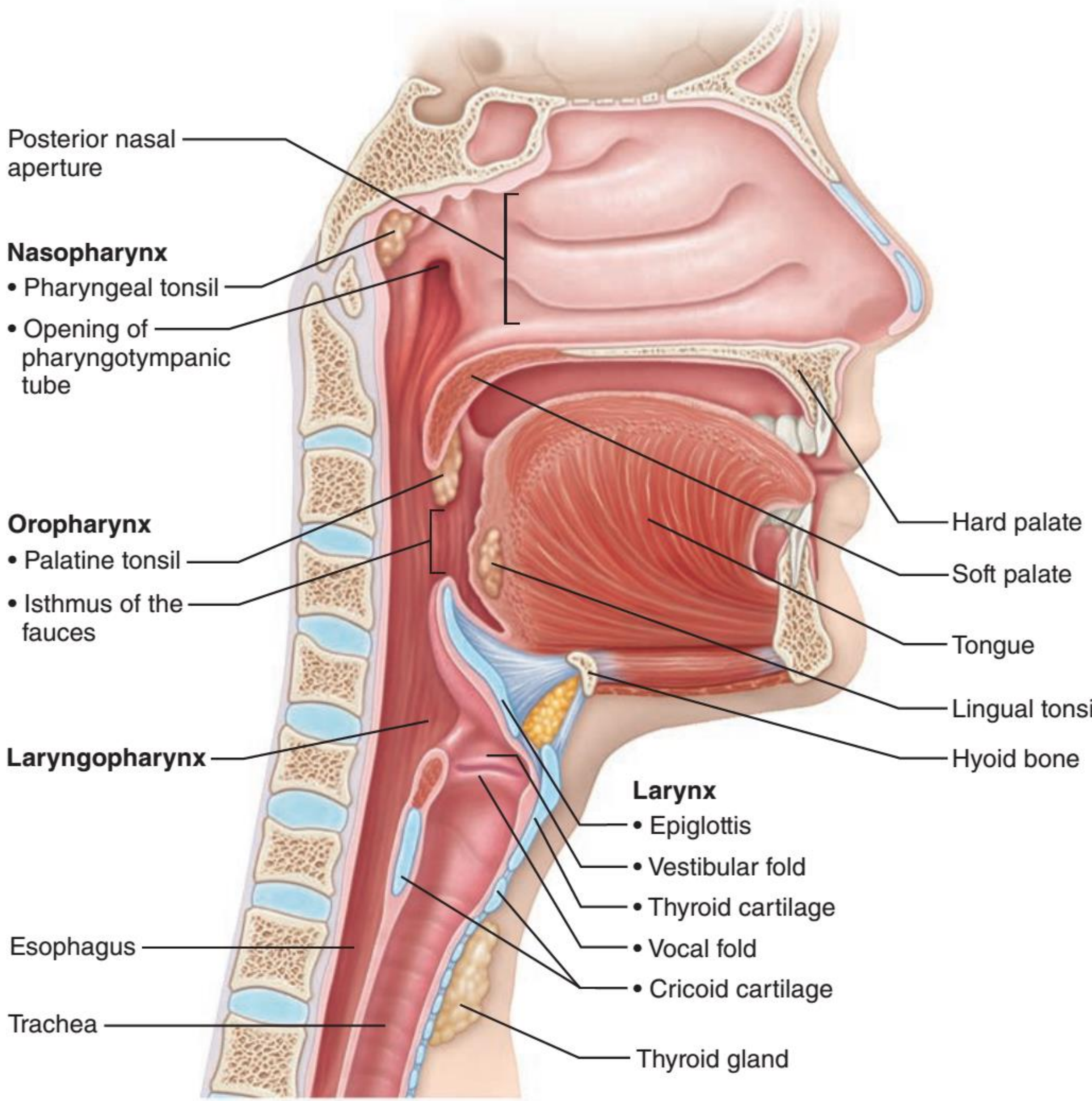
Paper- Zoo-103 (also for paper Applied Ellective-304 (Zoology))

Four processes of Respiration are

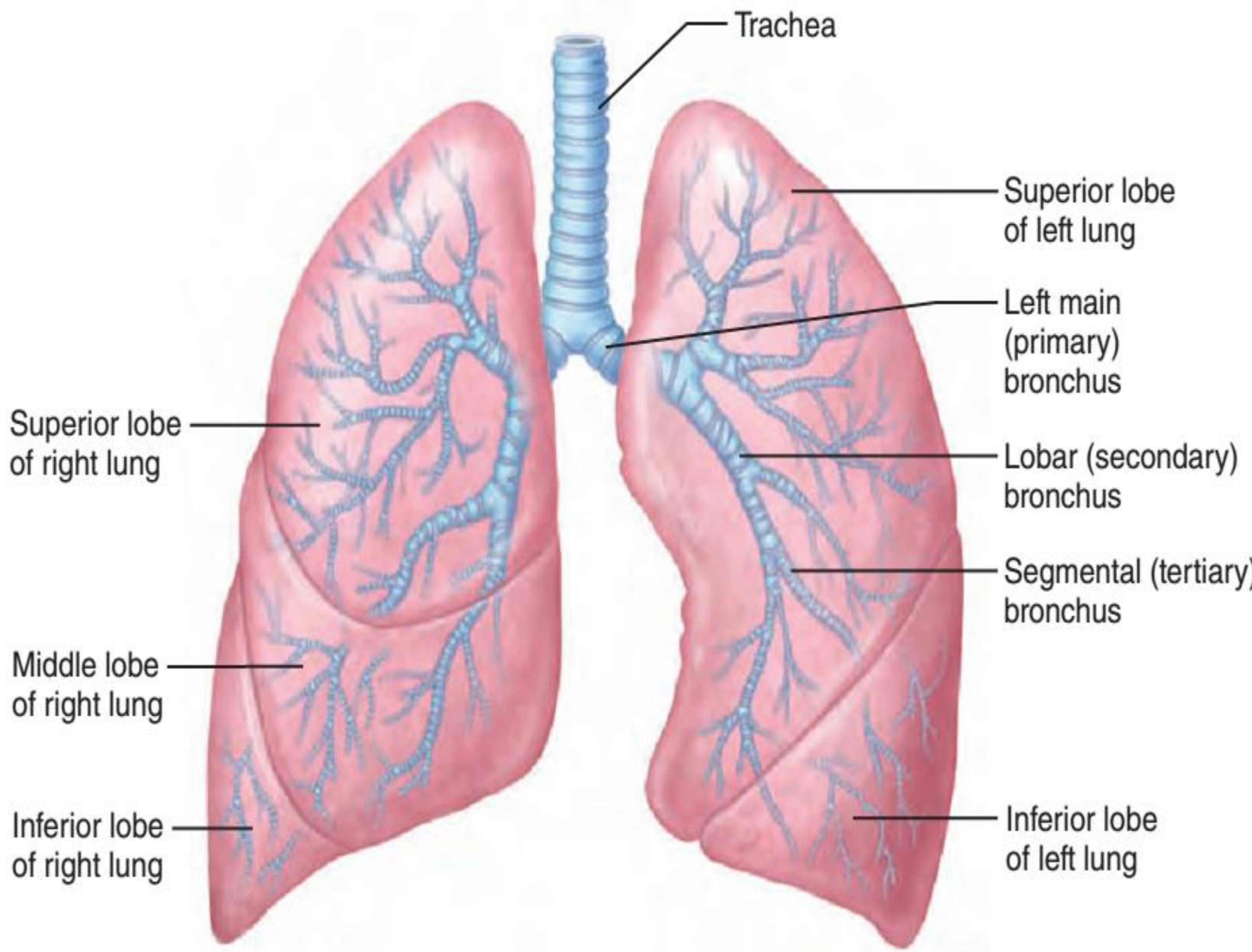
1. **Pulmonary ventilation** (commonly called breathing): Air is moved into and out of the lungs (during *inspiration* and *expiration*) so the gases there are continuously changed and refreshed.
2. **External respiration:** Oxygen diffuses from the lungs to the blood, and carbon dioxide diffuses from the blood to the lungs.
3. **Transport of respiratory gases:** Oxygen is transported from the lungs to the tissue cells of the body, and carbon dioxide is transported from the tissue cells to the lungs. The cardiovascular system accomplishes this transport using blood as the transporting fluid.
4. **Internal respiration:** Oxygen diffuses from blood to tissue cells, and carbon dioxide diffuses from tissue cells to blood.



The major respiratory organs in relation to surrounding structures.

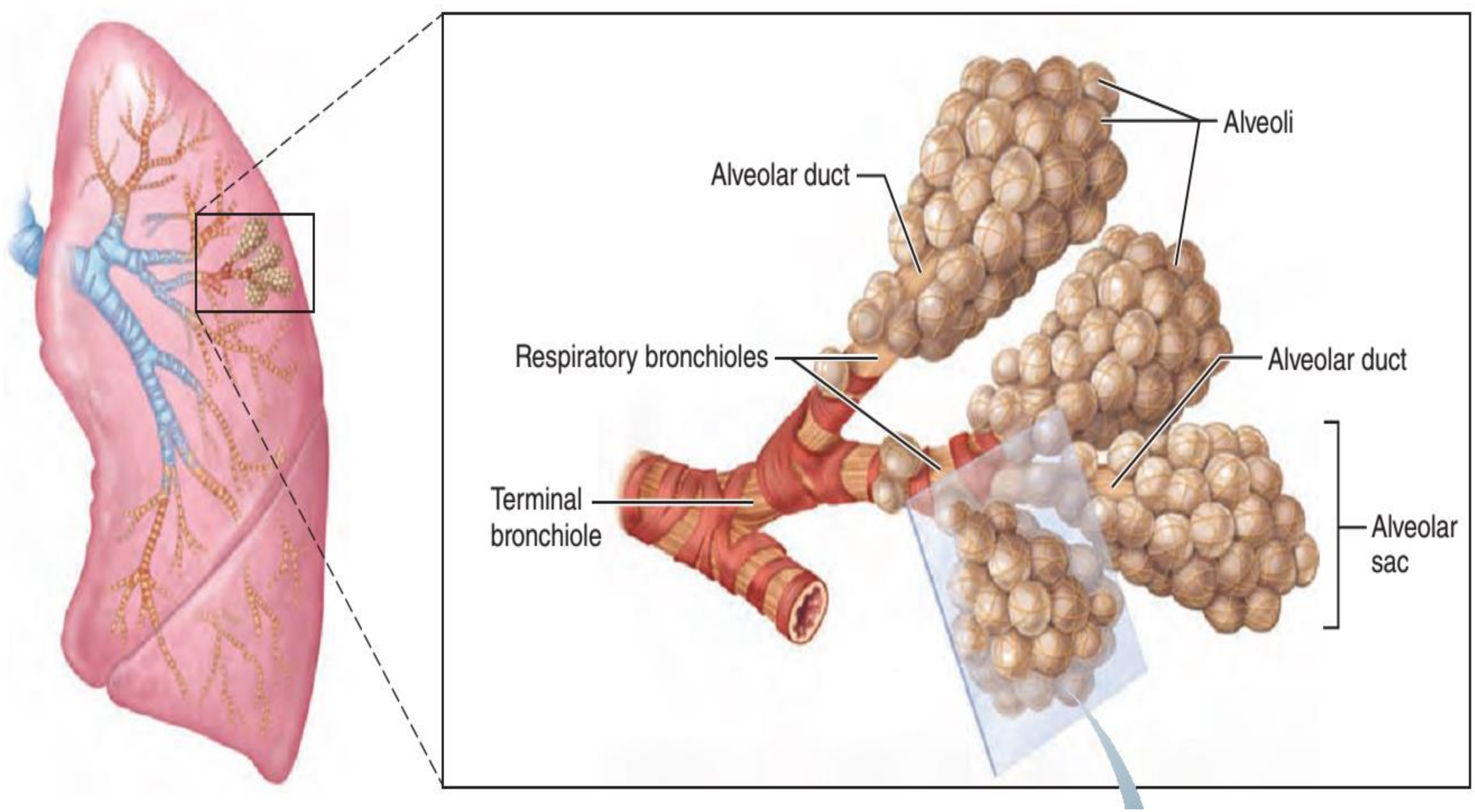


(b) Structures of the pharynx and larynx

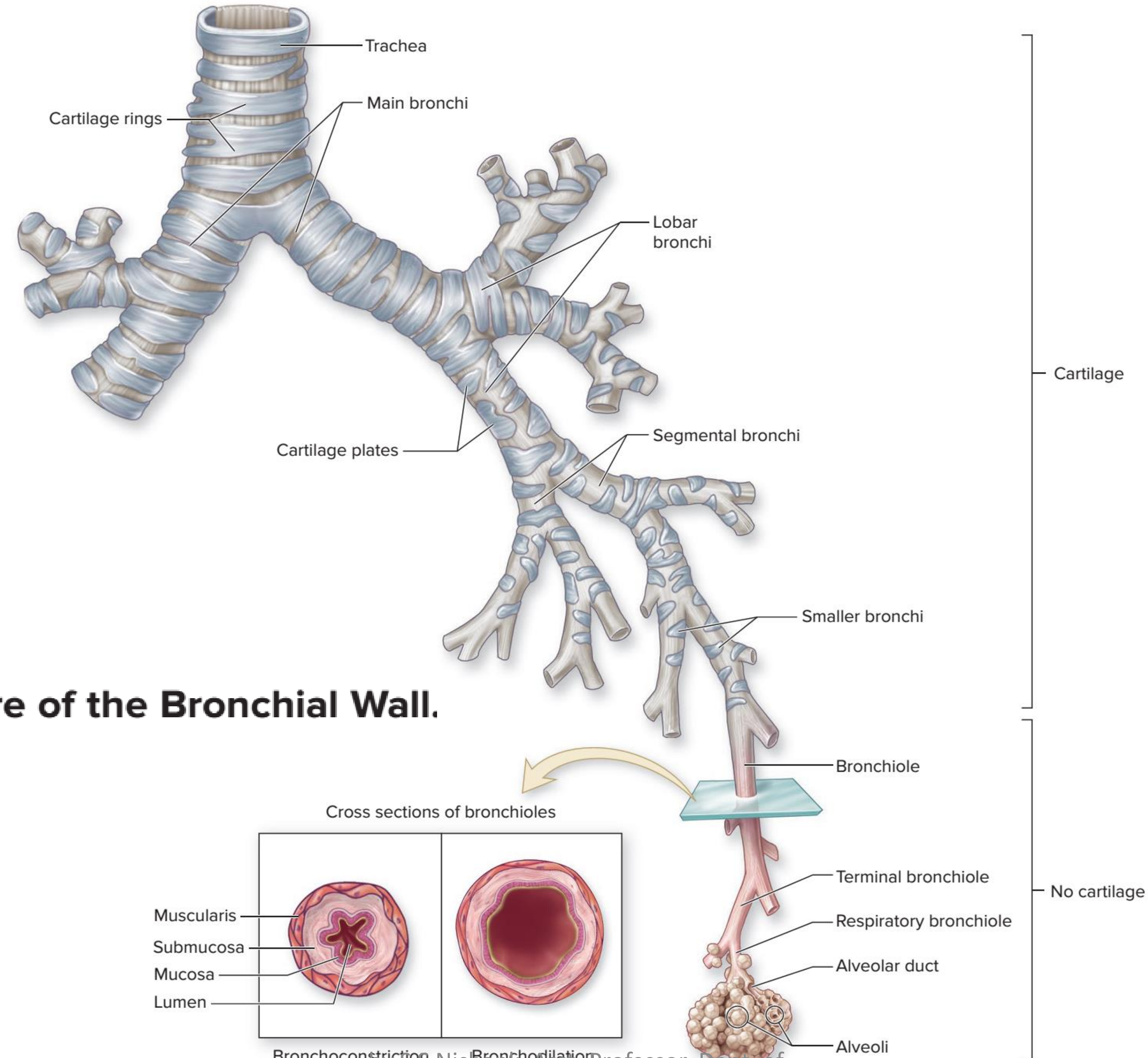


Conducting zone passages. The air pathway inferior to the larynx consists of the trachea and the main, lobar, and segmental bronchi, which branch into the smaller bronchi and bronchioles until reaching the terminal bronchioles of the lungs.

Respiratory zone structures



Structure of the Bronchial Wall.

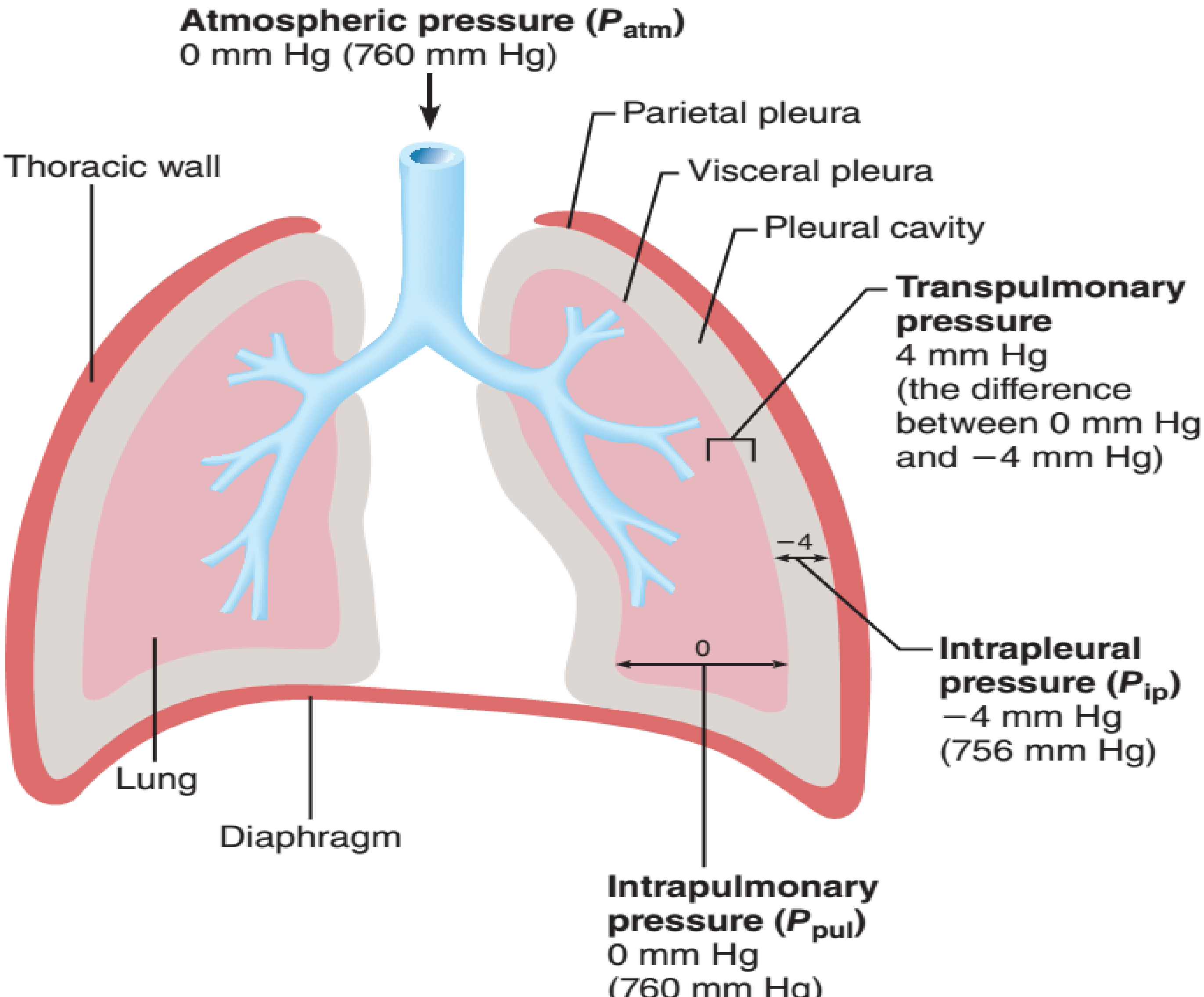


Pulmonary ventilation

Pressure Relationships in the Thoracic Cavity

- The pressure in the pleural cavity, the intrapleural pressure (P_{ip}), is always about 4 mm Hg less than P_{pul}. That is, P_{ip} is always negative relative to P_{pul}.
- What causes this negative intrapleural pressure?
- Two forces act to pull the lungs (visceral pleura) away from the thorax wall (parietal pleura) and cause the lungs to collapse: 1. The lungs' natural tendency to recoil; 2. The surface tension of the alveolar fluid.
- However, these lung-collapsing forces are opposed by strong adhesive force between the parietal and visceral pleurae.
- The net result of the dynamic interplay between these forces is a negative P_{ip}. The amount of pleural fluid in the pleural cavity must remain minimal to maintain a negative (P_{ip}). The pleural fluid is actively pumped out of the pleural cavity into the lymphatics continuously, as a result, a negative P_{ip} is maintained.
- Any condition that equalizes P_{ip} with the intrapulmonary (or atmospheric) pressure causes immediate lung collapse

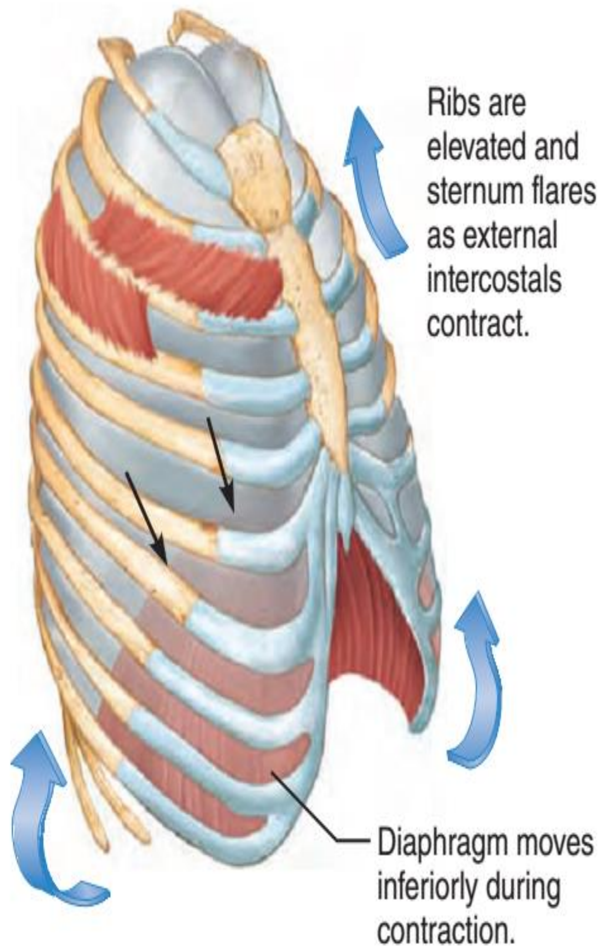
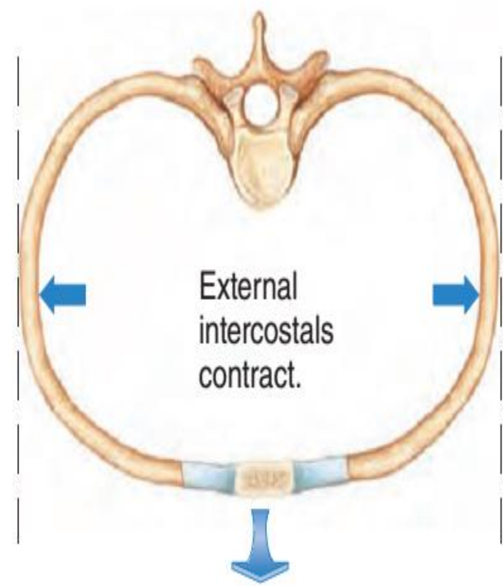
Intrapulmonary & intrapleural pressure relationships



- Pulmonary ventilation, depends on volume changes in the thoracic cavity. A rule to keep in mind is that volume changes lead to pressure changes, and pressure changes lead to the flow ofgases to equalize the pressure.

Boyle's law gives the relationship between the pressure and volume of a gas: At constant temperature, the pressure of a gas varies inversely with its volume. That is,

$$P_1V_1 = P_2V_2$$

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

Expiration

1. Inspiratory muscles relax (diaphragm rises; rib cage descends due to recoil of costal cartilages).

↓

2. Thoracic cavity volume decreases.

↓

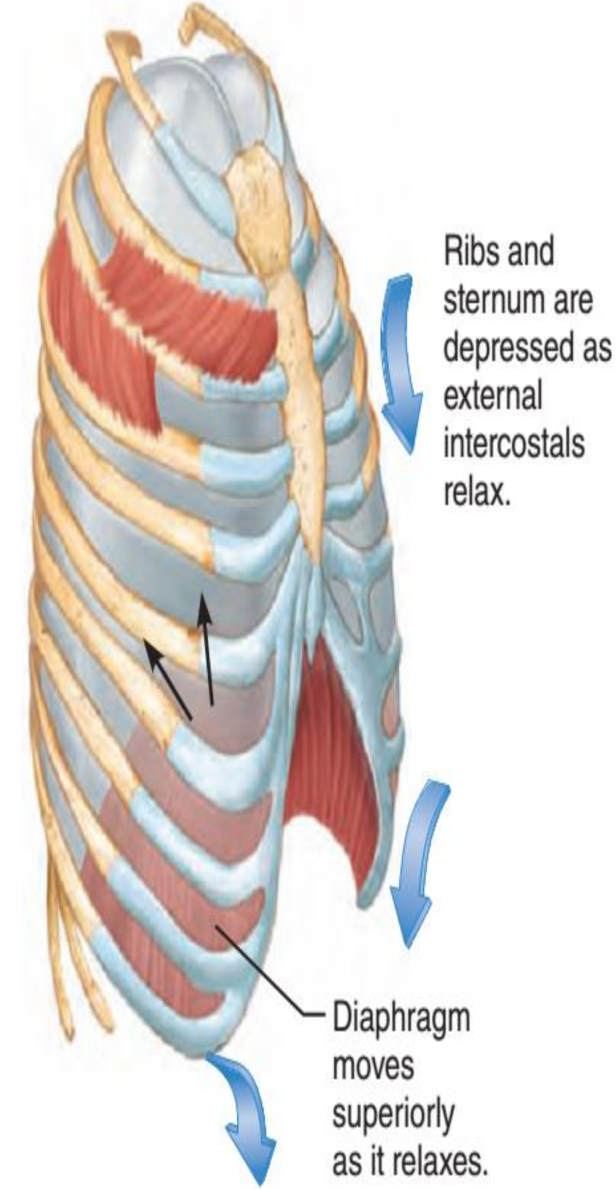
3. Elastic lungs recoil passively; intrapulmonary volume decreases.

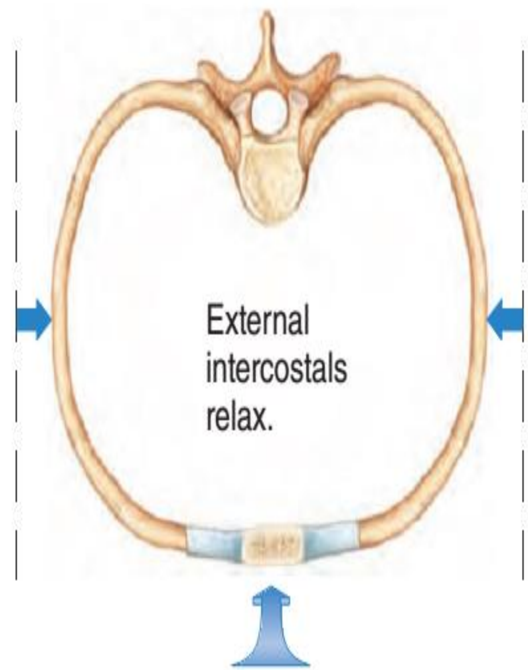
↓

4. Intrapulmonary pressure rises (to +1 mm Hg).

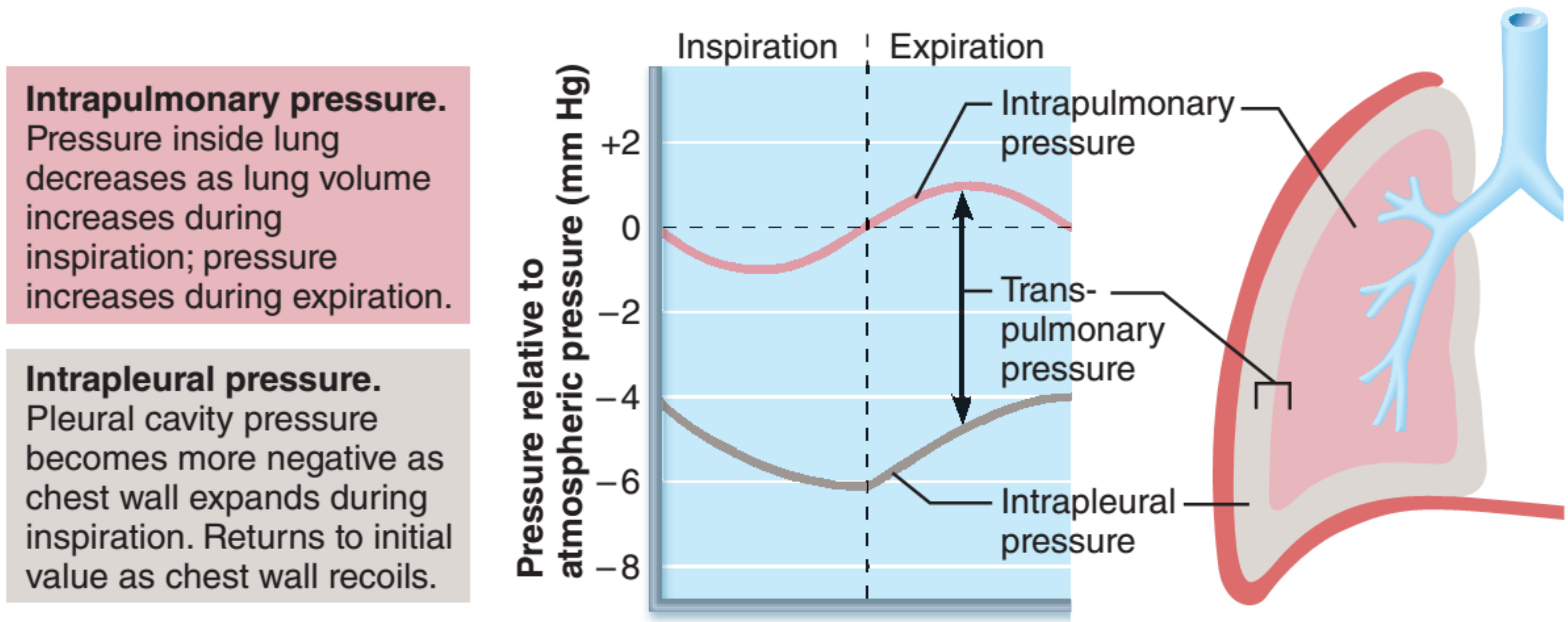
↓

5. Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0.

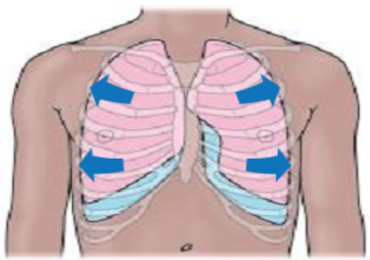




Changes in intrapulmonary and intrapleural pressures during inspiration and expiration



During the inspiration period, *P*ip declines to about −6 mm Hg relative to *P*atm

Factor		Sensory Receptor	Action
Oxygen	↓O_2	Peripheral chemoreceptors (located in the carotid and aortic bodies)	Low blood levels of oxygen cause peripheral chemoreceptors to send impulses to the medulla to increase the rate and depth of respirations. This brings more air, and therefore oxygen, into the lungs.
Hydrogen ions (pH)	pH	Central chemoreceptors (located in the brainstem)	Central chemoreceptors monitor the pH of cerebrospinal fluid (CSF), which mirrors the level of carbon dioxide in the blood. Falling pH levels indicate an excess of carbon dioxide. When this occurs, central chemoreceptors signal the respiratory centers to increase the rate and depth of breathing. This helps the body "blow off" excess carbon dioxide, raising the pH.
Stretch		Receptors in the lungs and chest wall	As the lungs inflate during inspiration, receptors detect the stretching and signal the respiratory centers to exhale and inhibit inspiration. Called the **Hering-Breuer reflex,** this mechanism prevents lung damage from overinflation.
Pain and emotion		Hypothalamus and limbic system	These areas of the brain send signals that affect breathing in response to pain and emotions (such as fear, anger, and anxiety).
Irritants (such as smoke, dust, pollen, noxious chemicals, and mucus)		Nerve cells in the airway	Nerve cells respond to irritants by signaling the respiratory muscles to contract, resulting in a cough or a sneeze. Coughing or sneezing propels air rapidly from the lungs, helping to remove the offending substance.

Physical Factors influencing Pulmonary ventilation

Airway Resistance

The major *nonelastic* source of resistance to gas flow is friction, or drag, encountered in the respiratory passageways. The following equation gives the relationship between gas flow (F), pressure (P), and resistance (R):

$$F = \frac{\Delta P}{R}$$

Where ΔP, the *difference* in pressure, or pressure gradient, between the external atmosphere and the alveoli.

Alveolar Surface Tension

At any gas-liquid boundary, the molecules of the liquid are more strongly attracted to each other than to the gas molecules. This unequal attraction produces a state of tension at the liquid surface, called **surface tension**, that (1) draws the liquid molecules closer together and reduces their contact with the dissimilar gas molecules, and (2) resists any force that tends to increase the surface area of the liquid.

Physical Factors influencing Pulmonary ventilation

Lung Compliance

Healthy lungs are unbelievably stretchy, and this distensibility is called **lung compliance**. Specifically, lung compliance (C_L) is a measure of the change in lung volume (ΔV_L) that occurs with a given change in transpulmonary pressure [$\Delta(P_{pul} - P_{ip})$]. This relationship is stated as

$$C_L = \frac{\Delta V_L}{\Delta(P_{pul} - P_{ip})}$$

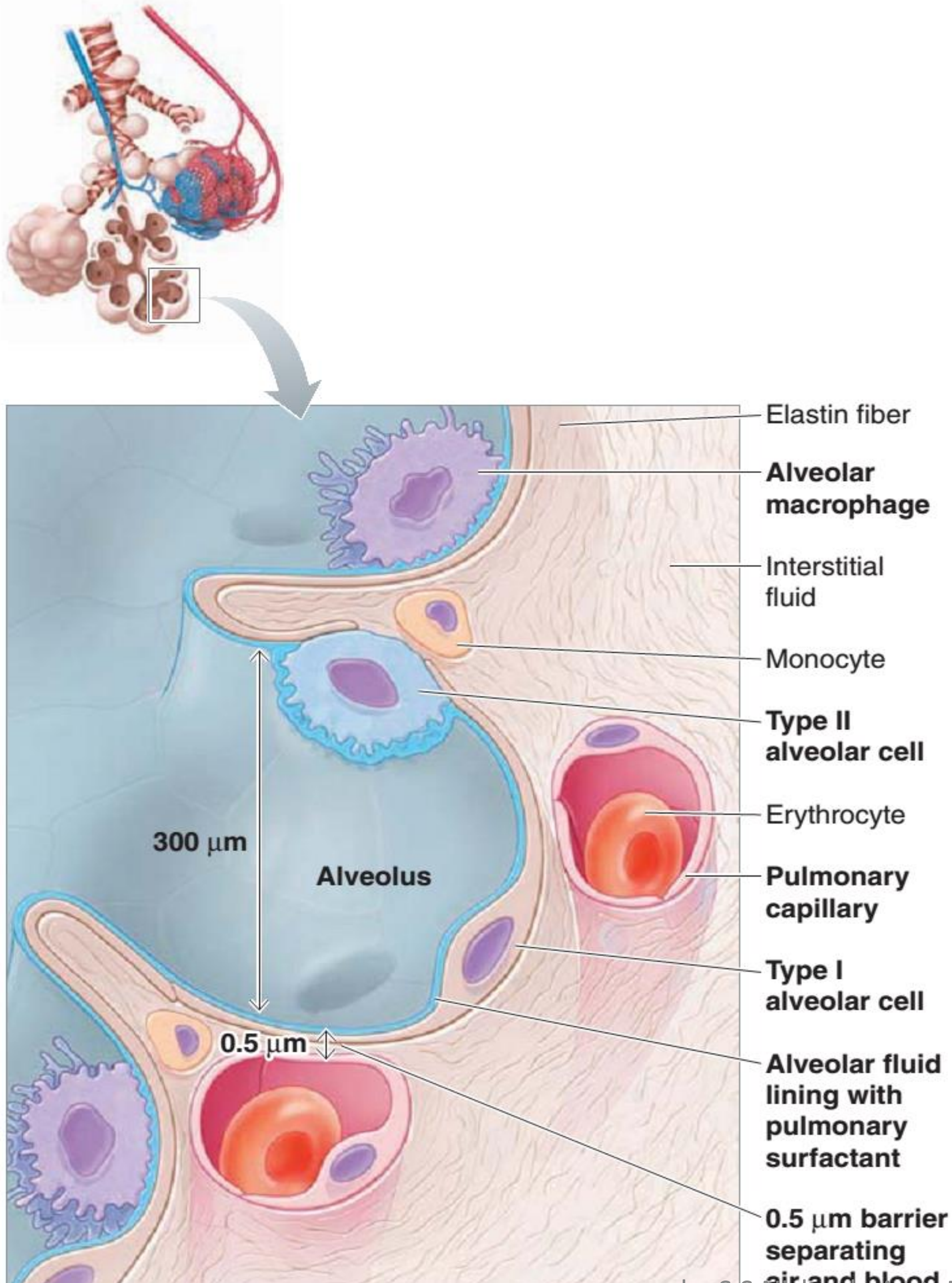
Lung compliance is determined largely by two factors:

- Distensibility of the lung tissue
- Alveolar surface tension

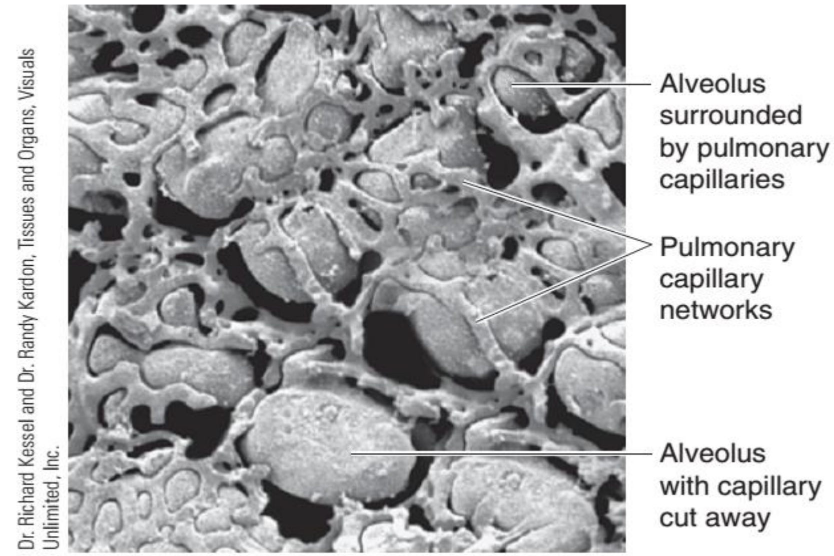
Respiratory surface

Gas exchange

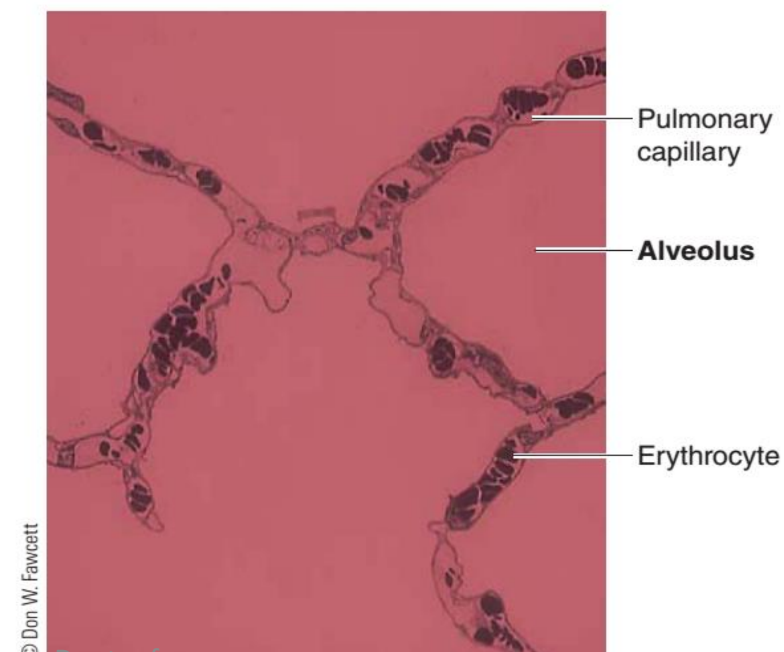
between the Blood, Lungs & Tissues



(a) Alveolus and surrounding pulmonary capillaries



(b) Scanning electron micrograph of alveoli and surrounding pulmonary capillaries



(c) Transmission electron micrograph of several alveoli and surrounding pulmonary capillaries

External Respiration

The following three factors influence external respiration:

- Partial pressure gradients and gas solubilities
- Thickness and surface area of the respiratory membrane
- Ventilation-perfusion coupling (matching alveolar ventilation with pulmonary blood perfusion)

Dalton's Law of Partial Pressures

Dalton's law states that the pressure exerted by a mixture of gases is equal to the sum of the pressures exerted by the individual gases occupying the same volume alone. The pressure exerted by an individual gas in a mixture is called the partial pressure of that gas.

Henry's Law

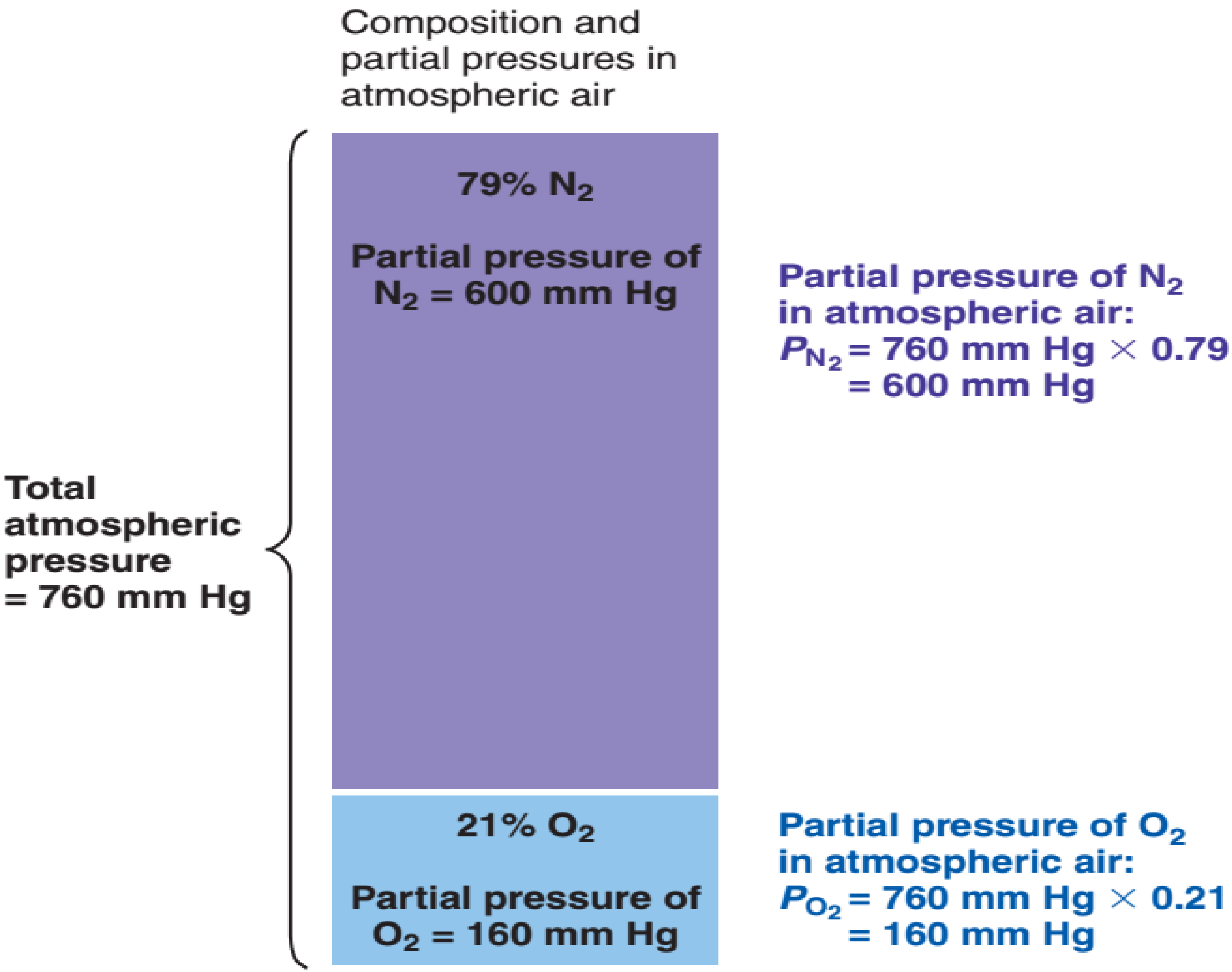
Henry's law states that when the temperature is constant, the concentration of a gas in a liquid is proportional to its partial pressure. The solubility of a gas in a liquid depends on temperature, the partial pressure of the gas over the liquid, the chemical properties of the gas, and the chemical properties of the liquid.

(according to Henry's law, $c = kP$, so as P increases, c increases).

The relationship among the concentration, partial pressure, and solubility of a gas is described by Henry's law, mathematically expressed as

$$c = kP$$

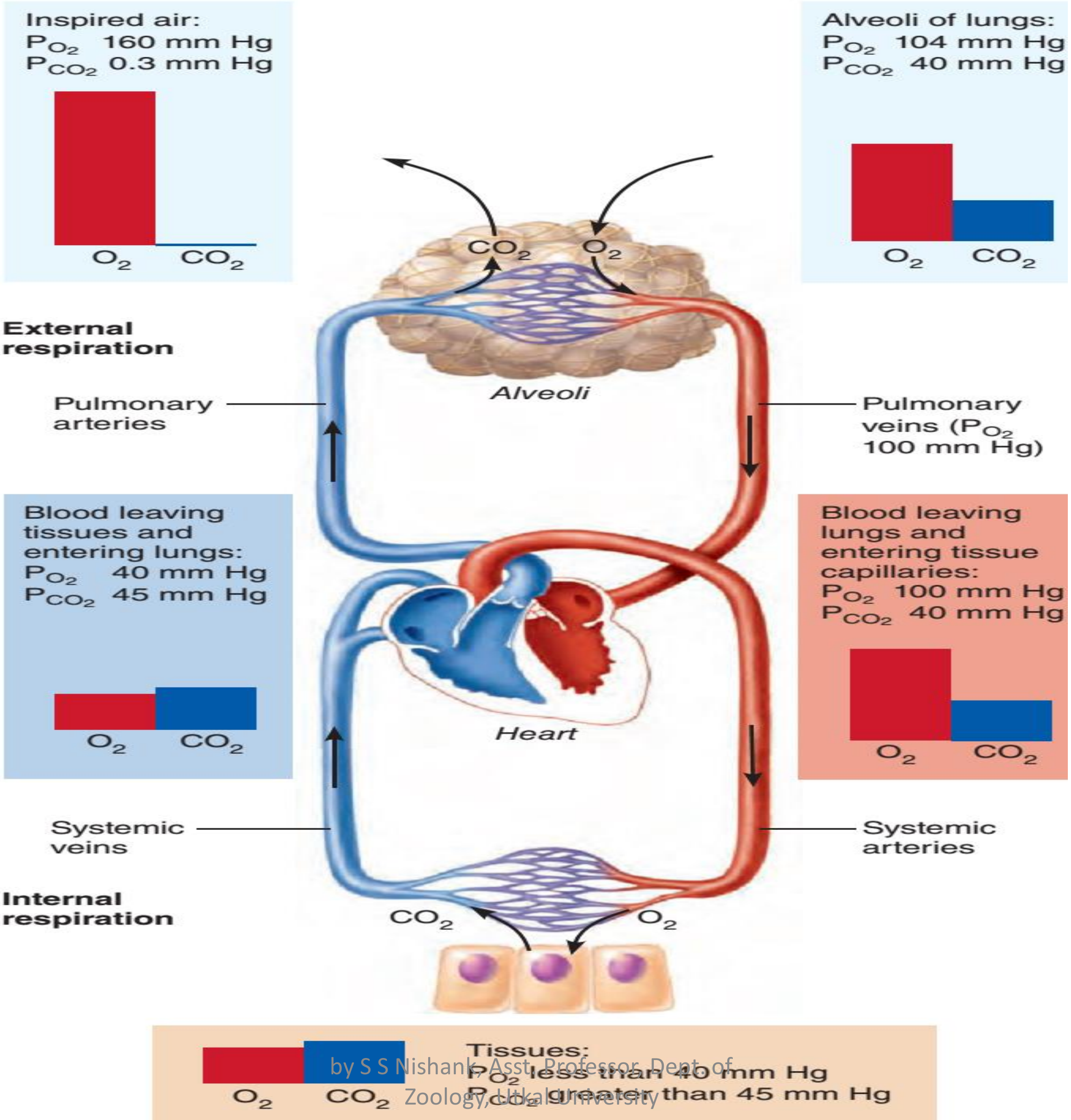
where c is the molar concentration of the dissolved gas (moles of gas per liter of liquid), P is the partial pressure of the gas in atmospheres (1 atmosphere = 760 mm Hg), and k is the Henry's law constant, which varies based on the gas and the temperature (see **Toolbox: Henry's Law and Solubility of Gases**).

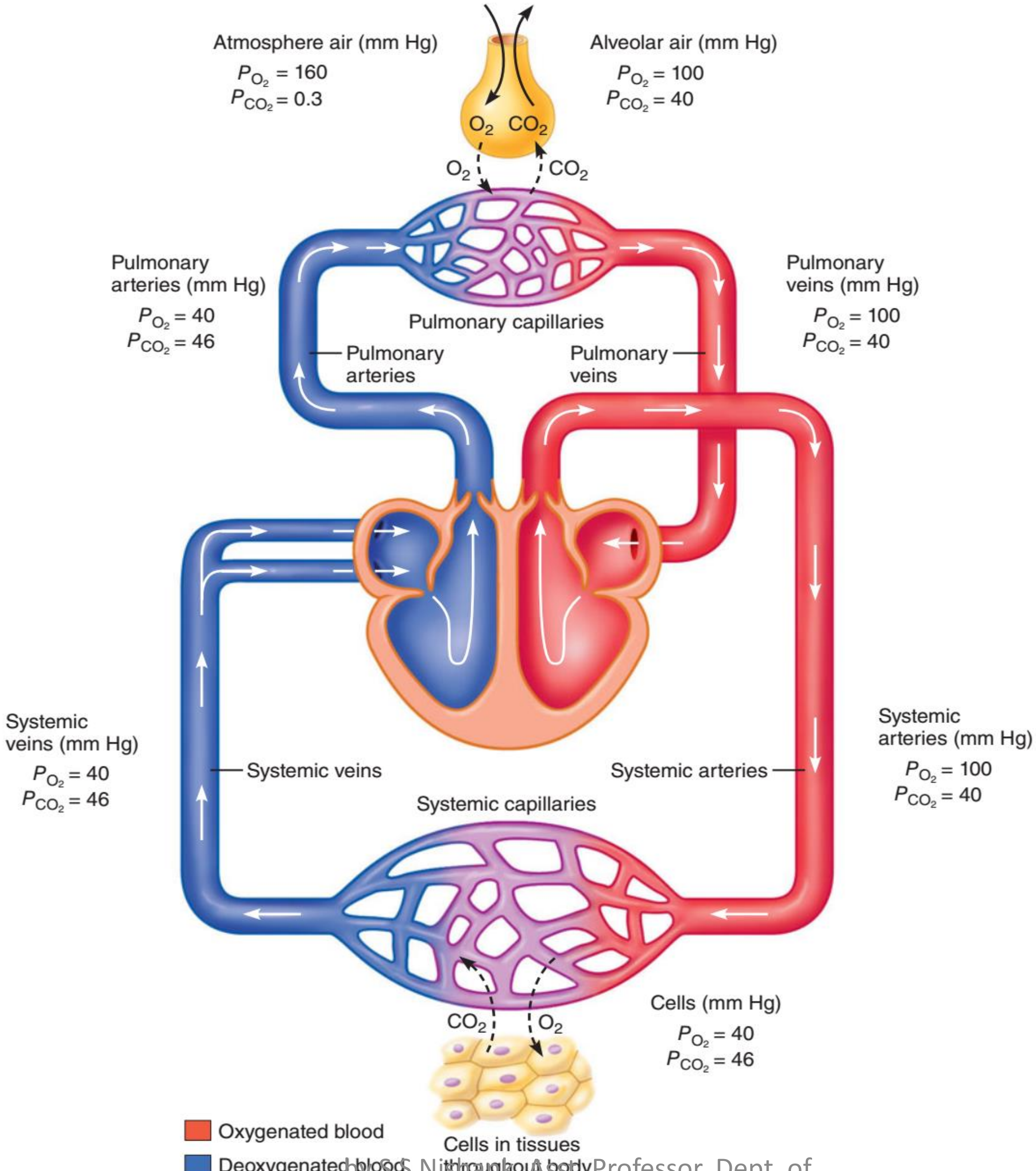


- **Concept of partial pressures.** The partial pressure exerted by each gas in a mixture equals the total pressure times the fractional composition of the gas in the mixture.

Comparison of Gas Partial Pressures and Approximate Percentages in the Atmosphere and in the Alveoli

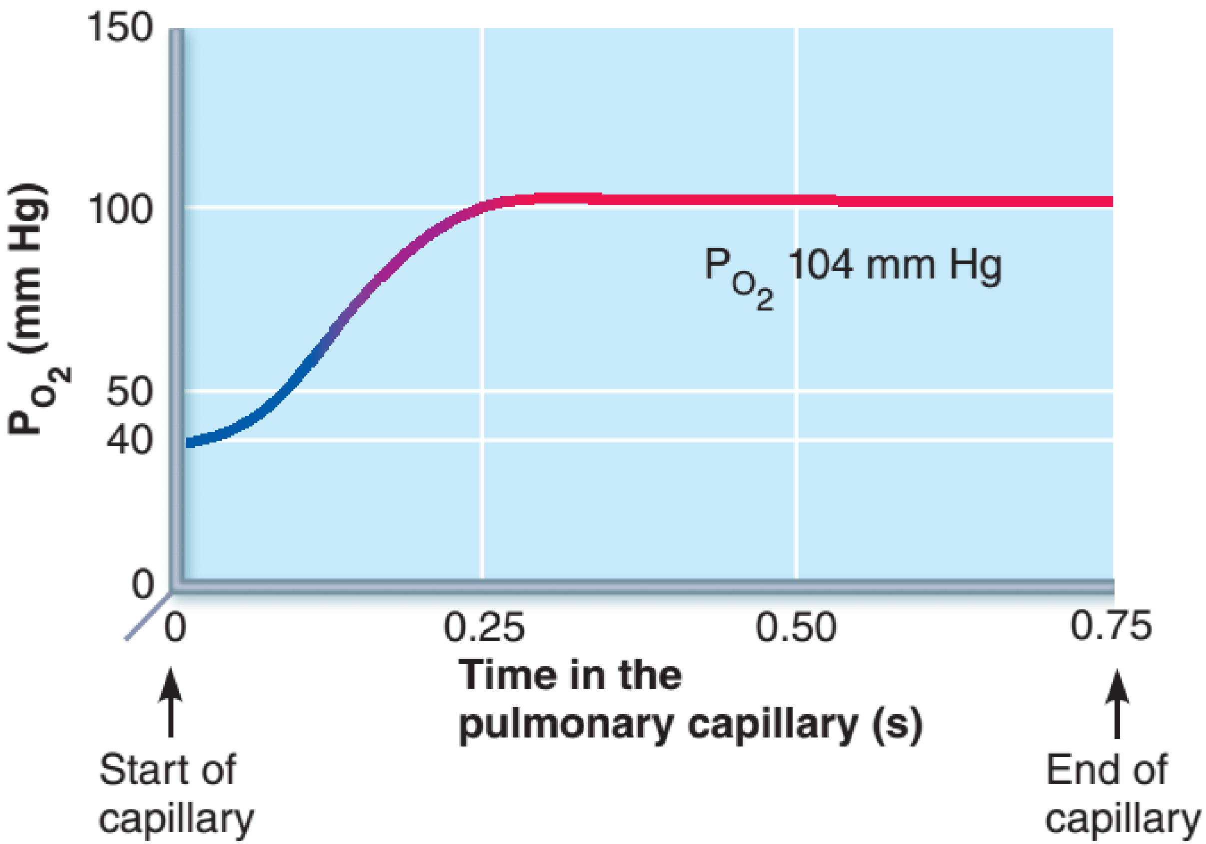
	ATMOSPHERE (SEA LEVEL)		*ALVEOLI*	
GAS	APPROXIMATE PERCENTAGE	PARTIAL PRESSURE (mm Hg)	APPROXIMATE PERCENTAGE	PARTIAL PRESSURE (mm Hg)
N_2	78.6	597	74.9	569
O_2	20.9	159	13.7	104
CO_2	0.04	0.3	5.2	40
H_2O	0.46	3.7	6.2	47
	100.0%	760	100.0%	760


Inspired air:
P_{O_2} 160 mm Hg
P_{CO_2} 0.3 mm Hg
O_2 CO_2
Alveoli of lungs:
P_{O_2} 104 mm Hg
P_{CO_2} 40 mm Hg
O_2 CO_2
CO_2 O_2
External respiration
Alveoli
Pulmonary arteries
Pulmonary veins (P_{O_2} 100 mm Hg)
Blood leaving tissues and entering lungs:
P_{O_2} 40 mm Hg
P_{CO_2} 45 mm Hg
O_2 CO_2
Blood leaving lungs and entering tissue capillaries:
P_{O_2} 100 mm Hg
P_{CO_2} 40 mm Hg
O_2 CO_2
Heart
Systemic veins
Systemic arteries
Internal respiration
CO_2 O_2
Tissues:
P_{O_2} less than 40 mm Hg
P_{CO_2} greater than 45 mm Hg
O_2 CO_2



Partial pressures of oxygen and carbon dioxide in atmospheric air, alveolar air, and

Thickness and Surface area of the Respiratory Membrane

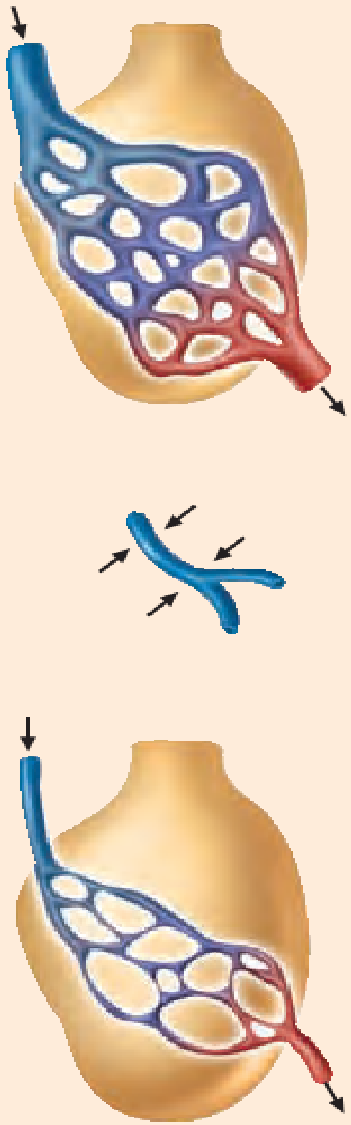


oxygenation of blood in the pulmonary capillaries at rest. Oxygen loading only takes about one-third of the time a red blood cell spends in the pulmonary capillary.

Ventilation-Perfusion Coupling

- For optimal gas exchange, there must be a close match, or coupling, between ventilation (the amount of gas reaching the alveoli) or the rate of air flow to the alveoli) and perfusion (the blood flow in pulmonary capillaries or rate of blood flow to the lung).
- P_{O2} controls perfusion by changing *arteriolar* diameter
- P_{CO2} controls ventilation by changing bronchiolar diameter.

(a) Ventilation less than perfusion



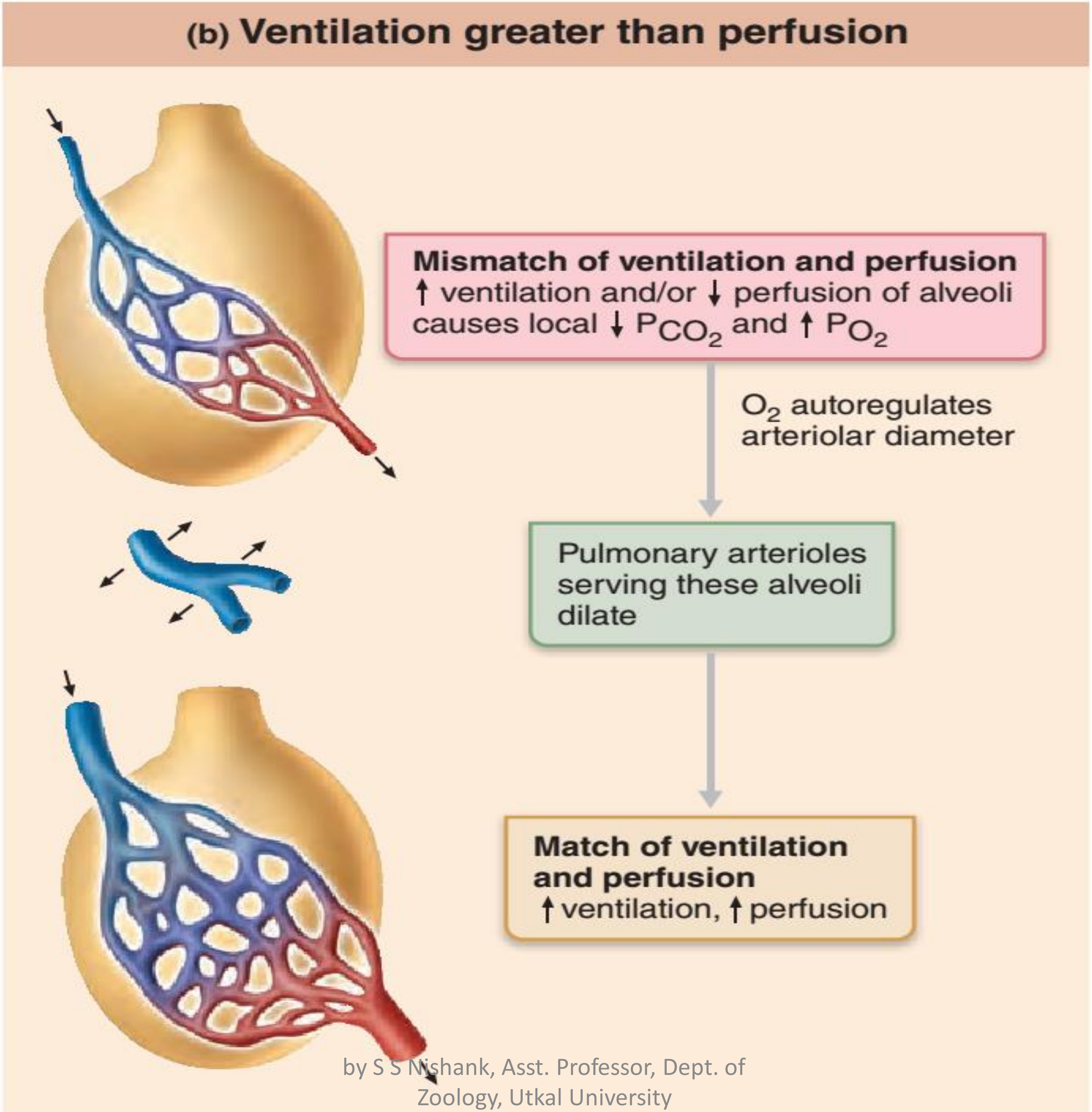
Mismatch of ventilation and perfusion
↓ ventilation and/or ↑ perfusion of alveoli causes local ↑ P_{CO_2} and ↓ P_{O_2}

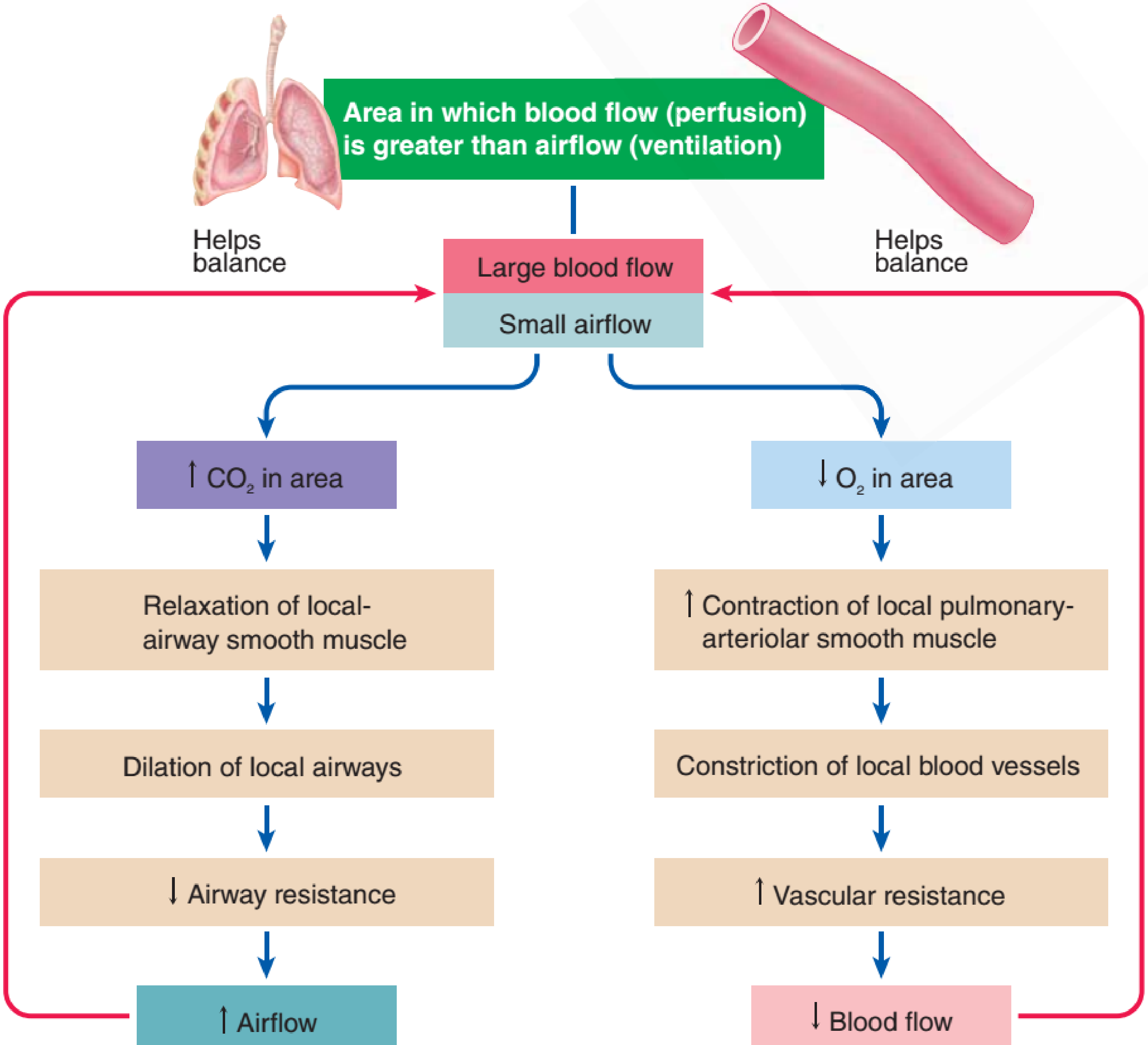
↓ O_2 autoregulates arteriolar diameter

Pulmonary arterioles serving these alveoli constrict

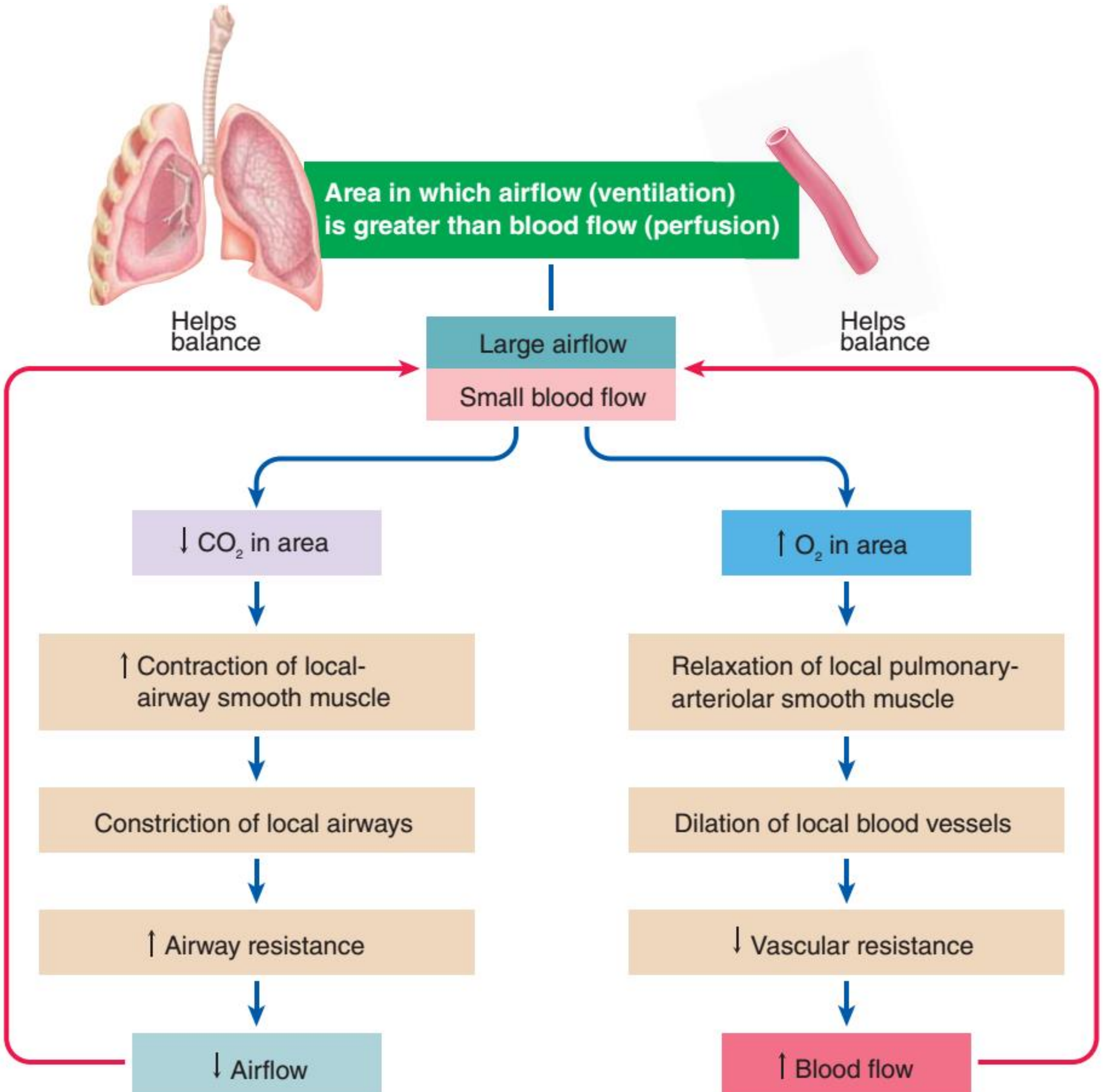
↓

Match of ventilation and perfusion
↓ ventilation, ↓ perfusion


(b) Ventilation greater than perfusion
Mismatch of ventilation and perfusion
↑ ventilation and/or ↓ perfusion of alveoli causes local ↓ P_{CO_2} and ↑ P_{O_2}
O_2 autoregulates arteriolar diameter
Pulmonary arterioles serving these alveoli dilate
Match of ventilation and perfusion
↑ ventilation, ↑ perfusion



Area in which blood flow (perfusion) is greater than airflow (ventilation)
Large blood flow
Small airflow
Helps balance
Helps balance
↑ CO_2 in area
↓ O_2 in area
Relaxation of local-airway smooth muscle
↑ Contraction of local pulmonary-arteriolar smooth muscle
Dilation of local airways
Constriction of local blood vessels
↓ Airway resistance
↑ Vascular resistance
↑ Airflow
↓ Blood flow


Area in which airflow (ventilation) is greater than blood flow (perfusion)
Helps balance
Helps balance
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↓ CO_2 in area
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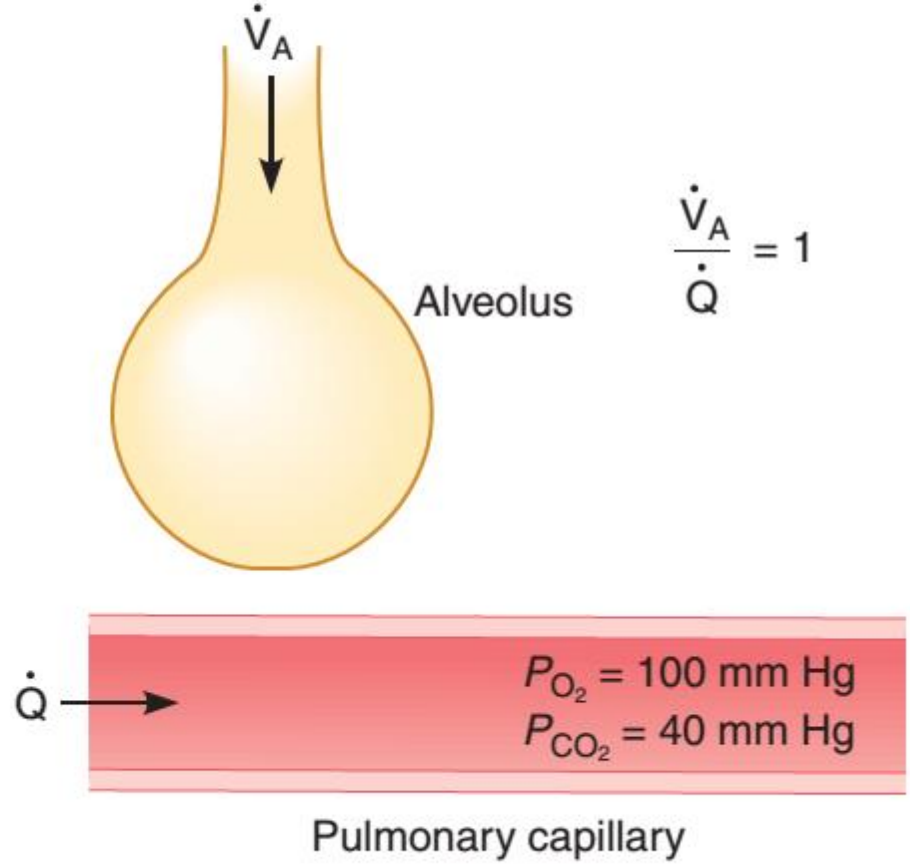
↑ Contraction of local-airway smooth muscle
Relaxation of local pulmonary-arteriolar smooth muscle
Constriction of local airways
Dilation of local blood vessels
↑ Airway resistance
↓ Vascular resistance
↓ Airflow
↑ Blood flow

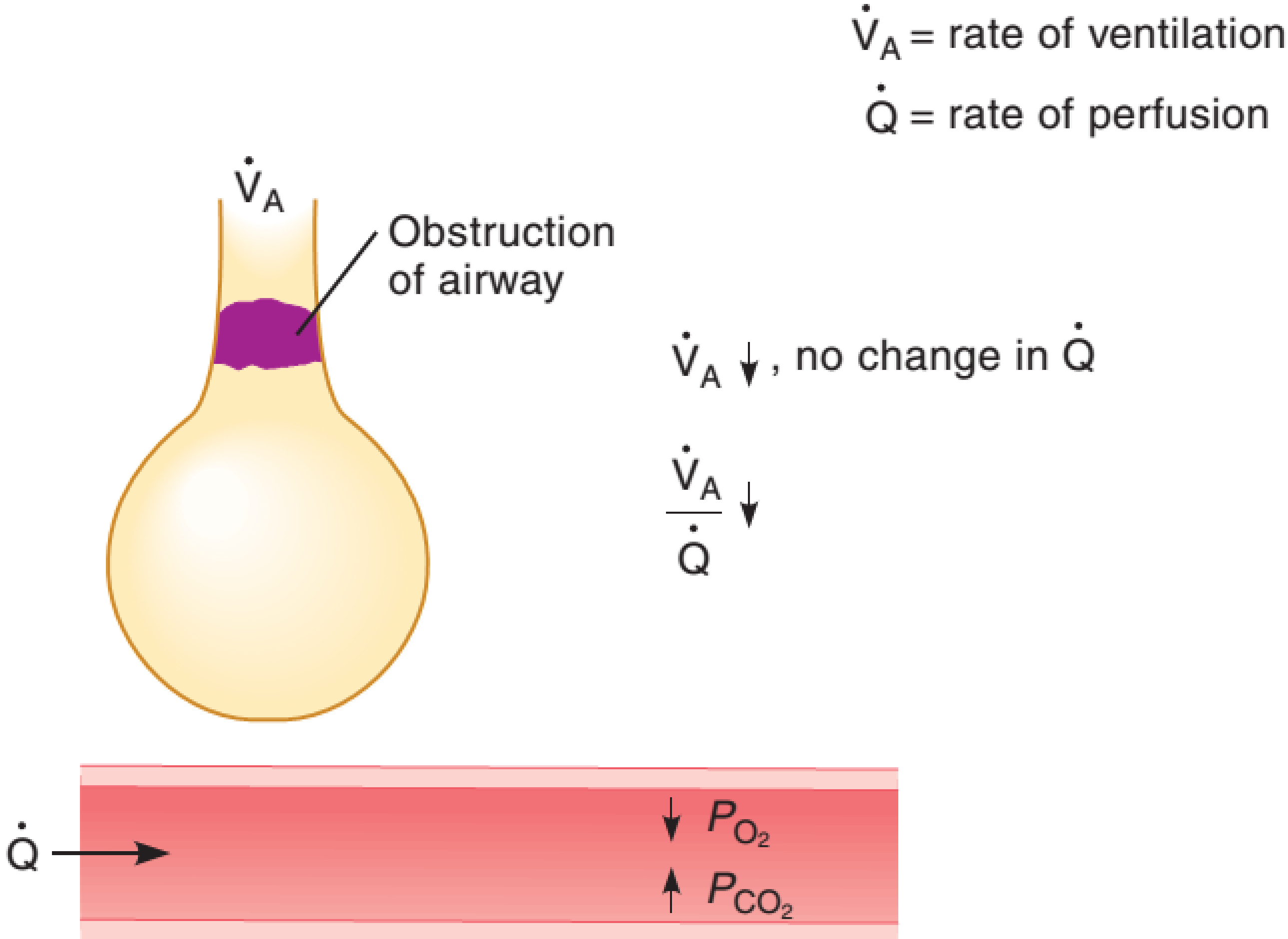
Factors That Influence the Rate of Gas Transfer across the Alveolar Membrane

Factor	Influence on the Rate of Gas Transfer Across the Alveolar Membrane	Comments
Partial Pressure Gradients of O_2 and CO_2	Rate of transfer ↑ as partial pressure gradient ↑	Major determinant of the rate of transfer
Surface Area of the Alveolar Membrane	Rate of transfer ↑ as surface area ↑	Surface area remains constant under resting conditions Surface area ↑ during exercise as more pulmonary capillaries open up when the cardiac output increases and the alveoli expand as breathing becomes deeper Surface area ↓ with pathological conditions such as emphysema and lung collapse
Thickness of the Barrier Separating the Air and Blood across the Alveolar Membrane	Rate of transfer ↓ as thickness ↑	Thickness normally remains constant Thickness ↑ with pathological conditions such as pulmonary edema, pulmonary fibrosis, and pneumonia
Diffusion Constant (Related to the Gas's Solubility and Molecular Weight)	Rate of transfer ↑ as diffusion constant ↑	Diffusion constant for CO_2 is 20 times that of O_2, offsetting the smaller partial pressure gradient for CO_2; therefore, approximately equal amounts of CO_2 and O_2 are transferred across the membrane

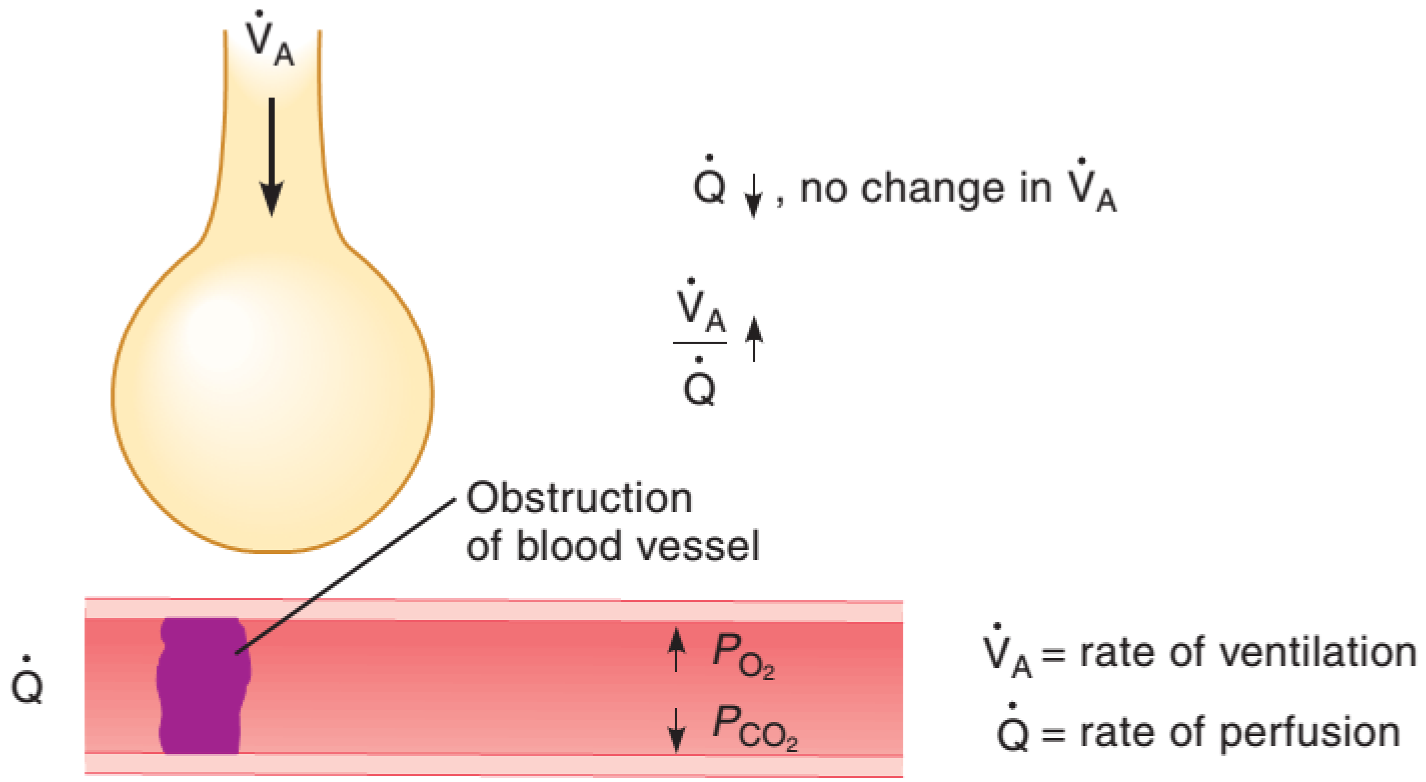
$\dot{V}_A$ = rate of ventilation
$\dot{Q}$ = rate of perfusion



(a) Normal

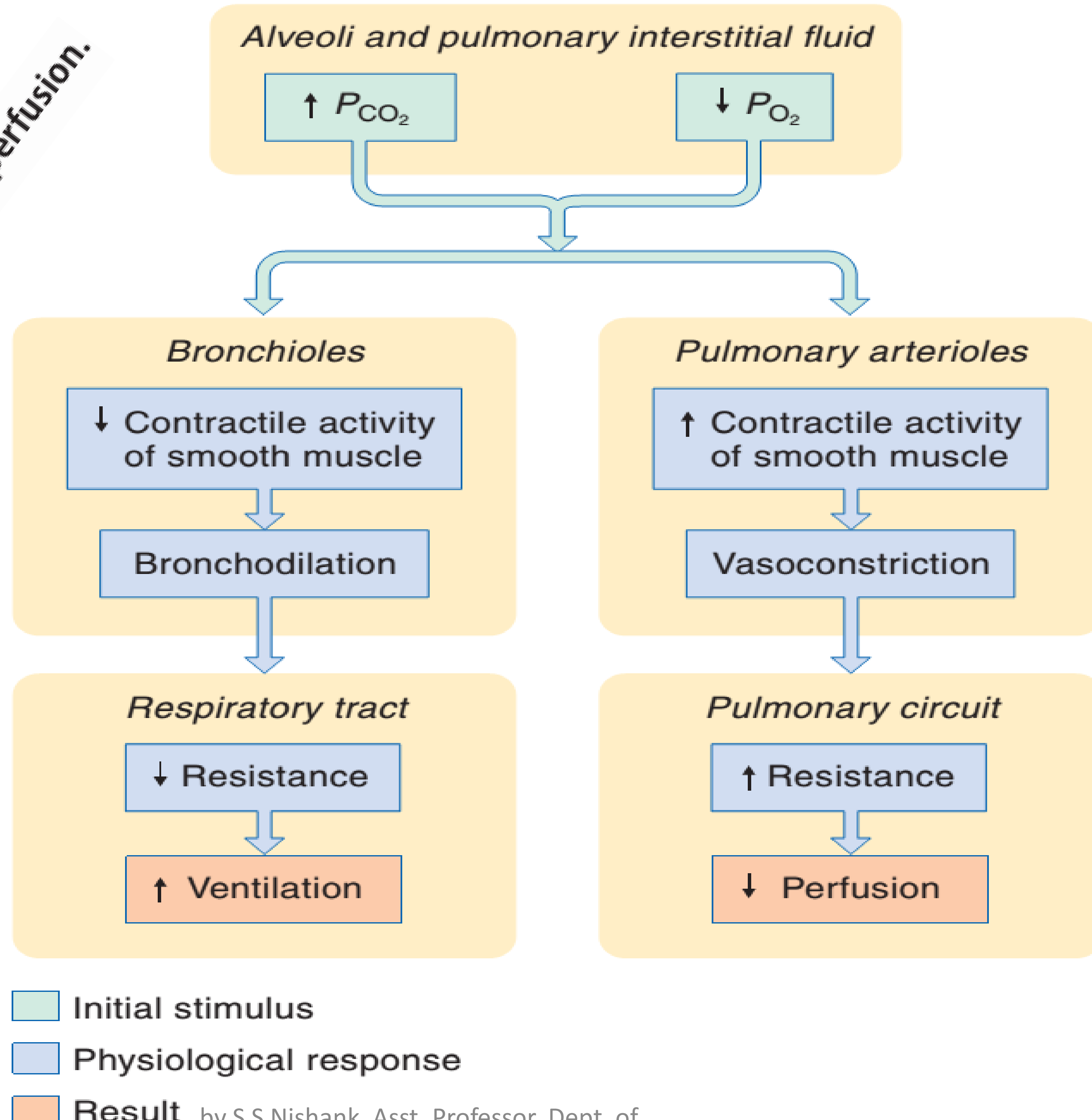


(b) Decreased ventilation



(c) Decreased perfusion

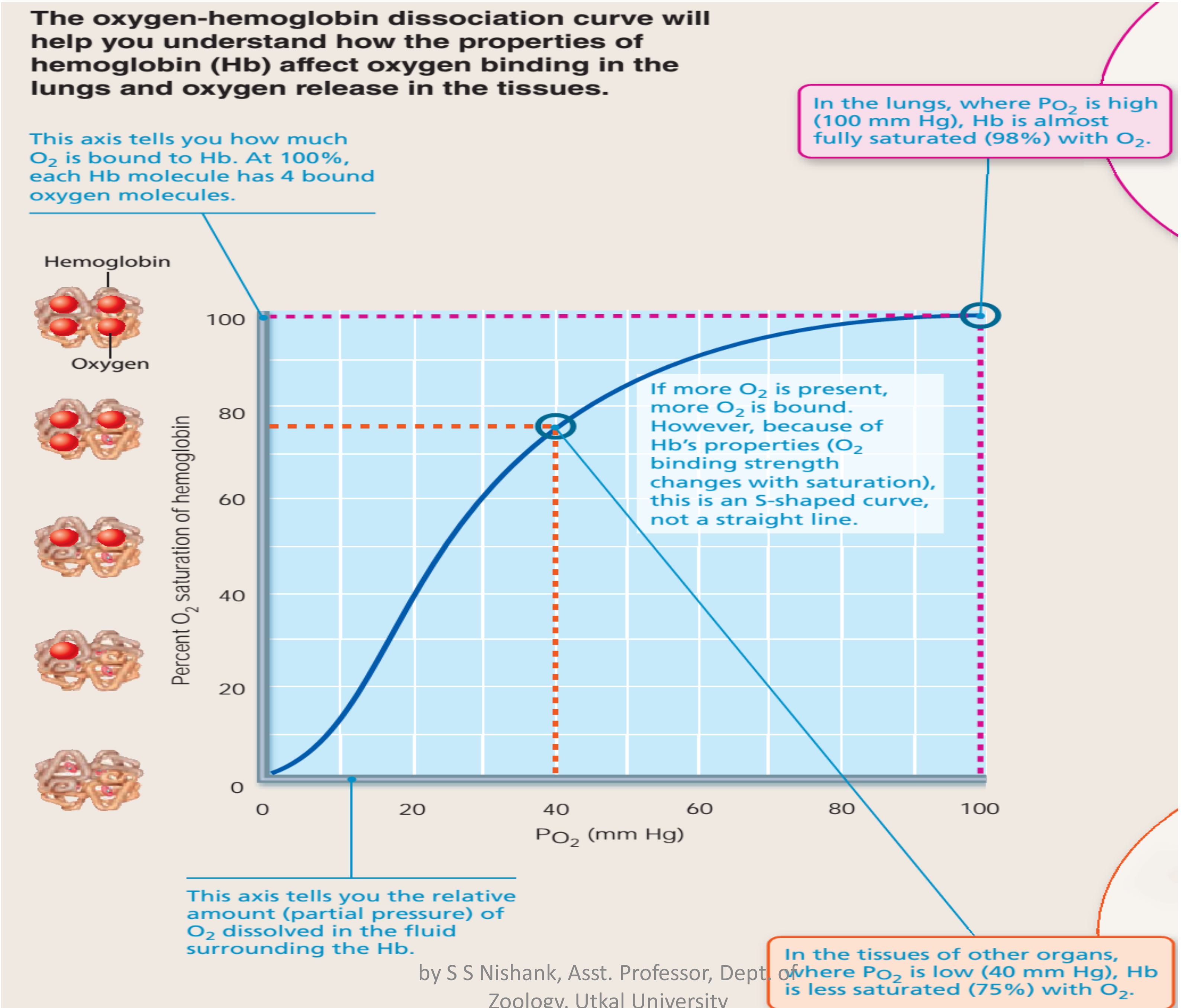
Local controls of ventilation and perfusion.

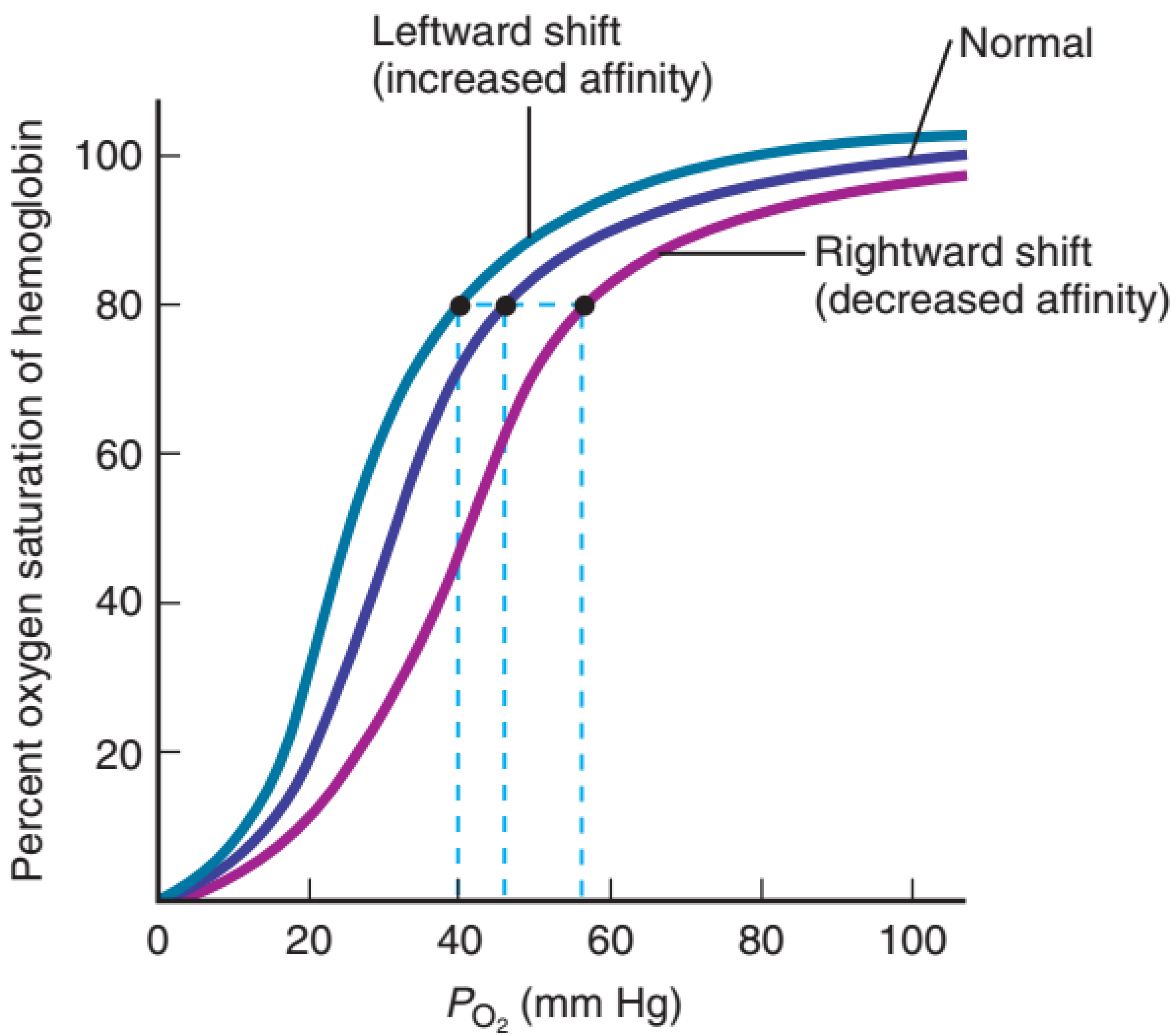


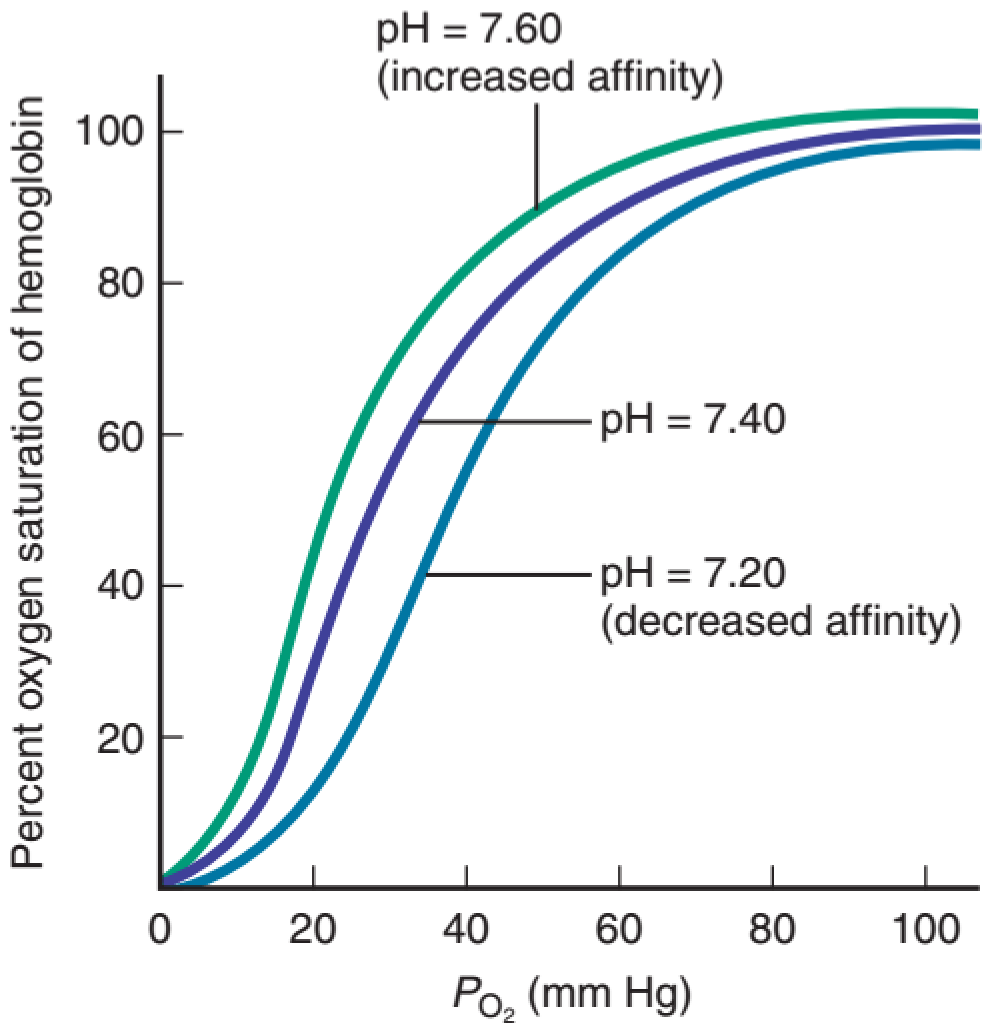
Transport of respiratory gases

Methods of Gas Transport in the Blood

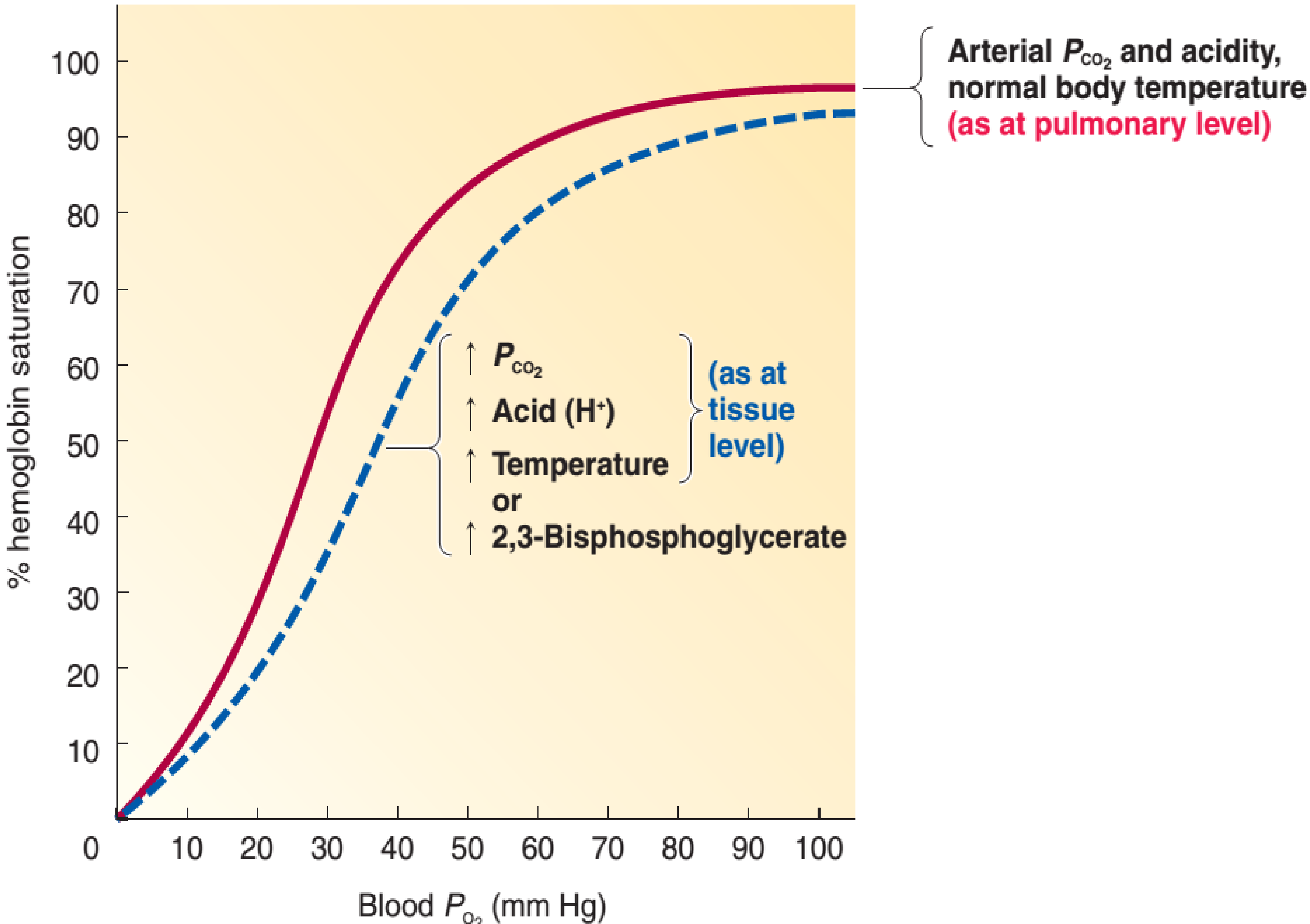
Gas	Method of Transport in Blood	Percentage Carried in This Form
O_2	Physically dissolved	1.5
	Bound to hemoglobin	98.5
CO_2	Physically dissolved	10
	Bound to hemoglobin	30
	As bicarbonate (HCO_3^-)	60


The oxygen-hemoglobin dissociation curve will help you understand how the properties of hemoglobin (Hb) affect oxygen binding in the lungs and oxygen release in the tissues.
This axis tells you how much O_2 is bound to Hb. At 100%, each Hb molecule has 4 bound oxygen molecules.
Hemoglobin
Oxygen
In the lungs, where P_{O_2} is high (100 mm Hg), Hb is almost fully saturated (98%) with O_2.
If more O_2 is present, more O_2 is bound. However, because of Hb's properties (O_2 binding strength changes with saturation), this is an S-shaped curve, not a straight line.
Percent O_2 saturation of hemoglobin
100
80
60
40
20
0
0
20
40
60
80
100
P_{O_2} (mm Hg)
This axis tells you the relative amount (partial pressure) of O_2 dissolved in the fluid surrounding the Hb.
In the tissues of other organs, where P_{O_2} is low (40 mm Hg), Hb is less saturated (75%) with O_2.

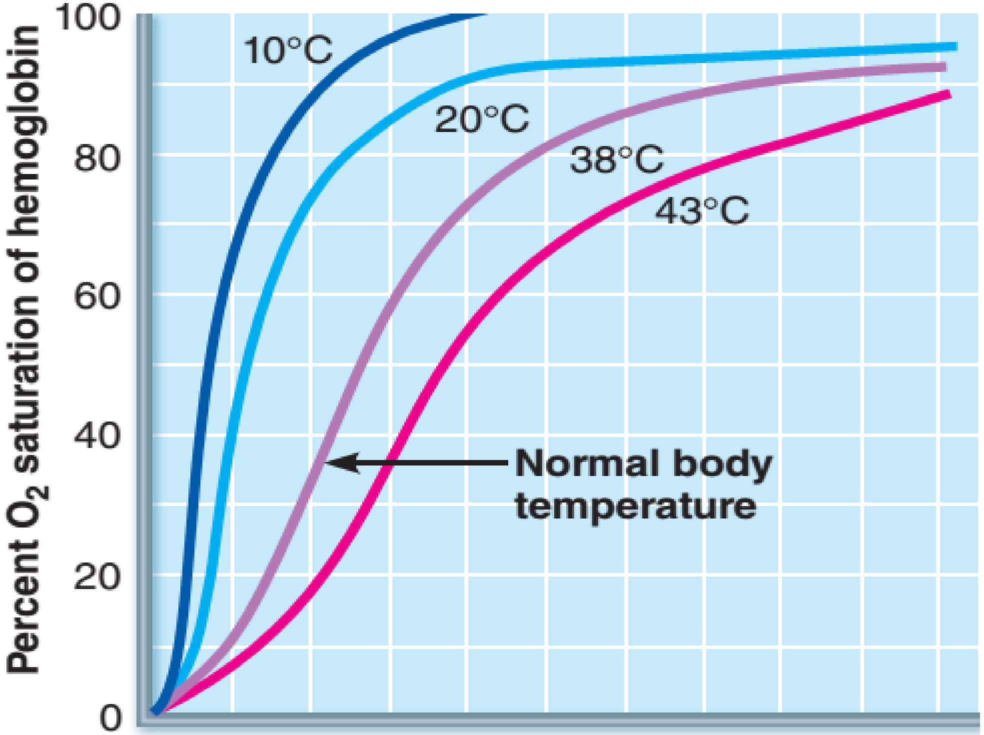

Leftward shift
(increased affinity)
Normal
Rightward shift
(decreased affinity)
Percent oxygen saturation of hemoglobin
100
80
60
40
20
0
20
40
60
80
100
P_{O_2} (mm Hg)

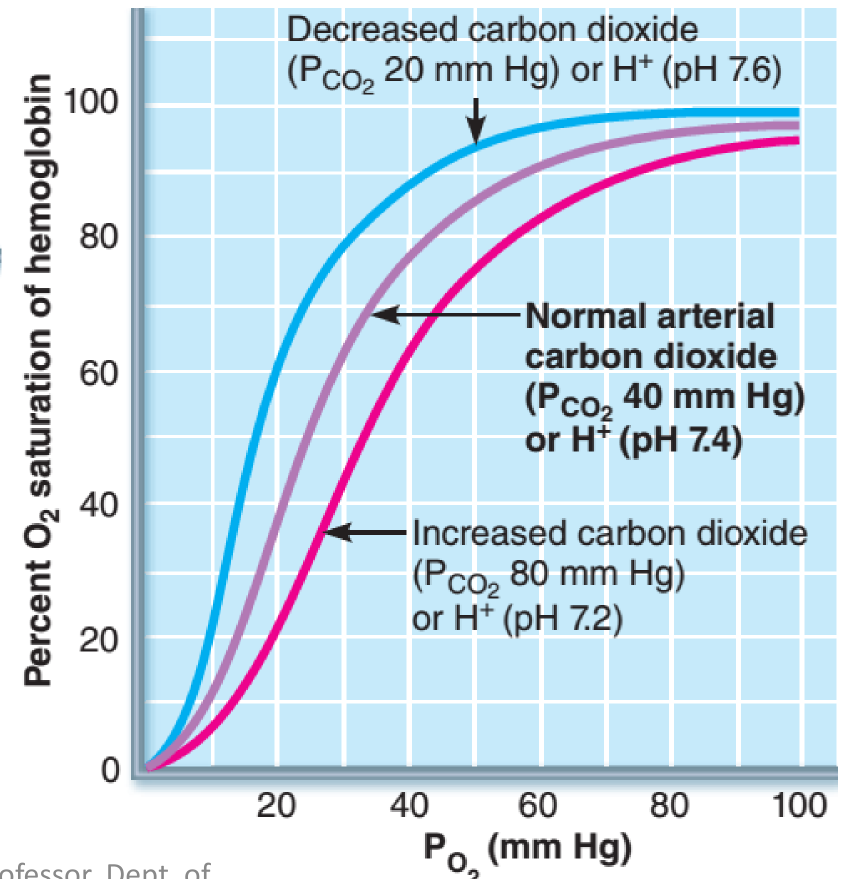


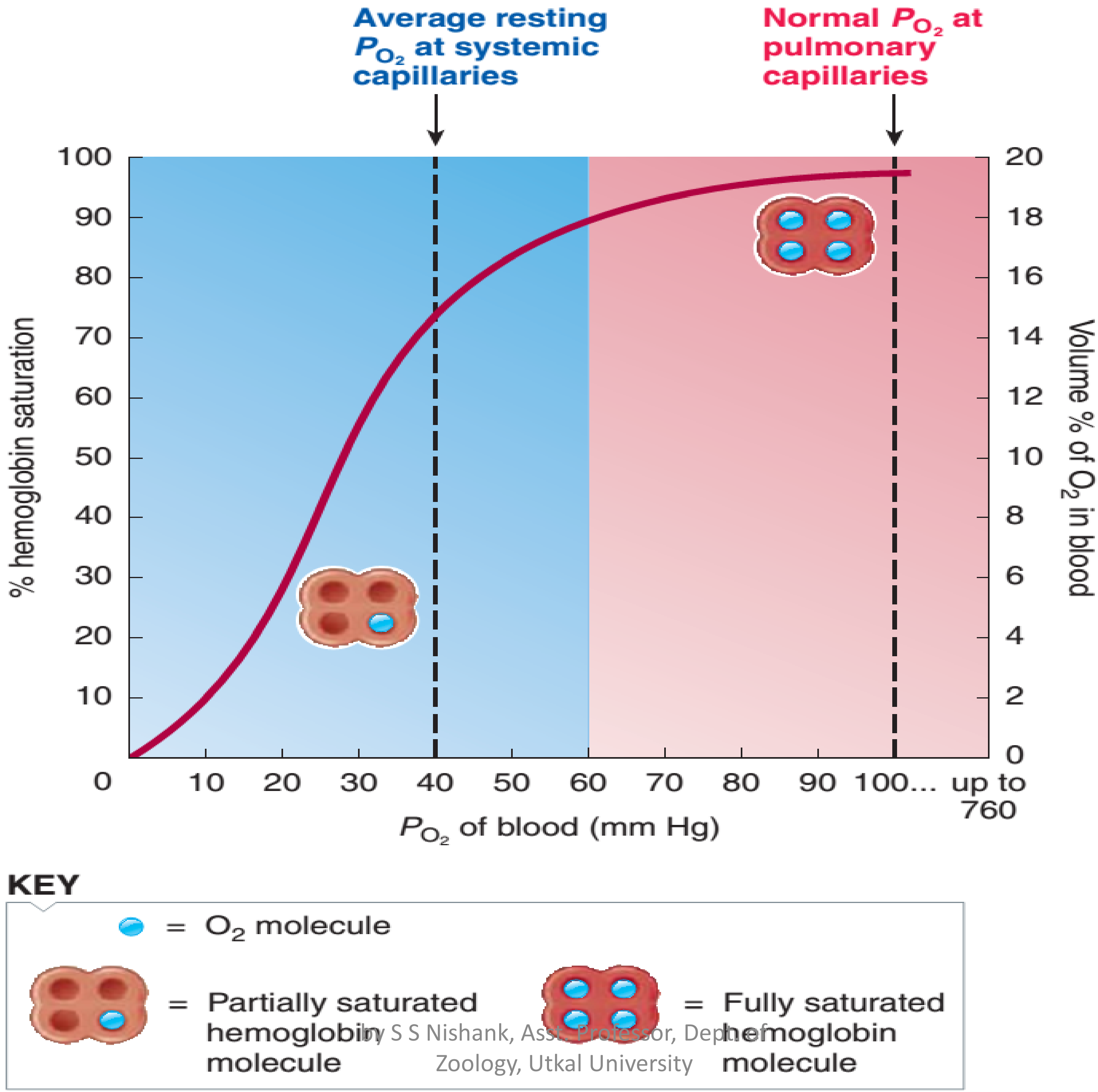
(b) Effects of pH



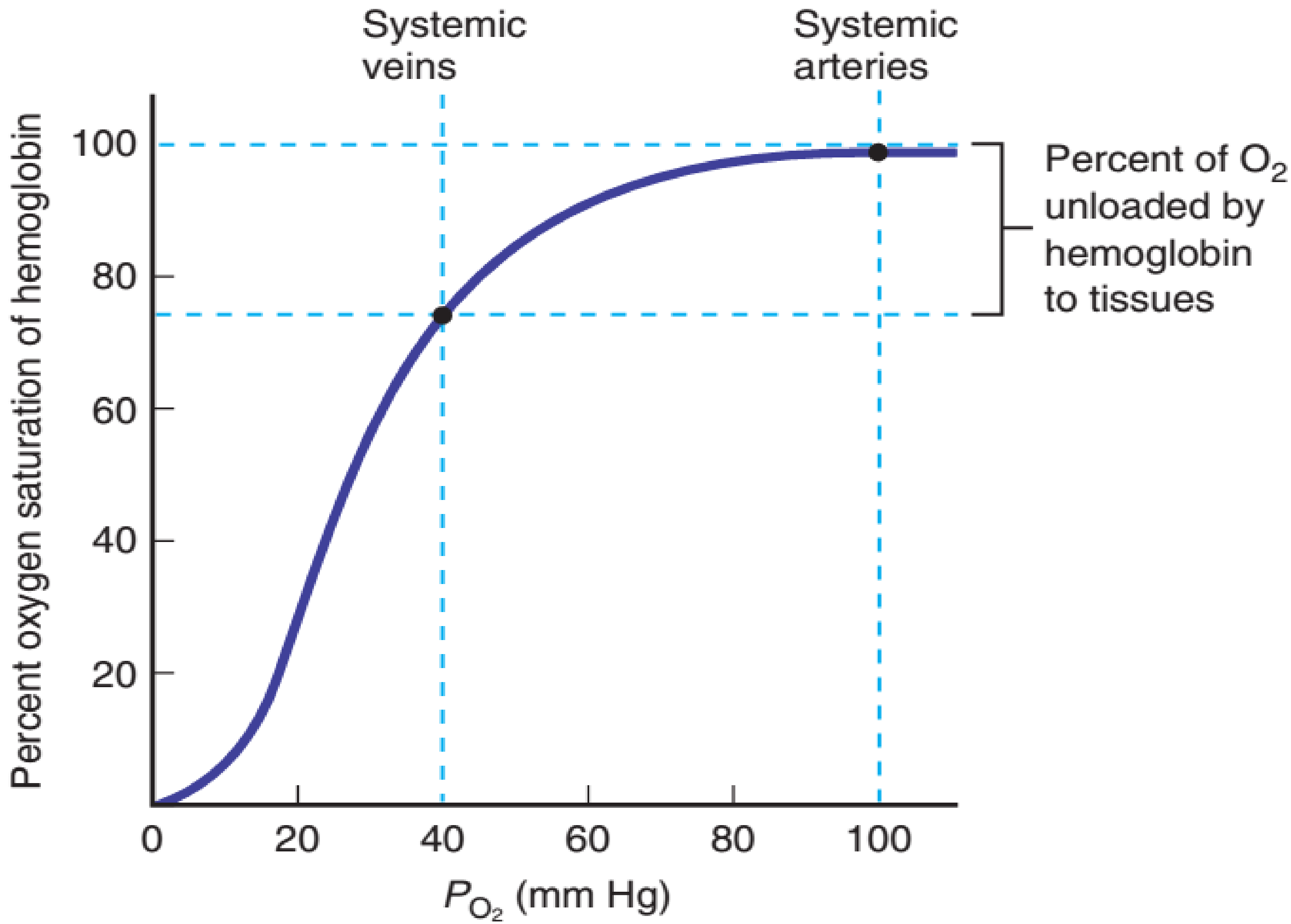
% hemoglobin saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
Blood P_{O_2} (mm Hg)
Arterial P_{CO_2} and acidity, normal body temperature
(as at pulmonary level)
↑ P_{CO_2}
↑ Acid (H^+)
↑ Temperature
or
↑ 2,3-Bisphosphoglycerate
(as at tissue level)


100
80
60
40
20
0
Percent O_2 saturation of hemoglobin
10°C
20°C
38°C
43°C
Normal body temperature


Decreased carbon dioxide (P_{CO_2} 20 mm Hg) or H^+ (pH 7.6)
Normal arterial carbon dioxide (P_{CO_2} 40 mm Hg) or H^+ (pH 7.4)
Increased carbon dioxide (P_{CO_2} 80 mm Hg) or H^+ (pH 7.2)
Percent O_2 saturation of hemoglobin
100
80
60
40
20
0
20
40
60
80
100
P_{O_2} (mm Hg)

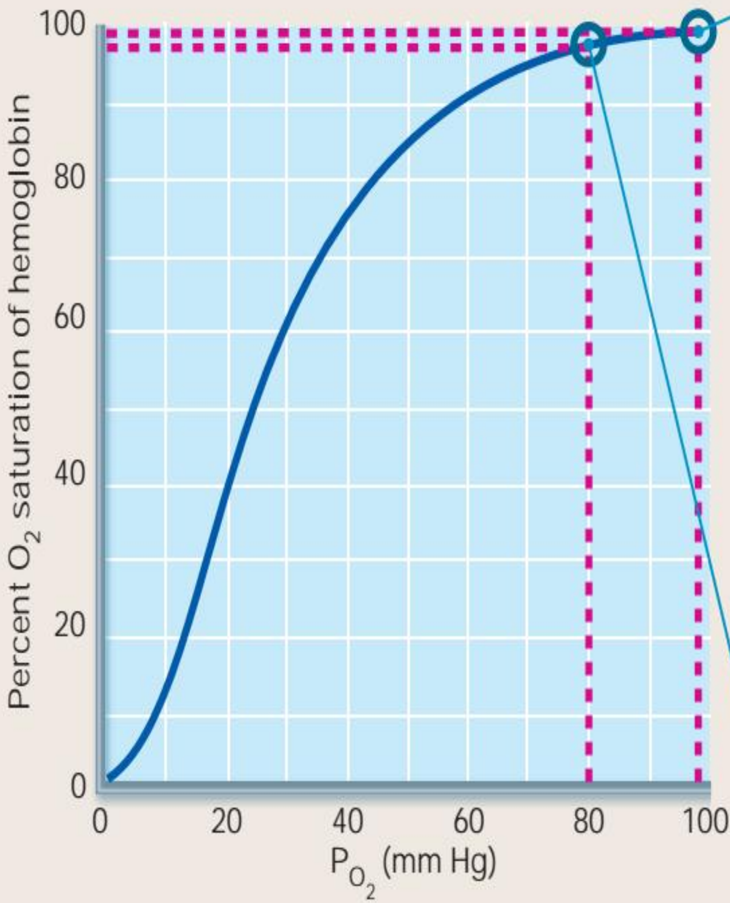


Average resting P_{O_2} at systemic capillaries
Normal P_{O_2} at pulmonary capillaries
100
90
80
70
60
50
40
30
20
10
0
% hemoglobin saturation
20
18
16
14
12
10
8
6
4
2
0
Volume % of O_2 in blood
10 20 30 40 50 60 70 80 90 100... up to 760
P_{O_2} of blood (mm Hg)
KEY
= O_2 molecule
= Partially saturated hemoglobin molecule
= Fully saturated hemoglobin molecule

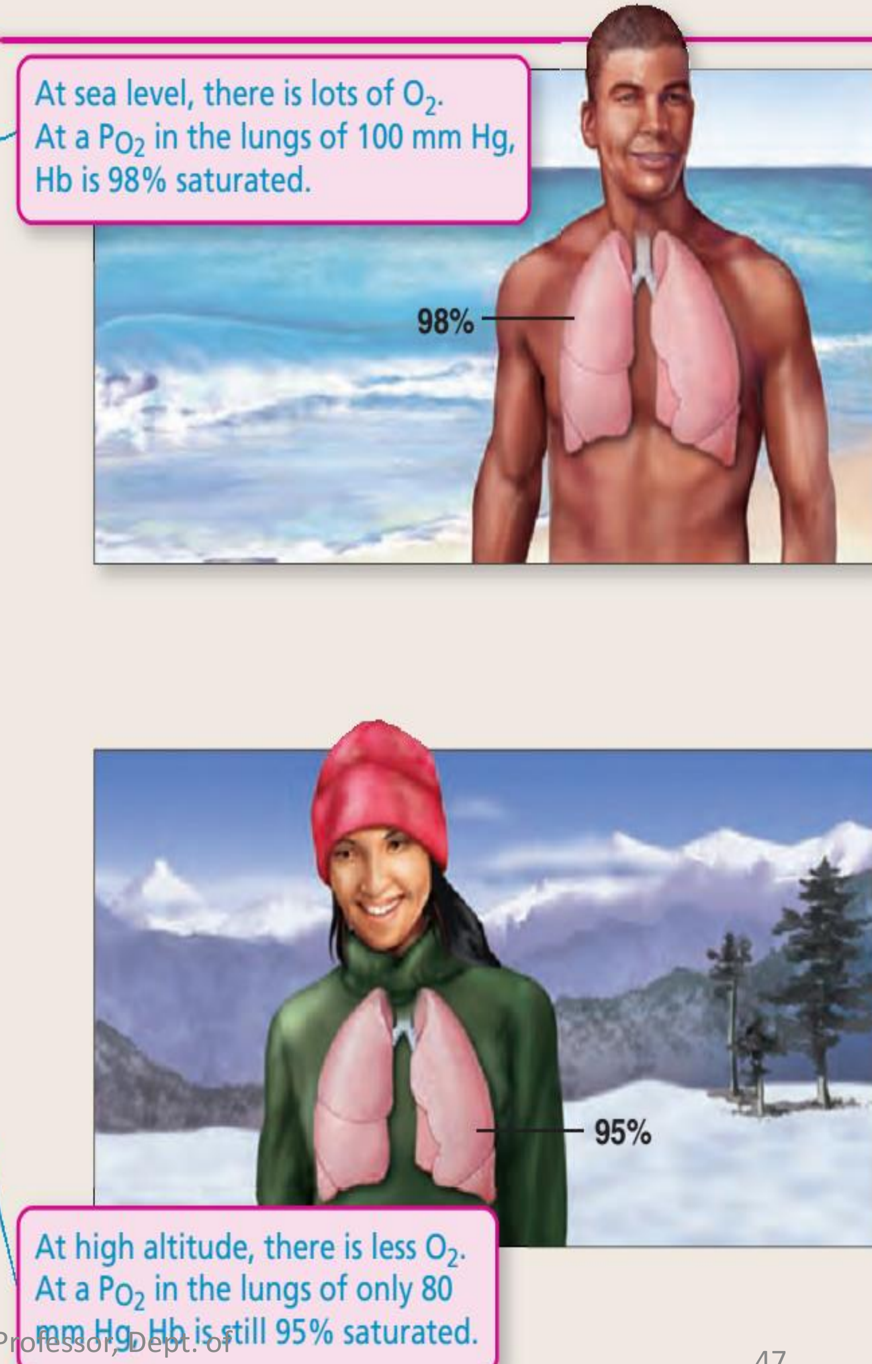


Hemoglobin-oxygen dissociation curve.

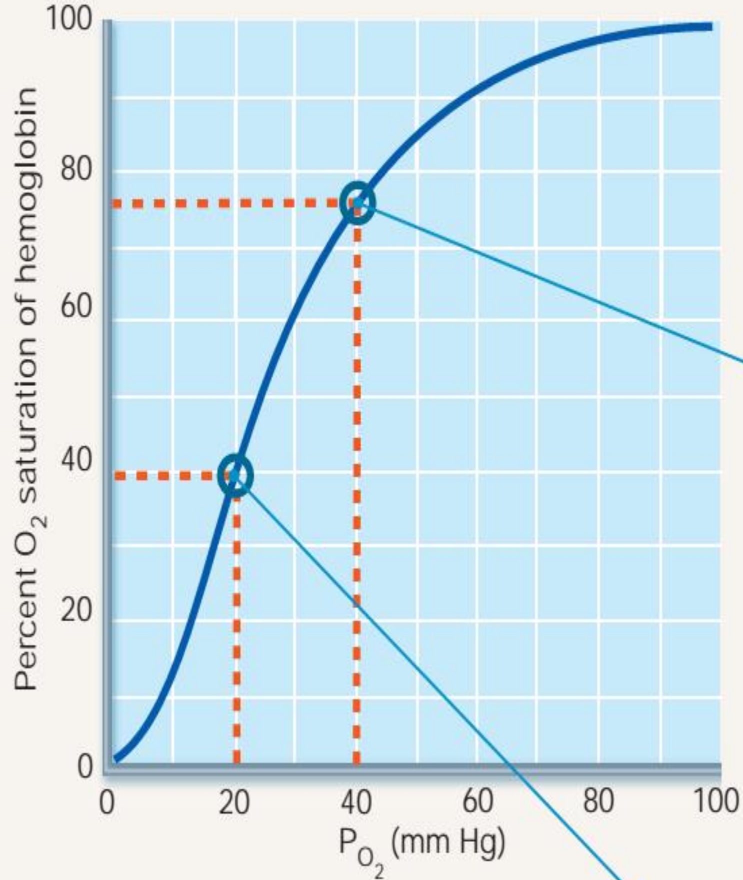
In the lungs



At high P_{O_2}, large changes in P_{O_2} cause only small changes in Hb saturation. Notice that the curve is relatively flat here. Hb's properties produce a *safety margin* that ensures that Hb is almost fully saturated even with a substantial P_{O_2} decrease. As a result, Hb remains saturated even at high altitude or with lung disease.

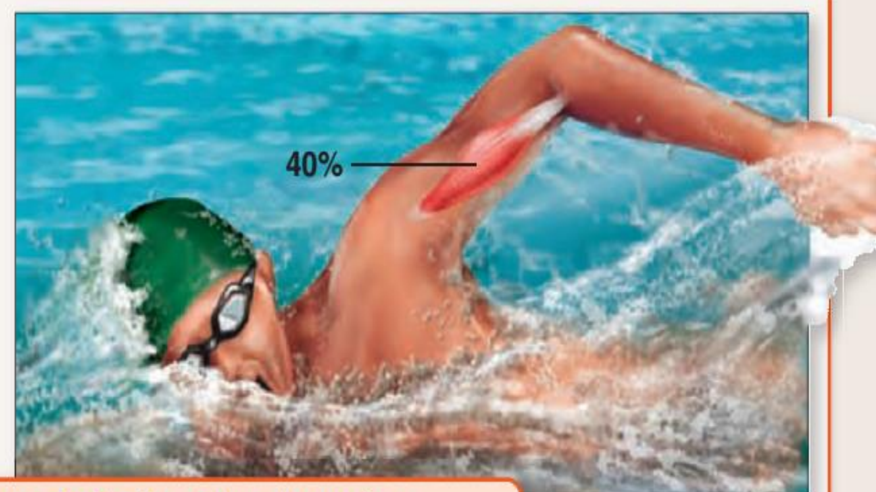


In the tissues

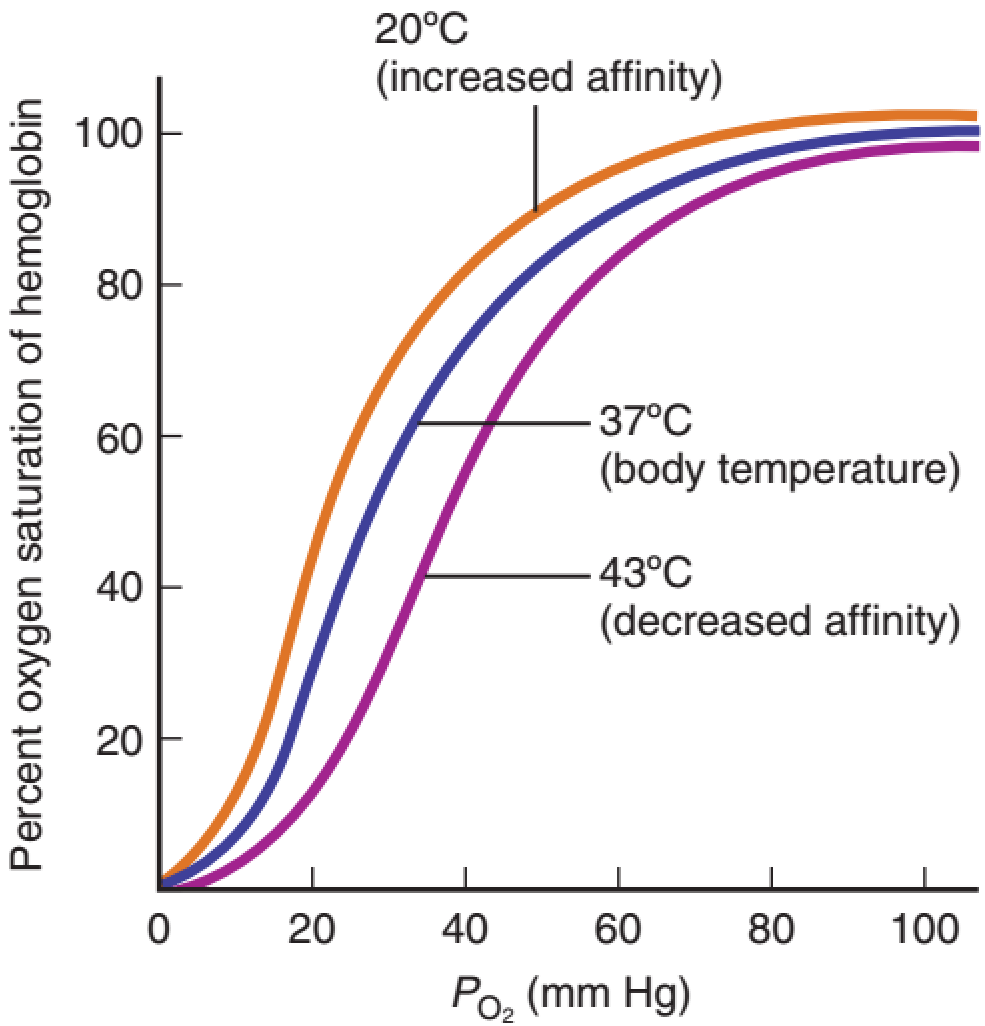


At low P_{O_2}, large changes in P_{O_2} cause large changes in Hb saturation. Tissues other than lungs have a low P_{O_2} because they consume O_2. Notice that the curve is relatively steep at low P_{O_2}. Hb's properties ensure that oxygen is delivered where it is most needed—when tissues need more, they get more.

In resting tissues, at a P_{O_2} of 40 mm Hg, Hb is 75% saturated—only 23% of O_2 carried by Hb is released.



In metabolically active tissues (e.g., exercising muscle), the P_{O_2} is even lower. At a P_{O_2} of 20 mm Hg, Hb is only 40% saturated—an additional 35% of O_2 has been unloaded for tissue use.



(a) Effects of temperature

Affinity of gases for hemoglobin

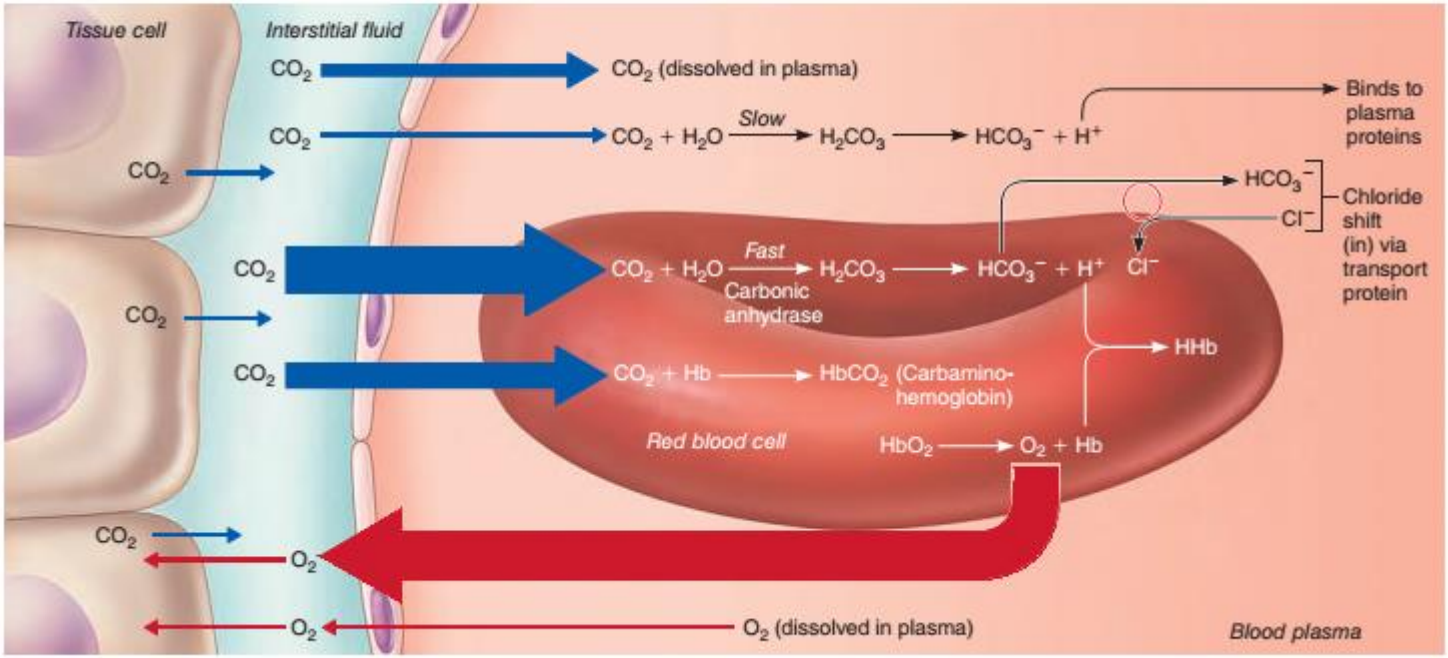
- **Bohr effect**: When *hydrogen ions bind to hemoglobin,* they decrease the *affinity of hemoglobin for oxygen*.

- **Carbamino effect**: When *carbon dioxide is bound to hemoglobin* it decreases the *affinity for oxygen*

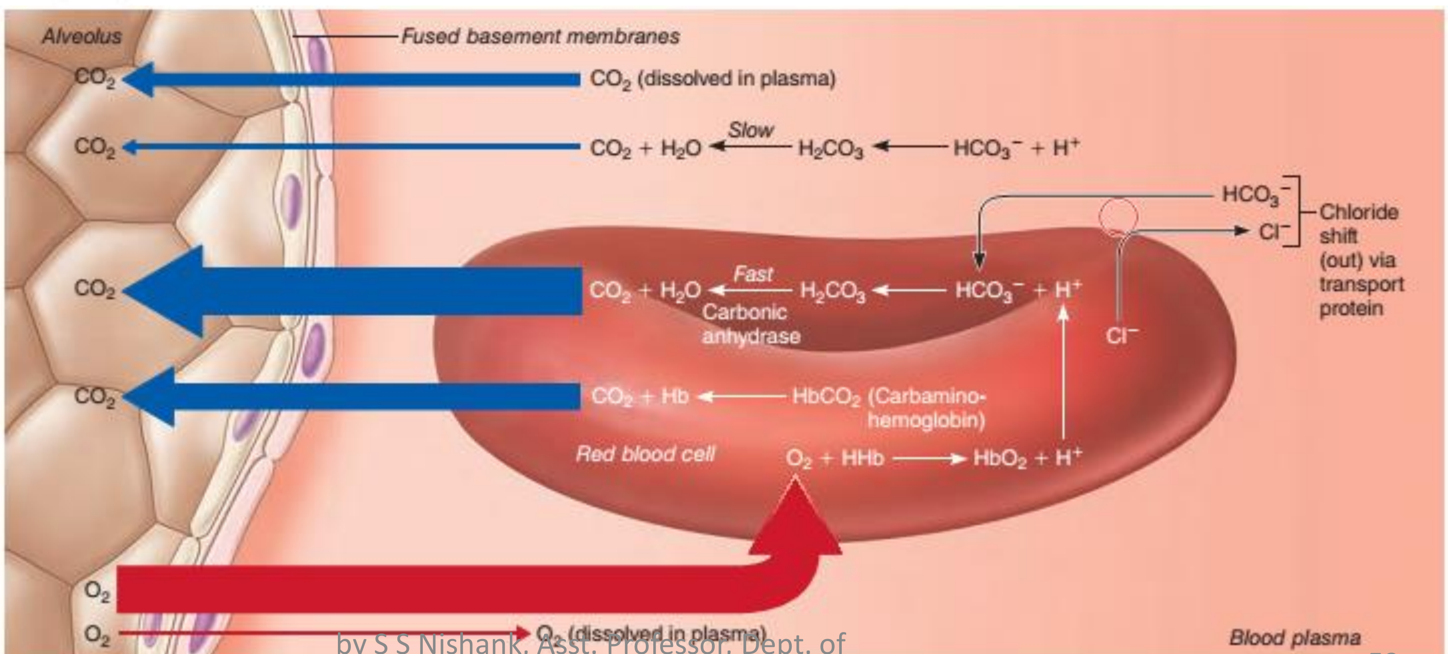
- **Haldane effect**: *Binding of oxygen to hemoglobin* decreases the *affinity of hemoglobin for carbon dioxide.*

CO_2 transport in blood

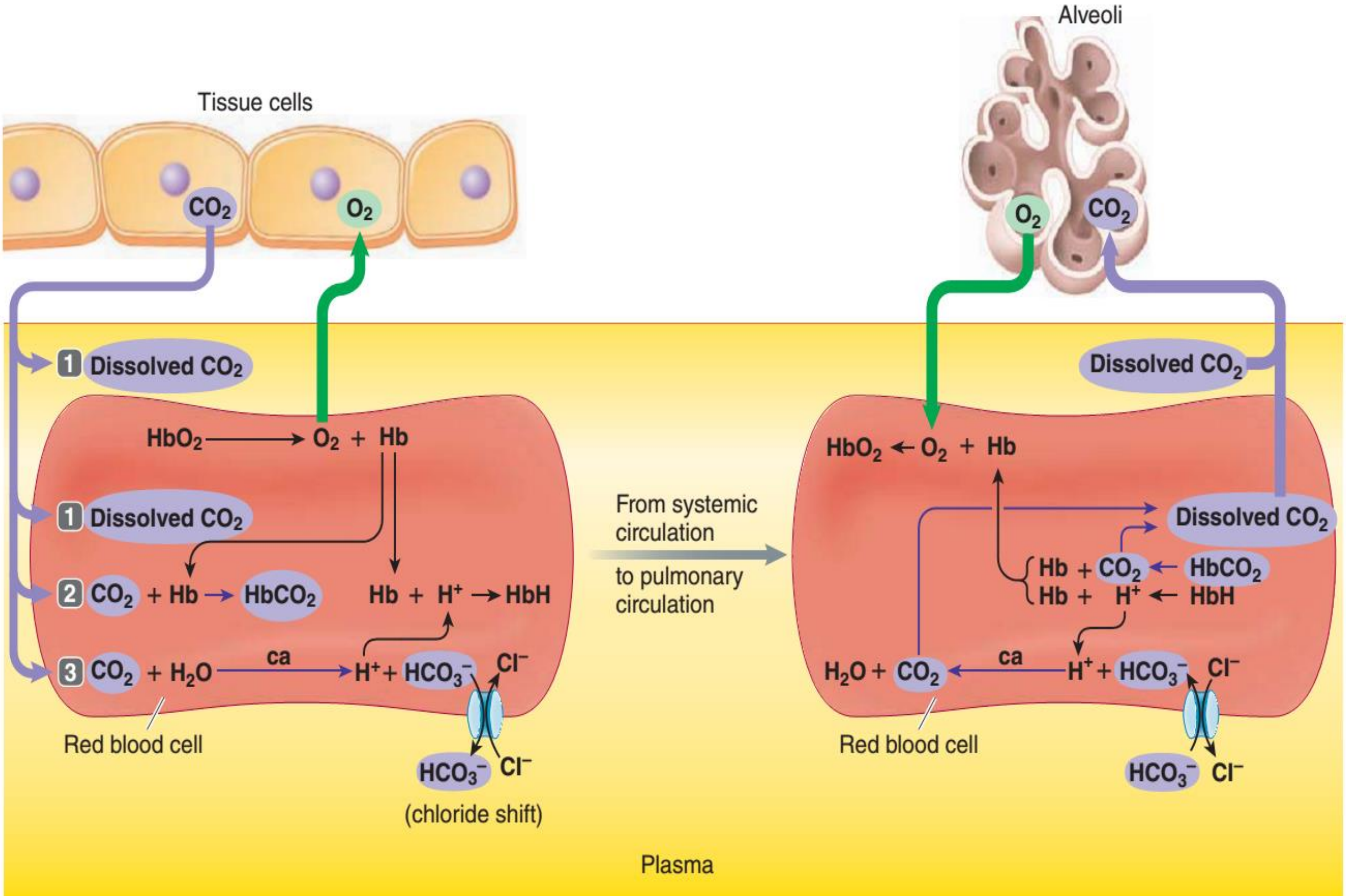
- 7 to 10% dissolved form in plasma
- 20% bound to hemoglobin as carbaminohemoglobin
- 70% dissolved as bicarbonate in RBC



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

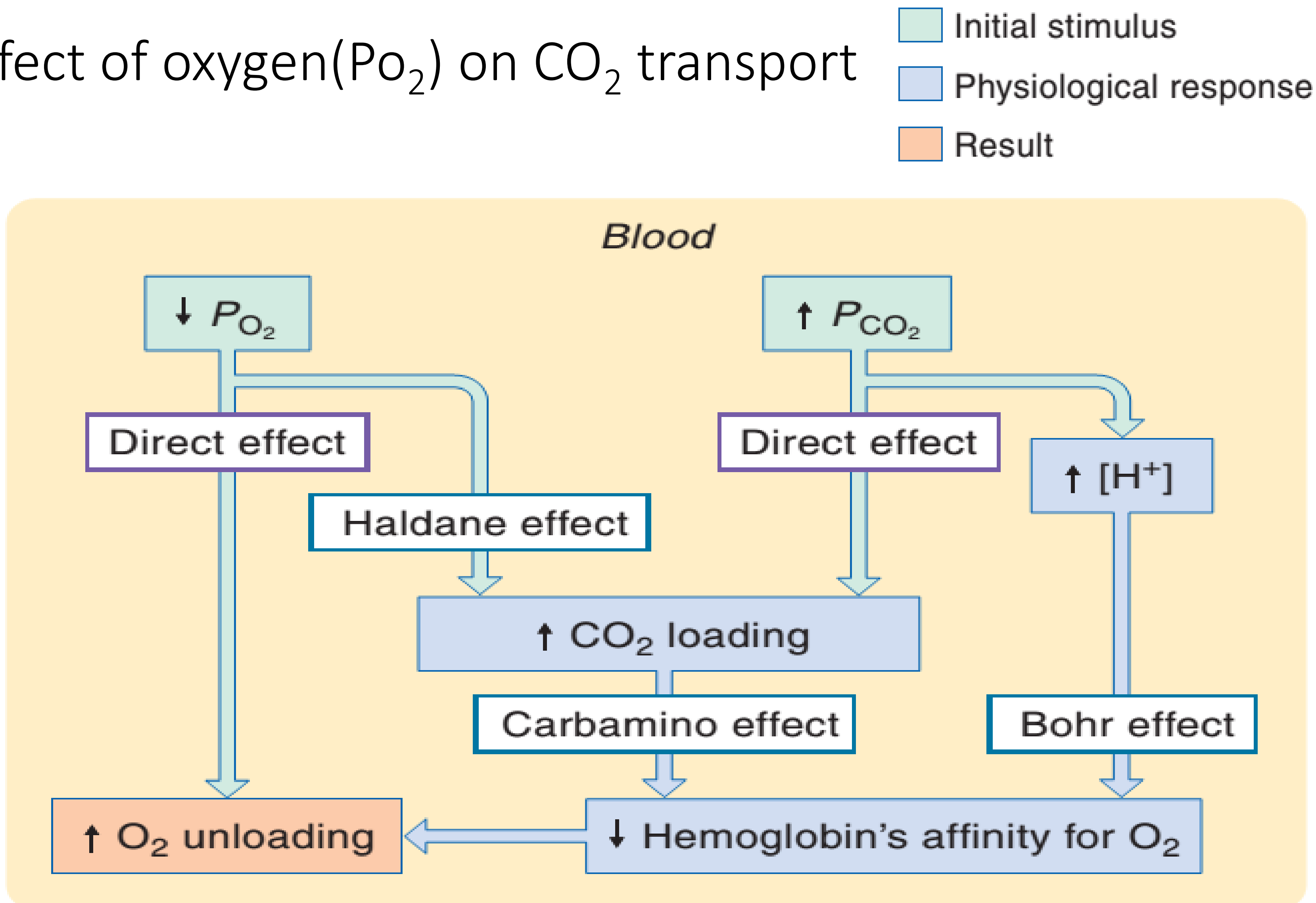


(b) Oxygen pickup and carbon dioxide release in the lungs



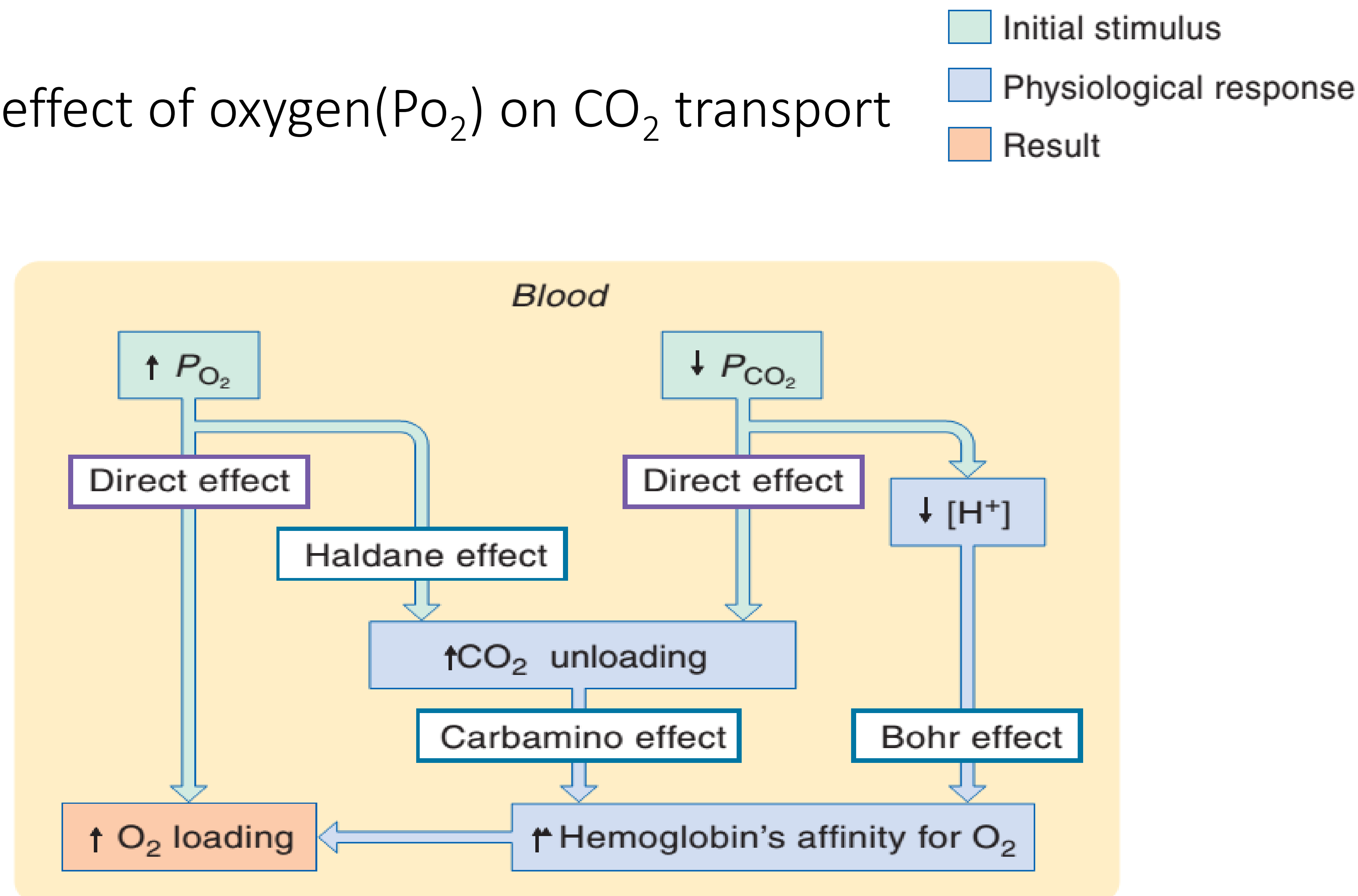
ca = Carbonic anhydrase

effect of oxygen(Po_2) on CO_2 transport



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

effect of oxygen(Po_2) on CO_2 transport

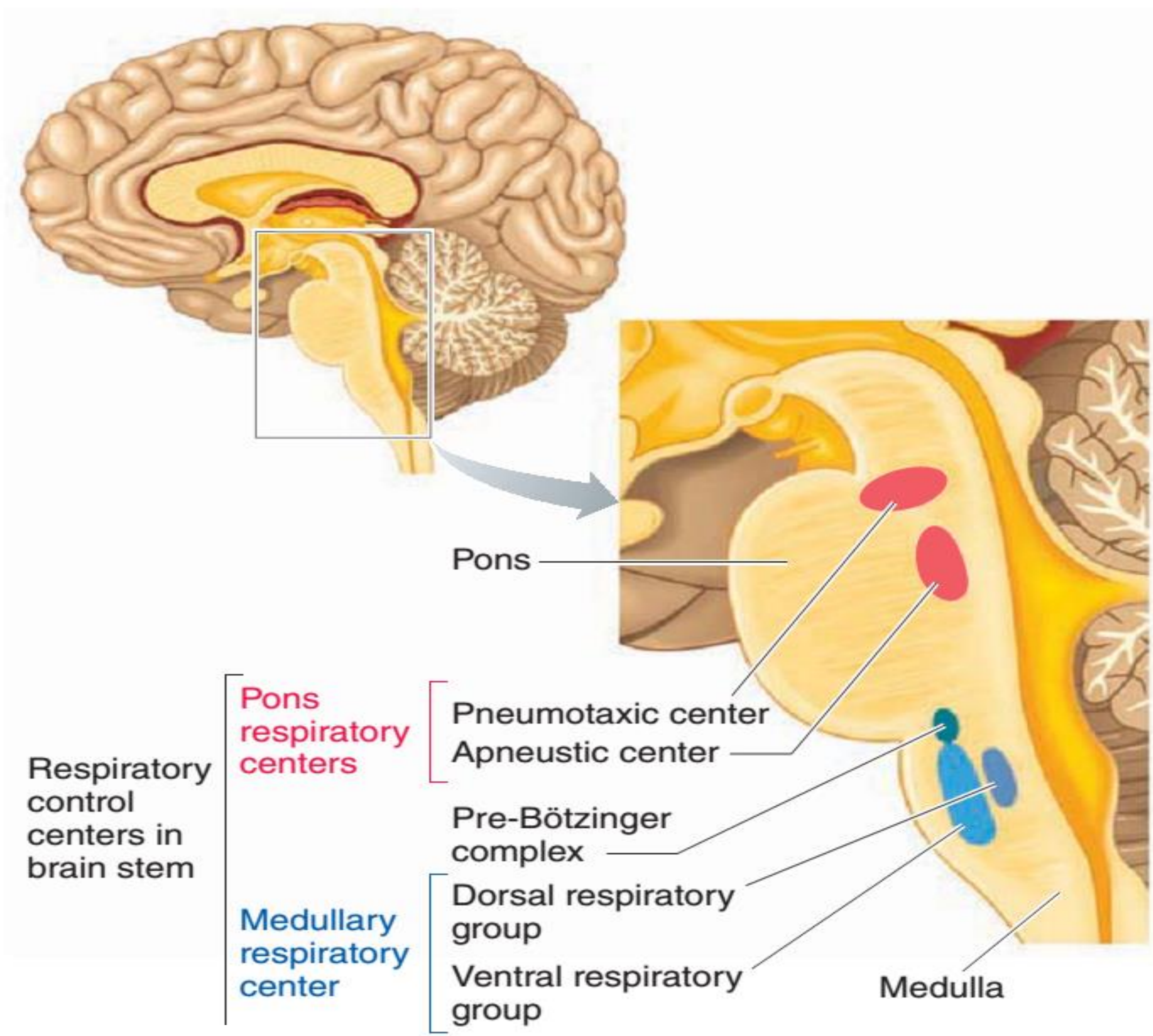


(b) CO_2 unloading and O_2 loading of hemoglobin in lungs

Regulation of Respiration

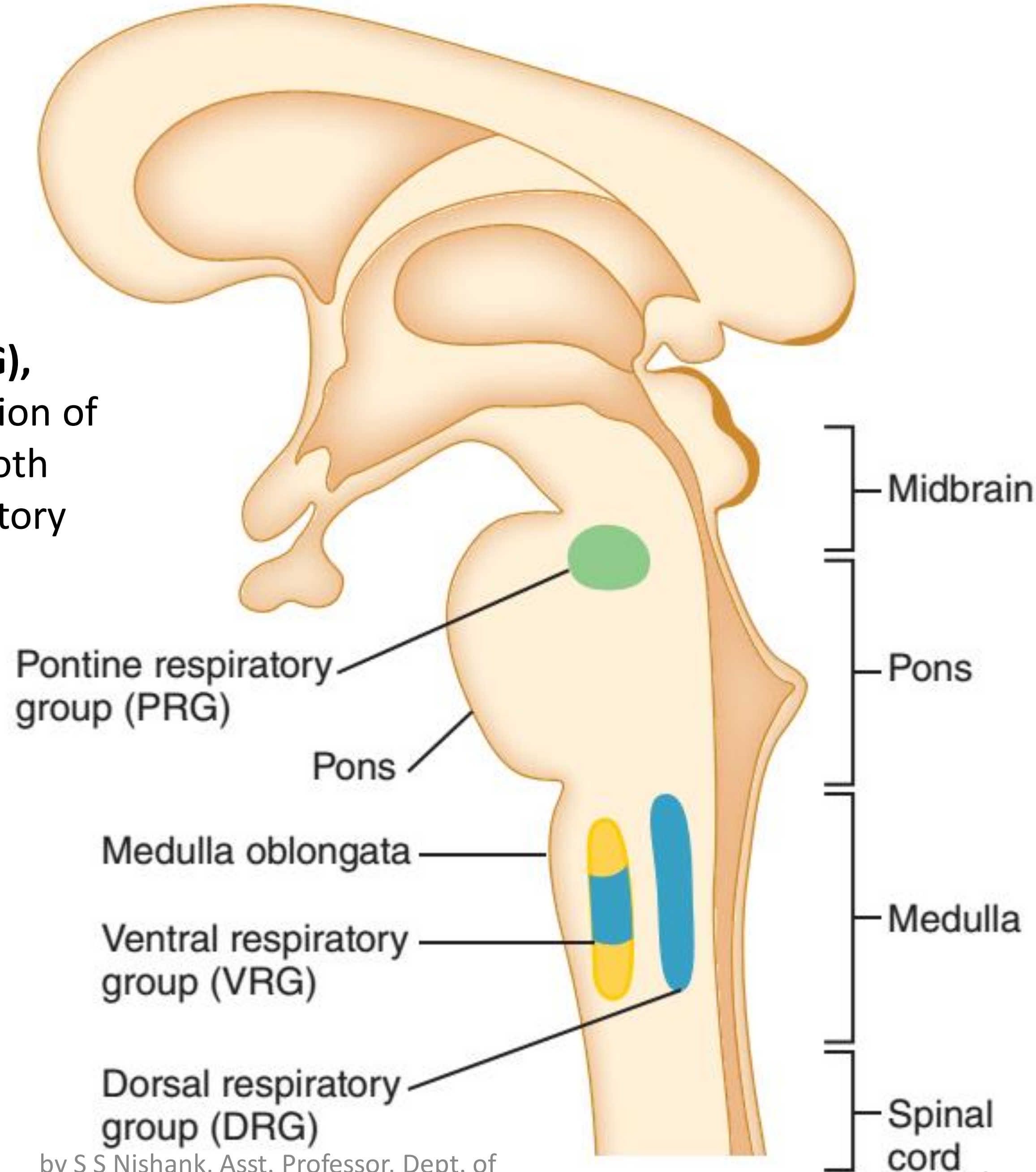
- Neural control by -
- 1.medullary respiratory center
- 2. pneumotaxic center
- 3. apneustic center
- &
- And Chemoreceptors such as
- peripheral chemoreceptors (stimulated by reduction in arterial pO_2)
- central chemoreceptors (stimulated by increase in pCO_2 or [H] concentration)

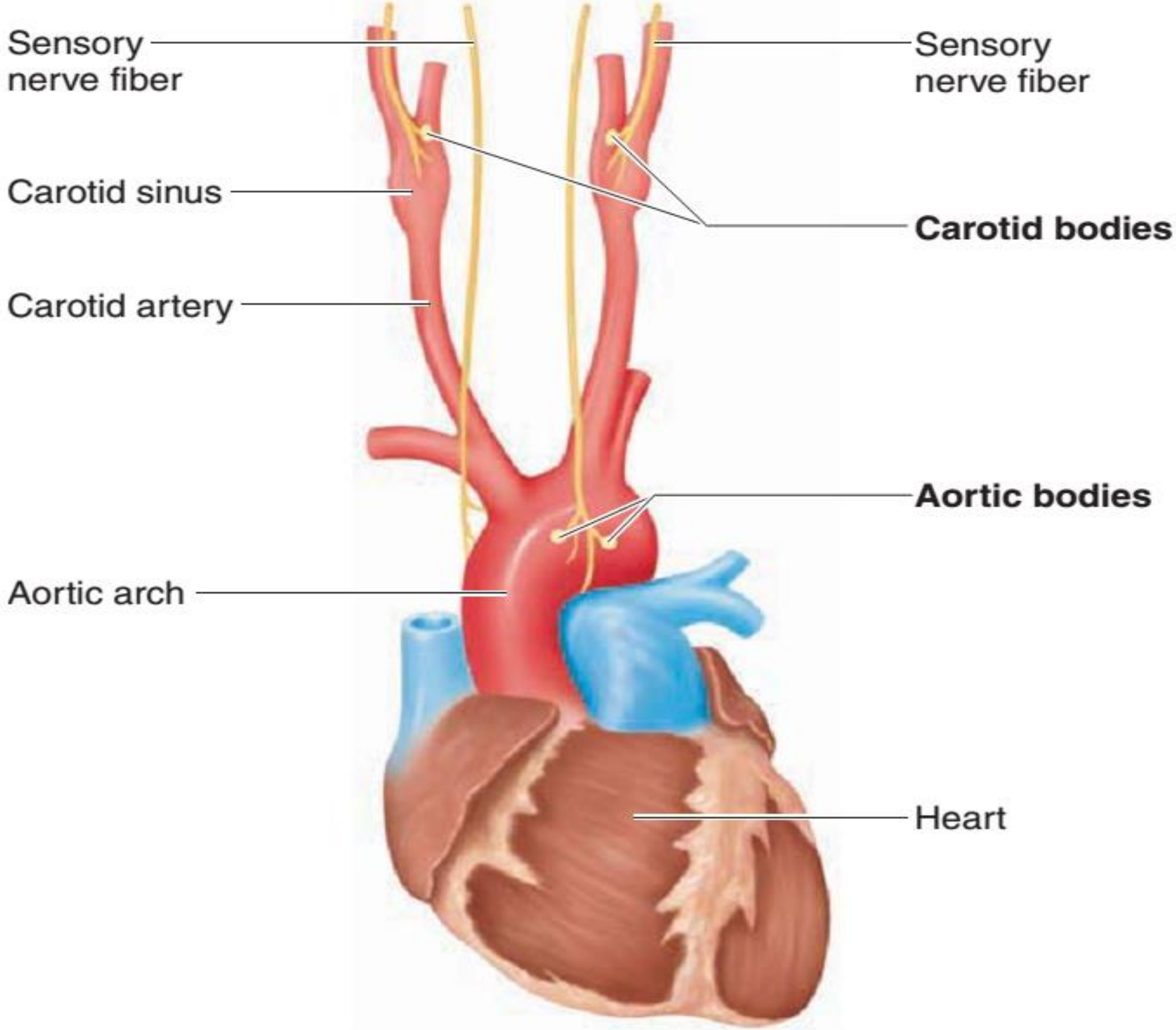
- **Central chemoreceptors** *monitor CSF:* H^+ levels in CSF (which is produced from blood CO_2) (lack proteins to buffer H^+).
- **Peripheral chemoreceptors** *monitor blood:* (1) CO_2 levels, (2) H^+ levels that are produced through metabolic processes (e.g., lactic acid, ketoacids), and (3) relatively large changes in O_2.



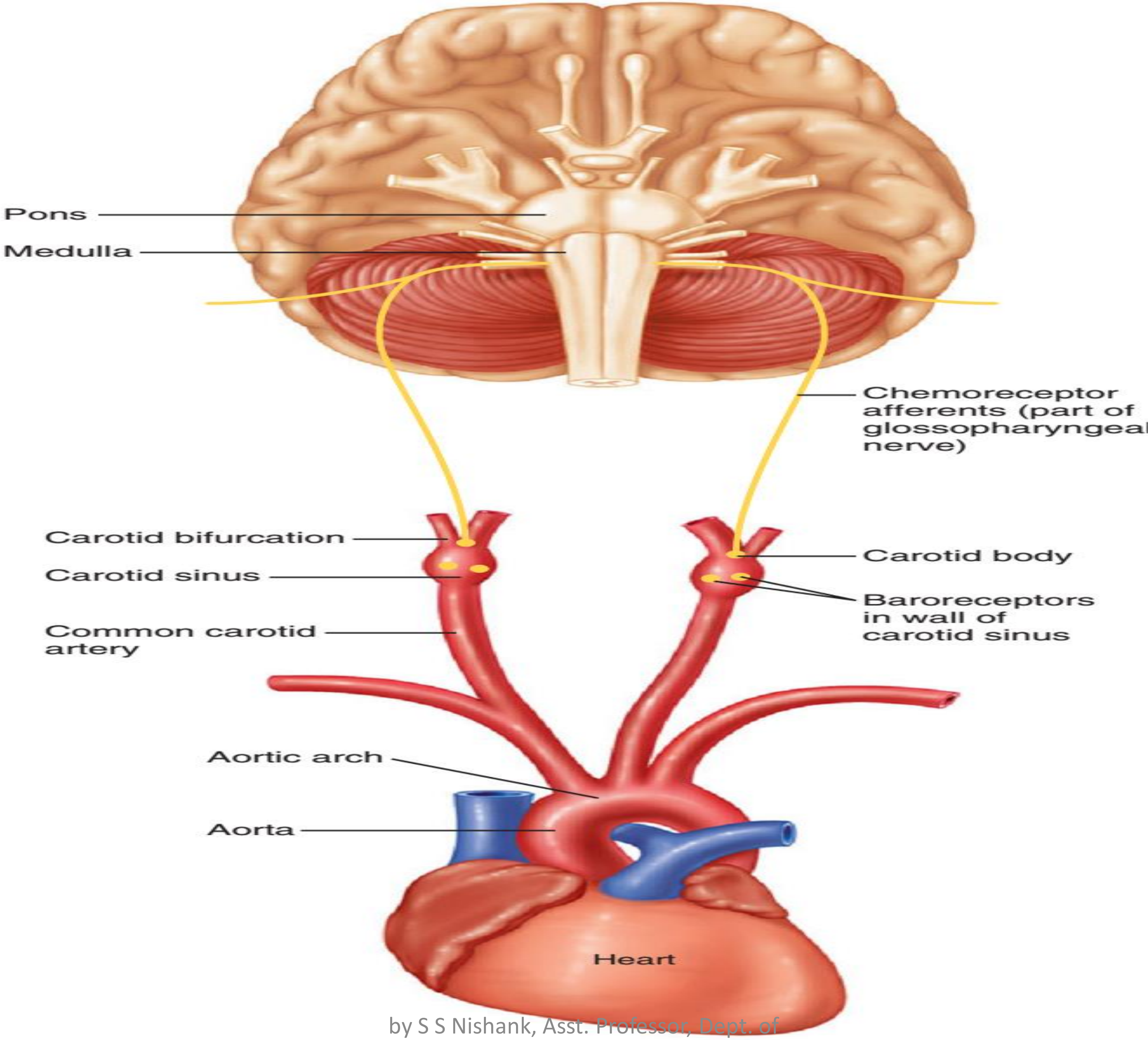
- **Respiratory control centers in the brain stem.**

ventral respiratory group (VRG), located within the anterior region of the medulla (which contains both inspiratory neurons and expiratory neurons)

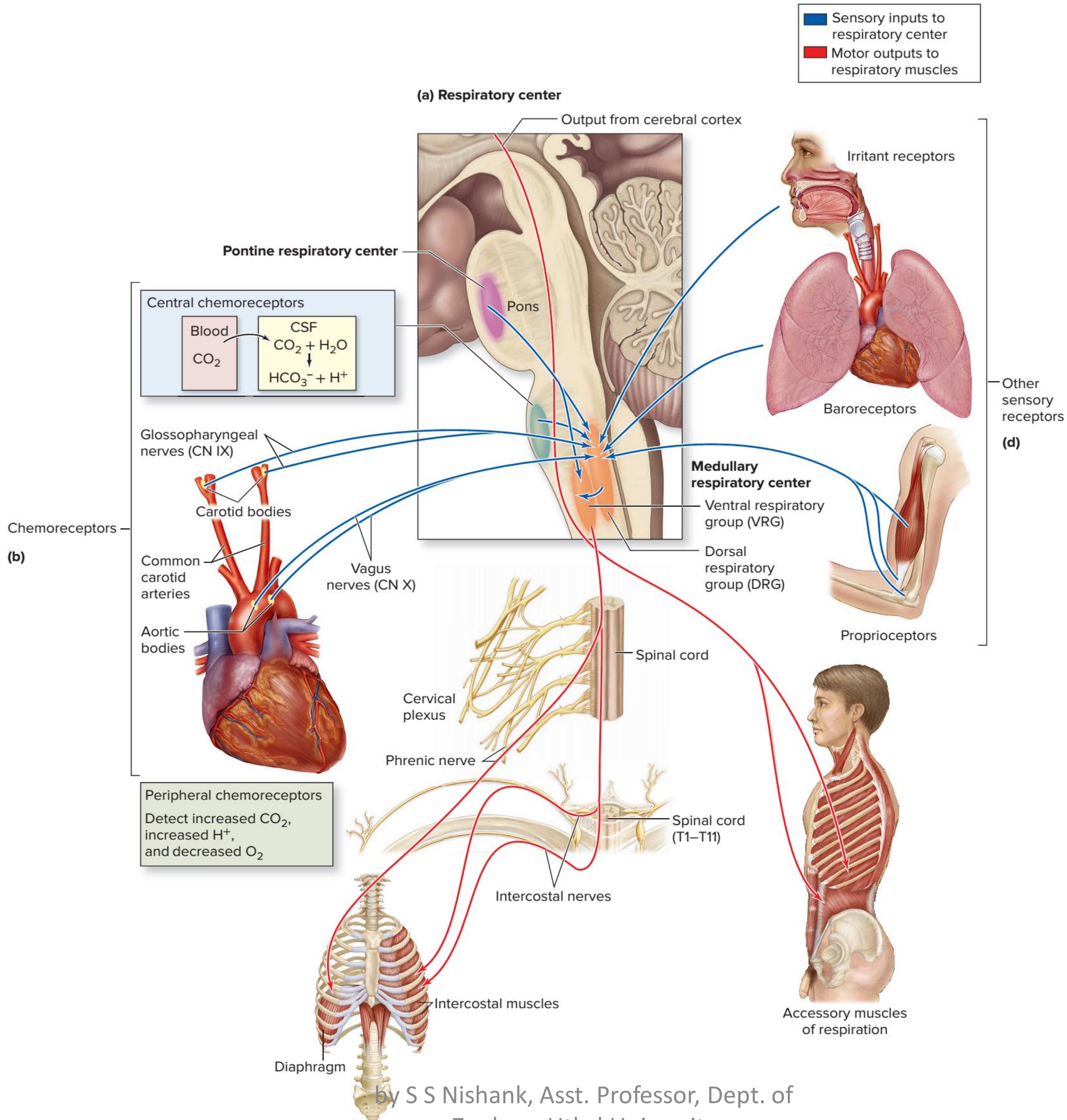




- **Location of the peripheral chemoreceptors.** The carotid bodies are located in the carotid sinus, and the aortic bodies are located in the aortic arch.



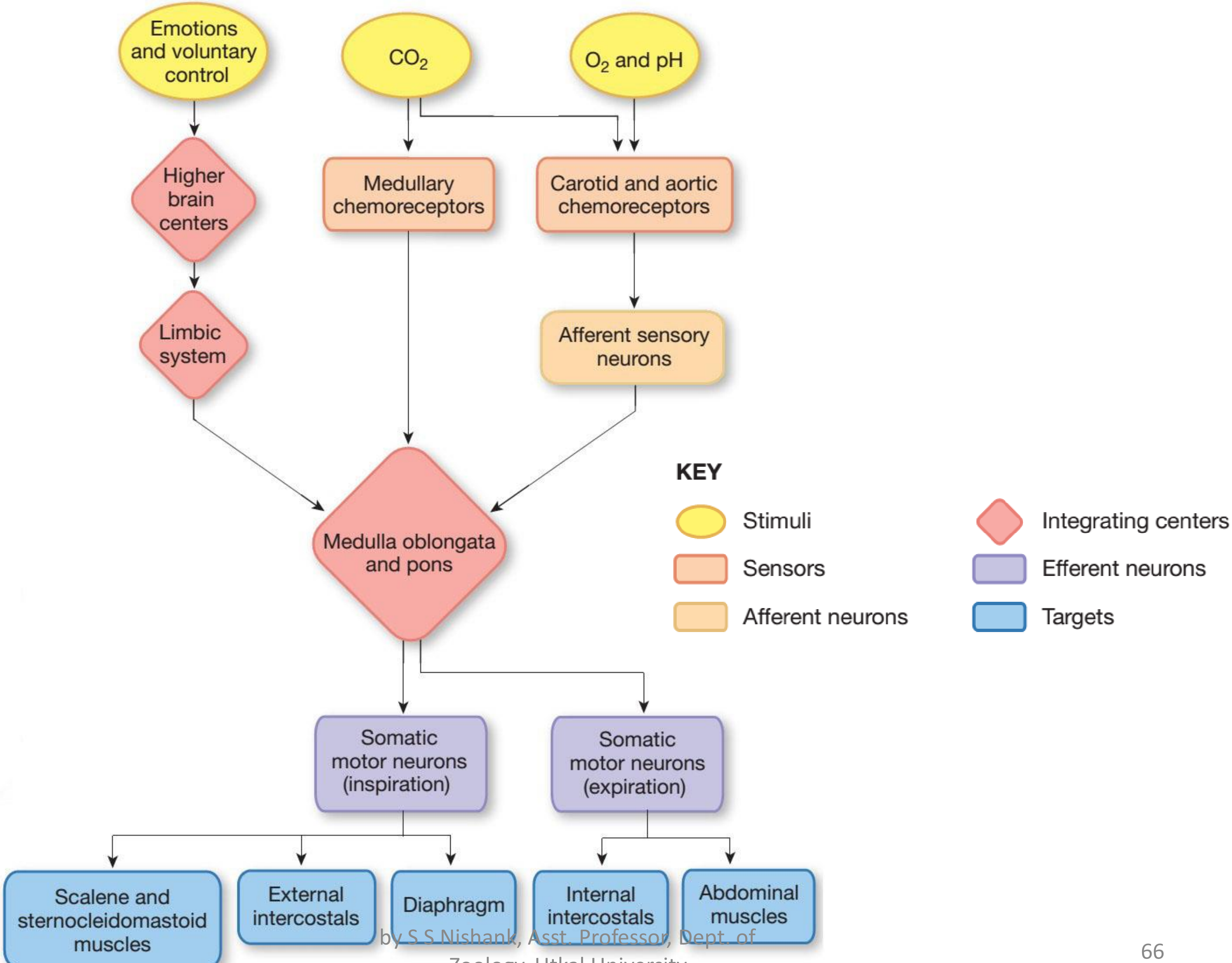
Location of peripheral chemoreceptors in the carotid bodies.

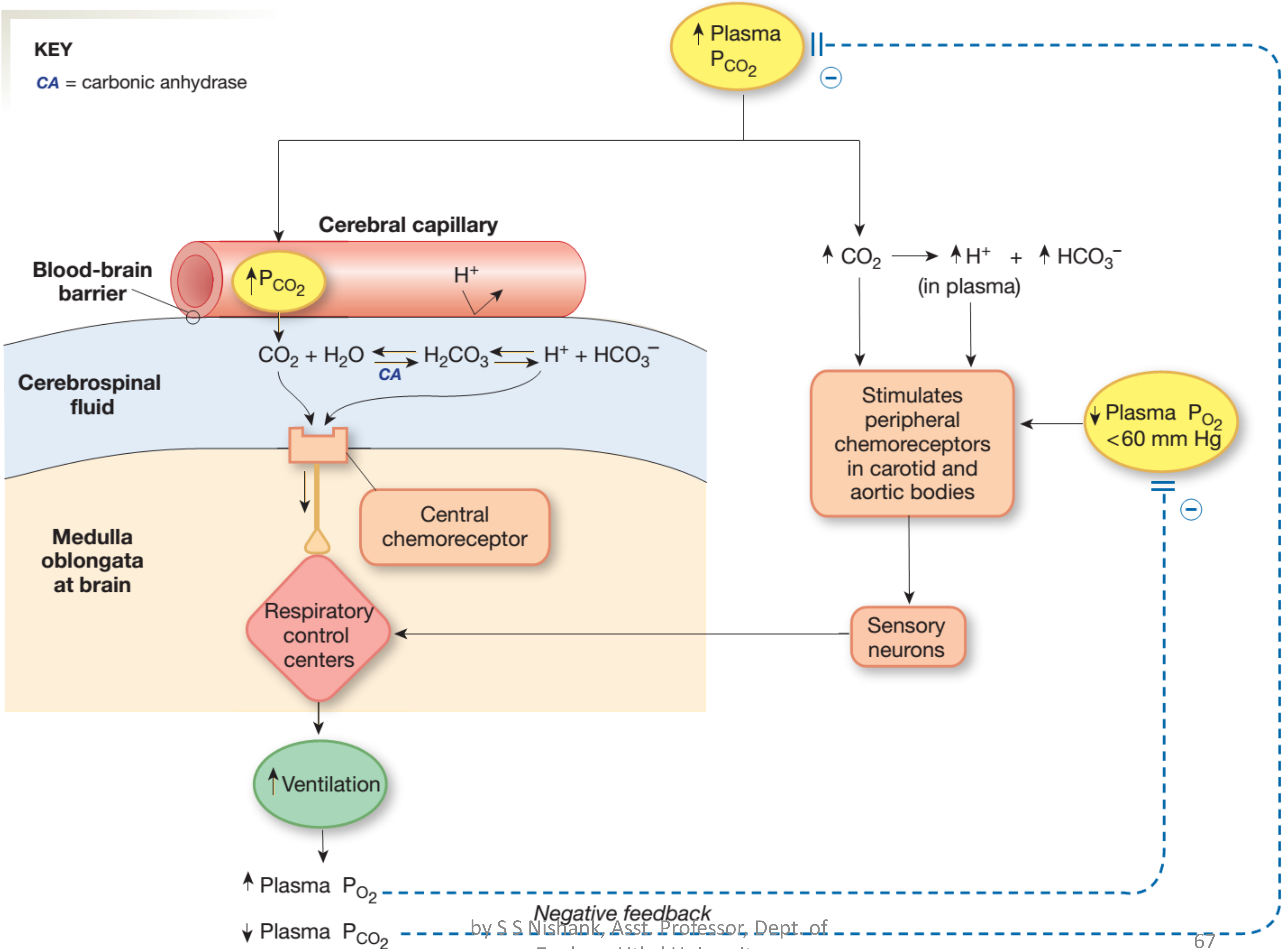

Sensory inputs to respiratory center
Motor outputs to respiratory muscles
(a) Respiratory center
Output from cerebral cortex
Irritant receptors
Pontine respiratory center
Central chemoreceptors
Blood
CO_2
CSF
$CO_2 + H_2O$
$HCO_3^- + H^+$
Pons
Baroreceptors
Other sensory receptors
(d)
Glossopharyngeal nerves (CN IX)
Medullary respiratory center
Ventral respiratory group (VRG)
Carotid bodies
Chemoreceptors
(b)
Common carotid arteries
Vagus nerves (CN X)
Dorsal respiratory group (DRG)
Aortic bodies
Proprioceptors
Spinal cord
Cervical plexus
Phrenic nerve
Peripheral chemoreceptors
Detect increased CO_2, increased H^+, and decreased O_2
Spinal cord (T1–T11)
Intercostal nerves
Intercostal muscles
Accessory muscles of respiration
Diaphragm
(c) Skeletal muscles of breathing

- Motor nerves from ventral respiratory group (VRG), located within the anterior region of the medulla (which contains both inspiratory neurons and expiratoryneurons) connect with phrenic nerves that innervate the diaphragm or the intercostal nerves that innervate the intercostal muscles. Accessory muscles of respiration are innervated by other individually named somatic nerves
- The phrenic nerves extend from the cervical plexus formed by the rami of spinal nerves C3–C5, whereas the intercostal nerves are the anterior rami of spinal nerves T1–T11
- Chemoreceptors are the primary sensory receptors involved in altering breathing. Chemoreceptors are housed both within the brain (central chemoreceptors) and within specific blood vessels (peripheral chemoreceptors):
- **Central chemoreceptors** are within the medulla oblongata in close proximity to the medullary respiratory center. Central chemoreceptors monitor only H+ changes of CSF induced by changes in blood Pco_2. It is important to note that unlike the blood, the CSF lacks proteins to buffer the gain or loss of H+
- **Peripheral chemoreceptors** are located both within the aortic arch (called the **aortic bodies**) and at the split of each common carotid artery into the external and internal carotid arteries (called **carotid bodies**).

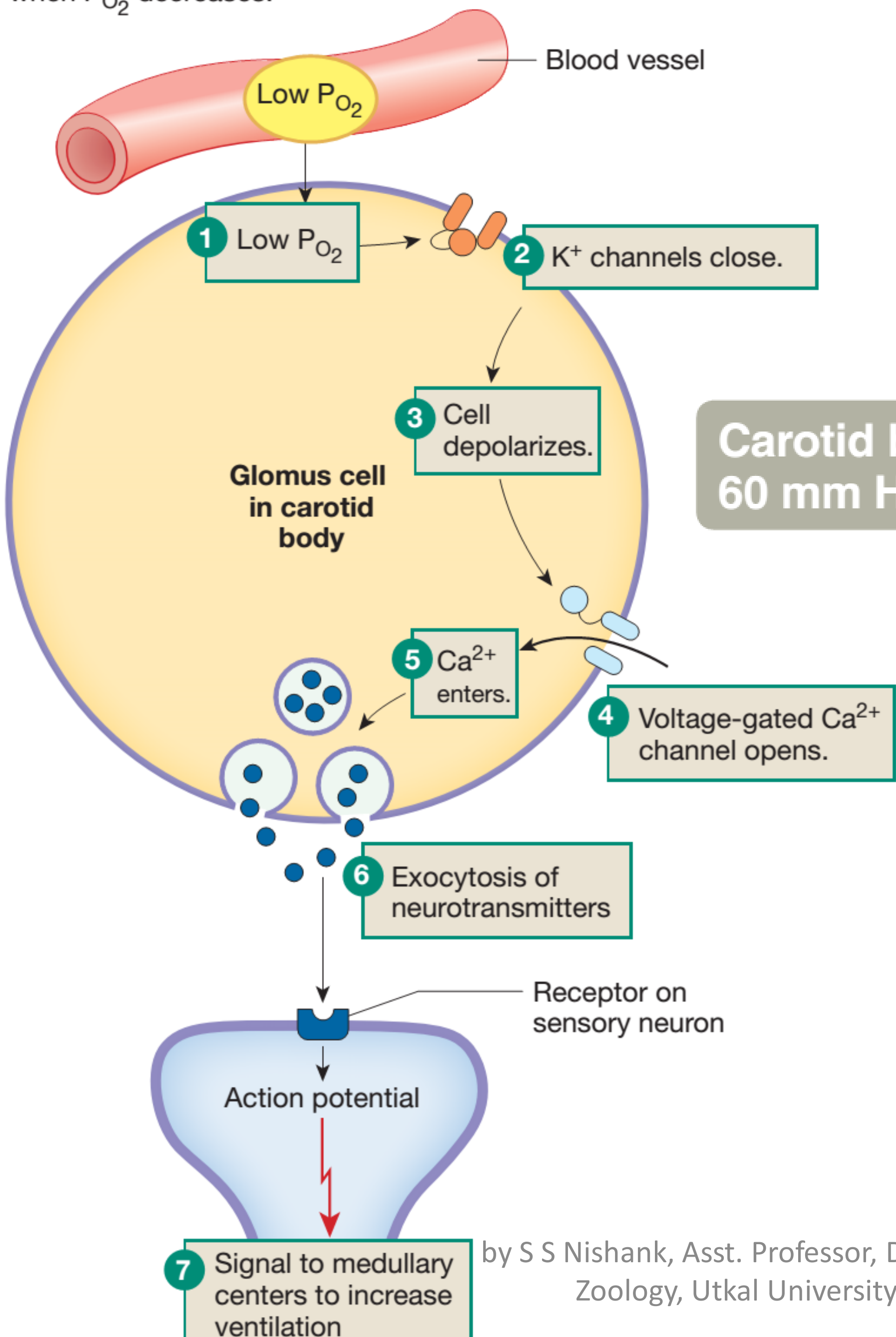
- Breathing rate and depth can be reflexively increased if either the central chemoreceptors detect an increase in H+ concentration in the CSF or the peripheral chemoreceptors detect an increase in blood H+ concentration, an increase in blood Pco_2, or both.
- The most important stimulus affecting breathing rate and depth is blood Pco2. The chemoreceptors are very sensitive to changes in blood Pco2 levels; increases in Pco_2 levels as small as 5 mm Hg will double the breathing rate.
- the arterial oxygen level in the blood must decrease substantially from its normal Po_2 level of 95 mm Hg to an abnormally low level of 60 mm Hg before it can stimulate the chemoreceptors independently of Pco_2.
- The combination of decreased Po2 and increased Pco2, along with the subsequent production of H+,causes greater stimulation of the chemoreceptors.

- Receptors other than chemoreceptors alter breathing patterns.
- (1) Proprioceptors within joints and muscles, when stimulated by body movement, increase nerve signals to the respiratory center with a subsequent increase in breathing depth.
- (2) Baroreceptors within both the visceral pleura and bronchiole smooth muscle are stimulated by stretch.
- These sensory receptors initiate a reflex to prevent overstretching of the lungs by inhibiting inspiration activities. This reflex is referred to as the inhalation reflex, or Hering-Breuer reflex. It effectively protects the lungs from damage due to overinflation. When overstretched, these baroreceptors send nerve signals through the vagus nerves to the respiratory center to shut off inspiration activity, thus resulting in expiration.
- (3) Irritant receptors, when stimulated, initiate either a sneezing or coughing reflex. A sneeze reflex is initiated by irritants within the nasal cavity and a cough reflex by irritants within the trachea and bronchi.


Emotions and voluntary control
CO_2
O_2 and pH
Higher brain centers
Medullary chemoreceptors
Carotid and aortic chemoreceptors
Limbic system
Afferent sensory neurons
Medulla oblongata and pons
KEY
Stimuli
Sensors
Afferent neurons
Integrating centers
Efferent neurons
Targets
Somatic motor neurons (inspiration)
Somatic motor neurons (expiration)
Scalene and sternocleidomastoid muscles
External intercostals
Diaphragm
Internal intercostals
Abdominal muscles

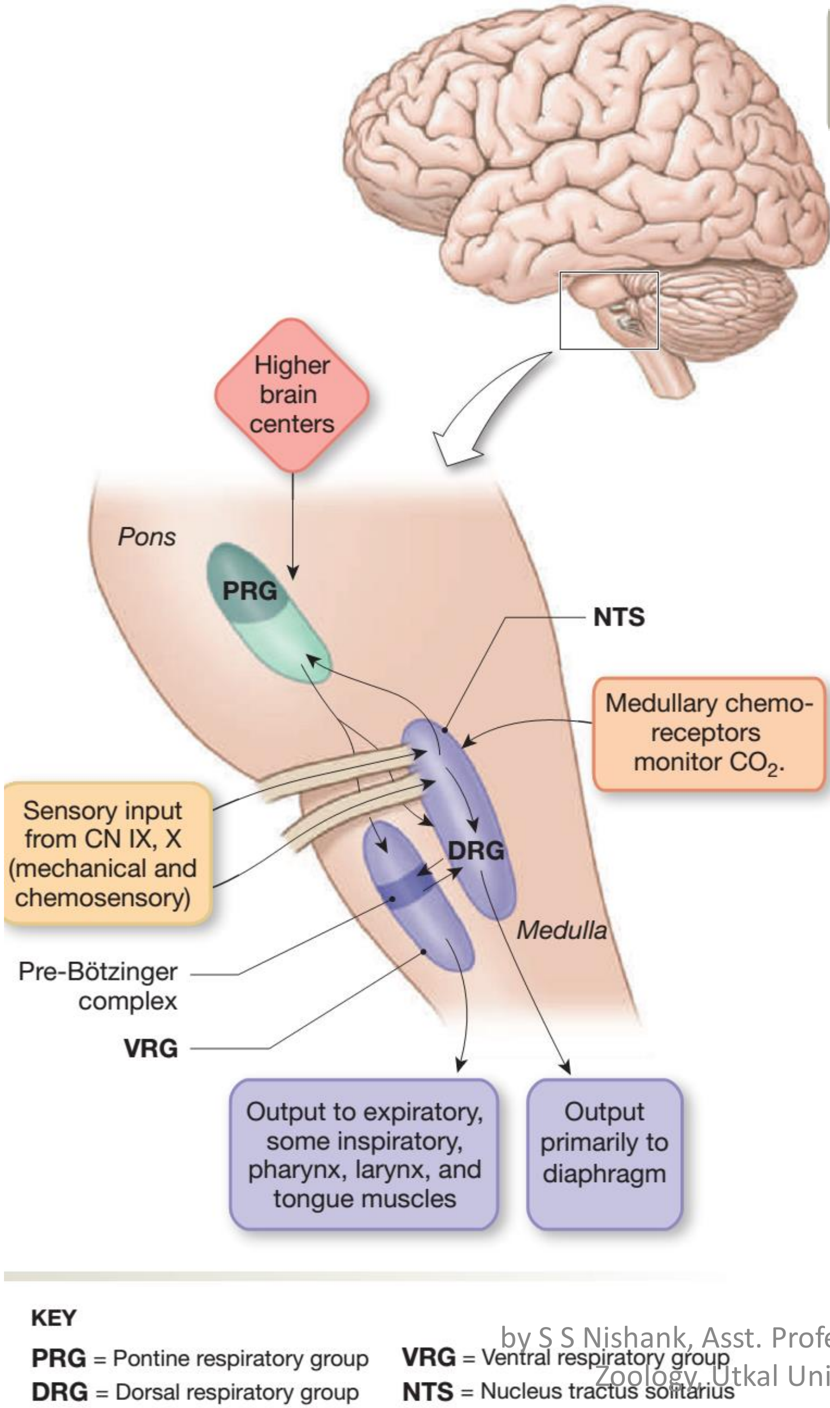

KEY
CA = carbonic anhydrase
↑ Plasma P_{CO_2}
Cerebral capillary
Blood-brain barrier
↑P_{CO_2}
H^+
$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
CA
Cerebrospinal fluid
Medulla oblongata at brain
Central chemoreceptor
Respiratory control centers
↑ Ventilation
↑ Plasma P_{O_2}
↓ Plasma P_{CO_2}
Negative feedback
↑ CO_2 → ↑ H^+ + ↑ HCO_3^-
(in plasma)
Stimulates peripheral chemoreceptors in carotid and aortic bodies
↓ Plasma P_{O_2} <60 mm Hg
Sensory neurons

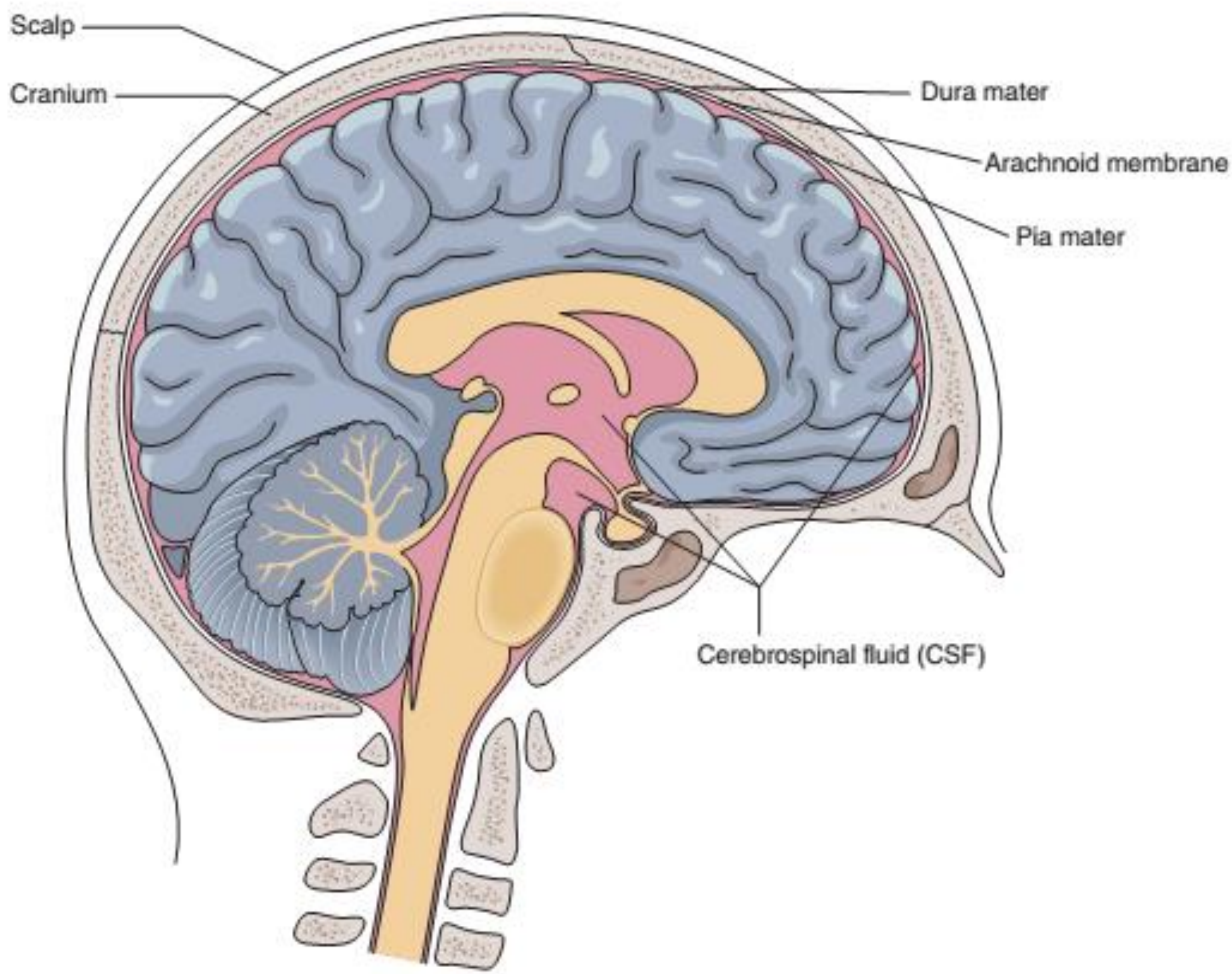
The carotid body oxygen sensor releases neurotransmitter when P_{O_2} decreases.



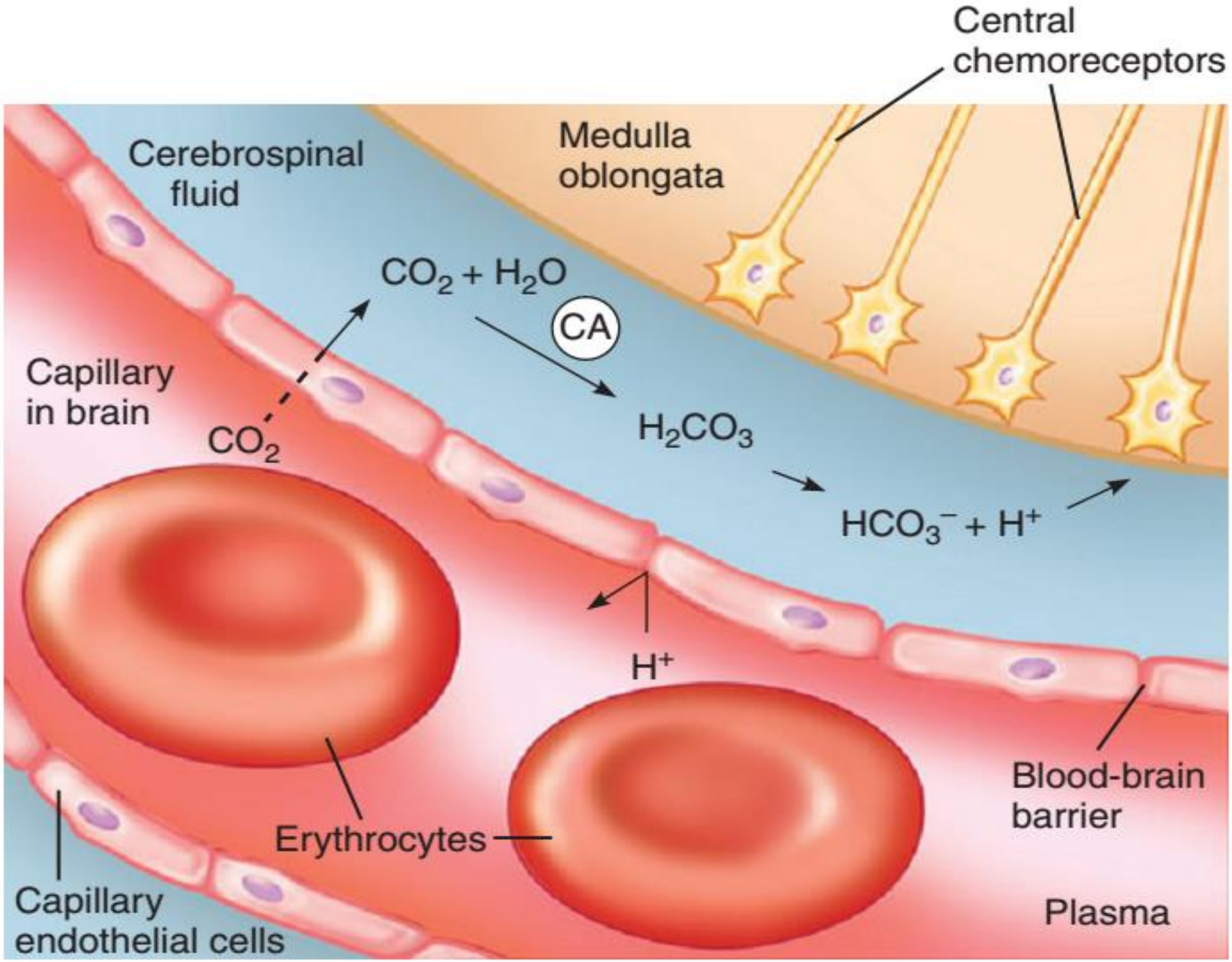
Carotid body cells respond to P_{O_2} below 60 mm Hg

Neural networks in the brain stem control ventilation

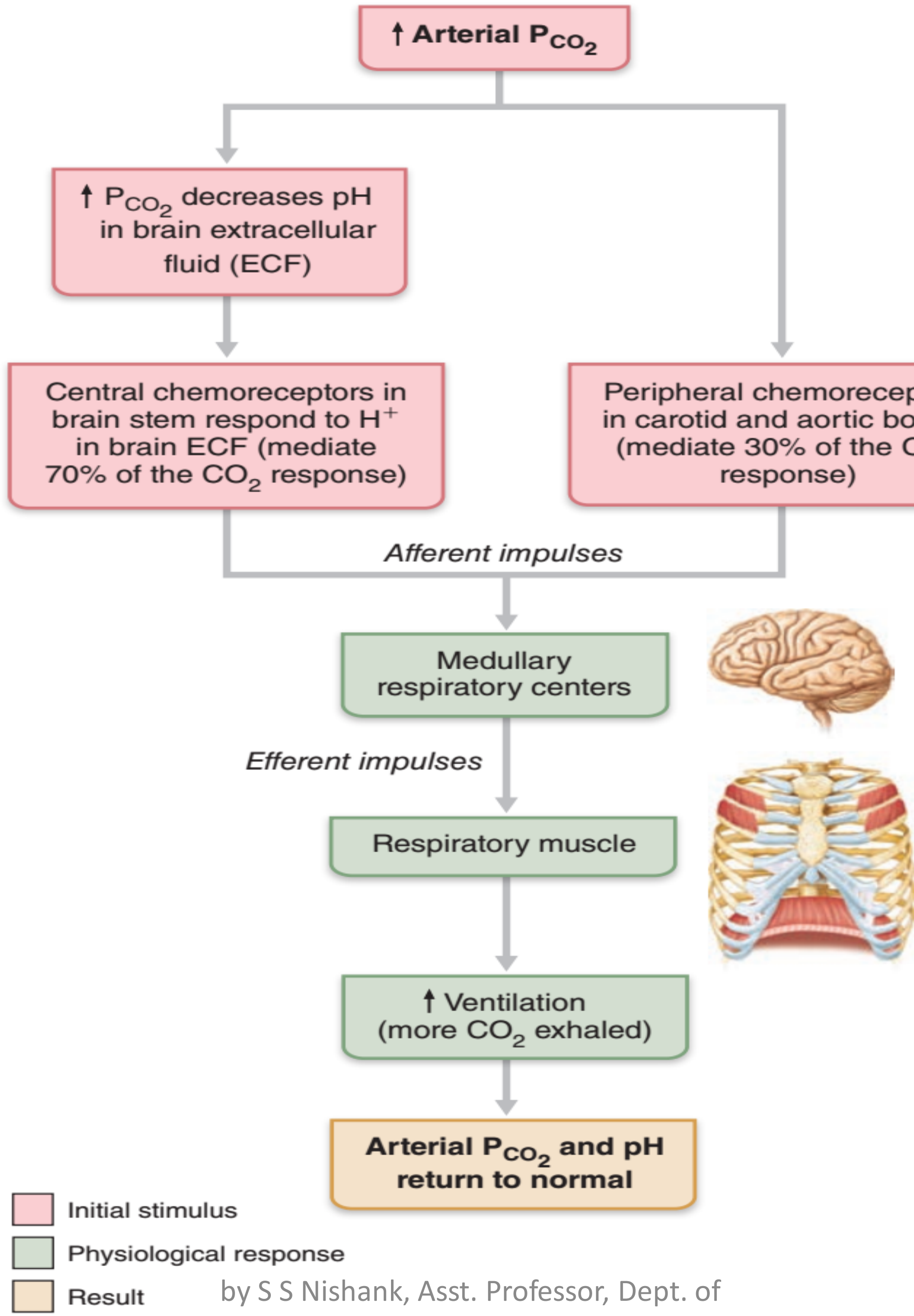




A cross-section of the brain showing the protective coverings. The cerebrospinal fluid is shown in pink.



Activation of central chemoreceptors in the medulla oblongata. Central chemoreceptors respond best to changes in pH in the



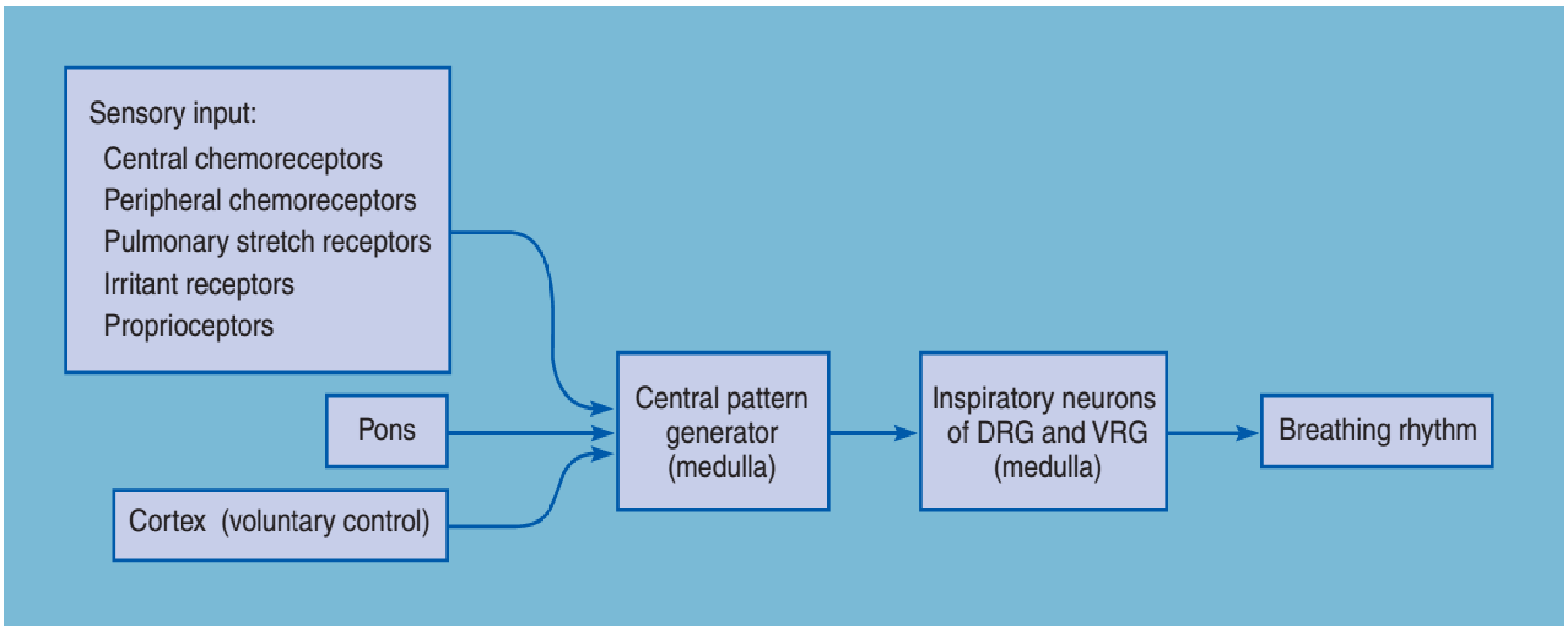
↑ Arterial P_{CO_2}
↑ P_{CO_2} decreases pH in brain extracellular fluid (ECF)
Central chemoreceptors in brain stem respond to H^+ in brain ECF (mediate 70% of the CO_2 response)
Peripheral chemoreceptors in carotid and aortic bodies (mediate 30% of the CO_2 response)
Afferent impulses
Medullary respiratory centers
Efferent impulses
Respiratory muscle
↑ Ventilation (more CO_2 exhaled)
Arterial P_{CO_2} and pH return to normal
Initial stimulus
Physiological response
Result

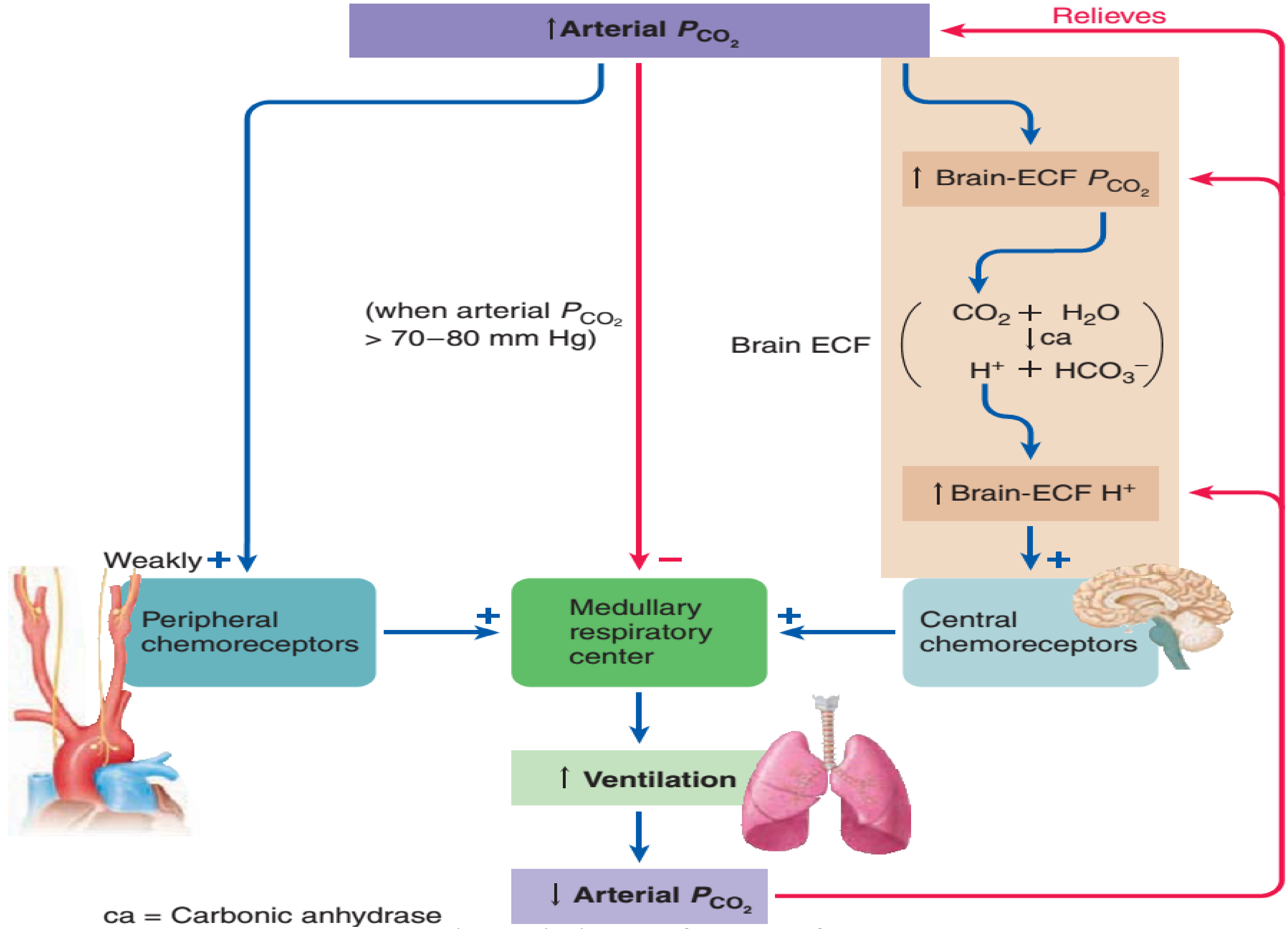
Influence of Chemical Factors on Respiration

Chemical Factor	Effect on the Peripheral Chemoreceptors	Effect on the Central Chemoreceptors
↓ P_{O_2} in the Arterial Blood	Stimulates only when the arterial P_{O_2} has fallen to the point of being life threatening ($<$ 60 mm Hg); an emergency mechanism	Directly depresses the central chemoreceptors and the respiratory center itself when $<$ 60 mm Hg
↑ P_{CO_2} in the Arterial Blood (↑ H^+ in the Brain ECF)	Weakly stimulates	Strongly stimulates; is the dominant control of ventilation (Levels $>$ 70–80 mm Hg directly depress the respiratory center and central chemoreceptors)
↑ H^+ in the Arterial Blood	Stimulates; important in acid–base balance	Does not affect; cannot penetrate the blood–brain barrier

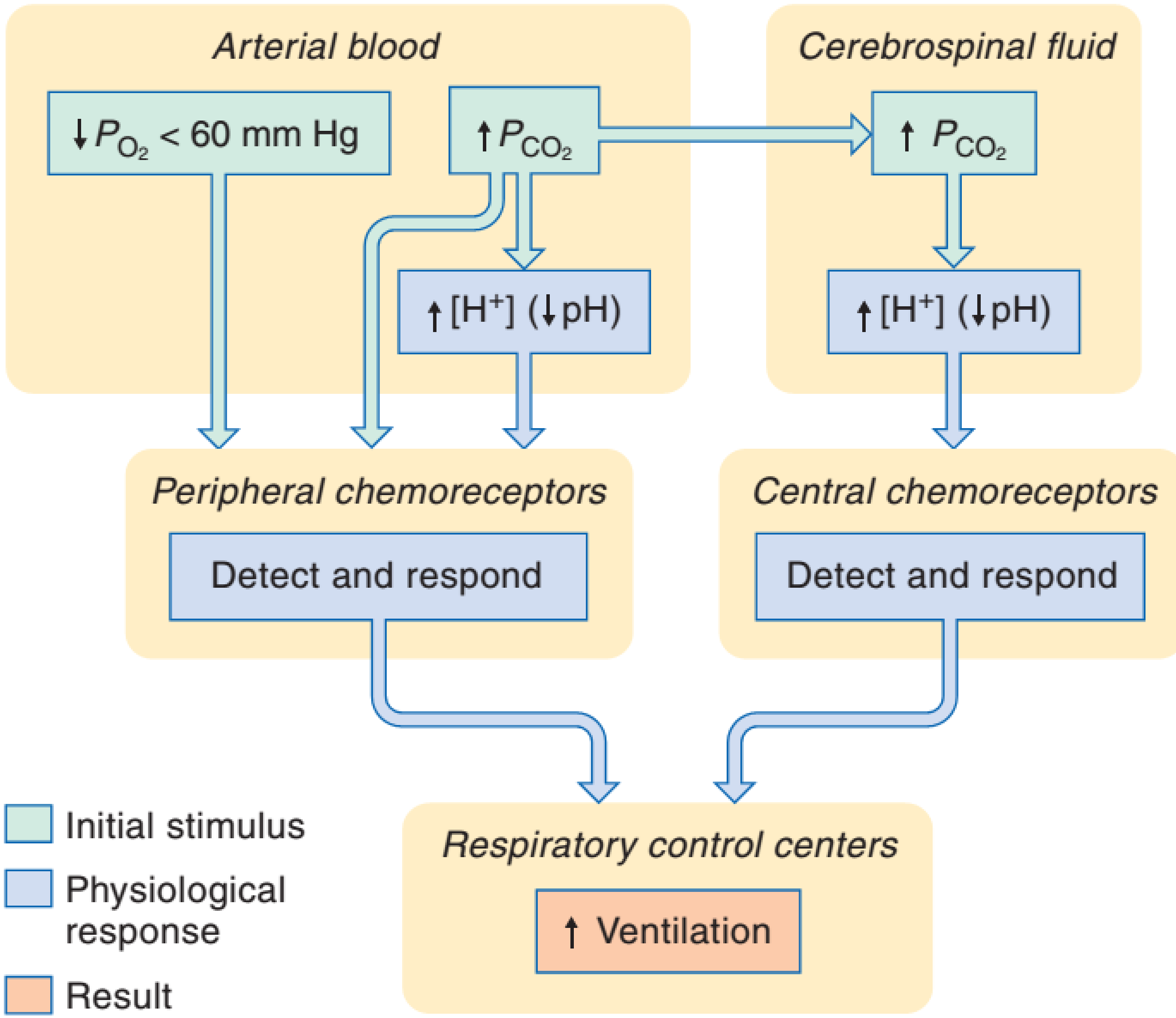
Nerve signals from chemoreceptors are sent along sensory neurons to the DRG. When the DRG is activated, nerve signals are subsequently relayed to the VRG, resulting in a change in the rate and depth of breathing.

Model of respiratory control during quiet breathing



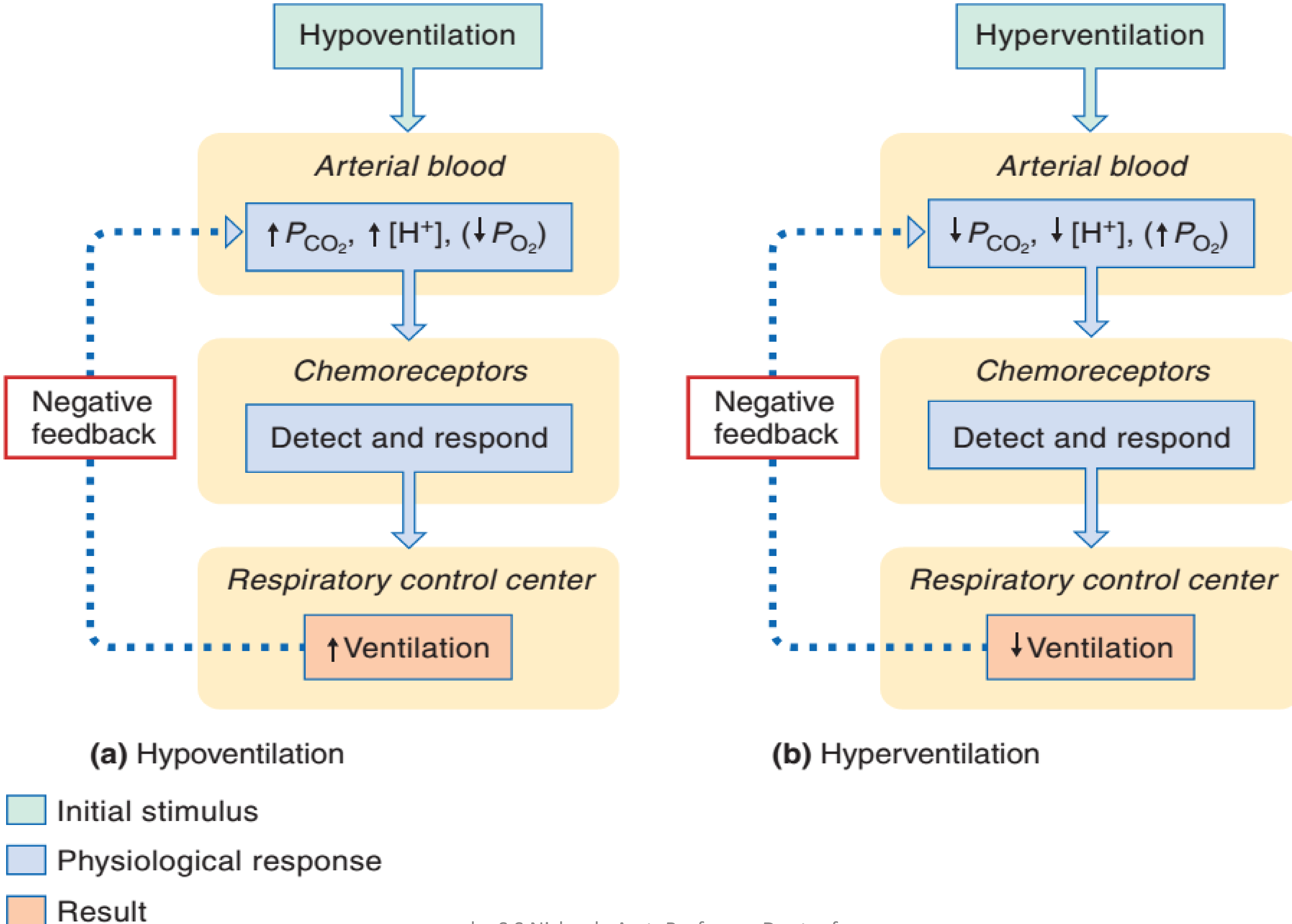


Effect of increased arterial P_{CO_2} on ventilation.



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

- In **hyperventilation**, alveolar ventilation exceeds the demands of the tissues; arterial PCO_2 decreases to less than 40 mm Hg, and PO_2 increases to greater than 100 mm Hg.
- In **hypoventilation**, alveolar ventilation is insufficient to meet the demands of the tissues; in this case, arterial PCO_2 rises above the normal value of 40 mm Hg, and arterial PO_2 decreases below the normal value of 100 mm Hg.



The effects of hypoventilation and hyperventilation on minute ventilation.