TRANSPORT OF OXYGEN AND CARBON DIOXIDE

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OXYGEN TRANSPORT

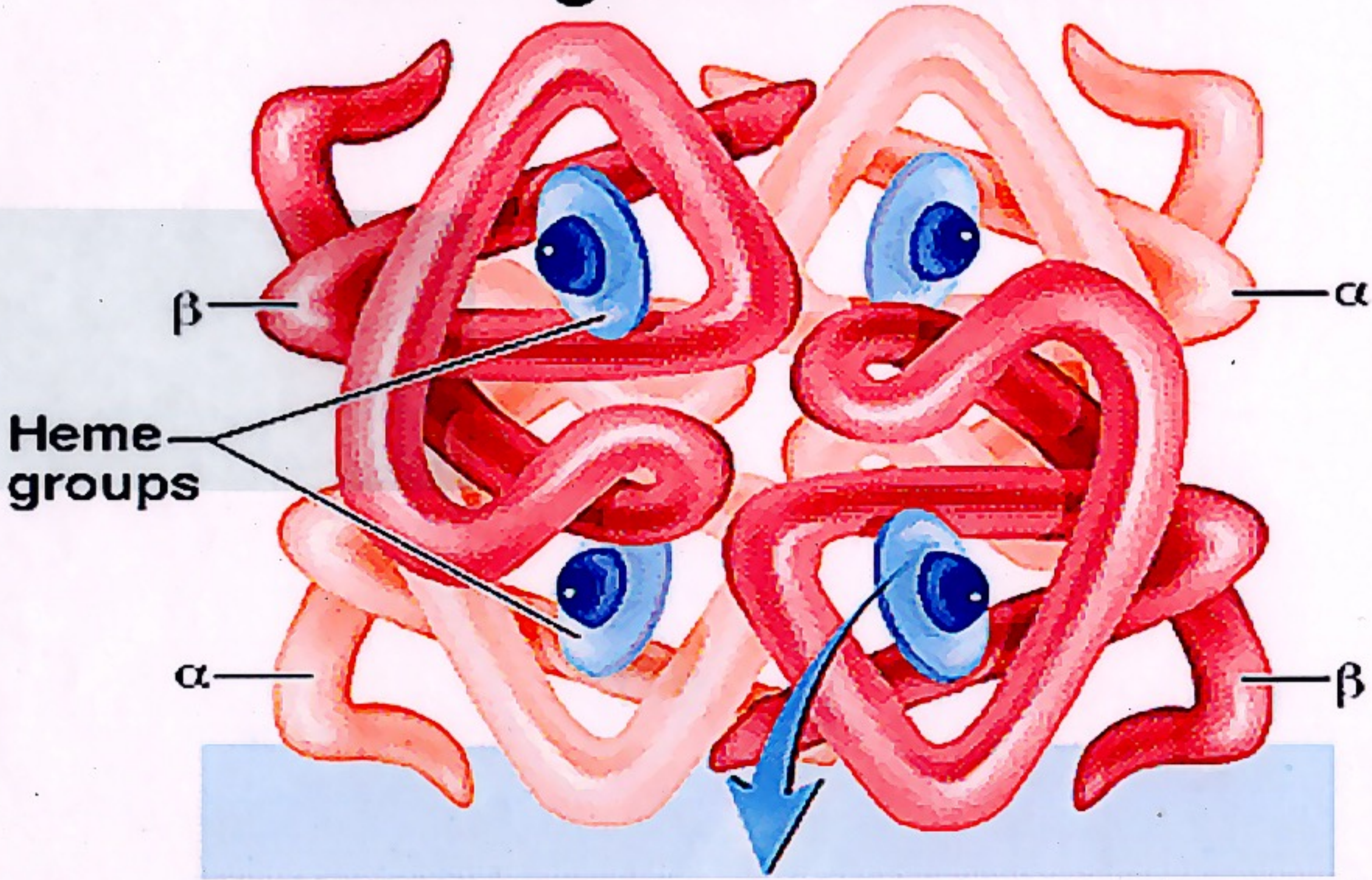
- Oxygen does not dissolve easily in water, so only about 1.5% of inhaled O2 is dissolved in blood plasma, which is mostly water.
- About 98.5% of blood O2 is bound to hemoglobin in red blood cells
- Each 100 mL of oxygenated blood contains the equivalent of 20 mL of gaseous O2.
- Using the percentages just given, the amount dissolved in the plasma is 0.3 mL and the amount bound to hemoglobin is 19.7 mL.

- Oxygen and hemoglobin bind in an easily reversible reaction to form **oxyhemoglobin**
- The 98.5% of the O2 that is bound to hemoglobin is trapped inside RBCs, so only the dissolved O2 (1.5%) can diffuse out of tissue capillaries into tissue cells.
- Thus, it is important to understand the factors that promote O2 binding to and dissociation (separation) from hemoglobin.

THE RELATIONSHIP BETWEEN HEMOGLOBIN AND OXYGEN PARTIAL PRESSURE

- The pressure of a specific gas in a mixture is called its *partial pressure* (Px);
- The most important factor that determines how much O2 binds to hemoglobin is the PO2;
- P_{O2} ↑ -- the more O2 combines with Hb.
- When reduced hemoglobin (Hb) is completely converted to oxyhemoglobin (Hb–O2), the hemoglobin is said to be **fully saturated**
- when hemoglobin consists of a mixture of Hb and Hb–O2, it is **partially saturated**
- The **percent saturation of hemoglobin** expresses the average saturation of hemoglobin with oxygen

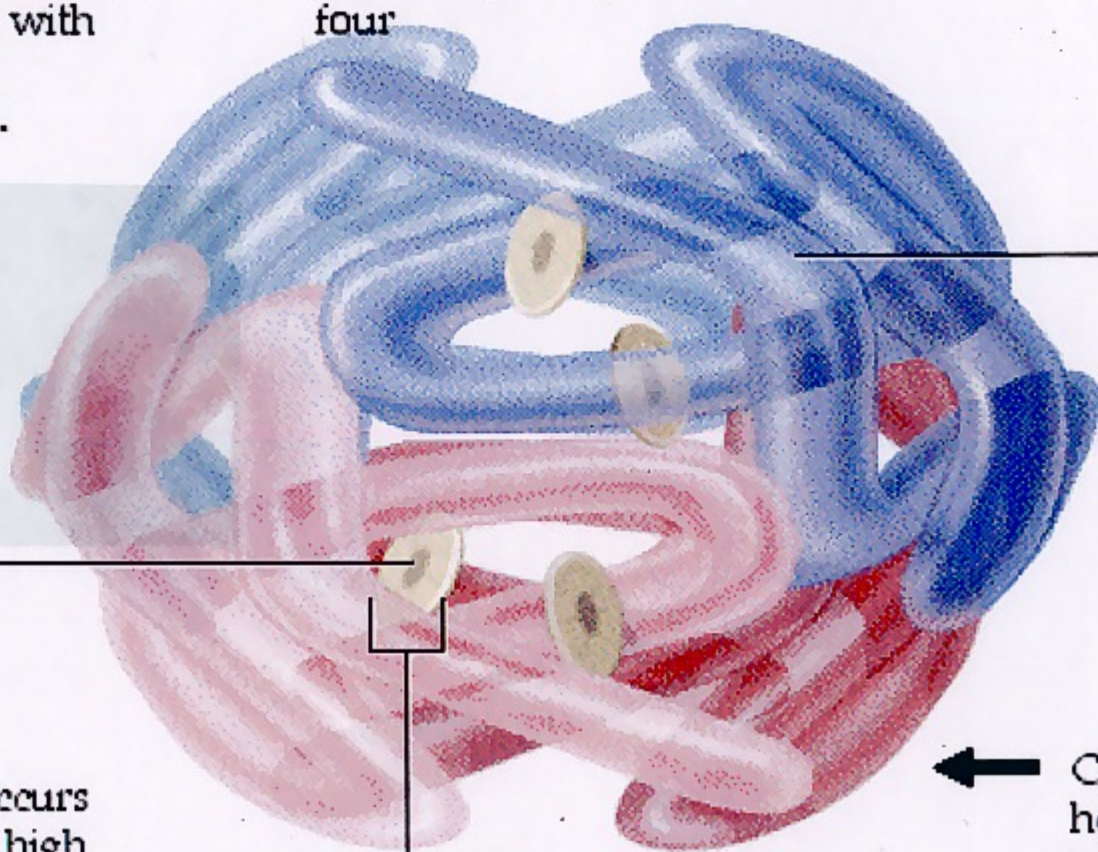
Hemoglobin Structure



HEMOGLOBIN

When $4O_2$'s are bound to hemoglobin, it is 100% saturated; with fewer O_2's, it is partially saturated.

Hemoglobin molecule can transport up to O_2's four

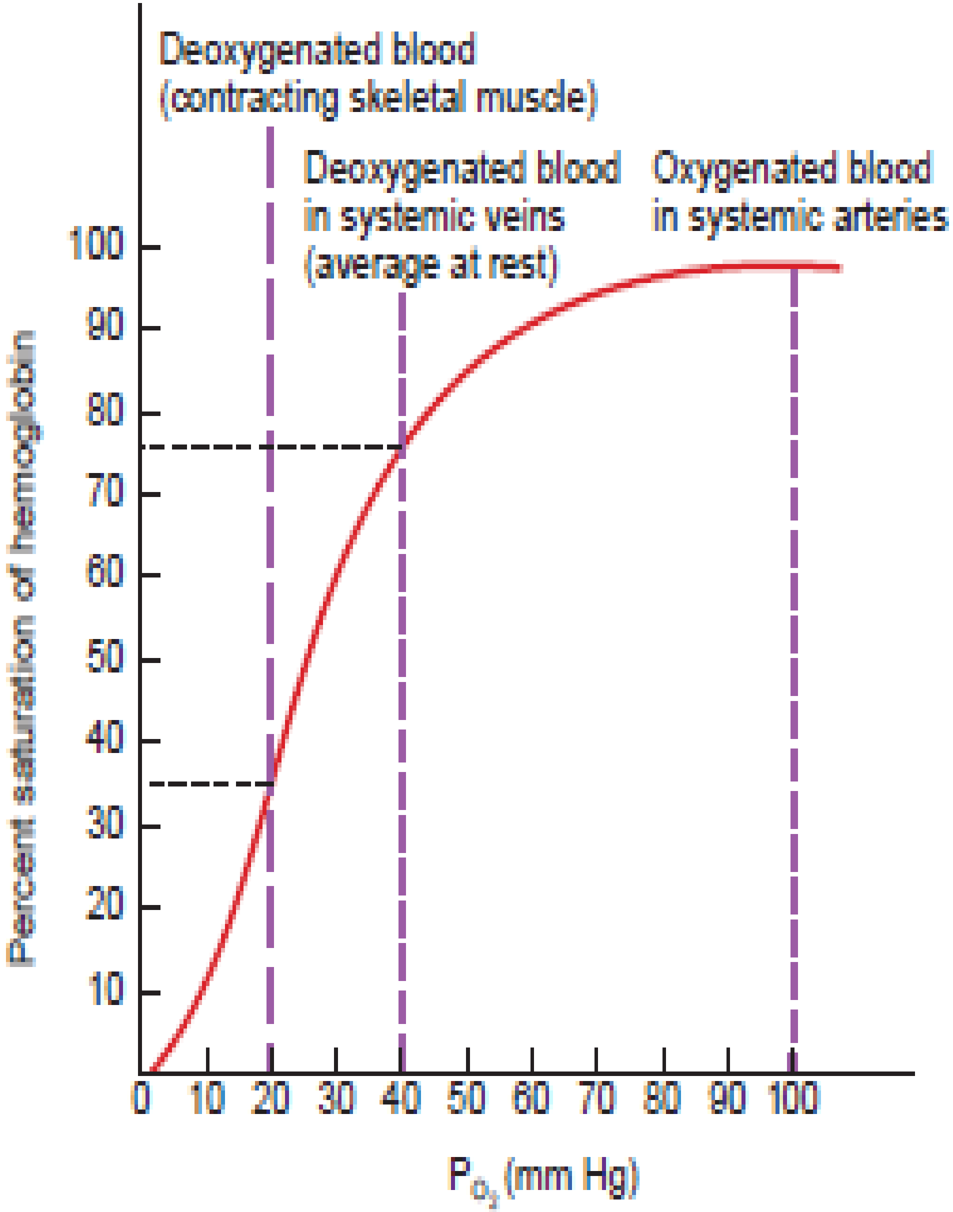


Oxygen binding occurs in response to the high P_{O_2} in the lungs.

Click the hemoglobin molecule to see oxygen loading.

THE OXYGEN–HEMOGLOBIN DISSOCIATION CURVE

- The relationship between the percent saturation of hemoglobin and PO2 is illustrated in **the oxygen-hemoglobin dissociation curve**



The relationship between Hb & PO_2

The oxygen dissociation curve of Hb

- The shape of the O_2 -Hb dissociation curve is "***sigmoid***"

When fully saturated :

1 g Hb combines with 1.34 mL O_2

[Hb] : 14.5 g/dL of blood -→

The total O_2 that could be carried as HbO would be :

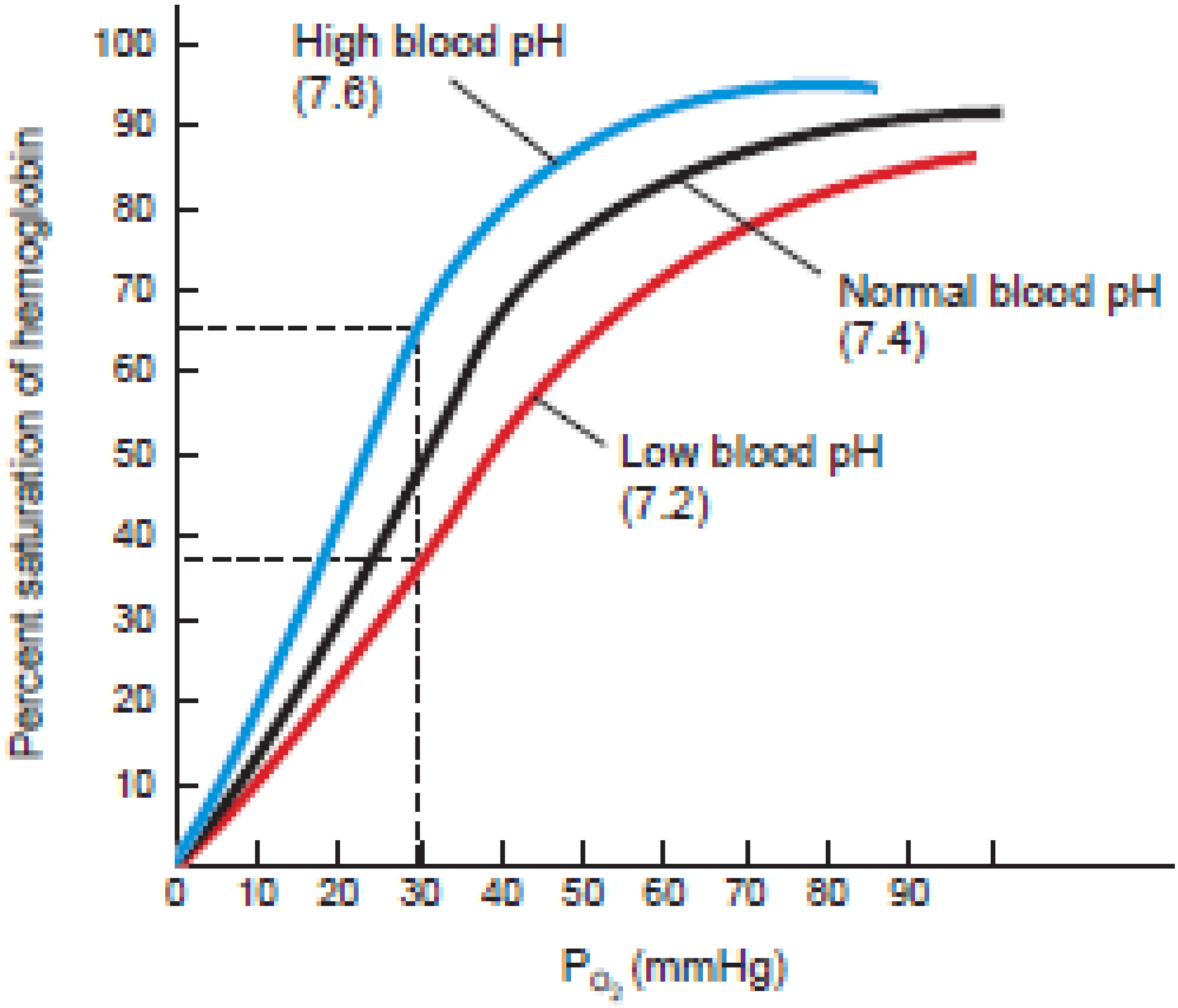
$$14.5 \times 1.34 = 19.4 \text{ mL/dL blood}$$

OTHER FACTORS AFFECTING THE AFFINITY OF HEMOGLOBIN FOR OXYGEN

1) ***Acidity (pH)***
2) ***Partial pressure of carbon dioxide***
3) ***Temperature***
4) **2,3-bisphosphoglycerate (BPG)**

1. ACIDITY (PH)

- acidity increases (pH decreases), the affinity of hemoglobin for O2 decreases, and O2 dissociates more readily from hemoglobin
- Increasing acidity enhances the unloading of oxygen from hemoglobin
- When pH ↓, the entire oxygen–hemoglobin dissociation curve shifts to the right; at any given PO2, Hb is less saturated with O2, a change termed the **Bohr effect.**

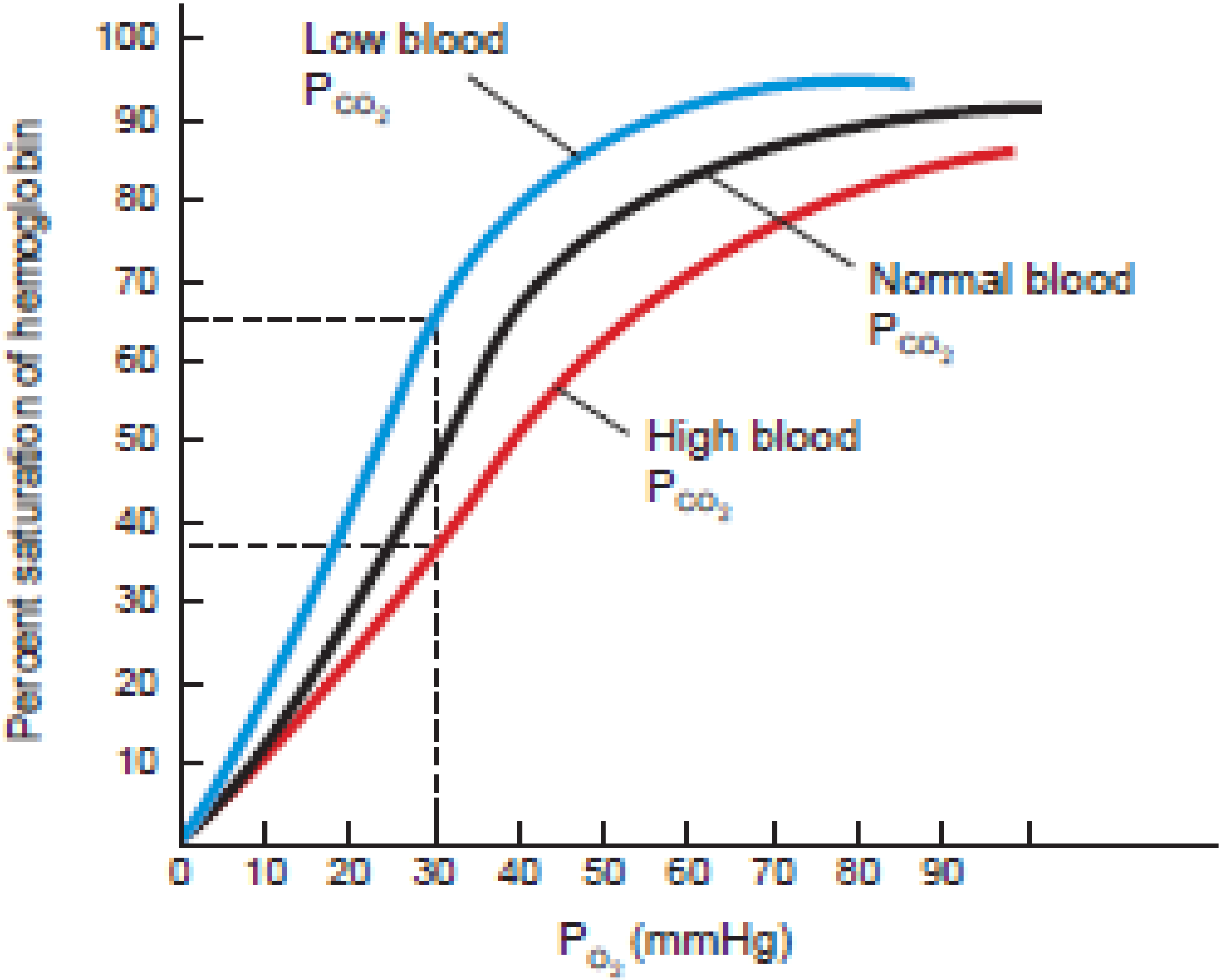


High blood pH
(7.6)
Normal blood pH
(7.4)
Low blood pH
(7.2)
Percent saturation of hemoglobin
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
P_{O_2} (mmHg)

2. PARTIAL PRESSURE OF CARBON DIOXIDE.

- CO2 also can bind to hemoglobin, and the effect is similar to that of H (shifting the curve to the right).
- As PCO2 rises, hemoglobin releases O2 more readily
- PCO2 and pH are related factors because low blood pH (acidity) results from high PCO2.
- As CO2 enters the blood, much of it is temporarily converted to carbonic acid (H2CO3), a reaction catalyzed by an enzyme in red blood cells called *carbonic anhydrase (CA)*:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \underset{}{\overset{CA}{\rightleftharpoons}} \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$



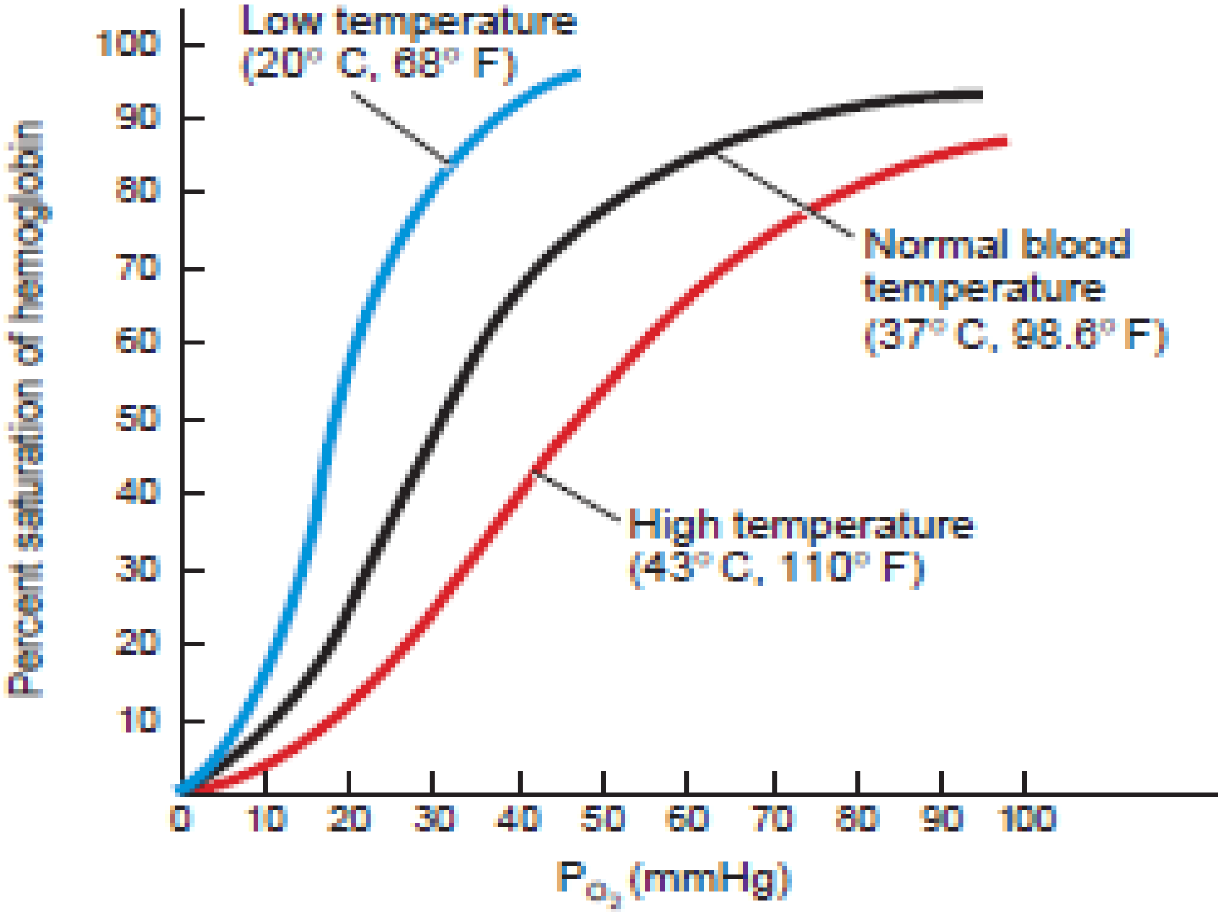
(b) Effect of P_{CO_2} on affinity of hemoglobin for oxygen

3. TEMPERATURE

- as temperature increases, so does the amount of O_2 released from hemoglobin
- Metabolically active cells require more O_2 and liberate more acids and heat.
- The acids and heat in turn promote release of O_2 from oxyhemoglobin.
- Fever produces a similar result.
- In contrast, during hypothermia (lowered body temperature) cellular metabolism slows, the need for O_2 is reduced, and more O_2 remains bound to hemoglobin (a shift to the left in the saturation curve)

Figure 23.21 **Oxygen–hemoglobin dissociation curves showing the effect of temperature changes.**

As temperature increases, the affinity of hemoglobin for O_2 decreases.

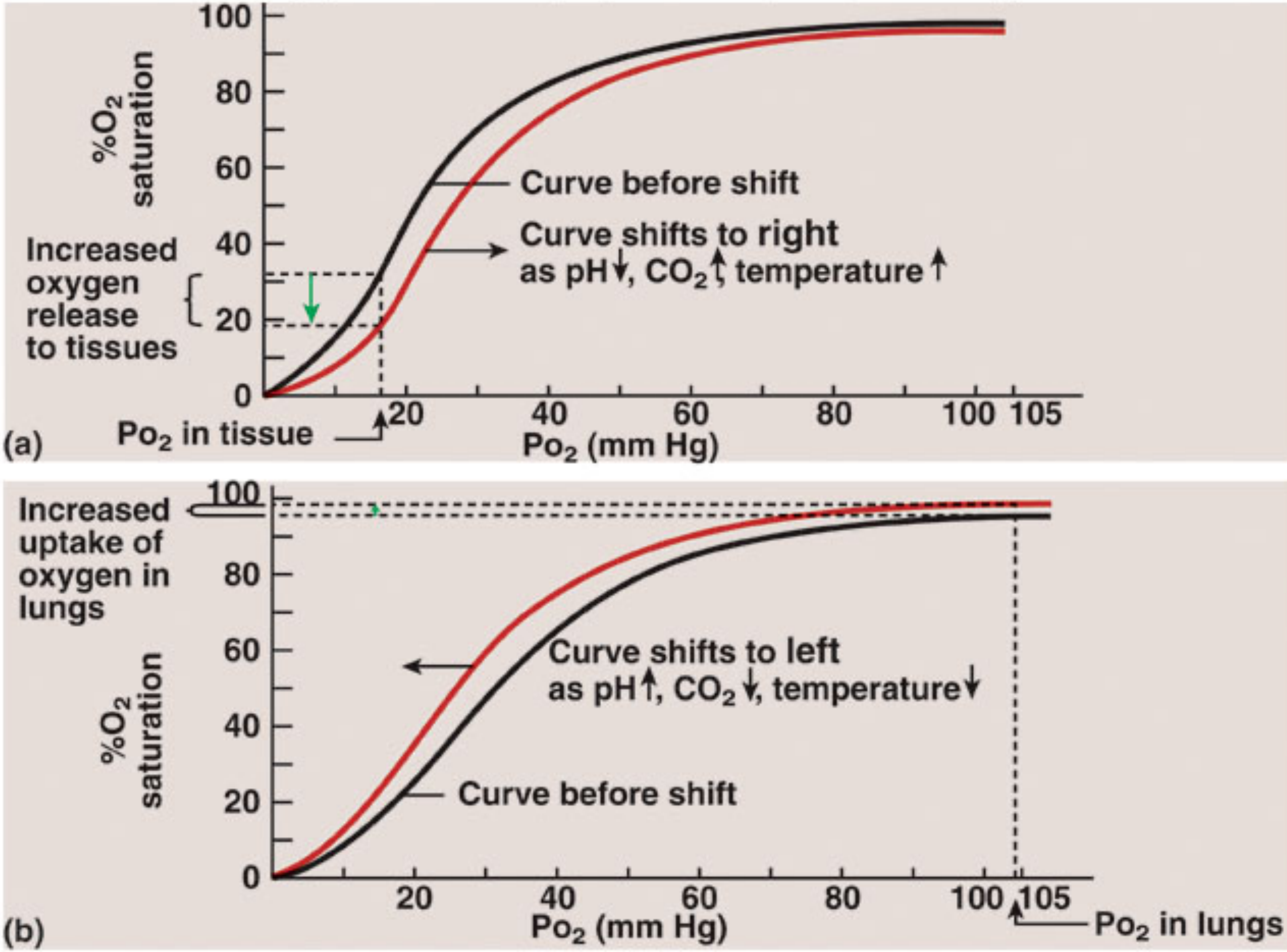


Is O_2 more available or less available to tissue cells when you have a fever? Why?

4. BPG

- decreases the affinity of hemoglobin for O2 and thus helps unload O2 from hemoglobin
- When BPG combines with hemoglobin by binding to the terminal amino groups of the two beta globin chains, the hemoglobin binds O2 less tightly at the heme group sites.
- The greater the level of BPG, the more O2 is unloaded from hemoglobin

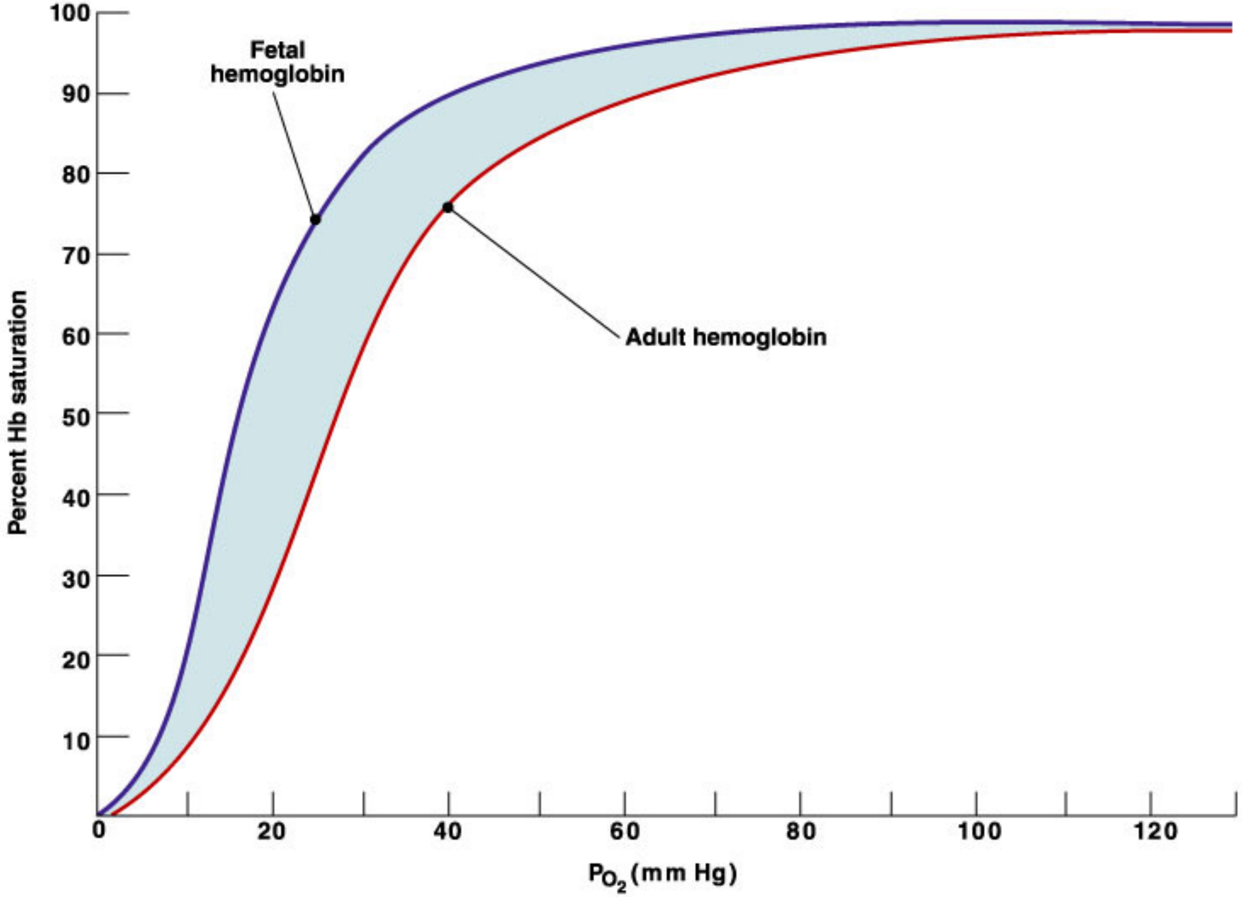
Shifting the Curve



5. Fetal Hemoglobin

Advantage

Increased O_2 release to the fetal tissues under the hypoxic condition.



CARBON DIOXIDE TRANSPORT

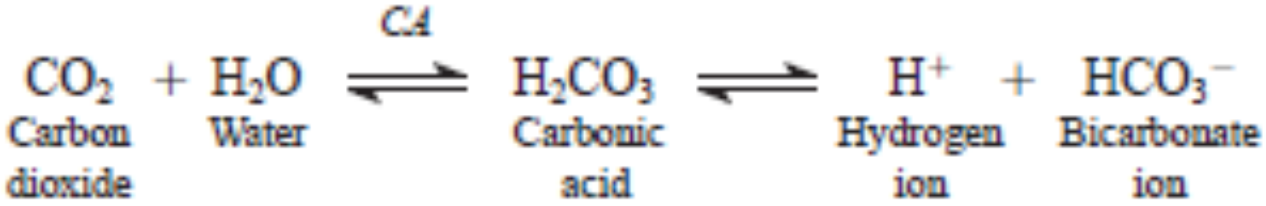
- Under normal resting conditions, each 100 mL of deoxygenated blood contains the equivalent of 53 mL of gaseous CO2, which is transported in the blood in three main forms:

1. ***Dissolved CO2 : 7%***
2. ***Carbamino compounds: 23%;*** Hemoglobin that has bound CO2 is termed **carbaminohemoglobin (Hb-CO2):**

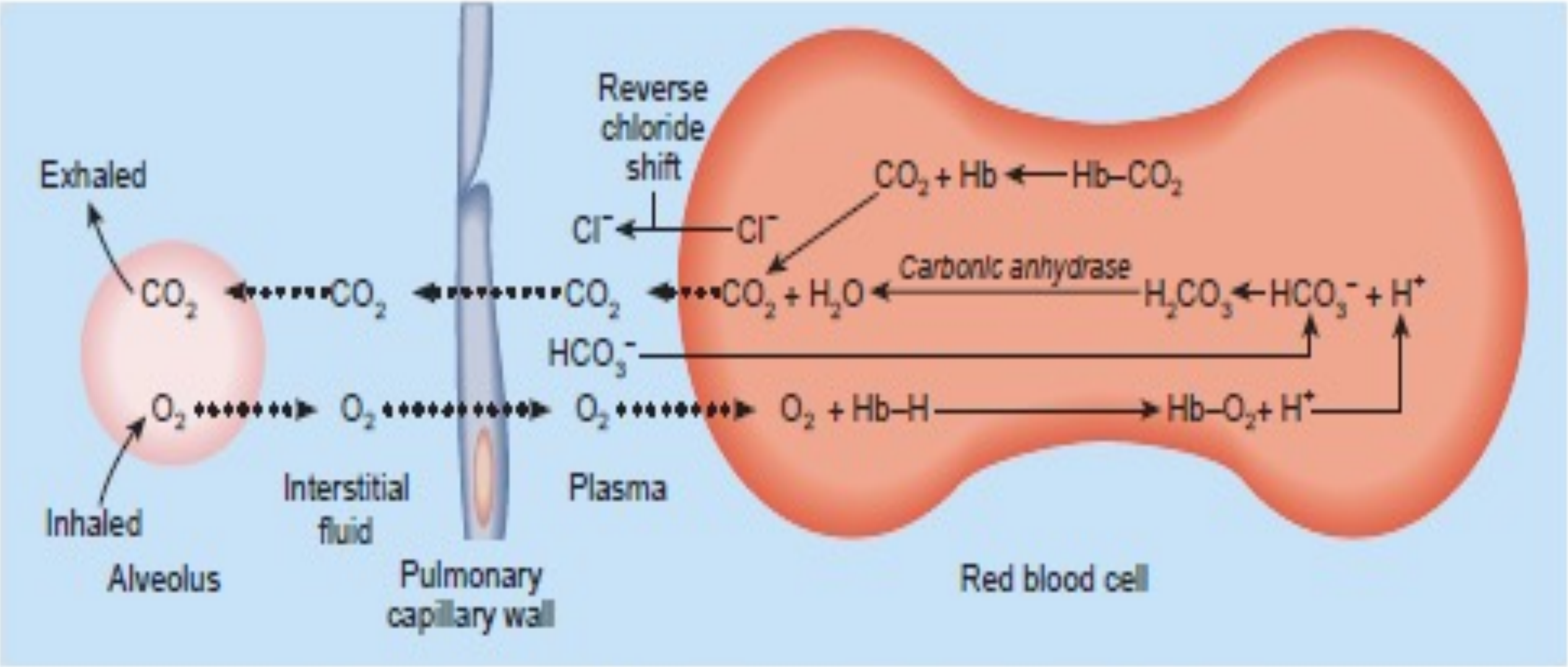
$$\underset{\text{Hemoglobin}}{Hb} + \underset{\text{Carbon dioxide}}{CO_2} \rightleftharpoons \underset{\text{Carbaminohemoglobin}}{Hb\text{–}CO_2}$$

3. *Bicarbonate ions* ($H_2CO_3^-$)*: 70%*

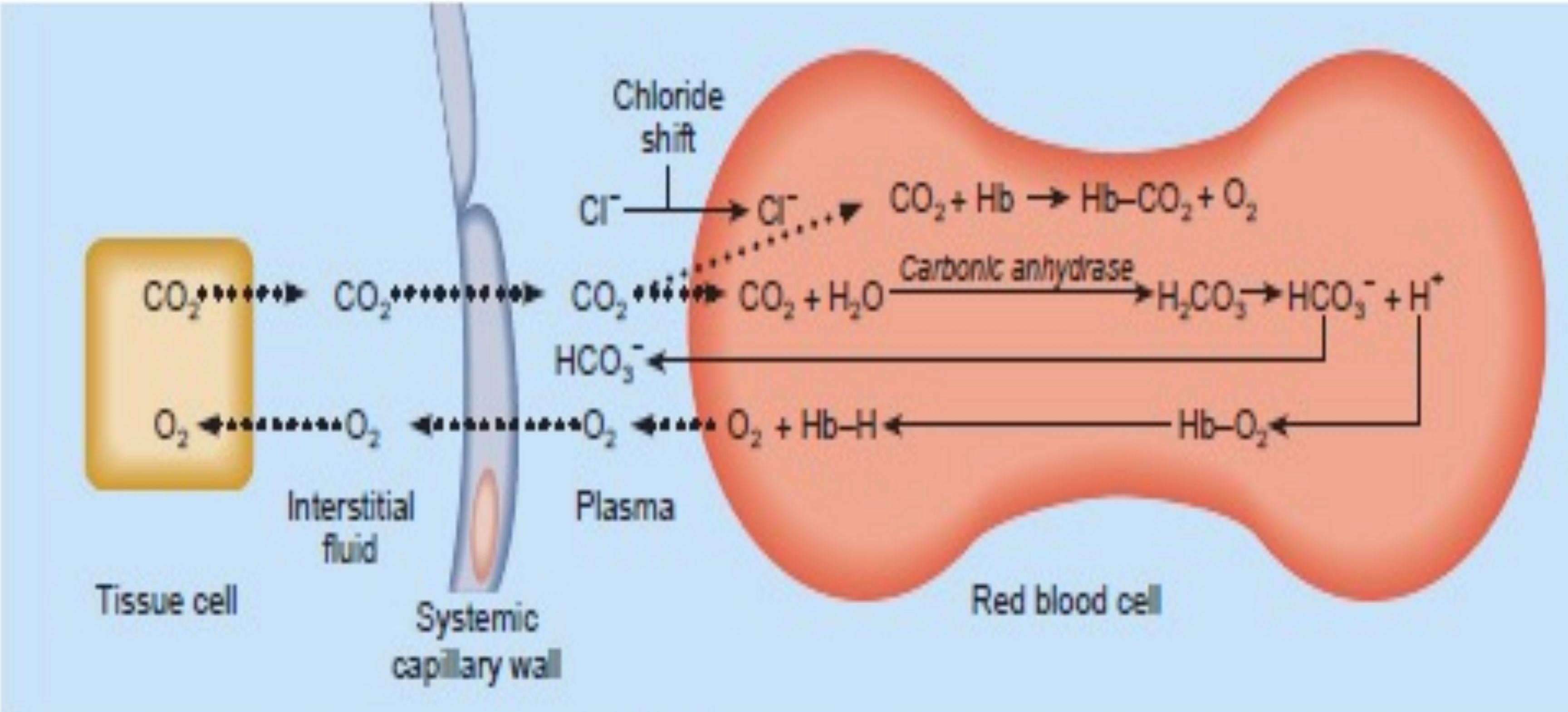
- As CO2 diffuses into systemic capillaries and enters red blood cells, it reacts with water in the presence of the enzyme carbonic anhydrase (CA) to form carbonic acid, which dissociates into H^+ and $H_2CO_3^-$



SUMMARY



(a) Exchange of O_2 and CO_2 in pulmonary capillaries (external respiration)



(b) Exchange of O_2 and CO_2 in systemic capillaries (internal respiration)

RESPIRATORY REGULATION OF ACID-BASE BALANCE

INTRODUCTION

- Major homeostatic challenge is keeping the H concentration (pH) of body fluids at an appropriate level.
- This task—the maintenance of acid-base balance—is of critical importance to normal cellular function.
- In a healthy person, several mechanisms help maintain the pH of systemic arterial blood between 7.35 and 7.45. (A pH of 7.4 corresponds to a H concentration of 0.00004 mEq/liter 40 nEq /liter.)
- Because metabolic reactions often produce a huge excess of H^+, the lack of any mechanism for the disposal of H^+ would cause H level in body fluids to rise quickly to a lethal level.

CONT..

- The removal of H from body fluids and its subsequent elimination from the body depend on the following three major mechanisms:

1. ***Buffer systems***
2. ***Exhalation of carbon dioxide***
3. ***Kidney excretion of*** H^+

EXHALATION OF CARBON DIOXIDE

- The simple act of breathing also plays an important role in maintaining the pH of body fluids.
- An increase in the carbon dioxide (CO2) concentration in body fluids increases H concentration and thus lowers the pH (makes body fluids more acidic).
- Because H2CO3 can be eliminated by exhaling CO2, it is called a **volatile acid.**
- Conversely, a decrease in the CO2 concentration of body fluids raises the pH (makes body fluids more alkaline).

- This chemical interaction is illustrated by the following reversible reactions:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

- Changes in the rate and depth of breathing can alter the pH of body fluids within a couple of minutes. With increased ventilation, more CO2 is exhaled.
- When CO2 levels decrease, H concentration falls, and blood pH increases.
- Doubling the ventilation increases pH by about 0.23 units, from 7.4 to 7.63. If ventilation is slower than normal, less carbon dioxide is exhaled.
- When CO2 levels increase, the H concentration increases, and blood pH decreases.
- Reducing ventilation to one-quarter of normal lowers the pH by 0.4 units, from 7.4 to 7.0.
- These examples show the powerful effect of alterations in breathing on the pH of body fluids.

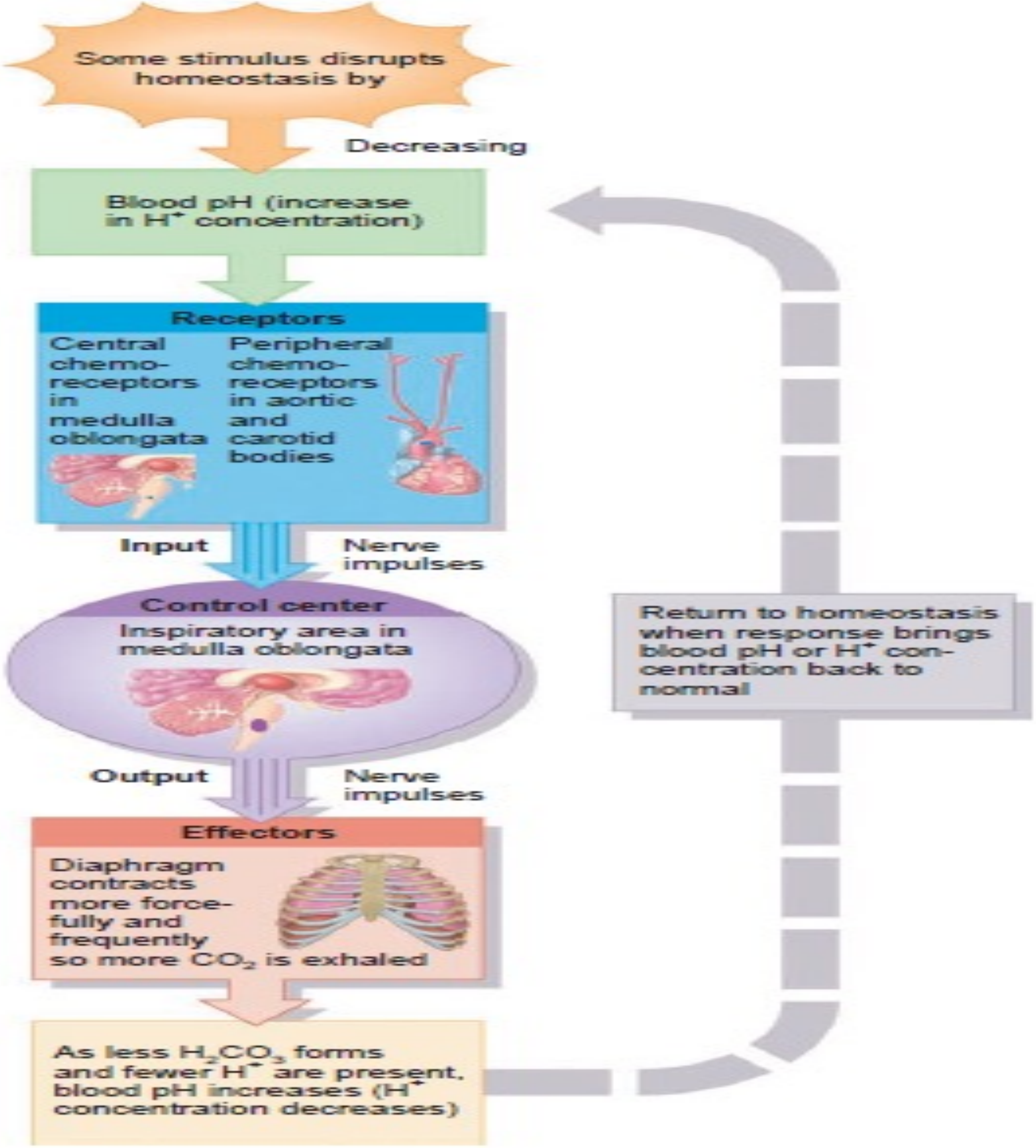
BOHR EFFECT

- When pH ↓, the entire oxygen–hemoglobin dissociation curve shifts to the right; at any given PO_2, Hb is less saturated with O_2, a change termed the **Bohr effect.**
- The Bohr effect works both ways:

1. An increase in H in blood causes O_2 to unload from hemoglobin,
2. The binding of O_2 to hemoglobin causes unloading of H from hemoglobin.

- The explanation for the Bohr effect is that hemoglobin can act as a **buffer** for hydrogen ions (H).
- But when H ions bind to amino acids in hemoglobin, they alter its structure slightly, decreasing its oxygen-carrying capacity → lowered pH drives O_2 off hemoglobin, making more O_2 available for tissue cells.
- ↑ pH increases the affinity of hemoglobin for O_2 and shifts the oxygen–hemoglobin dissociation curve to the left.

THE PH OF BODY FLUIDS AND THE RATE AND DEPTH OF BREATHING INTERACT
VIA A NEGATIVE FEEDBACK LOOP



THANK YOU
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