

# Gas Transport

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## Page 1. Introduction

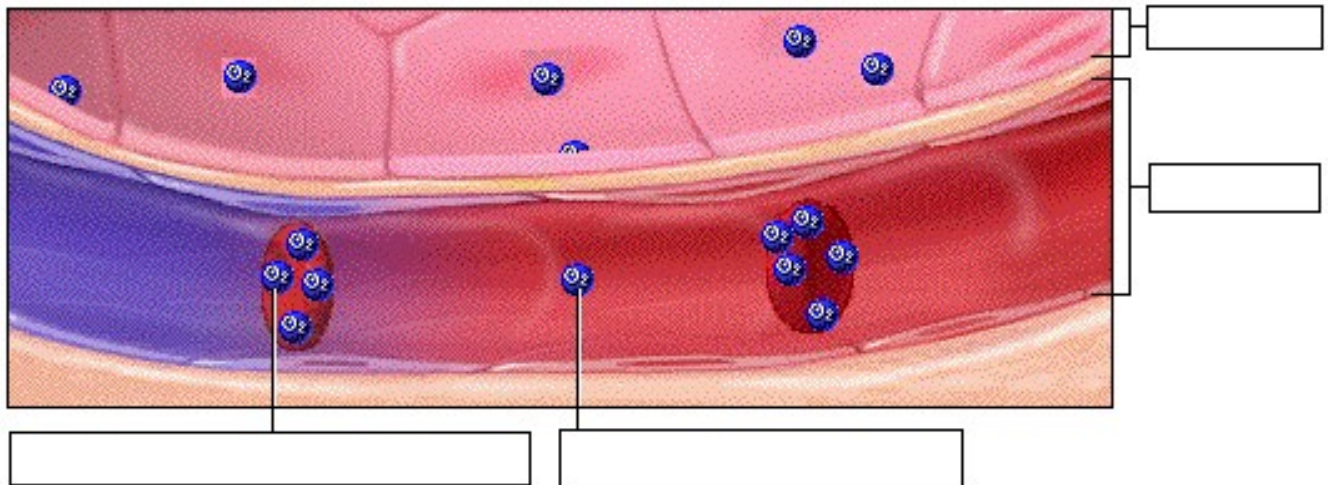
- The blood transports oxygen and carbon dioxide between the lungs and other tissues throughout the body.
- These gases are carried in several different forms:
  1. dissolved in the plasma
  2. chemically combined with hemoglobin
  3. converted into a different molecule

## Page 2. Goals

- To explore how oxygen is transported in the blood.
- To explore how carbon dioxide is transported in the blood.
- To understand the effect of variables, such as  $P_{O_2}$  and  $P_{CO_2}$ , on oxygen and carbon dioxide transport.

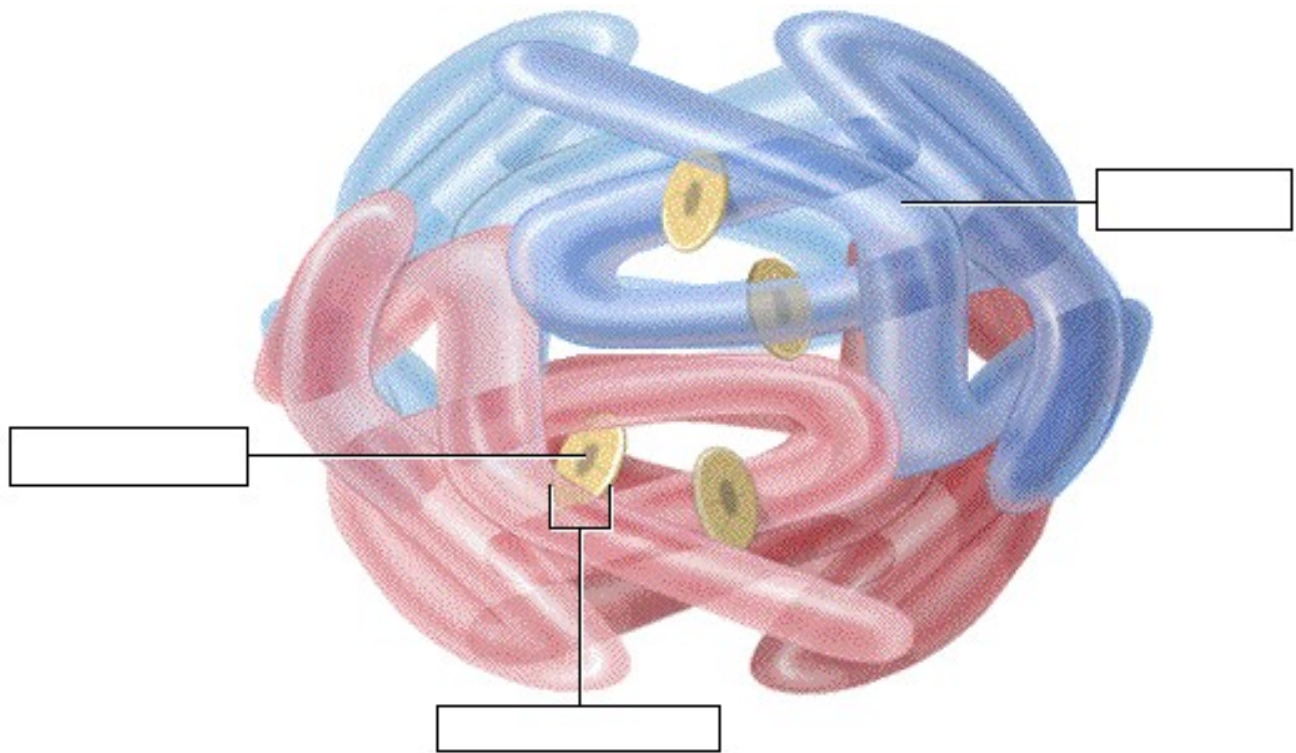
## Page 3. Oxygen Transport

- Transport of oxygen during external respiration:
  - With its low solubility, only approximately 1.5% of the oxygen is transported dissolved in plasma.
- The remaining 98.5% diffuses into red blood cells and chemically combines with hemoglobin.
- Label this diagram:



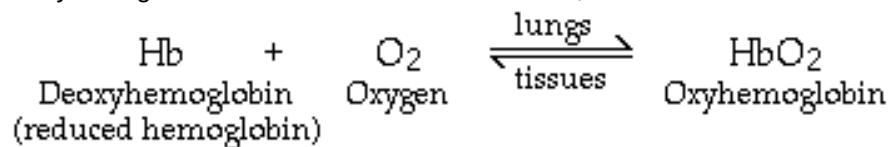
## Page 4. Hemoglobin

- Within each red blood cell, there are approximately 250 million hemoglobin molecules.
- Each hemoglobin molecule consists of:
  1. A globin portion composed of 4 polypeptide chains.
  2. Four iron-containing pigments called heme groups.
- Each hemoglobin molecule can transport up to 4 oxygen molecules because each iron atom can bind one oxygen molecule.
- When 4 oxygen molecules are bound to hemoglobin, it is 100% saturated; when there are fewer, it is partially saturated.
- Oxygen binding occurs in response to the high partial pressure of oxygen in the lungs.
- When hemoglobin binds with oxygen, it is called oxyhemoglobin.
- When one oxygen binds to hemoglobin, the other oxygen molecules bind more readily. This is called cooperative binding. Hemoglobin's affinity for oxygen increases as its saturation increases.
- Label this diagram:

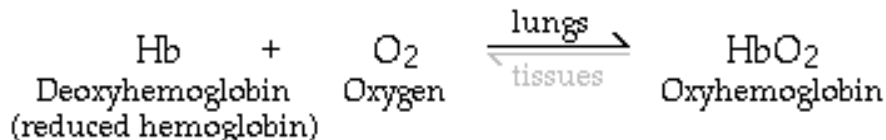


## Page 5. Oxyhemoglobin and Deoxyhemoglobin

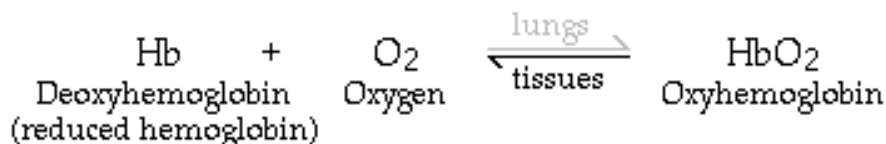
- The formation of oxyhemoglobin occurs as a reversible reaction, and is written as in this chemical equation:



- In reversible reactions, the direction depends on the quantity of products and reactants present.
- In the lungs, where the partial pressure of oxygen is high, the reaction proceeds to the right, forming oxyhemoglobin.



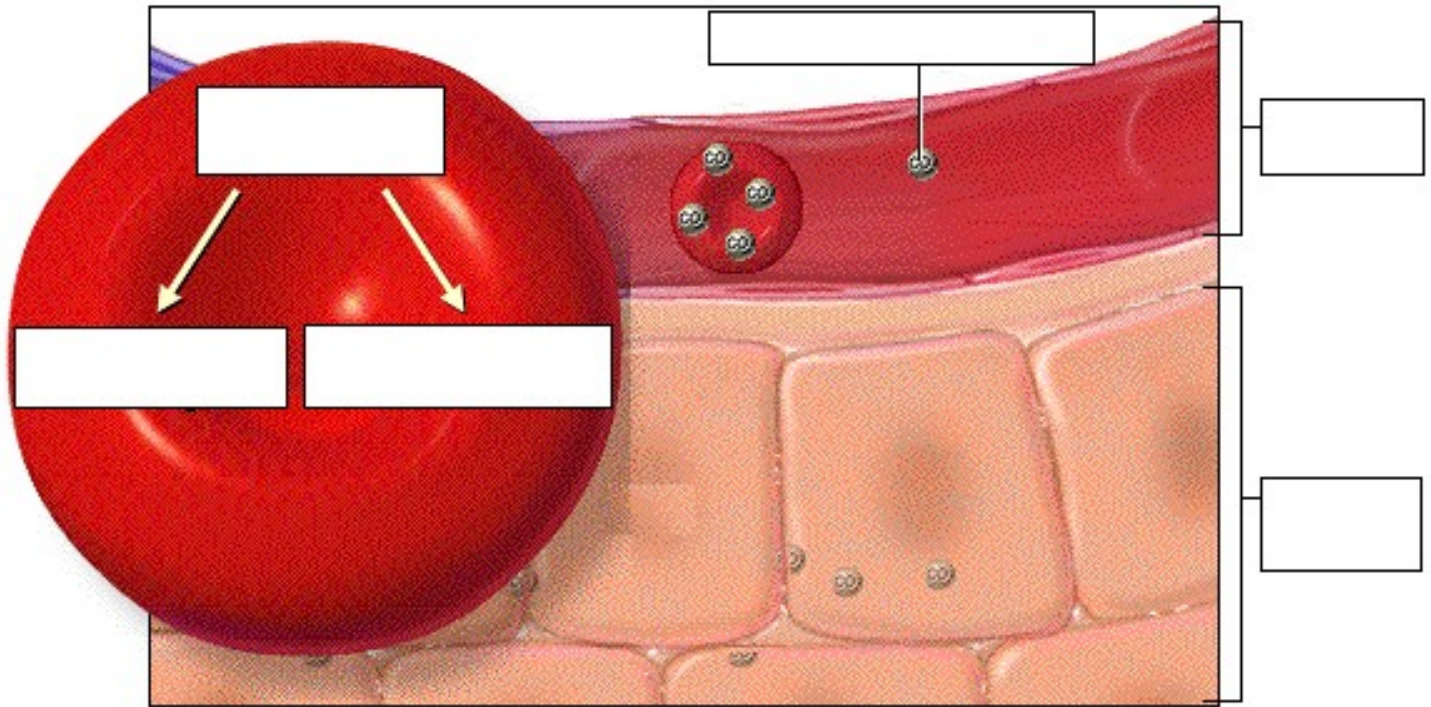
- In organs throughout the body where the partial pressure of oxygen is low, the reaction reverses, proceeding to the left. Oxyhemoglobin releases oxygen, forming deoxyhemoglobin, which is also called reduced hemoglobin.



- Notice that the affinity of hemoglobin for oxygen decreases as its saturation decreases.

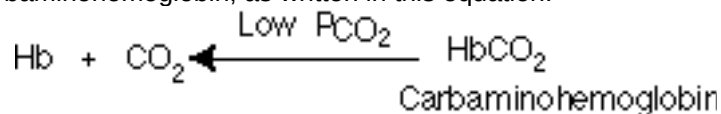
## Page 6. CO<sub>2</sub> Transport

- Carbon dioxide transport:
  - Carbon dioxide is produced by cells throughout the body.
  - It diffuses out of the cells and into the systemic capillaries, where approximately 7% is transported dissolved in plasma.
  - The remaining carbon dioxide diffuses into the red blood cells. Within the red blood cells, approximately 23% chemically combines with hemoglobin, and 70% is converted to bicarbonate ions, which are then transported in the plasma.
- Fill in this diagram:



### Page 7. CO<sub>2</sub> Transport: Carbaminohemoglobin (Tissues)

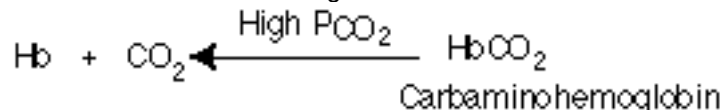
- Of the total carbon dioxide in the blood, 23% binds to the globin portion of the hemoglobin molecule to form carbaminohemoglobin, as written in this equation:



- Carbaminohemoglobin forms in regions of high  $P_{\text{CO}_2}$ , as blood flows through the systemic capillaries in the tissues.

### Page 8. CO<sub>2</sub> Transport: Carbaminohemoglobin (Lungs)

- The formation of carbaminohemoglobin is reversible.

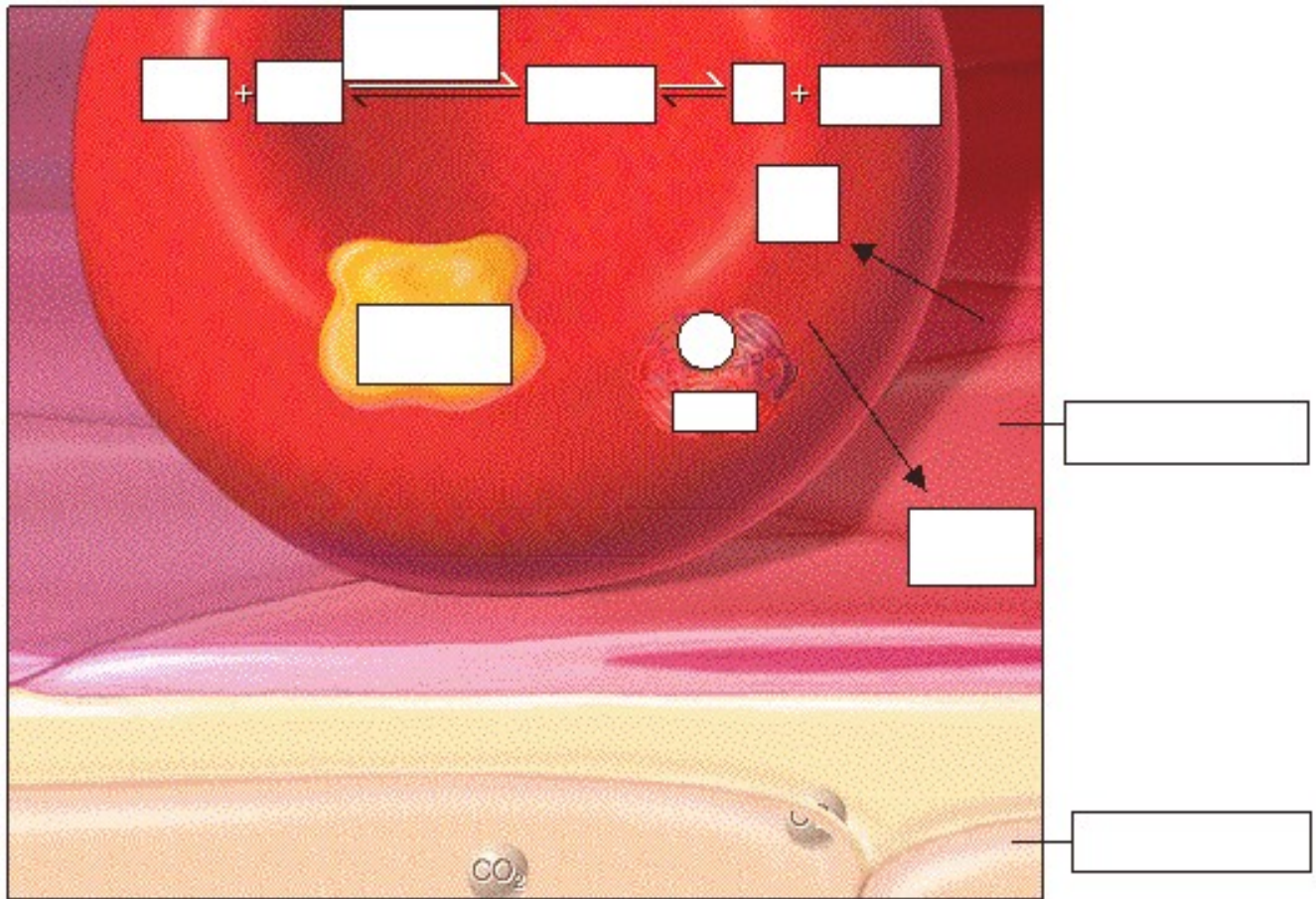


- In the lungs, which have a lower  $P_{\text{CO}_2}$ , carbon dioxide dissociates from carbaminohemoglobin, diffuses into the alveoli, and is exhaled.

### Page 9. CO<sub>2</sub> Transport: Bicarbonate Ions (Tissues)

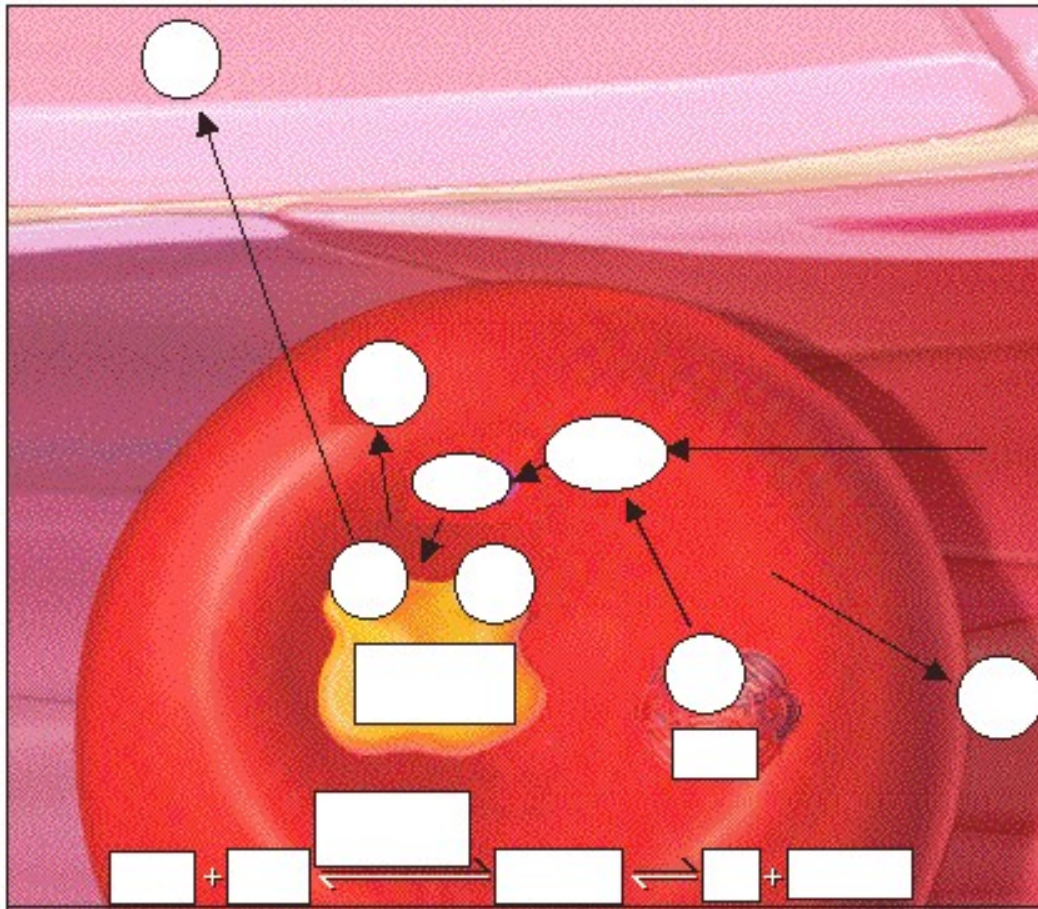
- Of the total carbon dioxide in the blood, 70% is converted into bicarbonate ions within the red blood cells, in a sequence of reversible reactions. The bicarbonate ions then enter the plasma.
- In regions with high  $P_{\text{CO}_2}$ , carbon dioxide enters the red blood cell and combines with water to form carbonic acid. This reaction is catalyzed by the enzyme carbonic anhydrase. The same reaction occurs in the plasma, but without the enzyme it is very slow.
- Carbonic acid dissociates into hydrogen ions and bicarbonate ions. The hydrogen ions produced in this reaction are buffered by binding to hemoglobin. This is written as HHb.
- In order to maintain electrical neutrality, bicarbonate ions diffuse out of the red blood cell and chloride ions diffuse in. This is called the chloride shift.
- Within the plasma, bicarbonate ions act as a buffer and play an important role in blood pH control.
- Label this diagram to show what happens at the tissues:





### Page 10. CO<sub>2</sub> Transport: Bicarbonate Ions (Lungs)

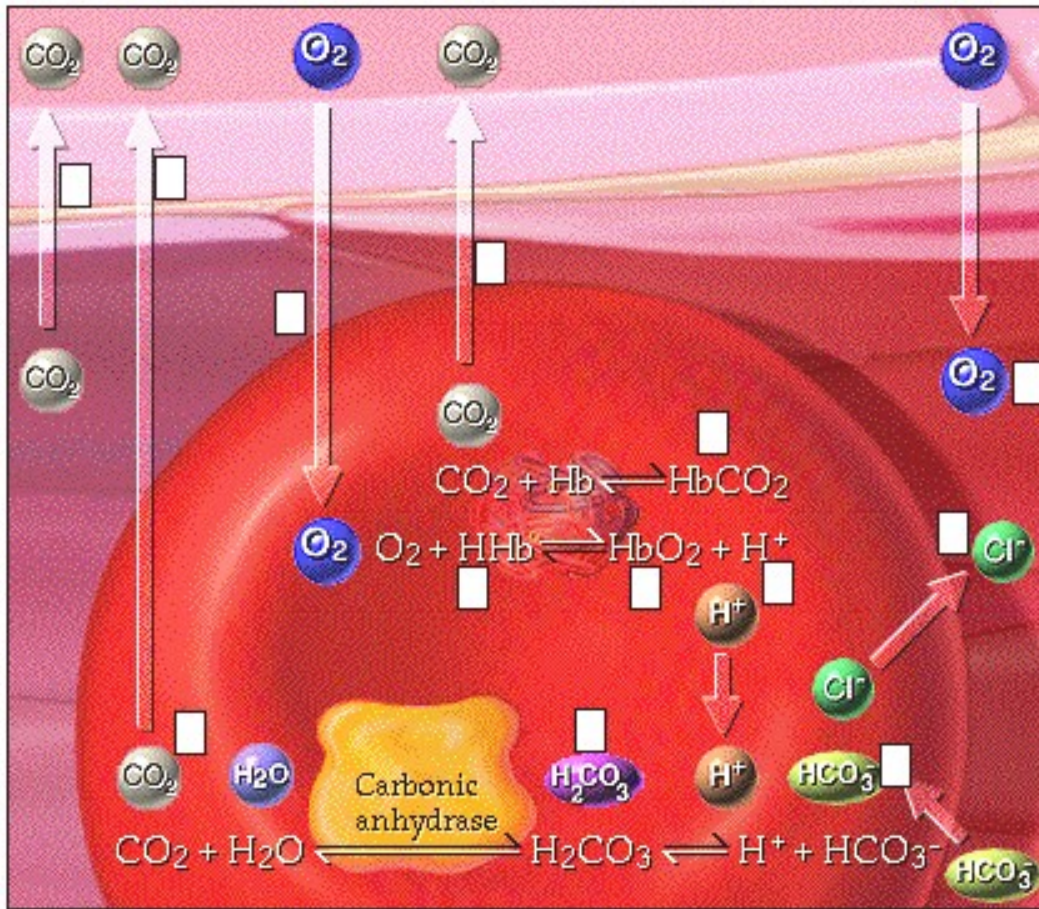
- In the lungs, carbon dioxide diffuses out of the plasma and into the alveoli. This lowers the  $P_{\text{CO}_2}$  in the blood, causing the chemical reactions to reverse and proceed to the left.
- In the lungs, the bicarbonate ions diffuse back into the red blood cell, and the chloride ions diffuse out of the red blood cell. Recall that this is called the chloride shift.
- The hydrogen ions are released from hemoglobin, and combine with the bicarbonate ion to form carbonic acid.
- Carbonic acid breaks down into carbon dioxide and water. This reverse reaction is also catalyzed by the enzyme carbonic anhydrase.
- Label this diagram:



## Page 11. Summary: Lungs

- Summary of external respiration in the lungs.
- Although we will look at the processes step by step, they actually occur simultaneously.
- Remember, gases always follow their partial pressure gradients.
- As you go through the steps, place the numbers that correspond with the steps in the blanks on this diagram:
  - During external respiration, a small amount of oxygen (1) remains dissolved in the plasma. However, the majority of the oxygen (2) continues into the red blood cells, where it combines with deoxyhemoglobin (3) to form oxyhemoglobin (4), releasing a hydrogen ion (5).
  - When hemoglobin is saturated with oxygen, its affinity for carbon dioxide decreases. Any carbon dioxide combined with hemoglobin (6) dissociates and diffuses out of the red blood cell (7), through the plasma and into the alveoli. In other words, oxygen loading facilitates carbon dioxide unloading from hemoglobin. This interaction is called the Haldane effect.
  - The hydrogen ion released from hemoglobin combines with a bicarbonate ion (8), which diffuses into the red blood cell from the plasma in exchange for a chloride ion (9). Recall that this exchange is the chloride shift. The reaction between hydrogen and bicarbonate ions forms carbonic acid (10).
  - Carbonic acid then breaks down into water and carbon dioxide (11), catalyzed by the enzyme carbonic anhydrase. The water produced by this reaction may leave the red blood cell, or remain as part of the cytoplasm. The carbon dioxide diffuses out of the red blood cell (12) into the plasma and then into the alveoli. The small amount of carbon dioxide transported in the plasma diffuses into the alveoli (13).

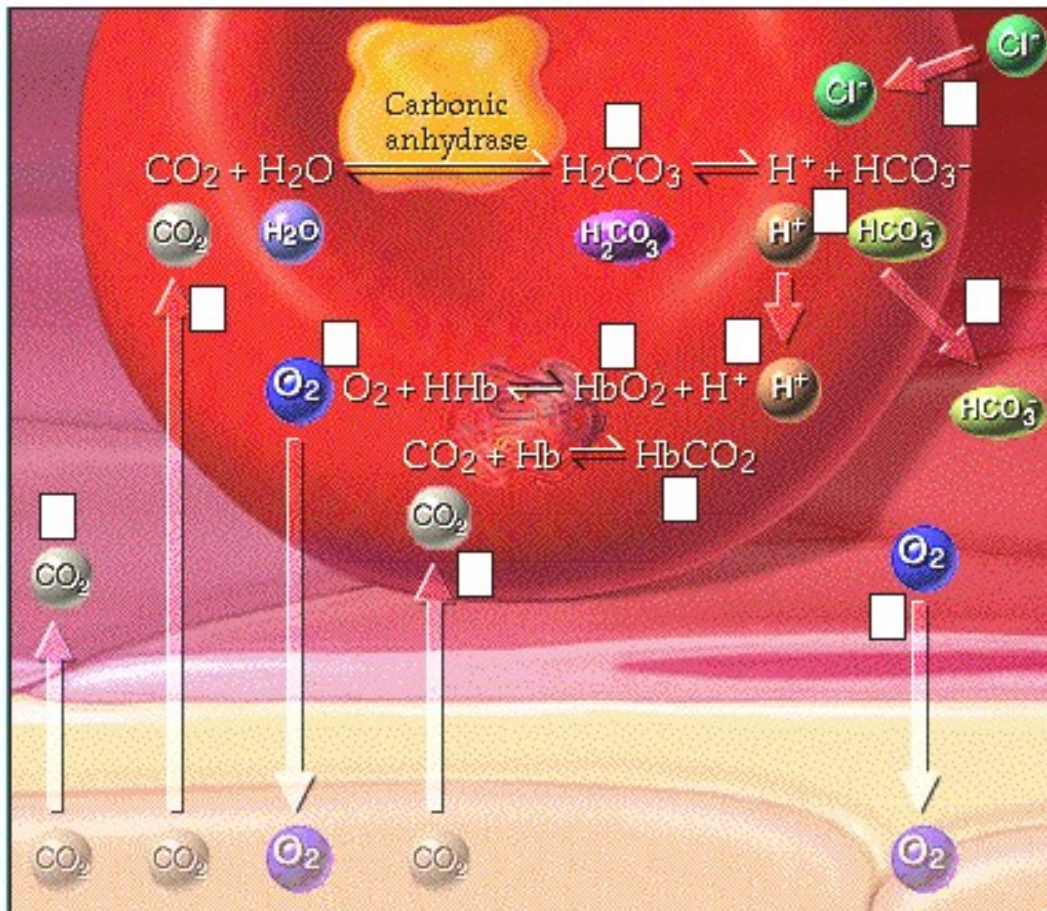




## Page 12. Summary: Tissues

Summary of internal respiration in the tissues.

- As you go through the steps, place the numbers that correspond with the steps in the blanks on this diagram:
  - During internal respiration, a small amount of carbon dioxide (1) remains dissolved in the plasma, but most of the carbon dioxide (2) continues into the red blood cells where much of it combines with water to form carbonic acid (3) or combines with hemoglobin to form carbaminohemoglobin (11). This reaction is catalyzed by carbonic anhydrase. The carbonic acid then dissociates into hydrogen and bicarbonate ions (4).
  - During the chloride shift, bicarbonate ions (5) diffuse out of the red blood cell in exchange for chloride ions (6). Bicarbonate ions act as buffers within the plasma, controlling blood pH.
  - Within the red blood cell, hydrogen ions (7) are buffered by hemoglobin (8). When hemoglobin binds hydrogen ions, it has a lower affinity for oxygen. As a result, oxygen (9) dissociates from hemoglobin, diffuses out of the red blood cell and into the tissues. The interaction between hemoglobin's affinity for oxygen and its affinity for hydrogen ions is called the Bohr effect. By forming hydrogen ions, carbon dioxide loading facilitates oxygen unloading.
  - The small amount of oxygen transported in the dissolved state (10) also diffuses out of the plasma and into the tissue cells.



### Page 13. Summary

- $\text{O}_2$  is transported in two ways:
  - dissolved in plasma, and
  - bound to hemoglobin as oxyhemoglobin
- $\text{CO}_2$  is transported in three ways:
  - dissolved in plasma
  - bound to hemoglobin as carbaminohemoglobin, and
  - converted to bicarbonate ions
- Oxygen loading facilitates carbon dioxide unloading from hemoglobin. This is known as the Haldane effect.
- When the pH decreases, carbon dioxide loading facilitates oxygen unloading. The interaction between hemoglobin's affinity for oxygen and its affinity for hydrogen ions is called the Bohr effect.

- \*\*** Now is a good time to go to quiz questions 1-6.
- Click the Quiz button on the left side of the screen.
  - Work through quiz questions 1-6.

### Notes on Quiz Questions:

#### Quiz Question #1: Oxygen and Hemoglobin

- This question asks you to watch an animation of oxygen binding to hemoglobin and determine where in the body the process occurs.

#### Quiz Question #2: Bicarbonate Ion Equation

- This question asks you to put together the reaction by which carbon dioxide and water form bicarbonate.

#### Quiz Question #3: Carbon Dioxide and Hemoglobin

- This question shows you an animation, then asks you to predict if the process occurs in areas of high or low  $\text{PCO}_2$ .

**Quiz Question #4: Gas Transport: Lungs**

- This question asks you to determine which direction reactions go in the lungs.

**Quiz Question #5: Gas Transport: Tissues**

- This question asks you to determine which direction reactions go in the tissues.

**Quiz Question #6: Lungs or Tissues?**

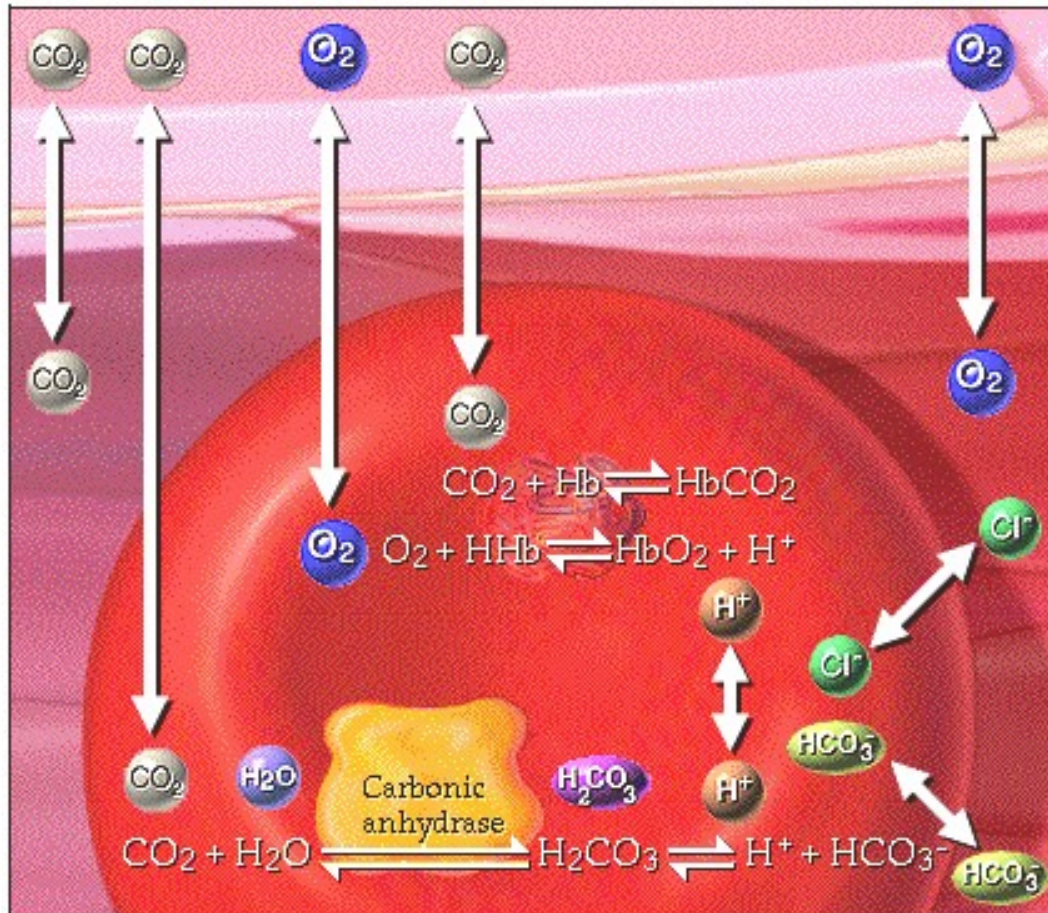
- This question asks you to determine if a number of different processes occur in the lungs or the tissues.

**Study Questions on Gas Transport:**

1. (Page 3.) When oxygen diffuses into the blood during external respiration, what two places within the blood does it end up? What percentage of oxygen ends up in each of these two places?
2. (Page 3.) Why does so little oxygen dissolve in the plasma?
3. (Page 3.) Label the diagram on p. 3.
4. (Page 4.) What are the two components of hemoglobin? What is each part made of?
5. (Page 4.) In each hemoglobin molecule:
  - a. How many polypeptide chains are there?
  - b. How many hemes are there?
  - c. How many irons are there?
  - d. How many oxygens can bind?
6. (Page 4.) Where, within the hemoglobin, does oxygen bind?
7. (Page 4.) a. When is hemoglobin said to be "saturated"? b. When is hemoglobin said to be "partially saturated"?
8. (Page 4.) What is hemoglobin called when oxygen is attached?
9. (Page 4.) Explain cooperative binding of oxygen to hemoglobin.
10. (Page 4.) Label the diagram of hemoglobin on p. 4.
11. (Page 5.) Give a name to each of these symbols:
  - a. Hb
  - b.  $\text{HbO}_2$
12. (Page 5.) Does this reaction occur at the lungs or at the tissues?  $\text{Hb} + \text{O}_2 \longrightarrow \text{HbO}_2$
13. (Page 5.) Does this reaction occur at the lungs or at the tissues?  $\text{Hb} + \text{O}_2 \longleftarrow \text{HbO}_2$
14. (Page 5.) The affinity of hemoglobin for oxygen \_\_\_\_\_ as its saturation decreases.
  - a. increases
  - b. decreases
15. (Page 6.) Label the diagram on page 6.
16. (Page 7.) 23% of the total carbon dioxide in the blood binds to the globin portion of the hemoglobin molecule. What is the name and symbol for the molecule formed?
17. (Page 8.) Does carbaminohemoglobin form in areas of high or low  $\text{PCO}_2$ ?
18. (Page 8.) Which of these occurs in the lungs? Which occurs in the tissues?
  - a.  $\text{Hb} + \text{CO}_2 \longrightarrow \text{HbCO}_2$
  - b.  $\text{Hb} + \text{CO}_2 \longleftarrow \text{HbCO}_2$
19. (Page 9.) Label the diagram on p. 9.
20. (Page 9.) What is the name of the enzyme that catalyzes the reaction of carbon dioxide and water to form carbonic acid?
21. (Page 9.) What happens to the hydrogen ions that are generated when carbonic acid dissociates into bicarbonate inside red blood cells?
22. (Page 9.) Explain the chloride shift at the tissues.
23. (Page 9.) Explain the chloride shift at the lungs.



24. (Page 10.) Label the diagram on p. 10.
25. (Page 10.) What happens to the hydrogen ions that are released from hemoglobin at the lungs?
26. (Page 11.) Number the diagram on page 11 to go along with the numbers in the description to illustrate processes that occur at the lungs.
27. (Page 11.) What is the Haldane effect? Where does it occur?
28. (Page 12.) What is the Bohr effect? Where does it occur?
29. (Page 12.) Number the diagram on page 12 to go along with the numbers in the description to illustrate processes that occur at the tissues.
30. (Summary) Do the following processes occur at the lungs or the tissues?
- a. CO<sub>2</sub> unloading
  - b. 75% hemoglobin saturation
  - c.  $O_2 + HHb \longrightarrow HbO_2 + H^+$
  - d. O<sub>2</sub> loading
  - e.  $H_2CO_3 \longleftarrow H^+ + HCO_3^-$
  - f. CO<sub>2</sub> loading
  - g.  $H_2CO_3 \longrightarrow H^+ + HCO_3^-$
  - h. 98% hemoglobin saturation
  - i.  $CO_2 + H_2O \longrightarrow H_2CO_3$
  - j.  $CO_2 + Hb \longleftarrow HbCO_3$
  - k.  $CO_2 + Hb \longrightarrow HbCO_3$
  - l.  $CO_2 + H_2O \longleftarrow H_2CO_3$
  - m. O<sub>2</sub> unloading
  - n.  $O_2 + HHb \longleftarrow HbO_2 + H^+$
31. (Summary) Identify the direction that each of the arrows would take in the lungs:



32. (Summary) Identify the direction that each of the arrows would take in the tissues:



