Gas Exchange

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Page 1. Introduction

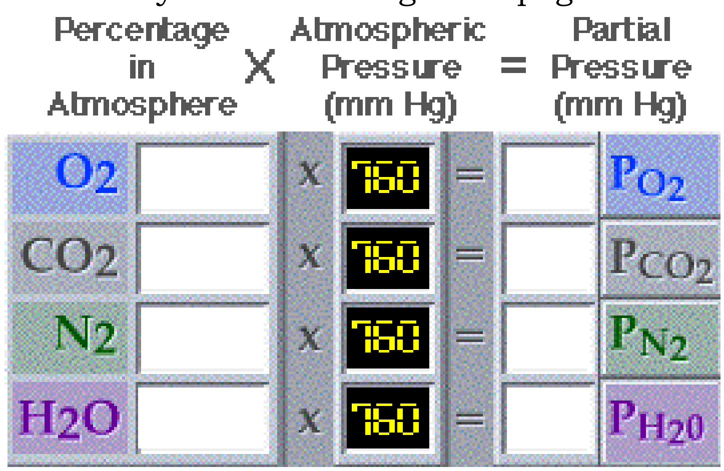
- Oxygen and carbon dioxide diffuse between the alveoli and pulmonary capillaries in the lungs, and between the systemic capillaries and cells throughout the body.
- The diffusion of these gases, moving in opposite directions, is called gas exchange.

Page 2. Goals

- To apply gas law relationships - between partial pressure, solubility, and concentration - to gas exchange.
- To explore the factors which affect external and internal respiration.

Page 3. Dalton's Law of Partial Pressures

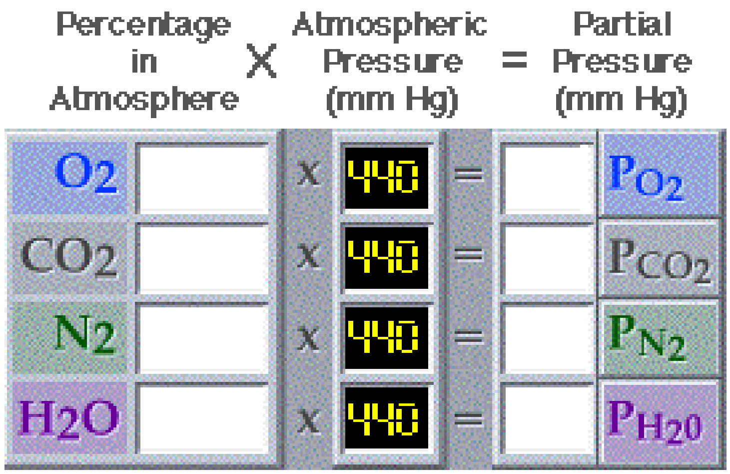
- Fill out this chart as you work through this page:



- In order to understand gas exchange, we must first understand the air we breathe. The atmosphere is a mixture of gases, including oxygen, carbon dioxide, nitrogen, and water.
- The combined pressure of these gases equals atmospheric pressure.
- At sea level, atmospheric pressure is 760 mm Hg, which means that the atmosphere pushes a column of mercury to a height of 760 millimeters. Each gas within the atmosphere is responsible for part of that pressure in proportion to its percentage in the atmosphere.
- Oxygen comprises 20.9% of the atmosphere. The pressure exerted by oxygen is 20.9% of the total pressure of 760 millimeters of mercury, which equals 159 millimeters of mercury. This value is known as the partial pressure of oxygen, and is written as "P" with the subscript "O_2".
- Notice that the partial pressures of the four gases add up to 760 millimeters of mercury, the total atmospheric pressure. This demonstrates Dalton's Law of Partial Pressures, which states that in a mixture of gases, the total pressure equals the sum of the partial pressures exerted by each gas. The partial pressure of each gas is directly proportional to its percentage in the total gas mixture.

Page 4. Effect of High Altitude on Partial Pressures

- Fill out this chart as you work through this page:



- Atmospheric pressure decreases with increasing altitude. For example, on the top of Mt. Whitney, atmospheric pressure drops to approximately 440 millimeters of mercury.
- Oxygen still makes up 20.9% of the atmosphere, but the P_{O_2} is 20.9% of 440 millimeters of mercury, or about 92 millimeters of mercury. Compare that to the P_{O_2} at sea level of 159 millimeters of mercury. Lower atmospheric pressure means fewer gas molecules, and therefore fewer oxygen molecules, are available. That explains why you may gasp for breath at high altitudes.
- As you can see, at high altitudes the partial pressures of all gases are lower than at sea level.

Page 5. Henry's Law

- Within the lungs, oxygen and carbon dioxide diffuse between the air in the alveoli and the blood, that is between a gas and a liquid.
- This movement is governed by Henry's Law, which states that the amount of gas which dissolves in a liquid is proportional to:
    1. the partial pressure of the gas
    2. the solubility of the gas
- In this container, the oxygen in the air is at equilibrium with the oxygen in the liquid. At equilibrium, the pressure of the oxygen in the air is the same as in the liquid, with the gas molecules diffusing at the same rate in both directions.
- If you increase the pressure in the container more oxygen molecules dissolve in the liquid, moving from a region of high pressure to a region of low pressure. Diffusion continues until a new equilibrium is reached. This is what happens when oxygen moves from the alveoli into the blood.
- Now let's look at the diffusion of carbon dioxide. Although both gases are at the same pressure, far more carbon dioxide dissolves in the liquid than oxygen. This occurs because carbon dioxide is much more soluble than oxygen. As stated in Henry's Law, the amount of oxygen and carbon dioxide which dissolves is proportional to the partial pressure and the solubility of each gas.

** Now is a good time to go to quiz questions 1-3:

- Click the Quiz button on the left side of the screen..
- Work through questions 1-3.
- After answering question 3, click the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen and choose "6. Sites of Gas Exchange".

Page 6. Sites of Gas Exchange

Sites of gas exchange in the body:

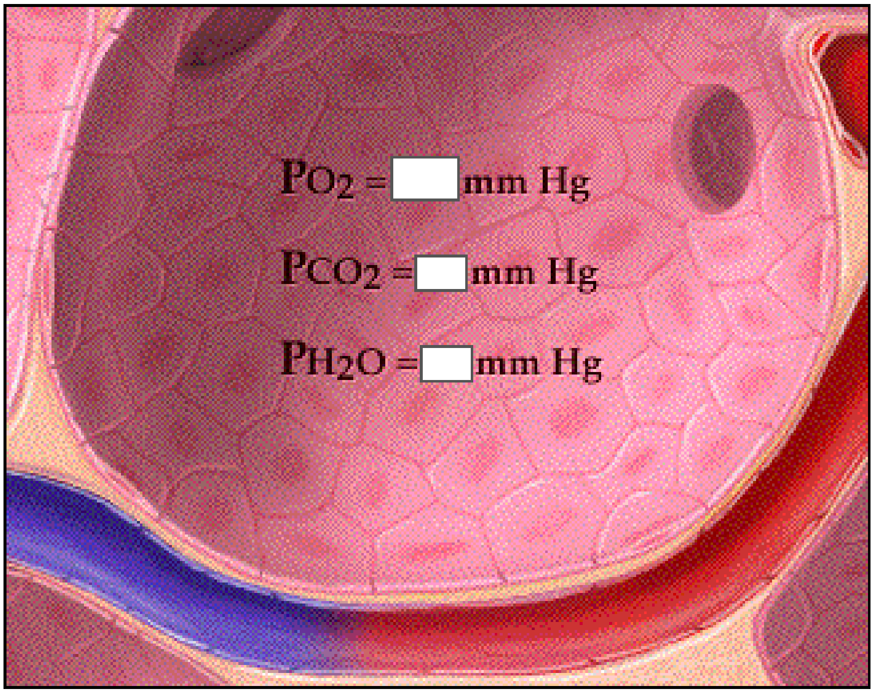
- **External Respiration.**
  - Blood that is low in oxygen is pumped from the right side of the heart, through the pulmonary arteries to the lungs.
  - External respiration occurs within the lungs, as carbon dioxide diffuses from the pulmonary capillaries into the alveoli, and oxygen diffuses from the alveoli into the pulmonary capillaries.
  - Oxygen-rich blood leaves the lungs and is transported through the pulmonary veins to the left side of the heart.
- **Internal Respiration.**
  - From there it is pumped through the systemic circuit to tissues throughout the body.
  - Internal respiration occurs within tissues, as oxygen diffuses from the systemic capillaries into the cells, and carbon dioxide diffuses from the cells into the systemic capillaries.

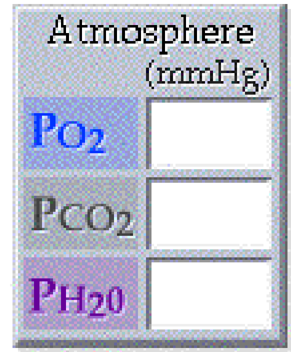
Page 7. Factors Influencing External Respiration

- Efficient external respiration depends on three main factors:
  1. The surface area and structure of the respiratory membrane. The 300 million alveoli, covered with a dense network of pulmonary capillaries, provide an enormous surface area for efficient gas exchange. In addition, the thinness of the respiratory membrane increases efficiency.
  2. The partial pressure gradients between the alveoli and capillaries.
  3. Efficient gas exchange requires matching alveolar airflow to pulmonary capillary blood flow.

Page 8. External Respiration: Partial Pressures

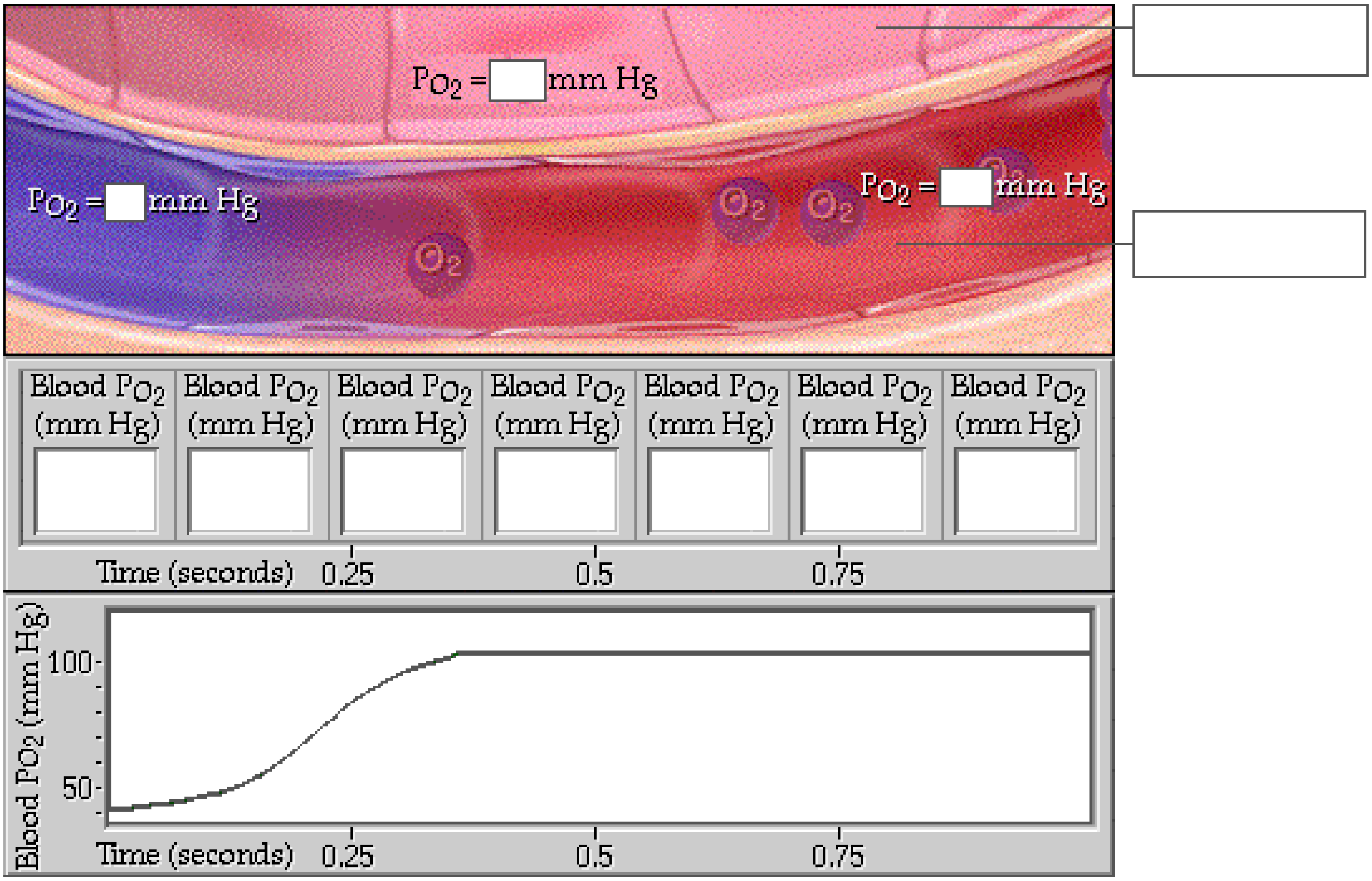
- Let's see how partial pressure gradients affect gas exchange between the alveoli and the pulmonary capillaries.
- Notice that the partial pressures in the alveoli differ from those in the atmosphere. This difference is caused by a combination of several factors:
  1. Humidification of inhaled air. As it travels through the respiratory passageways to the alveoli, air is humidified, picking up water molecules. This greatly increases the partial pressure of water.
  2. Gas exchange between the alveoli and pulmonary capillaries. A continuous exchange of oxygen and carbon dioxide occurs between the alveoli and pulmonary capillaries, changing the partial pressures of both gases. Oxygen diffuses out of the alveoli into the pulmonary capillaries and carbon dioxide diffuses from the pulmonary capillaries into the alveoli.
  3. Mixing of new and old air. Since the alveoli do not completely empty between breaths, the air in the alveoli is a mixture of new air and air remaining from previous breaths.
- Label this diagram:





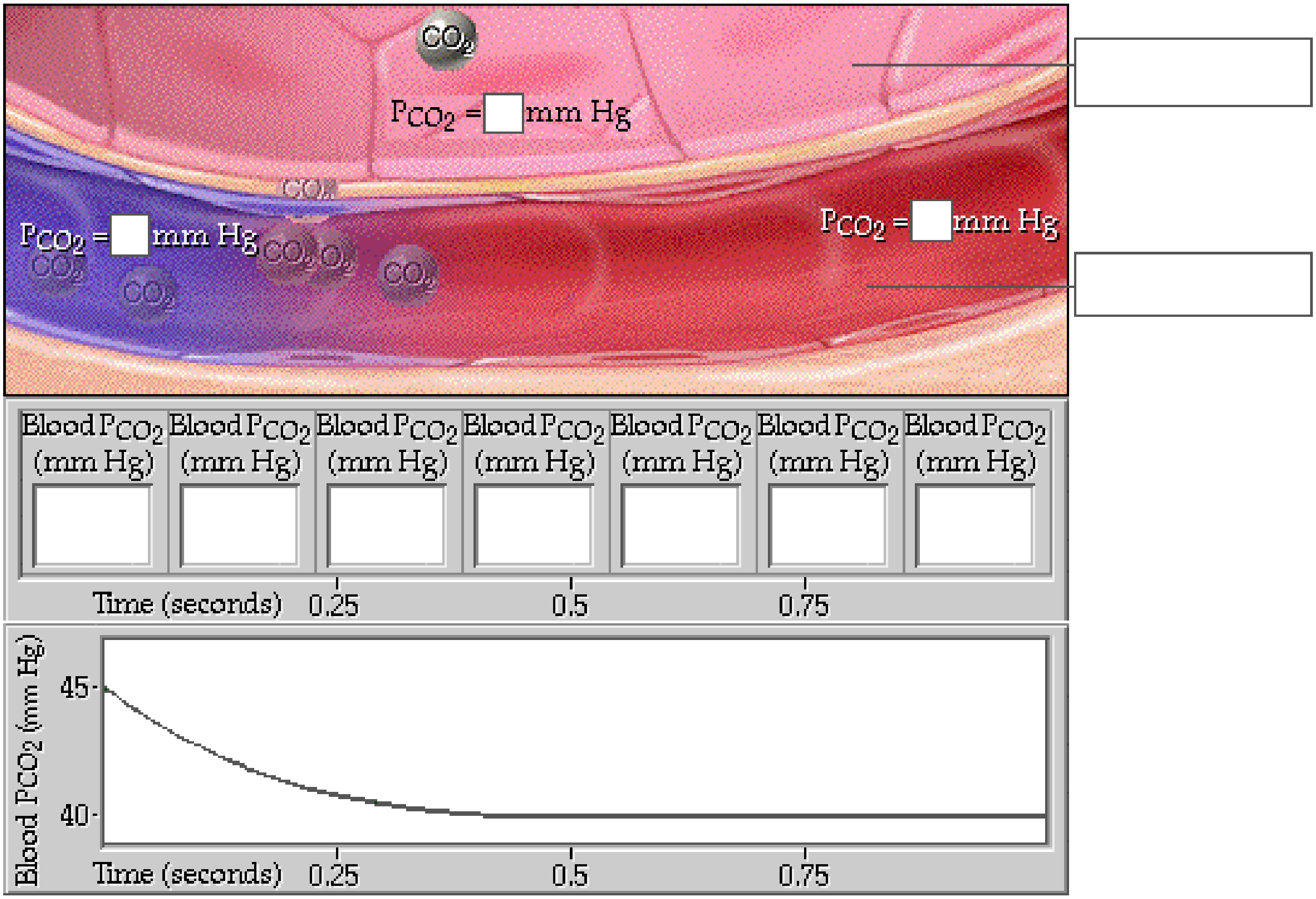
Page 9. External Respiration: Loading O_2

- Let's first look at the loading of oxygen into the blood. Each alveolus is surrounded by a network of capillaries. This diagram shows just one alveolus and one capillary.
- The P_{O_2} of the alveolar air is 104 mm Hg. At rest, the oxygen-poor blood entering the pulmonary capillaries has a P_{O_2} of 40 mm Hg.
- As blood flows past the alveolus, the P_{O_2} increases.
- Notice that there is a net diffusion of oxygen along its partial pressure gradient, from the alveolus into the blood, until equilibrium is reached. The P_{O_2} of the oxygen-rich blood has increased to 104 mm Hg.
- As indicated in the graph, equilibrium is reached rapidly, within the first third of the pulmonary capillary.
- Label this diagram:



Page 10. External Respiration: Unloading CO_2

- Now let's look at the unloading of carbon dioxide from the blood into the alveolus.
- The P_{CO_2} of the alveolar air is 40 millimeters of mercury. At rest, the P_{CO_2} of the blood entering the pulmonary capillaries is 45 millimeters of mercury.
- As blood flows past the alveolus, the P_{CO_2} decreases. Carbon dioxide diffuses along its partial pressure gradient, from the blood into the alveolus, until equilibrium is reached. The P_{CO_2} of the blood has decreases to 40 millimeters of mercury.
- Equilibrium is reached rapidly, within the first four tenths of the pulmonary capillary.
- Label this diagram:



Page 11. External Respiration O_2 and CO_2 Exchange

- Loading oxygen and unloading carbon dioxide occur simultaneously. As you inhale, you replenish oxygen, and as you exhale, you eliminate carbon dioxide.
- Notice how much smaller carbon dioxide's partial pressure gradient is than oxygen's. As Henry's law states, the number of molecules which dissolve in a liquid is proportional to both the partial pressure and the gas solubility. Since carbon dioxide is very soluble in blood, a large number of molecules diffuse along this small partial pressure gradient. Oxygen, which is less soluble, requires a much larger concentration gradient to provide adequate oxygen to the body.

Page 12. Ventilation-Perfusion Coupling: Effect of P_{O_2}

- The third factor in external respiration is ventilation-perfusion coupling, which facilitates efficient gas exchange. It does this by maintaining alveolar airflow that is proportional to the pulmonary capillary blood flow.
- When airflow through a bronchiole is restricted, as when blocked by mucus, the resulting low P_{O_2} causes the local arterioles to vasoconstrict. This response redirects the blood to other alveoli which have a higher airflow, and therefore have more oxygen available to be picked up by the blood.
- In regions with high airflow compared to their blood supply, the resulting high P_{O_2} causes the local arterioles to vasodilate. This brings more blood to the alveoli, allowing the blood to pick up the abundant oxygen.

Page 13. Ventilation-Perfusion Coupling: Effect of P_{CO2}

- We've seen that during ventilation-perfusion coupling, the arterioles respond to changes in P_{O2}. The bronchioles, on the other hand, respond to changes in P_{CO2}.
- When airflow through a bronchiole is lower than normal, the P_{CO2} rises. The bronchioles respond by dilating, thereby eliminating the excess carbon dioxide from the alveoli.
- When airflow through a bronchiole is high compared to its blood supply, the P_{CO2} drops. The bronchioles then constrict, reducing the airflow so it is proportional to the local blood flow.

Page 14. Predict the Effect of P_{O2} and P_{CO2}

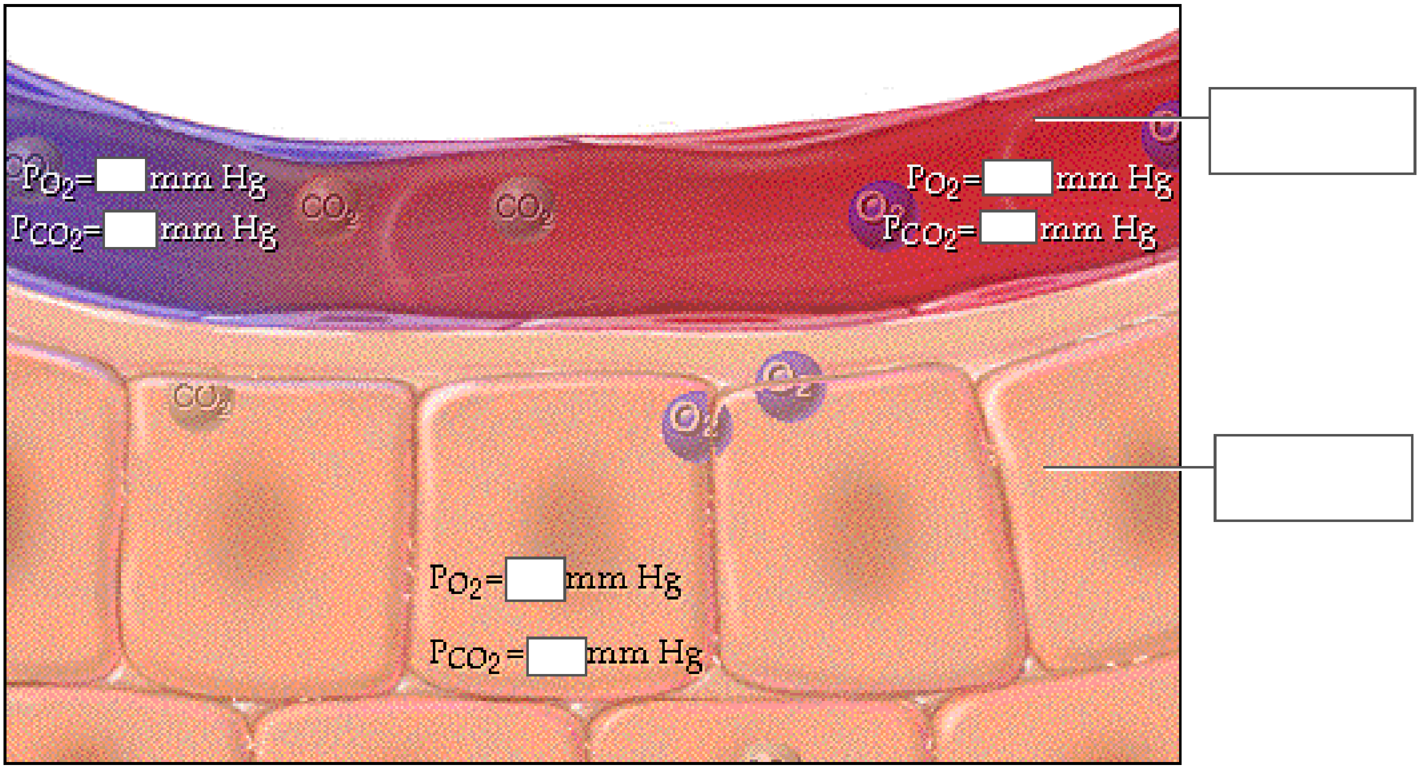
- Assume that ventilation to an alveolar sac is low, due to a small tumor growing in the bronchiole. The P_{O2} decreases because oxygen is not replenished, and the P_{CO2} increases, because the carbon dioxide is not eliminated. See if you can predict the response of the arterioles and bronchioles.
- The low P_{O2} causes the arterioles to constrict, and the high P_{CO2} causes the bronchioles to dilate. The airflow and blood flow are now in the proper proportions for optimum gas exchange. Notice that both the arterioles and bronchioles respond simultaneously.

Page 15. Internal Respiration

- During internal respiration:
  - Oxygen diffuses from the systemic capillaries into the cells.
  - Carbon dioxide diffuses from the cells into the systemic capillaries.
- Factors affecting the exchange of oxygen and carbon dioxide during internal respiration:
  1. The available surface area, which varies in different tissues throughout the body.
  2. Gases diffuse along their partial pressure gradients.
  3. The rate of blood flow in a specific tissue.
     - Blood flow in a tissue varies for many reasons, including the tissue's metabolic rate. Recall that during metabolism, cells use oxygen and produce carbon dioxide.

Page 16. Internal Respiration O_2 and CO_2 Exchange

- Label this diagram as you go through this page:



- The exchange of oxygen and carbon dioxide during internal respiration:
- In relatively inactive organs, the tissue cells have a P_{O_2} of 40 millimeters of mercury, and a P_{CO_2} of 45 millimeters of mercury.
- As the blood enters the systemic capillaries, it has a P_{O_2} of 100 millimeters of mercury, and a P_{CO_2} of 40 millimeters of mercury.
- Notice that the P_{O_2} of blood entering the systemic capillaries is lower than the alveolar P_{O_2} of 104 millimeters of mercury. This small decrease is due primarily to imperfect ventilation-perfusion coupling in the lungs.
- Gas exchange continues until equilibrium is reached. At equilibrium, the blood in the systemic capillaries has a P_{O_2} of 40 millimeters of mercury, and a P_{CO_2} of 45 millimeters of mercury.
- The oxygen-poor blood now returns, through the systemic veins, to the right side of the heart.

Page 17. Summary

- Gas laws show the relationship between partial pressure, solubility, and concentration of gases.
- Gases diffuse along their partial pressure gradients, from regions of high partial pressure to regions of low partial pressure.
- During external respiration, oxygen loads from alveoli into pulmonary capillaries and carbon dioxide unloads from pulmonary capillaries into alveoli.
- During internal respiration, oxygen unloads from systemic capillaries into cells and carbon dioxide loads from cells into systemic capillaries.
- Efficient gas exchange depends on several factors including surface area, partial pressure gradients, blood flow and airflow.

- During external respiration, ventilation-perfusion coupling maintains airflow and blood flow in proper proportions for efficient gas exchange.

** Now is a good time to go to quiz questions 4-8:

- Click the Quiz button on the left side of the screen.
- Click on the scrolling page list at the top of the screen and choose "4. External Respiration".
- Work through quiz questions 4-8.

Notes on Quiz Questions:

Quiz Question #1a:

- This question asks you to calculate the partial pressure of oxygen gas in an atmosphere in a fictitious situation.

Quiz Question #1b:

- This question asks you to determine the relative amount of carbon dioxide and oxygen dissolved in the blood in a fictitious situation.

Quiz Question #2a:

- This question asks you to determine gas solubility differences.

Quiz Question #2b:

- This question asks you to find ways to increase the solubility of nitrogen in the blood.

Quiz Question #3:

- This question asks you to predict what happens to the concentration of nitrogen gas in the blood of divers who are under pressure.

Quiz Question #4:

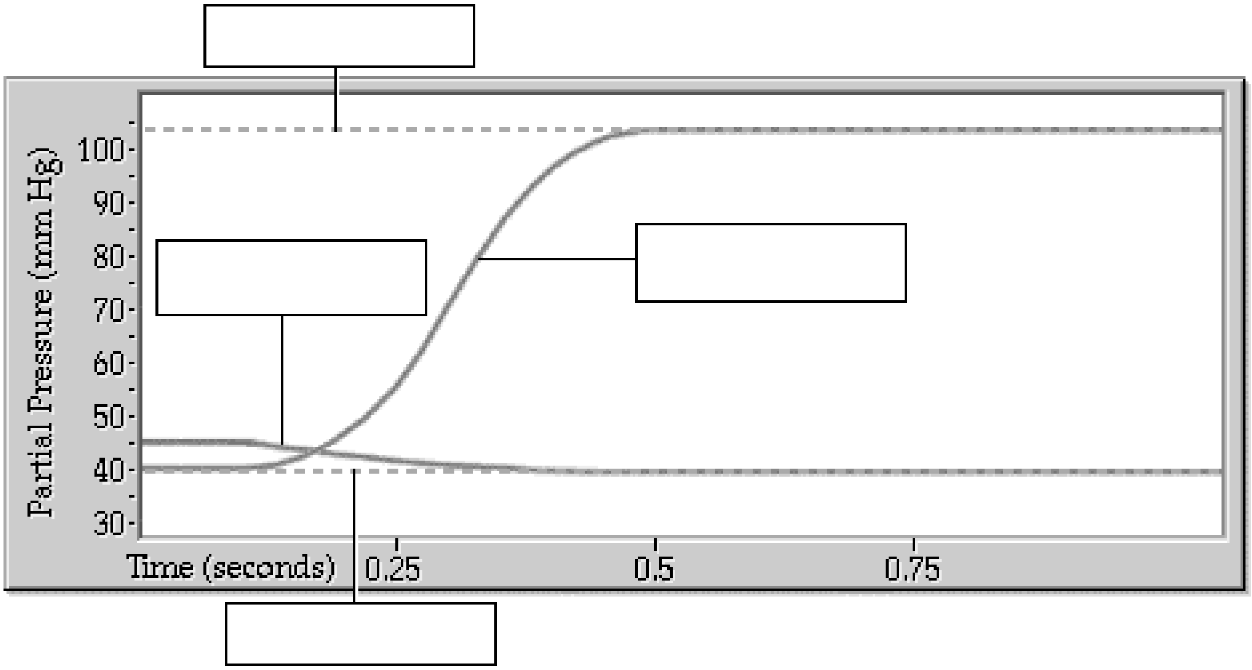
- This question asks you to recall the partial pressures of carbon dioxide and oxygen gas during external respiration.

Quiz Question #5:

- This question asks you to recall the partial pressures of carbon dioxide and oxygen gas during internal respiration.

Quiz Question #6:

- This question asks you to label a graph of partial pressures vs. time during external respiration.



Quiz Question #7:

- This question asks you to identify the factors that could increase the partial pressure of oxygen in the pulmonary capillaries.

Quiz Question #8:

- This question asks you to predict what happens during an asthma attack.

Study Questions on Gas Exchange:

1. (Page 1.) What four gases are found in the atmosphere?

2. (Page 1.) Each of these gases exerts a pressure, what is the total pressure of all the gases in the atmosphere called?

3. (Page 1.) What is a typical atmospheric pressure at sea level in millimeters of Hg?

4. (Page 1.) What is Dalton's Law of Partial Pressures?

5. (Page 2.) As altitude increases, what happens to the atmospheric pressure?

6. (Page 2.) Oxygen gas makes up 20.9% of the atmosphere at sea level where the atmospheric pressure is 760 mm Hg. a. What percentage of oxygen gas is there at a high altitude, where the atmospheric pressure is 440 mm Hg? b. Explain what happens to the partial pressure of oxygen gas at the high altitude.

7. (Page 3.) Henry's Law states that the amount of gas which dissolves in a liquid is proportional to what two factors?

8. (Page 4.) In a container containing water and oxygen gas, some of the oxygen dissolves in the water. When equilibrium is reached, the pressure of the oxygen gas above the water _____________ the pressure of oxygen in the liquid.

a. is greater than b. is less than c. is equal to

9. (Page 4.) In a container containing water and oxygen gas, some of the oxygen dissolves in the water. When equilibrium is reached, the rate of oxygen gas diffusing into the water ____________ the rate of oxygen gas diffusing out of the water.
a. is greater than b. is less than c. is equal to

10. (Page 4.) In a container containing water and oxygen gas, if you increase the pressure in the container ______ oxygen molecules dissolves in the liquid, moving from a region of _________ pressure.
a. more, low to high b. less, low to high
c. more, high to low d. less high to low

11. (Page 4.) If you have two closed containers of water and gas at the same pressure and one container contains oxygen gas and the other contains carbon dioxide gas, which of these statements is true?
a. Both gases dissolve equally in the water.
b. The carbon dioxide gas dissolves in the water to a greater extent than the oxygen gas.
c. The oxygen gas dissolves in the water to a greater extent than the carbon dioxide gas.

12. (Page 4.) Which is more soluble in water, carbon dioxide or oxygen?

13. (Page 6.) a. Where do both internal and external respiration occur? b. What happens to oxygen and carbon dioxide during both internal and external respiration?

14. (Page 7.) Efficient external respiration depends on what three main factors?

15. (Page 7.) What two factors account for the surface area and structure of the respiratory membrane allowing for efficient external respiration?

16. (Page 8.) What three factors account for the differences in the partial pressures in the alveoli from those in the atmosphere?

17. (Page 8.) As air travels through the respiratory passageways to the alveoli it is humidified, picking up water molecules. What effect does this have on the partial pressure of water?

18. (Page 8.) As gases are exchanged between the alveoli and pulmonary capillaries, what happens to the partial pressures of both gases?

19. (Page 8.) Do the alveoli completely empty between breaths?

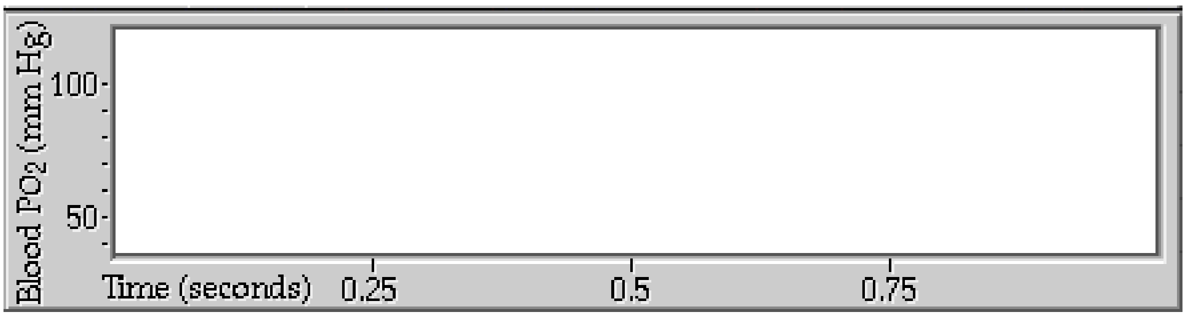
20. (Page 9.) The P_{O_2} of the alveolar air is 104 mm Hg. At rest, the oxygen-poor blood entering the pulmonary capillaries has a P_{O_2} of 40 mm Hg. As blood flows past the alveolus, the P_{O_2} ___________.
a. increases b. decreases

21. (Page 9.) The P_{O_2} of the alveolar air is 104 mm Hg. At rest, the oxygen-poor blood entering the pulmonary capillaries has a P_{O_2} of 40 mm Hg. During external respiration there is a net diffusion of oxygen along its partial pressure gradient, from the alveolus into the blood, until equilibrium is reached. As this occurs, the P_{O_2} of the blood _____________.

a. increases to 104 mm Hg b. decreases to 40 mm Hg

22. (Page 9.) During external respiration, oxygen equilibrium is reached ______________ of the pulmonary capillary.
a. at the end b. within the first half c. within the first third

23. (Page 9.) Fill out this graph to show what happens to the partial pressure of oxygen in the pulmonary arteries during external respiration:

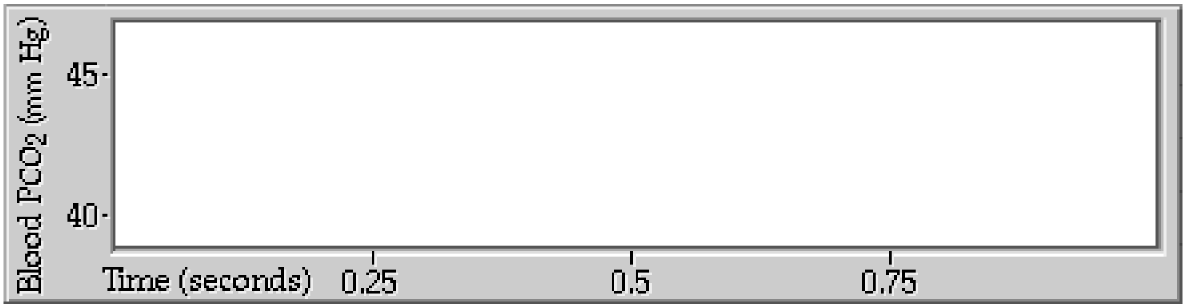


24. (Page 10.) The P_{CO_2} of the alveolar air is 40 millimeters of mercury. At rest, the P_{CO_2} of the blood entering the pulmonary capillaries is 45 millimeters of mercury. As blood flows past the alveolus, the P_{CO_2} ____________.
a. increases b. decreases

25. (Page 10.) The P_{CO_2} of the alveolar air is 40 millimeters of mercury. At rest, the P_{CO_2} of the blood entering the pulmonary capillaries is 45 millimeters of mercury. During external respiration carbon dioxide diffuses along its partial pressure gradient, from the blood into the alveolus, until equilibrium is reached. As blood flows past the alveolus, the P_{CO_2} ____________.
a. increases to 45 mm Hg b. decreases to 40 mm Hg

26. (Page 10.) During external respiration, carbon dioxide equilibrium is reached ______________ of the pulmonary capillary.
a. at the end b. within the last half c. within the first four-tenths

27. (Page 10.) Fill out this graph to show what happens to the partial pressure of carbon dioxide in the pulmonary arteries during external respiration:



28. (Page 11.) Why does carbon dioxide have a smaller partial pressure gradient than oxygen?

29. (Page 12.) Explain how ventilation-perfusion coupling facilitates efficient gas exchange.

30. (Page 12.) What factor causes vasoconstriction and vasodilation associated with ventilation-perfusion coupling?

31. (Page 13.) How do bronchioles respond to levels of blood gases?

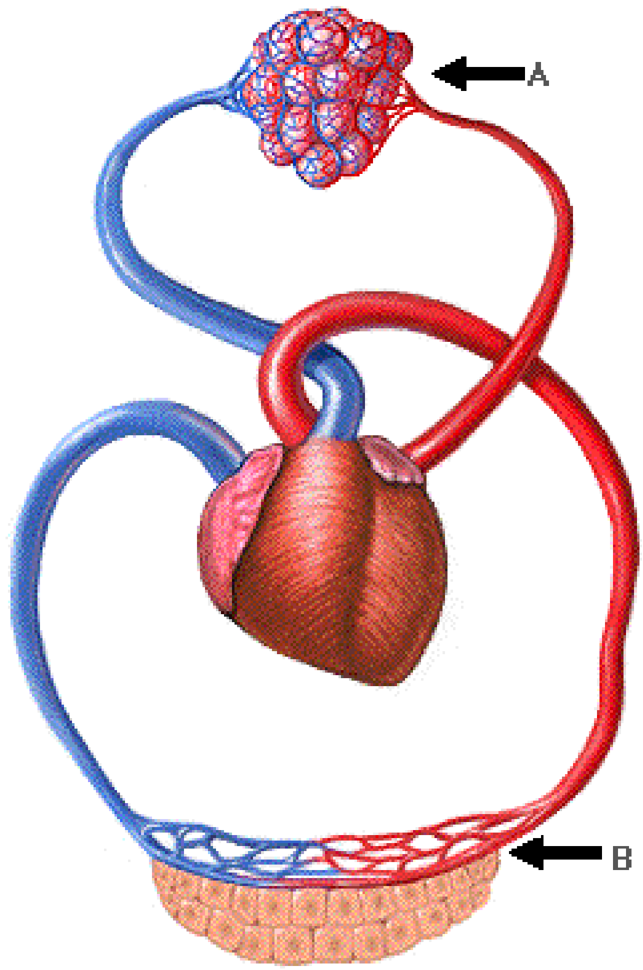
32. (Page 13.) What would cause the P_{CO_2} in the bronchioles to rise?

33. (Page 13.) During ventilation-perfusion coupling, the arterioles respond to changes in _________ and the bronchioles respond to changes in _____________ .
a. P_{O_2} b. P_{CO_2}

34. (Page 14.) Match the following:

a. Arterioles constrict	Low P_{CO_2}
b. Arterioles dilate	Low P_{O_2}
c. Bronchioles constrict	High P_{CO_2}
d. Bronchioles dilate	High P_{O_2}

35. (Page 15.) On this diagram, indicate where both internal and external respiration occurs.



36. (Page 15.) On this diagram, indicate where there would be a net movement of oxygen into the blood and carbon dioxide out of the blood.

37. (Page 15.) On this diagram, indicate where there would be a net movement of oxygen out of the blood and carbon dioxide into the blood.

38. (Page 15.) What three factors affect the exchange of oxygen and carbon dioxide during internal respiration?

39. (Page 16.) Why would the rate of blood flow vary within a tissue?

40. (Page 16.) As gases are exchanged between the tissues and systemic capillaries, what happens to the partial pressures of both gases?

41. (Page 16.) The P_{O_2} of the blood entering the systemic capillaries is 100 mm Hg. As blood flows through the systemic capillaries, the P_{O_2} ___________.

a. increases b. decreases

42. (Page 16.) The P_{CO_2} of the blood entering the systemic capillaries is 40 mm Hg. As blood flows through the systemic capillaries, the P_{CO_2} ___________.

a. increases b. decreases

43. (Page 16.) The P_{O_2} of the blood entering the systemic capillaries is 100 mm Hg. During internal respiration there is a net diffusion of oxygen along its partial pressure gradient, from the blood into the tissues, until equilibrium is reached. As this occurs, the P_{O_2} of the blood _____________.

a. increases to 104 mm Hg b. decreases to about 40 mm Hg

44. (Page 16.) The P_{CO_2} of the blood entering the systemic capillaries is about 40 millimeters of mercury. At rest, the P_{CO_2} of the blood leaving the systemic capillaries is about 45 millimeters of mercury. As blood flow through the systemic capillaries, the P_{CO_2} ____________.

a. increases b. decreases

45. (Page 16.) During internal respiration carbon dioxide diffuses along its partial pressure gradient until equilibrium is reached. As blood flows through the systemic capillaries, the P_{CO_2} ____________.

a. increases to about 45 mm Hg b. decreases to about 40 mm Hg