4.5.1

Gas Laws

Four main factors, also known as Fick’s Law, influence the rate at which gases will diffuse across the layers of the respiratory membrane. They are: 1) thickness of the membrane; 2) surface area of the membrane; 3) diffusion coefficient of gases in relation to the membrane; and 4) partial pressure differences of the gases.

The thicker the membrane the slower gases will diffuse across it. For example, fluid buildup inside the alveoli can happen with pulmonary edema when the left side of the heart doesn't pump adequately. Blood backs up into the pulmonary capillaries and excess fluid remains in the alveoli. Inflammatory processes and infections such as pneumonia can also cause fluid buildup in the alveoli.

The alveoli greatly increase the surface area for gas exchange. If some become damaged or destroyed in cases such as emphysema, lung cancer, or tuberculosis, the surface area available for gas exchange can be dramatically reduced.

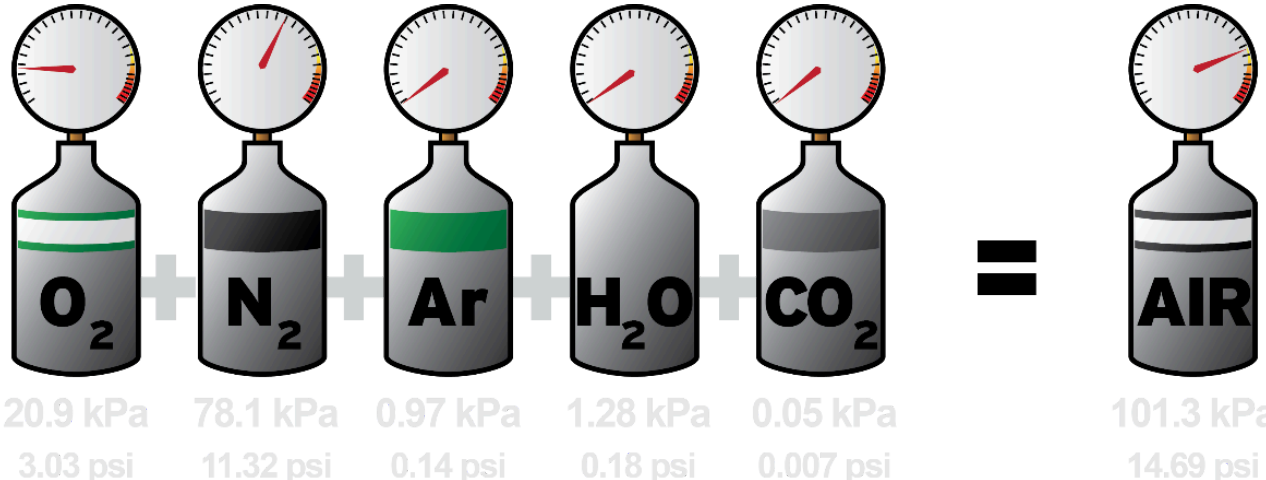
The diffusion coefficient of a gas is determined by molecule size and solubility of the gas in water. Taking these into account, carbon dioxide will cross the respiratory membrane 24 times more readily than oxygen.

Hopefully you have a solid understanding of the law of diffusion by now. Higher concentrations or pressures will seek to move toward the lower. Gases will flow from a region of higher partial pressure to lower partial pressure. This determines which direction the gases will go when crossing the membrane - always remember high to low. Oxygen partial pressures are higher in the alveoli compared to inside the pulmonary capillaries and carbon dioxide is the opposite. With increased ventilation rate, partial pressures inside the alveoli change even more - oxygen increases and carbon dioxide decreases. The gradients have been increased for both, so oxygen moves into the lung capillaries faster and carbon dioxide leaves the capillaries faster.

Oxygen is inhaled into the lungs and then moves into the blood stream for transport and eventually out of the blood stream and into the tissues. Carbon dioxide is released by the tissues and travels the reverse route and is ultimately exhaled. To understand how these gases move through the different areas in the body it is important to discuss Dalton's and Henry's gas laws.

Dalton’s Law

Dalton's law states that individual gases in a mixture of gases exert **partial pressures** and that by adding each partial pressure of the mixture, the total pressure exerted by the mixture of gases can be determined.



Dalton's Law: The total pressure of air is the sum of the partial pressure of each gas

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At sea level, the total pressure of the different gases in the atmosphere pushing down on us is 760 mm Hg or 1 atm. Nitrogen makes up 78.6% of this gas, oxygen 20.9%, carbon dioxide 0.04%, and water 0.46%. Each one of these gases contributes a portion to the total atmospheric pressure. We can determine their partial pressure by multiplying their percentage by 760 mm Hg.

Atmosphere

Nitrogen partial pressure = 78.6 % X 760 mmHg = 597 mmHg

Oxygen partial pressure = 20.9 % X 760 mmHg = 159 mmHg

Carbon dioxide partial pressure = 0.04 % X 760 mmHg = 0.3 mmHg

Water partial pressure = 0.46 % X 760 mmHg = 3.5 mmHg

Partial pressures in the alveoli for air is different than those of the atmosphere for several reasons including: 1) the air is humidified by respiratory structures on the way to the alveoli so the partial pressure of water becomes greater; 2) oxygen readily enters the blood at the alveoli so it is decreased; carbon dioxide enters the alveoli from the blood so it is increased; 3) and alveolar gases are only partially replaced by air from the atmosphere with each inhalation.

Alveoli

Nitrogen partial pressure = 74.9 % X 760 mmHg = 569 mmHg

Oxygen partial pressure = 13.7 % X 760 mmHg = 104 mmHg

Carbon dioxide partial pressure = 5.2 % X 760 mmHg = 40 mmHg

Water partial pressure = 6.2 % X 760 mmHg = 47 mmHg

Gases are transported to and from the lungs by the blood which is a liquid.

Henry's Law

Henry's law describes the influences that determine whether or not a gas will dissolve in a liquid. For instance, carbon dioxide gas dissolving in blood. The following two factors determine how readily a gas will enter a liquid.

1. The partial pressure of the gas surrounding the liquid. If the pressure of the gas around the liquid is high, movement of the gas into the liquid will be favored.
2. The solubility of the gas in a particular liquid or the tendency of the gas to "dissolve" in a liquid. Carbon dioxide is about 24 times more soluble in water or plasma compared to oxygen. And nitrogen is half as soluble as oxygen.

To summarize Henry's Law:

Gas Pressure X Coefficient of Solubility = Dissolved Gas Concentration

During respiration, Henry's law predicts how gas is exchanged in the alveoli and the bloodstream. The amount of oxygen that will dissolve is proportional to the partial pressure of oxygen. Because the partial pressure of oxygen is greater in the alveolar air than in deoxygenated blood, oxygen will dissolve into the blood. Carbon dioxide is just the opposite and has a greater partial pressure in the deoxygenated blood than in the alveolar air, so it will diffuse out of the solution and back into a gas in the alveoli. Because carbon dioxide has a much higher solubility in the blood than oxygen (24 times more), the difference in the partial pressures between the bloodstream and the alveoli can be much smaller. Because there is a wider difference in partial pressure gradients for oxygen, it's lower solubility isn't a problem during gas exchange.

Patients suffering from carbon monoxide poisoning are sometimes put in a hyperbaric oxygen chamber where oxygen pressures may be three times atmospheric pressure. This forces more oxygen into the blood, and greatly reduces the half-life of carbon monoxide.

Atmospheric pressure increases by about 760 mm Hg for each 33 feet below the water line. Upon descending 100 feet, the partial pressure of each gas is 4 times that at sea level, so according to Henry's law, nitrogen will more easily dissolve in the blood at these depths. As a diver ascends, nitrogen becomes less soluble and bubbles out of the blood and may cause clots or damage tissue. This is sometimes referred to as the "bends".