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Lecture # 41

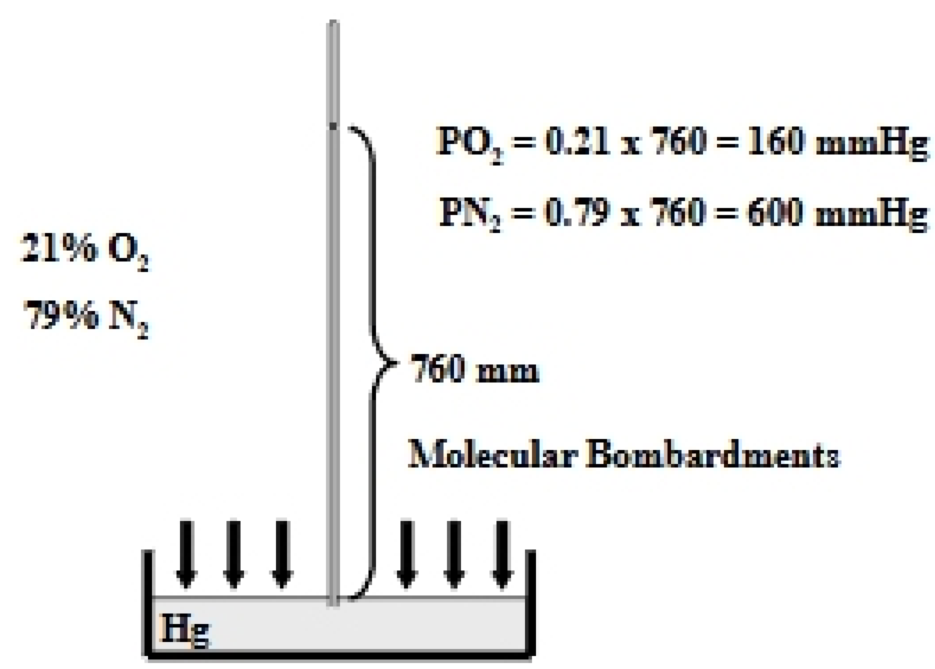
PULMONARY GAS EXCHANGE

Gas Exchange and Ventilation & Perfusion

References: L. Costanzo: Physiology, 4th Edition and John B. West: Respiratory Physiology (The Essentials), 7th Edition

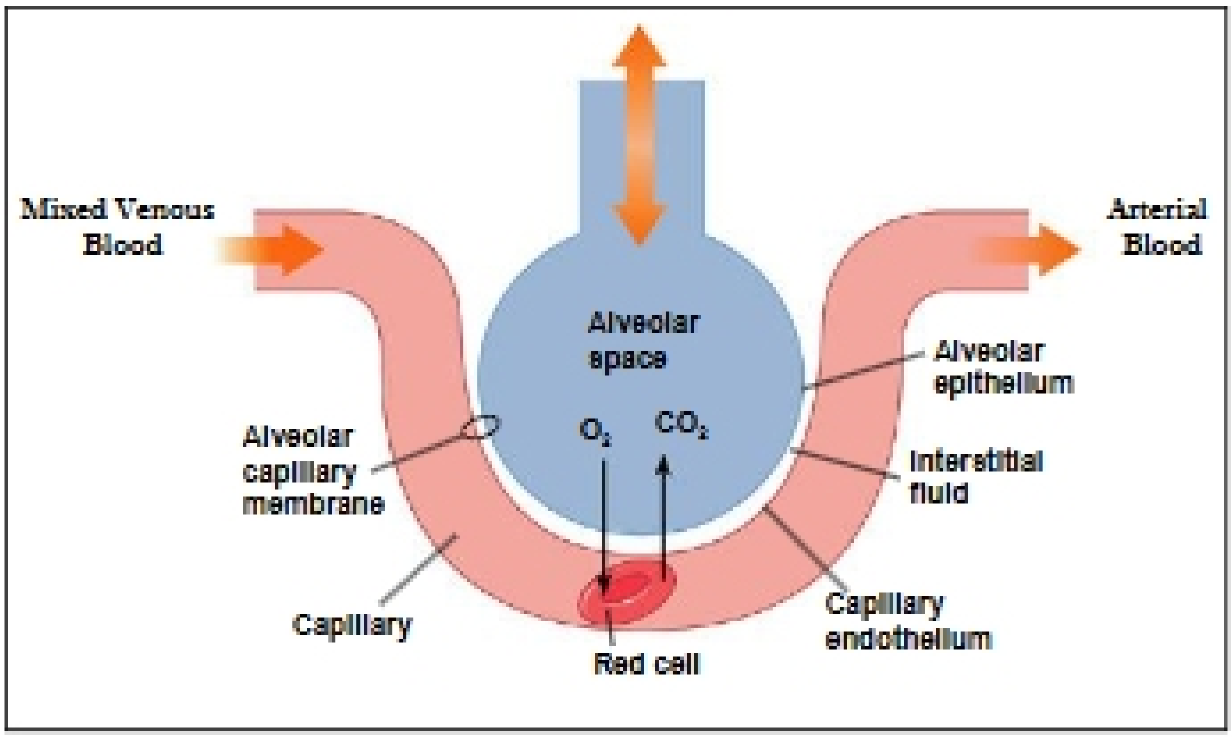
Gas Exchange

The result of the respiratory system working in harmony with the cardiovascular system is reflected in the composition of alveolar air. Normally the composition of air, which is a mixture of gases, is expressed in terms of the partial pressures of the individual gases of the mixture. The ***partial pressure*** of each type of gas molecule is the pressure that is generated by those molecules alone and is thus directly proportional to the concentration of the gas molecules. The sum of the partial pressures of the various gases equals the total atmospheric pressure.



A simple ***barometer*** for measuring total atmospheric pressure consists of a narrow tube filled with mercury and then inverted so the open end of the tube is below the surface of a mercury reservoir. The kinetic bombardment of atmospheric particles against the surface of the mercury reservoir will support a column of mercury 760mm in height (at sea level). Thus atmospheric air is said to have a pressure equal to 760 mm Hg. Since 21% of atmospheric particles are oxygen molecules, the partial pressure of oxygen (PO_2) equals 21% of 760 mm Hg, or 160 mm Hg.

Inspired air is essentially a mixture of 21% oxygen and 79% nitrogen with corresponding partial pressures of 160 and 600 mm Hg, respectively. Essentially no carbon dioxide is present. Some water vapor normally exists in an amount depending on the humidity, but typically the partial pressure for water vapor is less than 10 mm Hg.



Equilibration of inspired air with body temperature and saturation with water vapor occurs quickly as the inspired air passes through the nasal cavities, before it reaches the trachea. Saturation occurs because the airways and alveoli are internally covered with a thin layer of liquid. Even the inspired air that travels no farther than the anatomic dead space is saturated with water vapor. Vapor pressure depends on temperature, and *at body temperature water has a vapor pressure of 47 mm Hg.* No matter what the total atmospheric pressure is, at 37°C the vapor pressure of water will always account for 47 mm Hg of the total atmospheric pressure. Thus, in ***moist tracheal air*** oxygen molecules are diluted and form a smaller percentage of the total atmospheric pressure. Expressed another way, the partial pressure of oxygen is 21% of the pressure after vapor pressure is subtracted, i.e., 21% of (760 - 47) mm Hg. Thus, humidifying inspired air reduces the PO_2 from 160 to 150 mm Hg.

In alveoli, the blood is continually carrying oxygen away and carbon dioxide is continually being added to the alveolar air. The ratio of the amount of carbon dioxide released to the amount of oxygen taken up is called the **respiratory exchange ratio** (R). This ratio reflects the "**respiratory quotient**" (R.Q.) of the chemical reactions in tissues and depends on whether carbohydrates, fats or proteins are being metabolized. Carbohydrates such as glucose contain two hydrogen atoms for each oxygen atom, as in water. When carbohydrates are metabolized in the body, additional oxygen is united with the carbon, forming a volume of carbon dioxide equal to the volume of oxygen used. Thus, with carbohydrates as the sole source of energy, the respiratory quotient equals 1.

$$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$$

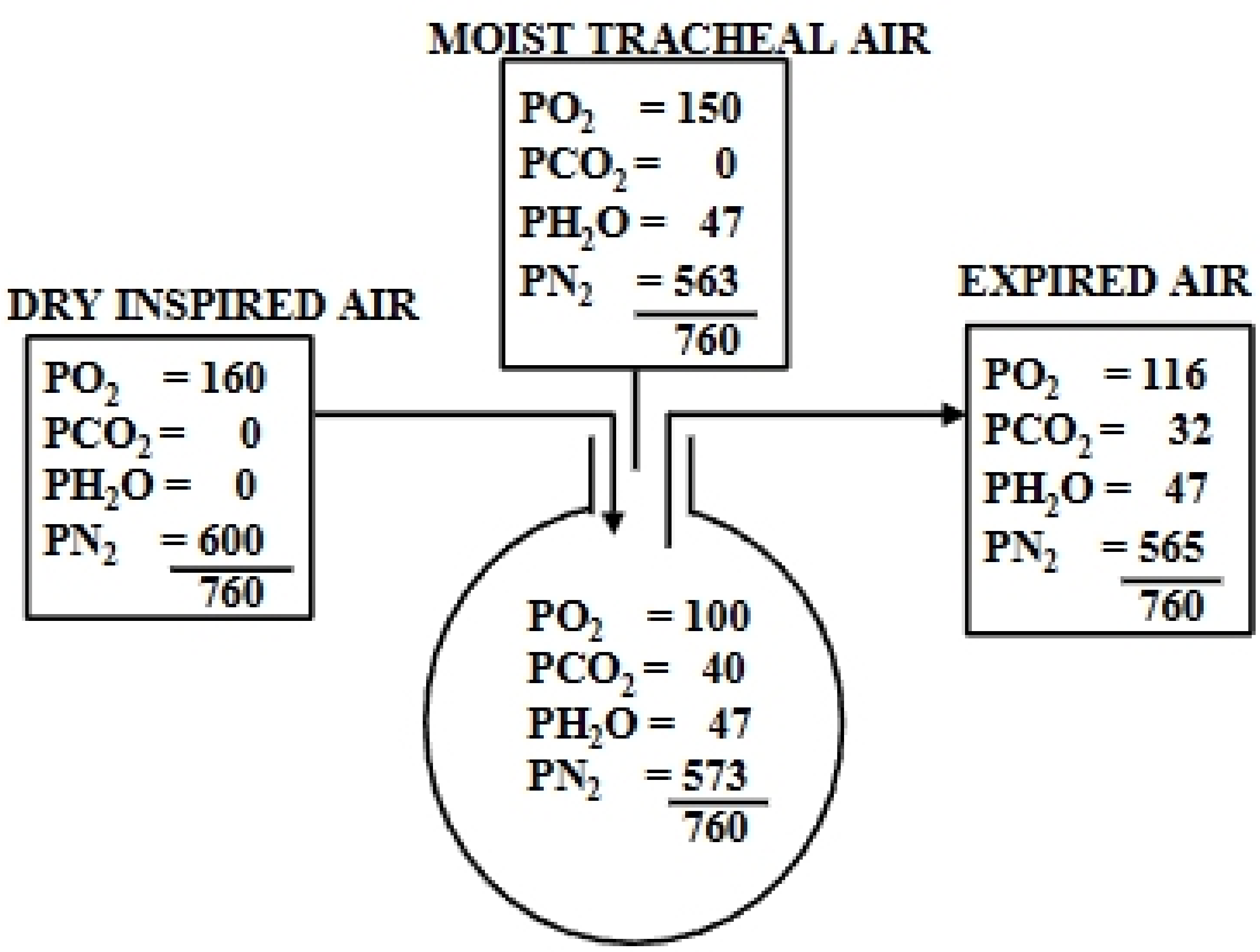
In contrast to carbohydrates, the metabolism of fats (such as tripalmitin) requires more oxygen than CO_2 produced since some oxygen is used in the formation of water. Thus, with fats as the sole source of energy, the respiratory quotient would be about 0.7.

$$2(C_{51}H_{98}O_6) + 145\ O_2 = 102\ CO_2 + 98\ H_2O$$

The R.Q. is not as easily calculated for proteins since amino acids are not completely oxidized in the body. However, the approximate quantitative relationship between O_2 and CO_2 with the metabolic oxidation of proteins gives a R.Q. of 0.8. *Under basal conditions the body is metabolizing carbohydrates and fats but few proteins and the R.Q. is typically 0.8*, i.e. the amount of oxygen taken up by the body (250 ml/min) is somewhat greater than the volume of carbon dioxide eliminated (200 ml/min).

The composition of ***alveolar air*** reflects the oxygen uptake by blood and carbon dioxide release from blood by having a lower PO_2 (100 mm Hg) and a higher PCO_2 (40 mm Hg) than that of atmospheric or moist tracheal air. The partial pressure of nitrogen is modified in the anatomic dead space by the addition of water vapor and further modified in the alveolar compartment as a result of the unequal O_2 and CO_2 exchange occurring. Both alveolar air and atmospheric air have the same total pressures, since open tubes of the anatomic dead space connect these compartments.

Alveolar air is typically represented as having a constant composition. This is justified because the fluctuations that occur in PO_2 and PCO_2 with each breathing cycle are very slight. Because the volume of fresh air entering the alveoli (350 ml) is very small compared to the "pool" of alveolar air already in the lungs (FRC = 2,200 ml), the inspired fresh air is so diluted that the PO_2 will increase and the PCO_2 decrease by only 1 or 2 mm Hg.



Assuming a constant oxygen uptake and carbon dioxide release by the body, the content of alveolar air will reflect the ventilation of the lungs. ***Hyperventilation*** makes alveolar air more like fresh air, raising alveolar PO_2 and lowering PCO_2. ***Hypoventilation***, in contrast, produces a lower PO_2 and an elevated PCO_2 in the alveoli. Similarly, not all areas of the lung have the same PO_2 and PCO_2. While some areas are relatively hyperventilated and have a high PO_2 and low PCO_2, other areas are simultaneously hypoventilated and have a low PO_2 and high PCO_2.