



THE RACE IS ON! O₂ VERSUS CO₂?

by Bill Wojciechowski, MS, RRT

As a respiratory therapist, you have certainly administered oxygen to countless patients, measured end-tidal carbon dioxide tensions via capnography and obtained innumerable arterial blood gas samples to analyze PO₂ and PCO₂ values. In the process of performing these procedures, however, have you ever contemplated the rate of diffusion of oxygen versus the rate of diffusion of carbon dioxide in the lungs? The likelihood is you have not, and the probability is that most respiratory therapists do not. The fact that *you* may have not does not make you negligent; you likely have been unaware of this consideration. However, after reading this article, you will become cognizant of how the rate of diffusion of these two gases compares, and where

in the lungs their rates differ.

Most therapists do no contemplate the rate of diffusion of oxygen versus carbon dioxide ...They should

As this concept is developed here, two gas laws will come into focus. They are Henry's law of solubility and Graham's law of diffusion. Henry's law will be cited, but Graham's law will be spotlighted. Graham's law of diffusion will be applied to the diffusion of O₂ and CO₂

in two contexts - *within* an alveolus and *across* the alveolar-capillary membrane. Pay heed to the italicized words, *within* and *across*.

Graham's Law of Diffusion within an Alveolus

Once gas molecules reach the alveoli, they are no longer under the influence of the pressure gradient that initiated inspiration. *Within* an acinus, (comprised of respiratory bronchioles, alveolar ducts, and alveolar sacs), movement of air is accomplished by way of molecular diffusion, not by convection or bulk flow. Inside an alveolus gas, molecules are in constant motion because of the kinetic energy imparted on them by the temperature of the body. The motion, or pathway of these gas molecules is characterized as zigzag, random, and chaotic.

For gases confined to a container, Graham's law of diffusion governs the diffusion of gas molecules and states that the lighter molecules diffuse and travel faster than the heavier molecules. In this context, an alveolus can be considered a container. Quantitatively speaking, the relative rates (*r*) of diffusion are inverse-

ly related to the square root of the densities (*D*) of the gases being compared. This relationship is represented as follows:

$$r_1 \sqrt{D_1} = r_2 \sqrt{D_2}$$

The relative rate of diffusion of O₂ and CO₂ within an alveolus will be determined using this equation. The rate of diffusion of O₂ (*r*O₂) will substitute for *r*₁ and the rate of diffusion of CO₂ (*r*CO₂) will replace *r*₂. The densities of O₂ and CO₂ are 1.43 g/L and 1.96 g/L, respectively. That is,

$$r_{O_2} \times \sqrt{DO_2} = r_{CO_2} \times \sqrt{DCO_2}$$
$$\frac{r_{O_2}}{r_{CO_2}} = \frac{1.4}{1.2} = 1.17$$

This quantitative relationship indicates that the rate of diffusion of O₂ is 1.17 times that of CO₂, i.e., O₂ diffuses faster than CO₂ within an alveolus. This outcome makes sense because O₂, which has a molecular weight of 32 daltons, is lighter than CO₂ with a molecular weight of 44 daltons. By the way, the molecular weights can substitute for the densities in Graham's law.

One might ask, "What would be the result of this equation if *r*CO₂ were placed in the numerator, and *r*O₂ were situated in the denominator?" The outcome would be the same. However, the answer indicates that the rate of diffusion of CO₂ is 0.85 that of O₂, i.e., CO₂ diffuses slower than O₂ within an alveolus.

When the relative rate of diffusion is less than 1.0, the gas shown in the numerator diffuses slower than the one in the denominator. Conversely, a ratio of > one indicates that the gas represented by the numerator diffuses faster than the gas in the denominator. If the result equals 1.0, the gases diffuse at the same rate.

Graham's Law of Diffusion across the Alveolar-Capillary Membrane

The application of Graham's law in this circumstance differs from that previously described because now O₂ and CO₂ will be viewed diffusing across a fluid membrane and not diffusing among gas molecules within a container, i.e., an alveolus.

The alveolar-capillary membrane is not a solid structure. It is described as a fluid mosaic, as it is comprised of various sub-



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stances. Because the alveolar-capillary membrane is a fluid barrier, Henry's law of solubility, which governs gases dissolving in liquids, applies. Henry's law states that the amount of gas that dissolves in a liquid at any temperature is directly proportional to the partial pressure of the gas above the surface of the liquid. In other words, having more gas molecules above the surface of a liquid causes more of those gas molecules to dissolve into that liquid.

This concept is the basis for increasing the FIO₂ of a patient who experiences hypoxemia. When the FIO₂ is increased, more O₂ molecules are deposited into the alveoli, thereby increasing the PAO₂. More molecules of O₂ are placed above the surface of the liquid, i.e., the plasma. As a result of the higher FIO₂, more O₂ molecules dissolve into the plasma, elevating the patient's PaO₂.

Based on Henry's law every gas has its own solubility coefficient. Physiologically, the solubility coefficients for CO₂ and O₂ are 0.510 ml CO₂/ml plasma/760 torr PCO₂, and 0.023 ml O₂/ml plasma/ 760 torr PO₂, respectively. These solubility coefficients are based on (1) plasma as the solvent, (2) body temperature, and (3) one atmosphere of the gas in question. Note 760 torr PCO₂ and 760 torr PO₂ in the units of these coefficients. The solubility coefficients of CO₂ and O₂ influence the rate of diffusion of these two gases across the alveolar-capillary membrane.

Quantitatively, Graham's law of diffusion describing the diffusion of gases through a fluid medium is:

$$\frac{r_1}{r_2} = \frac{\sqrt{D_2} (SC_1)}{\sqrt{D_1} (SC_2)}$$

The relative rate of diffusion of O₂ and CO₂ across the alveolar-capillary membrane can be calculated using this relationship. The rate of diffusion of CO₂ (rCO₂) will substitute for r₁, and rO₂ will represent r₂. Therefore,

$$\frac{rCO_2}{rO_2} = \frac{\sqrt{1.43g/L} (0.510)}{\sqrt{1.96g/L} (0.023)}$$

The difference between this application of Graham's law and that described regarding gases diffusing with an alveolus is the inclusion of the solubility coefficients for O₂ and CO₂ here. Consequently,

$$\frac{rCO_2}{rO_2} = \frac{\sqrt{1.43g/L} (0.510)}{\sqrt{1.96g/L} (0.023)} = \frac{19}{1}$$

Based on this relationship, CO₂ diffuses 19 times faster than O₂ across the alveolar-capillary membrane. Conversely, in this situation O₂ diffuses slower than CO₂ by a factor of 0.05 across the alveolar-capillary membrane. The factor 0.05 is simply the reciprocal of 19, or the ratio rO₂/rCO₂.

To summarize, a distinction exists between the rates of diffusion of O₂ and CO₂. This difference depends on where the rates of diffusion of these two gases are considered. Within an alveolus, O₂ diffuses faster than CO₂; across the alveolar capillary membrane, CO₂ diffuses faster than O₂. Cognizant now of the laws of Henry and Graham, perhaps, you will contemplate the relative rate of diffusion of O₂ versus CO₂ when performing various procedures involving these respiratory gases.

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