EFB 462 Animal Physiology: Environmental & Ecological
Henry's Law

One of the principle constraints in respiration is the availability of a respiratory gas, like oxygen, in either of the fluid media used to ventilate gas exchange organs. These fluid media are, of course, air and water. The quantity of oxygen present in a volume of ventilated fluid determines what quantity of fluid must be moved to provide oxygen at a particular rate. Let us assume, for example, that an organism consumes oxygen at a particular rate, $\dot{M}_{O2}$, moles O_2 s^{-1}. If the molar concentration of oxygen in the ventilated fluid is [O2] (moles cm^{-3}), the gas exchange organ will have to be ventilated at a minimum rate of $\dot{V} = \dot{M}_{O2} / [O_2]$. This is a minimum rate, because it assumes 100% extraction of dissolved oxygen. If, say only 50% oxygen is extracted from the ventilatory fluid, ventilation rate will be twice the minimum.

Water and air differ significantly in the capacity to hold various gases. In water, the molar quantity is expressed by Henry's Law, while in air, the ideal gas law is the more appropriate. In fact, both can be expressed with similar equations, which facilitate comparisons of ventilatory requirements for air and water.

Let us start with Henry's Law. Your textbook expresses it thus:

$$V_g = \alpha P_g V_{H2O} / 760 \qquad [1]$$

with terms defined as in the text. There are a number of ways this expression of Henry's Law falls short. A simpler way to express it is:

$$[G] = pG\ \alpha G \qquad [2]$$

where *p*G is the partial pressure of the gas (pascals), and α*G* is the gas's solubility in water.

An equation of similar form expressing the "molar solubility" of a gas in a gas mixture can be derived from the ideal gas law:

$$[G] = n_G / V = P_G / (RT) \qquad [3]$$

with terms as expressed as in the standard form of the ideal gas law. In this instance, the "solubility" of the gas α_G, is $(RT)^{-1}$., where *T* is absolute temperature (K) and *R* is the gas constant (8.314 J K^{-1} mol^{-1})

The differences in ventilation requirements for air and water are dramatically illustrated by using these two equations. In air at 20°C and 21% oxygen, for example, the molar concentration of oxygen is [21.3 kPa / (8.314 J mol^{-1} K^{-1})] = 8.8 mol m^{-3} or 8.8 mmol l^{-1}. In water, in contrast, solubility is much lower. In fresh water at 15°C, for example, solubility is α_{O2} = 13.7 μmol l^{-1} kPa^{-1}, and the molar concentration of oxygen in water under an atmosphere of 21% oxygen is (13.7 μmol l^{-1} kPa^{-1} * 21.3 kPa) = 0.292 mmol l^{-1}. This is roughly 30 times less than the molar concentration of oxygen in air. The implication? An animal that consumes oxygen at a particular rate must ventilate its gas exchange organs 30 times more vigorously if it breathes water than it would if it breathed air.