

**EFB 462 Animal Physiology: Environmental & Ecological  
Solubility of respiratory gases**

*Henry's Law*

Henry's Law refers to a relationship between molar concentration of a gas in solution and its partial pressure. A simpler and more robust version of Henry's Law than the one presented in your text is:

$$[G]_s = \alpha_G pG$$

where  $[G]_s$  = molar concentration of gas (mols l<sup>-1</sup>),  $\alpha_G$  = solubility of the gas (mols l<sup>-1</sup> Pa<sup>-1</sup>), and  $pG$  = partial pressure of the gas in question (Pa). Solubility depends upon several factors including the gas in question, the temperature of the water and the concentration of solutes. FYI, here are some values of  $\alpha$  for oxygen:

$\alpha_{O_2}$ ( $\mu\text{mol l}^{-1} \text{kPa}^{-1}$ )				
$T$ ( $^{\circ}\text{C}$ )	0 ‰	10 ‰	20 ‰	30 ‰
0	21.7	20.2	18.9	17.7
10	16.9	15.8	14.8	13.9
20	13.7	12.9	12.2	11.5
30	11.6	11.0	10.4	9.9
40	10.2	9.7	9.3	8.7

*The Ideal Gas Law and Henry's Law*

Because gas exchange often involves mixed media (air and water), it is useful to have an analog of Henry's Law for the molar concentration of gases in a gas mixture, like oxygen in air. This can be derived from the ideal gas law:

$$P \cdot 1000 V = n R T \tag{1}$$

where  $P$  = pressure (Pa)  $V$  = volume (m<sup>3</sup>),  $n$  = moles (mol)  $R$  = the gas constant (8.314 J mol<sup>-1</sup> K<sup>-1</sup>) and  $T$  = absolute temperature (K). Molarity (mols l<sup>-1</sup>) is simply:

$$n / 1000 V = P / R T \tag{2}$$

(The 1000 multiplier is to reconcile volume as m<sup>3</sup> to litres). This equation can also be expressed in terms of a gas's partial pressure:

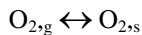
$$[G] = pG / (1000 R T) \tag{3}$$

The quantity  $\{1 / (1000 R T)\}$  is essentially a "solubility" of a gas in a gas mixture. For all gases, this is about 435  $\mu\text{mol l}^{-1} \text{kPa}^{-1}$ .

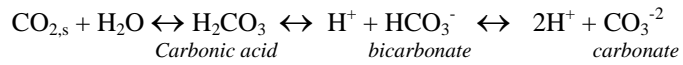
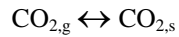
*Apparent solubility*

Not all gases have identical solubility. Nitrogen, for example, is about half as soluble in water as oxygen. This can have some interesting consequences for gas exchange, including the operation of bubble gills. Some gases, like carbon dioxide, appear to have enormously high solubility, nearly 30 times the oxygen solubility. There is a subtle reason for this.

When a gas like oxygen dissolves in water, it dissolves as oxygen, i.e. it does not react with water in any way:



A gas like carbon dioxide, however, reacts with water to form the weak acid, *carbonic acid*:



The equilibrium of this reaction is dependent upon pH. At low pH, the reaction tilts strongly to the left (this is why acid added to sodium bicarbonate bubbles vigorously). At “physiological pH” (6-9), however, the reaction tilts more to the right. Thus, water can hold large quantities of CO<sub>2</sub>, but not because the solubility of carbon dioxide gas in solution (CO<sub>2,s</sub>) is especially high. The apparent high solubility follows, rather, from the fact that most of the CO<sub>2</sub> that dissolves in water exists in the form of one of the anions of carbonic acid.