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^{-1}), α_G = solubility of the gas (mols l^{-1} Pa^{-1}), 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 α for oxygen:

$\alpha O2$ (μmol l^{-1} kPa^{-1})

T (°C)	0 °/oo	10 °/oo	20 °/oo	30 °/oo
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:

$$P\ 1000\ V = n\ R\ T \qquad [1]$$

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

$$n / 1000\ V = P / R\ T \qquad [2]$$

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

$$[G] = pG / (1000\ R\ T) \qquad [3]$$

The quantity {1 / (1000 R T)} is essentially a "solubility" of a gas in a gas mixture. For all gases, this is about 435 μmol l^{-1} 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:

$$O_{2,g} \leftrightarrow O_{2,s}$$

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

$$CO_{2,g} \leftrightarrow CO_{2,s}$$

$$CO_{2,s} + H_2O \leftrightarrow \underset{\textit{Carbonic acid}}{H_2CO_3} \leftrightarrow H^+ + \underset{\textit{bicarbonate}}{HCO_3^-} \leftrightarrow 2H^+ + \underset{\textit{carbonate}}{CO_3^{-2}}$$

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_2, but not because the solubility of carbon dioxide gas in solution ($CO_{2,s}$) is especially high. The apparent high solubility follows, rather, from the fact that most of the CO_2 that dissolves in water exists in the form of one of the anions of carbonic acid.