Henry's Law

Acid

$$H_{eff} \quad = \quad K_H \left(1 + \frac{K_1}{[H+]}\left(1 + \frac{K_2}{[H+]}\right)\right)$$

Base

$$H_{eff} \quad = \quad K_H \left(1 + \frac{K_1}{K_2}[H+]\right)$$

Where

$$\begin{aligned}
K_H &= \mathrm{kh}_{298}\ \exp(\mathrm{dh}_r\ (\frac{1}{T} - \frac{1}{298})) \\
K_1 &= \mathrm{k1}_{298}\ \exp(\mathrm{dh1}_r\ (\frac{1}{T} - \frac{1}{298})) \\
K_2 &= \mathrm{k2}_{298}\ \exp(\mathrm{dh2}_r\ (\frac{1}{T} - \frac{1}{298})) \\
[H+] &= 10^{-pH}
\end{aligned}$$

Example Derivation of H_{eff} for CO_2

Assume the compound and its anions are in equilibrium. Define a family for that species. For example,

$$C(IV) = H_2CO_3 + HCO_3^- + CO_3^=$$

Find the effective Henry's Law for that family,

$$H_{eff} = \frac{[C(IV)]}{p_{CO_2}}$$

where p_{CO_2} is the partial pressure of CO_2. Based on the equilibria,

$$\begin{aligned}
[H_2CO_3] &= K_H \, p_{CO_2} \\
\left[HCO_3^-\right] &= K_1 \, \frac{[H_2CO_3]}{[H+]} \\
[CO_3^=] &= K_2 \, \frac{[HCO_3-]}{[H+]}
\end{aligned}$$

substitute those equilibria into the $C(IV)$ equation giving

$$H_{eff} = \left(K_H p_{CO_2} + K_1 \frac{[H_2CO_3]}{[H+]} + K_2 \frac{[HCO_3^-]}{[H+]} \right) / p_{CO_2}$$

and further substitution gives

$$H_{eff} = K_H + K_H \frac{K_1}{[H+]} + K_H \frac{K_1 K_2}{[H+]^2}$$

resulting in

$$H_{eff} = K_H \left(1 + \frac{K_1}{[H+]} \left(1 + \frac{K_2}{[H+]} \right) \right)$$