

3. AERATION, ABSORPTION AND STRIPPING

HENRY'S LAW

Gas Transfer Applications

- Transfer of gas across a gas-liquid interface can be accomplished by **bubbles** or by **creating large surfaces** (interfaces).
- The following are some common applications of gas transfer in treatment process.

Gas Transfer Applications

1. Oxygen transfer to biological processes.
2. Stripping of volatile toxic organics (solvents).
3. CO₂ exchange as it relates to pH control.
4. Ammonia removal by stripping.
5. Odor removal – volatile sulfur compounds
6. Chlorination, ozonation for disinfection and odor control.

The materials of interest are **soluble** in water and **volatile** (i.e. they exert a significant vapor pressure).

Equilibrium and Solubility:

For such materials (soluble and volatile), there is an equilibrium established between the **liquid phase** and the **gaseous phase** if there is enough time allowed and if the environmental conditions are held constant. This equilibrium is usually modeled, for dilute solutions, as **Henry's Law**.

Pressure and Solubility of Gases

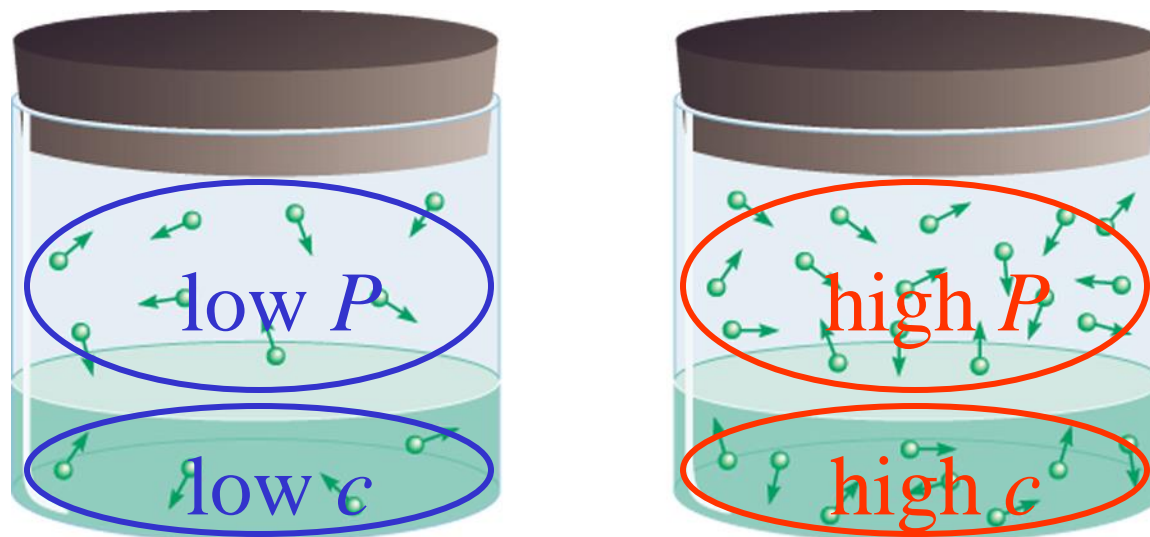
The solubility of a gas in a liquid is proportional to the pressure of the gas over the solution (*Henry's law*).

$$C = kP$$

C is the concentration (M) of the dissolved gas

P is the pressure of the gas over the solution

k is a constant for each gas (mol/L•atm)
that depends only on temperature



In general saturation goes up as T goes down and as TDS goes down.

There are various forms of Henry's law because gas phase and liquid phase concentrations can be defined by different terms as shown in the following figure.

Consider a closed gas-liquid system.

P_T, P_i, y_i	Gas phase
C_T, C_i, x_i	Liquid phase

, where

P_i = partial pressure of component i (atm)

P_T = total pressure of system = $\sum_{i=1}^n P_i$

y_i = mole fraction of component i in the gas phase = $\frac{P_i}{P}$

C_i = conc. of component i in the liquid phase (mole/L³)

C_T = total concentration = $\sum_{i=1}^n C_i$

x_i = mole fraction of component i in the liquid phase = $\frac{C_i}{C}$

Form of equation	H	Liquid phase conc.	Gas phase conc.
$P = H \cdot C$	$\frac{\text{atm} \cdot \text{m}^3}{\text{mol}}$	mol/m^3	atm
$C_g = H_c \cdot C_l$	dimensionless	mol/m^3	mol/m^3
$P = H_a \cdot X$	atm	mol/mol	atm
$y_i = K_H \cdot X_i$	dimensionless	mol/mol	mol/mol

Some typical “H” values:

gas	H _a (atm)
O ₂	4 x10 ⁴
He	12 x10 ⁴
CH ₄	3.76 x10 ⁴
CO ₂	0.14 x10 ⁴
H ₂ S	4.83 x10 ⁴

Volatile compound	H_c	H
Carbon tetrachloride	1.24	0.0304
Chloroform	0.15	0.00367
Vinyl chloride	1.14	0.0278

Henry's constants for various compounds are reported in a variety of forms so it's necessary to know how to convert between these forms.

Here is a sample calculation to show how to convert between various forms of "H"

Look at conversion between H_c (dimensionless) and $H(\text{atm}\cdot\text{m}^3/\text{mol})$.

Conversions

$$P = H \cdot C_1$$

$$C_g = H_c \cdot C_1$$

$$P \cdot V = n \cdot R \cdot T \text{ (ideal gas law)}$$

$$R = 0.0821 \text{ atm-L/mol-}^\circ\text{K}$$

$$= 0.0821 \times 10^{-3} \text{ atm-m}^3\text{/mol-}^\circ\text{K}$$

@ 25°C

$$T = 273 + 25 = 298^\circ\text{K}$$

$$C_{\text{g}} = \frac{n}{V} = H_{\text{c}} \cdot C_{\text{l}} \quad C_{\text{l}} = \frac{P}{H}$$

$$P \cdot V = n \cdot R \cdot T$$

$$\frac{n}{V} = \frac{P}{RT} = \frac{H_{\text{c}} \cdot P}{H}$$

$$\frac{H_{\text{c}}}{H} = \frac{1}{R \cdot T}$$

$$\frac{H_c}{H} = \frac{1}{R \cdot T}$$

@ 25°C

$$\frac{1}{R \cdot T} = \frac{1}{(0.0822 \times 10^{-3} \frac{\text{atm} \cdot \text{m}^3}{\text{mol} \cdot \text{K}}) \cdot (298 \text{K})} = 40.82$$

$$\frac{H_c}{H} = 40.82$$

	H_c	H
Carbon tetrachloride	1.24	0.0304

$$\frac{H_c}{H} = 40.82$$

$$H_c = 40.82 \times 0.0304 = 1.241$$

Conversions

$$K_H = \frac{y_i}{x_i} \qquad H_c = \frac{C_g}{C_l}$$

$$y_i = \frac{C_{i,g}}{C_{g,T}} = \frac{P_i}{P_T} \qquad x_i = \frac{C_{i,L}}{C_{L,T}}$$

$$K_H = \frac{y_i}{x_i} = \frac{\frac{C_{i,g}}{C_{g,T}}}{\frac{C_{i,L}}{C_{L,T}}} = H_c \cdot \frac{C_{L,T}}{C_{g,T}}$$

Conversions

$$C_{g_T} = \frac{n_T}{V} = \frac{P_T}{R.T}$$

$$C_{L_T} = C_{water}$$

$$d_{water} = 1 \frac{g}{cm^3} \times \frac{10^6 cm^3}{1 m^3} \times \frac{1 kg}{1000 g} = 1000 \frac{kg}{m^3}$$

$$C_{water} = 1000 \frac{kg}{m^3} \times \frac{1 mole}{18 \times 10^{-3} kg} = 5.56 \times 10^4 \frac{mole}{m^3}$$

Conversions

$$K_H = H_c \cdot \frac{C_{L,T}}{C_{g,T}}$$

$$K_H = H_c \cdot \frac{5.56 \times 10^4}{\frac{P_T}{RT}} = H_c \cdot \frac{5.56 \times 10^4 \times R \times T}{P_T}$$

At 1 atm P_T

$$K_H = H_c \times R \times T (5.56 \times 10^4)$$

$$H = \frac{P}{C_{i_L}}$$

$$H_a = \frac{P}{x_i}$$

$$x_i = \frac{C_{i_L}}{C_{L_T}}$$

$$H_a = \frac{P}{\frac{C_{i_L}}{C_{L_T}}} = P \times \frac{C_{L_T}}{C_{i_L}}$$

$$H = \frac{H_a}{5.56 \times 10^4}$$

Ex: Oxygen $H_{O_2} = 0.75 \frac{\text{atm}}{\text{mole} / \text{m}^3}$ @ 20 °C

a)
$$H_c = \frac{H}{R \cdot T}$$

$$H_c = \frac{H}{RT} = \frac{0.75 \text{ atm} / \text{mole} / \text{m}^3 \left(\frac{10^3 \text{ L}}{1 \text{ m}^3} \right)}{0.082 \frac{\text{atm} \cdot \text{L}}{\text{mole} \cdot \text{K}} (20 + 273) \text{ K}}$$