The chemical potential of (solvent) water in an aqueous solution can be related to the mole fraction composition of the solution. However, there is a possible disadvantage in an approach using the mole fraction scale to express the composition of a solution. We note that our interest is often in the properties of solutes in aqueous solutions, that the amount of solvent greatly exceeds the amount of solute in a solution, and that the sensitivity of equipment developed by chemists is sufficient to probe the properties of quite dilute solutions. Consequently the mole fraction scale for the solvent is not the most convenient method for expressing the composition of a given solution [1]. Hence another equation relating $\mu_1(\text{aq};T;p)$ to the composition of a solution finds favour.

By definition, for a solution containing a single solute, chemical substance $j$, [2],

$$\mu_1(\text{aq};T;p) = \mu_1^*(\ell;T;p) - \phi \cdot R \cdot T \cdot M_1 \cdot m_j$$  \hspace{1cm} (a)

In terms of the standard chemical potential for water at temperature $T$,

$$\mu_1(\text{aq};T;p) = \mu_1^*(\ell;T) - \phi \cdot R \cdot T \cdot M_1 \cdot m_j + \int_{p^0}^{p} V_i^*(\ell) \cdot dp$$  \hspace{1cm} (b)

$M_1$ is the molar mass of water; $\phi$ is the practical osmotic coefficient which is characteristic of the solute, molality $m_j$, temperature and pressure. By definition, $\phi$ is unity for ideal solutions at all temperatures and pressures.

$$\text{limit}(m_j \rightarrow 0) \phi = 1.0 \text{ at all } T \text{ and } p.$$  \hspace{1cm} (c)

Further for ideal solutions, the partial differentials $(\partial \phi / \partial T)_p$, $(\partial^2 \phi / \partial T^2)_p$ and $(\partial \phi / \partial p)_T$ are zero.

For an ideal solution [3],

$$\mu_1(\text{aq};T;p;\text{id}) = \mu_1^*(\ell;T;p) - R \cdot T \cdot M_1 \cdot m_j$$  \hspace{1cm} (d)

We rewrite equation (d) in the following form:

$$\mu_1(\text{aq};T;p;\text{id}) - \mu_1^*(\ell;T;p) = - R \cdot T \cdot M_1 \cdot m_j$$  \hspace{1cm} (e)
Hence with an increase in molality of solute in an ideal aqueous solution, the solvent is stabilised, being at a lower chemical potential than that for pure water. We contrast the chemical potentials of the solvent in real and ideal solutions using an excess chemical potential, \( \mu^E_1(\text{aq}; T; p) \);

\[
\mu^E_1(\text{aq}; T; p) = \mu_1(\text{aq}; T; p) - \mu_1(\text{id}; T; p)
\]

\[
= (1 - \phi) \cdot R \cdot T \cdot M_1 \cdot m_j
\]  

The term \((1-\phi)\) is often encountered because it expresses succinctly the impact of a solute on the properties of a solvent. At a given molality (and fixed temperature and pressure), \(\phi\) is characteristic of the solute.

**Footnote**

[1] Mole fractions of solvent \(x_1\) and solute \(x_j\) for aqueous solutions having gradually increasing molality of solute \(m_j\).

(a) \(m_j / \text{mol kg}^{-1} = 10^{-3}; \ x_1 = 0.999982 \ x_j = 1.8 \times 10^{-5}\)

(b) \(m_j / \text{mol kg}^{-1} = 10^{-2}; \ x_1 = 0.99982 \ x_j = 1.8 \times 10^{-4}\)

(c) \(m_j / \text{mol kg}^{-1} = 10^{-1}; \ x_1 = 0.9982 \ x_j = 1.8 \times 10^{-3}\)

(d) \(m_j / \text{mol kg}^{-1} = 0.5; \ x_1 = 0.9911 \ x_j = 8.9 \times 10^{-3}\)

(e) \(m_j / \text{mol kg}^{-1} = 1.0; \ x_1 = 0.9823 \ x_j = 1.77 \times 10^{-2}\)

[2] \( \text{[J mol}^{-1}] = \text{[J mol}^{-1}] - [1] \cdot [\text{J K}^{-1} \text{ mol}^{-1}] \cdot [\text{K}] \cdot [\text{kg mol}^{-1}] \cdot [\text{mol kg}^{-1}] \).  

[3] The definitions of ideal solutions expressed here and in terms of mole fraction of solvent are not in conflict. For an ideal solution these equations require that,

\[
- M_1 \cdot m_j = \ln(x_1)
\]

But \(\ln(x_1) = \ln(M_1^{-1} / (M_1^{-1} + m_j)) = -\ln(1.0 + m_j \cdot M_1)\)

Bearing in mind that \(M_1 = 0.018 \text{ kg mol}^{-1}\), for dilute solutions \(\ln(1.0 + m_j \cdot M_1) = m_j \cdot M_1\).