

The Determination of Standard Gibbs Energies of Ion Transfer across
Liquid|Liquid Interfaces with the Help of Three-Phase Electrodes

I n a u g u r a l d i s s e r t a t i o n

zur

Erlangung des akademischen Grades

doctor rerum naturalium (Dr. rer. nat.)

an der Mathematisch-Naturwissenschaftlichen Fakultät

der

Ernst-Moritz-Arndt-Universität Greifswald

vorgelegt von

Rubin Gulaboski

geboren am 29.11.1972

in Prilep, Mazedonien

Greifswald, _____

Introduction

When a solvent α containing the dissolved *neutral* solute A is brought into contact with another solvent β (immiscible with α) there will be a tendency of spontaneous passage of the solute A from the solvent α to the solvent β . This tendency arises due to the differences in the chemical potentials of the compound A in both liquids. The concentrations of A in α and β will remain constant when the chemical potentials of A in both solvents are equal:

$$\mu_A^\alpha = \mu_A^\beta \quad (1)$$

Since the chemical potential of the compound A in solvent α (the same holds true for the solvent β) is defined as:

$$\mu_A^\alpha = \mu_A^{\circ,\alpha} + RT \ln a_A^\alpha \quad (2),$$

it follows that at equilibrium

$$\mu_A^{\circ,\alpha} + RT \ln a_A^\alpha = \mu_A^{\circ,\beta} + RT \ln a_A^\beta \quad (3).$$

The ratio of the equilibrium activities of A in both solvents is therefore defined as:

$$\frac{a_A^\beta}{a_A^\alpha} = \exp\left(\frac{\mu_A^{\circ,\alpha} - \mu_A^{\circ,\beta}}{RT}\right) \quad (4).$$

μ_A° is the standard chemical potential of the compound A in the corresponding phase, while the meaning of other symbols is as usual. For constant temperature and pressure it holds that $\mu_A^{\circ,\alpha} = \Delta G_{r,A}^{\circ,\alpha}$. Therefore, Equation 4 can be rewritten as:

$$\frac{a_A^\beta}{a_A^\alpha} = \exp\left(\frac{\Delta G_{r,A}^{\circ,\alpha} - \Delta G_{r,A}^{\circ,\beta}}{RT}\right) \quad (5).$$

Since the standard reaction free energies $\Delta G_{r,A}^{\circ,\alpha}$ and $\Delta G_{r,A}^{\circ,\beta}$ in case of the *dissolution* of compound A are the *free solvation energies* of A in the solvents α and β , respectively, the difference between the standard Gibbs energies of solvation of A in both solvents is recognized as the *standard Gibbs energy of transfer* from solvent α to solvent β ($\Delta G_{A,\alpha}^{\circ,\beta}$).

Then, Equation 5 can be rewritten as follows:

$$\frac{a_A^\beta}{a_A^\alpha} = \exp\left(\frac{-\Delta G_{A,\alpha}^{\circ,\beta}}{RT}\right) \quad (6).$$

$$P_{A\alpha}^{\beta} = \exp\left(\frac{-\Delta G_{A,\alpha}^{\circ,\beta}}{RT}\right) \quad (7).$$

Equation 6 shows that the equilibrium activities of A in both solvents are determined by the value of the standard Gibbs energy of transfer of solute A between α and β .

The partition coefficient (or more precisely, the logarithm of the partition coefficient, $\log P$) is a parameter commonly used as a measure of the *lipophilicity* of compounds [1, 2]. Consequently, $\log P$ is exploited for the prediction a large number of biological properties: it is a valuable parameter in quantitative structure activities relationships (QSAR) and quantitative structure properties relationships (QSPR) that have been developed for pharmaceutical, environmental, biochemical and toxicological sciences [1, 2]. Moreover, many studies have revealed that $\log P$ is useful for correlating the transport of drug molecules and its interactions with receptor molecules, and changes in its structure with various biochemical or toxic effects [2]. Owing to these applications, there is a permanent need for a precise and reliable determination of the $\log P$ values. A number of different techniques such as chromatography [2, 4], shake-flask methods [4], potentiometric techniques [2] and so forth have been developed for determination of $\log P$ values of *neutral* compounds. Besides the experimental techniques, there are also several widely used essentially empirical methods for estimating of $\log P$ for neutral compounds. Rekker [3] first defined an arbitrary set of terminal fragments using a database of about 1000 compounds with known $\log P$ values. To estimate the partition coefficient of a certain compound one simply summarizes the group contributions. The approach of Leo and Hansch et al. [4] was to determine very accurately $\log P$ values of a set of small molecules, and to calculate the fragmental values from these data. Although $\log P$ values for the compounds included in the base sets of the last two references [3, 4] are reproducible, it is often a problem to correctly fragmentize a molecule, especially drug molecules. At this stage it is worth noting that the $\log P$ values measured in water/*n*-octanol have been widely recognized as a reference for $\log P$ values [4]. The amphiphatic properties of *n*-octanol i.e. a long

A fundamentally different situation from that described above arises when an *electrolyte* is dissolved in one of two immiscible adjacent solvents. In this case, the partitioning of the charged species between two adjacent phases (α and β) generates an interfacial region where an electrical Galvani potential difference ($\Delta\phi_\alpha^\beta$) is established:

$$\Delta\phi_\alpha^\beta = \phi^\beta - \phi^\alpha \quad (8),$$

(ϕ^α and ϕ^β are the inner potentials of the phases α and β , respectively).

For the ionic species “ i ”, the thermodynamic equilibrium is reached when the electrochemical potentials of i ($\tilde{\mu}_i$) in both phases are equal:

$$\tilde{\mu}_i^\alpha = \tilde{\mu}_i^\beta \quad (9).$$

Since the electrochemical potential is defined as

$$\tilde{\mu}_i^\alpha = \mu_i^{\circ,\alpha} + RT \ln a_i^\alpha + z_i F \phi^\alpha \quad (10),$$

then, at equilibrium it holds that

$$\mu_i^{\circ,\alpha} + RT \ln a_i^\alpha + z_i F \phi^\alpha = \mu_i^{\circ,\beta} + RT \ln a_i^\beta + z_i F \phi^\beta \quad (11).$$

After rearranging Equation 11, the Galvani potential difference $\Delta\phi_\alpha^\beta = \phi^\beta - \phi^\alpha$ is obtained as:

$$\Delta\phi_\alpha^\beta = \frac{\mu_i^{\circ,\alpha} - \mu_i^{\circ,\beta}}{z_i F} + \frac{RT}{z_i F} \ln \frac{a_i^\beta}{a_i^\alpha} \quad (12), \text{ or}$$

$$\Delta\phi_\alpha^\beta = \frac{-\Delta G_{i,\alpha}^{\circ,\beta}}{z_i F} + \frac{RT}{z_i F} \ln \frac{a_i^\beta}{a_i^\alpha} \quad (13).$$

The term $\frac{-\Delta G_{i,\alpha}^{\circ,\beta}}{z_i F}$ in Equation 13 is defined as the *standard potential of transfer* of the ion i from phase α to phase β ($\Delta\phi_{i,\alpha}^{\circ,\beta}$). In these equations z_i is the charge number of the ions (z_i is positive for cations and negative for anions), while F is the Faraday constant (96485 C mol⁻¹).

$$\Delta\phi_{i,\alpha}^{\circ,\beta} = \frac{-\Delta G_{i,\alpha}^{\circ,\beta}}{z_i F} \quad (14).$$

Therefore, Equation 13 can be rewritten as

$$\Delta\phi_\alpha^\beta = \Delta\phi_{i,\alpha}^{\circ,\beta} + \frac{RT}{z_i F} \ln \frac{a_i^\beta}{a_i^\alpha} \quad (15).$$

Keeping in mind the ratio $\frac{a_i^\beta}{a_i^\alpha} = P_{i,\alpha}^\beta$, it follows that