dU = T dS – P dV

\[ dw = F \, dx \]

dU = T dS – P dV + F dx

\[ dG = -S \, dT + V \, dP + F \, dx \]

Surface Tension:  \[ dw = \gamma \, d\sigma \]

\[ \gamma = J/m^2 \text{ or N/m} \]

\[ d\sigma = 8\pi r \, dr \]

<table>
<thead>
<tr>
<th>Interface</th>
<th>( \gamma ) (mN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water/air</td>
<td>72.8</td>
</tr>
<tr>
<td>ethanol/air</td>
<td>22.3</td>
</tr>
<tr>
<td>hexane/air</td>
<td>18.4</td>
</tr>
<tr>
<td>hexane/water</td>
<td>51.1</td>
</tr>
</tbody>
</table>

\[ dG = -S \, dT + V \, dP + \gamma \, d\sigma \]

Extension:  \[ dw = f \, dx \]

Spring: Hooke's Law  \[ f = kx \]

\[ dw = f \, dx \]

\[ dG = -S \, dT + V \, dP + kx \, dx \]

Chemical work:  \[ dw = \mu_i \, dn_i \]

\[ \mu_i = \left( \frac{\partial U}{\partial n_i} \right)_{S,V,n_j \neq n_i} \]

chemical potential

Two components:  \[ dw = \mu_1 \, dn_1 + \mu_2 \, dn_2 \]

\[ dU = T \, dS - P \, dV + \mu_1 \, dn_1 + \mu_2 \, dn_2 \]

\[ dG = -S \, dT + V \, dP + \mu_1 \, dn_1 + \mu_2 \, dn_2 \]

\[ dG = -S \, dT + V \, dP + \sum \mu_i \, dn_i = -S \, dT + V \, dP + \sum \nu_i \, \mu_i \, d\xi \]

Electricity:  \[ dw = \phi \, dq_i \]

\[ dG = -S \, dT + V \, dP + \sum \mu_i \, dn_i + \sum \phi \, dq_i \]

Electrical work for charging an ion in a solution at constant electric potential \( \phi \):

\[ dq_i = z_i \, F \, dn_i \]

\[ w = z_i \, n_i \, F \, \phi \]

\[ dG = -S \, dT + V \, dP + \sum \mu_i \, dn_i + \sum z_i \, F \, \phi \, dn_i \]

Electrochemical potential:

\[ \bar{\mu}_i = \mu_i + z_i \, F \, \phi \]

cst. \( T \) and \( P \), equilibrium:  \[ \Sigma \nu_i \, \bar{\mu}_i = 0 \]

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