1. Today

→ Continuum Solvation
→ Onsager
→ PCM
→ Embedding, ONIOM
→ QM/MM

2. Solvation

Looking at the di-chloryl ethane in the gas phase (trans vs gauche positions)
In the gas phase, we take the trans configuration as 0 energy, but the gauche configuration as 1 kcal/mole.
In a solvent, both energies are essentially the same due to the solvents high dielectric constant.
What is $\Delta E_{\text{elec,solv}}$ (solvation energy)?

$\Delta E_{\text{elec,solv}} = E_{\text{elec,liq}} - E_{\text{elec,gas}}$

Onsager’s reactions field method (JACS b8 (1936) 1486)
Essentially, the solvation sphere is embedded within a system of liquid of dielectric value $\epsilon$

$H_{pf} = H_o + H_1$ where $H_1$ is the perturbation of the solvent
This is all done with gas phase calculations (HF, DFT, etc)

$a_o^3 = \frac{3V_o}{4\pi N}$

$H_1 = -\mu \cdot \vec{R}$ where R is the ”reaction field”

$\vec{R} = gj\vec{\mu}$

$g = \frac{2(\epsilon-1)}{(2\epsilon+1)\alpha_o^2}$

3. Polarized Continuum Method - PCM

Jacobo Tomasi and coworkers
1) Choose $\vec{R}$
2) Solve SCF Problem w/H
3) Compute $\vec{R} = gj\vec{\mu}$

if $\vec{R}(3) \approx R(1)$ then done

Date: Fall 2004.
\[ \Delta E_{\text{gauche-trans}} \text{ for 1,2 dichloroethane (STP)} \]

<table>
<thead>
<tr>
<th>Medium</th>
<th>( \epsilon )</th>
<th>HF</th>
<th>MP2</th>
<th>experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>gas</td>
<td>1.00</td>
<td>1.96</td>
<td>1.64</td>
<td>1.20</td>
</tr>
<tr>
<td>organicsolvent</td>
<td>4.3</td>
<td>0.83</td>
<td>0.54</td>
<td>0.69</td>
</tr>
<tr>
<td>pureliquid</td>
<td>10.1</td>
<td>0.49</td>
<td>0.26</td>
<td>0.31</td>
</tr>
<tr>
<td>acetonitrile</td>
<td>35.9</td>
<td>0.30</td>
<td>0.09</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Assume solute has gas phase dipole moment \( \mu \) but no charge. It’s just polarizable. Cavity is “polarizable” w/charge distribution on surface of the cavity.

Treat the solute as a continuum charge distribution \( \rho(\vec{r}) \) in a cavity w/arbitrary shape.

Describe polarization of infinite dielectric by the creation of surfaces w/density \( \sigma(s) \)

\[
v(r) \text{ electrostatic potential} \]

\( v_{\rho}(r) + v_{\sigma}(r) \) are from solute and surface respectively

Solve \( \nabla^2 v(r) = 0 \) and match the boundary conditions via \( v(s)_{-} = v(s)_{+} \)

\[
(\frac{\delta v(s)}{\delta n})_{-} = (\sigma)_{-} = (\frac{\delta v(s)}{\delta n})_{+}
\]

\[
\sigma(s) = -[\frac{(e-1)}{4\pi\epsilon}]E(s) = v_{\sigma} \text{ Where } E(s)_{n} \text{ is the electric field produced by the solute.}
\]

\( H = H_{0} + v_{\sigma} \) Solve this self consistently

4. Embedding of Clusters (Sauer & coworkers)

Faujisite = 144 Atoms

ZSM-5 = 288 Atoms

proton affinity vs cluster size

<table>
<thead>
<tr>
<th>NumShells</th>
<th>( PA(HF)/STO - 36 )</th>
<th>( HF(Mixed/Embedded) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>388.2</td>
<td>298.0</td>
</tr>
<tr>
<td>2</td>
<td>381.0</td>
<td>299.4</td>
</tr>
<tr>
<td>3</td>
<td>363</td>
<td>299.6</td>
</tr>
<tr>
<td>4</td>
<td>391</td>
<td>299.2</td>
</tr>
</tbody>
</table>
But, cannot treat breaking and formation of bonds. QM only for small systems
Solution, combine the 2.

\[ E(s) = E_{QM}(I) + E_{MM}(o) + E(I - O) \]

interaction term using \( \text{mm} \approx E_{MM}(I - O) \)

\[ E_{MM}(I - O) + E_{MM}(O) = E_{MM}(s) - E_{MM}(I) \]

\[ \Rightarrow E(s) = E_{QM}(I) + E_{MM}(s) - E_{MM}(I) \]

Now, let

\[ E(s) = E_{QM}(c) + E_{MM}(O) + E_{MM}(I - O) - E_{MM}(I - O) - E_{QM}(L) - E_{QM}(I - L) \]

but \( E_{MM}(s) = E_{MM}(C) + E_{MM}(O) + E_{MM}(I - O) - E_{MM}(L) - E_{MM}(I_L) \)

\[ E(s) = E_{QM}(C) + E_{MM}(s) - E_{MM}(C) + \Delta \]

\[ \Delta = E_{MM}(L) - E_{QM}(L) + E_{M}(I - L) - E_{QM}(I - L) \]

If \( E_{MM} \approx E_{QM} \Rightarrow \Delta \approx 0 \)

5. QM/MM

Type of method, "double link atom"

QM is in a certain region, the rest is standard MM.