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Model Calculations on LIS, III[1]. A Simple Force Field Model for Ln(III)-Shift-Reagent—Substrate Complexes, 1. Carbinols

Short Communication

Peter Földesi and **Otmar Hofer***

Institut für Organische Chemie, Universität Wien,
A-1090 Wien, Austria

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A force field type of calculation ("FFLIS" model, force field aided LIS calculation) is presented allowing to predict the lanthanide(III) position *and* the relative LIS values for carbinol—*Ln*(III) complexes.

(Keywords: Lanthanide induced shifts; Nonbonded interactions)

Modelluntersuchungen zur Simulierung von LIS, III. Ein einfaches Kraftfeldmodell für Ln(III)-Verschiebungsreagens—Substrat Komplexe, 1. Carbinole (Kurze Mitt.)

Es wurde für Carbinol—*Ln*(III)-Komplexe ein einfaches Modell vom Typ der Kraftfeldrechnungen (force field) erprobt. Dieses „FFLIS"-Modell erlaubt die Berechnung der Lanthanidenposition *und* der relativen LIS-Werte (lanthanide induced shifts).

In the "classical LIS calculation"[2] using the *McConnell-Robertson* equation one observes in general that the *Ln*(III) positions avoid sterically crowded regions of the substrate molecules. This observation prompted us to develop a computer program to predict reasonable *Ln*(III) positions taking into account steric requirements of both substrate and reagent.

A complete force field treatment[3,4] of *Ln*(III)-reagent—substrate complexes with well above 100 atoms would obviously present a rather difficult task.

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We therefore introduced the following simplifications:

(i) We test a particular substrate geometry in relation to a particular idealized reagent geometry. The energy contributions within the substrate part of the complex are thus constant for all possible substrate—reagent combinations and require no evaluation for the purpose of finding the energy minimum.

(ii) Concerning the reagent part of the complex we endeavor to simulate the average "effective" axial symmetry[5] assumed in all LIS calculations. We simulate the complexing site of the reagent by a cavity of axial symmetry characterized by steep wells which account for the bulky ligands (for instance the six *tert*-butyl groups in the *dpm* ligand). For calculating nonbonded interactions no individual C, H, *Ln*, O (or F) atoms of the shift reagent are taken into account, but the nonbonded interactions between the substrate atoms and the *surface of the cavity* are taken as an estimate of the energy changes upon insertion of the substrate molecule into the cavity of the shift reagent. In practice this means that the nonbonded interaction of each substrate atom with a point on the surface of the reagent closest to the particular substrate atom is evaluated. Fig. 1 shows several typical cases (H_{i-l}). The most favorable arrangement is characterized by the overall minimum of all interaction energies.

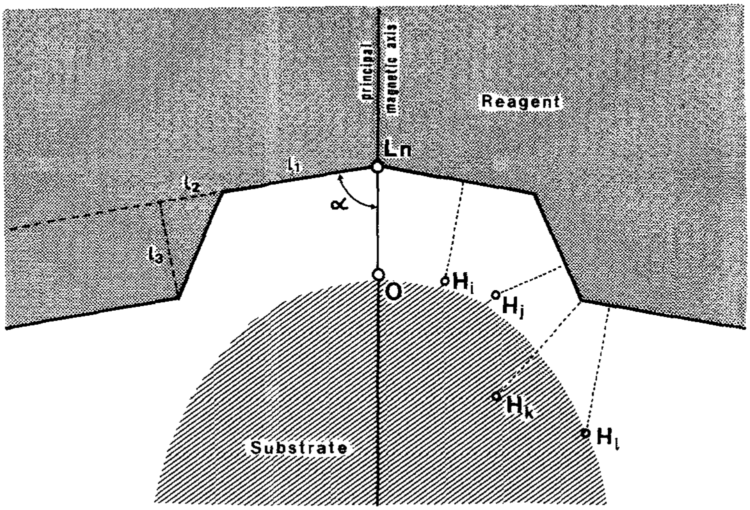

Fig. 1. Indealized cross section through the axially symmetrical FFLIS model

For estimating the nonbonded interactions a modified *Buckingham* potential[6] is used. A further simplification is introduced by taking into account only H-surface and *X*-surface interactions (corresponding to H—C and C—C in ref.[6]), with *X* standing for all common atoms like C, O, N etc.

Different shapes of the cavity were tested to simulate the "effective" axially symmetrical geometry of the reagent. The results are not very dependent on slight modifications of the cavity as long as the bulky ligands are simulated fairly reasonable. Finally we choose the cavity shown in Fig. 1; it is constructed starting out from the principal magnetic axis with the angle $\alpha = 80°$ and $l_1 = 4.2$, $l_2 = 1.6$, $l_3 = 2.5$ Å. Other shapes tested include wells constructed with the aid of angular functions (sin, $\sin^2$), a spherical form of cavity, simple cones without a pronounced cavity ($l_3 = 0$ in Fig. 1) or simply a disk ($l_3 = 0$, $\alpha = 90°$).

Table 1. *FF Calculated Ln(III) positions*[a] *together with the agreement factor R (%) for the corresponding LIS in comparison with the positions found by the classical LIS procedure*[b] *for compounds* **1—10**[8]

Compound	No.	$\rho_{FF}(\rho_{LIS})$	$\varphi_{FF}(\varphi_{LIS})$	$R_{FF}(R_{LIS, min})$
1-Adamantanol	**1**	0 (0)	—[c]	9.2 (8.2)
2-Adamantanol	**2**	30 (38)	60 (60)	5.8 (4.6)
trans-4-*tert*-Butyl-cyclohexanol	**3**	40 (49)	63 (60)	5.4 (2.7)
cis-4-*tert*-Butyl-cyclohexanol	**4**	50 (49)	58 (60)	7.9 (5.7)
Borneol	**5**	30 (45)	24 (3)	9.4 (3.6)
Isoborneol	**6**	30 (54)	84 (99)	13.3 (4.4)
Indanol	**7**	20 (38)	20 (40)	4.9 (2.6)
trans-2-Methylindanol	**8**	10 (11)	—[c]	6.6 (2.7)
cis-2-Methylindanol	**9**	20 (22)	36 (51)	4.1 (3.1)
7-Methylindanol	**10**	30 (34)	0 (20)	6.9 (4.4)

[a] Polar coordinates[7, 1] with C—C—O in the *z*-*x*-plane and the most space consuming part of the molecular in the negative *x*, *y*, *z* octant; $d_{FF} = 2.8$ Å.

[b] The centers of all positions with *R* between $R_{LIS, min}$ and $1.5 \times R_{LIS, min}$ are listed in order to avoid accidental *R* minima; d_{LIS} are found between 2.6 and 2.9 Å.

[c] For $\rho = 0$-$10°$ φ is not significant (at $\rho = 0°$ φ is undefined).

(iii) The bond lenght O···*Ln* is kept constant at 2.8 Å which corresponds formally to a very steep energy function with $d_0 = 2.8$; in the classical LIS procedure 2.8 ± 0.3 Å is commonly found and small deviations in the bond lenght are usually not of importance. In the case of carbinol complexes the introduction of special functions for the C—O—*Ln* bond angle or the C—C—O—*Ln* dihedral angle did not lead to any improvement of the calculated *Ln*(III) positions.

In the course of the computation the lanthanide ion together with the magnetic axis and the "reagent cavity" moves in increments relative to the substrate. The *Ln*(III) position corresponding to the complex geometry of minimal energy is used to calculate the relative LIS values on the basis of the *McConnell-Robertson* equation.

It should be emphasized that the classical quantitative LIS evaluation includes a direct fit of the observed LIS with the calculated LIS by optimizing the *Ln*(III) position. The force field procedure here described does not include a fit with the experimental LIS. The classical LIS calculation requires experimental data to arrive at an optimal *Ln*(III) position, whereas the FFLIS procedure predicts the lanthanide position *and* the LIS values. The results for ten test compounds are summarized in Table 1.

The force field aided LIS method (FFLIS) should be of particular interest for underdetermined systems (e.g. polyfunctional molecules).

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