Tetrahedron Letters, Vol. 34, No. 3, pp. 427-430, 1993
Printed in Great Britain

0040-4039/93 $5.00 + .00
Pergamon Press Ltd

Transition Structures for Radical Hydrogen Abstractions and Lithium Hydride Additions: Similitudes and Divarications†

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Abstract: Ab initio transition structures were obtained for the reactions of methane and hydrogen sulfide with the 1-hydroxyethyl radical, lithium hydride with acetaldehyde, hydrogen sulfide with 2-hydroxy-3-methylbutan-2-yl, and lithium hydride with methyl isopropyl ketone.

Giese, Curran, and their coworkers have recently studied radical hydrogen abstractions and have achieved stereoselectivities comparable to those for hydride reductions of carbonyls.[1,2] The similarity between stereoselectivities of the two reactions led them to propose that the transition structure for the radical reaction was similar to that of the hydride addition. Consequently the outcome of the radical process can be

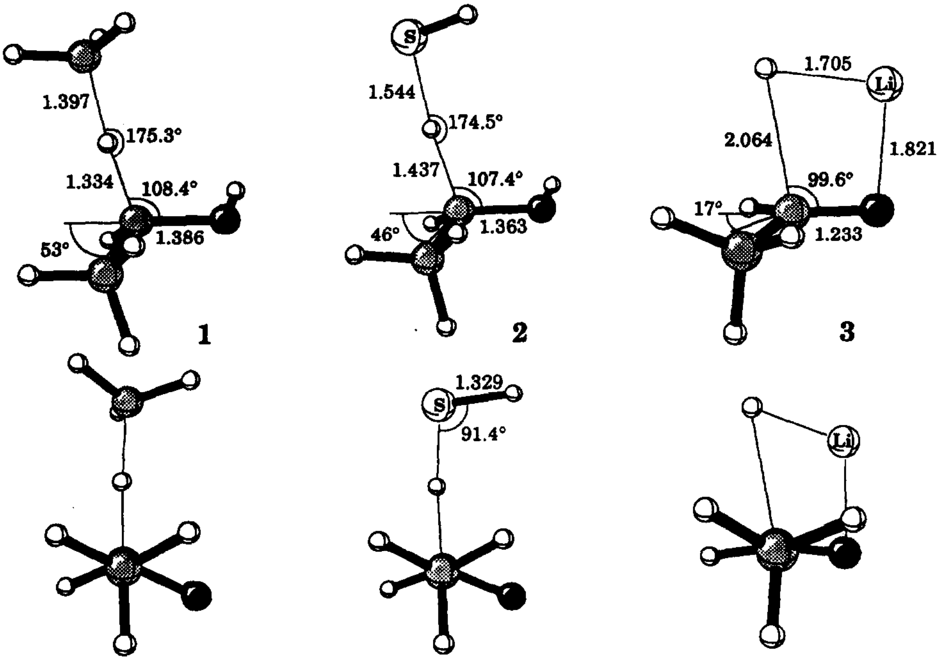

Figure 1. The top row shows the 6-31G* optimized structures for 1, 2 and 3. The bottom row shows the Newman projections with the radical center and the carbonyl carbon in the back.

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†A referee has proposed that these words are not widely known (similitudes = resemblances, divarications = divergences).

predicted by the Felkin-Anh model.[1-3] We have performed ab initio calculations on both the hydride/carbonyl and radical species and present a comparison and contrast of the two types of transition structures.

The transition structures for the reaction of methane and hydrogen sulfide with the 1-hydroxyethyl radical, **1** and **2**, lithium hydride with acetaldehyde, **3**, hydrogen sulfide with 2-hydroxy-3-methylbutan-2-yl, **4**, and lithium hydride with methyl isopropyl ketone, **5**, were optimized at the 6-31G* level,[4-6] with MP2/6-31G* single points on these geometries.

Figure 1 shows a comparison of the optimized structures for two radical and a nucleophilic reaction. Although the hydrogen abstraction of methane by the 1-hydroxyethyl radical is endothermic, it is included for comparison with the hydrogen sulfide reaction. Despite the differences in the reactions (abstraction from methane is late, and abstraction form H_2S is early), the transition structures are surprisingly similar. Both structures are pyramidal (the angle of deformation about the radical center is 53° for **1**, and 46° for **2**); the Newman projections show that the bonds are all staggered. The angle of attack is close to tetrahedral, 108° for **1**, and 107° for **2**, and the hydrogen abstraction is quite linear, 175° for **1**, and 174° for **2**.

The reaction of lithium hydride with acetaldehyde, **3**, is also shown in Figure 1. This structure is different from the radical transition structures in two ways. First, the structure is not as pyramidal (this is shown in the Newman projection); the angle of deformation is only 17°. Second, the angle of attack of the hydride is smaller, 100°. The smaller angle of attack is expected because of the four-center transition state. These results are similar to earlier work by Wu and Houk on sodium hydride addition to carbonyls.[7]

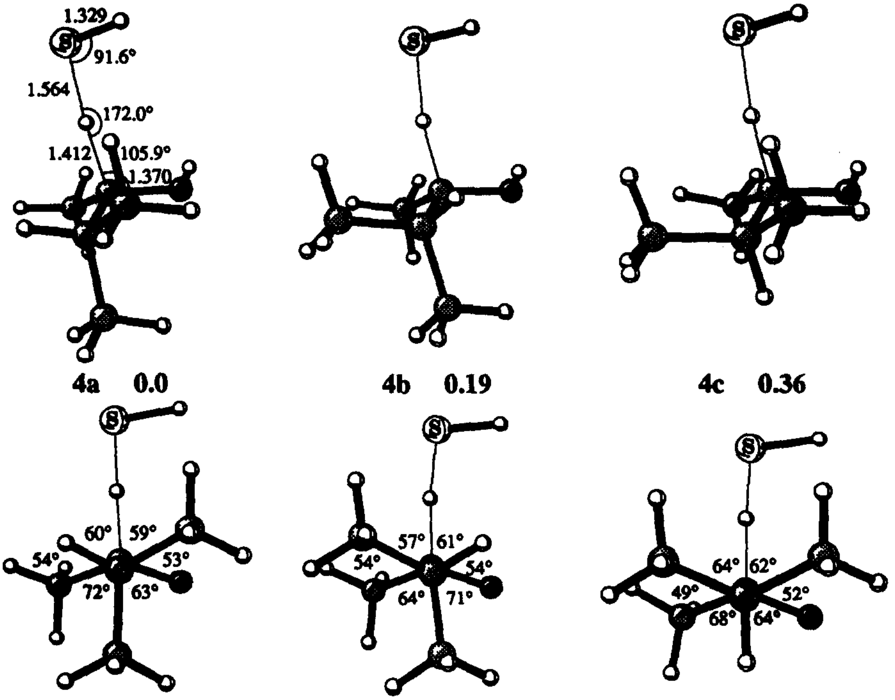

Figure 2. The top row shows the 6-31G* optimized structures for **4a**, **4b** and **4c**. The bottom row shows the Newman projections with the radical center in the back. Relative energies (kcal/mol) are shown.

Larger systems, which are better models for the experiments of Giese and Curran[1,2] are shown in Figures 2 and 3. The methyl groups were added as substituents to determine if the geometry of the transition structures changes considerably with a disubstituted α-carbon. The changes were small for both reactions.

Figure 2 shows the three conformers (**4a**, **4b** and **4c**) for the reaction of hydrogen sulfide with 2-hydroxy-3-methylbutan-2-yl. The lowest energy structure, **4a**, resembles the proposed Felkin-Anh transition structure with one substituent anti to the methyl group and gauche to the oxygen and the other substituent gauche to both the methyl group and the oxygen. In **4a**,. the angle of attack is 106°, and the hydrogen transfer is close to linear at 172°. The transition state is early with a C-H forming bond length of 1.41 Å and the S-H breaking bond length of 1.56 Å. The angle of deformation is 56°, indicating the radical center is pyramidal. The Newman projection of **4a** shows that the bonds are well staggered. The Newman projections also show the unfavorable gauche interactions in conformers **4b** and **4c**.

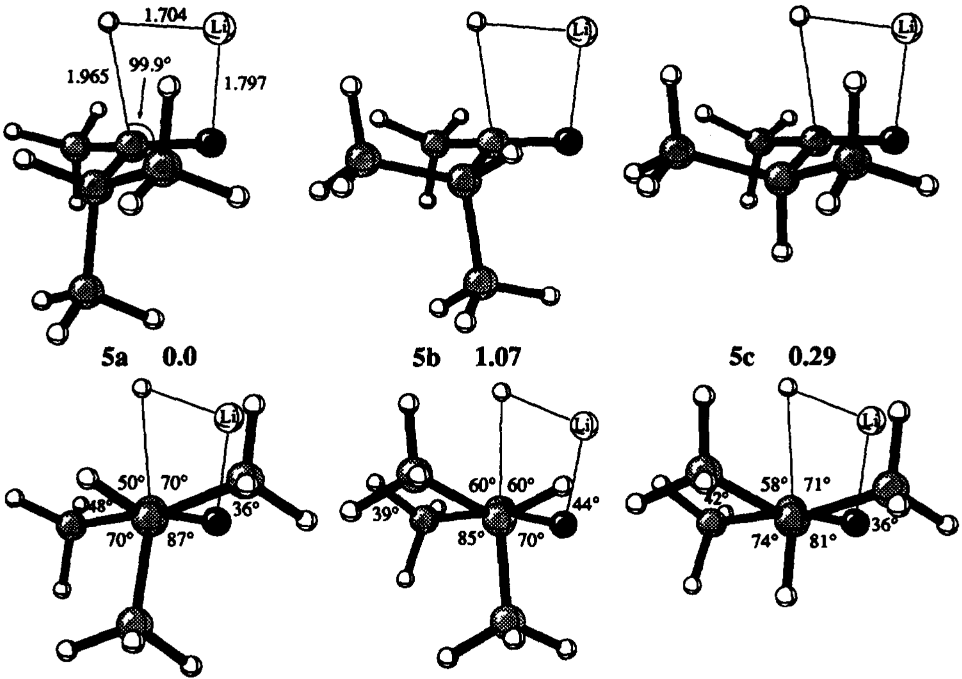

Figure 3. The top row shows the 6-31G* optimized structures for **5a**, **5b** and **5c**. The bottom row shows the Newman projections with the carbonyl carbon in the back. Relative energies (kcal/mol) are shown.

Figure 3 shows the corresponding conformations for the lithium hydride addition to methyl isopropyl ketone. Of the three conformers, **5a** is the lowest in energy and also corresponds to the Felkin-Anh model. The geometry at the reaction center of **5a** is similar to that of **3**. The angle of attack is 100° and the forming bond length is 1.96 Å. The angle of deformation is 24°; this is larger than the 17° of **3**.

The relative energy differences between the conformers of **4** and **5** differ, and the hydride addition transition structures are not as pyramidal as those of the radical. However both sets of calculations agree that the lowest energy conformer is the one that corresponds to the Felkin-Anh model.

Cieplak and Wiberg[8] have recently shown the importance of solvent effects in the nucleophilic additions to carbonyls, and indicate that the conformers preferred in the gas phase are not the ones preferred in solution. The radical reactions on the other hand should show less of a solvent effect since there is little charge separation.

Studies of chiral systems are in progress and will be reported in due course.

Acknowledgment. We are grateful to the National Institutes of Health for financial support of this research, and to Professors Giese, Curran, and to Wolfgang Damm for communications prior to publication.

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(3) Damm, W.; Dickhaut, J.; Wetterich, F.; Giese, B. accompanying communication.

(4) For the radical reactions with hydrogen sulfide, the 6-31G* basis set was modified to include diffuse and polarization functions on the hydrogen being transferred.

(5) For the radical systems, UHF/6-31G* calculations were performed.

(6) All calculations were done with GAUSSIAN 90, Frisch, M. J.; Head-Gordon, M.; Trucks, G. W.; Foresman, J. B.; Schlegel, H. B.; Raghavachari, K.; Robb, M. A.; Binkley, J. S.; Gonzalez, C.; Defrees, D. J.; Fox, D. J.; Whiteside, R. A.; Seeger, R.; Melius, C. F.; Baker, J.; Martin, R.; Kahn, L. R.; Stewart, J. J. P.; Topiol, S.; Pople, J. A., Gaussian Inc., Pittsburgh, PA, 1990.

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(Received in USA 24 September 1992; accepted 20 October 1992)