Ab Initio Molecular Orbital Study of Reactivity of Active Alkyl Groups. IV. Nitrosation of Acyclic Carbonyl Compound with Methyl Nitrite *via* "Open-Chain" Transition State

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The mechanism of the nitrosation of enolate anion of acetone $[CH_3COCH_2]^-$ (1) with methyl nitrite CH_3ONO (2) *via* an "open-chain" transition state without Na^+ in the C–N bond formation process was studied by the *ab initio* MO method. The complex $[CH_3COCH_2NO(OCH_3)]^-$ (C-II) was first formed from the adduct (C-I) of 1 and 2 through the transition state (TS1). Finally, *E*-1-hydroxyimino-2-oxo-propane $CH_3COCH{=}NOH$ (3*E*), together with *Z*-form (3*Z*), was obtained by way of the elimination process. It has become apparent that 3*E* is formed when C-II-A is produced in the C–N bond formation process.

Key words *ab initio* MO method; nitrosation; open-chain transition state; reaction mechanism; active alkyl group; elimination

The nitrosation of active alkyl compound $RCOCH_2R'$ with alkyl nitrite R″ONO being carried out using a base catalyst B^-M^+ to give *E*- and *Z*-hydroxyimino compound RCOCR′=NOH is generally expressed by Eq. 1.

$$RCOCH_2R' + R''ONO \xrightarrow{B^-M^+} RCOCR'{=}NOH + R''OH \quad (1)$$

The ratio of the yield of *E*- over that of *Z*-form produced in the nitrosation depends highly upon the bulkiness of substituents (R, R′, R″) and the reaction conditions of base, solvent and temperature.[1] In the case of the nitrosation of the methyl or ethyl group of carbonyl compound, *E*-form is obtained predominantly. The ratio *E*/*Z* decreases with increasing bulkiness of the substituents. In the nitrosation of isovalerophenone $PhCOCH_2CH(CH_3)_2$ (**4**) under protic conditions, *i.e.*, EtONa in EtOH, the yield of *E*-2-hydroxyimino-1-phenyl-3-methyl-1-oxo-butane (**5**) was 2.3 times that of *Z*-form (**6**). On the contrary, under aprotic conditions, *i.e.*, lithium diisopropylamide (LDA) in tetrahydrofuran (THF), the ratio of the yield of **5** over that of **6** was 3/4.[2]

The rate-determining step of the nitrosation is a C–N bond formation process. The ratio of *E*/*Z* is believed to vary greatly, whether or not the counter cation M^+ of base catalyst participates in this process. Two kinds of transition state (TS) in the C–N bond formation process were proposed to illustrate the variation of the ratio, *i.e.*, metal-chelated pericyclic TS ($TS_{CHELATED}$) and "open-chain" TS without metal (TS_{OPEN}).

In the previous paper[2] we reported on the nitrosation of sodium enolate of acetone $[CH_3COCH_2]^-Na^+$ with **2**. The *Z*-form is preferentially obtained when the nitrosation proceeds *via* $TS_{CHELATED}$. In the present study, the mechanism using TS_{OPEN} in the nitrosation of **1** with **2** shown in Eq. 2 was investigated stereochemically by the same *ab initio* MO method as that described earlier.[2] *E*-Hydroxyimino compound (**3***E*) was obtained when the reaction in the C–N bond formation process proceeds not *via* $TS_{CHELATED}$ but *via* TS_{OPEN}.

$$\underset{\mathbf{1}}{[CH_3COCH_2]^-} + \underset{\mathbf{2}}{CH_3ONO} \xrightarrow{CH_3ONa} \underset{\mathbf{3}}{CH_3COCH{=}NO^-} + CH_3OH \quad (2)$$

Experimental

Computational Procedure The MO calculations were carried out with the Gaussian 94 program.[3] The optimized geometries in the TS were determined with HF/6-31G, followed by intrinsic reaction coordinate (IRC) calculations. For energies of the complexes, the calculations were performed using the same method, MP3/6-31+G//HF/6-31G, as that previously described.[2] The conformation of **2** in the C–N bond formation process is the *trans*-form.[4]

Results and Discussion

As described,[2] the rate-determining step in the nitrosation is the C–N bond formation process. In this study, the MO calculation for the formation of **3** was carried out stepwise as follows: Eq. 2 was divided into two steps expressed by Eqs. 3 and 4 (Chart 1). The MO calculation for the C–N bond formation process expressed by Eq. 3 was performed, followed by that for the elimination process expressed by Eq. 4. In the C–N bond formation process, TS_{OPEN} was adopted. Paths A and B are considered with TS1-A and -B in Fig. 1 arising from the difference of the geometrical orientation of **2** toward **1**. This orientation is similar to that described,[2] except for the absence of Na^+. First, each geometry of TS1 was determined, and those of C-I and C-II were obtained from

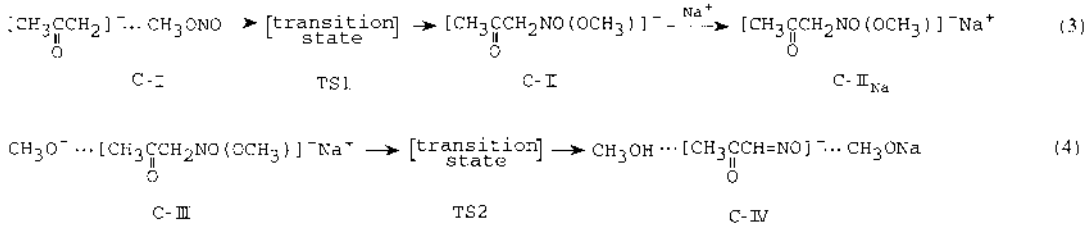

Chart 1

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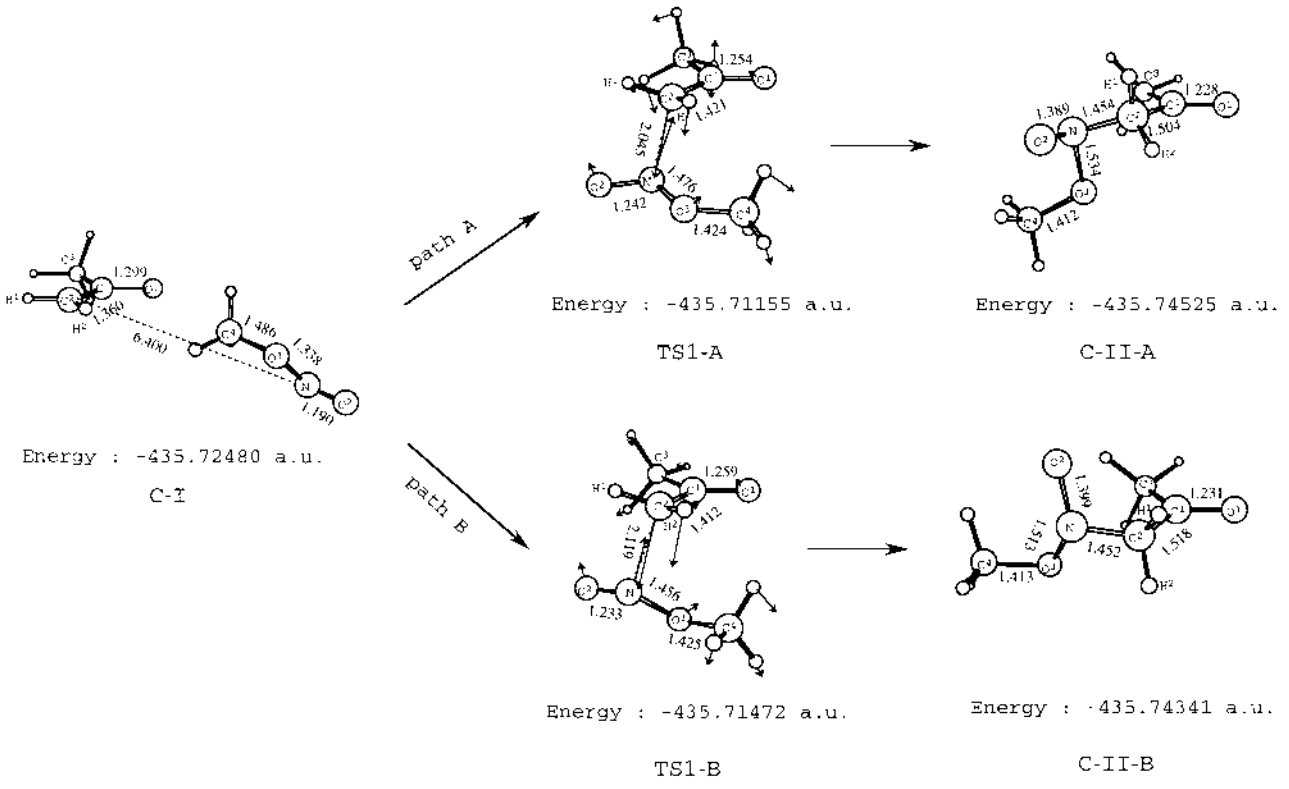

Fig. 1. C–N Bond Formation Process of Nitrosation

Imaginary frequency modes are shown with bold arrows in the structures of the TS.

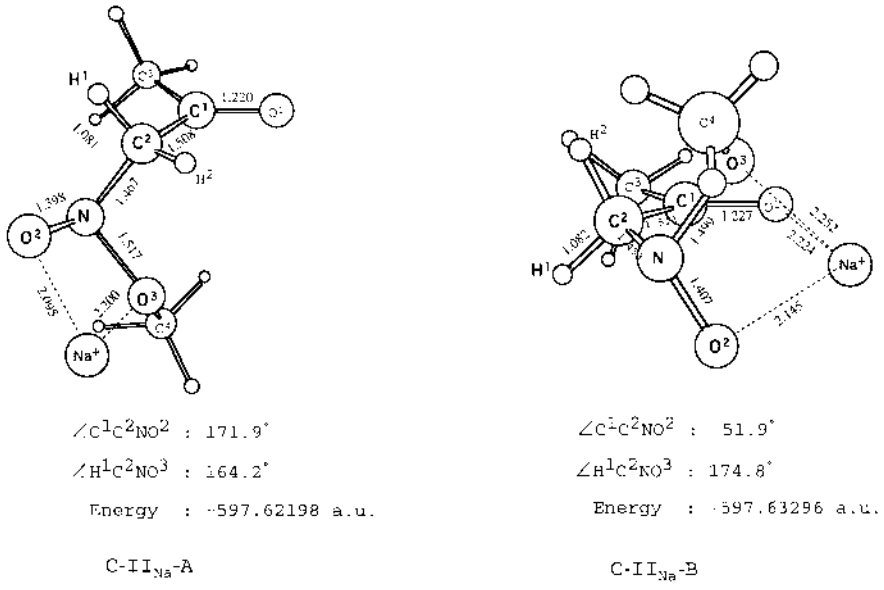

Fig. 2. Optimized Structures of C-II$_{Na}$-A and -B

TS1 using the IRC method. Prior to the calculation for the elimination process, to avoid the repulsion between $[CH_3COCH_2NO(OCH_3)]^-$ and CH_3O^-, a counter cation Na^+ of catalyst was added to the negative oxygen atom in C-II. The active hydrogen atom H^1 of the complex with Na^+(C-II$_{Na}$) was attacked by CH_3O^-, and the demethoxylation occurred first, followed by the deprotonation to give the hydroxyimino compound (C-IV).

C–N Bond Formation of the Enolate of Acetone with Methyl Nitrite *via* an "Open-Chain" TS The optimized bond parameters (Å) and the calculated energies of C-I, TS1 and C-II in paths A and B are shown in Fig. 1. Transformation from TS1 to C-II changed the structure of $[CH_3COCH_2]^-$ moiety from the enol- to the keto-form, and the *trans*-form of methyl nitrite moiety changed into the *cis*-form. The conformation of C-II-A already clearly shows the completion of the formation of **3***E*.

In order to prepare the following elimination, Na^+ was added to C-II, and the structure of C-II$_{Na}$ was optimized. The optimized geometrical parameters and the calculated ener-

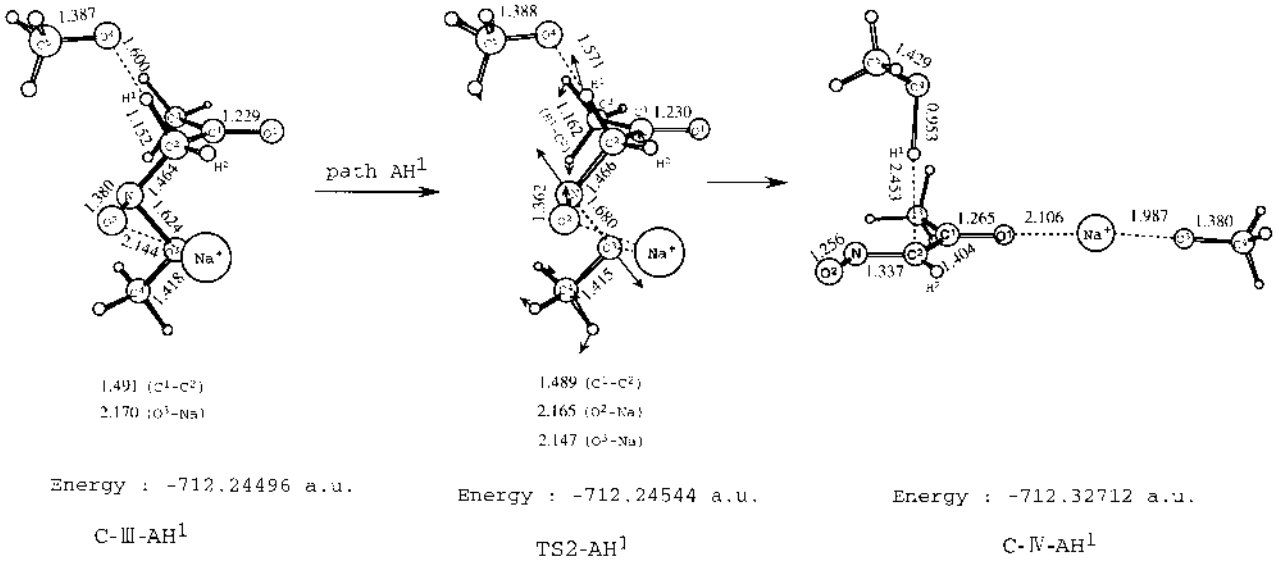

Fig. 3. Elimination Process of Nitrosation

Imaginary frequency mode is shown with bold arrows in the structure of the TS.

gies of C-II_{Na}-A and -B are shown in Fig. 2.

In the structures of C-II_{Na}-A and -B, two leaving groups, CH_3O^3 and H^1, are nearly antiperiplanar to one another. These conformations indicate that the elimination of these groups takes place easily. The structure of C-II_{Na}-B is the mirror image of that of C-II-A in path A described in the previous paper.[2)]

Elimination of Proton and Methoxide in C-II_{Na}-A with a Base When the reaction proceeds *via* path B, **3***Z* is obtained, because the elimination process *via* path B is the same as that *via* path H^1 in the previous paper.[2)] Therefore, only the reaction mechanism in path AH^1, shown in Fig. 3, was investigated in this elimination process.

The geometry of TS2-AH^1 was first determined, and those of C-III-AH^1 and C-IV-AH^1 were obtained from the TS2-AH^1 using the IRC method similar to that described above. The optimized bond parameters(Å) and the calculated energies of C-III-AH^1, TS2-AH^1 and C-IV-AH^1 are given in Fig. 3. In this process the reaction proceeds without an energy barrier to give **3***E* easily.

Concluding Remarks When the energy of the complex is increased to enable passing over the activation energy barrier for the TS in the C–N bond formation process, the elimination occurs readily and the final hydroxyimino compound is formed. It can be concluded that not only *Z*- but also *E*-form is obtained when the nitrosation proceeds *via* the "open-chain" TS without Na^+ in the C–N bond formation process.

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References and Notes

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4) *a*) In the MO calculation the *trans*-form of methyl nitrite was used, although the *cis*-form of methyl nitrite is slightly more stable than its *trans*-form, because we carried out our nitrosation experiments with *tert*-butyl nitrite (*trans*-form).; *b*) Pawar D., Mark H. L., Hosseini H., Harris Y., Noe E. A., *J. Phys. Chem*., **97**, 7480—7483 (1993).