

Electrospray Ionization Mass Spectrometric Observation of the Coordinative Interaction of α,β -Unsaturated Ketones with Cerium(III) Cation

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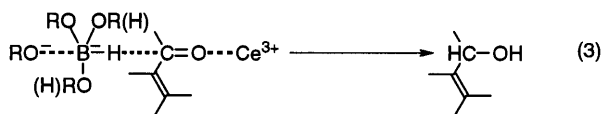
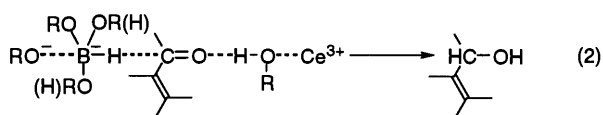
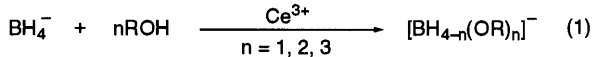
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The coordinative interaction of carbonyl oxygen of α,β -unsaturated ketones with the cerium(III) cation is observed by electrospray ionization mass spectrometry.

In 1978, Luche et al. reported that, in the presence of cerium chloride, α,β -unsaturated ketones are regioselectively reduced by sodium borohydride in methanol to give homoallylic alcohols in high yield.^{1,2} This selective 1,2-reduction of α,β -unsaturated ketones has become an extremely useful synthetic method because of the high regioselectivity, simple procedure, use of inexpensive reagents, and broad applicability.^{3,4}

The role of cerium(III) chloride in this regioselective reduction was investigated by Gemal and Luche.⁵ They proposed that the cerium(III) cation can both catalyze the methanolysis of the BH_4^- anion (Eq. 1) and activate the carbonyl group. The latter effect involves a hydrogen bonding interaction of the carbonyl oxygen with alcohol that coordinates to the cerium(III) cation (Eq. 2). We consider, however, the carbonyl group can be activated by the direct coordinative interaction with cerium ion (Eq. 3).



In our continuing study on the structure and reactivity relationships of rare earth complexes,⁶⁻⁸ we have investigated the activation process of the $\text{NaBH}_4/\text{CeCl}_3$ reduction of α,β -unsaturated ketones using electrospray ionization mass spectrometry (ESI-MS). ESI-MS has become a powerful tool for the identification of organic and organometallic reaction intermediates.⁹ This method is particularly useful for structural analyses in solution.^{10,11} Here we wish to report an evidence of the direct interaction of α,β -unsaturated ketone with the cerium(III) cation.

We chose 2-cyclopentenone as a model compound, because this substrate gives an excellent level of 1,2-reduction in comparison with that in the absence of cerium(III) chloride.⁵ A solution of $\text{CeCl}_3 \cdot (\text{H}_2\text{O})_7$ (37.3 mg, 0.1 mmol) and 2-cyclopentenone (10 μL , 0.1 mmol) in dry methanol (100 mL)

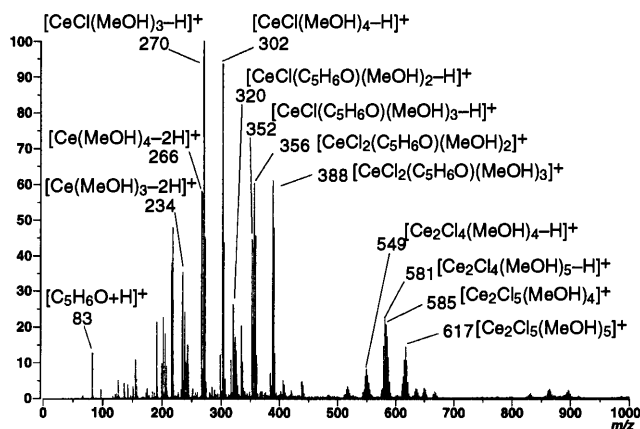


Figure 1. The ESI-MS spectrum of MeOH solution of $\text{CeCl}_3 \cdot (\text{H}_2\text{O})_7$ and 2-cyclopentenone.

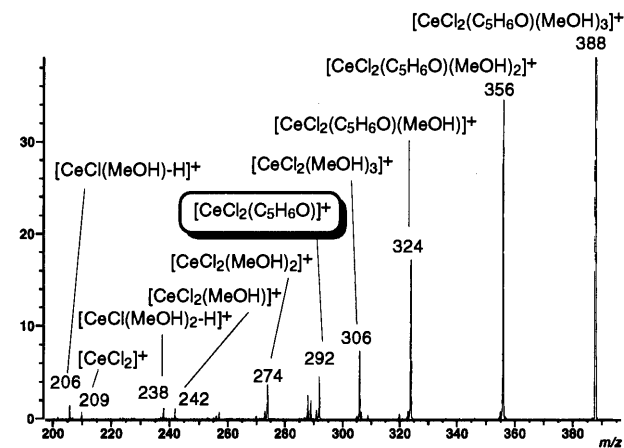


Figure 2. The MS/MS spectrum of $[\text{CeCl}_2(\text{C}_5\text{H}_6\text{O})(\text{MeOH})_3]^+$.

was prepared. This solution was introduced into ion source of the mass spectrometer by direct injection via a syringe pump. Figure 1 shows the measured ESI-MS spectrum.¹² The isotopic pattern of each peak was in good accordance with the calculated one. In order to assign the major ion peaks, each peak was subjected to tandem MS. A representative example (m/z 388) is given in Figure 2. Some of the observed peaks correspond to the fragments which were produced by dissociation of 2-cyclopentenone from the precursor ion. Thus, it is apparent that this precursor ion contains the 2-cyclopentenone. Especially, the observation of the fragment ion peak (m/z 292) corresponding to $[\text{CeCl}_2(\text{C}_5\text{H}_6\text{O})]^+$ shows that the 2-cyclopentenone coordinates directly to the cerium cation.

The regioselectivity of the $\text{NaBH}_4/\text{CeCl}_3$ reduction of α,β -unsaturated ketones is known to depend on the solvents.⁵ For

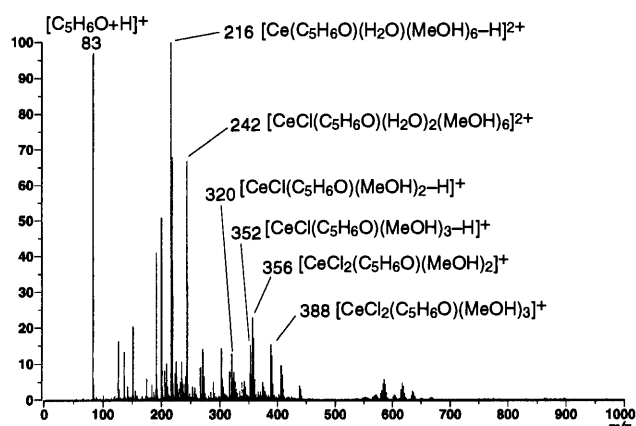
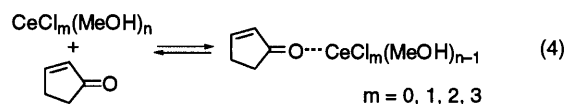


Figure 3. The ESI-MS spectrum of MeOH and H₂O (v/v=1) solution of CeCl₃·(H₂O)₇ and 2-cyclopentenone.

example, reduction of 2-cyclopentenone in methanol gives high 1,2-regioselectivity (97%), whereas the reduction in a mixture of methanol and water (v/v = 1) affords moderate 1,2-regioselectivity (50%). In order to reveal the nature of species existing in this mixed solvent, we measured the ESI-MS for the methanol and water (v/v = 1) solution of CeCl₃·(H₂O)₇ and 2-cyclopentenone (Figure 3). The several peaks of the complexes which methanol and cyclopentenone coordinated to cerium cation were also observed in this solvent system. On the contrary to our expectation, the peaks corresponding to the complexes containing several water molecules were not observed. However, the peaks of the complexes containing only cerium chloride and methanol, which were observed in the methanol solution, were scarcely detected. In these conditions divalent ion peaks such as *m/z* 216 or *m/z* 242 were observed instead. The ion *m/z* 83 arising from 2-cyclopentenone appeared as a prominent ion peak in this solvent, while the same peak was quite weak in methanol. The peak intensity of 2-cyclopentenone increased with increasing content of water, and this tendency was confirmed by ESI-MS measurement for the solution at several ratios of methanol to water. These results show that the presence of the excessive water increases the relative concentration of free 2-cyclopentenone. A similar tendency was also confirmed by the use of 2-cyclohexenone. It is concluded from these data that the increase of the content of uncoordinated α,β -unsaturated ketone is responsible for the lower regio-

lectivity of the 1,2-reduction.

In summary, we have obtained an evidence of direct coordinative interaction of α,β -unsaturated ketones with cerium(III) cation by using ESI-MS (Eq. 4). This fact suggests that the coordination of carbonyl oxygen to cerium(III) ion is responsible for the regioselective 1,2-reduction of α,β -enones in the presence of CeCl₃.



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References and Notes

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- 12 The ESI measurement was carried out under the following conditions: acceleration voltage; 5 kV, resolution; 1000, needle voltage (current); 2.0–3.0 kV (500 to 2000 nA), cone voltage; 80–100 V, desolvation chamber temperature; 80 °C, sample flow; 7 mLh⁻¹ and sheath gas flow; 1.5 Lmin⁻¹ (JEOL, JMS-700T).