with $\alpha(^1L_b) = 41°$. Changing $\alpha(^1L_b)$ in steps of 5° from 0 to 40° led to the best fit with $\alpha = 15°$ for $\alpha(^1L_a) = 60°$ as well as 90°. The theoretical curve (Figure 3b) is calculated with $\alpha(^1L_b) = 15°$ and $\alpha(^1L_a) = 75°$. The overall good agreement with the experimental curve allows us to assign (+)-4 to the 6a*R*,6b*R*,12b*R*,12c*R* configuration, also found in the X-ray crystallographic study by Saigo et al.[6c,d]

In the corresponding calculation on **5** (6a*R*,6b*S*,12a*R*,12b*S*) we found a nodal line for the ^1L_a transition between $\alpha = 60°$ and $\alpha = 90°$. The n → π* transition gave a positive band with nearly correct intensity for all the combinations of $\alpha(^1L_b)$ and $\alpha(^1L_a)$ discussed above. With $\alpha(^1L_a) = 60°$, the ^1L_a couplet has the right sign with respect to the n → π* band but is too intense, but with $(^1L_a) = 90°$ the sign is reversed. The ^1L_b band has the same sign as the n → π* band expect with $\alpha(^1L_b) = 0°$, $\alpha(^1L_a) = 60°$. With use of $\alpha(^1L_b) = 15°$ and $\alpha(^1L_a) = 75°$, a rather good agreement was obtained for all transitions in the near UV region (Figure 4b). The influence of the benzene ^1B transitions does not seem to be important for $\lambda > 200$ nm.

Summing up, we propose the 6a*R*,6b*S*,12a*R*,12b*S* configuration for (+)-**5**, and the general agreement between experimental and calculated CD spectra for (+)-**4** and (+)-**5** indicates that the chosen directions for the transition moments are reasonable.

Finally, it might be pointed out that the calculations predict only one ^1L_b band, the short wavelength component of the ^1L_b couplet always being weak and cancelled by the neighboring bands of opposite sign.

As has been clearly shown by Collet[29] and also follows from our experience with the ^1L_a transition in **5**, the question of transition moment directions must be treated with great circumspection when using the coupled-oscillator method. Safer conclusions can be drawn when several transitions can be reproduced, like in the present case.

(29) Collet, A. *Tetrahedron* **1987**, *43*, 5725–5759.

Reactions of Carbonyl Compounds with Grignard Reagents in the Presence of Cerium Chloride

Tsuneo Imamoto,* Nobuyuki Takiyama, Kimikazu Nakamura, Toshihiko Hatajima, and Yasuo Kamiya

Contribution from the Department of Chemistry, Faculty of Science, Chiba University, Yayoi-cho, Chiba 260, Japan. Received November 4, 1988

Abstract: The addition of Grignard reagents to ketones is significantly enhanced by cerium chloride with remarkable suppression of side reactions, particularly enolization. Some esters, which are prone to side reactions, also react readily with Grignard reagents in the presence of cerium chloride to give normal reaction products in reasonable to high yields.

The Grignard reaction of carbonyl compounds to yield alcohols is undoubtedly one of the most fundamental and versatile reactions in all of organic chemistry and has wide-spread synthetic applications.[1] Nevertheless, it is also well recognized that the Grignard reaction is often accompanied by so-called abnormal reactions such as enolization, reduction, condensation, conjugate addition, and pinacol coupling. In some cases such abnormal reactions prevail over the "normal reaction" resulting in poor yields of desired products.

It is synthetically important to enhance the yields of normal reaction products and reduce the yields of abnormal products. Several research groups have devised procedures to suppress abnormal reactions by changing solvent[2] or using additives such as

$MgBr_2$,[3] $(n\text{-}C_4H_9)_4N^+Br^-$,[4] $LiClO_4$,[4] $(i\text{-}C_3H_7O)_3TiCl$,[5,6] or $(n\text{-}C_4H_9O)_3ZrCl$.[5] While these reported methods are effective in some cases, they are not always efficient and lack general applicability. For some years, we have been interested in this important problem and have worked to develop a new method which is highly effective in circumventing the abnormal reactions and also one which has broad synthetic applicability.

We previously observed that organocerium(III) reagents, generated by the reaction of organolithiums with cerium(III) halides, undergo efficient carbonyl addition, even though the substrates are susceptible to enolization or conjugate addition with

(1) For excellent reviews, see the following: (a) Kharasch, M. S.; Reinmuth, O. *Grignard Reactions of Nonmetallic Substances*; Prentice-Hall: New York, 1954. (b) Nützel, K. In *Methoden der Organishen Chemie*; (Houben-Weyl) Georg Thime Verlag: Stuttgart, 1973; Vol. XIII-2a, p 49. (c) Ashby, E. C. *Q. Rev., Chem. Soc.* **1967**, *21*, 259. (d) Thayer, J. S. *Adv. Organomet. Chem.* **1975**, *13*, 1. (e) Stowell, J. C. *Carbanion in Organic Synthesis*; Wiley: New York, 1979. (f) Negishi, E. *Organometallics in Organic Synthesis*; Wiley: New York, 1980; Vol. 1. (g) Lai, Y.-H. *Synthesis* **1981**, 585. (h) Wakefield, B. J. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, F. G. A., Abel, E. W., Eds.; Pergamon Press: Oxford, 1982, Vol. 7, Chapter 44.

(2) (a) Gocmen, M.; Soussan, G. *J. Organomet. Chem.* **1974**, *80*, 303. (b) Canonne, P.; Foscolos, G.; Caron, H.; Lemay, G. *Tetrahedron* **1982**, *38*, 3563.

(3) (a) Swain, C. G.; Boyles, H. B. *J. Am. Chem. Soc.* **1951**, *73*, 870. (b) McBee, E. T.; Pierce, O. R.; Higgins, J. F. *J. Am. Chem. Soc.* **1952**, *74*, 1736. (c) Chastrette, M.; Amouroux, R. *Bull. Soc. Chim. Fr.* **1970**, 4348.

(4) Chastrett, M.; Amouroux, R. *J. Chem. Soc., Chem. Commun.* **1970**, 470.

(5) (a) Weidmann, B.; Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1983**, *22*, 31. (b) Seebach, D.; Weidmann, B.; Widler, L. In *Modern Synthetic Methods*; Scheffold, R., Ed.; Verlag: Frankfurt, 1983; Vol. 3, pp 217–353 and references cited therein.

(6) Reetz, M. T. *Organotitanium Reagents in Organic Synthesis*; Springer-Verlag: Berlin, 1986 and references cited therein.

Table I. Reactions of 1,3-Diphenyl-2-propanone with Butylorganometallic Reagents in the Presence of Cerium Chloride

$$(PhCH_2)_2CO \xrightarrow{n\text{-}C_4H_9MgBr/CeCl_3} (PhCH_2)_2C(OH)C_4H_9\text{-}n$$
$$\mathbf{1} \qquad\qquad\qquad\qquad\qquad \mathbf{2}$$

entry	reagent	method	conditions[a]	% yield of **2**[b]
1	n-C$_4$H$_9$MgBr		THF	18–36
2	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	THF	98
3	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	B	THF	93
4[c]	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	THF	85
5	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:0.5)	A	THF	84
6	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:0.33)	A	THF	35
7	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:0.1)	A	THF	21
8	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	THF/ether (4:1)	91
9	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	ether	45
10	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	toluene/THF (4:1)	39
11	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	B	toluene/THF (4:1)	47
12	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	CH$_2$Cl$_2$/THF (4:1)	18
13	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	B	CH$_2$Cl$_2$/THF (4:1)	52
14	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	A	DME/THF (4:1)	12
15	n-C$_4$H$_9$MgBr/CeCl$_3$ (1:1)	B	DME/THF (4:1)	37
16	n-C$_4$H$_9$Li/CeCl$_3$ (1:1)	A	THF, -78 °C	96
17[d]	n-C$_4$H$_9$Li/CeCl$_3$ (1:1)	A	THF	trace[e]

[a] All reactions were carried out at 0 °C unless otherwise stated. [b] Isolated yield. [c] Commercially available anhydrous cerium chloride (Aldrich) was used without drying. [d] The cerium reagent prepared at -78 °C was warmed to room temperature and maintained at that temperature for 1 h. The reagent was then cooled to 0 °C and was allowed to react with 1,3-diphenyl-2-propanone. [e] 1,3-Diphenyl-2-propanol was isolated in 28% yield and the starting ketone was recovered in 50% yield.

simple organolithiums.[7,8] These observations prompted us to study the reactions of Grignard reagents with carbonyl compounds in the presence of cerium chloride. We now describe the detailed results of these reactions together with the mechanistic aspects as determined by this study.[9]

Results and Discussion

Reactions of 1,3-Diphenyl-2-propanone with Butylmagnesium Bromide in the Presence of Cerium(III) Chloride. In order to establish optimum reaction conditions, the effects of solvents and molar ratios of substrates were examined for the reaction of readily enolizable 1,3-diphenyl-2-propanone (**1**) with butylmagnesium bromide by employing the following two methods.

Method A. Butylmagnesium bromide is added to the suspension of cerium chloride in a solvent at 0 °C and the mixture is well stirred for 1.5 h at the same temperature. Then, 1,3-diphenyl-2-propanone is added to the mixture.

Method B. The Grignard reagent is added at 0 °C to the mixture of ketone and cerium chloride, which has previously been well stirred for 1 h at room temperature.

The obtained results are summarized in Table I. Entry 1 shows a reference experiment in which no cerium chloride was added. In this case the addition product **2** was produced in 18–36% yield and a large amount of **1** was recovered. The result is ascribed to the strong basicity of the Grignard reagent and the nature of

the ketone substrate **1**, which is prone to enolization in the presence of a base. The yield of the addition product was significantly improved by the use of cerium chloride. The reagent system (n-C$_4$H$_9$MgBr/CeCl$_3$) with a molar ratio of 1:1 afforded the addition product in almost quantitative yield (entry 2).[10] The reverse addition procedure (method B) also provided a satisfactory result (entry 3). The use of diminished amounts of cerium chloride decreased the yield of the product (entries 5 and 6); no catalytic activity of cerium chloride was observed (entry 7).

The choice of solvent is important for this reaction in both methods. Tetrahydrofuran (THF) or a mixed solvent of THF and ether provided high yields, while the reaction in ether alone resulted in lower yields. Toluene, dichloromethane, and 1,2-dimethoxyethane were found unsuitable, although some yield improvement was observed in method B.

It is noted that at this cerium chloride promoted Grignard addition can be carried out at 0 °C.[11] These mild reaction conditions are in contrast to those of organocerium reagents prepared from organolithiums. The reactions of organocerium reagents are usually carried out at low temperature, usually at -40 to -78 °C; at room temperature reagents such as butylcerium dichloride decompose, presumably through β-hydride elimination, generating low valent cerium species.[7] Therefore, such reactions with carbonyl compounds at elevated temperature give rise to secondary alcohols rather than addition products, as exemplified by entry 17.

Reactions of Ketones with Grignard Reagents/Cerium Chloride. On the basis of the cursory experiments described above, we examined the reactions of various ketones with Grignard reagents in the presence of cerium chloride in order to clarify the scope and limitation of the methodology. Our attention was focused on the addition reactions which are difficult to achieve by currently employed methods. Table II summarizes the results obtained by using the reagent system (RMgX/CeCl$_3$) together with those by using the Grignard reagents alone.

It should be emphasized that easily enolizable ketones were subjected to treatment with RMgX/CeCl$_3$ and remarkable suppression of enolization was observed. The reaction of 3,3-di-

(7) (a) Imamoto, T.; Kusumoto, T.; Tawarayama, Y.; Sugiura, Y.; Mita, T.; Hatanaka, Y.; Yokoyama, M. *J. Org. Chem.* **1984**, *49*, 3904. (b) Imamoto, T.; Sugiura, Y.; Takiyama, N. *Tetrahedron Lett.* **1984**, *25*, 4233. (c) Imamoto, T.; Kusumoto, T.; Yokoyama, M. *J. Chem. Soc., Chem. Commun.* **1982**, 1042. (d) Imamoto, T.; Kusumoto, T.; Sugiura, Y.; Suzuki, N.; Takiyama, N. *J. Chem. Soc. Jpn.* **1985**, 445. (e) Imamoto, T.; Sugiura, Y. *J. Organomet. Chem.* **1985**, *285*, C21. (f) Imamoto, T.; Sugiura, Y. *J. Phy. Org. Chem.* In press.
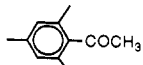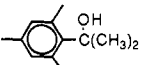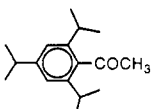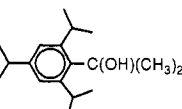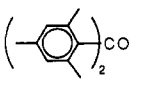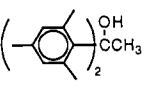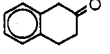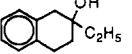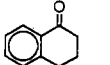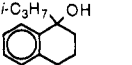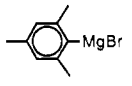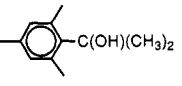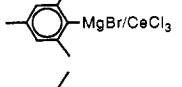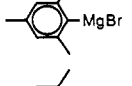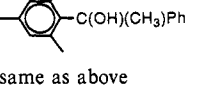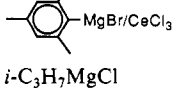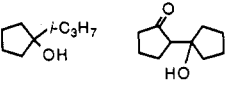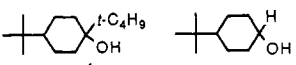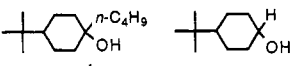
(8) Other research groups have recently employed organocerium reagents for the preparation of key intermediates to biologically active compounds. (a) Suzuki, M.; Kimura, Y.; Terashima, S. *Chem. Lett.* **1984**, 1543. (b) Suzuki, K.; Ohkuma, T.; Tsuchihashi, G. *Tetrahedron Lett.* **1985**, *26*, 861. (c) Tamura, Y.; Sato, M.; Ohe, H.; Akai, A.; Kita, Y. *Tetrahedron Lett.* **1985**, *26*, 1549. (d) Nagasawa, K.; Kanbara, H.; Matsushita, K.; Ito, K. *Tetrahedron Lett.* **1985**, *26*, 6477. (e) Paquette, L. A.; Learn, K. S. *J. Am. Chem. Soc.* **1986**, *108*, 7873. (f) Paquette, L. A.; Learn, K. S.; Romine, J. L.; Lin, H.-S. *J. Am. Chem. Soc.* **1988**, *110*, 879. (g) Johnson, C. R.; Tait, B. D. *J. Org. Chem.* **1987**, *52*, 281. (h) Denmark, S. E.; Weber, T.; Piotrowski, *J. Am. Chem. Soc.* **1987**, *107*, 2224. (i) Guo, B. S.; Doubleday, W.; Cohen, T. *J. Am. Chem. Soc.* **1987**, *109*, 621. (j) Hart, D. J.; Huang, H.-C. *J. Am. Chem. Soc.* **1988**, *110*, 1634. (k) Corey, E. J.; Ha, D-C. *Tetrahedron Lett.* **1988**, *29*, 3171. (l) Robson, J. N.; Rowland, S. *J. Tetrahedron Lett.* **1988**, *29*, 3837.

(9) Preliminary report: Imamoto, T.; Takiyama, N.; Nakamura, K. *Tetrahedron Lett.* **1985**, *26*, 4763.

(10) The reaction using lanthanum chloride, neodymium chloride, or praseodymium chloride in place of cerium chloride provided the addition product in 80, 98, or 95% yield, respectively. Cerium chloride is recommended for use for economical reasons as cerium is one of the least expensive rare earth elements.
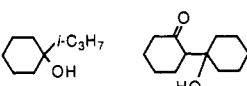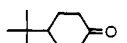
(11) The reaction of vinylic Grignard reagents by method A was carried out at -78 °C (*vide infra*), because the vinylic Grignard reagents rapidly decomposed on contact with cerium chloride at 0 °C.

Table II. Reactions of Carbonyl Compounds with Grignard Reagents in the Presence of Cerium Chloride or with Grignard Reagents Alone[a]

entry	carbonyl compound	reagent	method	product(s)	% yield[b]
1	$(C_2H_5)_3CCOCH_3$	CH_3MgBr		$(C_2H_5)_3CC(OH)(CH_3)_2$	0
2	$(C_2H_5)_3CCOCH_3$	$CH_3MgBr/CeCl_3$	A	$(C_2H_5)_3CC(OH)(CH_3)_2$	95
3	$(C_2H_5)_3CCOCH_3$	$C_2H_5MgCl/CeCl_3$	A	$(C_2H_5)_3CC(OH)(CH_3)C_2H_5$	16
4	$(C_2H_5)_3CCOCH_3$	$C_2H_5MgBr/CeCl_3$	A	$(C_2H_5)_3CC(OH)(CH_3)C_2H_5$	5
5	$(C_2H_5)_3CCOCH_3$	$i\text{-}C_3H_7MgCl/CeCl_3$	A	$(C_2H_5)_3CC(OH)(CH_3)(i\text{-}C_3H_7)$	trace
6	$(C_2H_5)_3CCOCH_3$	$i\text{-}C_3H_7MgCl/CeCl_3$	B	$(C_2H_5)_3CC(OH)(CH_3)(i\text{-}C_3H_7)$	trace
7	[structure: trimethylphenyl–COCH₃]	CH_3MgBr		[structure: trimethylphenyl–C(CH₃)₂ with OH]	trace
8	same as above	$CH_3MgBr/CeCl_3$	A	same as above	47
9	[structure: triisopropylphenyl–COCH₃]	$CH_3MgBr/CeCl_3$	A	[structure: triisopropylphenyl–C(OH)(CH₃)₂]	0
10	same as above	$CH_3MgBr/CeCl_3$	B	same as above	0
11	[structure: (tetramethylphenyl–CO)₂]	$CH_3MgBr/CeCl_3$	B	[structure: (tetramethylphenyl–CCH₃ with OH)₂]	0
12	[structure: 2-tetralone]	C_2H_5MgCl		[structure: 2-tetralol with OH, C₂H₅]	8
13	same as above	$C_2H_5MgCl/CeCl_3$	A	same as above	76
14	same as above	$C_2H_5MgI/CeCl_3$	A	same as above	39
15	[structure: 1-tetralone]	$i\text{-}C_3H_7MgCl$		[structure: 1-tetralol, i-C₃H₇, OH]	15
16	same as above	$i\text{-}C_3H_7MgCl/CeCl_3$	A	same as above	73
17	[structure: 2-cyclopentenone]	$PhMgBr$		[structure: cyclopentenyl, Ph, OH]	47
18	same as above	$PhMgBr/CeCl_3$	A	same as above	93
19	$(CH_3)_2CO$	[structure: aryl–MgBr]		[structure: aryl–C(OH)(CH₃)₂]	22
20	same as above	[structure: aryl–MgBr/CeCl₃]	A	same as above	57
21	$PhCOCH_3$	[structure: aryl–MgBr]		[structure: aryl–C(OH)(CH₃)Ph]	5
22	same as above	[structure: aryl–MgBr/CeCl₃]	A	same as above	73
23	[structure: cyclopentanone]	$i\text{-}C_3H_7MgCl$		[structures: cyclopentanol with i-C₃H₇, OH; and acyl cyclopentane with HO]	3,[c] 80
24	same as above	$i\text{-}C_3H_7MgCl/CeCl_3$	B	same as above	72, trace
25	[structure: cyclohexanone]	$i\text{-}C_3H_7MgCl$		[structures: cyclohexanol with i-C₃H₇, OH; and acyl cyclohexane with HO]	30, 35
26	same as above	$i\text{-}C_3H_7MgCl/CeCl_3$	A	same as above	80, 0
27	$(i\text{-}C_3H_7)_2CO$	$i\text{-}C_3H_7MgCl$		$(i\text{-}C_3H_7)_3C(OH)$ $(i\text{-}C_3H_7)_2CHOH$	3, 58
28	$(i\text{-}C_3H_7)_2CO$	$i\text{-}C_3H_7MgCl/CeCl_3$	A	$(i\text{-}C_3H_7)_3C(OH)$ $(i\text{-}C_3H_7)_2CHOH$	52, 31
29	[structure: 4-tert-butylcyclohexanone]	$t\text{-}C_4H_9MgCl$		[structures: t-C₄H₉/OH and H/OH cyclohexanols]	38,[d] 40
30	same as above	$t\text{-}C_4H_9MgCl/CeCl_3$	A	same as above	89,[e] 10
31	same as above	$n\text{-}C_4H_9MgBr$		[structures: n-C₄H₉/OH and H/OH cyclohexanols]	69,[f] 18
32	same as above	$n\text{-}C_4H_9MgBr/CeCl_3$	A	same as above	97,[g] 1
33	$(PhCH_2)_2CO$	$t\text{-}C_4H_9MgCl$		$(PhCH_2)_2C(OH)C_4H_9\text{-}t$	trace
34	$(PhCH_2)_2CO$	$t\text{-}C_4H_9MgCl/CeCl_3$	A	$(PhCH_2)_2C(OH)C_4H_9\text{-}t$	67
35	$PhCOCH_2Br$	$CH_2{=}CHMgBr$		$PhC(OH)(CH_2Br)CH{=}CH_2$	66
36[h]	$PhCOCH_2Br$	$CH_2{=}CHMgBr/CeCl_3$	A	$PhC(OH)(CH_2Br)CH{=}CH_2$	95

[a] All reactions were carried out in THF at 0 °C with a molar ratio of 1:1.5:1.5 (ketone/Grignard reagent/cerium chloride) unless otherwise stated. [b] Isolated yield. [c] This compound was previously prepared in 23% yield by slow addition of cyclopentanone to four molar excess of $i\text{-}C_3H_7MgBr$. Skinner, G. S.; Florentine, F. P., Jr. *J. Am. Chem. Soc.* **1954**, *76*, 3200. [d] axial alcohol:equatorial alcohol = 92:8. [e] ax.:eq = 84:16. [f] ax.:eq = 72:28. [g] ax.:eq = 69:31. [h] The reaction was carried out at −78 °C.

ethyl-2-pentanone with methylmagnesium bromide is a typical example. The reaction without cerium chloride afforded no trace of the addition product, 3,3-diethyl-2-methyl-2-pentanol: enolization occurred almost exclusively.[12] In sharp contrast, the reaction in the presence of cerium chloride provided the adduct in 95% yield. Similarly, readily enolizable ketones such as 2,4,6-trimethylacetophenone, 1,3-diphenyl-2-propanone, β-tetralone, α-tetralone, and 3-cyclopentenone reacted with various Grignard reagents in the presence of cerium chloride to give the corresponding tertiary alcohols in satisfactory yields. The reaction of a bulky Grignard reagent, (2,4,6-trimethylphenyl)magnesium bromide, with acetone or acetophenone was also promoted by cerium chloride.

Another prominent feature of this method is the suppression of aldol condensation. The reaction of cyclopentanone with isopropylmagnesium chloride is known to provide the aldol as the major product rather than the addition product.[1] In contrast to the conventional method, our method provided the addition product in good yield. A similar result was also obtained in the reaction of cyclohexanone with isopropylmagnesium chloride.

It should be noted that the reduction of carbonyl compounds with the Grignard reagents having β-hydrogens is suppressed by this method. An example is described of the reaction of 2,4-dimethyl-3-pentanone with i-C_3H_7MgCl. The reaction in the absence of cerium chloride afforded the reduction product and addition product in 58% and 3% yields, respectively.[13] In contrast, a complete reversal of product ratio was achieved when cerium chloride was used. Other striking examples as shown in the reaction of *tert*-butyl Grignard reagent with ketones. Contrary to the general recognition that the *tert*-butyl Grignard reagent acts as a good reducing reagent rather than a nucleophile,[14,15] the cerium chloride reagent system provides for facile nucleophile attack of the *t*-butyl group to ketones (entries 30 and 34).

It may be worthy of mention that the reaction of phenacyl bromide with CH_2=$CHMgBr/CeCl_3$ proceeded smoothly to give the expected adduct in 95% yield. The result is compared with that obtained without cerium chloride in which accompanying side reactions such as reduction, enolization, and S_N2 displacement reaction are expected to occur.[16]

Our interests in the application of this methodology to practical organic synthesis, particularly to the efficient preparation of key intermediates to natural products, led to the preliminary trials shown below. We interpret the results as indicating that the present method is advantageous over the previously reported method.[17-19] The number of examples is limited, but we believe that this method will be successfully applicable to many other cases.

Reactions of α-Enones with RMgX/CeCl₃. The reaction of Grignard reagents with α-enones is an important method of synthesizing allyl alcohols and is frequently employed in organic syntheses.[1] The reaction, however, is often accompanied by undesirable 1,4-addition which may dominate 1,2-addition in some cases, particularly in the reactions of α-enones conjugated with an aromatic group.[21] We believed that our method using cerium chloride was capable of retarding 1,4-addition. The idea behind the following experiments was based on the previously reported facts that α-enones are regioselectively reduced with $NaBH_4$/$CeCl_3$ to yield allyl alcohols[22] and that some organolanthanoid
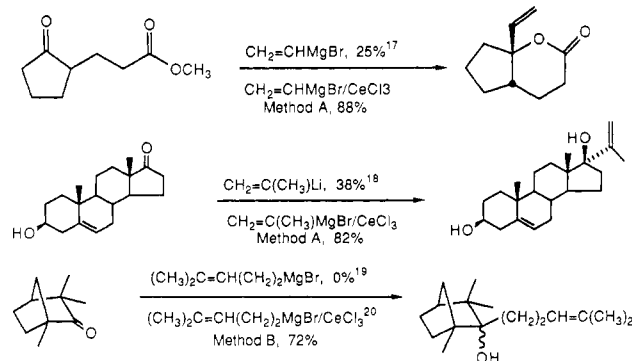
reagents react with α-enones in high 1,2-selectivity.[23]

Our initial trial was undertaken with the reaction of 1,3-diphenyl-2-propen-1-one with the phenyl Grignard reagent. The results are shown in Table III. The reaction without cerium chloride afforded the 1,4-adduct as the major product (entry 1), as is well described in earlier literature.[1] The yield of the 1,2-adduct was increased by the addition of cerium chloride; the reagent system with a molar ratio of 1:1 afforded the 1,2- and 1,4-adducts in 58% and 33% yield, respectively (entry 2), and the use of a large excess of cerium chloride enhanced the 1,2-selectivity (entries 3 and 4). It is noted that the reverse addition of the Grignard reagent provided almost the same result (entry 4). The effect of temperature is also worth noting. Higher 1,2-selectivity was observed at elevated temperature (0–40 °C) than at low temperature (–78 °C).

Several other α-enones were studied under similar conditions in order to establish the scope of the method. The results are shown in Table III. Most of the reactions in the presence of cerium chloride gave rise to 1,2-adducts in higher yields than those of the Grignard reagents alone. The 1,2-selectivities of $RMgX/CeCl_3$ can be compared advantageously with those of organolithium reagents (entries 9, 10, 15, 16, and 25), but they are slightly lower than those of organocerium reagents (entries 11, 17, and 26).[24] It is also noted that no remarkable effect of cerium chloride was observed in the reactions of isopropylmagnesium chloride with 1,3-diphenyl-2-propen-1-one or 4-phenyl-3-buten-2-one. These limitations are probably ascribed to steric effects.

This method, although it is not completely general, offers a tool for the preparation of allyl alcohols by selective 1,2-addition to α-enones.

Reactions of Esters, Amides, and Nitriles with RMgX/CeCl₃. The reactivities of $RMgX/CeCl_3$ toward esters, amides, and nitriles were examined with several model substrates which are prone to abnormal reactions. Some representative results are summarized in Table IV.

It is well known that the reaction of esters with 2 molar equiv of the Grignard reagent yields tertiary alcohols. In special cases, however, abnormal reactions prevail over the normal addition reaction. Typically, methyl phenylacetate, when treated with i-C_3H_7MgCl, is converted to the Claisen condensation product in 71% yield. We found that this reaction course was dramatically changed by the use of cerium chloride. Thus, the reaction in the presence of cerium chloride proceeded smoothly to give 3-benzyl-2,4-dimethyl-3-pentanol in almost quantitative yield.

The reactions of esters with vinyl Grignard reagent are reported to afford mixtures of products.[25] A major product frequently results from conjugate addition of a second mole of the Grignard reagent to the initially formed vinyl ketone. In contrast, the

(12) Whitmore, F. C.; Lewis, C. E. *J. Am. Chem. Soc.* **1942**, *64*, 2964.
(13) Whitmore, F. C.; George, R. S. *J. Am. Chem. Soc.* **1942**, *64*, 1239.
(14) General review: Morrison, J. D.; Mosher, H. S. In *Asymmetric Organic Reactions*; Prentice Hall: New York, 1971; pp 177–202.
(15) A recent report dealing with reduction of carbonyl compounds with *tert*-butyl Grignard reagent: Maruoka, K.; Itoh, T.; Sakurai, M.; Nonoshita, K.; Yamamoto, H. *J. Am. Chem. Soc.* **1988**, *110*, 3588.
(16) Reference 1a; pp 181–196.
(17) Kinney, W. A.; Coghlan, M. J.; Paquette, L. A. *J. Am. Chem. Soc.* **1985**, *107*, 7352.
(18) Loughead, D. G. *J. Org. Chem.* **1985**, *50*, 3931.
(19) A similar result was reported by Buchbauer. Buchbauer, G. *Tetrahedron Lett.* **1977**, 7.
(20) A molar ratio of 1:2:3 ketone/Grignard reagent/CeCl₃ was employed.
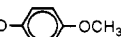(21) Sjöholm, R.; Stahlström, V. *Finn. Chem. Lett.* **1982**, 46.
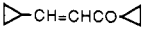
(22) Gemal, A. L.; Luche, J.-L. *J. Am. Chem. Soc.* **1981**, *103*, 5454 and references cited therein.
(23) (a) Yokoo, K.; Yamanaka, Y.; Fukagawa, T.; Taniguchi, H.; Fujiwara, Y. *Chem. Lett.* **1983**, 1301. (b) Sigalov, A. B.; Petrov, E. S.; Rybakova, L. F.; Beletskaya, I. P. *Izv. Akad. Nauk. SSSR, Ser. Khim.* **1983**, 2615. (c) Schumann, H.; Müller, J.; Bruncks, N.; Lauke, H.; Pickardt, J. *Organometallics* **1984**, *3*, 69.
(24) For selective 1,2-addition of organocerium reagents to α-enones, see ref 7e,f.
(25) Watanbe, S.; Suga, K.; Fujita, T.; Saito, N. *Aust. J. Chem.* **1977**, *30*, 427.

Table III. Reactions of α,β-Unsaturated Ketones with Grignard Reagents in the Presence of Cerium Chloride or with Grignard Reagents Alone[a]

entry	α,β-enone	reagent	method	% yields of products[b]	
				1,2-adduct	1,4-adduct
1	PhCH=CHCOPh	PhMgBr		5	81
2	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1)	A	58	33
3[c]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	A	89	11
4[c]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	B	88	9
5[c,d]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	A	29	60
6[c,d]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	B	15	66
7[c,e]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	A	82	5
8[c,e]	PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1.7)	B	67	26
9[f,g]	PhCH=CHCOPh	PhLi		62	26
10[f,h]	PhCH=CHCOPh	PhLi		77	18
11[d,f]	PhCH=CHCOPh	PhLi/CeCl₃ (1:1)	A	95	2
12[f]	PhCH=CHCOPh	PhLi/CeCl₃ (1:1)	B	85	2
13	PhCH=CHCOPh	CH₃MgBr		52	41
14	PhCH=CHCOPh	CH₃MgBr/CeCl₃ (1:1)	A	92	6
15[i,j]	PhCH=CHCOPh	CH₃Li		54	22
16[i,k]	PhCH=CHCOPh	CH₃Li		62	27
17[l]	PhCH=CHCOPh	CH₃Li/CeCl₃ (1:1)	A	97	1
18	PhCH=CHCOPh	i-C₃H₇MgCl		32	59
19	PhCH=CHCOPh	i-C₃H₇MgCl/CeCl₃ (1:1)	A	35	53
20	PhCH=CHCOPh	i-C₃H₇MgCl/CeCl₃ (1:1)	B	37	53
21	(Z)-PhCH=CHCOPh	PhMgBr		15[l]	83
22	(Z)-PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1)	A	67[m]	19
23	PhCH=CHCO-⟨⟩-OCH₃	PhMgBr		35	62
24	(Z)-PhCH=CHCOPh	PhMgBr/CeCl₃ (1:1)	A	90	10
25[d,n]	(Z)-PhCH=CHCOPh	PhLi		85	10
26[d,o]	(Z)-PhCH=CHCOPh	PhLi/CeCl₃ (1:1)	A	90	4
27	PhCH=CHCOCH₃	n-C₄H₉MgBr		21	69
28	PhCH=CHCOCH₃	n-C₄H₉MgBr/CeCl₃ (1:1)	A	78	6
29	PhCH=CHCOCH₃	i-C₃H₇MgCl		41	40
30	PhCH=CHCOCH₃	i-C₃H₇MgCl/CeCl₃ (1:1)	A	46	24
31	PhCH=CHCOCH₃	i-C₃H₇MgCl/CeCl₃ (1:1)	B	51	27
32[d,p]	PhCH=CHCOCH₃	i-C₃H₇Li/CeCl₃ (1:1)	A	49	29
33	PhCH=CHCO-◁	PhMgBr		35	62
34	PhCH=CHCOCH₃	PhMgBr/CeCl₃ (1:1)	A	90	10
35	▷-CH=CHCO◁	PhMgBr		21	52
36	PhCH=CHCOCH₃	PhMgBr/CeCl₃ (1:1)	A	78	0
37	⬡=O	PhMgBr		41	33
38	PhCH=CHCOCH₃	PhMgBr/CeCl₃ (1:1)	A	85	11
39	PhCH=CHCOCH₃	i-C₃H₇MgCl		12	53
40	PhCH=CHCOCH₃	i-C₃H₇MgCl/CeCl₃ (1:1)	A	91	5

[a] All reactions were carried out in THF at 0 °C with a molar ratio of 1:1.5:1.5 (ketone/Grignard reagent/cerium chloride) unless otherwise stated. [b] Isolated yield. [c] Molar ratio of 1:1.5:2.5 (ketone/Grignard reagent/CeCl₃). [d] The reaction was carried out at -78 °C. [e] At 40 °C. [f] In THF/ cyclohexane/ether (18:2.4:1). [g] Phenyllithium was added to the solution of PhCH=CHCOPh in THF. [h] The ketone was added to the solution of phenyllithium. [i] In THF/ether (6:1). [j] Methyllithium was added to the solution of PhCH=CHCOPh in THF. [k] The ketone was added to the solution of methyllithium. [l] Z-Isomer (9%) and E isomer (6%). [m] Z Isomer (61%) and E isomer (6%). [n] In THF/ether (3:1). [o] In THF/ether (8:1). [p] In THF/pentane (6:1).

reaction in the presence of cerium chloride proceeded with the suppression of the conjugate addition to yield a tertiary allyl alcohol as the major product.

The reaction of amides with Grignard reagents was also accelerated by cerium chloride and the expected ketones and/or tertiary alcohols were obtained in satisfactory yields.

The reactions of phenylacetonitrile with Grignard reagents in the presence of cerium chloride may be worth mentioning. The reaction with Grignard reagents alone underwent exclusive proton abstraction, and the starting phenylacetonitrile was recovered quantitatively after quenching. In contrast, nucleophilic addition reactions proceeded in the presence of cerium chloride, although the yields of the products were only moderate.

Mechanistic Aspect of Carbonyl Addition with RMgX/CeCl₃. Cerium chloride has strong oxophilicity, and is capable of activating carbonyl components by coordination.[26,27] This activation

may be the most important driving force for cerium chloride promoted carbonyl additions. Another important factor may be the strong basicity of Grignard reagents is weakened by mixing with cerium chloride.

Grignard reactions of α-enones are thought to proceed through a single-electron-transfer (SET) pathway.[28] We examined the reaction of 4,4-(ethylenedioxy)-2,6-dimethyl-2,5-cyclohexadienone (3) which was proposed by Liotta et al. as a useful probe for detecting SET processes.[29] Methyl, butyl, and isopropyl Grignard

(26) For discussions of the coordination properties of lanthanoids, see: (a) Rueben, J. In *Handbook on the Physics and Chemistry of Rare Earths*; Gschneider, K. A., Jr., Eyring, L., Eds.; North-Holland: Amsterdam, 1979; Vol. 4, pp 515–552. (b) Moeller, T. In *Comprehensive Inorganic Chemistry*; Bailar, J. C., Emeléus, H. J., Nyholm, R. Eds.; Pergamon Press: Oxford, 1973, Vol. 4, pp 1–101.

(27) For representative reviews dealing with organic reactions with lanthanoids, see: (a) Kagan, H. B.; Namy, J. L. *Tetrahedron* **1986**, *42*, 6573. (b) Marks, T. J.; Ernst, F. D. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, G.; Abel, F. G. A. Eds.; Pergamon Press: Oxford, 1982; Vol. 3, p 173. (c) Schumann, H. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 474. (d) Evans, W. J. *Polyhedron* **1987**, *6*, 803. (e) Natale, N. R. *Org. Prep. Proc. Int.* **1983**, *15*, 389. (f) Long, J. R. *Aldrichimica Acta* **1985**, *18*, 87. (g) Imamoto, T. *J. Syn. Org. Chem. Jpn.* **1988**, *46*, 540.

(28) For representative reviews on mechanistic studies on the Grignard reaction of carbonyl compounds, see: (a) Ashby, E. C.; Laemmle, J. T.; Newmann, H. M. *Acc. Chem. Res.* **1974**, *2*, 272. (b) Griller, D.; Ingold, K. U. *Acc. Chem. Res.* **1980**, *13*, 317. (c) Dagonneau, M. M. *Bull. Soc. Chim. Fr.* **1982**, *II*, 269. (d) Ashby, E. C.; Laemmle, J. T. *Chem. Rev.* **1975**, *75*, 521. (e) Ashby, E. C. *Pure Appl. Chem.* **1980**, *52*, 545. (f) Okubo, M.; Maruyama, K. *Kagaku (Kyoto)*, **1980**, *35*, 338, 467.

Table IV. Reactions of Esters, Amides, and Nitriles with Grignard Reagents in the Presence of Cerium Chloride or Grignard Reagents Alone[a]

| entry	substrate	reagent	method	product	% yield[b,c]
1[d]	$PhCH_2CO_2CH_3$	$i\text{-}C_3H_7MgCl$		$PhCH_2COCH(Ph)CO_2CH_3$	71 (10)
				$PhCH_2COC_3H_7\text{-}i$	19
				$PhCH_2C(OH)(C_3H_7\text{-}i)_2$	0
2[e]	$PhCH_2CO_2CH_3$	$i\text{-}C_3H_7MgCl/CeCl_3$	A	$PhCH_2COCH(Ph)CO_2CH_3$	0
				$PhCH_2COC_3H_7\text{-}i$	0
				$PhCH_2C(OH)(C_3H_7\text{-}i)_2$	97
3[e]	$PhCH_2CO_2CH_3$	$i\text{-}C_3H_7MgCl/CeCl_3$	B	$PhCH_2COCH(Ph)CO_2CH_3$	0
				$PhCH_2COC_3H_2\text{-}i$	0
				$PhCH_2C(OH)(C_3H_7\text{-}i)_2$	96
4[d]	$t\text{-}C_4H_9CO_2C_2H_5$	$i\text{-}C_3H_7MgCl$		$t\text{-}C_4H_9COC_3H_7\text{-}i$	trace (>95)
				$t\text{-}C_4H_9CHOHC_3H_7\text{-}i$	trace
5[e]	$t\text{-}C_4H_9CO_2C_2H_5$	$i\text{-}C_3H_7MgCl/CeCl_3$	A	$t\text{-}C_4H_9COC_3H_7\text{-}i$	15
				$t\text{-}C_4H_9CHOHC_3H_7\text{-}i$	61
6[d]	$PhCO_2CH_3$	$CH_2{=}CHMgBr$		complex mixture	
7[e]	$PhCO_2CH_3$	$CH_2{=}CHMgBr/CeCl_3$	B	$PhC(OH)(CH{=}CH_2)_2$	35 (28)
8[d]	$PhCH{=}CHCO_2C_2H_5$	$CH_2{=}CHMgBr$		$PhCH{=}CHC(OH)(CH{=}CH_2)_2$	24
				$PhCH{=}CHCO(CH_2)_2CH{=}CH_2$	39
9[e]	$PhCH{=}CHCO_2C_2H_5$	$CH_2{=}CHMgBr/CeCl_3$	B	$PhCH{=}CHC(OH)(CH{=}CH_2)_2$	68
				$PhCH{=}CHCO(CH_2)_2CH{=}CH_2$	9
10[f]	$PhCH_2CON(CH_3)_2$	$n\text{-}C_4H_9MgBr$		$PhCH_2COC_4H_9\text{-}n$	8 (82)
11[g]	$PhCH_2CON(CH_3)_2$	$n\text{-}C_4H_9MgBr/CeCl_3$	B	$PhCH_2COC_4H_9\text{-}n$	66 (32)
12[f]	$PhCH_2CON(CH_3)_2$	$CH_2{=}C(CH_3)MgBr$		$PhCH_2COC(CH_3){=}CH_2$	51
13[g]	$PhCH_2CON(CH_3)_2$	$CH_2{=}C(CH_3)MgBr/CeCl_3$	B	$PhCH_2COC(CH_3){=}CH_2$	49
				$PhCH_2C(OH)\{C(CH_3){=}CH_2\}_2$	43
				$PhCH_2COCH(CH_3)CH_2C(CH_3){=}CH_2$	8
14[f]	$PhCH_2CN$	$n\text{-}C_4H_9MgBr$		$PhCH_2COC_4H_9\text{-}n$	0 (100)
15[h]	$PhCH_2CN$	$n\text{-}C_4H_9MgBr/CeCl_3$	A	$PhCH_2COC_4H_9\text{-}n$	24 (76)
16[h]	$PhCH_2CN$	$n\text{-}C_4H_9MgBr/CeCl_3$	B	$PhCH_2COC_4H_9\text{-}n$	28 (72)
17[f]	$PhCH_2CN$	$CH_2{=}C(CH_3)MgBr$		$PhCH_2COC(CH_3){=}CH_2$	0 (100)
18[h]	$PhCH_2CN$	$CH_2{=}C(CH_3)MgBr/CeCl_3$	B	$PhCH_2COCH(CH_3)CH_2C(CH_3){=}CH_2$	22 (ca. 60)

[a] All reactions were carried out at 0 °C in THF. [b] Isolated yield. [c] The figures in parentheses indicate the yields of recovered starting material. [d] Molar ratio: ester/Grignard reagent = 1:3. [e] Molar ratio: ester/Grignard reagent/$CeCl_3$ = 1:3:3. [f] Molar ratio: amide or nitrile/Grignard reagent = 1:1.5. [g] Molar ratio of amide/Grignard reagent/$CeCl_3$ = 1:3:3. [h] Molar ratio of nitrile/Grignard reagent/$CeCl_3$ = 1:1.5:1.5.

Table V. Reactions of Ketone 3 with RMgX and RMgX/$CeCl_3$

reagent	method[a]	products (% yield)[b]		
		4	5	6
CH_3MgBr		95	5	0
$CH_3MgBr/CeCl_3$	A	98	2	0
$CH_3MgBr/CeCl_3$	B	96	4	0
$n\text{-}C_4H_9MgBr$		44	56	0
$n\text{-}C_4H_9MgBr/CeCl_3$	A	58	42	0
$n\text{-}C_4H_9MgBr/CeCl_3$	B	63	37	0
$i\text{-}C_3H_7MgCl$		0	42	58
$i\text{-}C_3H_7MgCl/CeCl_3$	A	0	41	59
$i\text{-}C_3H_7MgCl/CeCl_3$	B	0	38	62
$i\text{-}C_3H_7MgCl/CeCl_3$	B[c]	0	26	74

[a] All reactions in the presence of $CeCl_3$ were carried out in THF at 0 °C for 30 min with a molar ratio of 1:2:2 (3/Grignard reagent/$CeCl_3$). [b] The yields of products were determined by ^1H NMR (500 Mz). [c] At −78 °C.

reagents were treated with **3** at 0 °C in the presence of cerium chloride; at the same time the reactions of Grignard reagents alone were conducted under similar conditions for reference. The yields of products were determined from the 500-MHz NMR spectra of the crude reaction mixtures (Table V).
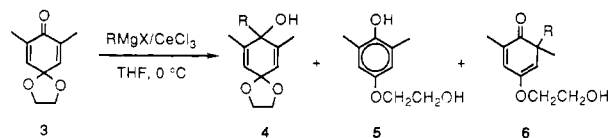
In the case of $CH_3MgBr/CeCl_3$ the addition product **4** was produced in high yield. A phenol derivative **5**, which is considered to form via a ketyl intermediate, was also produced although the yields were very poor. $n\text{-}C_4H_9MgBr/CeCl_3$ provided a substantial amount of **5** together with **4**. The reaction of $i\text{-}C_3H_7MgCl/CeCl_3$

afforded **6**[30] instead of **4**; a significant amount of **5** was also formed in this case. These results, which are almost the same as those obtained with the Grignard reagents alone,[31] suggest the operability of similar mechanisms in the reactions of RMgX- and RMgX/$CeCl_3$ and point to the SET process.

Summary

We have found that anhydrous cerium chloride significantly promotes addition reactions of Grignard reagents to carbonyl compounds with remarkable suppression of abnormal reactions. Various tertiary alcohols, which are difficult to prepare by the conventional Grignard reaction, can be synthesized by this method. This cerium chloride methodology has potential synthetic utility in its application to a variety of organic syntheses. Cerium chloride as its hydrate is readily available and is relatively inexpensive. The low toxicity[32] of cerium adds to the attraction of the present process.

Experimental Section

General Procedures. All experiments were carried out under an argon atmosphere. The products were isolated by preparative thin-layer chromatography on silica gel (Wakogel B-5F) or medium pressure liquid chromatography on silica gel (Wakogel C-300).

Microanalyses were performed at the Chemical Analysis Center of Chiba University.

Materials. Lanthanoid chloride ($LaCl_3{\cdot}7H_2O$, $CeCl_3{\cdot}7H_2O$, $NdCl_3{\cdot}6H_2O$, $SmCl_3{\cdot}6H_2O$, $YbCl_3{\cdot}6H_2O$) was purchased from Wako Chemicals Industries, Ltd. Praseodymium chloride ($PrCl_3{\cdot}7H_2O$) was prepared by the reaction of praseodymium oxide with hydrochloric acid.

(29) Liotta, D.; Saindane, M.; Waykole, L. *J. Am. Chem. Soc.* **1983**, *105*, 2922.

(30) This compound might be produced through direct addition of isopropyl group to 2-position of compound **3** with carbon–oxygen bond scission of the ketal ring. The reaction might proceed through a 6-membered transition state.

(31) Before the experiments, we had expected that RMgX/$CeCl_3$ reagent system would provide **4** in much higher yield than RMgX alone. The unexpected results obtained might be explained by assuming that cerium(III) coordinates with ketal oxygen atoms to facilitate the cleavage of carbon–oxygen bond of the initially formed ketyl radical.

(32) Haley, T. J. In *Handbook on the Physics and Chemistry of Rare Earths*; Gschneider, K. A. Jr., Eyring, L.; Eds.; North-Holland: Amsterdam, 1979; Vol. 4, pp 553–585.

Grignard reagents were prepared by the standard method and the concentrations (1–1.5 M) were determined by titration.[33]

The following organic materials were prepared according to procedures in the literature: 3,3-Diethyl-2-pentanone,[34] 2,4,6-triisopropylacetophenone,[35] 3-cyclopentenone,[36] methyl 3-(2-oxocyclopentyl)-propionate,[37] 1-cyclopropyl-3-phenyl-2-propen-1-one,[38] (Z)-1,3-diphenyl-2-propen-1-one,[39] 4,4-(ethylenedioxy)-2,6-dimethyl-2,5-cyclohexadienone.[29,40]

1,3-Dicyclopropyl-2-propen-1-one was prepared from cyclopropanecarboxaldehyde and cyclopropyl methyl ketone according to the standard procedure:[41] colorless oil; bp 110 °C (bath temperature of Kugelrohr apparatus) (0.3 mmHg); IR (neat) 2980, 1675, 1640 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.5–1.2 (m, 8 H), 1.3–1.7 (m, 2 H), 1.8–2.1 (m, 2 H), 6.15–6.30 (m, 2 H); HRMS m/e 136.0884 (calcd for C$_9$H$_{12}$O 136.0885).

Other simple chemicals were purchased and purified by distillation under reduced pressure or recrystallization before use.

Method A. Cerium chloride (CeCl$_3$·7H$_2$O) (560 mg, 1.5 mmol) was quickly and finely ground to a powder in a mortar and placed in a 30-mL two-necked flask. The flask was immersed in an oil bath and heated gradually to 135–140 °C with evacuation (ca. 0.1 Torr). After maintenance of the cerium chloride at a constant temperature for 1 h, a magnetic stirrer bar was placed in the flask and the cerium chloride was completely dried in vacuo by stirring at the same temperature for an additional 1 h.[42] While the flask was still hot, argon gas was introduced and the flask was then cooled in an ice bath. Tetrahydrofuran (5 mL)[43] freshly distilled from sodium benzophenone was added all at once with vigorous stirring. The ice bath was removed and the suspension was well stirred overnight under argon at room temperature.[44] The flask was

again immersed in an ice bath and the Grignard reagent (1.5 mmol) was added. After stirring for 1.5 h at 0 °C, the carbonyl compound (1.0 mmol) was added and the stirring was continued for 30 min. The reaction mixture was treated with 10% aqueous acetic acid (10 mL). The product was extracted into ether, and combined extracts were washed with brine and NaHCO$_3$ solution and brine and dried with MgSO$_4$. The solvent was evaporated and the residue was subjected to preparative TLC to give the addition product.

Method B. The carbonyl compound (1 mmol) was added to a suspension of cerium chloride (1.5 mmol) prepared by the procedure described above. The mixture was well stirred at room temperature for 1 h and cooled to 0 °C. Grignard reagent (1.5 mmol) was added with vigorous stirring. After 30 min the reaction mixture was worked up by the same procedure detailed above.

2-(2,4,6-Trimethylphenyl)-2-propanol: mp 110–111 °C; IR (KBr) 3300 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ 1.68 (s, 7 H), 2.21 (s, 3 H), 2.44 (s, 6 H), 6.75 (s, 2 H). Anal. Calcd for C$_{12}$H$_{18}$O: C, 80.85; H, 10.18. Found: C, 80.88; H, 10.07.

1-Bromo-2-phenyl-3-buten-2-ol: oil; IR (neat) 3500 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 2.57 (s, 1 H), 3.56 (s, 2 H), 4.98–5.38 (m, 2 H), 5.80–6.06 (m, 1 H), 6.88–7.36 (m, 5 H). Anal. Calcd for C$_{10}$H$_{11}$BrO: C, 52.89; H, 4.99. Found: C, 52.76; H, 4.93.

1-Cyclopropyl-1,3-diphenyl-2-propen-1-ol: oil; IR (neat) 3395 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.28–0.68 (m, 4 H), 1.00–1.48 (m, 1 H), 1.74 (s, 1 H), 6.12 (d, J = 16 Hz, 1 H), 6.58 (d, J = 16 Hz, 1 H), 6.96–7.56 (m, 10 H). Anal. Calcd for C$_{18}$H$_{18}$O: C, 86.36; H, 7.25. Found: C, 86.39; H, 7.27.

1-Cyclopropyl-3,3-diphenyl-1-propanone: mp 46–48 °C; IR (neat) 1685 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.50–0.96 (m, 4 H), 1.58–1.90 (m, 1 H), 3.12 (d, J = 16 H, 2 H), 4.52 (t, J = 16 Hz, 1 H), 7.1 (s, 10 H). Anal. Calcd for C$_{18}$H$_{18}$O: C, 86.36; H, 7.25. Found: C, 86.37; H, 7.32.

1,3-Dicyclopropyl-1-phenyl-2-propen-1-ol: oil; IR (neat) 3400 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.1–1.6 (m, 11 H), 5.14 (q, J = 12 Hz, 1 H), 5.60 (d, J = 12 Hz, 1 H), 6.9–7.5 (m, 5 H). Anal. Calcd for C$_{15}$H$_{18}$O: C, 84.07; H, 8.47. Found: C, 83.96; H, 8.57.

1,3-Dicyclopropyl-3-phenyl-1-propanone: oil; IR (neat) 1685 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.1–1.3 (m, 9 H), 1.5–1.9 (m, 1 H), 2.3–2.6 (m, 1 H), 2.80–3.00 (m, 2 H), 7.1 (s, 5 H). Anal. Calcd for C$_{15}$H$_{18}$O: C, 84.07; H, 8.47. Found: C, 83,81; H, 8.54.

(Z)-1,1,3-Triphenyl-2-propen-1-ol: mp 87–89 °C; IR (KBr) 3525, 1595 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 2.72 (s, 1 H), 6.26 (d, J = 13 Hz, 1 H), 6.60 (d, J = 13 Hz, 1 H), 6.9–7.4 (m, 15 H). Anal. Calcd for C$_{21}$H$_{18}$O: C, 88.08; H, 6.34. Found: C, 88.10; H, 6.41.

2,6-Dimethyl-4-(2-hydroxyethoxy)-6-isopropyl-2,4-cyclohexadienone (6): oil; IR (neat) 3400, 1640 cm^{-1}; ^{1}H NMR (CCl$_4$) δ 0.63 (d, J = 7 Hz, 3 H), 0.90 (d, J = 7 Hz, 3 H), 1.08 (s, 3 H), 1.81 (s, 3 H), 1.77–2.27 (m, 1 H), 2.95 (br s, 1 H), 3.77 (s, 4 H), 4.92 (d, J = 3 Hz, 1 H), 6.54 (m, 1 H); ^{13}C NMR (CDCl$_3$) δ 15.2, 16.9, 18.2, 24.6, 38.4, 52.1, 61.2, 68.5, 107.4, 134.8, 137.3, 149.5, 206.5; MS m/e 225 (M + 1), 224 (M). Anal. Calcd for C$_{13}$H$_{20}$O$_3$: C, 69.61; H, 8.99. Found: C, 69.54; H, 9.03.

(33) Fieser, L. F.; Fieser, M. *Reagents for Organic Synthesis*; John Wiley: New York, 1967; Vol. 1, p 417.

(34) Whitmore, F. C.; Lewis, C. E. *J. Am. Chem. Soc.* **1942**, *64*, 1618.

(35) Newton, A. *J. Am. Chem. Soc.* **1943**, *65*, 2444.

(36) Suzuki, M.; Oda, Y.; Noyori, R. *J. Am. Chem. Soc.* **1979**, *101*, 1623.

(37) Stork, G.; Brizzolara, A.; Landesman, H.; Szmuszkovicz, J.; Terrell, R. *J. Am. Chem. Soc.* **1963**, *85*, 207.

(38) Bunce, S. C.; Dorsman, H. J.; Popp, F. D. *J. Chem. Soc.* **1963**, 303.

(39) Lutz, R. E.; Jordan, R. H. *J. Am. Chem. Soc.* **1950**, *72*, 4090.

(40) Liotta, D. Private Communication. We are grateful to Professor Liotta, who kindly informed us of the experimental procedure for the preparation of this compound.

(41) Nielsen, A. T.; Houlihan, W. J. *Org. React.* **1968**, *16*, 1.

(42) The following procedure for the preparative-scale production of anhydrous cerium chloride is recommended. Cerium chloride heptahydrate (ca. 20 g) is placed in a round-bottomed flask connected to a dry ice trap. The flask is evacuated and heated at 100 °C for 2 h. The resulting opaque solid is quickly pulverized in a mortar and again heated in vacuo at the same temperature for 2 h with occasional swwirling. A spinning bar is then placed in the flask and the bath temperature is raised to 135–140 °C. At this temperature cerium chloride is completely dried in vacuo with stirring for 2–3 h.

Anhydrous cerium chloride obtained can be stored under argon. Ceriuim chloride is extremely hygroscopic, and hence it is recommended that it be dried in vacuo at ca. 140 °C for 1–2 h before use.

(43) Use of hot THF is prohibited. Addition of hot THF to cerium chloride frequently results in the formation of solid materials like pebbles, which are hard to suspend.

(44) For the success of the reaction, stirring of the suspension for at least 2 h is essential.