

## ORGANOCERIUM REAGENTS FROM IODINE ACTIVATED CERIUM METAL AND ORGANIC IODIDES: THEIR REACTIONS WITH CARBONYL COMPOUNDS

SHIN-ICHI FUKUZAWA\*, TATSUO FUJINAMI, and SHIZUYOSHI SAKAI

*Department of Applied Chemistry, Faculty of Engineering, Shizuoka University, Hamamatsu 432 (Japan)*

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### Summary

Cerium metal activated by a trace of iodine reacted smoothly with alkyl, allyl, and aryl iodides to give the corresponding organocerium reagents. The reaction of the organocerium reagents thus prepared in situ with carbonyl compounds gave not only Grignard-type adducts but also reduction and reductive coupling products.

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### Introduction

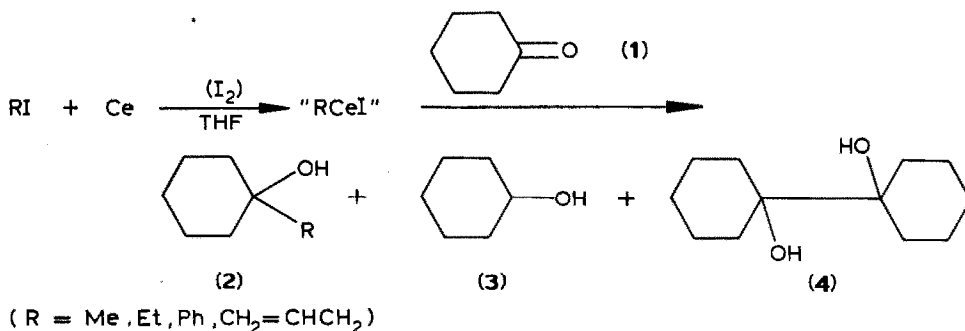
The chemistry of organolanthanoid compounds is growing steadily especially with regard to organic synthesis [1]. Organolanthanoid  $\sigma$ -complexes are amongst the effective reagents for carbon-carbon bond formation [2,3], which are directly prepared from lanthanoid metals and organic iodides in tetrahydrofuran (THF) [4,5] or indirectly from organolithium compounds and lanthanoid chlorides [3b,c], and also organomercury compounds and lanthanoid metals [6]. Cerium is one of the less expensive lanthanoids and is also suitable for practical use in organic synthesis. It is, however, less reactive with organic halides than other lanthanoids such as ytterbium and samarium, and needs activation. An amalgam of cerium seems to be a common and effective method for its activation, but it has the disadvantages of using toxic mercury and of having a complicated procedure [3a,c]. After searching for several other activation methods instead of an amalgam, we noticed that a trace of iodine is sufficient to initiate the reaction between cerium metal and an organic iodide to generate an organocerium reagent and also the method seems to be easier.

Next, when the reagent was treated with some carbonyl compounds, we found that the reaction gave reduction and reductive coupling products as well as a nucleophilic addition product (Grignard-type adduct). This result was interesting and noteworthy and contrasted with the fact that the organocerium reagent prepared from cerium amalgam gives exclusively an addition product. Here, we present this new aspect of the reaction between various organocerium reagents and some carbonyl compounds.

## Results and discussion

Our initial purpose was to examine whether cerium metal reacted with organic iodides without the use of cerium amalgam. It barely reacted without activation but the reaction proceeded smoothly to form an organocerium reagent after treating the cerium metal with a trace amount of iodine (1 mol% for cerium) \*. Methyl, ethyl, and allyl iodides reacted with cerium in a few minutes, while iodobenzene took longer (over 20 to 30 min). For less reactive iodides, the use of trace amounts of 1,2-diiodoethane was suitable to initiate the reaction.

Secondly, we tested the reactivity of the organocerium reagents thus prepared with carbonyl compounds. When an equimolar amount of "allylcerium iodide" was treated with cyclohexanone at  $-20^{\circ}\text{C}$ , the corresponding homoallylic alcohol (**2**;  $\text{R} = \text{CH}_2=\text{CHCH}_2$ ) was produced in 40% yield. In addition to this, we noticed the formation of cyclohexanol (**3**) and cyclohexylpinacol (**4**) in significant amounts (21



and 28% yields, respectively) \*\*. In view of the fact that the organocerium reagents prepared from cerium amalgam or phenylttrerbium iodide undergoes Grignard-type reaction exclusively [2a,3a,c] \*\*\*, the organocerium reagent prepared by our method seems to differ from the former reagents. The product distribution of **2**, **3**, and **4**, was almost unaffected by varying the reaction temperature and time. In other words, even if the reaction was carried out at a lower temperature ( $-78^{\circ}\text{C}$ ), an improvement of the selectivity to **2** was unsuccessful. The use of double molar amounts of the allylcerium reagent for **1** increased the yield of the addition product to some extent. Other organocerium reagents such as methyl-, ethyl-, and phenyl-cerium reagents underwent similar reactions: nucleophilic addition, reduction, and reductive coupling. When ethyl- and phenyl-cerium reagents were used, reductive coupling was dominant. These results are summarized in Table 1.

We then investigated whether the reaction procedure would affect the reaction and the product distribution. Our procedure was a two-step Grignard-type procedure (method A), while the reaction using cerium amalgam was carried out in a

\* We know the reaction has started by temperature rise.

\*\* Since the reaction in the absence of an organic iodide, using 1 mol% of iodine to cerium and a carbonyl compound gave a pinacol in 1% yield, the organocerium reagent participated in pinacol formation, although  $\text{Ce}/\text{I}_2$  (1/1) is known to give a pinacol from carbonyl compounds [8].

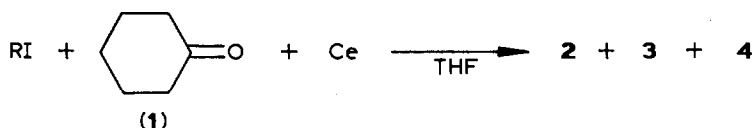
\*\*\* We independently confirmed that the use of cerium amalgam did not give rise to reduction and reductive coupling, the reaction of **1** with allyl iodide giving an homoallyl alcohol in 52% yield, with 40% of the unreacted **1** recovered. See Table 1.

TABLE 1  
REACTION OF ORGANOCERIUM REAGENTS WITH CYCLOHEXANONE (1)<sup>a</sup>

R in RI	Temperature (°C)	Time (h)	Method <sup>b</sup>	Products (%) <sup>c</sup>		
				Addition 2	Reduction 3	Reductive coupling 4
CH <sub>2</sub> =CHCH <sub>2</sub>	-20	3	A	40	21	28
	0	5	A	40	28	21
	0	5	A <sup>d</sup>	50	27	20
	-78	3	A	35	25	40
	-78 ~ r.t.	5	B	35	27	34
	-78 ~ r.t.	5	B <sup>d</sup>	50	13	36
	25	1	B <sup>d</sup>	50	14	35
	25	1	B <sup>d,e</sup>	52 <sup>f</sup>	0	0
Me	-20	3	A	42	20	10
Et	-20	3	A	20	18	51
Ph	-20	3	A	24	20	51

<sup>a</sup> Cerium (2 mmol), RI (2 mmol), **1** (2 mmol), THF (5 ml), and I<sub>2</sub> (0.02 mmol). <sup>b</sup> A: Two-step procedure, B: one-step procedure, see Experimental. <sup>c</sup> Determined by GLC. <sup>d</sup> Cerium (2 mmol), RI (2 mmol), and **1** (1 mmol). <sup>e</sup> Cerium amalgam (2 mmol) was used. <sup>f</sup> 40% of **1** was recovered.

one-step Barbier-type procedure without preformation of organocerium reagents\*. Consequently, the reaction was checked again by the Barbier-type procedure (method B). The results, however, showed that the reaction was not affected at all by the

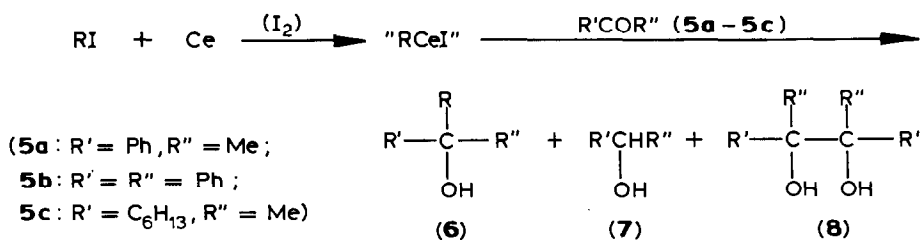


reaction procedure, i.e., reduction and reductive coupling accompanied the addition.

The conclusion is as follows. (1) The organocerium reagent prepared from iodine activated cerium showed somewhat distinct chemical behaviour from the reagent so far reported. (2) The reaction was independent from the reaction conditions and procedures. (3) The yield of addition products could be improved by using a double equivalent amount of organocerium reagent per ketone.

The reaction was then extended to various combinations of carbonyl compounds with organocerium reagents. The reaction procedure usually consisted of the two-step method (method A) and an equimolar amount of organocerium reagent was employed for carbonyl compounds. Acetophenone, benzophenone, and 2-octanone similarly reacted with various organocerium reagents under the appropriate conditions to give the corresponding addition products **6**, alcohol **7**, and pinacols **8**. This demonstrates the potential use of the reduction and reductive coupling reactions discussed. Methyl- and allyl-cerium reagents again showed higher nucleophilic

\* We further checked if the quantity of cerium would influence the reaction. This problem was resolved soon by the use of three different quantities of cerium. Reduction and reductive coupling took place in almost the same percentages regardless of the quantity of cerium used. See Experimental.



ability for these ketones. The use of double molar amounts of the allylcerium reagent remarkably improved the yields of addition products from acetophenone and benzophenone (over 90%), suggesting that this facile method is quite comparable to that using cerium amalgam in order to obtain a reasonable amount of the addition product. Results are shown in Table 2.

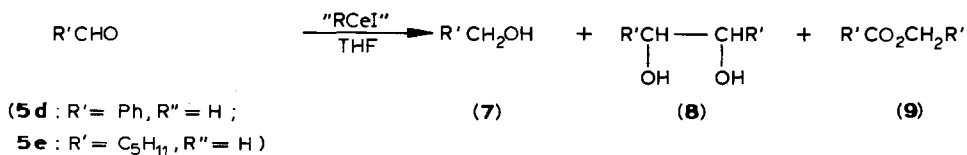
The reaction of aldehydes with organocerium reagents is noteworthy. With either benzaldehyde or hexylaldehyde, any organocerium derivative gave hardly any addition products even if an excess of the reagent was used, the pinacols being formed predominantly (Table 2). According to the literature [7], Tishchenko-type products

TABLE 2  
 REACTION OF ORGANOCERIUM REAGENTS WITH VARIOUS CARBONYL COMPOUNDS<sup>a</sup>

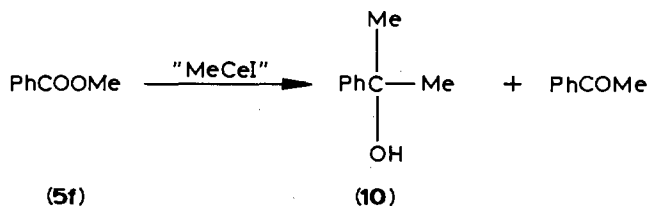
R in RI	R'COR''	Temperature (°C)	Time (h)	Method <sup>b</sup>	Products (%) <sup>c</sup>		
					Addition 6	Reduction 7	Reductive coupling 8
CH <sub>2</sub> =CHCH <sub>2</sub>	5a	25	1	B	46	5	31
	5a	25	1	B <sup>d</sup>	90	5	1
	5a	-20	3	A	40	5	51
Me	5a	-20	3	A	55	10	33
	5a	-20	3	A <sup>d</sup>	91	3	0
Et	5a	-20	3	A	30	5	50
Ph	5a	-20	3	A	12	16	33
CH <sub>2</sub> =CHCH <sub>2</sub>	5b	25	1	B <sup>d</sup>	95	2	trace
	5b	-20	3	A	63	5	trace
	5b	-20	3	A	12	8	30
Me	5c	-20	3	A	45	5	23
Ph	5c	-20	3	A	16	10	20
CH <sub>2</sub> =CHCH <sub>2</sub>	5d	-20	3	A	0	25	63 <sup>e</sup>
	5d	25	1	B	5	20	60 <sup>e</sup>
Me	5d	-20	3	A	0	30	26 <sup>e</sup>
Et	5d	-20	3	A	0	26	63 <sup>f</sup>
Ph	5d	-20	3	A	0	24	63
CH <sub>2</sub> =CHCH <sub>2</sub>	5e	-20	3	A	0	16	44
	5e	-20	3	A	0	38	44
	5e	-20	3	A	0	14	44
Me	5f	-20	3	A <sup>d</sup>	49 <sup>g</sup>	3	trace
Ph	5f	-20	3	A	0	0	10

<sup>a</sup> Cerium (2 mmol), R'COR'' (2 mmol), RI (2 mmol), THF (5 ml), and I<sub>2</sub> (0.02 mmol). <sup>b</sup> See footnote in Table 1. <sup>c</sup> Determined by GLC. <sup>d</sup> Cerium (2 mmol), R'COR'' (1 mmol), and RI (2 mmol). <sup>e</sup> Another product; benzyl benzoate (2 ~ 3%). <sup>f</sup> Another product; benzyl benzoate (7%). <sup>g</sup> 2-Phenyl-2-propanol (46%) and acetophenone (3%).

are formed in the reaction of aromatic aldehydes catalyzed by ethyllanthanoid iodides. In our case, such products (9) were also detected, but their yields were negligibly low (2–7%) \*.



When methyl benzoate was treated with a double molar amount of "methylcerium iodide", acetophenone and 2-phenyl-2-propanol (10) were produced in 3 and 46% yields, respectively. The tertiary alcohol was still a major product even though an equimolar amount of the methylcerium reagent was employed. "Phenylcerium iodide" failed to give triphenylmethanol, resulting in only 10% of the pinacol with 60% of the unreacted ester.



The formation of a Grignard-type adduct may be simply explained by nucleophilic attack of the organocerium species on a carbonyl group, in which the reaction path has anionic character. On the other hand, reduction and reductive coupling was probably induced by a low valent cerium species such as  $\text{CeI}_2$  [8], which may be generated from a possible disproportionation of an organocerium iodide \*\*. The reaction process would involve one-electron transfer from a low valent cerium to a carbonyl group.

In a Tishchenko-type reaction of aromatic aldehydes catalyzed by ethyllanthanoid iodides, the actual reacting species is considered to be a lanthanoid hydride, formed through a  $\beta$ -hydrogen elimination process [7]. In our case, the presence of such species might be assumed, but we cannot rule out the possibility of a divalent organocerium species acting itself as a reducing agent. Anyhow it is not yet clear why the organocerium reagent prepared from iodine activated cerium undergoes reduction but that from cerium amalgam does not, although similar species could be present in either case. Further work is necessary to elucidate the detailed reaction mechanisms.

\* The Tishchenko-type reaction catalyzed by organolanthanoid reagents was usually carried out at 65°C, while we carried out the reaction at a low temperature (–20°C). Reduction may be in preference to the Tishchenko-type reaction at a low temperature.

\*\*  $2 \text{RCeI} \rightleftharpoons \text{R}_2\text{Ce} + \text{CeI}_2$  Another possibility,  $2 \text{RCeI} \rightleftharpoons \text{R-R} + 2 \text{CeI}$ , can be denied since the formation of homocoupling products of  $\text{RCeI}$  was negligible.

## Experimental

$^1\text{H}$  NMR spectra were recorded with a Hitachi R-24 (60 MHz) spectrometer in  $\text{CCl}_4$ . GLC analyses were carried out by using a Shimadzu 6AM apparatus with EGSS-X (3%)-Chromosorb-W (1 and 3 m), PEG 20M (20%)-Celite (2 m), Casterwax (10%)-Neopak 1A (2 m), and Silicon DC QF-1 (5%)-Chromosorb-W (1 m) columns ( $\text{N}_2$  as carrier gas).

THF was distilled from lithium aluminum hydride under nitrogen. Cerium chips were purchased from Mitsuwa Chemicals (99.9% purity, type 42898) and Kanto Chemicals (99.5% purity, type 910E0189), which was scraped by a rasp then used as powders (ca. 30–40 mesh). Separately, cerium powder was commercially available (Aldrich Chemicals Co. Inc., ~ 40 mesh, 99.9% purity, type 1028LK). All starting compounds were commercially available and used without further purification. Reaction products were analysed by GLC measurements. Authentic samples were prepared from the reaction of carbonyl compounds with Grignard reagents or with  $\text{TiCl}_4/\text{Zn}$  [9].

### *General procedure for the reaction of carbonyl compounds with organocerium reagents*

Method A: Cerium powder (280 mg, 2 mmol) and a trace of iodine (5 mg, 0.02 mmol) were placed in a two-necked round-bottomed flask (20 ml) equipped with a magnetic stirring bar. The flask was several times flushed with nitrogen. An organic iodide (2 mmol) in THF (2 ml) was added to the cerium through a rubber septum with a syringe. In a few minutes an exothermic reaction occurred and extra THF (3 ml) was then added and the mixture was cooled to  $-20^\circ\text{C}$ . When the cerium powder was completely consumed, a carbonyl compound (1 or 2 mmol) was added to the solution. The mixture was stirred for 1–3 h, and then treated with diluted HCl and extracted with diethyl ether ( $3 \times 30$  ml). After being washed with brine, and dried over  $\text{MgSO}_4$ , the ethereal solution was analysed by GLC.

Method B: A THF solution of a carbonyl compound (1 or 2 mmol) and organic iodide (2 mmol) was added to cerium powder (280 mg, 2 mmol) treated with a trace of iodine (5 mg, 0.02 mmol) under nitrogen, at room temperature. A few minutes after the reaction started the temperature rose and extra THF (3 ml) was added to the mixture, which was then cooled to  $-78^\circ\text{C}$ . After being stirred for 1–5 h, the resulting mixture was worked up in the usual manner.

## References

- 1 For reviews: (a) T. Imamoto, Y. Tawarayama, T. Kusumoto, and M. Yokoyama, *Yuki Gosei Kagaku Kyokaiishi*, 42 (1984) 143; (b) Y. Fujiwara, *Kagaku Zokan*, 105 (1985) 111; (c) H. Schumann, *Angew. Chem. Int. Ed. Engl.*, 23 (1984) 474.
- 2 For ytterbium: (a) T. Fukagawa, Y. Fujiwara, K. Yokoo, and H. Taniguchi, *Chem. Lett.*, (1981) 1771; (b) T. Fukagawa, Y. Fujiwara, and H. Taniguchi, *ibid.*, (1982) 601; (c) K. Yokoo, Y. Yamanaka, T. Fukagawa, H. Taniguchi, and Y. Fujiwara, *ibid.*, (1983) 1301; (d) K. Yokoo, Y. Kijima, Y. Fujiwara, and H. Taniguchi, *ibid.*, (1984) 1321; (e) K. Yokoo, T. Fukagawa, Y. Yamanaka, H. Taniguchi, and Y. Fujiwara, *J. Org. Chem.*, 49 (1984) 3237; (f) G.B. Deacon and T.D. Tuong, *J. Organomet. Chem.*, 205 (1981) C4.
- 3 For cerium: (a) T. Imamoto, Y. Hatanaka, Y. Tawarayama, and M. Yokoyama, *Tetrahedron Lett.*, 22 (1981) 4987; (b) T. Imamoto, T. Kusumoto, and M. Yokoyama, *J. Chem. Soc., Chem. Commun.*, (1982) 1042; (c) T. Imamoto, T. Kusumoto, Y. Tawarayama, Y. Sugiura, T. Mita, Y. Hatanaka, and M. Yokoyama, *J. Org. Chem.*, 49 (1984) 3904.

- 4 D.F. Evans, G.V. Fazakerley, and R.F. Phillip, *J. Chem. Soc. A*, (1971) 1932, and ref. 2 and 3.
- 5 (a) A.B. Sigalov, E.S. Petrov, L.F. Rybakova, and I.P. Beletskaya, *Izv. Akad. Nauk SSSR, Ser. Khim.*, (1983) 2615; *Chem. Abstr.*, 100 (1984) 139255p; (b) O.P. Syutkina, L.F. Rybakova, E.S. Petrov, and I.P. Beletskaya, *J. Organomet. Chem.*, 280 (1985) C67.
- 6 (a) G.B. Deacon and D.G. Vince, *J. Organomet. Chem.*, 112 (1976) C1; (b) G.B. Deacon, W.D. Raverty, and D.G. Vince, *ibid.*, 135 (1977) 103; (c) G.B. Deacon and A.J. Koplick, *ibid.*, 146 (1978) C43; (d) G.B. Deacon, A.J. Koplick, W.D. Raverty, and D.G. Vince, *ibid.*, 182 (1979) 121.
- 7 K. Yokoo, N. Mine, H. Taniguchi, and Y. Fujiwara, *J. Organomet. Chem.*, 279 (1985) C19.
- 8 T. Imamoto, T. Kusumoto, Y. Hatanaka, and M. Yokoyama, *Tetrahedron Lett.*, 23 (1982) 1353. The production of a pinacol is also known in the reaction of a trivalent organocerium reagents with a carbonyl compound at room temperature. Low valent cerium is assumed to be involved in the reaction [3b,c].
- 9 T. Mukaiyama, T. Sato, and J. Hanna, *Chem. Lett.*, (1973) 1041.