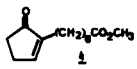
Table I

Starting material[a]	Lanthanides used	Yields %[b]	Allylic alcohol %[c]	Saturated alcohol[d]
 1	none*	100*	89	11
	Ce	100	100	0
 2	none	100	0	100
	Ce	100	97	3
	Sm	100	94	6
	Eu	100*	93	7
 3	none	95*	38	62
	Sm	96*	96	4
	Ce	100	99	1
 4	none	100	95	5
	Sm	92	100	0
 5	none	100*	51	49
	Sm	98	93	7
	Ce	100	>99	traces
 6	none	98*	90	10
	Ce	100	100	0
 7	none	98*	90	10
	Ce	100	100	0

[a] The following standard procedure was adopted: 1 mmol of starting material is dissolved in 2.5 mL of the 0.4 M $LnCl_3 \cdot nH_2O$ methanol solution and $NaBH_4$ (1 mmol) is slowly added (2 min) with stirring. The mixture is allowed to react for 3–5 min, followed by hydrolysis and extraction with ether. [b] Isolated yields except in specified cases (asterisk) in which they were obtained by VPC (2 m × 2 mm i.d. Carbowax 20M column on Chromosorb WAW, 15 mL of N_2/min Carlo Erba Fractovap 1501 chromatograph). [c] Identification of these compounds was made by the usual spectral methods (IR, UV, NMR) and by comparison with authentic samples. [d] The relative percentage of these reduction compounds and their identity were ascertained by TLC and/or VPC.

Lanthanides in Organic Chemistry. 1. Selective 1,2 Reductions of Conjugated Ketones[1]

Sir:

Although rare earth complexes have enjoyed considerable utility as shift reagents in NMR spectroscopy,[2] there are limited applications of these elements in synthetic chemistry. With the exception of cerium^{4+}, which is employed as an efficient oxidation agent,[3] the lanthanides have received only limited uses as catalysts, in petrochemical reactions,[4] epoxide rearrangement,[5] or optical resolution,[6] and an unusual reaction of secondary amines with acetonitrile.[7] Recent reports[8] concerning the synthetic potential of lanthanides prompt us to communicate our preliminary results using rare earth halides and sodium borohydride for the selective conversion of α,β-unsaturated ketones to allylic alcohols.

Treatment of an equimolecular amount of a ketone (2-hexanone, cyclohexanone, acetophenone) and samarium chloride hexahydrate in ethanol[9] with sodium borohydride (1 molar equiv) produces an evolution of hydrogen coupled with a quantitative yield of the corresponding alcohol in 5–10 min. Application of this procedure (in methanol[9]) to α,β-unsaturated ketones produced high yields of the corresponding allylic alcohols, in many cases uncontaminated with the 1,4 reduction product. Several representative examples are presented in Table I.

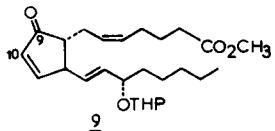
Such selectivity has been noted with other reducing systems,[10] but the previous methods usually suffer from limitations. Thus, of the recently developed reagents, $NaBH_3CN$,[11] is unreliable with certain cyclic enones, giving mixtures resulting from 1,2 and 1,4 additions. 9-Borabicyclononane (9-BBN) has a decreased reactivity with sterically hindered carbonyl groups,[12] which requires long reaction times and/or refluxing solvent for reduction. Diisobutylaluminium hydride (Dibah) is not selective for carbonyl groups[13] and must be used at low temperature. The last two reagents are expensive and require anhydrous conditions in an inert atmosphere.

Of the lanthanides tested, samarium and cerium appear to offer the best combination of yield and selectivity (Table I). The method evidently offers the following advantages. First, nearly exclusive selective 1,2 reduction is obtained under conditions which do not affect carboxylic acids, esters, amides, halides, and cyano and nitro groups.[14] Even 2-cyclopentenone, which is especially prone to undergo the 1,4 addition reaction, can be reduced to 2-cyclopentenol with a selectivity as high as 97%. Furthermore, the reactions may be conducted at room temperature, without special exclusion of air or moisture, and

0002-7863/78/1500-2226$01.00/0

excellent yields of products are obtained within 5 min. Provided its concentration is <5%, water has little effect on selectivity. 2-Cyclopentenone produces cyclopentenol in 95 and 91% yield, respectively, when reduced in methanol solution with 10 and 15% water. This allows use of the lanthanide chlorides in the commercially inexpensive hexahydrate form. Steric hindrance has no detectable effect on the rate of the reduction: 3-methylene 2-norbornanone **8** undergoes exclusively the 1,2 reduction with the same rate as with sodium borohydride, and the PGA_2 derivative **9** yields the 9-OH Δ-10 compounds (91% isolated yield of the 1:1 mixture of epimers) within minutes. We obtained extremely slow reductions of **8** and **9** with 9-BBN (>24 h at room temperature), and, with $NaBH_4$, **9** yields only saturated alcohols.

8



9

The mechanism of the reaction process has not yet been extensively studied, but does not involve a catalytic role for the lanthanide since reduction of 2-cyclopentenone in the presence of 0.1 equiv of Sm^{3+} gave a 1:4 mixture of cyclopentenol and cyclopentanol. A complex reduction scheme via the +2 oxidation state of the rare earth[15] also seems unlikely for in this state the lanthanides are only slightly reactive with ketones.[8] Reduction by a lanthanide borohydride, formed in situ[16] (at least as a transient species), might explain the observed regioselectivity according to the hard and soft acids bases theory.[17] Another possible hypothesis is that a reduction by $NaBH_4$ of a carbonyl compound–rare earth complex[18] is occurring. Although the NMR and UV spectra of cyclohexenone in methanol solution with or without cerium trichloride are quite similar, this possibility cannot be excluded in the absence of precise kinetic data. Further investigation of the mechanism and stereochemistry of the reductions is in progress. Reductions of various terpenoid, steroid, and prostanoid α-enones will be published in a next paper.[19]

Acknowledgment. The author thanks Professor P. Crabbé for encouragement and stimulating discussions and Drs. A. E. Greene and A. F. Orr for valuable suggestions.

References and Notes

(1) Contribution 23 of the Laboratoire de Chimie Organique (CERMO). For 22 see P. Crabbé, J. M. Dollat, J. Gallina, J. L. Luche, M. Maddox, E. Velarde, and L. Tökès, *J. Chem. Soc., Perkin Trans. 1*, in press.
(2) R. E. Sievers, Ed., "Nuclear Magnetic Resonance Shift Reagents," Academic Press, New York, N.Y., 1973.
(3) (a) M. Fieser and L. Fieser, "Reagents for Organic Synthesis", Vol. 5, Wiley, New York, N.Y., 1975; (b) Tse Lok Ho, *Synthesis*, 347 (1973).
(4) Inter alia: (a) D. Kruzkova, J. M. Beruk, J. Obloj, R. Chojnacki, M. Popowicz, W. Tecza, and Z. Linicki, *Pol*, 78336 (*Chem. Abstr.*, **85**, 10781z (1976)); (b) T. Saito, T. Kikuchi, T. Awano, and G. Sato, *Japan Kokai*, **76**, 36429 (*Chem. Abstr.* **85**, 77874a (1976)).
(5) B. M. Trost and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **95**, 5321 (1973).
(6) B. T. Golding, P. J. Sellars, and A. K. Wong, *J. Chem. Soc., Chem. Commun.*, 570 (1977).
(7) J. H. Forsberg, T. M. Balasubramanian, and J. T. Spaziano, *J. Chem. Soc., Chem. Commun.*, 1060 (1976).
(8) (a) J. L. Namy, P. Girard, and H. B. Kagan, *Nouv. J. Chim.*, 5 (1977), and references cited; (b) P. Girard and H. B. Kagan, *Tetrahedron Lett.*, 4513 (1975).
(9) In contrast to α,β-unsaturated ketones, saturated ketones and aldehydes and α,β-unsaturated aldehydes easily form ketals in methanolic lanthanide chlorides solution. This ketalization does not occur in ethanol. These findings will be discussed in a future paper.
(10) Inter alia: (a) H. O. House, "Modern Synthetic Reactions", Benjamin, Menlo Park, Calif., 1972; (b) E. R. H. Walker, *Chem. Soc. Rev.*, **15**, 23 (1976); (c) M. R. Johnson and B. Rickborn, *J. Org. Chem.*, **35**, 1041 (1970).
(11) R. O. Hutchins and D. Kandasamy, *J. Org. Chem.*, **40**, 2530 (1975).
(12) (a) H. C. Brown, S. Krishnamurthy, and N. M. Yoon, *J. Org. Chem.*, **41**, 1778 (1976); (b) S. Krishnamurthy and H. C. Brown, *ibid.*, **42**, 1197 (1977).
(13) E. Winterfeldt, *Synthesis*, 617 (1975).
(14) Inter alia, diethyl malonate, ethyl heptanoate, 5-bromopentanoic acid, 3, 3-dimethylacrylic acid, benzyl bromide, 1-iodoundecane, *p*-bromonitrobenzene, *o*-nitrophenol, *N*-benzoylglycine, *N*-acetylleucine, and benzonitrile remain unaffected under the specified conditions.
(15) L. B. Asprey and B. B. Cunningham, *Prog. Inorg. Chem.*, **8**, 267 (1960).
(16) (a) T. J. Marks and J. R. Kolb, *Chem. Rev.*, **77**, 263 (1977); (b) A. Brucki and K. Rossmanith, *Monatsh. Chem.*, **90**, 481 (1959).
(17) (a) For a review, see Tse Lok Ho, *Chem. Rev.*, **75**, 1 (1975). (b) J. Bottin, O. Eisenstein, C. Minot, and Nguyen Trong Anh, *Tetrahedron Lett.*, 3015 (1972).
(18) Such a complexation may explain the enhanced solubility of substrates in methanol in the presence of lanthanides halides. Even glucose and saccharose can be dissolved under these conditions in concentrations as high as 0.2 M.
(19) J. L. Luche, L. Rodriguez-Hahn, and P. Crabbé, unpublished work.

Jean-Louis Luche
Laboratoire de Chimie Organique
Université Scientifique et Médicale, CERMO
Boîte Postale No. 53, 38041 Grenoble, France
Received October 13, 1977

0002-7863/78/1500-2227$01.00/0