

Lanthanoid Complex as a Novel Carbon Dioxide Carrier for the Carboxylation of Active Methylene Compounds under Mild Conditions

Hiroshi Abe and Shohei Inoue*

Department of Synthetic Chemistry, Faculty of Engineering, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113, Japan

A lanthanoid complex, formed by the addition of a lanthanoid alkoxide to an isocyanate, serves as a novel carbon dioxide carrier for the rapid carboxylation of active methylene compounds under mild conditions.

In connection with increasing interest in studies of the chemical fixation of carbon dioxide,¹ carbon dioxide carriers for the carboxylation of active methylene compounds have been of interest in relation to the action of biotin-enzyme in biochemical carboxylation² and in possible applications to organic synthesis. Representative examples so far reported include magnesium compounds such as alkoxide³ and ureide complexes.⁴

Lanthanoid compounds recently have attracted much attention in organic synthesis.⁵ In the course of our studies on organic synthesis with lanthanoid alkoxides,⁶ we have found that a lanthanoid complex, formed by the addition of a lanthanoid alkoxide to an isocyanate, serves as a novel carbon dioxide carrier for the rapid carboxylation of active methylene compounds under mild conditions (room temperature and atmospheric pressure).

A typical procedure is exemplified by the carboxylation of phenylacetone. To a tetrahydrofuran (THF) solution (0.5 mol dm⁻³) of La(OPrⁱ)₃ (0.5 mmol; 1 cm³), phenyl isocyanate (1 mmol) was added under argon and the mixture was stirred for 15 min at room temperature. Dimethylformamide (DMF) (3 cm³) was added and then dry carbon dioxide was bubbled through the solution for 30 min at the same temperature. Finally phenylacetone (0.5 mmol) was added and the mixture was stirred. The reaction was stopped by adding ice-hydrochloric acid, and the mixture was extracted with ether. The ether extract was dried (MgSO₄) and evaporated to leave a colourless liquid, to which was added methanol and trimethylsilyldiazomethane to produce methyl α-cyanophenylacetate. The product was formed in 69% yield after 1 min; longer reaction times resulted in lower yields. Use of dimethyl sulfoxide (DMSO) instead of DMF led to lower yields. In DMF the carboxylation proceeded even at -40 °C. When 1 or 3 equiv. of phenyl isocyanate was used, the yield was lower. In order to exclude the possibility of carboxylation by 'free' carbon dioxide dissolved in the system, the La(OPrⁱ)₃-phenyl isocyanate-carbon dioxide reaction mixture in DMF was evaporated *in vacuo*, but the residual solid was found to retain the ability to carboxylate phenylacetone in DMF in 44% yield after 30 min. Systems from other lanthanoid alkoxides† such as Sm(OPrⁱ)₃ and Yb(OPrⁱ)₃ similarly exhibited high activities to give the carboxylated product in 59 and 50% yield at room temperature after 3 min, respectively. Butyl isocyanate could be used instead of phenyl isocyanate, but yields were lower, but phenyl isothiocyanate and dicyclohexylcarbodiimide (DCC) were shown to be ineffective for the carboxylation under similar conditions.

Using a similar procedure, various active methylene compounds such as fluorenes, ketones and esters afforded the corresponding carboxylated products as shown in Table 1. It is interesting that *S*-benzyl thiopropionate was effectively carboxylated to give the thiol ester of 2-methylmalonate in good yield, since this reaction is related to the biological carboxylation of propionyl-coenzyme A to 2-methylmalonyl-coenzyme A with a biotin enzyme.

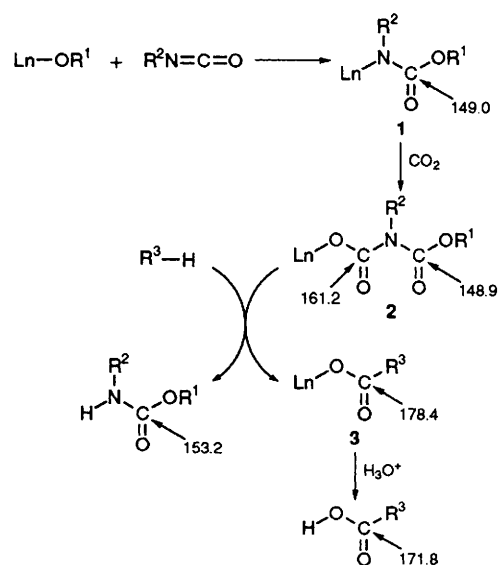
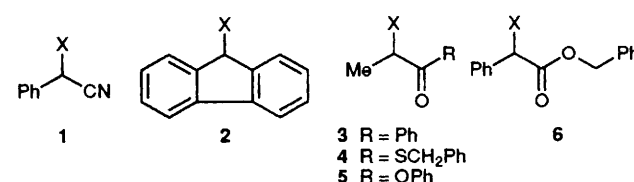
The reaction is considered to proceed through the sequence shown in Scheme 1 according to ¹³C NMR analysis of the reaction mixture (Ln = La, R¹ = Prⁱ, R² = Ph, R³ = fluorenyl) in (CD₃)₂SO. The reaction of La(OPrⁱ)₃ with 2 equiv. of phenyl isocyanate gives the carbamate-type complex **1** (δ

149.0)‡ which gives isopropyl phenylcarbamate almost quantitatively after hydrolysis. The reaction of **1** with carbon dioxide is considered to give an iminodicarboxylate-type complex **2** (δ 161.2) as suggested by the reaction with ¹³C enriched carbon dioxide. After the addition of fluorene, a set of signals

Table 1 Carboxylation of active methylene compounds with the La(OPrⁱ)₃-PhNCO-CO₂ system^a

Substrate, X = H	Product, X = CO ₂ Me, yield (%) ^b
1	69, ^c 57, 42, ^d 36 ^e
2	66
3	47
4	61
5	16
6	17

^a La(OPrⁱ)₃, 0.5 mmol; phenyl isocyanate, 1 mmol; DMF, 3 cm³; substrate, 0.5 mmol; CO₂ bubble, 30 min; room temperature, 1 h. ^b Determined by ¹H NMR. ^c Reaction time, 1 min. ^d Reaction temperature, -40 °C. ^e DMSO was used instead of DMF.



Scheme 1 Ln = La, R¹ = Prⁱ, R² = Ph, R³ = fluorenyl; in (CD₃)₂SO. ¹³C NMR data are indicated (δ values).

assignable to the corresponding carboxylated product **3** (δ 178.4) δ and free isopropyl phenylcarbamate (δ 153.2) appeared.

aluminium carbamate-type complex, see T. Hirabayashi, H. Imaeda, K. Itoh, S. Sakai and Y. Ishii, *J. Organomet. Chem.*, 1969, **19**, 299).
 δ For La(OAc) $_3$: δ 181.9.

Received, 4th January 1994; Com. 4/00011K

Footnotes

\dagger La(OPr) $_3$ was commercially available from Kojundo Chemical Laboratory Co., Ltd. Sm(OPr) $_3$ and Yb(OPr) $_3$ were prepared by refluxing propan-2-ol suspensions of metal grains in the presence of mercury(II) chloride (L. M. Brown and K. S. Mazdiyasi, *Inorg. Chem.*, 1970, **9**, 2783).

\ddagger IR(KBr): ν (C=O) 1719 cm^{-1} , ν (N \cdots C \cdots O) 1551 cm^{-1} (For a similar

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