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

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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 carboxylation[2] and in possible applications to organic synthesis. Representative examples so far reported include magnesium compounds such as alkoxide[3] 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 phenylacetonitrile. To a tetrahydrofuran (THF) solution (0.5 mol dm^{-3}) of $La(OPr^i)_3$ (0.5 mmol; 1 cm^3), phenyl isocyanate (1 mmol) was added under argon and the mixture was stirred for 15 min at room temperature. Dimethylformamide (DMF) (3 cm^3) was added and then dry carbon dioxide was bubbled through the solution for 30 min at the same temperature. Finally phenylacetonitrile (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 ($MgSO_4$) 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 $La(OPr^i)_3$–phenyl isocyanate–carbon dioxide reaction mixture in DMF was evaporated *in vacuo*, but the residual solid was found to retain the ability to carboxylate phenylacetonitrile in DMF in 44% yield after 30 min. Systems from other lanthanoid alkoxides† such as $Sm(OPr^i)_3$ and $Yb(OPr^i)_3$ 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.

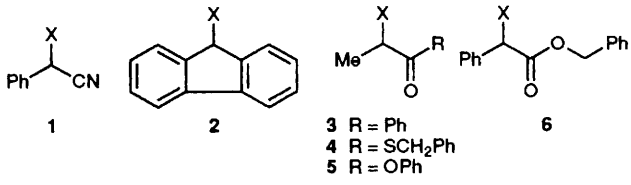
Using a similar procedure, various active methylene compounds such as fluorenes, ketones and esters afforded the corresponding carboxylated products as shown in Table 1. It is interesting that *S*-benzyl thiopropionate was effectively carboxylated to give the thiol ester of 2-methylmalonate in good yield,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

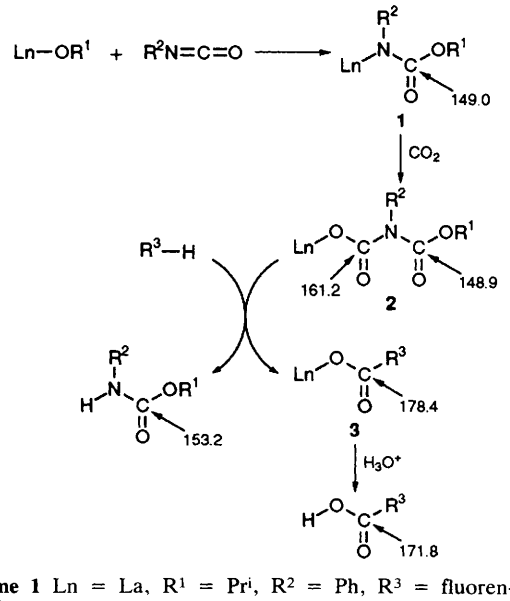
The reaction is considered to proceed through the sequence shown in Scheme 1 according to ^{13}C NMR analysis of the reaction mixture (Ln = La, R^1 = Pr^i, R^2 = Ph, R^3 = fluorenyl) in $(CD_3)_2SO$. The reaction of $La(OPr^i)_3$ with 2 equiv. of phenyl isocyanate gives the carbamate-type complex **1** (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 ^{13}C enriched carbon dioxide. After the addition of fluorene, a set of signals

Table 1 Carboxylation of active methylene compounds with the $La(OPr^i)_3$–PhNCO–CO_2 system[a]

Substrate, X = H	Product, X = CO_2Me, yield (%)[b]
1	69,[c] 57, 42,[d] 36[e]
2	66
3	47
4	61
5	16
6	17

[a] $La(OPr^i)_3$, 0.5 mmol; phenyl isocyanate, 1 mmol; DMF, 3 cm^3; substrate, 0.5 mmol; CO_2 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, R^1 = Pr^i, R^2 = Ph, R^3 = fluoren-9-yl; in $(CD_3)_2SO$. ^{13}C NMR data are indicated (δ values).

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

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Footnotes

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

‡ IR(KBr): ν(C=O) 1719 cm^{-1}, ν(N···C···O) 1551 cm^{-1} (For a similar aluminium carbamate-type complex, see T. Hirabayashi, H. Imaeda, K. Itoh, S. Sakai and Y. Ishii, *J. Organomet. Chem.*, 1969, **19**, 299).

§ For $La(OAc)_3$: δ 181.9.

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