

Communication

Formation of carbenoid intermediates in the reaction of ditertibutyl ketone with low-valent titanium reagents

Claude Villiers ^a, Alain Vandais ^b, Michel Ephritikhine ^{a,*}^a Service de Chimie Moléculaire, DSM, DRECAM, CNRS URA 331, CEA Saclay, 91191 Gif sur Yvette, France^b Service des Molécules Marquées, DSV, DBCM, CEA Saclay, 91191 Gif sur Yvette, France

Received 2 August 2000; accepted 1 September 2000

Abstract

Treatment of $t\text{-Bu}_2\text{CO}$ with TiCl_4 and Li(Hg) in THF gave the hydrocarbon $t\text{-Bu}_2\text{CH}_2$ as the major product (40% yield); 60% of the total quantity of $t\text{-Bu}_2\text{CH}_2$ was liberated after hydrolysis of the reaction mixture. Similar experiments with $\text{THF-}d_8$ and D_2O afforded $t\text{-Bu}_2\text{CHD}$ and $t\text{-Bu}_2\text{CD}_2$, indicating that carbenoid species $t\text{-Bu}_2\text{C}=[\text{Ti}]$ are likely intermediates in the reaction of $t\text{-Bu}_2\text{CO}$ with low-valent titanium reagents. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Carbenoid species; McMurry reaction; Ditertibutyl ketone; Low-valent titanium reagents

1. Introduction

Recently we reported that metallocpinacols are not, contrary to generally accepted ideas, the only intermediates in the so-called McMurry reaction, i.e. the reductive coupling of carbonyl compounds into alkenes by means of low-valent titanium reagents [1,2]. Careful analysis of the products obtained by treatment of R_2CO ($\text{R} = \text{Me}, \text{Et}, t\text{-Pr}$) with the $\text{MCl}_4\text{--Li(Hg)}$ system ($\text{M} = \text{Ti}, \text{U}$) revealed that the coupling process could also proceed via a carbenoid species, a route which is followed preferentially by the most sterically encumbered ketones (Scheme 1). Thus, acetone was quantitatively transformed into a uranium pinacolate which was isolated and further deoxygenated into tetramethylethylene; in contrast, tetraisopropylethylene resulting from coupling of $t\text{-Pr}_2\text{CO}$ was not produced from a pinacolate species but rather from a carbenoid intermediate which also explains the formation of 2,4-dimethyl-2-pentene by H migration.

Although the McMurry reaction proved to be very efficient for the synthesis of sterically hindered and strained olefins, it failed in the reductive coupling of ditertibutyl ketone [3,4], and the long awaited tetratertibutylethylene could never be prepared, despite many synthetic approaches [5,6]. We decided however to examine in detail the reactivity of $t\text{-Bu}_2\text{CO}$ towards low-valent titanium reagents, with the hope of gaining further insight into the species which are actually formed under the conditions of the McMurry reaction; the results presented here confirm the formation of carbenoid species in the reaction of sterically encumbered ketones.

2. Results and discussion

Ditertibutylketone (**1**) reacted for 24 h at 20°C in tetrahydrofuran (THF) with TiCl_4 and Li(Hg) in the molar ratio of 1:1:4 to give, after hydrolysis, a mixture of the corresponding alcohol **2** (25%) and alkane **3** (40%) as the major products (Eq. (1)), smaller amounts of the alkenes **4** (20%), **5** (5%) and **6** (8%), and a trace of the cyclopropyl derivative **7** (ca. 1%). These compounds were characterized by their $^1\text{H-NMR}$ and

* Corresponding author. Tel.: +33-1-69086436; fax: +33-1-69086640.

E-mail address: ephri@nanga.saclay.cea.fr (M. Ephritikhine).

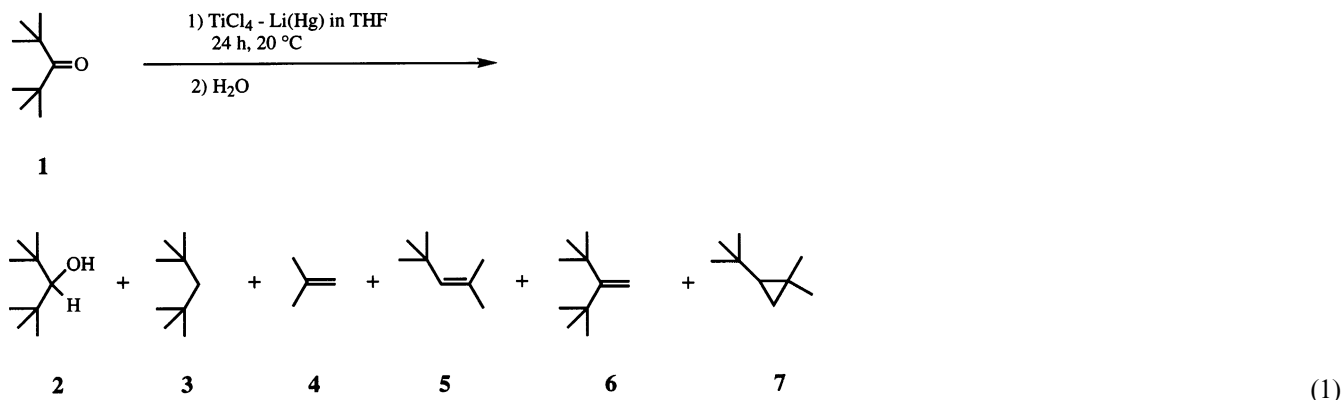


Table 1
Percentages of 3-*d*₀, 3-*d*₁ and 3-*d*₂ produced in the reaction of ^tBu₂CO with the TiCl₄–Li(Hg) system in THF and THF-*d*₈

	Before deuterolysis		After deuterolysis	
	THF	THF- <i>d</i> ₈	THF	THF- <i>d</i> ₈
3- <i>d</i> ₀	100	73	0	0
3- <i>d</i> ₁	0	27	75	60
3- <i>d</i> ₂	0	0	25	40

GCMS spectra which were identical to those of authentic samples. Other minor products, which represent about 1% of the total yield, were not identified.

To our knowledge, formation of these hydrocarbons has never been noticed in such McMurry reactions of **1**, and the alcohol **2** was the only product characterized. However, reduction of ketones into the corresponding alkanes during McMurry reactions was previously observed in a few cases [7]; the mechanism of formation of these alkanes was not elucidated.

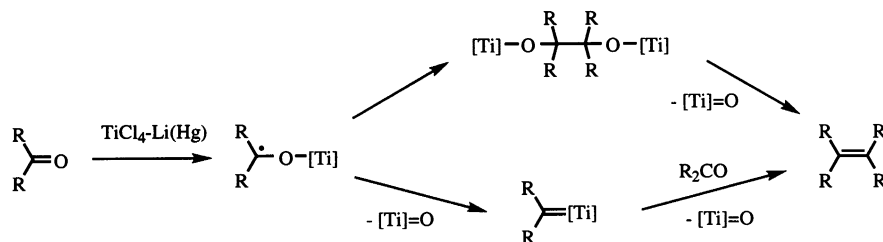
The presence of the cyclopropyl compound **7** among the products provided a strong indication of the involvement of carbenoid species in reaction (1), since **7** was the major hydrocarbon resulting from thermal or photochemical decomposition of the carbene precursors ^tBu₂CN₂PPh₃ [6] or ^tBu₂CN₂ [8].

While the hydrocarbons **3**–**7** were observed before hydrolysis of the reaction mixture, it was important to note that the alkane **3** was also formed, together with the alcohol **2**, upon addition of water (Table 1). In fact,

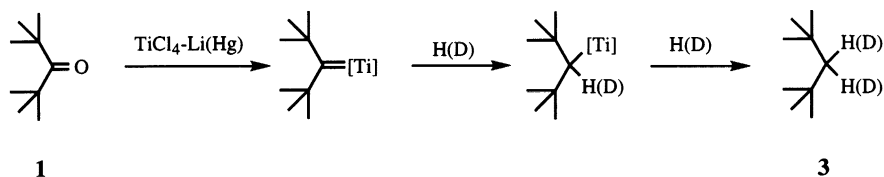
about 60% of the total quantity of **3** was liberated after hydrolysis. Deuterolysis of the reaction mixture led to the formation of ^tBu₂CHD **3**-*d*₁ and ^tBu₂CD₂ **3**-*d*₂ in the ratio 75:25; this ratio was equal to 60:40 when the reaction was performed in THF-*d*₈ and in that case the alkane **3** which was first formed before deuterolysis was partially deuteriated, with [3-*d*₀]:[3-*d*₁] = 73:27. The alcohol **2** produced in each of these experiments was not deuteriated at the 1 position.

Incorporation of deuterium into the fraction of **3** which is liberated upon deuterolysis clearly supports the presence of carbenoid species [Ti]–C[•]Bu₂ in reaction (1); these would be transformed into the alkane, via an alkyl intermediate [Ti]CH[•]Bu₂, by successive addition of H atoms (Scheme 2). The actual carbenoid and alkyl species could not be separated from the alkoxide ^tBu₂CHOM (M = Li or Ti) and their exact composition was not determined. It is possible that such species adopt a dinuclear structure with bridged oxo and alkylidene or alkyl ligands, [Ti]₂(μ-O)(μ-C[•]Bu₂) or [Ti]₂(μ-O)(μ-CH[•]Bu₂), similar to those obtained by reaction of ketones with lanthanide metals or electron-rich metal complexes [9].

Treatment of **1** with the TiCl₄–Li(Hg) system in THF-*d*₈, which afforded non-deuteriated **2** after deuterolysis and partially deuteriated **3** (3-*d*₁:3-*d*₀ = 27:73) in the first step of the reaction, revealed that hydrogen atoms were provided by the ketone. It is quite plausible that formation of H atoms has to be related to that of isobutylene **4** which would itself result from H abstraction from a tertibutyl radical. The lack of C5



Scheme 1. The dual nature of the mechanism of the McMurry reaction.



Scheme 2. Formation of the alkane 3.

hydrocarbons among the products suggests that a $\text{Bu}^\bullet$ radical could not be produced by cleavage of the carbenoid or alkyl species. On the other hand, dissociation of $\text{Bu}^\bullet$ from the ketyl radical would give an acyl derivative $[\text{Ti}]\text{COBu}$ which would be unstable and decompose by decarbonylation into a titanium carbonyl $[\text{Ti}]\text{CO}$ and another $\text{Bu}^\bullet$ radical.

The results presented here confirm that carbenoid species can be readily formed by reaction of sterically hindered ketones R_2CO with low-valent titanium reagents. The first step is the electron transfer from the metal to the carbonyl, giving the ketyl radical $[\text{Ti}]\text{-O-CR}_2^\bullet$ which is further deoxygenated into $[\text{Ti}]=\text{CR}_2$. When $\text{R} = ^i\text{Pr}$, this carbenoid species was found to undergo facile rearrangement by α -H migration into 2,4-dimethyl-2-pentene, the major product, or react with another molecule of ketone to give the coupling alkene, tetraiso-propylethylene; addition of H atoms onto $[\text{Ti}]=\text{C}^i\text{Pr}_2$ also occurred, affording a small amount of $^i\text{Pr}_2\text{CH}_2$ [2]. The carbenoid species issued from **1** exhibited a distinct behaviour since it did not react with the ketone, certainly because of steric hindrance, and its rearrangement into **7** by migration of a β -hydrogen atom was not favoured; the alkane **3** was then formed preferentially. In fact, the species $[\text{Ti}]=\text{C}^i\text{Bu}_2$, which were present in the reaction mixture before hydrolysis, appeared to be much more stable than $[\text{Ti}]=\text{C}^i\text{Pr}_2$, thus permitting a more direct characterization by deuterolysis.

Formation of **5** and **6** is difficult to explain, although it apparently results from CH_2 migration between two ditertiobutylmethylene fragments; we are currently trying to determine the way in which these alkenes are produced. We are also studying the reactions of the carbenoid species $[\text{Ti}]=\text{C}^i\text{Bu}_2$ with various substrates, especially those with aldehydes and ketones which are less sterically encumbered than **1**, in order to prepare cross-coupling products and confirm that such carbenoid species are intermediates in the reductive coupling of carbonyl compounds. This work will be presented in a forthcoming paper.

3. Experimental

3.1. General procedures

All reactions were carried out under argon using

standard Schlenk-vessel and vacuum-line techniques or in a glove box. Solvents were dried and deoxygenated by standard methods and distilled before use. Deuterated solvents were dried over Na–K alloy. The ^1H -NMR spectra were recorded on a Bruker DPX-200 instrument and were referenced internally using the residual protio solvent resonances relative to TMS (δ 0). The GLC analyses were performed on a Chrompack CP 9002 apparatus equipped with a capillary CP Wax 57 CB column. The mass spectra were obtained using a Hewlett–Packard 6890-5973 instrument operating in the ionization mode and equipped with a HP 23 (60 m) chromatography column. The commercial compounds (Aldrich) TiCl_4 and **5** were used as received; lithium amalgam (1.05% Li) was prepared by addition of Li to Hg in boiling *p*-cymene [10]. The hydrocarbons **3** [11], **6** [12] and **7** [6] were synthesized by published methods.

3.2. Reactions of $^i\text{Bu}_2\text{CO}$ with TiCl_4 and Li(Hg)

These reactions were monitored by NMR spectroscopy. In a typical experiment, an NMR tube was charged with TiCl_4 (6.3 μl , 0.058 mmol) and 1.05% Li(Hg) (170 mg, 0.232 mmol Li) in THF or $\text{THF-}d_8$ (0.4 ml). The ketone **1** (10 μl , 0.058 mmol) was introduced into the tube. The mixture was stirred at 20°C for 24 h by attaching the tube perpendicular to the axis of an electrical rotor. The solvent and the volatile products of the reaction were transferred under vacuum into another NMR tube cooled in liquid nitrogen. The NMR, chromatography and mass spectrometry analyses showed the formation of **3** (15%), **4** (20%), **5** (5%), **6** (8%) and **7** (1%). When the reaction was performed in $\text{THF-}d_8$, the ratio $[\text{3-}d_0]:[\text{3-}d_1]$ was equal to 73:27. The non-volatile products of the reaction were deuterolyzed (10 μl of D_2O) in $\text{THF-}d_8$ (0.4 ml), leading to the formation of the alcohol **2** (25%) and the alkane **3** (25%). The ratio $[\text{3-}d_1]:[\text{3-}d_2]$ was equal to 75:25 and 60:40 when the reaction was performed in THF and $\text{THF-}d_8$, respectively.

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