

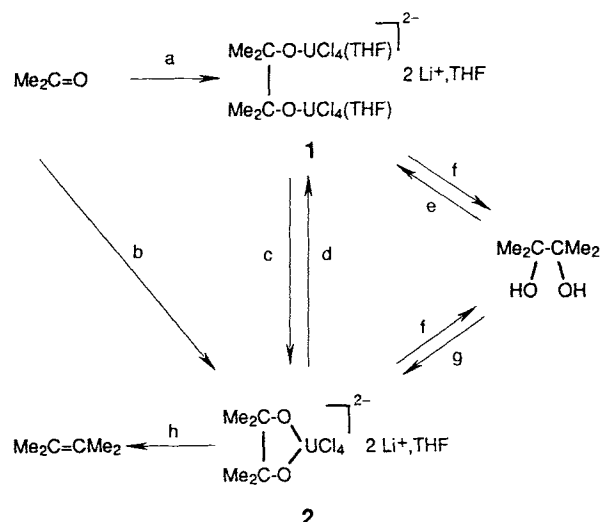
Metallopinacolate Intermediates in the Reductive Coupling of Acetone Promoted by Uranium Reagents

Olivier Maury, Claude Villiers, and Michel Ephritikhine*

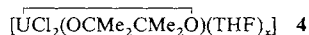
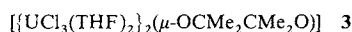
Reductive coupling of carbonyl compounds by means of low-valent metal species is an extremely useful reaction in organic synthesis, and many efforts have been made to improve the efficiency and to understand the mechanisms of these processes.^[1] A number of titanium systems, prepared from TiCl_4 or TiCl_3 and various reducing agents under different conditions, have been used for coupling ketones. The nature of the products, diols or alkenes, was found to depend markedly upon the structure of the active titanium species and the experimental conditions.^[2] A complete rationale for these results is still lacking.^[3] In this context, we thought it of interest to consider the potential of uranium compounds in such transformations. Complexes of uranium and Group 4 elements exhibit strong analogies in structure and reactivity, and highly reactive uranium metal powder was effective in the reductive coupling of aromatic ketones.^[4] Moreover, the paramagnetic uranium complexes can be easily identified by their NMR spectra. They often crystallize readily and are therefore valuable auxiliaries in synthetic organic chemistry.^[5, 6] We reported that benzophenone could be coupled in the presence of uranium tetrachloride and sodium amalgam. For the first time, the pinacolate intermediate previously postulated was isolated, characterized, and transformed into the corresponding alkene, tetraphenylethylene.^[6] Subsequently, we found that aliphatic ketones could also be treated with UCl_4 and Na/Hg or Li/Hg to give pinacols or alkenes in good yields. The reaction of the simplest ketone, acetone, was studied in more detail, and the results reported here provide new insights into the intermediates and elementary steps of the coupling and deoxygenation processes. The influence of the reducing agent in these McMurry-type reactions is also defined.

A solution of acetone in tetrahydrofuran (THF) reacted with UCl_4 and Li/Hg in a molar ratio of 1:1:1 to give the bimetallic pinacolate complex **1** (Scheme 1). The mixture was stirred for 3 h at 20 °C and, after filtration and crystallization, **1** was isolated as a greenish powder in 90% yield. An analogous reaction with the components in a 2:1:2 molar ratio led to the formation of the green mononuclear compound **2**, which was also obtained in almost quantitative yield from **1** and two equivalents of Me_2CO and Li/Hg . Comproportionation of **2** and UCl_4 gave **1**. Unequivocal synthesis of **1** and **2** could be achieved in THF by alcoholysis of the amido(chloro)uranium derivatives $[\text{U}(\text{NEt}_2)_3(\text{THF})]$ and $[\text{U}(\text{NEt}_2)_2\text{Cl}_2]$ ^[7] with pinacol in the presence of LiCl . Compounds **1** and **2** were characterized by their elemental analyses (C, H, Cl) and their ¹H NMR spectra, which exhibit very shifted paramagnetic signals corresponding to the methyl groups, at $\delta = +108$ and $+26$, respectively.^[8]

Other products resulted when sodium amalgam was used in place of Li/Hg . The reaction of acetone with UCl_4 and Na/Hg in the molar ratio of 1:1:1 afforded the neutral metallopinacol **3** as the major product (> 60% yield), and NaCl precipitated. When a molar ratio of 2:1:2 was employed, the main product was the neutral metallopinacol **4** in similar yields. Other compounds resulting from aldolization of the ketone were also



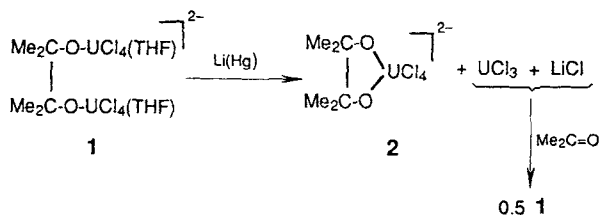
Scheme 1. Synthesis, interconversion, and deoxygenation of the metallopinacols **1** and **2**. Reagents (molar ratios) and reaction times. a) Me_2CO , UCl_4 , Li/Hg (1:1:1), 3 h; b) Me_2CO , UCl_4 , Li/Hg (2:1:2), 8 h; c) **1**, Me_2CO , Li/Hg (1:2:2), 4 h; d) UCl_4 , 1 h; e) $[\text{U}(\text{NEt}_2)_2\text{Cl}_2]$, $\text{Me}_2\text{C}(\text{OH})\text{C}(\text{OH})\text{Me}_2$, LiCl (2:1:2), 2 h; f) H_2O , 10 min; g) $[\text{U}(\text{NEt}_2)_2\text{Cl}_2]$, $\text{Me}_2\text{C}(\text{OH})\text{C}(\text{OH})\text{Me}_2$, LiCl (1:1:2), 2 h; h) 2 Li/Hg , 24 h. All reactions in THF at 20 °C except reaction (h) at 65 °C. The coordination of THF molecules in **1** and **2** is not known; in the formulas here written, uranium is hexacoordinate, as most frequently encountered.



formed and are currently under investigation. These reactions with Na/Hg , which required three days for completion, were much slower than those with Li/Hg . As expected, complexes **3** and **4**, which were synthesized independently by treating $[\text{U}(\text{NEt}_2)_3\text{Cl}_3(\text{THF})]$ and $[\text{U}(\text{NEt}_2)_2\text{Cl}_2]$ with pinacol, were converted into **1** and **2** by addition of LiCl . The bimetallic compound **3** was characterized by its ¹H NMR spectrum, which showed a broad resonance at $\delta = +126$. The derivative $[\{\text{UCl}_3(\text{HMPA})_2\}_2(\mu\text{-OCMe}_2\text{CMe}_2\text{O})]$, prepared by replacement of the THF ligands with hexamethylphosphoric triamide (HMPA), gave satisfactory elemental analyses (C, H, N) and its structure was confirmed by X-ray crystallography.^[9] Complex **4**, which presumably has a polymeric structure with Cl bridges, is insoluble in organic solvents and could not be purified by extraction or crystallization.

Complexes **1–4** are the first metallopinacolate intermediates to be isolated in the reductive coupling of an aliphatic ketone. A bimetallic species similar to **1** and **3** could not be identified in the reactions of benzophenone with the systems UCl_4 and M/Hg ($\text{M} = \text{Li}$ or Na). However, metallopinacols have been synthesized recently by reaction of dialdehydes and ketoaldehydes with tin hydrides^[10] and by treatment of fluorenone with a samarium(II) alkoxide,^[11] these complexes are not intermediates in McMurry-type reactions. Not surprisingly, hydrolysis of **1–4** led to the immediate and quantitative liberation of pinacol. More interesting is the formation of the alkene product, which, as previously demonstrated,^[6] required further treatment of the pinacolate complexes with the reducing agent. In fact, reaction of **1** with one equivalent of lithium amalgam at 20 °C in THF did not afford the alkene but gave after 4.5 h the metallacycle **2** in 85% yield. Since the violet uranium(III) chloride concomitantly formed, LiUCl_4 (or $\text{UCl}_3 + \text{LiCl}$), is precisely that obtained from UCl_4 and Li/Hg , it was not surprising to observe its total conversion into **1** after further addition of one equivalent of acetone (NMR experiments). These results (Scheme 2) confirmed that **1** is an intermediate in the synthesis of **2** and revealed

[*] Dr. M. Ephritikhine, O. Maury, Dr. C. Villiers
Service de Chimie Moléculaire, DSM, DRECAM, CNRS URA 331
CEA Saclay, F-91191 Gif sur Yvette (France)
Fax: Int. code + (1) 69 08 66 40
e-mail: ephri@nanga.saclay.cea.fr



Scheme 2. The role of **1** as an intermediate in the formation of **2**.

two unsuspected points of the reaction mechanism. Firstly, acetone is not involved in the transformation **1** → **2**, which is induced by Li/Hg reduction and generates UCl₃ and LiCl. Secondly, **2** is the true precursor of the alkene, tetramethylethylene. Indeed, **2** was smoothly reduced at 20 °C by Li/Hg to give a not yet identified uranium(III) alkoxide, and complete formation of the alkene could be achieved after the mixture was heated at reflux for 24 h. In agreement with these observations, the reductive coupling of acetone to give pinacol or tetramethylethylene was performed in a one-pot reaction by using the proper quantities of UCl₄ and Li/Hg; the diol was formed by hydrolysis after 8 h at room temperature, whereas the alkene was obtained by heating for 24 h under reflux (quantitative yields by NMR). When the UCl₄ and Na/Hg system was used, the yield of tetramethylethylene did not exceed 10% after 48 h at 65 °C. This difficulty in forming the alkene could be clearly related to the sluggish reduction of the pinacolato intermediate **4**, which was quite inert towards Na/Hg at 20 °C; even after 30 h at 65 °C only about 20% was converted into tetramethylethylene. In contrast, **4** was readily reduced by Li/Hg and transformed completely into the expected alkene after 10 h in refluxing tetrahydrofuran.

We have found that in the reductive coupling of acetone, quite distinct conditions are necessary for both the coupling process leading to the pinacolato intermediates and for the subsequent deoxygenation step giving tetramethylethylene. These differences can be used to achieve remarkable selectivity like that observed with some titanium systems.^[12] The results also underline the major role of the reducing agent, which determines the structure of the intermediates and is of particular importance in the deoxygenation step. If the first intermediate, a bimetallic species with a bridging O(CMe₂)₂O ligand, readily reacts with the reducing agent to give a cyclic mononuclear metallopinacol, only this intermediate is transformed under more forcing conditions into the corresponding alkene.

Experimental Procedure

¹H NMR (TMS int.): Bruker WP60 (60 MHz). All experiments were carried out under argon (<5 ppm oxygen and water) using standard Schlenk-vessel and vacuum-line techniques or in a glove box. Solvents were thoroughly dried and deoxygenated by standard methods and distilled immediately before use.

1: A mixture of UCl₄ (354 mg, 0.93 mmol), 1% Li/Hg (640 mg, 0.93 mmol of Li), and acetone (68 μL, 0.93 mmol) in THF (15 mL) was stirred for 3 h at 20 °C. The green solution was filtered and its volume reduced to 5 mL. The green microcrystals of **1** that precipitated upon addition of pentane (10 mL) were filtered off, washed with pentane, and dried under vacuum (464 mg, 90%).

2: By using the same procedure as for **1**, green microcrystals of **2** were isolated in 76% yield from the reaction of UCl₄ (337 mg, 0.88 mmol), 1% Li/Hg (1215 mg, 1.76 mmol of Li) and acetone (102 mg, 0.51 mmol).

3: A mixture of [U(NEt₂)Cl₃(THF)] (253 mg, 0.51 mmol) and pinacol (30.2 mg, 0.25 mmol) in THF (15 mL) was stirred for 2 h at 20 °C. The green solution was filtered and concentrated to dryness, leaving a green powder, which was washed with pentane and dried under vacuum (256 mg, 92%).

4: A mixture of [U(NEt₂)₂Cl₂] (310 mg, 0.68 mmol) and pinacol (81 mg, 0.68 mmol) in THF (15 mL) was stirred for 2 h at 20 °C. The gray precipitate was filtered off, washed with pentane, and dried under vacuum (328 mg).

Received: January 15, 1996 [Z 87181E]

German version: *Angew. Chem.* **1996**, *108*, 1215–1216

Keywords: McMurry reactions · pinacol derivatives · reductive couplings · uranium compounds

- [1] K. G. Pierce, M. A. Barteau, *J. Org. Chem.* **1995**, *60*, 2405; A. Fürstner, A. Hupperts, *J. Am. Chem. Soc.* **1995**, *117*, 4468; B. Bogdanovic, A. Bolte, *J. Organomet. Chem.* **1995**, *502*, 109; T. Wirth, *Angew. Chem.* **1996**, *108*, 65; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 61, and references therein.
- [2] Y. Dang, H. J. Geise, *Janssen Chim. Acta* **1988**, *6*, 3; J. E. McMurry, *Chem. Rev.* **1989**, *89*, 1513; A. Fürstner, *Angew. Chem.* **1993**, *105*, 171; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 164.
- [3] D. Lenoir, *Synthesis* **1989**, 883.
- [4] B. E. Kahn, R. D. Rieke, *Chem. Rev.* **1988**, *88*, 733; *Organometallics* **1988**, *7*, 463.
- [5] R. Adam, C. Villiers, M. Lance, M. Nierlich, J. Vigner, M. Ephritikhine, *New J. Chem.* **1993**, *17*, 455; R. Adam, C. Villiers, M. Ephritikhine, *Tetrahedron Lett.* **1994**, *35*, 573; C. Villiers, M. Ephritikhine, *J. Chem. Soc. Dalton Trans.* **1994**, 3397.
- [6] C. Villiers, R. Adam, M. Lance, M. Nierlich, J. Vigner, M. Ephritikhine, *J. Chem. Soc. Chem. Commun.* **1991**, 1144.
- [7] J. C. Berthet, C. Boisson, M. Lance, J. Vigner, M. Nierlich, M. Ephritikhine, *J. Chem. Soc. Dalton Trans.* **1995**, 3019.
- [8] ¹H NMR (60 MHz, [D₆]THF, 30 °C). **1**: δ = 108 (Me, *W*_{1/2} = 75 Hz); **2**: δ = 26 (Me, *W*_{1/2} = 50 Hz); **3**: δ = 126 (Me, *W*_{1/2} = 310 Hz).
- [9] O. Maury, C. Villiers, M. Lance, M. Nierlich, M. Ephritikhine, unpublished results.
- [10] D. S. Hays, G. C. Fu, *J. Am. Chem. Soc.* **1995**, *117*, 7283.
- [11] Z. Hou, T. Miyano, H. Yamazaki, Y. Wakatsuki, *J. Am. Chem. Soc.* **1995**, *117*, 4421.
- [12] T. Mukaiyama, T. Sato, J. Hanna, *Chem. Lett.* **1973**, 1041.

Molecular Tweezers as Synthetic Receptors in Host–Guest Chemistry: Inclusion of Cyclohexane and Self-Assembly of Aliphatic Side Chains**

Frank-Gerrit Klärner,* Johannes Benkhoff, Roland Boese, Ulrich Burkert, Markus Kamieth, and Ulf Naatz

Simple synthetic receptors with molecular pockets or cavities can act as models for far more complicated biological systems,^[1] for example they are important for protein folding or molecular recognition of substrates in enzymatic processes. The study of such receptors should provide information about the stability and structure of receptor–substrate complexes and the noncovalent interactions responsible for their formation. Besides the relatively strong and therefore often dominant hydrogen bonding^[1c–h] and the hydrophobic effects^[1d, 2g] in aqueous solutions, the arene–arene interaction^[2] seems to be of some importance. Here we report on syntheses and some supramolecular properties (complex formation and self-assembly) of the novel molecular tweezers^[3] **1a–c**, **2**, and **3**, which because of their rigid ribbon-type structure should be excellently preorganized for the formation of complexes with aromatic guest molecules

* Prof. Dr. F.-G. Klärner, Dr. J. Benkhoff, Dipl.-Chem. U. Burkert, Dipl.-Chem. M. Kamieth, Dipl.-Chem. U. Naatz
Institut für Organische Chemie der Universität Gesamthochschule Essen, D-45117 Essen (Germany)
Fax: Int. code + (201)1833082
e-mail: klaerner@oc1.orgchem.uni-essen.de

Prof. Dr. R. Boese
Institut für Anorganische Chemie der Universität Gesamthochschule Essen (Germany)

** This work was supported by the Deutsche Forschungsgemeinschaft and the Fonds der Chemischen Industrie. We thank H. Bandmann for conducting the NMR experiments and D. Bläser for performing the crystal structure analyses.