

Reaction of *N*-methylidihydropyridines with alkoxy-carbene complexes of chromium and tungsten: sequential use of three carbonyl ligands of Cr(CO)₆ for the formation of polyoxygenated compounds

Henri Rudler,^{*a} Andrée Parlier,^a Blanca Martin-Vaca,^a Eva Garrier^a and Jacqueline Vaissermann^b

^a Laboratoire de Synthèse Organique et Organométallique, UMR 7611, Université Pierre et Marie Curie T44-45, 4 place Jussieu 75252, Paris Cedex 5, France. E-mail: rudler@ccr.jussieu.fr

^b Laboratoire de Chimie des Métaux de Transition, URA 419, Université Pierre et Marie Curie T44-45, 4 place Jussieu 75252, Paris Cedex 5, France.

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N-methylpyridinium ylide complexes obtained from alkoxy-carbene complexes of chromium and *N*-methylidihydropyridines easily insert successively a CO ligand to give α -alkoxy chromium acyl complexes, then a tethered triple bond and two additional CO groups to yield bicyclic butenolides.

The use of stoichiometric amounts of transition metal complexes for the synthesis of organic compounds can only be acceptable if elaborate molecules are obtained and if, ideally, most of the ligands around the metal center can be incorporated in the final products. As examples of such reactions we can cite those involving Fischer carbene complexes for the cyclopropanation of olefins,¹ and for the synthesis of phenols² and pyrrolinones³ from alkynes. As far as the balance of the metal ligands in these reactions is concerned, whereas only one CO ligand is used in the first case to form the carbene group which is then transferred to the double bond, two CO ligands of M(CO)₆ are incorporated in the two latter examples, one for the formation of the starting carbene complexes, the other one for the formation of respectively a phenol and a lactam.

The purpose of this communication is to describe for the first time a straightforward, room temperature triple insertion of CO groups from Cr(CO)₆ via carbene complexes, providing finally polycyclic polyoxygenated compounds *without* the need of external CO.⁴

The starting carbene complexes, containing either a tethered triple or double bond, were prepared from Cr(CO)₆ and W(CO)₆ via known routes.^{5,6} Interaction of **1a** (M = Cr, R¹ = CH₂Ph) (2.02 g, 4.2 mmol) in CH₂Cl₂ (110 ml) at -10 °C, with an excess (3 equiv., 0.84 ml) of a mixture of 1,2 and 1,4 *N*-methylidihydropyridines in CH₂Cl₂ (10 ml) gave after 12 h at room temperature, the tetrahydrobenzofuranones **2a** (0.95 g,

65%) as a 77:23 mixture of two diastereoisomers which could be separated by fractional crystallization into an oil for the major isomer and white crystals (mp 153 °C) for the minor one. The microanalysis confirmed the insertion of two CO groups in the organic ligand of complex **1a**.[†] Both the IR spectrum (ν CO, 1751 cm⁻¹, ν C=C, 1662 cm⁻¹) and the ¹³C NMR spectrum (δ CO, 172.9 and δ C=C, 161.2 and 124.9) were in agreement with the presence of a butenolide. The fitting of the various carbon atoms was established by extensive NMR spectroscopy. The structure of the minor stereoisomer could finally be assessed by an X-ray analysis (Fig 1).[‡] It confirmed the reduction of the starting carbene complex, the insertion of the triple bond and of two CO ligands and also established the stereochemistry of the various substituents with respect to H-7a, the hydrogen at the ring junction. The stereochemistry of the major product could be assessed by ¹H-¹H COSY and NOE experiments: in both compounds, the benzyl group is equatorial and *trans* with respect to H-7a.

Complex **1b** (M = Cr, R¹ = H) behaved similarly and led to a 10:1 mixture of diastereoisomers **2b**, the less abundant being obtained as white crystals, mp 90 °C. Its structure and thus the relative stereochemistry was again established both by NMR and by X-ray crystallography.[§]

When the same reaction was carried out on complex **1a** (M = W, R¹ = CH₂Ph), then the course of the reaction was different: product **3a** was isolated in 62% yield as a 2:1 mixture of isomers which were separated by silica gel chromatography. The NMR data of the minor isomer (yellowish crystals, mp 78 °C) confirmed the presence of a low field singlet at δ 7.70, of two diastereotopic hydrogens of an ethoxy group and of a carbonyl group, δ CO 200.7, belonging to a cyclohexenone.[¶] Confirmation of structure **3** arose again from an X-ray analysis (Fig. 2).[‡] As far as the mechanism of these transformations is concerned, we had already established that alkoxy-carbene

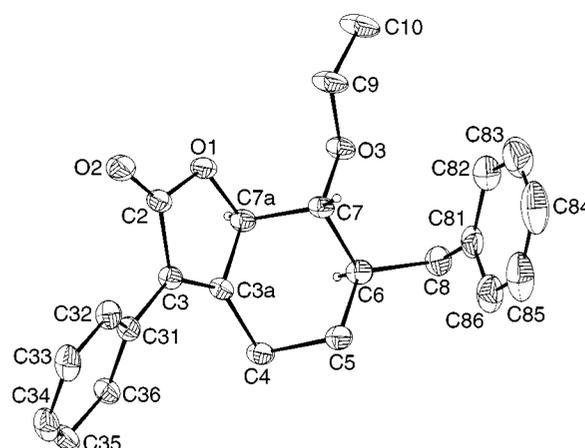
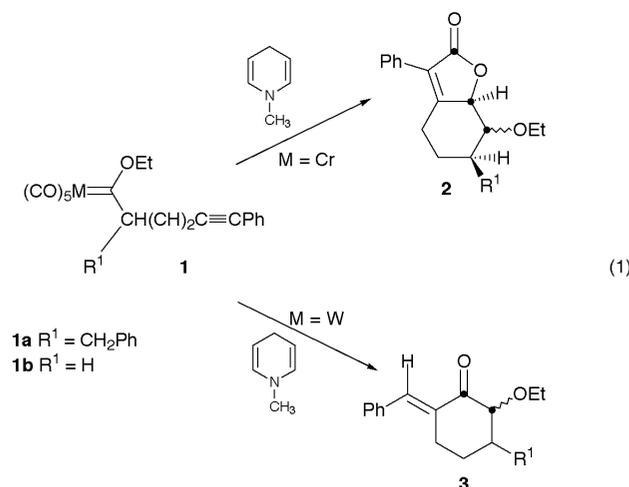


Fig. 1

Bulleted atoms represent those arising from the carbonyl ligands of M(CO)₆

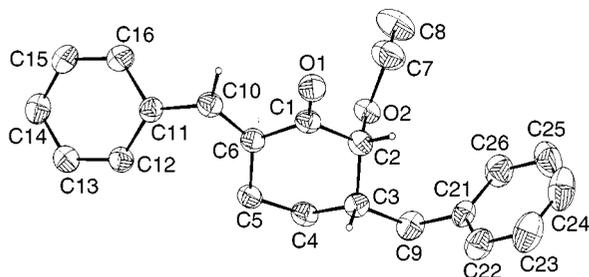
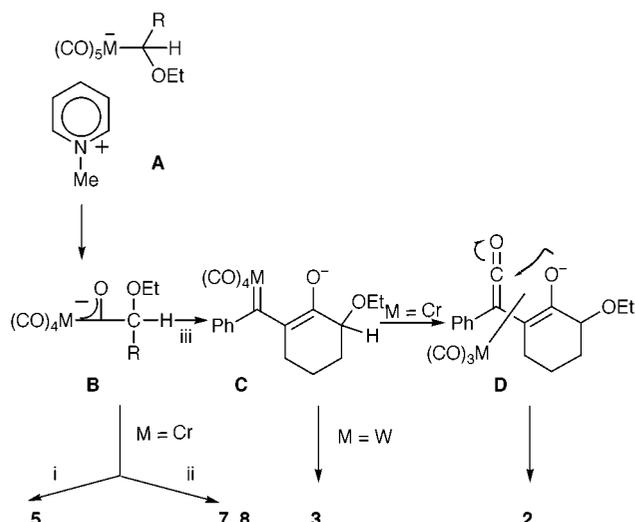


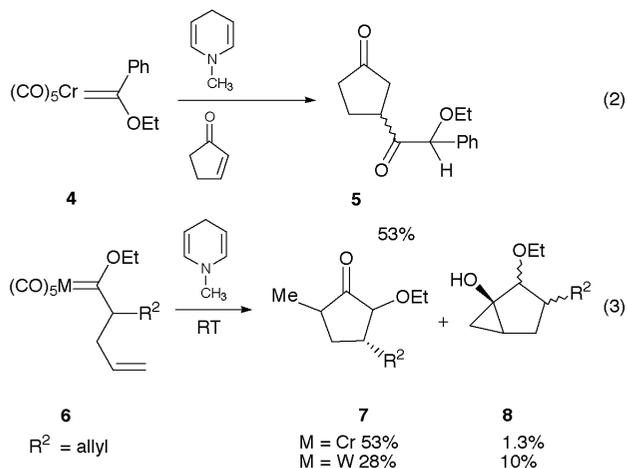
Fig. 2



Scheme 1 i, R = Ph; ii, R = (CH₂)₂CH=CH₂; iii, R = (CH₂)₃C≡CPh.

complexes of chromium and tungsten were reduced by *N*-methylaldihydropyridines into pyridinium metallates **A** (Scheme 1).⁷

Two sets of reactions allowed the assessment of the origin of **2** and **3** starting from the intermediate **A**: first, the reaction of **4** with *N*-methylaldihydropyridines in the presence of cyclopent-2-en-1-one led to the 1,4 dicarbonyl compound **5** in 53% yield. This confirmed the formation of an ethoxy acyl metallate **B** from **A** and its addition to the conjugated ketone.^{8–10}



Second, reaction of complex **6** containing a tethered double bond led to a mixture of two possible products, **7** as the result of its intramolecular cyclopropanation by the oxycarbene function of **B**, and **8**, as the result of its insertion in the metal acyl bond of **B**.

If instead the R group in **A** and **B** contains a triple bond, then its insertion into the metal–carbon double bond of the

oxycarbene complex **B** leads to a new carbene complex **C**: in the case of tungsten, no further reaction but protonation takes place giving **3**.

In the case of chromium, an additional CO insertion occurs leading to a ketene complex **D**. A nucleophilic intramolecular interaction between the oxygen atom and the central carbon of the ketene function, a reaction which has been well established in the case of aminocarbene complexes, will then give the lactone **2**.^{3,10}

Thus, starting from M(CO)₆, and depending on the nature of the metal, either two (M = W) or three CO groups (M = Cr) were inserted leading to elaborate, functionalized molecules. This result confirms again the higher propensity of chromium to induce the insertion of carbonyl ligands and demonstrates for the first time that up to three carbonyl ligands of Cr(CO)₆ can be used as successive building blocks.

Notes and references

† Selected data for **2a**: δ_H 7.46–7.18 (m, 1H, ArH), 4.84 (d, *J* 4, 1H, H-7a), 4.20 (m, 1H, OCH), 3.70 (m, 1H, OCH), 3.35 (dd, *J* 13.5 and 8, 1H, PhCH), 3.00 (dd, *J* 10.2 and 8.2, 1H, H-7), 2.98 (m, 1H, H-4), 2.35 (dd, *J* 13.5 and 9.6, 1H, PhCH), 2.21 (dt, *J* 13.7 and 5, 1H, H-4), 1.96 (m, 2H, H-6, H-5), 1.33 (t, *J* 7.1, 3H, CH₃), 1.07 (m, 1H, H-5); δ_C 172.9, 162.2, 140.1, 129.9–124.9, 86.5, 86.4, 68.3, 43.2, 37.9, 29.4, 25.9, 16.0. Found: C, 79.24; H, 7.00. Calc. for C₂₃H₂₄O₃: C, 79.31; H, 6.89%.

‡ Crystal data for C₂₃H₂₄O₃ **2a**; M = 348.4, monoclinic, space group *Pc*, *a* = 11.198(5), *b* = 6.867(1), *c* = 12.192(18) Å, β = 90.26(7)°, Z = 2, D_c = 1.23 g cm⁻³, μ = 0.75 cm⁻¹. 3075 data collected at room temperature on a Nonius CAD4 diffractometer. No absorption correction was applied. Anomalous dispersion terms and correction of secondary extinction were applied. The structure was solved by direct methods (SHELXS)¹¹ and refined by least-squares analysis using anisotropic thermal parameters for all non-hydrogen atoms. H atoms were located on a difference Fourier map, and only one overall isotropic parameter was refined. 1806 reflections, with *I* < 3σ(*I*) were used to solve and refine the structure to *R* = 0.0511 and *R*_w = 0.0643 (Chebychev weighting scheme), 237 least-squares parameters. The programs used were CRYSTALS and CAMERON. For C₂₂H₂₄O₂ **3a**; M = 320.4, monoclinic, space group *P2₁/n*, *a* = 9.028(4), *b* = 8.436(8), *c* = 24.178(8) Å, β = 99.33(3)°, Z = 4, D_c = 1.17 g cm⁻³. 3663 data collected and structure solved as above with 1319 reflections to *R* = 0.0544 and *R*_w = 0.0645. CCDC 182/1297. See <http://www.rsc.org/suppdata/cc/1999/1439/> for crystallographic data in .cif format.

§ The crystals of **2b** were not satisfactory for a precise X-ray structure determination.

¶ Selected data for **3a**: δ_H 7.70 (s, 1H, =CHPh), 7.30–7.12 (m, 10H, ArH), 4.35–4.27 (dq, *J* 8.9 and 7.0, 1H, OCHH), 3.59–3.51 (dq, *J* 8.9 and 7.0, 1H, OCHH), 3.45 (d, *J* 10, 1H, OCH), 3.23–3.18 (dd, *J* 13.3 and 4.1, 1H, CHHPh), 2.66–2.59 (dtd, *J* 16.2, 4.6, and 1.3, 1H, =CCH), 2.41–2.35 (dd, *J* 13.3 and 9.2, 1H, CHHPh), 2.24–2.19 (m, 1H, CHCH₂), 2.09–2.05 (m, 1H, =CCH), 1.67–1.61 (m, 1H, CHHCH₂), 1.37 (dd, *J* 7 and 7, 3H, CH₃), 1.05–0.99 (m, 1H, CHHCH₂); δ_C 202.2 (CO), 139.5, 137.5, 135.1 (CH=), 130.2, 129.5, 128.6, 128.4, 126.2, 86.0, 67.3, 43.1, 38.7, 27.2, 26.6, 15.5. Found: C, 82.26; H, 7.54. Calc. for C₂₂H₂₄O₂: C, 82.46; H, 7.55%.

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