

## Fischer Carbene Cyclizations

**Nickel(0)-Mediated [3+2+2] and [2+2+2+1] Cyclization Reactions of Chromium Fischer Carbene Complexes and Alkynes\*\***

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Although Fischer carbene complexes of Group 6 metals have demonstrated great potential in synthetic organic chemistry,<sup>[1]</sup> such complexes of late transition metals are almost unknown. Wilke et al.<sup>[2]</sup> and Pinhas and Simunic<sup>[3]</sup> reported the complexes  $[L_2Ni=C(NR_2)Ph]$  and  $[(CO)_3Ni=C(OSiMe_3)Bu]$ , respectively.<sup>[4]</sup> The feasibility of the transmetalation reaction

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[<sup>†</sup>] X-ray crystal structure analysis.

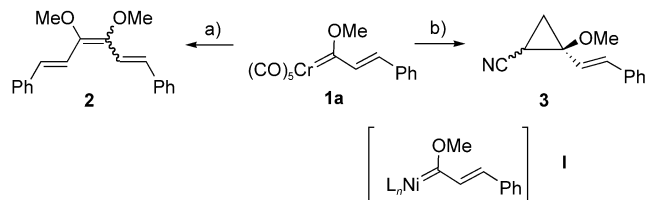
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Supporting information for this article is available on the WWW under <http://www.angewandte.org> or from the author, and includes experimental procedures, spectral and analytical data for all products, and X-ray data for compounds **5b** and **8e**.

as a route to these carbene complexes has been studied by us<sup>[5]</sup> and others.<sup>[6–8]</sup> Because of our interest in this area, as well as the importance of nickel carbene complexes as catalysts in carbon–carbon bond formation,<sup>[9]</sup> we explored the reactivity of chromium Fischer carbene complexes toward alkynes in the presence of Ni<sup>0</sup> complexes, which allowed us to discover a new synthetic potential for chromium carbene complexes.

First, the active role of nickel was seen (Scheme 1) in the formation of dimer **2** (1:1 *Z/E* mixture, 90 %) from complex **1a** and [Ni(cod)<sub>2</sub>] (cod = 1,5-cyclooctadiene; 10 mol %, THF,



**Scheme 1.** Ni<sup>0</sup>-catalyzed dimerization and cyclopropanation of chromium carbene complex **1a**. Reagents and conditions: a) [Ni(cod)<sub>2</sub>] (10 mol %), THF, 25 °C, 2 h, 90 %; b) acrylonitrile, [Ni(cod)<sub>2</sub>] (10 mol %), MeCN, 25 °C, 3 h, 85 %.

2 h), and of cyclopropane **3** (1:1 *cis/trans* mixture, 85 %) from **1a**, acrylonitrile, and [Ni(cod)<sub>2</sub>] (10 mol %, MeCN, 25 °C, 3 h). Neither reaction occurs in the absence of nickel catalyst. On the basis of previous reports<sup>[5,10]</sup> we realized that some nickel alkoxycarbene species **I** might act as the active nickel intermediate.<sup>[11]</sup>

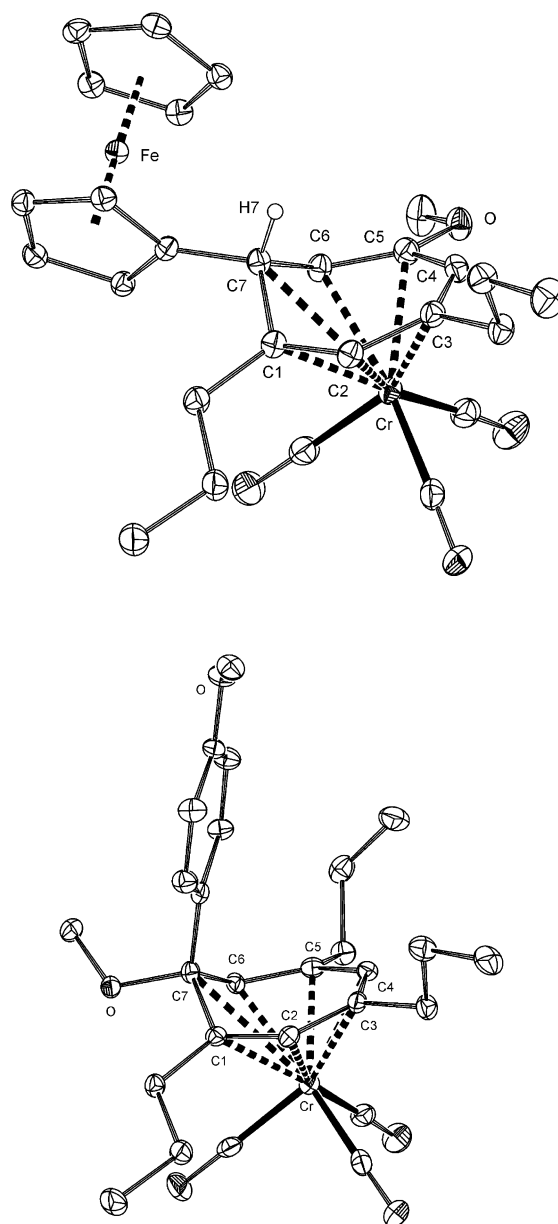
Therefore, we decided to investigate whether the hypothetical alkoxycarbene complex **I** might display a new type of carbene reactivity. Among a number of unsaturated substrates, we selected alkynes since their thermal reaction with chromium carbene complexes to give substituted phenols—the so-called benzannulation or Dötz reaction—is the most emblematic reaction of Fischer carbene complexes.<sup>[12]</sup> Thus, alkenyl carbene complexes **1** were mixed with terminal alkynes **4** at –10 °C in acetonitrile in the presence of a stoichiometric amount of [Ni(cod)<sub>2</sub>]. The reaction mixture was allowed to warm to 20 °C over 2 h. Removal of the solvent and column chromatography of the residue afforded cycloheptatriene tricarbonyl chromium(0) complexes **5** in good yields (Table 1, entries 1–6). In the case of phenylacetylene (entry 7), a mixture of **5g** (30 % yield) and decomposed cycloheptatriene **6g** (40 % yield) was formed. This nickel-mediated [3+2+2] cyclization of Fischer carbene complexes and alkynes takes place with complete regio- and stereo-selectivity, the *endo* isomer being solely formed. Electron-poor alkynes also undergo this cyclization; for example, methyl propynoate affords the functionalized cycloheptatriene **6h** (entry 8). Phenol derivatives arising from the Dötz reaction were usually detected in less than 5 % yield, while no higher oligomerization products were observed in the crude reaction mixtures.

The *endo* configuration of compounds **5** is based on the <sup>3</sup>J<sub>H6,H7</sub> coupling constant (3.3–4.4 Hz),<sup>[13]</sup> and the unambiguous structure of **5b** was determined by an X-ray analysis (Figure 1).<sup>[14]</sup>

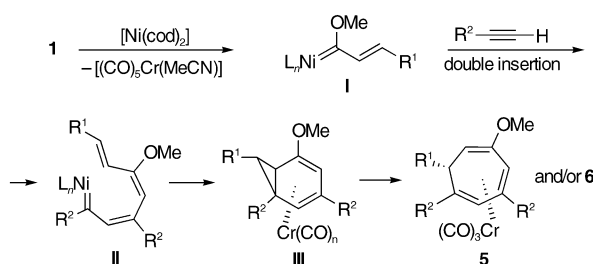
**Table 1:** [3+2+2] cyclization of chromium alkenyl carbene complexes **1** with alkynes **4**.

entry	R <sup>1</sup>	R <sup>2</sup>	<b>5</b> [%] <sup>[b]</sup>	<b>6</b> [%] <sup>[b]</sup>
1	Ph	<i>n</i> Pr	<b>5a</b> (86)	–
2	ferrocenyl	<i>n</i> Pr	<b>5b</b> (73)	–
3	2-furyl	<i>n</i> Pr	<b>5c</b> (76)	–
4	<i>n</i> Pr	<i>n</i> Pr	<b>5d</b> (62)	–
5	Ph	Me <sub>3</sub> Si	<b>5e</b> (80)	–
6	Ph	(CH <sub>2</sub> ) <sub>3</sub> CN	<b>5f</b> (78)	–
7	2-furyl	Ph	<b>5g</b> (30)	<b>6g</b> (40)
8	Ph	CO <sub>2</sub> Me	–	<b>6h</b> (75)

[a] MeCN, 1:4:[Ni(cod)<sub>2</sub>] 1:3:1.1, –10 to 20 °C, 2 h. [b] Yields of isolated products.



**Figure 1.** Top: ORTEP plot (30 % ellipsoids) for **5b**; bottom: ORTEP plot (30 % ellipsoids) for **8e**.



**Scheme 2.** Proposed mechanism for the formation of **5** and **6**.

A possible pathway for the formation of **5** is depicted in Scheme 2. First, chromium–nickel exchange forms the nickel species **I** (where L denotes cod, MeCN, or alkyne).<sup>[15]</sup> Formation of the pentacarbonyl(acetonitrile)chromium(0) complex is expected to facilitate metal exchange.<sup>[5]</sup> The nickel complex **I** undergoes a double regioselective alkyne insertion<sup>[16]</sup> to produce the new nickel carbene complex **II**, which then cyclizes to give **5** and/or **6**. This cyclization probably proceeds by intramolecular cyclopropanation (see Scheme 1) to form the norcaradiene species **III**, which isomerizes to the cycloheptatriene ring.<sup>[17]</sup>

We were further intrigued whether 1-nickela-1,3,5,7-octatetraenes of type **II** might also be available by assembling simple chromium carbene complexes **7** and three alkyne units. This goal was achieved by using terminal alkynes **4** and [Ni(cod)<sub>2</sub>] (1.1 equiv), which, under the reaction conditions given above, gave complexes **8** in high yields (Table 2). In this

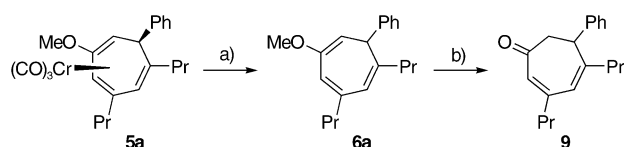
**Table 2:** [2+2+2+1] cyclization of chromium carbene complexes **7** with alkynes **4**.

entry	R <sup>1</sup>	R <sup>2</sup>	<b>8</b> [%] <sup>[b]</sup>	syn:anti <sup>[c]</sup>
1	Me	nPr	<b>8a</b> (92)	> 98:2
2	Me	Me <sub>3</sub> Si	<b>8b</b> (65)	> 98:2
3	Me	(CH <sub>2</sub> ) <sub>3</sub> CN	<b>8c</b> (96)	> 98:2
4	c-C <sub>3</sub> H <sub>5</sub>	nPr	<b>8d</b> (75)	> 98:2
5	p-MeOC <sub>6</sub> H <sub>4</sub>	nPr	<b>8e</b> (83)	> 98:2
6	2-furyl	nPr	<b>8f</b> (86)	90:10
7	Ph	nPr	<b>8g</b> (68)	60:40

[a] MeCN, **7**:**4**:**[Ni(cod)<sub>2</sub>]** 1:4:1.1, –10 to 20 °C, 2 h. [b] Yields of isolated products. [c] <sup>1</sup>H NMR spectroscopy (300 MHz) on the crude reaction mixture.

novel [2+2+2+1] cyclization three consecutive alkyne insertion reactions are efficiently accomplished in a regioselective manner. The *syn* isomer was found to be the sole (entries 1–5) or the major isomer (entries 6 and 7). The structural assignment of *syn*-**8a–d** was based on NMR spectroscopic data. Moreover, an X-ray analysis was performed on compound **8e** (Figure 1).<sup>[14]</sup>

Apart from the synthetic importance of the cycloheptatriene chromium complexes,<sup>[18]</sup> the corresponding metal-free



**Scheme 3.** Decomplexation of **5a** and hydrolysis of **6a**. Reagents and conditions: a) CO (35 bar), MeCN, 25 °C, 48 h, quantitative; b) 1 N HCl, THF, 25 °C, 2 h, 95 %.

systems are readily accessible by CO exchange (Scheme 3). For instance, cycloadduct **5a** was demetalated under CO pressure (35 bar, MeCN, 25 °C, 48 h) to provide **6a** quantitatively, which was in turn hydrolyzed (1 N HCl, THF, 25 °C, 2 h) to give ketone **9** (95 % yield).

In conclusion, we have reported a novel reactivity pattern for chromium Fischer carbene complexes. Specifically, [3+2+2] and [2+2+2+1] cyclization reactions, which are rarely found in the literature,<sup>[19,20]</sup> between these complexes and alkynes are very efficient in the presence of Ni<sup>0</sup>. These reactions are based on a facile chromium–nickel exchange and on the particular reactivity of the assumed nickel carbene species. In this context, some points are noteworthy: 1) the new Fischer alkoxy carbene complexes of nickel(0) readily undergo consecutive alkyne insertion reactions, 2) the first cyclopropanation reaction of nickel carbene complexes is reported here, and 3) no heptannulation reactions mediated or catalyzed by nickel carbene species have been hitherto reported.<sup>[16a]</sup>

Thus, the reactivity of Fischer carbene complexes can be modified not only in a quantitative way,<sup>[8]</sup> but also in a qualitative manner. The synthetic potential of Fischer carbene complexes should be expandable by combination with appropriate transition metals. Further work to develop a catalytic process<sup>[21]</sup> and to design an asymmetric version of the reaction is underway.

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**Keywords:** alkynes · carbene ligands · chromium · cyclization · nickel

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