

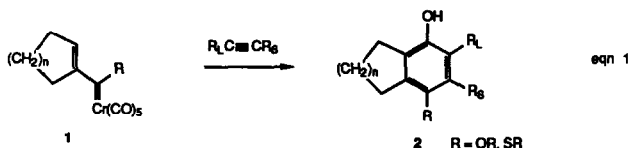
THE *IN SITU* GENERATION OF NON-STABILIZED CARBENE COMPLEXES VIA INTRAMOLECULAR ACETYLENE INSERTION: A NEW TWO-ALKYNE ANNULATION AND A NEW PREPARATION OF γ -KETO ESTERS

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Abstract: Non-heteroatom stabilized carbene complexes can be generated in solution by mild thermolysis (50^o C) of 4-hexynyl and 5-heptynyl (methoxymethylene) complexes of chromium and tungsten pentacarbonyl. These intermediates react with acetylenes to give a new type of two-alkyne annulation product. In the absence of acetylenes, these intermediates can be trapped with methanol as their carbonylated products which results in a new synthesis of γ -keto esters.

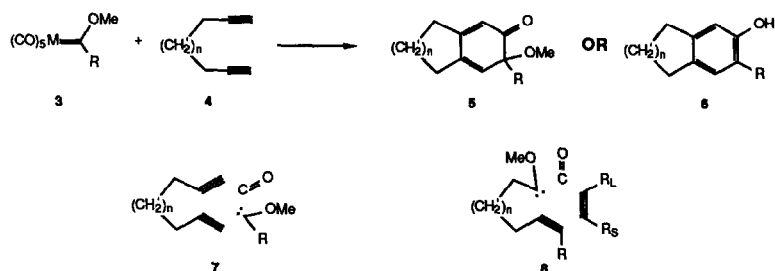
The reactions of the pentacarbonyl carbene complexes of the group 6 metals with acetylenes are of established utility in synthetic organic chemistry which in large part is due to the fact that under the proper conditions they produce functionalized aromatic rings in a regioselective manner in high yields under neutral conditions at near ambient temperatures.¹ In addition to the benzannulated products, these reactions also produce four and five-membered ring products, heteroaromatic and non-aromatic six-membered ring products that have potential in organic synthesis. As indicated by the structure 1, the benzannulation reaction requires that one of the substituents of the carbene-carbon in these complexes be α,β -unsaturated, and the other substituent is ancillary in that it does not participate in the reaction and simply becomes a substituent in the annulated product 2. The ancillary substituent must be either oxygen or sulfur^{1a,2} since those complexes bearing carbon are not normally stable, and in the few complexes that are stable (diaryl), the benzannulation reactions do not appear to be useful.⁴



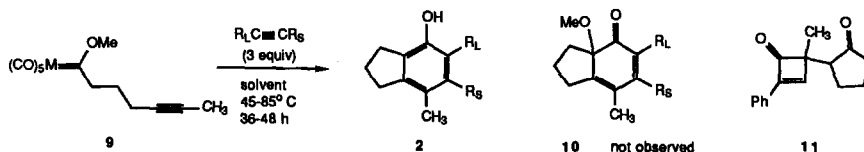
A possible solution to the limited range of R in complex 1 in the normal benzannulation indicated in equation 1 can be envisioned from a consideration of the two-alkyne annulation of group 6 carbene complexes. We have previously reported that a group 6 pentacarbonyl carbene complex will react with a diyne with incorporation of both acetylene functional groups leading to the isolation of either the bicyclohexa-2,4-dienone 5 or the bicyclic phenol 6.^{1a,5} Without a consideration of the mechanism, the dienone product 5 can be seen to be the overall result of the assembly of the pieces

indicated in 7. As is illustrated by the assembly 8, a permutation of the pieces in 7 should lead to the construction of the phenol 2 and in contrast to the reaction in equation 1, it is expected that the acetylene substituent R would not be limited to heteroatomic groups. We report herein the first examples of an intra/intermolecular two-alkyne annulation leading to phenols of the type 2 according to the construction indicated in 8.⁶

Scheme 1



The intra/intermolecular two-alkyne annulations of the chromium and tungsten 4-hexynyl complexes **9a** and **9b** (which can be efficiently prepared by alkylation)^{5b} with various acetylenes is presented in Table I. These reactions give variable yields of the phenol **2**, and no case could the non-reduced product **10** be isolated. The mass balance of these reactions is low and except where indicated no other minor products could be isolated from elution of the crude reaction mixture from silica gel. The efficiency of phenol production is solvent and metal dependent and these two factors are interestingly complimentary. The best results for the chromium complex **9a** is with acetonitrile as solvent which gives a 43 % of **2**, whereas the same reaction in THF gives only a 7 % yield of **2**. Almost the opposite results are observed for the tungsten complex **9b**, with the exception that in this case the cyclobutenone **11** is also formed.^{1,3b} The reasons for the low yields and the effects of the metal and solvent on the reaction are not understood at this time.

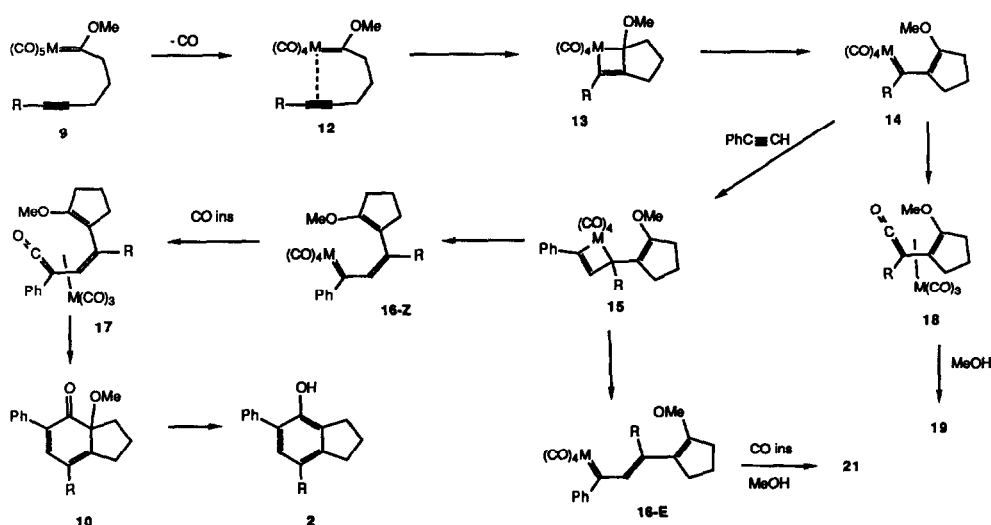
Table I Two-Alkyne Annulation of Complexes **9a** and **9b**.

complex	M	R _L	R _S	solvent	phenol	% yield 2
9a	Cr	Ph	H	THF	2a	7
9a	Cr	Ph	H	CH ₃ CN	2a	43
9b	W	Ph	H	THF	2a	50 ^a
9b	W	Ph	H	CH ₃ CN	2a	8 ^b
9b	W	Ph	Ph	THF	2b	7
9b	W	<i>n</i> -Bu	H	THF	2c	26 ^c

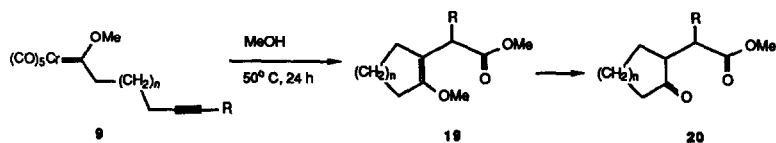
^aA 24 % yield of a mixture of isomers of triphenylbenzene was also obtained. ^bA 40 % yield of the cyclobutenone **11** was also obtained. ^cA 42 % yield of a mixture of isomers of tri-*n*-butylbenzene was also obtained

The mechanism for this new intra/intermolecular two-alkyne annulation that is presented in Scheme II is reconstructed from what has been proposed¹ for the normal benzannulation (equation 1) but it should be pointed out that there are other mechanistic possibilities that can account for the formation of the phenols **2** and these will be considered and discussed in subsequent publications. Dissociation of carbon monoxide from the starting complex opens a coordination site setting the stage for the formation of a carbon-carbon bond between the carbene-carbon and the acetylene carbon that results in the formation of the metallacycle **13**. Electrocyclic ring-opening gives the intermediate **14** which is formally the result of an overall acetylene insertion into the metal-carbene bond of **9**, a process that generates *in situ* complexes of the type **1** which are not preparable when R is not a heteroatom.⁷ A repetition of this process in an intermolecular fashion generates the intermediate **16**, from which the phenol products can be accounted for by carbon monoxide insertion, electrocyclic ring-closure and an *in situ* reduction.

Scheme II

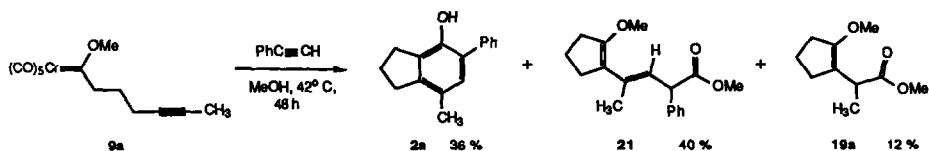


In order to probe whether the low yields of the phenols **2** are the result of events occurring in the first or second alkyne incorporation, the experiments summarized in Table II were performed. It was thought that if the intermediate **14** did not have access to an external acetylene, that a carbon monoxide insertion would occur to generate the vinyl ketene complex **18**, the trapping of which with methanol^{1a,8} may perhaps give an idea of the efficiency of the intramolecular acetylene insertion. The complex **9a** gave a 73 % yield of the methanol trapping product **19a** indicating that the first alkyne insertion for this complex is quite facile. This also was found to be true for five of the six complexes examined, and the data in Table II suggest that these reactions may be useful for the synthesis of γ -keto esters. The reaction of the complex **9a** with phenyl acetylene in the presence of methanol reveals that it is likely that the source of the problem in this two-alkyne annulation occurs after the second alkyne is incorporated and at the point of the electrocyclic ring-opening of the chromacyclobutene intermediate **15** which is not selective for the Z-isomer of **16** which is required for cyclization to occur. The mass balance of this reaction is high (88 %) and in addition to the phenol **2a** and the ester **19a**, only the E-isomer⁹ of the trapping product of the ketene intermediate **17** was observed. Further studies on the mechanism and synthetic potential of this intra/intermolecular two-alkyne annulation reaction are in progress.

Table II. γ -Keto Esters from an Intramolecular Acetylene Insertion/Carbonylation of Complex 9.

complex	R	n	product	% yield
9a	CH ₃	1	19a	73
9c	C(CH ₃)CH ₂	1	19b	81 ^a
9d	Ph	1	19c	75 ^b
9e	H	1	20a	11
9f	SiMe ₃	1	20a ^c	78 ^d
9g	CH ₃	2	19d	58

^a19b was isolated as a 6:1 mixture of two compounds that was the result of substantial (98 %) conjugation of the double-bond in the R group. ^b16 % of the isolated material had a chromium tricarbonyl bound to the phenyl ring. ^cR = H. ^done-third of the isolated product was obtained as the dimethyl ketal.



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