Dirhodium(II) Tetraacetate-Mediated Decomposition of Ethyldiazoacetate and Ethyldiazomalonate in the Presence of Fullerene. A New Procedure for the Selective Synthesis of [6-6]-Closed Methanofullerenes

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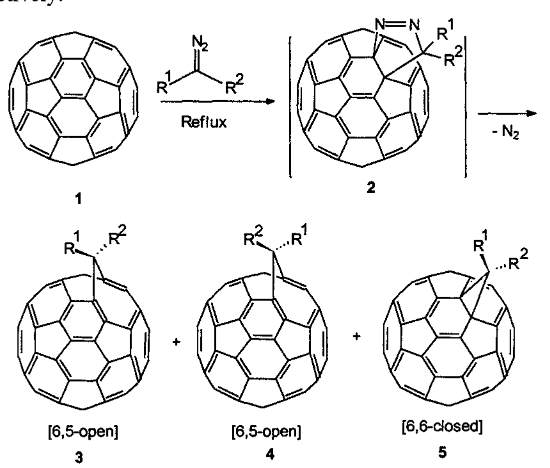
Received 27 June 1997

Abstract: The reaction of C_{60} fullerene with carboalkoxycarbenoids generated by $Rh_2(OAc)_4$-catalyzed decomposition of α-diazoester precursors is reported. This reaction is the first example of a transition metal catalyzed carbenoid reaction with fullerene and represents a significative improvement in terms of reaction conditions, selectivity of the products obtained, and yields over previously reported methods.

The possibility to utilize fullerene derivatives in fields ranging from medicine to material sciences motivates a continuing quest for synthetic methodologies aimed at the functionalization of this new allotropic form of carbon endowed with an unusual chemical profile.[1] The chemistry of C_{60} (**1**) is indeed largely governed by its unique properties of electron-deficient polyolefin able to undergo [*n*+2] cycloadditions with a number of nucleophilic species.[2] Diazo compounds, in particular, have been shown to react with C_{60} (**1**) to give a variety of synthetically versatile substituted methanofullerenes.[3] In 1991, Suzuki and Wudl first reported that the thermal addition of diphenyldiazomethane to C_{60} fullerene[4] affords a mixture of three products, identified as the two [6-5]-open fulleroids (**3**) and (**4**) and the [6-6]-closed methanofullerene (**5**), respectively.[5]



Scheme 1

The same methodology has subsequently been extended to α-diazoacyl compounds, including α-diazoesters,[6] α-diazoamides,[7] and α-diazoketones.[8] In all the examples so far reported, the reaction of diazo compounds with C_{60} (**1**) has been described as a formal [3+2] cycloaddition proceeding through the formation of the pyrazoline intermediate **2** resulting from the addition of the diazocarbonyl compounds to the [6-6] double bond,[9] followed by thermal extrusion of nitrogen from the pyrazoline ring to give a mixture of three isomers, among which the kinetically favored [6-5]-fulleroids (**3**) and (**4**) are predominantly formed. The transformation under thermal conditions of the fulleroid (**3**) and (**4**) into the thermodynamic product [6-6]-methanofullerene (**5**) has also been described.[9]

Organofunctionalization of C_{60} (**1**) with Fischer-type carbene complexes such as (methyl(methoxymethylene)-pentacarbonyl-chromium[10] or with carbenes generated by thermal decomposition of diazirines[11] or oxadiazolines[12] has also been studied and shown to lead to the selective formation of the corresponding [6-6]-methanofullerene derivatives.

As a part of an ongoing project aimed at the preparation of biologically active fullerene derivatives, we have directed our attention to the reaction, so far unreported, of C_{60} (**1**) with carboalkoxycarbenoids generated by dirhodium(II) tetraacetate catalyzed decomposition of diazocarbonyl precursors such as ethyldiazoacetate (EDA) and ethyldiazomalonate (EDM).[13]

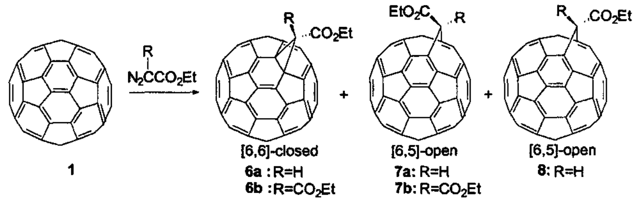
Results and Discussion

The reaction of C_{60} with EDA in the presence of dirhodium(II) tetraacetate was investigated first and compared with the thermal addition of EDA to C_{60} (**1**) reported by Diederich *et al.*[14] in 1993 (Table 1, entry 1). Numerous conditions were examined and after considerable experimentation we found that the highest yields and selectivities of formation of carboalkoxymethanofullerenes are obtained by using a stoichiometric amount of dirhodium(II) tetraacetate in α-methylnaphthalene (Table 1). Crucial to the outcome of the reaction are the amount of $Rh_2(OAc)_4$ and the solvent employed. Indeed, when catalytic (i.e. 20% w/w) instead of stoichiometric amounts of dirhodium(II) tetraacetate were utilized, the yield of conversion decreased dramatically. Furthermore, solvent insertion reactions become predominant with respect to C_{60} addition if solvent favoring carbenoid insertion (i.e. toluene or xylene) are used. In any cases, however, solvent insertion reactions and dimerization of carboalkoxycarbenoid intermediates could not be avoided but their formation was minimized by controlling parameters such as the rate of addition of the diazo compound to the reaction mixture and choosing solvents relatively inactivated towards carbenoid insertion.

The best results were obtained when the reaction between C_{60} (**1**) and EDA was carried out in α-methylnaphthalene as solvent at rt in the presence of an equimolar amount of dirhodium(II) tetraacetate (Table 1, entry 3).[15] Thus, 12.5 equivalents of ethyldiazoacetate were added dropwise within 8 h to a magnetically stirred solution of fullerene / $Rh_2(OAc)_4$ 1:1 in α-methylnaphthalene. Evaporation of the solvent, chromatography of the residue and elution with hexane / toluene (9:1, then 1:1) afforded in 42 % yield a methanofullerene product identified by ^1H-NMR as the [6-6]-closed carboethoxymethanofullerene (**6a**). HPLC analysis revealed **6a** in 98% with trace amounts (<2%) of [5-6]-open fulleroids **7a** and **8a**. The dirhodium(II)-catalyzed addition of EDA to C_{60} (**1**) therefore represents a considerable improvement either in terms of yield or product selectivities over the corresponding thermal decomposition, which afforded in overall 35% yield a 1:4:2 mixture of [6-6]-closed methanofullerene (**6a**) and [5-6]-open fulleroids (**7a** and **8a**), respectively (Table 1, entry 1).[14]

The reaction with the less reactive ethyldiazomalonate (EDM) was also investigated. The thermal addition of EDM to C_{60} (**1**) was first studied by Diederich and shown to require strong conditions (110°C, 20h in refluxing toluene) yielding a mixture of the corresponding [6-6]-closed biscarboethoxymethanofullerene (**6b**) and [5-6]-open fulleroid (**7b**)

Table 1. Comparison between thermal and $Rh_2(OAc)_4$-catalyzed decomposition of EDA and EDM in the presence of fullerene

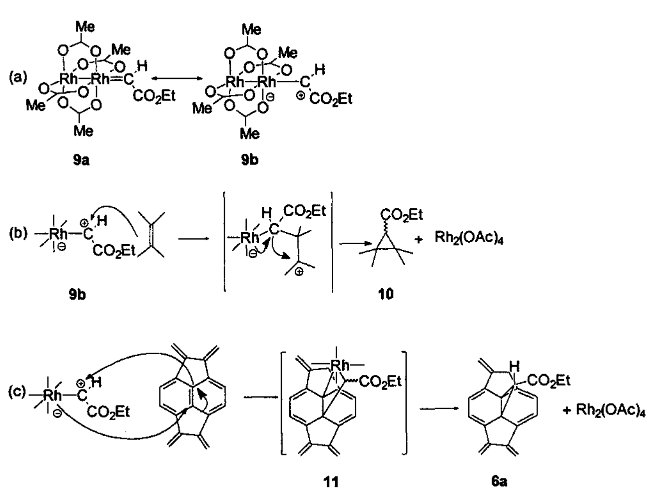


Entry	Condition	R	Solvent	T (°C)	t (h)	Yield (%)	Ratio 6	7	8
1.	Thermal[a]	H	PhMe	110	7	35	1	4	2
2.	Rh-stoich.	H	PhMe	rt	20	21	14	1	1
3.	Rh-stoich.	H	1MeNap	rt	8	42	52	1	-
4.	Thermal[a]	CO_2Et	PhMe	110	20	10		N.D[c]	
5.	Rh-stoich.	CO_2Et	1MeNap	80	32	33	9	1	-

[a] See ref. 14. [b] See ref. 16. [b] not determined

with a yield of conversion low (10 %, Table 1, entry 4).[16] In our case, when EDM was added to an equimolar solution of C_{60} fullerene (**1**) and $Rh_2(OAc)_4$ in α-methylnaphthalene kept at 80°C (Table 1, entry 5)[17], [6-6]-closed bis-carboethoxymethanofullerene (**6b**) was obtained as the only reaction product in 33% yield, significantly higher than that obtained in the thermal decomposition of EDM in the presence of fullerene.[16,18]

The mechanism of the dirhodium(II)-mediated cyclopropanation of C_{60} (**1**) is intriguing. Currently accepted mechanisms[19] for the dirhodium(II)-mediated cyclopropanation of olefins by diazo compounds involve the formation of a metal-carbenoid complex as a reactive intermediate. This intermediate can be represented as a metal-stabilized carbocation (**9b**) where the carbenoid α-carbon atom is the electrophilic center which undergoes nucleophilic attack by the electron-rich double bond of olefins on route to cyclopropane **10**.[19] A similar mechanism can be excluded in our case in view of the electrophilic nature of the 6-6 double bonds of fullerene. A mechanistic rationale that can account for the predominant formation of the [6-6]-methanofullerenes **6a** and **6b** involves the formation of a rhodium-based metallocycle **11** resulting from the nucleophilic attack of the rhodium atom directly connected to the carbene carbon atom to the 6-6-double bond (Scheme 2). Previously, an analogous mechanism was proposed by Wenkert *et al.* to explain the results of the dirhodium(II)-catalyzed decomposition of ethyldiazoacetate in the presence of furan.[20]



Scheme 2

In summary, we describe here the first example of a transition metal catalyzed carbenoid addition of α-diazoesters to C_{60} fullerene (**1**). In view of the mildness and high specificity, this methodology can usefully be employed in the selective synthesis of carboalkoxy-substituted [6-6]-methanofullerenes. Further studies to extend the scope of this reaction and to better define its mechanistic details are in progress.

References and Notes

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(13) In the only previously reported related example, the reaction of C_{60} (**1**) with diazomethane in the presence of $Pd(OAc)_2$ was shown to give the [6-6]-closed methanofullerene in low yield: A. B. Smith III, R. M. Strongin, L. Brard, G. T. Furst, W. J. Romanow, K. G. Owens, R. J. Goldschimdt, R. C. King, *J. Am. Chem. Soc.* **1995**, *117*, 5492.

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(15) Typical procedure for **6a**: A solution of 11.9 mg (1.04 mmol) of ethyldiazoacetate in anhydrous α-methylnaphthalene (10 mL) was added within 8h at room temperature via syringe pump to a magnetically stirred solution of C_{60} fullerene (**1**) (150 mg, 0.208 mmol) and $Rh_2(OAc)_4$ (92 mg, 0.208 mmol) in anhydrous α-methylnaphthalene (60 mL). The solvent was evaporated under vacuum (0.8 Torr, 74°C) and the resulting solid was added with 10 g of silica (70-230 mesh) in toluene and then concentrated. The resulting solid was poured on the top of a silica gel column and eluted first with hexane / toluene (9 : 1) to remove residual C_{60} fullerene (**1**) (10 mg) and then with hexane / toluene (1 : 1). The major product fraction (70 mg) was isolated and characterized as carboethoxy-[6-6]-methanofullerene (**6a**) (42% yield). The purity of carboethoxy-[6-6]-methanofullerene (**6a**) was established to be higher than 98% by HPLC. Spectral data (^{1}H-NMR and ^{13}C-NMR) are in agreement with those previously reported.[14]

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(17) Typical procedure for compound **6b**: A solution of 774 mg (4.16 mmol) of ethyldiazomalonate in anhydrous α-methylnaphthalene (40 mL) was added within 32h at 80 °C via syringe pump to a

magnetically stirred solution of C_{60} (**1**) (600 mg, 0.832 mmol) and $Rh_2(OAc)_4$ (360 mg, 0.832 mmol) in anhydrous α-methylnaphthalene (240 mL). The solvent was evaporated under vacuum (0.8 Torr, 74°C) and the resulting solid was added with 10 g of silica (70-230 mesh), diluted with toluene and then concentrated. The resulting solid was added on the top of a silica gel column and eluted first with hexane / toluene (1 : 1) to remove residual C_{60} (**1**) and then with toluene. 0.245 mg (32%) of bis-carboethoxy-[6-6]-methanofullerene (**6b**) were obtained with a purity of 90 % by HPLC. Spectral data (^{1}H-NMR and ^{13}C-NMR) are in agreement with those previously reported.[16]

(18) In spite of the improvement represented by our methodology, the method of choice for the preparation of bis-carboethoxy-[6-6]-methanofullerene (**6b**) remains the Michel addition of bromodiethylmalonate to fullerene: C. Bingel, *Chem. Ber.* **1993**, *126*, 1957.

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