Synthesis and oxidation of vinyl derivatives of *N*-methyl[60]fullereno[*c*]pyrrolidine

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Novel organometallic derivatives of *N*-methyl[60]fullereno[*c*]pyrrolidine bearing the vinyl fragment at the position 2 of the pyrrolidine ring were synthesized. Their oxidation with 3-chloroperoxybenzoic acid to give *N*-oxides and epoxides was studied in detail.

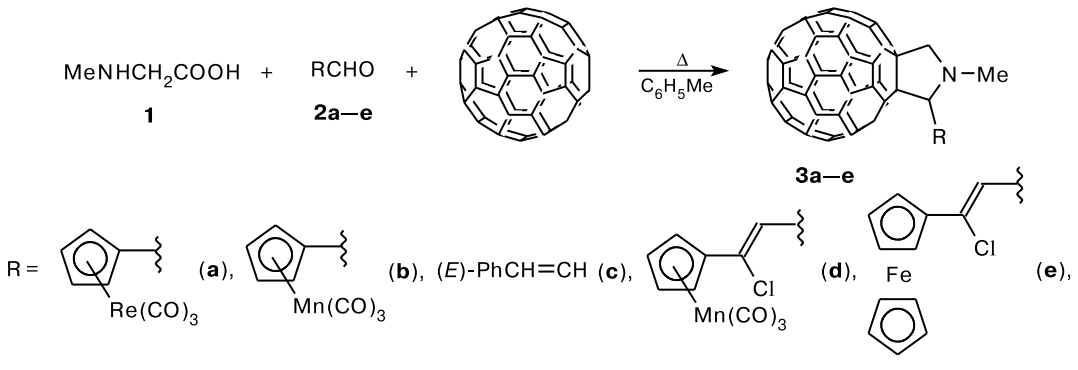
Key words: *N*-methyl[60]fullereno[*c*]pyrrolidine, chlorovinylcymantrene, chlorovinylferrocene, cymantrene, cyclopentadienylrhenium tricarbonyl, *N*-oxides, 3-chloroperoxybenzoic acid, Prato reaction.

It is known from the numerous publications on fullerenes that [60]fullerene can be modified by 1,3-dipolar cycloaddition of azomethine ylides (the Prato reaction), which led to various fullerenopyrrolidines.[1,2]

Oxidation of fullerenopyrrolidine derivatives at the nitrogen atom to give fullerenopyrrolidine *N*-oxides[3] could be regarded as one of the promising methods for further functionalization of this class of compounds. Studying this reaction is of interest because the *N*-oxides are used to protect an amino group during subsequent transformations of the molecule. A number of *N*-oxides bearing organic substituents at the position 2 of the pyrrolidine ring were synthesized.[3] Organometallic derivatives of fullerenopyrrolidines are of interest due to the effect of the metal atom on the oxidation. Besides, fullerene derivatives bearing double bond are promising because in their case both the oxidation of the nitrogen atom and the formation of an epoxide could occur. In the present work with the aim at studying this process, from *N*-methylglycine **1** and aldehydes **2a**—**e**, we synthesized the corresponding fullerenopyrrolidines **3a**—**e** (Scheme 1).

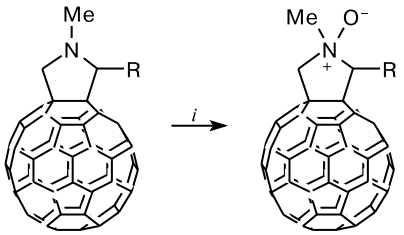
Oxidation of organometallic derivatives of fullerenopyrrolidines **3a,b** with equimolar amount of 3-chloroperoxybenzoic acid (mCPBA) resulted in compounds **4a,b** in the yields of 34 and 44%, respectively. In the ^{1}H NMR spectra of the synthesized compounds, all signals shifted downfield by 0.6—1.0 ppm with respect to the starting fullerenopyrrolidines. This fact is consistent with the published data[3] suggesting that the oxidation occurred at the nitrogen atom of the pyrrolidine fragment. The downfield shift of the signal for the NMe group is the most characteristic. Thus, these shifts are 0.5 and 0.8 ppm for compounds **4a** and **4b**, respectively. No paramagnetism was observed in the NMR spectra of the compounds synthesized indicating that the metal atom in the organometallic fragment of the molecule does not oxidized, *i.e.*, the presence of the metal atom does not affect the oxidation of the fullerenopyrrolidine with mCPBA.

Scheme 1



Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 10, pp. 1914—1916, October, 2010.

Scheme 2

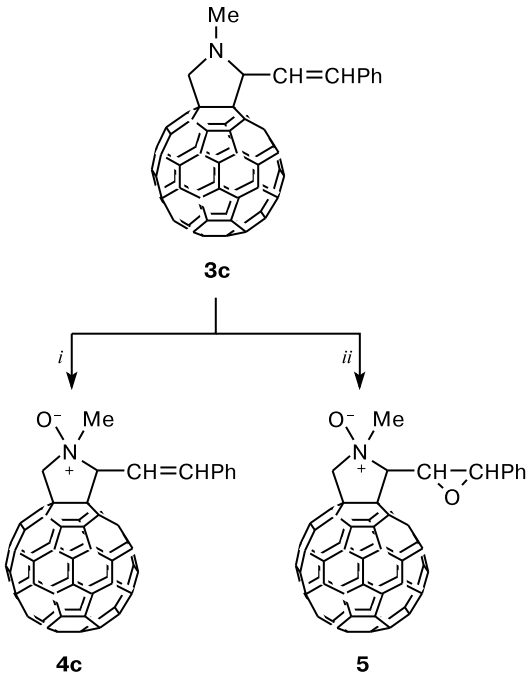


3a,b **4a,b**

i. mCPBA (1 eqiuv.), $CHCl_3$, 1 h

Oxidation of fullerenopyrrolidine **3c** was carried out stepwise (Scheme 3). Since compound **3c** contains two reactive centers (the nitrogen atom and the double bond), the oxidation of **3c** could result in both epoxide and *N*-oxide.

Scheme 3



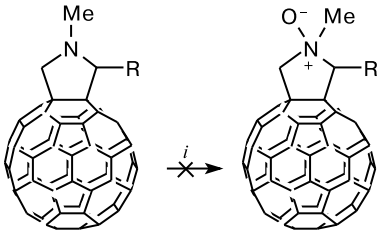
i. mCPBA (1 equiv.), $CHCl_3$, 1 h; *ii*. mCPBA (2 equiv.), $CHCl_3$, 1 h.

Oxidation of **3c** with 1 equivalent of mCPBA afforded compound **4c**. The changes in the chemical shifts in the ^{1}H NMR spectrum, namely, downfield shift of the signal for the protons of the *N*-methyl group by 0.68 ppm (δ 3.36 with respect to δ 2.68 for compound **3c**), confirm the formation of the *N*-oxide. Other signals also shifted downfield compared with the signals for the starting compound by an average of 0.6—1.0 ppm. The ^{1}H NMR spectrum of **4c** exhibited signals for the CH=CH group suggesting no epoxidation.

Oxidation of **3c** with twofold excess of mCPBA yielded compound **5** (see Scheme 3). In the ^{1}H NMR spectrum of **5**, the signal for the protons of the *N*-methyl group shifted downfield by 1.3 ppm (with respect to **3c**) suggesting formation of the *N*-oxide. Therefore, no signals for the double bond were observed, while the multiplets at δ 3.50 and 3.75 were attributed to the protons of the epoxide ring. These data suggest that the second equivalent of mCPBA reacts with **3c** giving epoxide **5**. Thus, oxidation of **3c** with twofold excess of mCPBA involves both the nitrogen atom and the double bond and does not affect the double bonds of the fullerene cage; it is of note that the *N*-oxide is the first product formed upon oxidation. Like many other fullerene derivatives, the compounds synthesized are difficult for an elemental analysis; the content of carbon could be very low due to insufficient combustion. In this series, acceptable results of elemental analyses were obtained for compounds **3d,e**.

An attempt to prepare compounds **4d,e** by oxidation of chlorovinyl fullerenopyrrolidine derivatives **3d,e** failed even when threefold excess of mCPBA was used (Scheme 4). Thus, the electron-withdrawing chlorine atom prevents oxidation of not only the double bond, but also of the remote tertiary nitrogen atom.

Scheme 4



3d,e **4d,e**

i. mCPBA (3 equiv.), $CHCl_3$, 1 h

Experimental

Commercially available [60]fullerene (99.9% pure, G. A. Razuvaev Institute of Organometallic Chemistry, Russian Academy of Sciences, Nizhny Novgorod) was used. Formylcyclopentadienylrhenium tricarbonyl (**2a**)[4] formylcyclopentadienylmanganese tricarbohyl (**2b**)[5] were synthesized by the known methods. 3-Ferrocenylacrolein was synthesized from acetylferrocene according to the known procedure[6], acetylcymantrene was prepared by published method.[7] *N*-Methyl-2-(cyclopentadienyl)tricarbonylrhenium[60]fullereno[*c*]pyrrolidine (**3a**), *N*-methyl-2-(cyclopentadienyl)tricarbonylmanganese[60]fullereno[*c*]pyrrolidine (**3b**), and *N*-methyl-2-styryl[60]fullereno-[*c*]pyrrolidine (**3c**) were synthesized and characterized in our laboratory earlier.[8,9] ^{1}H and ^{13}C NMR spectra were recorded on a Bruker 400 HX spectrometer; chemical shifts were determined relative to the residual solvent signal and refined to Me_4Si. Electrospray ionization mass spectrum was recorded on a Agilent 1100

Series LC/MSD Trap mass spectrometer operating in both the positive and negative ion modes.

3-Chloro-3-cymantrenyl acrolein (2d). To a solution of acetylcymantrene (1 g, 0.004 mol) in anhydrous DMF (6 mL), a freshly prepared solution of $POCl_3$ (1.25 mL, 2.09 g, 0.013 mol) in anhydrous DMF (4 mL) was added under argon at 0 °C. The reaction mixture was stirred at 0 °C for 15 min and 2 h at room temperature. Then 10% aqueous solution of AcONa (30 mL) was added and stirring was continued for 1.5 h. The mixture was extracted with CH_2Cl_2 (3×50 mL), the organic phases were washed twice with water, and dried with Na_2SO_4. The crude product was purified by column chromatography (SiO_2, elution with hexane—ethyl acetate, 5 : 1) to give **2d** (0.75 g, 72%). ^{1}H NMR ($CDCl_3$), δ: 4.95 (br.m, 2 H, Cp); 5.5 (br.m, 2 H, Cp); 6.48 (br.s, 1 H, CCl=CH); 10.14 (br.s, 1 H, CHO).

***N*-Methyl-2-(3-chlorovinyl-3-cymantrenyl)[60]fullereno[*c*]pyrrolidin (3d).** A mixture of [60]fullerene (0.1 g, 0.138 mmol), aldehyde **2d** (0.048 g, 0.153 mmol), and *N*-methylglycine (0.0245 g, 0.275 mmol) in toluene (100 mL) was refluxed for 3 h under argon. The column chromatography (SiO_2, elution with hexane—toluene, 1 : 1) afforded **3d** (25.8 mg, 18%). Found (%): C, 79.87; H, 1.40; N, 1.23. $C_{73}H_{11}ClMnNO_3$. Calculated (%): C, 84.28; H, 1.07; N, 1.35. ^{1}H NMR ($CDCl_3$), δ: 2.89 (s, 3 H, NMe); 4.19, 4.85 (both d, 1 H, CH_2, J = 9.5 Hz); 4.68, 4.80, 5.23, 5.25 (all m, 1 H, Cp); 5.08 (d, 1 H, CH, J = 9.2 Hz); 6.5 (d, 1 H, CH=CCl, J = 8.9 Hz). MS (ESI), m/z: 1042.4 [M^+]; 896 [M − 3 CO − ClC=CH]$^+$.

***N*-Methyl-2-(3-chlorovinyl-3-ferrocenyl)[60]fullereno[*c*]pyrrolidine (3e).** A mixture of [60]fullerene (0.1 g, 0.138 mmol), aldehyde **2e** (0.042 g, 0.153 mmol), and *N*-methylglycine (0.0245 g, 0.275 mmol) in toluene (100 mL) was refluxed for 5 h under argon. Purification by column chromatography (SiO_2, elution with hexane—toluene, 1 : 1) yielded compound **3e** (22.6 mg, 16%). Found (%): C, 88.38; H, 1.52; N, 1.23. $C_{75}H_{16}ClFeN$. Calculated (%): C, 88.11; H, 1.57; N, 1.37. ^{1}H NMR ($CDCl_3$), δ: 2.92 (s, 3 H, NMe); 4.05 (s, 5 H, C_5H_5); 4.21 (d, 1 H, CH_2, J = 9.5 Hz); 4.31, 4.34, 4.55, 4.67 (all m, 1 H, C_5H_4); 4.90 (d, 1 H, CH, J = 9.7 Hz); 5.18 (d, 1 H, CH_2, J = 9.0 Hz); 6.42 (d, 1 H, CH=CCl, J = 9.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 40.2 (NMe); 66.7 (C); 68.0 (CH_2); 69.6 (CH=CCl); 70.0 (Cp); 140.3—147.3 (C_{60}).

***N*-Methyl-2-(cyclopentadienyl)tricarbonylrhenium[60]fullereno[*c*]pyrrolidine *N*-oxide (4a).** To a stirred solution of fullerene **3a** (0.02 g, 0.018 mmol) in $CHCl_3$ (100 mL), a solution of mCPBA (0.0031 g, 0.018 mmol) in $CHCl_3$ (15 mL) was added dropwise over a period of 1 h and stirring was continued for 30 min. The reaction progress was monitored by TLC. Purification by column chromatography (SiO_2, elution with CH_2Cl_2—EtOH, 10 : 1) afforded compound **4a** (7 mg, 34%). IR, ν/cm^{-1}: 2040, 1965 (CO); 1075 (NO). ^{1}H NMR ($CDCl_3$) δ: 3.30 (s, 3 H, NMe); 3.40—3.60 (m, 3 H, CH, CH_2); 4.10—4.50 (m, 4 H, C_5H_4).

***N*-Methyl-2-(cyclopentadienyl)tricarbonylmanganese[60]fullereno[*c*]pyrrolidine *N*-oxide (4b).** To a solution of fullerene **3b** (0.02 g, 0.0204 mmol) in $CHCl_3$ (100 mL), a solution of mCPBA (0.0031 g, 0.018 mmol) in $CHCl_3$ (15 mL) was added dropwise over a period of 1 h and stirring was continued for 30 min. The reaction progress was monitored by TLC. Purification by column chromatography (SiO_2, elution with CH_2Cl_2—EtOH, 10 : 1) afforded compound **4b** (9 mg, 44%). IR, ν/cm^{-1}: 2020, 1955 (CO); 1070 (NO). ^{1}H NMR ($CDCl_3$), δ: 3.98 (s, 3 H, NMe); 4.26—4.32 (m, 3 H, CH, CH_2); 4.34, 4.57, 4.40, 4.42 (all m, 1 H, C_5H_4).

***N*-Methyl-2-styryl[60]fullereno[*c*]pyrrolidine *N*-oxide (4c).** To a solution of fullerene **3c** (0.02 g, 0.0228 mmol) in $CHCl_3$ (100 mL), a solution of mCPBA (0.0031 g, 0.018 mmol) in $CHCl_3$ (15 mL) was added dropwise over a period of 1 h and stirring was continued for 30 min. The reaction progress was monitored by TLC. Purification by column chromatography (SiO_2, elution with CH_2Cl_2—EtOH, 10 : 1) afforded compound **4c** (9 mg, 44%). ^{1}H NMR ($CDCl_3$), δ: 3.36 (s, 3 H, NMe); 5.37 (m, 1 H, CH_2); 5.62 (d, 1 H, CH); 5.71 (m, 1 H, CH_2); 6.75 (m, 1 H, CH=CH); 7.10 (d, 1 H, CH=CH); 7.39 (m, 3 H, C_6H_5); 7.60 (m, 2 H, C_6H_5).

***N*-Methyl-2-epoxystyryl[60]fullereno[*c*]pyrrolidine *N*-oxide (5).** To a solution of fullerene **3c** (0.04 g, 0.045 mmol) in $CHCl_3$ (150 mL), a solution of mCPBA (0.0062 g, 0.036 mmol) was added dropwise over a period of 1 h and stirring was continued for 30 min. The reaction progress was monitored by TLC. Purification by column chromatography (SiO_2, elution with CH_2Cl_2—EtOH, 10 : 1) afforded compound **5** (16.08 mg, 39%). IR, ν/cm^{-1}: 1085 (NO). ^{1}H NMR ($CDCl_3$), δ: 3.50, 3.75 (m, 2 H, epoxide); 4.10 (s, 3 H, NMe); 5.35, 5.67 (both d, 2 H, CH_2); 6.50 (d, 2 H, CH); 8.02 (m, 3 H, Ph); 8.15 (m, 2 H, Ph).

The authors are grateful to A. S. Peregudov for the ^{1}H and ^{13}C NMR spectroscopy and Prof. Cui Xiuling (Zhengzhou University, Public´s Republic of China) for the mass spectrometry.

This work was financially supported by the Russian Foundation for Basic Research (Project No. 08-03-00169).

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Received February 27, 2010;
in revised form July 21, 2010