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Highly Efficient Retro-cycloaddition Reaction of Isoxazolino[4,5:1,2][60]- and -[70]fullerenes

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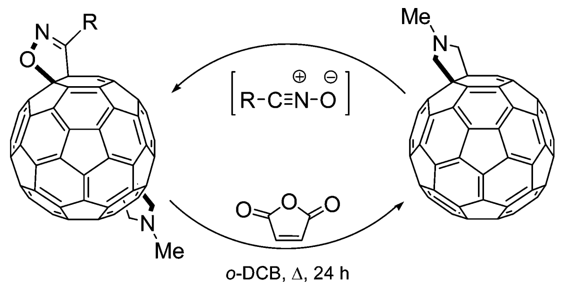

Isoxazolino[4,5:1,2][60]- and -[70]fullerenes undergo an efficient retro-cycloaddition reaction to pristine fullerene by thermal treatment in the presence of an excess of a dienophile and Cu(II) catalysis, which can be selectively used in the presence of malonate or pyrrolidine cycloadducts. Trapping experiments using *N*-phenylmaleimide as dipolarophile have shown that the reaction mechanism occurs by thermal removal of the nitrile oxide 1,3-dipole, in a process which is favored by the presence of Cu(II) as the catalyst. The ESI-MS study supports the observed retro-cycloaddition process for both C_{60} and C_{70} derivatives. In contrast to previous electrochemical retro-cycloaddition processes observed in fulleropyrrolidines, isoxazolinofullerenes were stable under oxidative conditions.

Introduction

1,3-Dipolar cycloadditions to C_{60} are among the most useful reactions for the preparation of modified fullerenes for application in fields such as medicinal chemistry and materials science.[1] A wide variety of 1,3-dipoles have been reacted with C_{60} as well as C_{70} and, more recently, with higher fullerenes such as endohedrals like $Sc_3N@C_{80}$.[2] In this regard, although pyrrolidino[3,4:1,2][60]fullerenes (familiarly known as fulleropyrrolidines) have been by far the most studied and versatile derivatives obtained from 1,3-dipolar cycloadditions,[3] other fullerene-fused pentagonal heterocyclic rings, such as isoxazolino[4,5:1,2][60]fullerenes, are also known to show appealing chemical, electrochemical, and photophysical properties.[4] Isox-

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azolinofullerenes have been readily obtained by addition of nitrile oxides to [60]fullerene to form stable brown solids in moderate yields. Starting nitrile oxides are in turn efficiently prepared by dehydrochlorination of chloroximes, obtained by chlorination of the respective oximes.[5] Despite the huge amount of work devoted to the preparation of fullerene cycloadducts and particularly to those obtained by 1,3-dipolar cycloaddition reactions, much less is known about their chemical and thermal stability. Thus, we recently reported the thermally induced transition metal-catalyzed quantitative retro-cycloaddition reaction of pyrrolidino[3,4:1,2]fullerenes and proved its utility as a new and useful protection−deprotection protocol.[6] We recently showed a similar reaction induced via electrochemical oxidation of the pyrrolidine adduct.[7] In this communication we report that isoxazolinofullerenes also undergo a retro-cycloaddition thermal reaction under the same relatively mild experimental conditions used previously for fulleropyrrolidines to afford pristine fullerenes efficiently, thus proving that they can also be used as a protection−deprotection protocol compatible with other cycloadduct derivatives present on the same fullerene sphere, including fulleropyrrolidines.

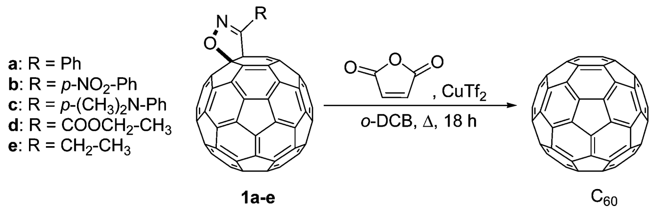
In contrast to other pentagonal heterocycles, isoxazolines undergo a variety of reactions resulting in the ring cleavage. Opening isoxazolines involves N−O and C═N bond reduction, and different reagents, such as $TiCl_3$, diisobutyl aluminum hydride, lithium aluminum hydride, Birch reduction, or hydrogen and Raney nickel,[8−10] have been used to reduce aliphatic and aromatic isaxazolines. However, the chemical reduction of isoxazolinofullerenes presents a problem since fullerenes themselves are very easy to reduce[11] and are likely to be reduced before the isoxazoline moiety.

The electroreduction of isoxazolines has been used to prepare precursors for a variety of organic compounds including aldehydes, alcohols, lactones, amino acids, thiiranes, and olefins.[12,13] Electrochemical reduction or oxidation has never been used to attempt the retro-cycloaddition reaction of isoxazolinofullerenes. Therefore, we have carried out controlled potential electrolysis (CPE) in the present study to investigate the electrochemical stability of isoxazolinofullerenes.

Results and Discussion

Although isoxazolinofullerenes have been reported to be resistant to further functionalization, they revert back to [60]fullerene at very high temperatures in the range of 280−400 °C.[9] Prato and co-workers reported that treatment of isoxazolinofullerenes with $Mo(CO)_6$ in refluxing chlorobenzene leads quantitatively to pristine fullerene and the respective nitrile, resulting from the further reduction of the nitrile oxide formed in the retro-cycloaddition process. Similar results were also obtained by treatment with excess of DIBAL-H in toluene at room temperature.[9] In order to determine the scope of the experimental conditions used for the retro-cycloaddition reactions of fulleropyrrolidines,[6] we have applied the same reagents excess of dipolarophile (maleic anhydride) as well as the use of $CuTf_2$ as a catalyst to the retro-cycloaddition of isoxazolinofullerenes. The results obtained show that they efficiently undergo the retro-cycloaddition process, and that the electronic nature of the substituent on the isoxazoline ring has a strong influence on the reaction outcome. Furthermore, these conditions can be also successfully applied to higher fullerenes (C_{70}) or to remove, selectively, the isoxazoline ring from the fullerene surface in the presence of other Bingel−Hirsch[1] or Prato[3] cycloadducts.

SCHEME 1. Retro-cycloaddition Reaction of Isoxazolino[60]fullerenes 1a−e



Following previously reported standard procedures,[4,8] we have synthesized a series of isoxazolinofullerenes **1a**−**e** (Scheme 1).

When these compounds were heated at reflux in *o*-dichlorobenzene (*o*-DCB) for 24 h, pristine C_{60} was obtained in a variable amount (16−55%) together with other unidentified compounds which were observed by HPLC (entries 1−5, Table 1).

In an attempt to increase the retro-cycloaddition procces, we carried out the same reactions but in the presence of a big excess (30 equiv) of a highly efficient dipolarophile, such as maleic anhydride, according to our previously reported method.[6] Under these conditions, although the yields were improved (25−90%) and the reactions were significantly more clean (HPLC), the efficiency of the retro-cycloaddition process was remarkably lower than that found for the related fulleropyrrolidines.

It is interesting to note, however, that compound **1c** bearing a *p*-(*N*,*N*-dimethylamino)phenyl substituent on the isoxazoline ring (entry 8, Table 1) showed a remarkable conversion efficiency (90.2%) in just 12 h, whereas the *p*-nitrophenyl group (entry 7, Table 1) showed the lowest (25%) conversion. These findings clearly suggest the strong impact that the electronic effect has on the stabilization of the 1,3-dipole resulting from the retro-cycloaddition process. The negative charge in the 1,3-dipole should be localized on the more electronegative oxygen atom, and the positive charge on the benzylic carbon, which is stabilized by the presence of the strongly electron-releasing *N*,*N*-dimethylamino group (**1c**) and destabilized by the electron-withdrawing nitro group (**1b**). In agreement with these data, the presence of the ethoxycarbonyl group (**1d**) or an alkyl substituent (**1e**), which do not stabilize the respective 1,3-dipoles, also led to remarkably low conversion efficiencies (entries 9, 10, Table 1).

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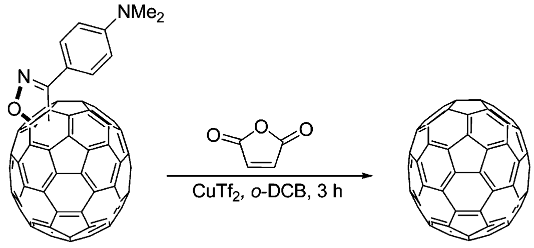
TABLE 1. Experimental Conditions for the Retro-cycloaddition Reaction of Isoxazolinofullerenes[a]

entry	compound	dipolarophile[b]	catalyst	t (h)	conv (%)[c]
1	**1a**	-	-	24	55.8
2	**1b**	-	-	24	15.9
3	**1c**	-	-	24	31.2
4	**1d**	-	-	24	18.6
5	**1e**	-	-	24	29.2
6	**1a**	maleic anhydride	-	24	65.9
7	**1b**	maleic anhydride	-	24	25.0
8	**1c**	maleic anhydride	-	12	90.2
9	**1d**	maleic anhydride	-	24	31.8
10	**1e**	maleic anhydride	-	24	30.6
11	**1a**	maleic anhydride	$CuTf_2$[d]	24	81.6
12	**1b**	maleic anhydride	$CuTf_2$	24	75.5
13	**1c**	maleic anhydride	$CuTf_2$	3	98.2
14	**1d**	maleic anhydride	$CuTf_2$	24	84.3
15	**1e**	maleic anhydride	$CuTf_2$	24	98.0
16	**2**	maleic anhydride	$CuTf_2$	3	98.5
17	**3**	-	-	24	77.8
18	**3**	maleic anhydride	-	24	92.7
19	**3**	maleic anhydride	$CuTf_2$	24	79.3
20	**5**	maleic anhydride	$CuTf_2$	24	92.0
21[e]	**5**	maleic anhydride	$CuTf_2$	24	99.0

[a] All the reactions were carried out in *o*-DCB at reflux (3−24 h). [b] 30 equiv dipolarophile used. [c] Conversion determined by HPLC. [d] 1 equiv $CuTF_2$ [copper(II) trifluoromethylsulfonate] used. [e] Temperature: 150 °C, 99% of compound **6**.

SCHEME 2. Retro-cycloaddition Reaction of C_{70} Derivative 2



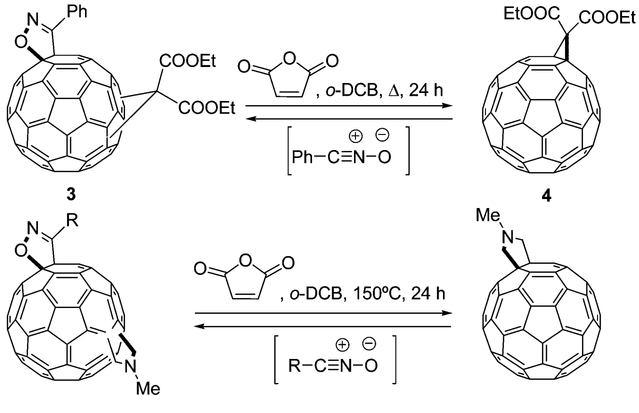
2 (isomeric mixture)

C_{70}

To further improve the efficiency of the retro-cycloaddition reaction, we carried out the thermally induced process in the presence of a metal Lewis acid ($CuTf_2$) since coordination to the heteroatom should activate the retro-reaction. Under these reaction conditions (entries 11−15, Table 1), very high or practically quantitative yields (determined by HPLC) were obtained after 24 h refluxing in *o*-DCB. Remarkably, compound **1c** bearing the *N*,*N*-dimethylamino group showed a quantitative conversion efficiency after just 3 h of reaction. Again, the lowest yields were observed for compounds **1b** (75.5%) and **1d** (84.3%). The reaction was also highly efficient with the monoadduct mixture of the three isomers of isoxazolino[70]-fullerenes **2**,[14] which afforded pristine C_{70} under these conditions in quantitative yield (by HPLC; see entry 16, Table 1 and Scheme 2).

The retro-cycloaddition reaction of isoxazolinofullerenes has also been carried out in the presence of a malonate- or pyrrolidine-type cycloadducts. Thus, hetero-bisadduct **3** was obtained as a regioisomeric mixture[15] from malonate derivative **4** by reacting with nitrile oxide under standard conditions. Analogously, compound **5**[15] was prepared as a mixture of regioisomers from **6** (Scheme 3).

SCHEME 3. Selective Removal of the Isoxazoline Ring in Hetero-bisadducts 3 and 5



3

4

5 (R = p-$(CH_3)_2N$-Ph)

6

Thermal treatment of **3** in refluxing *o*-DCB led to the monoadduct **4** in 77.8% yield (entry 17, Table 1). The presence of an excess of dienophile afforded **4** in 92.7% yield after 24 h refluxing in *o*-DCB (entry 18, Table 1), and the addition of cooper(II) triflate led to the same product **4** but in a lower yield (79.3%, entry 19). This unexpected finding could be accounted for by the possible coordination of the oxygen atoms present in the malonate moiety to the Cu^{2+}, thus reducing the effectiveness of the catalyst.

Finally, refluxing hetero-bisadduct **5** in *o*-DCB overnight afforded pristine C_{60} quantitatively (entry 20). However, it is possible to selectively remove the isoxazoline ring from **5** by carefully controlling the experimental conditions. Thus, fulleropyrrolidine **6** was obtained in a quantitative yield from **5** by heating in *o*-DCB at 150 °C for 24 h. These findings indicate that it is possible to have a control on the selective elimination of different cycloadducts from the fullerene surface by controlling the temperature. Furthermore, the electronic nature of the substituents on the isoxazoline ring has a strong influence on the efficiency of the retro-cycloaddition process. This finding is important in order to control the selectivity of the retro-

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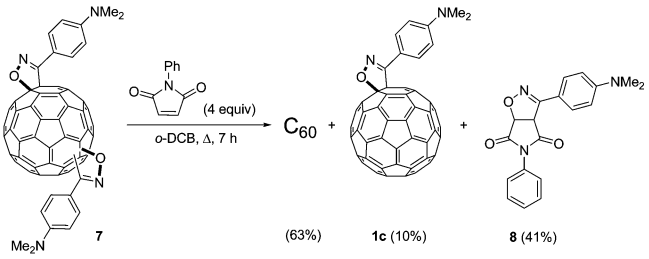
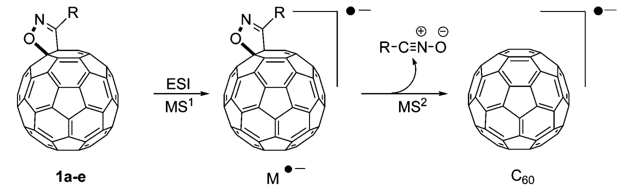
(14) HPLC showed the presence of three regioisomers; see Supporting Information. For related systems, see Meier, M. S.; Poplawska, M.; Compton, A. L.; Shaw, J. P.; Selegue, J. P.; Guarr, T. F. *J. Am. Chem. Soc.* **1994**, *116*, 7044.

(15) HPLC showed the presence of at least two different regioisomers for **3** and **5**, see Supporting Information.

SCHEME 4. Retro-cycloaddition Reaction of Bis-isoxazolinofullerenes



SCHEME 5. Proposed Fragmentation Pathway of $M^{\bullet-}$ Ions from 1a−e



a: R = Ph; M = 839
b: R = *p*-NO_2-Ph; M = 884
c: R = *p*-$(CH_3)_2N$-Ph; M = 882
d: R = $COOCH_2$-CH_3; M = 835
e: R = CH_2-CH_3; M = 791

cycloaddition reaction when other cycloadducts are present on the fullerene sphere.

In order to confirm experimentally the hypothesis of loss of the nitrile oxide 1,3-dipole in the thermally induced retro-cycloaddition process, we have carried out a trapping experiment using *N*-phenylmaleimide as an efficient dipolarophile able to form stable derivatives (Scheme 4). Thus, reaction of a regioisomeric mixture of bis-adducts **7** with *N*-phenylmaleimide (4 equiv) in refluxing anhydrous *o*-dichlorobenzene for 7 h afforded a mixture of pristine C_{60} (63%), monoadduct **1c** (10%) and cycloadduct **8** resulting from the 1,3-dipolar cycloaddition of nitrile oxide, formed in the retro-cycloaddition process, to *N*-phenylmaleimide. Compound **8** is obtained as a mixture of enantiomers in 41% yield. The structural characterization was carried out by spectroscopic techniques and by comparison with that previously obtained in the literature.[16]

These experimental findings clearly confirm the thermal cleavage of the isoxazoline ring in compounds **1a**−**e**, affording the parent C_{60} and the respective nitrile oxides. The presence of a big excess of a very efficient dipolarophile such as maleic anhydride (or *N*-phenylmaleimide) traps the dipole, thus favoring the quantitative recovery of pristine [60]fullerene.

In order to support the loss of the 1,3-dipole in the observed chemical retro-cycloaddition reaction, we have studied the collision-induced dissociation (CID) spectra of the isoxazoline derivatives **1a**−**e**. Because of the electron affinity and low ionization potential of fullerene derivatives, they can be pre-ionized in solution prior to ESI by addition of either an electron-donor or acceptor.[17] The behavior of the ESI source as an electrolytic cell makes it possible to generate radical cations and anions from electroactive species through electrochemical oxidation or reduction.[18] Thus, the electrochemical properties of fullerene derivatives permit the analysis of these molecules by ESI mass spectrometry.[19−22]

The MS/MS spectra of the radical anions generated under ESI conditions reveal that the elimination of a nitrile oxide fragment leads to the formation of $C_{60}^{\bullet-}$ (*m/z* 720) (Scheme 5, Figure SI1). No differences were found for the different R groups attached at the isoxazoline moiety. Moreover, the C_{70} isoxazoline derivative undergoes the same process, indicating that the size of the fullerene core does not seem to play any role in the elimination process (Scheme SI1 and Figure SI2).

The positive ion mode of detection was also employed to record the mass spectra of compounds **1a**−**e**. In contrast to the results obtained using the negative mode of detection, even-electron ions corresponding to $[M + H]^+$ were detected. The presence of the electronegative nitrogen and oxygen atoms allow the formation of protonated molecular ions.[22,23] These ions undergo, however, a different fragmentation pattern. The direct retro-cycloaddition does not take place. In this case, the loss of a nitrile group affords the corresponding protonated fullerene epoxide which in the subsequent MS^3 spectrum shows that oxygen has been eliminated to form $[C_{60}H]^+$ (Scheme SI2 and Figure SI3).

Electrochemical Behavior of Isoxazolinofullerenes. Since we recently demonstrated that pyrrolidine adducts can be easily and conveniently removed from fullerenes, we decided to investigate the electrochemical properties of the isoxazoline derivatives. Controlled potential electrolysis was recently reported as another useful tool for the selective removal of pyrrolidine addends from the fulleropyrrolidine derivatives.[7] An efficient oxidative electrochemical retro-cycloaddition reaction takes place due to the addend's intrinsic instability upon oxidation.[7] A similar methodology was employed in the present study with the isoxazoline adducts to establish their stability under electrochemically oxidative conditions.

The cyclic voltammograms of compounds **1a**−**e** in acetonitrile/toluene mixture (1:4, v/v) and benzonitrile showed three reduction waves, corresponding to the three reversible reductions of the fullerene core, and one irreversible oxidative wave[24] (Figure 1 and Table 2). The isoxazoline ring is electron rich, so the potentials of the isoxazolines are more positive than those of C_{60}. The reduction potentials shift to more positive values when the substituents on the isoxazoline ring are more electron-withdrawing. The largest shift was observed for the *p*-nitrophenyl derivative **1b** and unsubstituted C_{60}, −0.94 and −0.99 V vs Fc/Fc^+, respectively. Other isoxazolines exhibit about 10

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(24) The CV of isoxazolinofullerenes show a slightly better electron affinity in comparison with pristine C_{60} and significantly less negative reduction potential values than the related fulleropirrolidines, due to the presence of an electronegative oxygen atom, as well as an imine sp^2 carbon atom, directly connected to the carbon sphere. However, to the best of our knowledge, the oxidative behavior of these fullerene derivatives has not previously been reported. For more details, see (a) Irngartinger, H.; Escher, T. *Tetrahedron* **1999**, *55*, 10753. (b) Irngartinger, H.; Fetter, P. W.; Escher, T.; Tinnefeld, P.; Nord, S.; Saüer, M. *Eur. J. Org. Chem.* **2000**, 455. (c) de la Cruz, P.; Díaz-Ortiz, A.; García, J. J.; Gómez-Escalonilla, M. J.; de la Hoz, A.; Langa, F. *Tetrahedron* **1999**, *40*, 1587. (d) Langa, F.; de la Cruz, P.; Espíldora, E.; de la Hoz, A.; Bourdelande, J. L.; Sánchez, L.; Martín, N. *J. Org. Chem.* **2001**, *66*. 5033.

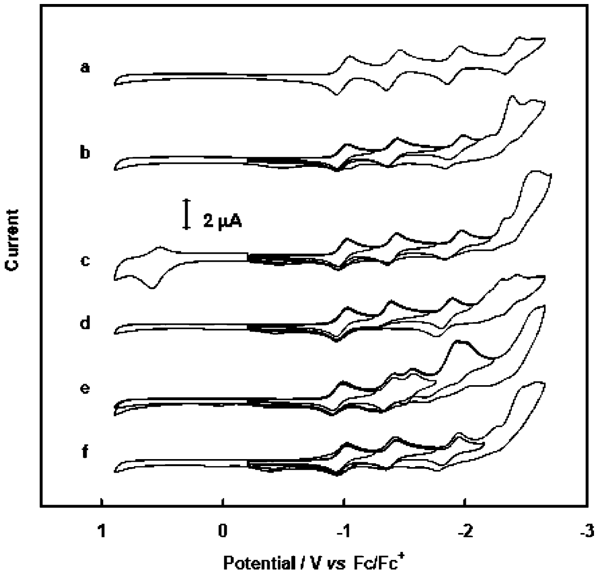

FIGURE 1. Cyclic voltammograms recorded on a Pt electrode (1.5 mm) in acetonitrile/toluene (1:4, v/v) mixture containing 0.1 M (n-Bu)$_4$NPF$_6$ as supporting electrolyte and (a) 6.3 × 10^{-4} M C$_{60}$. (b) 6.4 × 10^{-4} M **1e**. (c) 5.8 × 10^{-4} M **1c**. (d) 6.6 × 10^{-4} M **1d**. (e) 5.7 × 10^{-4} M **1b**. (f) 6.1 × 10^{-4} M **1a**. Sweep rate was 100 mV s^{-1}.

mV differences when compared with C$_{60}$. Around the fourth electrochemical reduction process there are many waves observed, most likely due to the reduction processes of the groups attached to the isoxazoline ring.

Isoxazoline derivatives **1b** and **1d** show some electrochemical differences in the negative potential range relative to the other three isoxazolines. For better characterization, the electrochemical properties of the complete series of isoxazolines was done using differential pulse voltammetry (Figure 2). Thus, two additional reduction waves at −1.52 and −1.87 V vs Fc/Fc$^+$ corresponding most probably to the p-nitrophenyl group were found in **1b** (Figure 2e, peaks 2* and 3* not included in the table). Analysis indicated that the first peak (−1.52 V) is a one-electron, reversible reduction, whereas the second peak (−1.87 V) was not well defined. The electrochemical reduction properties of **1d** bearing an ester group indicated that the first and third processes are one-electron reversible reductions of the C$_{60}$ core. Multiple scans and a study of the current as a function of the scan rate showed chemical irreversibility for the second reduction of the C$_{60}$ core.

Reductive electrochemistry of **1c** showed three, one-electron reversible reductions of the C$_{60}$ core. In the anodic scan an unusual oxidation wave was observed at +0.50 V vs Fc/Fc$^+$, probably due to the oxidation of the dimethylaniline group. The CV behavior in an acetonitrile/toluene mixture with (n-Bu)$_4$NPF$_6$ indicated that this oxidative process is irreversible. Even after the medium was changed to o-dichlorobenzene, and vacuum conditions were used, the oxidative process was still irreversible although the chemical reversibility was somewhat improved (Figure SI4). The study of the current as a function of the scan rate showed that the oxidative process is diffusion-controlled in the sweep range between 25 and 500 mV s^{-1}, while the reoxidative process is diffusion-controlled in the whole scan rate range. The peak separation increased from 70 to 200 mV, for 25 to 2000 mV s^{-1} scan rates, respectively.

The irreversible oxidative process in the positive potential range suggested chemical instability of the isoxazolinofullerene derivatives upon electrochemical oxidation of the isoxazoline rings. The very positive potential values of isoxazolines, near the oxidative potential value of pure C$_{60}$, and close to the limit of the solvent potential window, suggested that oxidative removal of the rings from the fullerenes would be significantly more difficult than the corresponding pyrrolidines (Figure 3).[7]

As a representative example, the electrolysis of **1e** was conducted at 1.8 V in benzonitrile containing 0.1 mol L^{-1} (n-Bu)$_4$NPF$_4$, with the exclusion of oxygen (Figure SI5). The potential applied was determined from differential pulse voltammetric investigations (DPV) (Figure 3 and Table 2). Oxidation proved to be difficult, even after increasing the electrolysis potential to +2.0 V. After transferring a total charge corresponding to 1.9 electrons per molecule and reduction of the solution at 0 V, no changes were observed in the cyclic voltammogram of the electrolyzed solution compared to that of **1e**. The reaction mixture was characterized by CV, TLC, MALDI-TOF MS, and ^{1}H NMR, and product analysis showed only the presence of the starting material. Therefore, and contrary to that observed for fulleropyrrolidines,[7] isoxazolinofullerenes exhibit remarkable stability under oxidative conditions.

In summary, we have carried out the synthesis of a series of mono- and bis-adducts of isoxazolino[4,5:1,2][60]- and -[70]-fullerene which efficiently undergo a thermal retro-cycloaddition process affording the parent [60]- or [70]fullerene, respectively. The highest efficiency is obtained by refluxing the isoxazolinofullerene in o-DCB using an excess of dienophile (maleic anhydride or N-phenylmaleimide) and copper triflate as the catalyst.

In order to determine the reaction mechanism, trapping experiments were carried out using N-phenylmaleimide as the dienophile. In addition to pristine C$_{60}$, a mixture of enantiomers resulting from the trapping of the nitrile oxide 1,3 dipole thermally generated by the dienophile was formed. These experimental findings we also supported by ESI-MS studies which confirmed the loss of the 1,3 dipole fragment from the starting isoxazolinofullerenes.

These results give an insight to unravel the mechanism involved in other related fullerene cycloadducts. Theoretical and experimental studies are currently under investigation in our laboratories.

Experimental Section

Chemical shifts in the NMR spectra are reported in ppm downfield from tetramethylsilane (TMS). FTIR spectra were recorded as KBr pellets. All the ESI-MS experiments were carried out using an ion trap spectrometer in negative and positive mode of detection. A syringe pump was used to deliver solutions (1.5 × 10^{-5} mol L^{-1}, solvent:dichloromethane/acetonitrile/methanol/formic acid 75:15:9:1) of the corresponding fullerene derivative through a short length of 254 mm i.d. PEEK tubing with a flow rate of 3 mL min^{-1}. The stainless-steel capillary was held at a potential of 5.0 kV. Nitrogen was used as nebulizer gas in a flow-rate of 6.0 mL min^{-1} (nebulizer pressure 14 psi) at 150 °C. The spectra reported are the averages of five scans (from 300 to 1350 m/z) using 250 ms as the accumulation time. MS^n spectra were carried out using collision-induced dissociation (CID) with helium after isolation of the appropriate precursor ions. An isolation width of 0.4 m/z was used, and the fragmentation amplitude was maintained at 0.60 V with a fragmentation time of 40 ms.

The supporting electrolytes, tetra(n-butyl)ammonium hexafluro-phosphate ((n-Bu)$_4$NPF$_6$, 98%), tetra(n-butyl)ammonium perchlorate ((n-Bu)$_4$NClO$_4$, 98%), and tetra(n-butyl)ammonium tetrafluroborate ((n-Bu)$_4$NBF$_4$, 99%), were recrystallized three times from ethanol

TABLE 2. Electrochemical Reduction[a] and Oxidation[b] Potentials vs Fc/Fc$^+$ of Isoxazolinofullerenes 1a−e and Pristine C_{60} for Comparison

	potential, V vs Fc/Fc$^+$				
compound	$E^{0/+}$	$E^{0/-}$ (peak 1)	$E^{-/2-}$ (peak 2)	$E^{2-/3-}$ (peak 3)	E3$^{-/4-}$ (peak 4)
C_{60}	+1.24	−0.99	−1.40	−1.90	−2.39
1a	+1.21	−0.98	−1.37	−1.88	−2.37
1b	+1.17	−0.94	−1.36	−1.97	−2.47
1c	+1.20	−0.98	−1.39	−1.92	−2.44
1d	+1.18	−0.98	−1.33	−1.84	−2.36
1e	+1.14	−0.98	−1.39	−1.93	−2.32

[a] Differential pulse voltammograms were recorded in acetonitrile/toluene mixture containing 0.1 mol L^{-1} $(n\text{-Bu})_4NPF_6$. [b] Differential pulse voltammograms were recorded in benzonitrile containing 0.1 mol L^{-1} $(n\text{-Bu})_4NBF_4$.

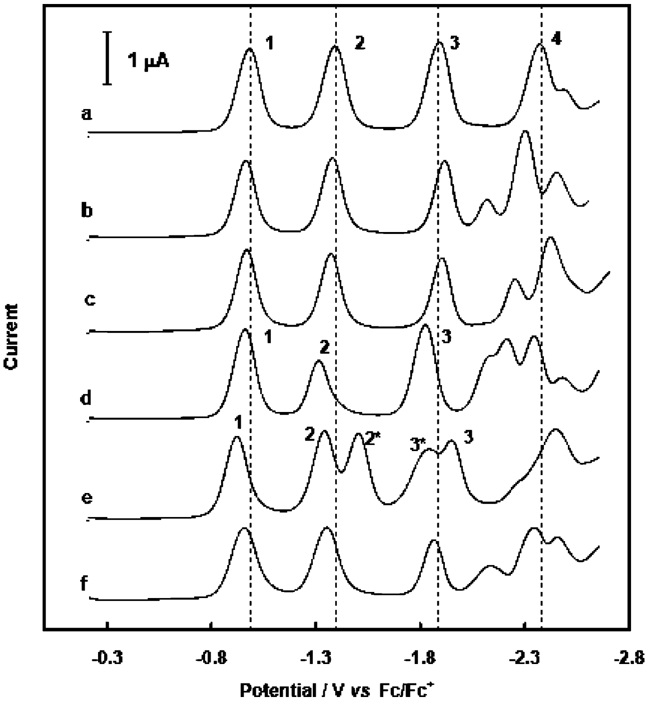

FIGURE 2. Differential pulse voltammetry curves recorded on a GC electrode (1 mm) in toluene/acetonitrile (4:1, v/v) mixture containing 0.1 M $(n\text{-Bu})_4NPF_6$ as supporting electrolyte and (a) 6.3 × 10^{-4} M C_{60}. (b) 5.8 × 10^{-4} M **1e**. (c) 4.8 × 10^{-4} M **1c**. (d) 5.2 × 10^{-4} M **1d**. (e) 5.1 × 10^{-4} M **1b**. (f) 5.7 × 10^{-4} M **1a**. Amplitude 0.05 V, pulse width 0.05 s, sampling width 0.0167 s, pulse period 0.2 s.

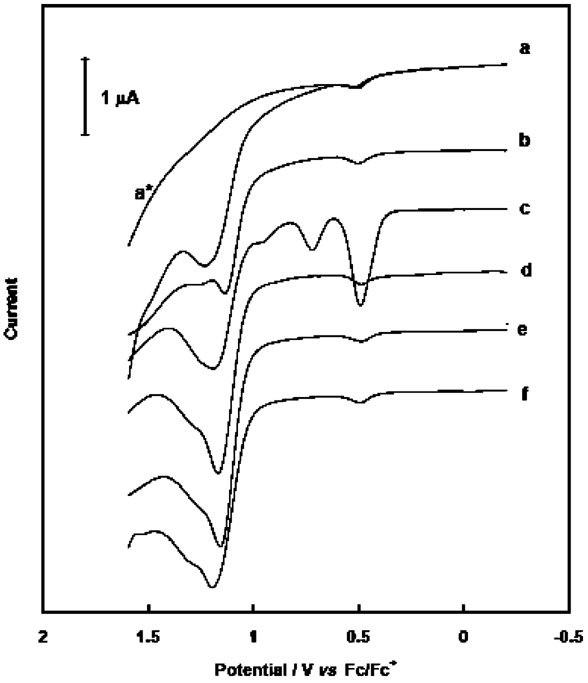

FIGURE 3. Differential pulse voltammetry curves recorded on a Pt electrode (1.5 mm) in benzonitrile solution containing 0.1 M $(n\text{-Bu})_4NPF_4$ as supporting electrolyte and (a) 6.3 × 10^{-4} M C_{60} (dashed line-backround). (b) 6.4 × 10^{-4} M **1e**. (c) 5.8 × 10^{-4} M **1c**. (d) 6.6 × 10^{-4} M **1d**. (e) 5.7 × 10^{-4} M **1b**. (f) 6.1 × 10^{-4} M **1a**. The curves were recorded in the potential range from 0 to 1.8 V. Amplitude: 0.05 V, pulse width 0.05 s, sampling width 0.0167 s, pulse period 0.2 s.

and were dried under vacuum for 24 h prior to use. Benzonitrile (anhydrous, 99%), acetonitrile (anhydrous, 99.8%), toluene (anhydrous, 99.8%), and 1,2-dichlorobenzene (anhydrous, 99%) were dried with CaH_2 under vacuum for a few hours prior to use. Isoxazolines[4,5:1,2][C_{60}] (**1a**−**e**) were dried under vacuum for 2 h prior to use.

Voltammetric experiments were performed using a potentiostat/galvanostat with a three-electrode cell placed in a Faraday cage. The working electrodes were a platinum disk with a diameter of 1.5 mm and a glassy carbon disk (GC) with a diameter of 1.0 mm. The surfaces of the electrodes were polished using extra fine carborundum paper followed by 0.3 μm alumina and 0.25 μm diamond polishing compound. Next, the electrodes were sonicated in water in order to remove the traces of alumina from the metal surface, washed with water, and dried. A silver wire immersed in 0.01 mol dm^{-3} silver nitrate and 0.09 mol dm^{-3} $(n\text{-Bu})_4NClO_4$ in acetonitrile and separated from the analysis solution by a ceramic tip served as the reference electrode. The silver perchlorate solution was replaced daily, because of the instability of Ag^+ to photoreduction. The stability of the reference electrode was examined by recording the ferrocene oxidation potential in the solvent studied as a function of time. The formal potential of the ferrocene−ferrocenium system was found to be stable for about 12 h. The counter electrode was made from platinum mesh (0.25 mm). The solution was deaerated for 20 min with argon prior to the electrochemical measurements.

Compound 1b (yield 31%, 64% based on recovered C_{60}). ^{1}H NMR ($CDCl_3/CS_2$, 298 K, 300 MHz): δ = 8.47−8.38 (m, H−Ar); ^{13}C NMR ($CDCl_3/CS_2$, 298 K, 125 MHz): δ = 152.7; 149.4; 147.8; 146.9; 146.5; 146.4; 146.2; 145.8; 145.7; 145.6; 145.0; 144.9; 144.4; 144.1; 144.0; 143.5; 143.4; 142.9; 142.7; 142.4; 142.2; 140.9; 140.8; 137.8; 137.1; 135.7; 130.15; 124.7; 77.7; FTIR (KBr) ν = 1558, 1521, 1340, 846, 526 cm^{-1}. MS (ESI) *m/z* 884 [M$^{\bullet -}$].

Compound 2 (isomeric mixture) (yield 35%). ^{1}H NMR ($CDCl_3/CS_2$, 298 K, 500 MHz): δ = 8.48−8.46 (m, H−Ar), 7.91−7.86 (m, H−Ar), 7.06−7.04 (m, H−Ar), 6.80−6.74 (m, H−Ar), 3.64−2.91 (m, CH_3). MS (ESI) *m/z* 1002.4 [M$^{\bullet -}$].

Synthesis of Hetero-bisadducts 3 and 5. To a solution of 0.5 mmol of the appropriate oxime in 20 mL of dry chloroform was added 0.1 mL of dry pyridine. The mixture was cooled to 0 °C. *N*-Chlorosuccinimide (0.52 mmol, 70 mg) was added to the solution, an the mixture was stirred for 15 min. To the chlorooxime solution was added 0.29 mmol of **4** (for compound **3**) or **6** (for compound **5**) in 50 mL of toluene and 1.68 mmol (60 mg) of triethylamine. The mixture was stirred 2 h at room temperature. The corresponding isoxazolinofullerenes were purified by flash chromatography on silica gel eluting with toluene/CS_2.

Compound 3 (isomeric mixture) (yield 20%). ^{1}H NMR ($CDCl_3$/CS_2, 298 K, 500 MHz): $\delta = 8{,}36-8.32$ (m, H−Ar), 8.02−7.94 (m, H−Ar), 7.63−7.45 (m, H−Ar), 4.48−4.38 (bq, CH_2), 1.45−1.25 (m, CH_3). HPLC-MS (ESI) *m*/*z* 997 [$M^{\bullet-}$].

Compound 5 (isomeric mixture) (yield 25%). ^{1}H NMR ($CDCl_3$/CS_2, 298 K, 500 MHz): $\delta = 8.41-7.87$(m, H−Ar), 6.96−6.66 (m, H−Ar), 4.67−3.91 (m,CH_2−N), 3.13−2.82 (m, CH_3). HPLC-MS (ESI) *m*/*z* 939 [$M^{\bullet-}$].

Compound 8[16] (yield 43%). ^{1}H NMR ($CDCl_3$/CS_2, 298 K, 500 MHz): $\delta = 7.52-7.42$ (m, 3H, H−Ar), 7.32−7.26 (m, 2H, H−Ar), 5.70 (d, 1H, $J = 10.1$ Hz, O−CH), 4.88 (d, 1H, $J = 10.1$ Hz, O−CH), 4.43 (AB syst, 2H, O−CH_2), 1.40 (t, 3H, $J = 7.1$ Hz, CH_3).

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Supporting Information Available: UV spectra and details of HPLC traces of compounds **2**, **3**, and **5**. Details of ESI-MS experiments. This material is available free of charge via the Internet at http://pubs.acs.org.

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