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Benzylamine imines as versatile precursors to azomethine and nitrile ylides in the [2 + 3] cycloaddition reactions with [60]fullerene

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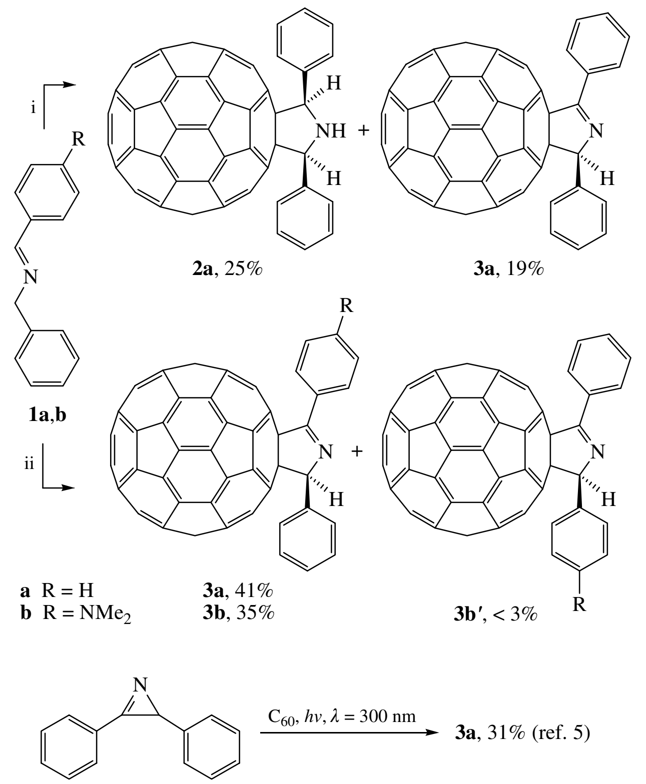
Pyrrolidino- and pyrrolinofullerenes were prepared using readily available benzylamine imines as reagents; the cyclic voltammetry measurements revealed that the C=N double bond mediates an electronic communication between the fullerene π-system and a substituent attached to the *sp*^{2} carbon of the pyrroline ring.

The [2 + 3] cycloaddition of 1,3-dipoles (ylides and related compounds) is an efficient method for fullerene derivatization.[1] The treatment of α-amino acids with aldehydes, accompanied by elimination of water and CO_2 molecules under heating, is a commonly used way for generation of azomethine ylides in fullerene chemistry (Prato reaction). However, the insolubility of amino acids in low polarity solvents, where fullerenes can be dissolved (*e.g.*, toluene and 1,2-dichlorobenzene), makes these reactions heterogeneous and limits the product yields to 25–45%. To avoid this problem, highly soluble imines were suggested as superior precursors to azomethine ylides. For instance, fullerene reactions with the imines of α-amino acid esters afford pyrrolidinofullerenes in approximately two times higher yields (57–78%) than the classical Prato method.[2] We found that the imines of picolylamines are even more potent reagents for fullerene derivatization because high product yields (up to 88%) are reached together with an exceptional degree of diastereoselectivity (97–100%).[3]



Scheme 1 *Reagents and conditions*: i, C_{60}, $PrCO_2H$, argon; ii, C_{60}, $PrCO_2H$, air.

We report here the acid-promoted preparation of pyrrolidinofullerenes and pyrrolinofullerenes from benzylamine imines that possess no stabilizing electron withdrawing units (Scheme 1). Typically, imine **1a** (50.7 mg, 0.26 mmol), C_{60} (105 mg, 0.15 mmol) and butyric acid (1.2 ml) were heated at reflux in 1,2-dichlorobenzene (50 ml) in an argon atmosphere for 10 h to result in a moderate fullerene conversion. The following chromatographic separation afforded pyrrolidinofullerene **2a** and pyrrolinofullerene **3a** in 25 and 19% yields, respectively. The composition of these compounds was confirmed by MALDI TOF mass spectrometry. The spectra of **2a** (M = 915.1) and **3a** (M = 913.1) were very similar and exhibited intense peaks at m/z 720 (C_{60}^{+}), 914 ([**2a** – H]$^+$ and [**3a** + H]$^+$), and 1002 ([**2a** – H + C_3H_8COO]$^+$ and [**3a** + C_3H_8COOH]$^+$). It is likely that **2a** is initially oxidised to form **3a** (loss of 2H) under the MALDI ionisation conditions, which then accepts a proton or C_3H_8COOH to give peaks at m/z 914 and 1002, respectively. We also observed such oxidation for some other pyrrolidinofullerenes under the given conditions.

Both ^1H and ^{13}C NMR spectra of **2a** evidenced that it is an individual C_s-symmetrical diastereomer with the *cis*-arrangement of phenyl rings. Such a high diastereoselectivity of [2 + 3] cycloaddition reactions was observed previously in the preparation of 2,5-disubstituted pyrrolidinofullerenes bearing bulky groups.[3,4] To the best of our knowledge, the formation of **2a** from **1a** is the first example of azomethine ylide generation *via* the tautomerization of benzylamine imines.

The ^1H NMR spectrum of **3a** exhibited resonances due to unequal phenyl rings along with a singlet at 7.23 ppm assigned to the methine proton of the heterocyclic ring. There are 53 resonances due to the fullerene cage *sp*^{2} carbons in the ^{13}C NMR spectrum of **3a**, which is typical of C_1 symmetrical fullerene derivatives. Two of three expected *sp*^{3} carbon resonances

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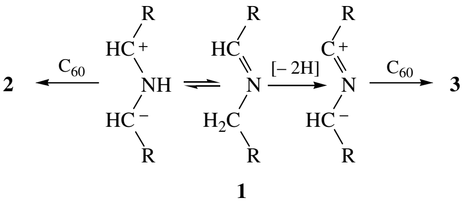


Scheme 2

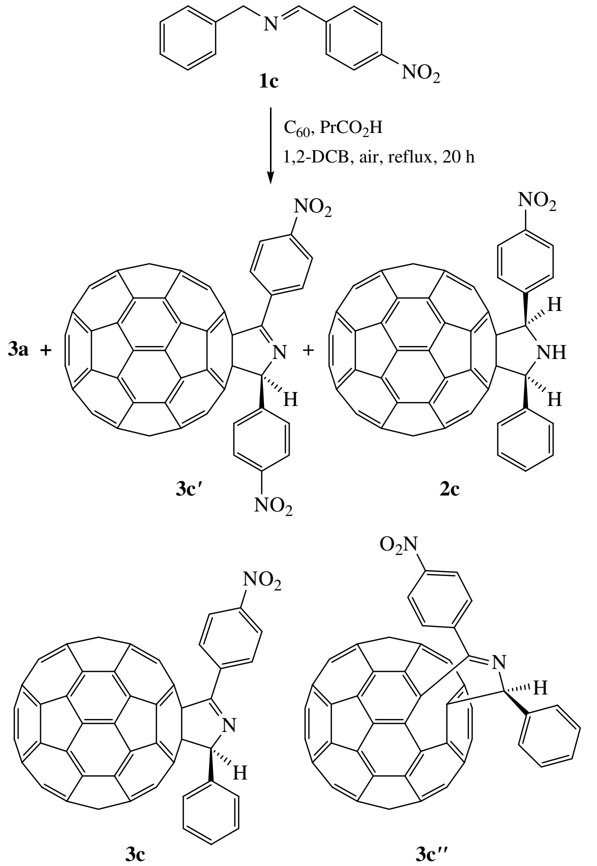
were observed in the high field part of the spectrum because of the incidental overlap of two peaks at 88.3–88.5 ppm. The same spectral data were reported for **3a** when this pyrrolinofullerene was prepared by the photochemical addition of 2,3-diphenylazirine to C_{60} (Scheme 1).[5]

The formation of pyrrolinofullerenes under the described conditions is quite surprising. Most probably, the reaction proceeds *via* dehydrogenation of starting imine **1a** to the corresponding nitrile ylide (Scheme 2). Similar dehydrogenation was observed previously for reactions of C_{60} with secondary amines.[6] Molecular oxygen can potentially play a role of an oxidizer; therefore, the reaction of **1a** with C_{60} was conducted in air under reflux in 1,2-dichlorobenzene. The reaction mixture was additionally irradiated by a 60 W incandescent light bulb to enhance the fullerene-sensitized generation of singlet oxygen. Pyrrolinofullerene **3a** was the only product formed in this case in 41% yield (Scheme 1).

Thus, the *in situ* oxidation of imines to nitrile ylides can be considered as a useful synthetic route to pyrrolinofullerenes. It requires very simple chemicals and can be used for the preparation of a wide range of products. Note that other known methods for the preparation of pyrrolinofullerenes require hardly available starting reagents (substituted azirines,[5] imidoyl halides[7] and imidodithioates[8]) or give products with very specific structures (addition of imines formed from glycine esters and benzophenone under oxidation with CBr_4/DBU,[9] and copper-catalysed addition of isocyanides[10]).

The reactions of [60]fullerene with imines **1b** and **1c** were also studied. The oxidative addition of **1b** to C_{60} proceeded smoothly and gave compound **3b** as a major product in 35% yield (Scheme 1). A minor impurity in the samples of **3b** (below 5–7%) that corresponds to other isomer of this pyrrolinofullerene **3b′** was revealed from the ^1H NMR spectra. The assignment of the structures of **3b** and **3b′** on the basis of NMR data is described in Supplementary Materials.

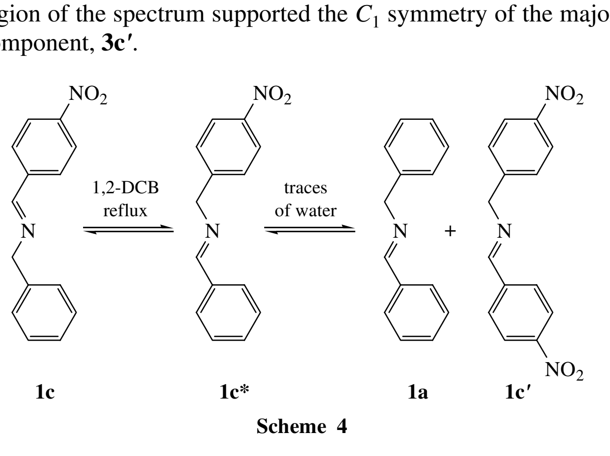
The fullerene conversion in the reaction with imine **1c** was just 35% even after 20 h; two fractions of products were isolated by column chromatography, and each of them consisted of two major components according to the NMR data. The first sample was revealed to be a virtually 1:1 mixture of 4-nitrobenzaldehyde and pyrrolinofullerene **3a**; the former was removed with methanol to afford pure **3a** in ~8% yield (or 25% based on consumed C_{60}). The second fraction was a 4:1 mixture of pyrrolinofullerene **3c′** and pyrrolidinofullerene **2c**; a small amount of another unidentified product was also observed. The calculated yields of **3c′** and **2c** were 17 and 4 or 51 and 13% based on consumed C_{60}, respectively. It is remarkable that expected pyrrolinofullerene **3c** was not observed among the isolated products. The repeatable column chromatography on silica did not result even in a partial separation of **3c′** and **2c**; therefore, their mixture was subjected to the spectroscopic characterization.



Scheme 3

Surprisingly, the 400 MHz ^1H and 100 MHz ^{13}C NMR spectra of the sample fitted very well to the data reported for the open-caged pyrrolinofullerene **3c″** prepared in the reaction of C_{60} with *N*-benzyl-4-nitrobenzimidoyl chloride.[7] The ^1H NMR shifts were the same to within ±0.05 ppm except for the resonances of protons neighbouring to the NO_2 groups that were strongly affected by solvent and concentration. The only detected sp^3-carbon signal was at 87.45 ppm, which is comparable to 87.74 ppm reported for **3c″**. Taking into account that open-caged **3c″** has one more double bond and thus the different π-system in comparison with the closed-cage pyrrolinofullerenes **3a**,**b** and **3c′**, much stronger deviations in the NMR chemical shifts should be expected for these compounds. For instance, considerable differences in the NMR spectra were reported previously for 6-6 closed and 5-6 opened cycloadducts formed by the addition of carbenes to C_{60}.[11] Therefore, we can doubt the preparation and isolation of the open-caged pyrrolinofullerene **3c″** reported earlier.[7]

The 600 MHz ^1H NMR spectrum evidenced the presence of two 4-nitrophenyl groups in **3c′**, as well as all signals expected for **2c**. The 150 MHz ^{13}C NMR spectrum revealed three sp^3-carbon signals at 84–89 ppm, as expected for the structure of **3c′** along with a set of four minor signals at 74–78 ppm corresponding to the sp^3 carbons of **2c**. The presence of 60 intense peaks (besides low intensity signals of **2c**) in the sp^2 region of the spectrum supported the C_1 symmetry of the major component, **3c′**.



Scheme 4

Thus, the reaction of C_{60} with imine **1c** afforded two symmetrically substituted pyrrolinofullerenes (**3a** with two phenyl groups and **3c′** bearing two 4-nitrophenyl units) and unsymmetrical pyrrolidinofullerene **2c**. Control experiments showed that starting **1c** gives a mixture of several products under reflux in 1,2-dichlorobenzene in the presence of butyric acid but without fullerene. Most probably, the double bond in **1c** is quite labile that allows for rearrangement to **1c*** (Scheme 4). The presence of an organic acid and, perhaps, trace amounts of water in the reaction mixture makes possible the metathesis reaction that yields imines **1a** and **1c′**. The similar reagent metathesis was observed previously for the reactions of imines of α-substituted amino acid esters with [60]fullerene.[12] Afterwards, the complex set of competition reactions between four different imines (**1c**, **1c***, **1a**, **1c′**) and C_{60} with and without the involvement of oxygen provides pathways for the formation of three isolated products.

Fullerene was used as an acceptor block in numerous photosensitive donor–acceptor assemblies.[13] It is important to provide some electronic channel between donor and acceptor counterparts in such systems.[14] We showed here that pyrrolinofullerenes that possess the C=N double bond in a close proximity to the fullerene cage can be a system of choice for such a kind of applications.

Indeed, the electrochemical reduction potentials of the prepared compounds determined from the cyclic voltammetry measurements[§] depend strongly on the structure of the substituent attached to the sp^2 carbon of the pyrroline ring. As shown in Table 1, the first reduction potentials of pyrrolinofullerenes are decreasing in the order **3c′** > **3a** > **3b**. The difference in the $E^1_{1/2}$ values between **3c′** and **3b** amounts 90 mV, which clearly indicates the existence of some electronic communications between the substituents in the pyrroline ring and the fullerene π-system. We assume that this effect arises particularly from conjugation of the imine double bond and the neighbouring aryl group in the –(Ar)–C=N– moiety. Therefore, the electronic effect of the substituent attached to the *para* position in the Ar group (H for **3a**, Me_2N for **3b** and p-O_2N for **3c′**) influences strongly the reduction of the fullerene core in these compounds (potentials given in Table 1). At the same time, the observed substituent effect on the reduction potentials of pyrrolinofullerenes **3a**–**c′** evidences that the C=N bond interacts efficiently with the fullerene π-system. An easier reduction of pyrrolinofullerene **3a** in comparison with pyrrolidinofullerene **2a** also supports this conclusion.

In summary, the reported method for the oxidative generation of nitryl ylides can be considered as an easy approach to the preparation of substituted pyrrolinofullerenes from readily available precursors. The potential of these fullerene reactions might be also transferred to the chemistry of other dipolarophiles in the syntheses of some pyrrolidine and pyrroline ring-containing targets. The electrochemical reduction of pyrrolinofullerenes was investigated for the first time; it was shown that the C=N double bond mediates electronic communications between the substituents in the pyrroline ring and the fullerene π-system. This effect can potentially find valuable applications in the design of photoactive covalently linked donor–acceptor dyads.

Table 1 CVA data for prepared compounds.

Compound	Reduction potentials $E_{1/2}$ *vs.* SCE/V		
	$E^1_{1/2}$	$E^2_{1/2}$	$E^3_{1/2}$
2a	–0.70	–1.12	–1.65
3a	–0.68	–1.06	–1.60
3b	–0.73	–1.13	–1.66
3c′	–0.64	–1.09	–1.65
C_{60}	–0.50	–0.94	–1.40

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Online Supplementary Materials

A spectral assignment of the structures of **3b** and **3b′**, a description of the synthetic procedures, ^1H and ^{13}C NMR shifts and graphs with all NMR and MALDI TOF MS spectra are presented in Online Supplementary Materials which can be found in the online version at doi:10.1016/j.mencom.2007.03.022.

References

1 (*a*) M. Prato and M. Maggini, *Acc. Chem. Res.*, 1998, **31**, 519; (*b*) M. A. Yurovskaya and I. V. Trushkov, *Izv. Akad. Nauk, Ser. Khim.*, 2002, 343 (*Russ. Chem. Bull., Int. Ed.*, 2002, **51**, 367); (*c*) G. M. Fazleeva, V. P. Gubskaya, F. G. Sibgatullina, V. V. Yanilkin, N. V. Nastapova, Sh. K. Latypov, A. A. Balandina, I. E. Ismaev, V. V. Zverev, Yu. Ya. Efremov and I. A. Nuretdinov, *Izv. Akad. Nauk, Ser. Khim.*, 2006, 489 (*Russ. Chem. Bull., Int. Ed.*, 2006, **55**, 507); (*d*) V. I. Sokolov, N. V. Abramova, N. S. Khrushcheva and S. M. Peregudova, *Izv. Akad. Nauk, Ser. Khim.*, 2003, 2612 (*Russ. Chem. Bull., Int. Ed.*, 2003, **52**, 2764); (*e*) I. P. Romanova, E. I. Musina, A. A. Nafikova, V. V. Zverev, D. G. Yakhvarov and O. G. Sinyashin, *Izv. Akad. Nauk, Ser. Khim.*, 2003, 1660 (*Russ. Chem. Bull., Int. Ed.*, 2003, **52**, 1750).

2 S. H. Wu, W. Q. Sun, D. W. Zhang, L. H. Shu, J. H. M. Wu, F. Xu and X. F. Lao, *J. Chem. Soc., Perkin Trans. 1*, 1998, 1733.

3 P. A. Troshin, A. S. Peregudov, D. Muhlbacher and R. N. Lyubovskaya, *Eur. J. Org. Chem.*, 2005, 3064.

4 P. A. Troshin, S. I. Troyanov, G. N. Boiko, R. N. Lyubovskaya, A. N. Lapshin and N. F. Goldshleger, *Fullerene Sci. Technol.*, 2004, **12**, 435.

5 J. Averburg, E. Albrecht, J. Lauterwein, H. Luftman, J. Mattey, H. Mohn, W. H. Muller and H.-U. ter Meer, *Chem. Ber.*, 1994, **127**, 787.

6 K. D. Kampe, N. Egger and M. Vogel, *Angew. Chem., Int. Ed. Engl.*, 1993, **32**, 1174.

7 A. Ovcharenko, V. A. Chertkov, A. V. Karchava and M. A. Yurovskaya, *Tetrahedron Lett.*, 1997, **38**, 6933.

8 G. Naxakis, P. Sofou and Y. Elemes, *Fullerenes Nanotubes Carbon Nanosctruct.*, 2004, **12**, 781.

9 G. E. Ball, G. A. Burley, L. Chaker, B. C. Hawkins, J. R. Williams, P. A. Keller and S. G. Pyne, *J. Org. Chem.*, 2005, **70**, 8572.

10 Y. Tsunenishi, H. Ishida, K. Itoh and M. Ohno, *Synlett.*, 2000, 1318.

11 Z. Li, K. H. Bouhadir and P. B. Shevlin, *Tetrahedron Lett.*, 1996, **37**, 4651.

12 P. A. Troshin and R. N. Lyubovskaya, *Fullerenes Nanotubes Carbon Nanostruct.*, 2005, **13**, 345.

13 D. Guldi, *Chem. Commun.*, 2000, 321.

14 F. T. Tat, Z. Zhou, S. MacMahon, F. Song, A. L. Rheingold, L. Echegoyen, D. I. Schuster and S. R. Wilson, *J. Org. Chem.*, 2004, **69**, 4602.

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[§] The cyclic voltammetry measurements were performed for *ca.* 1×10^{-3} M solutions of the fullerene compounds in 1,2-dichlorobenzene in a cell equipped with glassy carbon working electrode ($d = 2$ mm^2), platinum wires as counter electrode, SCE as a reference electrode. Scan rate was 200 mV s^{-1}. The 0.1 M solution of Bu_4NPF_6 was used as supporting electrolyte.