

The chemical retro-Bingel reaction: selective removal of bis(alkoxycarbonyl)methano addends from C₆₀ and C₇₀ with amalgamated magnesium

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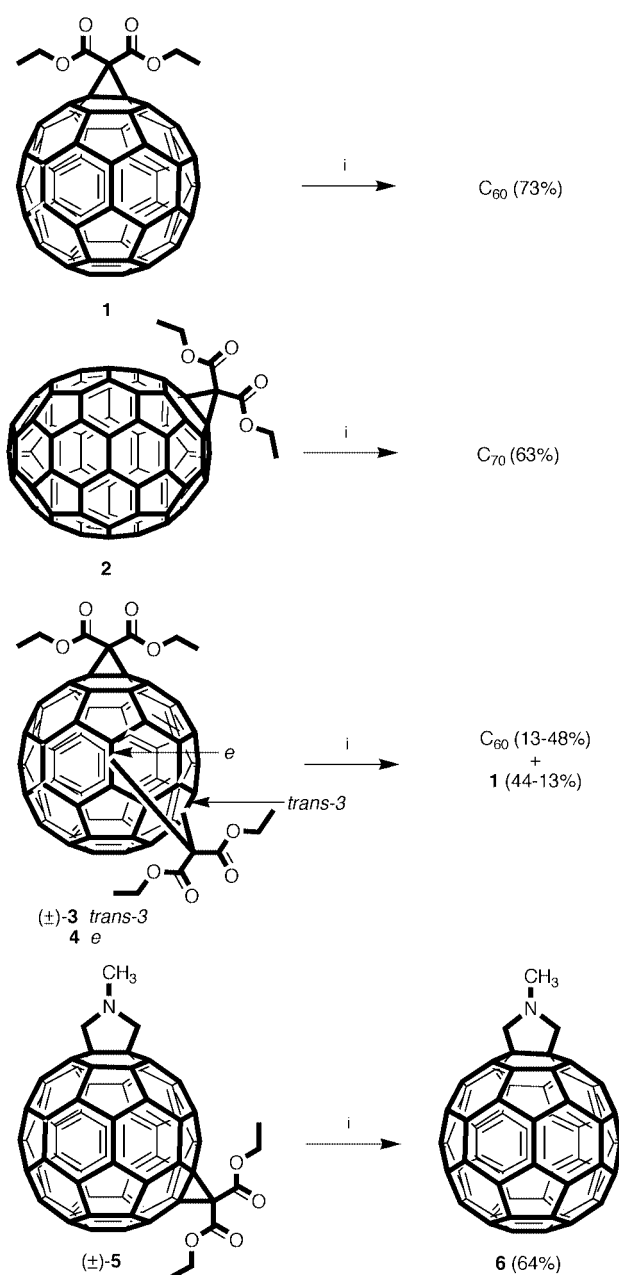
Bis(alkoxycarbonyl)methano addends are removed from C₆₀ and C₇₀ derivatives by reaction with amalgamated magnesium in dry THF; this facile and selective retro-Bingel reaction, which leaves pyrrolidine rings fused to C₆₀ intact, opens up the possibility of using bis(alkoxycarbonyl)methano addends as protecting and reversible directing groups in the regioselective multiple functionalization of fullerenes.

Regioselective multiple functionalization of fullerenes is a subject of great interest. A major strategy used to accomplish this task is tether-directed remote functionalization.¹ Another protocol, often used in combination with tether-directed remote functionalization,² is the temporary introduction of an addend which protects specific positions and, at the same time, directs new incoming addends regioselectively to other bonds on the carbon sphere. Examples for such addends, which are readily introduced and removed, are the [9,10]anthracene bridge³ as well as fullerene-fused cyclohexene^{2,4} and isoxazoline⁵ rings.

One of the most common fullerene functionalization methods is the nucleophilic cyclopropanation with 2-halomalonates, the so-called Bingel reaction.⁶ Although the resulting bis(alkoxycarbonyl)methanofullerenes are generally quite stable, there were early hints that the Bingel-type addends may be removed under certain circumstances.⁷ Closer investigations led to the discovery of the electrochemical retro-Bingel reaction, consisting of the preparative removal of bis(alkoxycarbonyl)methano addends from fullerene adducts by exhaustive electrochemical reduction.⁸ The first successful applications of the Bingel–electrochemical retro-Bingel reaction sequence were reported in the chemistry of the higher fullerenes, with the preparation of enantiomerically pure D₂-C₇₆⁸ and D₂-C₈₄,^{9a} pure D_{2d}-C₈₄^{9a} and a new C₈₄ isomer,^{9a} and C_{2v}-symmetric C₇₈.^{9b} The potential of bis(alkoxycarbonyl)methano addends as general protecting and reversible directing groups in fullerene chemistry prompted us to investigate the possibility of carrying out the retro-Bingel reaction under chemical conditions. Such a method would have the advantages of not requiring electrochemical equipment, avoiding the use of supporting electrolyte, and allowing conversions on a larger scale.

Initial attempts to remove the Bingel-type addend from **1** by electron transfer from Na metal or sodium naphthalenide in THF failed, leading only to materials that were insoluble in THF or toluene. Another convenient reducing agent which is easy to handle is metallic magnesium. Heating **1** with Mg powder (25 equiv.) in dry refluxing THF under Ar led to the formation of a brownish precipitate after ca. 1 d, and after 3 d, varying yields of up to 81% of C₆₀ could be isolated from the mixture. In analogy to Grignard reactions, starting the retro-Bingel reaction with pure Mg sometimes proved to be quite difficult. This situation could only be partially improved through activation of the metal by treatment with I₂ prior to the addition of the fullerene derivative. Use of the highly active Rieke magnesium¹⁰ only led to products that were insoluble in THF or toluene. Also, treatment of the commercial magnesium with

CuCl₂ did not lead to better or more reproducible yields. The best and most consistent results were obtained by amalgamation of the Mg powder with 10% HgBr₂ in THF, followed by a replacement of the solvent with fresh THF, addition of the



Scheme 1 Reagents and conditions: i, Mg/Hg, THF, Ar, 80 °C, 3 d.

methanofullerene and heating to reflux for 3 d.† Under these conditions, **1** afforded C₆₀ in 73% yield while unchanged starting material was recovered in 23% yield (Scheme 1). Similarly, the C₇₀ mono-adduct **2** provided 63% of the parent fullerene. These yields are comparable to those obtained by the electrochemical retro-Bingel reaction.⁸ Traces of as yet unidentified by-products, which may provide useful information with regard to the reaction mechanism, were detected during chromatographic purification of the products.

Zn dust and the Zn/Cu couple¹¹ are both active reducing agents in the retro-Bingel reaction of **1**, but the yields (Zn: 47% C₆₀, Zn/Cu: 29% C₆₀) are lower and, particularly with pure Zn, the amount of unidentified by-products is higher.

In the case of Bingel-type bis-adducts of C₆₀, the yields were variable (Scheme 1). In different experiments, the reduction of the pure *trans*-**3** and *e* regioisomers (\pm)-**3** and **4**, or of a mixture of the seven known regioisomers,¹² with Mg (100 equiv.) amalgamated with 10% HgBr₂ afforded between 48% C₆₀ (and 13% mono-adduct **1**) and 13% C₆₀ (and 44% **1**). These fluctuations contrast the clean conversion (up to 75% yield) of the bis-adducts to C₆₀ by the electrochemical retro-Bingel protocol,⁸ but the reasons for these differences are not yet understood. Interestingly, whereas the product mixture recovered from the non-exhaustive electrochemical reduction of constitutionally pure bis-adducts contained regioisomers of the starting material resulting from an intramolecular 'walk-on-the-sphere' rearrangement,¹³ such isomerization was not detected in the reduction of pure (\pm)-**3** or **4** with amalgamated Mg.

Fused pyrrolidines introduced by 1,3-dipolar cycloaddition are among the most versatile addends in fullerene chemistry. We therefore explored whether a bis(dialkoxycarbonyl)methano addend could be removed from bis-adducts such as (\pm)-**5**¹⁴ while leaving the methaniminomethano bridge intact. When (\pm)-**5**¹⁵ was reacted for 3 d with amalgamated Mg (50 equiv.), fulleropyrrolidine **6**¹⁶ was isolated in 64% yield, showing that the heterocycle is stable under the conditions of the chemical retro-Bingel reaction. This result opens up the possibility of using Bingel-type addends as protecting and reversible directing groups in future syntheses of fullerene multi-adducts that are not otherwise accessible. Investigations along these lines are now under way.

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Notes and references

† In a typical experiment, a mixture of Mg powder (50–150 mesh, purity \geq 99.8%; 14 mg, 576 mmol) and HgBr₂ (20 mg, 57 mmol) (both reagents from Fluka) was sonicated in dry THF (8 ml) for 30 min under Ar, after

which the solvent was replaced by fresh dry THF (8 ml) and C₆₀ monoadduct **1** (20 mg, 23 mmol) was added. The mixture was sonicated for another 30 min and then heated to reflux for 3 d. Column chromatography (SiO₂; toluene–hexane 1 : 1) provided 12 mg (73%) of C₆₀.

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