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A novel electron-transfer mediated reaction leading to lepidopterene

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Abstract—(Anthracen-9-yl)methanamines were found to undergo single electron-transfer mediated C–N bond cleavage in the presence of excess dimethyl acetylenedicarboxylate (DMAD) in non-polar solvents leading to the formation of lepidopterene (**4**) and 1,2-bis(9-anthracenyl)ethane (**3**). The structure of lepidopterene was confirmed on the basis of NMR data and by X-ray crystallography.

Lepidopterenes are benzenoid hydrocarbons of butterfly-like geometry, first obtained as undesired isomeric by-products in the preparation of 1,2-bis(9-anthracenyl)ethanes by the Grignard reaction of 9-(halomethyl)anthracenes.[1] Free radical intermediates were proposed to account for the formation of lepidopterenes but no evidence was found. Later, Becker et al.[2] described another synthesis of lepidopterenes by the reaction of 9-(halomethyl)anthracenes with stannous chloride dihydrate in dioxane at 70 °C. An ionic mechanism[2,3] involving the 9-anthracenemethyl anion generated from (9-anthracenemethyl)tin trihalide was suggested to account for the formation of lepidopterene. Lepidopterene has also been prepared through oxidation of 9-methylanthracene with copper(II) peroxydisulfate,[4] via photolysis and pyrolysis of 9-anthracenemethyl sulfides and selenides,[5] as a product of photolysis from 9-(phenoxymethyl)anthracene[6] and by reduction of 9-anthraldehyde and subsequent reactions.[7] Fernandez et al.[8] synthesized this compound from 9-(chloromethyl)anthracene by a reaction with 1.1 equiv of sodium iodide in dry acetone. Traces of 1,2-bis(9-anthracenyl)ethane were also formed and thus a free radical mechanism was proposed.[8] The fact that this compound can be obtained through a wide variety of processes involving different mechanisms, along with its relevant photochemical properties[9–14] have aroused considerable interest in the study of this compound and its derivatives.

In this letter we report the formation of lepidopterene through electron transfer by thermal initiation from a suitable electron donor to an electron acceptor. When a mixture of (anthracen-9-yl)-*N*,*N*-dimethylmethanamine (**1a**) and dimethyl acetylenedicarboxylate (DMAD) was refluxed in non-polar solvents under a nitrogen atmosphere, tetrabenzotetracyclotetradecatetraene or lepidopterene (**4**) was obtained in moderate yields along with 1,2-bis(9-anthracenyl)ethane (**3**) as a minor product (Scheme 1).

This unusual reaction may be viewed to take place through a single electron transfer from the tertiary amine to DMAD followed by C–N bond cleavage generating the 9-anthracenemethyl radical **6** (Scheme 2). The 9-anthracenemethyl radical thus formed underwent dimerization, followed by intramolecular Diels–Alder reaction to form lepidopterene. The 9-anthracenemethyl radical **6** can undergo various reactions depending on the reaction conditions employed. Mostly, in non-polar solvents, it undergoes dimerization to **3** and **7**.[5] Formation of **4** involved the α/*para* dimer **7** followed by intramolecular Diels–Alder reaction.[2] (Scheme 3). In order to establish the involvement of DMAD in the observed transformation, we carried out a blank run by refluxing **1a** in toluene for 48 h. Unchanged **1a** was recovered in quantitative amounts in this case.

The preferential formation of dimer **7** may be explained on the basis of theoretical calculations. AMI

Keywords: Lepidopterene; Electron transfer; 9-aminomethylanthracene; C–N bond cleavage.

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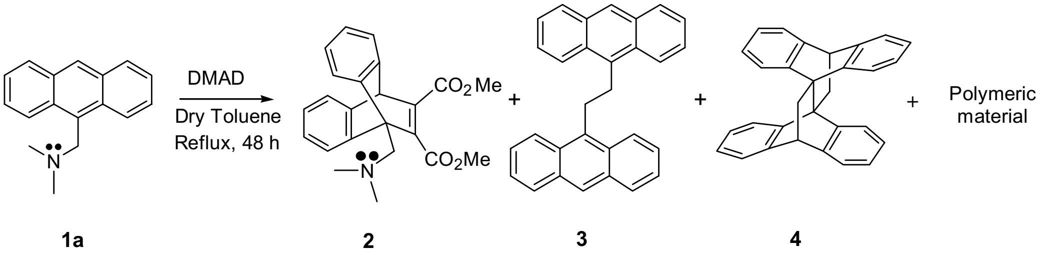
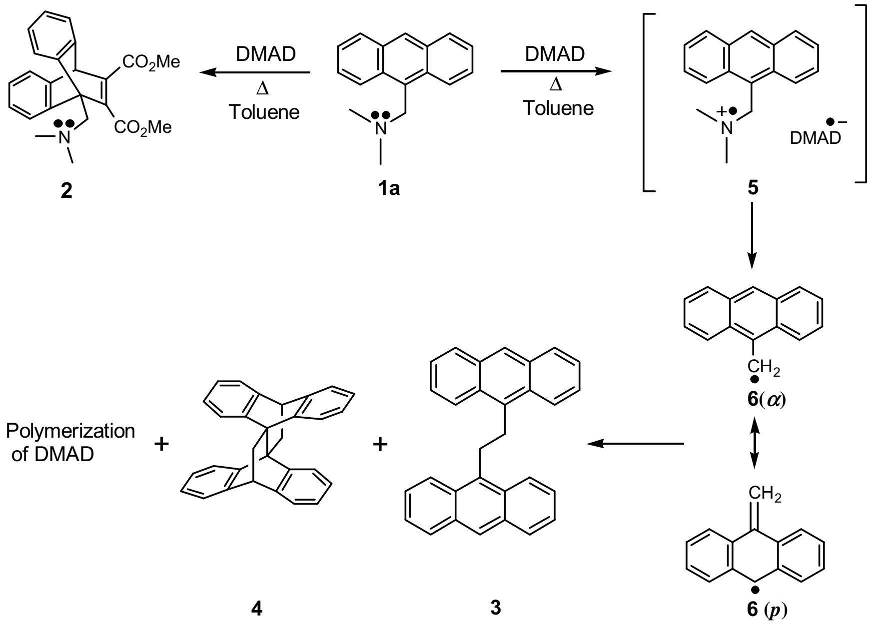
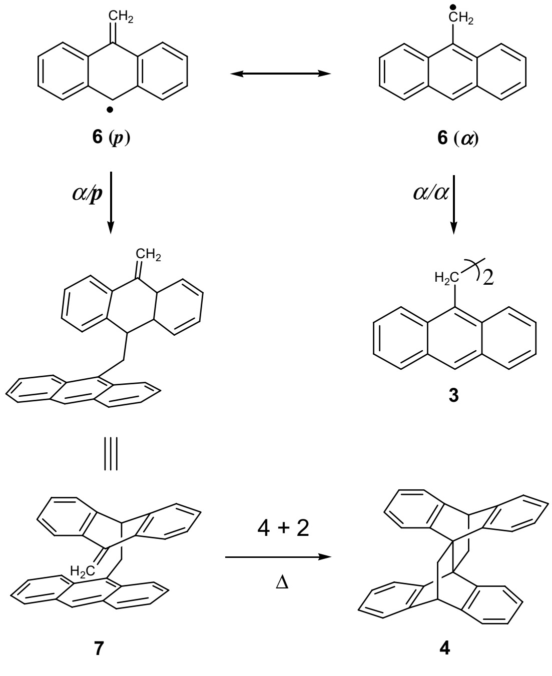


Scheme 1.



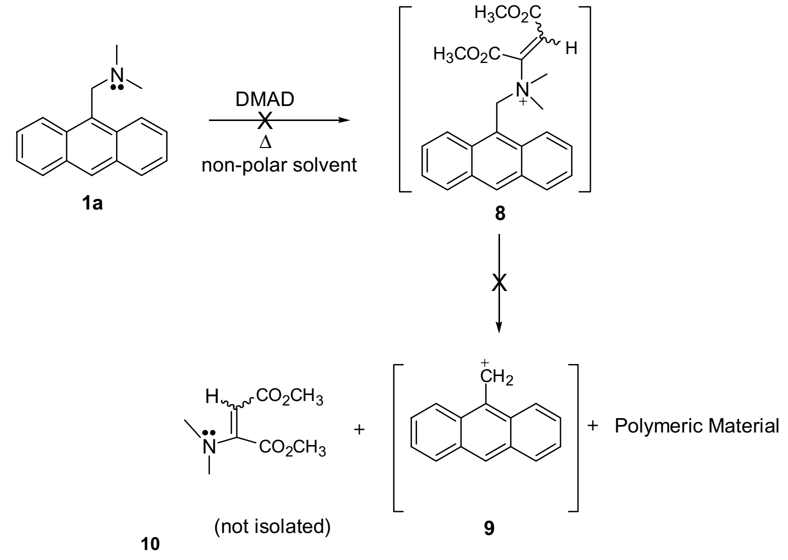
Scheme 2.



Scheme 3.

calculations[15] have shown that the ground state of the radical **6** has 3-fold higher spin density in the *para* than in the α position, which facilitates the α/*p* attack to form **7**. The structure of lepidopterene was established on the basis of spectral data, crystal studies[16] and literature precedence.[1–7]

It may be noted that radical formation through single electron transfer and consequent reactions occur in competition with other reactions including: (a) Diels–Alder reaction between anthracene and DMAD, (b) nucleophilic addition of **1a** to DMAD followed by C–N bond cleavage leading to an anthracenemethyl cation and the corresponding *N*,*N*-dialkylaminofumarate/maleate (Scheme 4). In order to explore these possibilities by examining the formation of other products under the conditions employed by us, we carried out GC–MS and ^{1}H NMR spectral analysis of the crude product mixture obtained from reaction between **1a** and DMAD. GC–MS analysis[17] of the crude reaction mixture indicated the presence of unchanged **1a** in substantial amounts along with a very minor component ($m/z = 377$), attributable to the expected Diels–Alder adduct **2**. Our attempts to isolate this component in pure form were unsuccessful. ^{1}H NMR analysis of the prod-



Scheme 4.

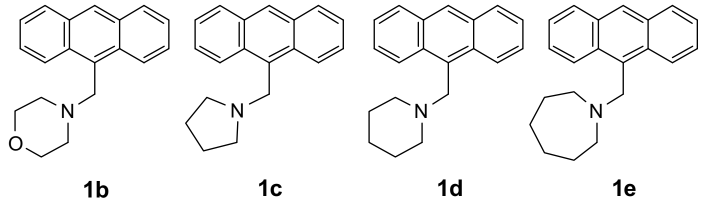


Chart 1.

uct mixture indicated the presence of **3**, **4** and unchanged **1a** in a roughly 1:10:60 ratio. Neither GC–MS nor ^{1}H NMR spectral data indicated the formation of 9-methylanthracene and *N*,*N*-dimethylaminofumarate/maleate in detectable amounts.

Based on these results, we conclude that electron-transfer mediated C–N bond cleavage followed by dimerization and intramolecular Diels–Alder reaction to form lepidopterene is the major reaction under the conditions employed by us. The absence of 9-methylanthracene is not surprising since benzylic radicals prefer dimerization to hydrogen abstraction from the solvent.[18] However, in the presence of excess DMAD the expected Diels–Alder adduct was formed as only a minor product. The absence of *N*,*N*-dimethylaminofumarate/maleate in the product mixture rules out the possibility of an ionic mechanism leading to the anthracenemethyl cation as depicted in Scheme 4. As expected, at higher temperatures a major portion of DMAD underwent polymerization.[19]

Reactions with other (anthracen-9-yl)methanamines, viz., 4-((anthracen-9-yl)methyl)morpholine (**1b**), 1-((anthracen-9-yl)methyl)pyrrolidine (**1c**), 1-((anthracen-9-yl)methyl)piperidine (**1d**) and 1-((anthracen-9-yl)methyl)azepane (**1e**) also gave lepidopterene in 12%, 20%, 16% and 12% yields, respectively (Chart 1). Substantial amounts of unchanged **1b**–**e** (36%, 22%, 29% and 31%, respectively), and trace amounts of 1,2-bis(9-anthracenyl)ethane (**3**, <2%) were also isolated from the reaction mixtures. Reaction of **1a** with other dienophiles, including diphenylacetylene, propiolic acid and 1,4-benzoquinone did not give the intermolecular (4+2) addition products or products arising through electron transfer reactions (**3** and **4**) in appreciable amounts; unchanged **1a** was recovered in substantial amounts in these cases. In an attempt to minimize the electron transfer reaction (and thereby to increase the yield of the Diels–Alder adduct **2**), we repeated the reaction of **1a** with DMAD in toluene in the presence of acetic acid. Addition of acetic acid (5 equiv) did not affect either the product distribution or yield. Details of these studies will be published elsewhere.

The results reported support a radical mechanism for the formation of lepidopterene initiated by a single electron transfer between tertiary amines and the electron deficient dienophiles. We propose anthracene methanamine radical cation **5** as a possible intermediate. Similar radical cations have been invoked as possible intermediates in certain nucleophilic substitution reactions.[20] This in turn alludes to the possibility of electron-transfer mediated substitution reactions in the case of (anthracen-9-yl)methanamines. We expect this to be an efficient method to effect nucleophilic substitution on systems, which are reluctant to undergo classical nucleophilic substitution reactions due to the presence of poor leaving groups, the possibilities of which are currently being explored by us.

In summary, we have illustrated a novel electron-transfer mediated reaction between tertiary amines and highly electron deficient dienophiles such as DMAD leading to the formation of a compound of high structural and synthetic importance: lepidopterene. Furthermore, our findings are consistent with Pross's intrepretation[21] that the energetics of a single electron shift and/or electron transfer dictates the course of organic reactions.

The experimental procedure for the reaction between aminomethylanthracenes and dienophiles is as follows: In a typical experiment, DMAD (3.46 mL, 28.10 mmol) was added to a solution of (anthracen-9-yl)-*N*,*N*-dimethylmethanamine (**1a**, 1.88 g, 8.00 mmol) in dry toluene (15 mL) and the mixture refluxed under a nitrogen atmosphere for 48 h. The solvent was removed under reduced pressure and the residue was purified by column chromatography on silica gel using hexane–methylene chloride (1:8) to give **3** (traces) and further elution with hexane–methylene chloride (1:9) gave lepidopterene (**4**) (290 mg, 19%), which was characterized by NMR and crystal studies.[16] ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.71–7.34 (16H, m, aromatic protons), 4.63 (2H, t, $J = 2.5$ Hz), 2.90 (4H, d, $J = 3.0$ Hz). Anal. Calcd for $C_{30}H_{22}$: C, 94.20; H, 5.80; Found: C, 94.30; H, 5.71. Crystallographic data for **4** is already reported in Ref. 11.

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