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Octamethoxydibenzochrysenes: Isolation and X-ray Crystallographic Characterization of a Twisted Polyaromatic Cation Radical

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Abstract

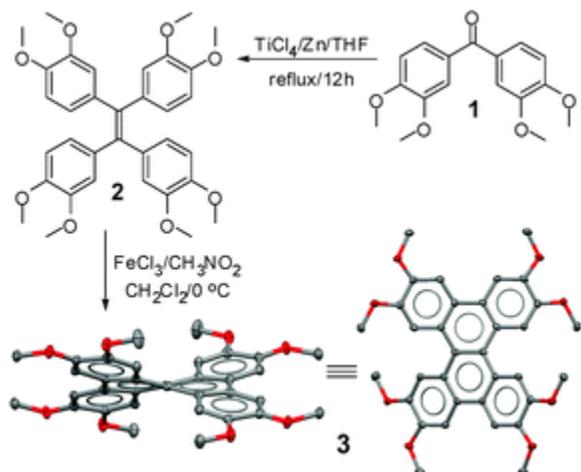
The isolation and X-ray crystal structure determination of octamethoxydibenzochrysenes (**3**) [cation radical](#) together with DFT calculations allow us to delineate evidence that the complex structural

changes (*i.e.* elongation and shortening of various bonds) in a polyaromatic [hydrocarbon](#) can be predicted based on the positioning of the largest bonding and antibonding character of the HOMO.

The study of polyaromatic [hydrocarbons](#) has attracted considerable attention since these molecules hold potential to serve as building blocks for the preparation of functional electronic and optoelectronic devices.¹ Of these, dibenzochrysene, a twisted polyaromatic [hydrocarbon](#), and its derivatives have been explored by Swager and coworkers² and others³ for the preparation of sensors, non-linear optical and liquid-crystalline materials, *etc.* The aromaticity and structure of parent dibenzochrysene and its dication (formed by 2-electron oxidation) has been probed both theoretically⁴ and experimentally,⁵ however, structural information is completely lacking.

Our continuing interest in the design and syntheses of stable [organic cation](#) radicals, or hole carriers, which are of fundamental importance to organic materials science,⁶ prompted the synthesis of octamethoxydibenzochrysene (**3**), and isolation and X-ray crystallographic characterization of its cation-radical salt. The availability of the X-ray structural data on the first cationic dibenzochrysene allows us to provide definitive evidence as to how a hole (formed by 1e⁻ oxidation) induces complex bond length changes in a polyaromatic [hydrocarbon](#) as well as a verification of the experimentally observed structural changes by DFT calculations. The details of these preliminary findings are described herein.

The octamethoxydibenzochrysene (**3**) was obtained by an oxidative cyclodehydrogenation of tetrakis(3,4-dimethoxyphenyl)ethylene (**2**) using [FeCl₃](#) as an oxidant in a mixture of [dichloromethane](#) and [nitromethane](#) in 60% isolated yield. The tetraveratrylene (**2**), in turn, was prepared from McMurry coupling of the corresponding tetramethoxybenzophenone (**1**) in 92% yield (see [Scheme 1](#)). The structure of **3** was established by ¹H/¹³C NMR spectroscopy and further confirmed by [X-ray crystallography](#) (see [Scheme 1](#) and ESI for the experimental details[†]).



Scheme 1 Synthesis of octamethoxydibenzochrysene (**3**) and its ORTEP diagrams with twisted structure (thermal ellipsoids: 50% probability).

The [electron donor](#) strength of octamethoxydibenzochrysene (**3**) was evaluated by electrochemical oxidation at a platinum electrode as a 2×10^{-3} M solution in [dichloromethane](#) containing 0.2 M *n*-Bu₄NPF₆ as the supporting electrolyte. The cyclic

voltammograms of **3**, if terminated before the start of the third oxidation event, showed two reversible oxidation waves (Fig. 1A), which consistently met the reversibility criteria at various scan rates of 25–500 mV s^{-1} , as they all showed cathodic/anodic peak current ratios of $i_a/i_c = 1.0$ (theoretical) as well as the differences between anodic and cathodic peak potentials of $E_{pa} - E_{pc} \approx 70$ mV at 22 °C (Fig. 1B). The reversible oxidation potentials of **3** were calibrated with ferrocene as internal standard ($E_{ox} = 0.45$ V vs. SCE) and were found to be 0.91 and 1.27 V vs. SCE corresponding to the formation of monocation and dication, respectively. It is noted that the third oxidation wave in the cyclic voltammogram of **3** displays a quasi-reversible oxidation wave ($E_{ox3} = 1.69$ V) which, in turn, distorts the other waves corresponding to the first and second oxidation events (see Fig. 1A).

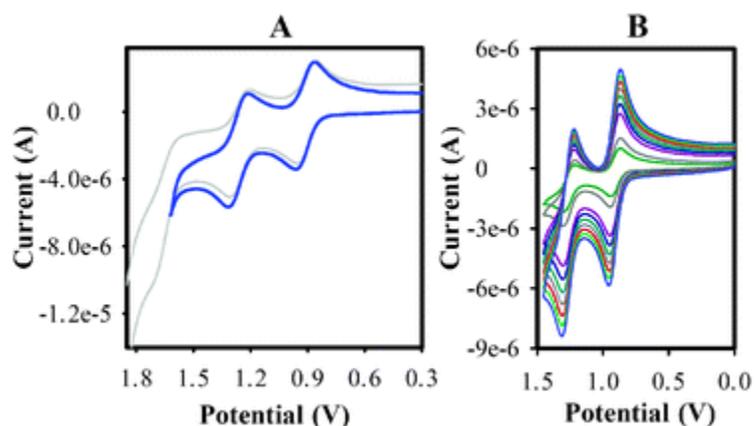
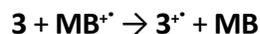


Fig. 1 (A) Cyclic voltammograms of 2×10^{-3} M **3** in CH_2Cl_2 containing 0.2 M $n\text{-Bu}_4\text{NPF}_6$ at a scan rate of 200 mV s^{-1} and (B) cyclic voltammograms of **3** at scan rates of 25–500 mV s^{-1} at 22 °C.

The electrochemical reversibility of **3** and its relatively low oxidation potential permits its ready oxidation to the corresponding cation radical using either a hydroquinoneethercation radical ($\text{CRET}^+ \text{SbCl}_6^-$; $E_{red} = 1.11$ V vs. SCE)⁸ or magic blue ($\text{MB}^+ \text{SbCl}_6^-$; $E_{red} = 1.15$ V vs. SCE)⁹ as oxidants.

Thus, Fig. 2A shows the spectral changes attendant upon the reduction of blue MB^+ ($\lambda_{max} = 728$ nm, $\log \epsilon_{728} = 4.45$) by incremental additions of sub-stoichiometric amounts of **3** in dichloromethane at 22 °C. The presence of multiple isosbestic points at $\lambda = 355, 387, 564,$ and 783 nm (see Fig. 2A) indicates a simple electron transfer from **3** to MB^+ without decomposition of MB^+ . Furthermore, a plot of formation of MB^+ (i.e. an increase in the absorbance at 890 nm against the increments of added **3**, Fig. 2B) established that MB^+ was completely consumed after the addition of 1 equiv. of **3**; and the resulting highly structured absorption spectrum of the MB^+ [with intense absorption bands at $\lambda_{max} = 890$ ($\log \epsilon_{890} = 4.37$), 513, 458, and 394 nm and relatively weak bands at $\lambda_{max} = 636$ ($\log \epsilon_{634} = 3.67$) and 784 nm] remained unchanged upon further addition of neutral **3**, i.e., eqn (1).



It is noted that although an identical [spectrum](#) of 3^+ was obtained when $CRET^+$ was treated with an equimolar amount of **3**, a clean spectral [titration](#) plot with isosbestic point could not be obtained owing to an overwhelming overlap of the absorption band of $CRET^+$ at 518 nm with that of 3^+ (see [ESI†](#)). It is further noted that the intensely colored solution of 3^+ , obtained according to [eqn \(1\)](#) or using $CRET^+$, was stable at ambient temperature and did not show any decomposition during a 48 h period at 22 °C, as confirmed by [UV-Vis spectroscopy](#). Moreover, a reduction of 3^+ with zinc dust regenerated the neutral **3** quantitatively as confirmed by [\$^1H\$ NMR spectroscopy](#).

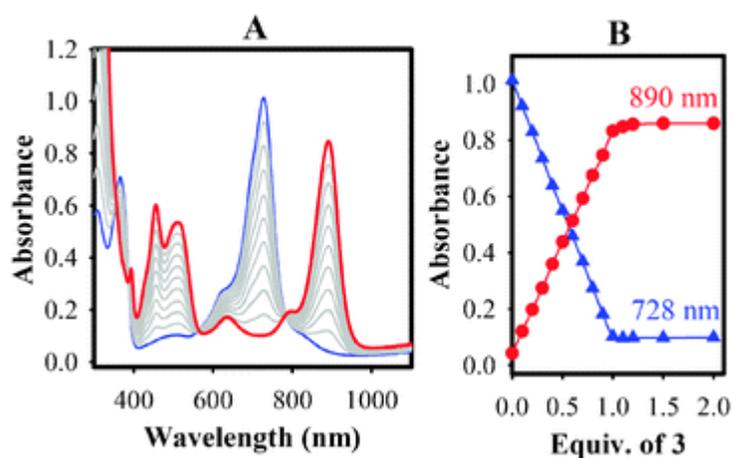


Fig. 2 (A) The spectral changes observed upon the reduction of 3.6×10^{-5} M MB^+ by an incremental addition of substoichiometric amounts of **3** in CH_2Cl_2 at 22 °C. (B) A plot of depletion of absorbance of MB^+ (blue triangles, at 728 nm) and an increase of the absorbance of 3^+ (red circles, at 890 nm) against the equivalents of added neutral **3**.

The high stability of $3^+ SbCl_6^-$ in solution prompted us to attempt the isolation of its crystalline salt as follows. For example, an excellent crop of dark-colored crystals, suitable for X-ray crystallographic studies, were obtained by a slow diffusion of [toluene](#) in a dichloromethane solution of $3^+ SbCl_6^-$, obtained using a 1 : 1 mixture of **3** and $CRET^+ SbCl_6^-$, during a period of 24 h at ~ 0 °C.

The crystal structure of $3^+ SbCl_6^-$ revealed that cationic dibenzochrysene moieties form infinite stacks along the z axis with non-equivalent interplanar separations of 3.31 and 3.44 Å. The robust π - π stacking arrangements amongst the molecules of the cationic **3** leads to a [clathrate](#) structure with large channels that are filled with $SbCl_6^-$ counter anions and multiple [dichloromethane](#) molecules (see [Fig. 3A/B](#)). In contrast, the packing in the crystal structure of neutral **3** is dominated not by π - π but by $CH \cdots \pi$ interactions amongst the [methoxy groups](#) and the electron-rich [aromatic](#) rings of the neighboring molecules. The resulting honeycomb-like layers, formed perpendicular to the crystallographic x-axis, are interspaced by disordered [dichloromethane](#) molecules (see [Fig. 3D](#)); and the layers are separated by copious amounts of [acetonitrile](#) molecules (see [Fig. 3C](#)).[†]

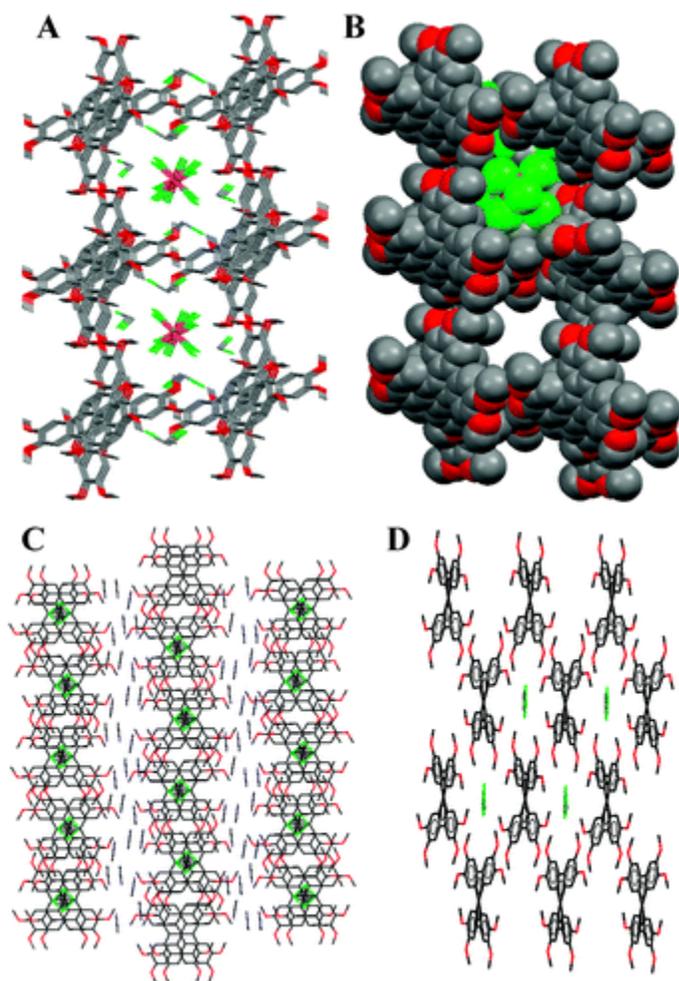


Fig. 3 (A) The packing diagram of 3^+SbCl_6^- showing that the channels formed by stacked 3^+ are filled with SbCl_6^- and CH_2Cl_2 molecules. (B) Space filling representation of the packing diagram of 3^+SbCl_6^- where one of the channels is shown without SbCl_6^- and CH_2Cl_2 molecules. (C) The packing diagram of neutral **3** showing the layered structure where the layers are separated by [acetonitrile](#) molecules. (D) The arrangement of **3** with embedded CH_2Cl_2 molecules within a single layer of neutral **3**.

An inspection of the bond length changes in the [cation radical](#) 3^+ , together with a comparison of its neutral form, points to the following salient features. (i) Neutral **3** has a crystallographic 2-fold symmetry and its planarity is substantially distorted by twisting around the central C=C bond (denoted as **A**, see [Table 1](#)) by 25.8° and around the central bonds of “[biphenyl](#)” fragments (denoted by **I**) by 11.4° . One electron oxidation of **3** results only in a minor amplification of the distortions as judged by the slightly increased twist angles of 29.1 and 11.9° for bonds **A** and **I**, respectively. (ii) As in various other aryl-methyl [ether](#) cation radicals,¹⁰ O–C(ar) bonds (denoted as **J** and **L**) in 3^+ exhibit shortening by ~ 1.3 pm due to an increased p– π dative interaction. (iii) Although the rearrangement of the lengths of various bonds (*i.e.* elongation and shortening) in the polyaromatic moiety in 3^+ has a complex character (see [Table 1](#)), the changes clearly correspond to the predominant contributions from the resonance structures I/II, as judged by the significant lengthening of bonds **A**, **C**, **F**, **I**,

and **M** and shortening of bonds **B**, **G**, **J**, and **L** and only a minor contribution from the resonance structures III/IV (see below).

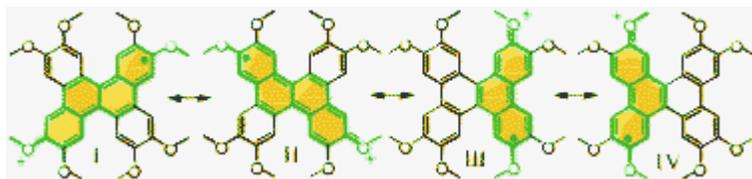
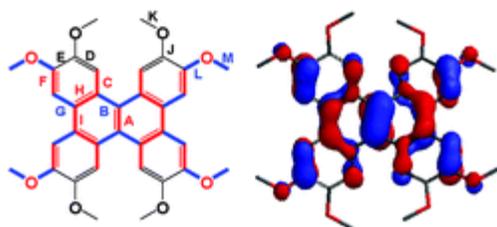


Table 1 Experimental and theoretical bond lengths of the neutral and [cation radical](#) of **3** presented in picometres (pm). Numbering scheme for the skeleton of **3** and its HOMO, obtained by DFT calculations at B3LYP/6-31G* level



Bond ^a	B3LYP/6-31G*			X-Ray data		
	3	3 ⁺	Δ	3	3 ⁺	Δ
<i>a</i> Average of equivalent bonds.						
A	140.3	144.0	+3.7	141.4	143.0	+1.6
B	145.8	144.1	-1.7	145.5	143.9	-1.4
C	142.2	142.4	+0.2	141.5	142.3	+0.8
D	138.1	138.0	-0.1	136.9	136.9	0.0
E	142.4	143.0	+0.6	141.9	142.5	+0.6
F	138.1	139.3	+1.2	137.8	138.2	+0.4
G	141.7	140.4	-1.3	142.0	140.1	-1.9
H	141.7	142.2	+0.5	141.6	141.6	0.0
I	145.2	146.3	+1.1	145.3	146.5	+1.2
J	136.3	135.1	-1.2	137.0	135.8	-1.2
K	141.6	142.3	+0.7	143.3	143.2	-0.1
L	136.2	134.1	-2.1	136.3	134.9	-1.4
M	141.6	142.7	+1.1	142.9	144.2	+1.3
σ	—	—	—	0.5	0.4	—

The experimental observations of the bond length changes in **3⁺** were found to be in reasonable agreement with the calculated values using DFT calculations at the B3LYP/6-31G* level (see [Table 1](#)). Furthermore, the experimentally observed elongation and shortening of the bonds in **3⁺** tracked

remarkably well with the positioning of the largest bonding and antibonding character of HOMO in **3** (see [Table 1](#)).

In summary, octamethoxydibenzochrycene (**3**) is easily accessed from readily available starting materials and it undergoes reversible electrochemical oxidation and forms a highly robust cation-radical salt. The X-ray crystal structure determination of $3^+SbCl_6^-$ as well as neutral **3** together with DFT calculations provides unequivocal evidence that an introduction of a cationic charge (or polaron) in polyaromatic [hydrocarbon](#) **3** leads to a complex elongation and shortening of the various bonds. The observed bond length changes in 3^+ can be readily reconciled by the positioning of the largest bonding and antibonding character of the HOMO in neutral **3**. The close packing of the molecules of the cationic **3** in the crystals produces large channels akin to those found in [zeolites](#) and may allow the preparation of potentially useful conducting materials by utilizing electro-active counter anions.¹¹

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Notes and references

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Footnotes

† Electronic supplementary information (ESI) available: Synthetic details of **3** and procedure for the isolation of its [cation radical](#). CCDC 720096–720097. For ESI and [crystallographic data](#) in CIF or other electronic format see DOI: [10.1039/b903133b](https://doi.org/10.1039/b903133b)

‡ *Crystal structure data for 3* [$C_{34}H_{32}O_8 \cdot CH_2Cl_2 \cdot (CH_3CN)_4$] (raj2z): FW = 817.74, monoclinic, $C2/c$, $a = 31.6750(8)$ Å, $b = 7.3983(2)$ Å, $c = 18.0078(4)$ Å, $\beta = 106.7180(10)^\circ$, $Z = 4$, $V = 4041.60(17)$ Å³, $D = 1.344$ Mg m⁻³, $T = 100$ K, 6231 reflections measured, 3114 unique reflections, $R_{int} = 0.0174$, 342 parameters refined, $R(all) = 0.0944$, $wR(all) = 0.2397$, $S = 1.066$ (CCDC 720097). *Crystal structure data for 3*⁺ SbCl₆⁻ [$C_{34}H_{32}O_8 \cdot SbCl_6 \cdot (CH_2Cl_2)_2$] (raj3d): FW = 1072.90, triclinic, $P\bar{1}$, $a = 13.6451(5)$ Å, $b = 14.0770(5)$ Å, $c = 14.3621(5)$ Å, $\alpha = 61.672(2)^\circ$, $\beta = 62.275(2)^\circ$, $\gamma = 70.899(2)^\circ$, $Z = 2$, $V = 2129.39(13)$ Å³, $d = 1.673$ Mg m⁻³, $T = 100$ K, 16984 reflections measured, 6159 unique reflections, $R_{int} = 0.0343$, 644 parameters refined, $R(all) = 0.0307$, $wR(all) = 0.0728$, $S = 1.039$ (CCDC 720096).