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On the synthesis and functionalisation of the 4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd*,*mn*]pyrenium system

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Abstract—The preparative use of the reaction between tris(2,6-dimethoxyphenyl)carbenium tetrafluoroborate and excess of an arylamine such as 4-methylaniline or 4-bromoaniline to yield firstly the aryl functionalised acridinium derivatives and then further in situ reaction to yield the desired functionalised triangulenium salts was found to be problematic. A preparative route for the triangulenium salts is presented along with a demonstration of the further derivatisation by a standard Suzuki coupling reaction.
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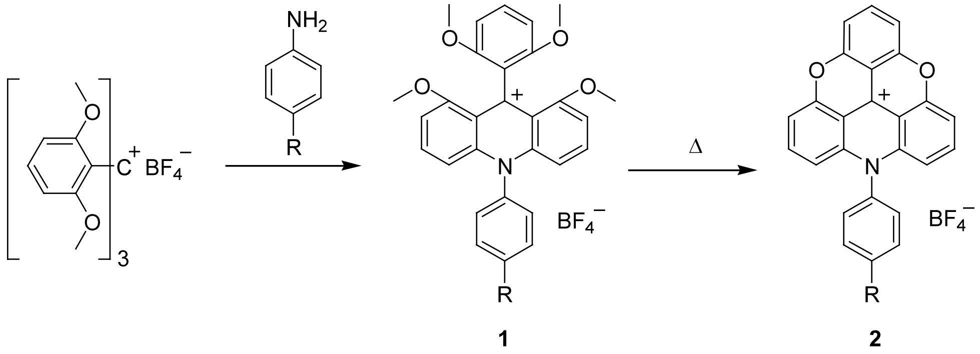
The triangulene system and its heteroatom derivatives have received considerable attention covering aspects ranging from synthesis[1,2] through geometric/supramolecular considerations[3–7] and photophysical studies[8,9] to material properties.[10–12] Recently the reaction between tris(2,6-dimethoxyphenyl)carbenium salts and an alkyl or aryl amine was reported that allows for the introduction of sequentially one, two or three primary alkyl amine functionalities.[2,9] When the amine is a poorer nucleophile, such as an arylamine, only one amine functionality can be introduced readily.[9] The intermediate acridine **1** first obtained then undergoes ring closure in situ to give the desired *N*-arylazadioxatriangulene (ADOTA), **2**. The reaction employed reflux in excess arylamine and while this is practical for aniline itself and 4-methylaniline the reaction is not useful for preparative scale synthesis of different derivatives where the arylamine may be unavailable in vast quantities, the arylamine may be very high boiling, very high melting or unstable to high temperatures under ionic/acidic reaction conditions (Scheme 1).

Here I wish to present the efficient synthesis of aryl functionalised ADOTA molecules and the easy applica-



1a (R = CH_3), **1b** (R = Br), **2a** (R = CH_3), **2b** (R = Br)

Scheme 1.

Keywords: azadioxatriangulenes; functionalisation; dyes; synthesis; co-crystals; Suzuki reaction.

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tion of the standard Suzuki reaction for further synthetic elaboration of the ADOTA molecule.

The azadioxatriangulene (ADOTA) system is a chromophore that absorbs in the visible range (from 400 to 550 nm)[9] with extinction coefficients of the order of 10^4 M^{-1} cm^{-1}. The potential use of these dye molecules for light harvesting requires, aside from a preparative scale synthetic procedure leading to the chromophore itself, a versatile method for derivatisation that allows the chromophore to undergo further synthetic elaboration or attachment onto another molecular system. The original procedure leading to the *N*-aryl-ADOTA system involved simply refluxing a tris(2,6-dimethoxyphenyl)carbenium salt in excess arylamine. This procedure is not feasible for the synthesis of the *N*-aryl-ADOTA system on a large scale (i.e. 10 g scale). Further, when using 4-methylamine the product isolated was a co-crystal of the desired product with half a mole of the amine. The co-crystal has the nature of a tight complex as it can be recrystallised several times and yet the recovered product is the co-crystal. There are at least three possible explanations for this: (1) interaction between the cation and the arylamine; (2) interaction between the anion and the arylamine; (3) very favourable crystal packing effects or a combination of these three. To find an explanation for the interactions that were responsible for this the crystal structures were solved (Fig. 1) and this showed that the structure for the cation sub-lattice consists of layers of cation dimers. The polar cation-pair layers are separated by layers containing the apolar substituent aryl groups. The anions are found closely associated with the cation dimers. The structure can be viewed as alternate polar/ionic layers and apolar aromatic side groups. The co-crystallised arylamine was found to be in the apolar layer with the amine functionality extending towards the anions. The anion sublattice was thus found to consist of a ladder type arrangement of anion pairs spaced by the co-crystallised and disordered arylamine. For comparison the native *N*-aryl-ADOTA system containing no co-crystallised arylamine was obtained by dissolving the salt in acetonitrile followed by addition of excess HBF_4(aq.) and subsequent precipitation with ether. The structure of this system was very different and, aside from a very poor crystal quality, the only structural similarity was that the cation pairs were observed. The distribution of cation pairs and ions in the crystal is observed to be even with no separation into a layered structure. The ladder type arrangement of the anion pairs with disordered 4-methylaniline between the two anions offer the obvious replacement of 4-methylaniline with 1,4-phenylenediamine which has similar steric requirements. Further, 1,4-phenylenediamine offers a stronger interaction through the two aniline functionalities and the molecule can occupy a position of an inversion centre without disorder. When mixing **2a** in acetonitrile with one equivalent of 1,4-phenylenediamine large crystals formed immediately. The two salts containing co-crystallised 4-methylaniline and 1,4-phenylenediamine were found to be isostructural, as expected with negligible deviations in lattice parameters. The synthesis of tangible quantities of the *N*-aryl-ADOTA system was achieved by avoiding an excess of the aniline component by reaction of stoichiometric quantities of the tris(2,6-dimethoxyphenyl)carbenium tetrafluoroborate salt and the aniline component in boiling 2,6-lutidine for typically less than half an hour.

The choice of 2,6-lutidine is both due to the solubility properties and the boiling point. The condensation between the arylamine and tris(2,6-dimethoxyphenyl)carbenium tetrafluoroborate to form the acridine derivative takes place just above 100°C. When the mixture is heated beyond 150°C, in the case of 4-bromoaniline for instance, a rapid polymerisation takes place. The reaction is very easy to follow as there is a distinct colour change from the intensely blue/purple colour of the tris(2,6-dimethoxyphenyl)carbenium salt to the dark red colour of the *N*-aryl-acridine, **1**. It was found easiest to stop the reaction at this point and isolate the acridine. Compound **1** could be isolated in pure form but could also be used directly for the ring closure. The ring closure was achieved simply by heating **1** in pyridine hydrochloride in the same manner as Martin et al. did for the trioxatriangulene system.[1]

Further, reaction is limited due to the cationic nature of the ADOTA system which does not allow for strongly nucleophillic reagents to be employed. Mild reaction conditions in terms of nucleophillicity such as Suzuki aryl–aryl couplings was found to be remarkably efficient when employing the traditional Na_2CO_3(aq.)/toluene two phase solvent system at reflux using an arylboronic acid and $(PPh_3)_2PdCl_2$ as catalyst. The reaction was complete in 1 h at reflux temperature and as shown in Scheme 2, compound **2b** was easily converted into the biphenyl derivative **3**.

In summary, I have shown that the preparative scale synthesis of the *N*-aryl-ADOTA system by the conventional method employing excess arylamine was hampered by a very strong tendency for the formation of co-crystals between the product and the arylamine. I have offered a plausible explanation, a strong driving force stabilises the layering of the amphiphillic *N*-aryl substituted ADOTA system by arylamines particularly when they can extend across the apolar layer in the structure. An efficient 10 g scale synthetic procedure which employs refluxing stoichiometric amounts of the tris(2,6-dimethoxyphenyl)carbenium salt and an arylamine in 2,6-lutidine followed by isolation of the intermediate acridine and final ring closure in pyridinium hydrochloride is presented along with further synthetic elaboration of the *N*-aryl-ADOTA system by using a simple Suzuki aryl–aryl coupling.

Supplementary information: Description of crystallographic methods. Further, crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC-193031, CCDC-193032 and CCDC-193033. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44)1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).

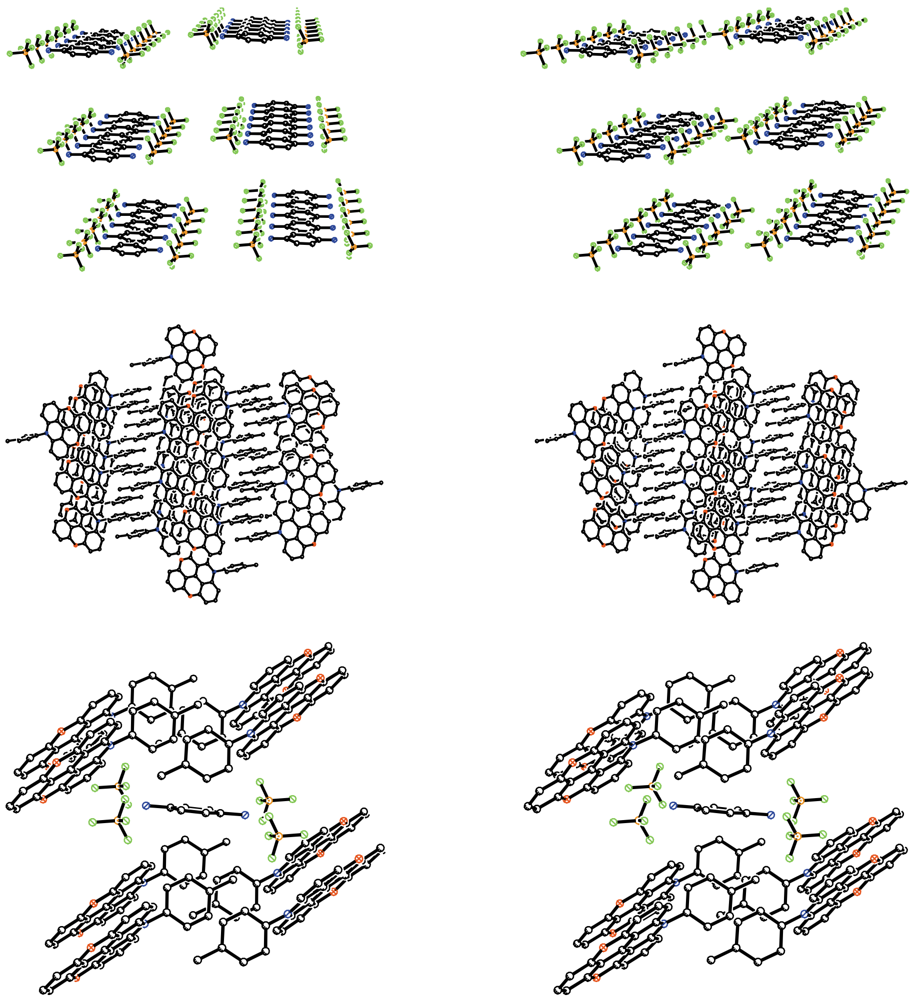
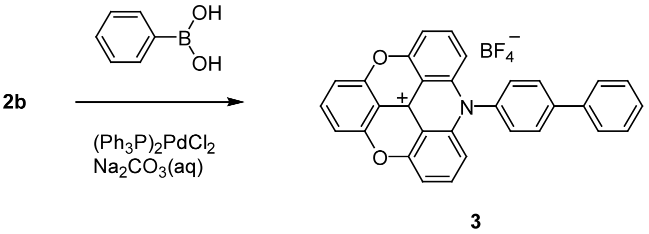


Figure 1. Stereoview of the crystal structure of **2a**. The anion sub-lattice with the cocrystallised 1,4-phenylenediamine (above). The cation sub-lattice showing the arrangement of the cations into layers (middle). The cocrystallised 1,4-phenylenediamine situated in the layer composed of the aryl sidegroups (below).



Scheme 2.

9-(4-Methylphenyl)-10-(2,6-dimethoxyphenyl)acridinium tetrafluoroborate (1a). Tris(2,6-dimethoxyphenyl)-carbenium tetrafluoroborate[9] (2.51 g, 5 mmol) was mixed with 4-methylaniline (0.55 g, 5.1 mmol) in 2,6-lutidine (20 mL) in a conical flask (50 ml) and the mixture was heated under argon to reflux temperature with an air condenser. The colour was initially dark purple/blue and vigorous stirring ensured that the colour of the reaction mixture could be monitored. There was a sudden change in colour from purple/blue to dark red. The mixture was left at reflux for 30 min and was then cooled and poured into a vigorously stirred mixture of ether and heptane (1:1, 300 mL). A dark red material precipitated. The product was filtered, washed with ether and dried. The crude material was dissolved in acetonitrile (20 mL) and the solution was filtered. Ether (200 mL) was carefully layered on top of the acetonitrile solution followed by light petrol (100 mL). Upon standing dark red crystals formed. Filtering and drying gave 2.65 g (96%) of **1a** as red crystals: mp 230–231°C; ^{1}H NMR (250 MHz, DMSO-d_6) δ 8.07 (t, ^3J(H,H) = 8 Hz, 2H), 7.69 (s, 4H), 7.44 (t, ^3J(H,H) = 8 Hz, 1H), 7.22 (d, ^3J(H,H) = 8 Hz, 2H), 6.88 (d, ^3J(H,H) = 8 Hz, 2H), 6.84 (d, ^3J(H,H) = 8 Hz, 2H), 3.59 (s, 6H), 3.56 (s, 6H), 2.57 (s, 2H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 160.3, 158.1, 155.9, 142.8, 141.7, 140.2, 136.5, 132.1, 128.2, 123.4, 119.6, 119.3, 111.3, 107.3, 104.3, 57.7, 56.4, 21.4. Anal. calcd for $C_{30}H_{28}BF_4NO_4$: C, 65.12; H, 5.10; N, 2.53. Found: C, 64.64; H, 5.05; N, 2.49.

9-(4-Bromophenyl)-10-(2,6-dimethoxyphenyl)acridinium tetrafluoroborate (1b). Tris(2,6-dimethoxyphenyl)-carbenium tetrafluoroborate (25.1 g, 50 mmol) was reacted with 4-bromoaniline (8.8 g, 51 mmol) in 2,6-lutidine (200 mL) as above. This gave 29 g (94%) of **1b** as red crystals: mp 212–213°C; ^{1}H NMR (250 MHz, DMSO-d_6) δ 8.04–8.11 (m, 4H), 7.83 (d, ^3J(H,H)$=$8 Hz, 2H), 7.47 (t, ^3J(H,H)$=$8 Hz, 1H), 7.22 (d, ^3J(H,H)$=$8 Hz, 2H), 6.91 (d, ^3J(H,H)$=$8 Hz, 2H), 6.85 (d, ^3J(H,H)$=$8 Hz, 2H), 3.59 (s, 6H), 3.56 (s, 6H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 160.3, 158.5, 155.9, 142.7, 140.4, 138.2, 134.9, 130.8, 130.0, 125.2, 119.6, 119.3, 111.3, 107.3, 104.3, 57.7, 56.4. Anal. calcd for $C_{29}H_{25}BBrF_4NO_4$: C, 56.34; H, 4.08; N, 2.27. Found: C, 56.72; H, 4.02; N, 2.56.

4-(4-Methylphenyl)-4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd,mn*]pyrenium tetrafluoroborate (2a). Compound **1a** (5.53 g, 10 mmol) was heated under argon with pyridine hydrochloride (75 g) at 180°C. During the first half hour the colour changes from dark to light red and a shiny solid precipitates. After 1 h the reaction was stopped and poured into ice/water (250 mL). HBF_4(aq.) (40%, 50 mL) was added and the mixture filtered. The product was redissolved in MeCN (50 mL) and ether (250 mL) was added. The product was filtered and dried to give 3.55 g (77%) of **2a** as glistening red crystals: mp >300°C; ^{1}H NMR (250 MHz, DMSO-d_6) δ 8.09–8.23 (m, 3H), 7.74 (d, ^3J(H,H)$=$8 Hz, 2H), 7.54–7.64 (m, 6H), 6.89 (d, ^3J(H,H)$=$8 Hz, 2H), 2.57 (s, 3H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 152.6, 152.3, 141.9, 141.7, 141.4, 140.7, 134.4, 132.8, 128.1, 112.2, 111.6, 109.8, 108.5, 105.8, 21.4. (One signal missing. This is ascribed to accidental isochrony.) Anal. calcd for $C_{26}H_{16}BF_4NO_2$: C, 67.71; H, 3.50; N, 3.04. Found: C, 67.38; H, 3.42; N, 3.22%. *Crystal data*: $C_{26}H_{16}BF_4NO_2$, $M=461.21$, monoclinic space group *Cc*, $a=24.894(6)$, $b=11.134(3)$, $c=15.615(4)$ Å; $\beta=111.737(4)°$, $V=4020.1(16)$ Å^3, $Z=8$, $D_{\text{calcd}}=1.524$ g cm^{-3}, $T=120(2)$ K, $\mu=0.121$ cm^{-1}, $wR_2=0.3608$ (25474 independent reflections), $R=0.1366$ [$I>2\sigma(I)$].

4-(4-Methylphenyl)-4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd,mn*]pyrenium tetrafluoroborate 4-methylaniline co-crystal (2a·(4-methylaniline)$_{0.5}$). Compound **2a** (0.46 g, 1 mmol) was dissolved in acetonitrile (10 mL) and a solution of 4-methylaniline (0.11 g, 1 mmol) dissolved in acetonitrile (5 mL) was added. Large dark red crystals formed upon standing while allowing for partial evaporation of the solvent. This gave the **2a**·(4-methylaniline)$_{0.5}$ co-crystal in quantitative yield: mp >300°C. Anal. calcd for $C_{59}H_{41}B_2F_8N_3O_4$: C, 68.83; H, 4.01; N, 4.08. Found: C, 68.72; H, 3.85; N, 4.12%. *Crystal data*: $C_{29.5}H_{20.5}BF_4N_{1.5}O_2$, $M=514.78$, triclinic space group *P*-1, $a=7.7651(18)$, $b=9.250(2)$, $c=16.333(4)$ Å; $\alpha=78.685(4)$, $\beta=81.326(4)$, $\gamma=71.138(4)°$, $V=1083.7(4)$ Å^3, $Z=2$, $D_{\text{calcd}}=1.578$ g cm^{-3}, $T=120(2)$ K, $\mu=0.122$ cm^{-1}, $wR_2=0.1751$ (14203 independent reflections), $R=0.0561$ [$I>2\sigma(I)$].

4-(4-Methylphenyl)-4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd,mn*]pyrenium tetrafluoroborate 1,4-phenylenediamine co-crystal (2a·(1,4-phenylenediamine)$_{0.5}$). Compound **2a** (0.46 g, 1 mmol) was dissolved in acetonitrile (10 mL) and a solution of 1,4-phenylenediamine (0.10 g, 1 mmol) dissolved in acetonitrile (5 mL) was added. Black crystals formed immediately. The mixture was left to stand while allowing for partial evaporation of the solvent. This gave the **2a·(1,4-phenylenediamine)$_{0.5}$** co-crystal in quantitative yield: mp 296–298°C. Anal. calcd for $C_{58}H_{40}B_2F_8N_4O_4$: C, 67.60; H, 3.91; N, 5.44. Found: C, 67.62; H, 3.73; N, 5.57%. *Crystal data*: $C_{29}H_{20}BF_4N_2O_2$, $M=515.28$, triclinic space group *P*-1, $a=7.8632(9)$, $b=9.9175(12)$, $c=15.8006(18)$ Å; $\alpha=79.221(2)$, $\beta=81.526(2)$, $\gamma=68.554(2)°$, $V=1122.4(2)$ Å^3, $Z=2$, $D_{\text{calcd}}=1.525$ g cm^{-3}, $T=120(2)$ K, $\mu=0.118$ cm^{-1}, $wR_2=0.1696$ (14552 independent reflections), $R=0.0537$ [$I>2\sigma(I)$].

4-(4-Bromophenyl)-4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd,mn*]pyrenium tetrafluoroborate (2b). Compound **1b** (12.36 g, 20 mmol) was heated under argon with pyridine hydrochloride (150 g) at 180°C. Work-up as above for **2a**. This gave 9.94 g (85%) of **2b** as red crystals: mp >300°C; ^{1}H NMR (250 MHz, DMSO-d_6) δ 8.12–8.29 (m, 5H), 7.65–7.74 (m, 6H), 6.96 (d, ^3J(H,H)$=$8 Hz, 2H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 152.8, 152.5, 142.0, 141.9, 141.5, 140.9, 136.3, 135.5, 130.9, 125.1, 112.4, 111.6, 109.9, 108.6, 106.1. Anal. calcd for $C_{25}H_{13}BBrF_4NO_2$: C, 57.08; H, 2.49; N, 2.66. Found: C, 56.67; H, 2.23; N, 2.66%.

4-(4-Biphenyl)-4-aza-8,12-dioxa-4,8,12,12c-tetrahydrodibenzo[*cd,mn*]pyrenium tetrafluoroborate (3). Compound **2b** (0.52 g, 1 mmol), phenylboronic acid (0.13 g, excess), Na_2CO_3 (10 g), water (100 mL) and toluene (150 mL) were mixed and degassed with argon. The mixture was heated and $(PPh_3)_2PdCl_2$ (0.1 g, catalyst) was added. At reflux everything dissolved. After 1 h the mixture was cooled to room temperature. The dark mixture was filtered and the toluene phase separated. HBF_4(aq.) (10 mL, 40%) was added to the toluene phase followed by ether (500 mL) and the mixture was filtered. The dark product was dissolved in acetonitrile (20 mL) and filtered. Ether (100 mL) was carefully layered on top of the acetonitrile phase and the mixture left to stand. The bright red product was filtered and dried. This gave 0.45 g (87%) of **3** as shiny red crystals: mp 290–292°C; ^{1}H NMR (250 MHz, DMSO-d_6) δ 8.19–8.30 (m, 5H), 7.49–7.89 (m, 11H), 7.00 (d, ^3J(H,H)$=$8 Hz, 2H); ^{13}C NMR (63 MHz, $CDCl_3$) δ 152.8, 152.5, 143.3, 142.0, 141.8, 141.5, 140.8, 139.0, 136.1, 130.4, 129.7, 129.0, 128.9, 127.5, 112.4, 111.6, 109.9, 108.7, 106.1. Anal. calcd for $C_{31}H_{18}BF_4NO_2$: C, 71.15; H, 3.47; N, 2.68. Found: C, 70.37; H, 3.44; N, 2.53%.

Acknowledgements

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