Halogenation of Tröger's base analogues

Masoud Faroughi,[a] Paul Jensen,[b] and Andrew C. Try[a]*

[a]*Department of Chemistry and Biomolecular Sciences, Macquarie University, North Ryde, NSW 2109, Australia*
[b]*Crystal Structure Analysis Facility, School of Chemistry, The University of Sydney, Sydney, NSW 2006, Australia*
E-mail: andrew.try@mq.edu.au

Abstract
The reaction of four Tröger's base analogues with NBS and NCS to afford mono and / or di-halogenated products is described. They constitute the first examples of introducing a halogen onto the aryl rings of a Tröger's base framework bearing pre-existing substituents and offer access to non-symmetric (hybrid) compounds

Keywords: Tröger's base, halogenation, X-ray structure

Introduction

Tröger's base **1** is a rigid V-shaped molecule that is prepared from an acid-catalysed condensation reaction of *p*-toluidine and formaldehyde.[1] The compound is chiral by virtue of two stereogenic nitrogen atoms in a methano-strapped diazocine ring that is fused to two aryl rings.[2] These aryl rings are held at approximately 90° with respect to one another, creating a cavity in the molecule.[3] A wide range of functionalised analogues have been prepared from appropriately substituted amino-aryls and these compounds have been used in applications such as molecular recognition, [4-11] DNA binding studies [12-16] and catalysis.[17-20]

In the last few years halogenated Tröger's base analogues have been prepared from haloanilines[21-24] and proven to be extremely valuable in the synthesis of other analogues as the halogens act as "handles" for further functionalisation.[25-28] As part of a preliminary study aimed at alternate ways of accessing functionalised Tröger's base analogues, a methodology to brominate and chlorinate four Tröger's base compounds, as racemic mixtures, (Figure 1) was investigated.

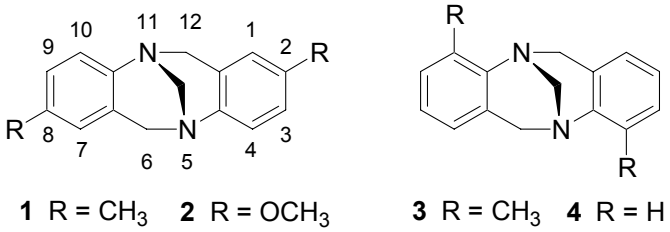
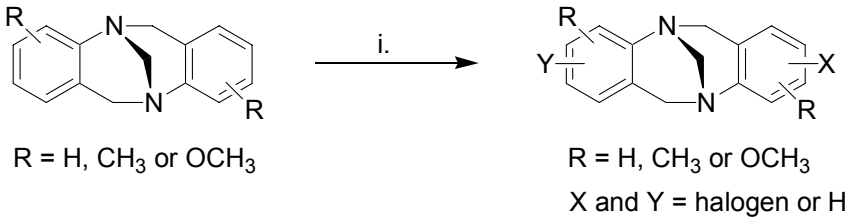


Figure 1. The four substrates used in this study.

Numerous methods to halogenate aromatic compounds exist,[29-34] however, in terms of ease of handling and health issues, *N*-halosuccinimides are excellent reagents, especially if benzylic halogenation is suppressed.[33]

Results and Discussion

The first set of reactions that were investigated involved the reaction of **1** and **2** with NBS in the presence of ammonium nitrate[33] as outlined in Scheme 1, with the results detailed in Table 1. Reactions were also carried out in the presence of iron(III) chloride (in place of ammonium nitrate), however in all cases the yields were lower than those listed in Table 1.

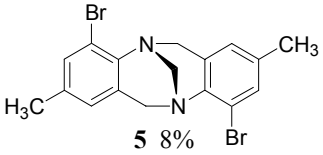
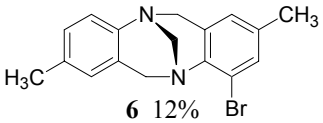
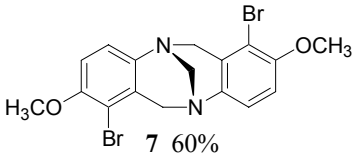
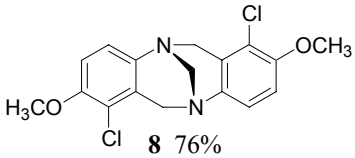
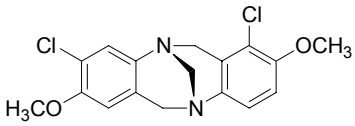
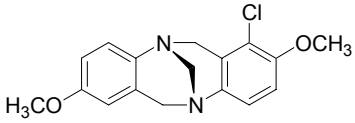
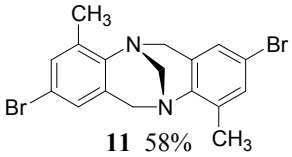
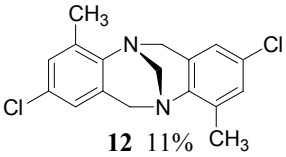
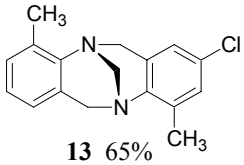
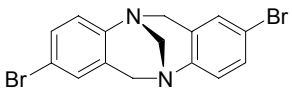
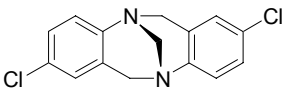
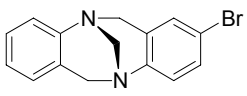
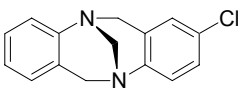


Scheme 1. i. NBS or NCS, NH_4NO_3, CH_3CN, CH_2Cl_2.

A similar approach was recently reported, that involved **4** as the only substrate and employed NBS in DMF to effect bromination and ICl in acetonitrile in the presence of $Hg(OTf)_2$ to effect iodination, although the focus of the study was to achieve mono-halogenation.[35]

In the present investigation, bromination of **1** afforded di- and mono-bromo compounds, **5** and **6**, after 4 h at room temperature in yields of 12% and 8%, respectively (Table 1). A number of other unidentified products were formed, however no starting material was evident by examination of a ^{1}H NMR spectrum of the crude material obtained upon work-up. The analogous chlorination reaction was unsuccessful, as only a trace of mono-chlorinated product was evident from analysis of a ^{1}H NMR spectrum of a crude sample, with the majority of the reaction mixture consisting of unreacted **1**.

Table 1. Yields of the various halogenated products (yields refer to analytically pure material)

Substrate	Bromination Products	Chlorination Products
1	 **5** 8%	No analytically pure product was obtained
	 **6** 12%	
2	 **7** 60%	 **8** 76%
		 **9** 5%
		 **10** 18%
3	 **11** 58%	 **12** 11%
		 **13** 65%
4	 **14** 73%	 **16** 32%
	 **15** 23%	 **17** 10%

The site of bromination, exclusively at the 4- and/or 10-sites, *i.e.*, at the *ortho* position relative to the nitrogens of the diazocine bridge, is consistent with the nitrogen atoms functioning in the same manner as the nitrogen of *N*,*N*-dimethylaniline, albeit with reduced reactivity. Whilst the reaction is not a synthetically viable route to the halogenated products (**5** can be prepared from the reaction 2-bromo-4-methylaniline and parafomaldehyde in TFA in a yield of 85% [36]), it demonstrates for the first time that it is possible to halogenate a substituted Tröger's base framework and thereby provides an alternate means of preparing functionalised analogues of Tröger's base. Importantly, the formation of **6**, albeit currently in low yields, offers direct access to non-symmetric compounds, *i.e.*, compounds in which the two aryl rings are differentially substituted.

The ability to monobrominate **4** in the 2-position was recently reported,[35] however **6** has the bromo group in the 4-position. Mono-halogenated compounds are also available *via* a stepwise route[37] or desymmetrisation of dihalogenated compounds *via* lithium-halogen exchange reactions.[26]

Bromination of the more electron-rich substrate **2** for 1 h afforded the 1,7-dibromo compound **7** in 60% yield as the major Tröger's base material. Neither starting material nor mono-brominated product was evident by tlc or ^{1}H NMR analysis of the crude reaction mixture after work-up. It is noteworthy that the sole product of the bromination reaction results in the halogens substituting at the more hindered site *ortho*- to the electron-rich methoxy groups (the 1,7-positions) rather than either the less hindered *ortho*-site (the 3,9-positions) or the site *ortho*- to the nitrogen atoms of the bridge (the 4,10-positions). An X-ray crystal structure of **7** was obtained and the unit cell was found to contain two unique molecules with dihedral angles (between the planes defined by the aromatic rings) measured as 97.5° and 92.2° (Figure 2).

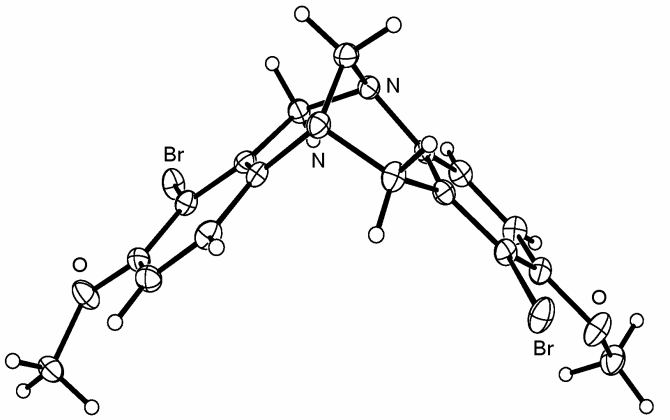


Figure 2. X-ray crystal structure of **7**, showing one of the two unique molecules in the unit cell.

These dihedral angles are typical of simple methano-strapped dibenzo Tröger's base compounds, where the data on over 25 structures reveals that the lower and upper limits for the dihedral angles are 82° [38] and 110.9°,[39] respectively.

Chlorination of **2** afforded three products: symmetric 1,7-dichloro-2,8-dimethoxy Tröger's base **8**, non-symmetric 1,9-dichloro-2,8-dimethoxy Tröger's base **9** and a mono-halogenated compound, 1-chloro-2,8-dimethoxy Tröger's base **10**. This reaction was run over an extended reaction time of 4 days, as little conversion had taken place after 1 h. As was the case with the bromination of **3**, all halogenation occurred *ortho* to the methoxy groups, albeit with some chlorination occurring at the less hindered site *ortho* the methoxy group (at the 9-position). An X-ray crystal structure was also obtained of **8** and in this instance the dihedral angle was measured as 101.6° (Figure 3).

Both **7** and **8** (with a 1,7-dihalo substitution pattern) would be difficult to obtain from a traditional Tröger's base forming reaction as the required anilines have two inequivalent positions *ortho* to the amino group, and can therefore theoretically afford a mixture of three Tröger's base products (two symmetric and one non-symmetric) in each case. For example, the use of 3-bromo-4-methylaniline and 3-chloro-4-methylaniline afforded the 1,7-dihalo Tröger's base isomers in yields of 24% and 23%, respectively, as one of three isomers,[36] and under slightly different conditions the 1,7-dibromo-2,8-dimethyl isomer was obtained in 38% yield.[40]

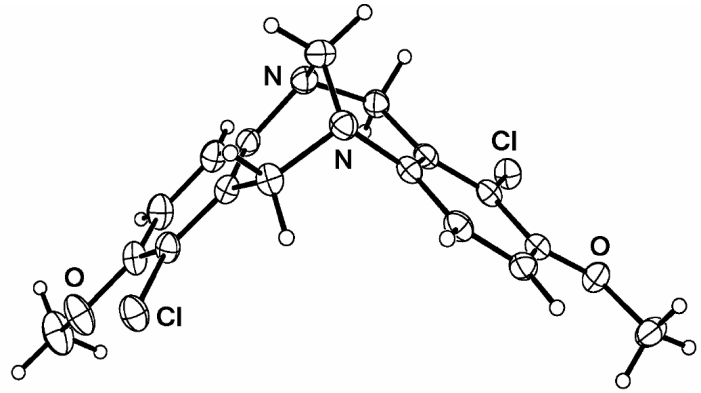


Figure 3. X-ray crystal structure of **8**.

The next two substrates that were examined were unsubstituted in the 2,8-positions, thus sites *para*- to the bridge nitrogens were available for substitution. Bromination of **3** afforded substitution exclusively *para* to the nitrogens of the diazocine bridge (the 2,8-positions) in good yield, in keeping with the notion that the nitrogens are able to function as directing groups. The maximum yield of **11** was obtained after a reaction time of 24 h.

Chlorination of **3** over the same time period afforded a mixture of 2,8-dichloro-4,10-dimethyl Tröger's base **12** and 2-chloro-4,10-dimethyl Tröger's base **13**, with **13** obtained as the major product. An X-ray crystal structure of **12** revealed that dihedral angle was 107.0°, at the upper end of the measured range (Figure 4).

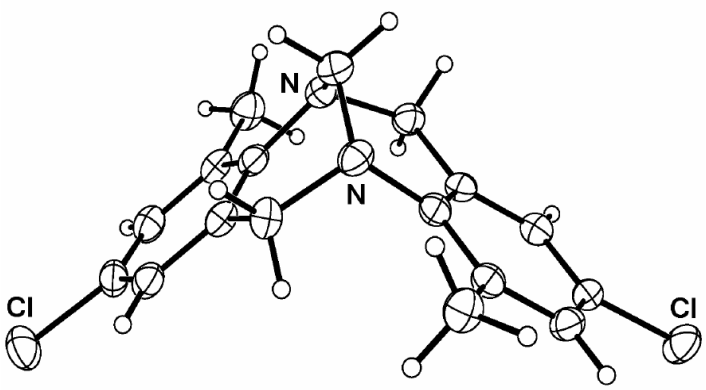


Figure 4. X-ray crystal structure of **12**.

Unsubstituted Tröger's base **4** also afforded substitution at the position *para* to the nitrogens. The disubstituted product **14** was obtained in 73% yield after 7 days. Once again, this product can be obtained from the traditional route of 4-bromoaniline and paraformaldehyde in a similar yield,[41, 42] however the halogenation reaction also affords the mono-bromo product **15** in 23% yield.

The chlorination of **4** was more sluggish, as a 32% yield of 2,8-dichloro Tröger's base **16** was obtained after the same reaction time, together with a 10% yield of 2-chloro Tröger's base **17**.

Conclusions

In summary, we have demonstrated a new methodology that affords a degree of control over the site of halogenation on Tröger's base derivatives, as the halogenation site is highly dependent on the nature and pattern of pre-exisiting substitution on the Tröger's base framework. We are currently exploring the use of other Tröger's base analogues in these reactions. An important aspect to this approach is the synthesis of mono-halogenated products such as **6**, **10**, **13**, **15** and **17** that are otherwise difficult to obtain. The ultimate goal of this work is to perform optimised halogenation reactions on pre-resolved Tröger's base analogues to afford optically pure mono- and dihalogenated products. This would result in the advantage of forming newly halogenated compounds in enantiomerically pure form, without the need to specifically resolve the halogenated material.

Experimental Section

General Procedures. Melting points were determined using a TA Instruments DSC 2010 Differential Scanning Calorimeter. Microanalytical analyses were carried out using a Perkin

Elmer 2400 Series II CHNS/O Analyser. High resolution mass spectrometry (HRMS) was obtained either at the School of Chemistry, University of New South Wales (FAB) or The Research School of Chemistry, Australian National University (EI, Fissons VG-Autospec). ^{1}H NMR spectra were recorded on a Bruker WM AMX 400 spectrometer (400 MHz) at 300 K unless otherwise stated. Signals were recorded in terms of chemical shifts, multiplicity, coupling constants (in Hz). The following abbreviations for multiplicity are used: s, singlet; d, doublet; t, triplet; m, multiplet; dd, doublet of doublets. Solvents and reagents were purified using standard techniques. All commercial solvents were routinely distilled prior to use. Hexane refers to the fraction of b.p. 60-80 °C. Where solvent mixtures are used, the portions are given by volume. Column chromatography was routinely carried out using the gravity feed column techniques on Merck silica gel type 9385 (230-400 mesh) with the stated solvent systems. Analytical thin layer chromatography (tlc) analyses were performed on Merck silica gel 60 F_{254} protected sheets (0.2 mm). Tröger's base substrates **1** and **2** were prepared from *p*-toluidine and *p*-anisidine, respectively, using TFA as the acid and solvent and paraformaldehyde as the formaldehyde source. The synthesis of substrate **3** is outlined below. Substrate **4** was prepared as outlined in the literature.[43]

4,10-Dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b,f*][1,5]diazocine (3). A mixture of 2,8-dibromo-4,10-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b,f*][1,5]diazocine **5** [41] (5.0 g, 12.25 mmol) and 10% palladium on carbon (80 mg) in ethanol (100 mL) and dichloromethane (20 mL) was stirred under an atmosphere of hydrogen in the dark for 2 days. The mixture was then filtered through celite, the solvent was removed *in vacuo*, and the residue was dissolved in dichloromethane. The organic layer was basified with saturated sodium bicarbonate solution and separated, washed with brine, dried over anhydrous sodium sulfate, filtered and evaporated to dryness. The crude solid was chromatographed (silica gel, dichloromethane) to afford **3** (2.97 g, 97%) as a white solid, mp 97-98 °C (lit.[44] 96-98 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.48 (6H, s), 4.06 (2H, d, *J* = 16.8 Hz), 4.39 (2H, s), 4.65 (2H, d, *J* = 16.8 Hz), 6.83 (2H, d, *J* = 8.2 Hz), 6.98 (2H, app t, *J* = 7.4 Hz), 7.11 (2H, d, *J* = 8.2 Hz). The data are in agreement with those reported in the literature.[44]

General procedures for halogenation

The Tröger's base (0.4 mmol), ammonium nitrate (13 mg, 0.16 mmol) and the appropriate *N*-halosuccinimide (1.6 mmol) were dissolved in a mixture of dichloromethane and acetonitrile (3 mL; 1:2) and stirred at room temperature for a time period specified below (at which point point no starting material was evident by tlc). The reaction mixture was washed with water (50 mL) and basified by the addition of a saturated sodium hydrogen carbonate solution (50 mL) and then the crude material was extracted into dichloromethane (2 x 50 mL). The combined organic layers were washed with brine (50 mL), dried over anhydrous sodium sulfate, filtered and evaporated to dryness. The compounds were purified as detailed below.

Bromination of 2,8-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b,f*][1,5]diazocine (1). Starting with **1** (100 mg, 0.4 mmol), the mixture was stirred for 4 h and the crude material was chromatographed (silica gel, ethyl acetate:dichloromethane 1:9) to afford **5** (13 mg, 8%) as a white solid, mp 192-194 °C (lit.[36] 194.0-194.9 °C, lit.[45] 192 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.21 (6H, s), 4.28 (2H, d, *J* = 17.3 Hz), 4.35 (2H, s), 4.54 (2H, d, *J* = 17.3 Hz), 6.73 (2H, app. s), 7.26 (2H, app. s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.50, 55.37, 67.78, 119.50, 126.72, 130.26, 131.90, 135.42, 141.92. The data are in agreement with those reported in the literature.[36] Subsequently, **6** was eluted from the column (16 mg, 12%) as an off-white solid, mp 138-139 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.20 (3H, s), 2.23 (3H, s), 4.08-4.14 (1H, d, *J* = 16.7 Hz), 4.26-4.41 (3H, m), 4.56 (1H, d, *J* = 17.2 Hz), 4.63 (1H, d, *J* = 16.7 Hz), 6.66-6.69 (1H, m), 6.75-6.78 (1H, m), 6.94-7.00 (1H, m), 7.04 (1H, d, *J* = 8.2 Hz), 7.24-7.28 (1H, m); ^{13}C NMR (100 MHz, $CDCl_3$) 20.48, 20.86, 55.09, 58.72, 67.40, 119.48, 124.67, 126.68, 127.36, 127.56, 128.24, 129.86, 132.56, 134.10, 135.26, 142.18, 144.81; HRMS (FAB$^+$) *m/z* calcd for $C_{17}H_{17}BrN_2$ $[M+H]^+$ 351.0467, observed 351.0470; Anal. Calcd for $C_{17}H_{17}BrN_2$: C 62.02; H 5.20; N 8.51. Found C 62.25; H 5.25; N 8.50 %.

Bromination of 2,8-dimethoxy-6*H*,12*H*-5,11-methanodibenzo[*b,f*][1,5]diazocine (2). Starting with **2** (100 mg, 0.35 mmol), the mixture was stirred for 1 h and the crude material was chromatographed (silica gel, ethyl acetate:dichloromethane 1:1) to afford **7** (92 mg, 60%) as a white solid, mp 246-247 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.83 (6H, s), 4.19 (2H, d, *J* = 17.1 Hz), 4.20 (2H, s), 4.46 (2H, d, *J* = 17.1 Hz), 6.80 (2H, d, *J* = 8.8 Hz), 7.15 (2H, d, *J* = 8.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.47, 60.35, 66.10, 111.06, 111.50, 124.67, 128.63, 142.33, 152.38; Anal. Calcd. for $C_{17}H_{16}Br_2N_2O_2$: C 46.39; H 3.66; N 6.36. Found C 46.47; H 3.60; N 6.29 %.

Chlorination of 2,8-dimethoxy-6*H*,12*H*-5,11-methanodibenzo[*b,f*][1,5]diazocine (2). Starting with **2** (300 mg, 1.06 mmol), the mixture was stirred for 4 days and the crude material was chromatographed (silica gel, ethyl acetate:dichloromethane 1:4) to afford **8** (302 mg, 76%) as a white solid, mp 225-227 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.19 (6H, s), 4.24 (2H, d, *J* = 17.4 Hz), 4.50 (2H, d, *J* = 17.3 Hz), 6.82 (2H, d, *J* = 8.8 Hz), 7.09 (2H, d, *J* = 8.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.25, 57.77, 65.95, 111.12, 120.16, 123.76, 127.02, 141.95, 151.35; HRMS (EI$^+$) *m/z* calcd for $C_{17}H_{16}Cl_2N_2O_2$ $[M]^+$ 350.0589, observed 350.0591. Subsequently, **9** (20 mg, 5%) was eluted from the column as white solid, mp 190-191 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.78 (3H, s), 3.83 (3H, s), 4.08 (2H, d, *J* = 16.7 Hz), 4.16-4.28 (3H, m), 4.48 (1H, d, *J* = 17.1 Hz), 4.65 (1H, d, *J* = 16.8 Hz), 6.43 (1H, s), 6.83 (1H, d, *J* = 8.8 Hz), 7.08 (1H, d, *J* = 8.8 Hz), 7.20 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.26, 56.35, 57.53, 58.58, 66.43, 109.59, 111.17, 120.51, 121.47, 123.50, 126.50, 126.77, 127.05, 151.64, 151.87; HRMS (EI$^+$) *m/z* calcd for $C_{17}H_{16}Cl_2N_2O_2$ $[M]^+$ 350.0589, observed 350.0596. The final major compound eluted from the column was **10** (60 mg, 18%) as a white solid, mp 135-136 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.70 (3H, s), 3.82 (3H, s), 4.01 (1H, d, *J* = 16.7 Hz), 4.17-4.32 (3H, m), 4.48 (1H, d, *J* = 17.3 Hz), 4.66 (1H, d, *J* = 16.7 Hz), 6.40 (1H, d, *J* = 2.8 Hz), 6.75 (1H, dd, *J* = 8.8 Hz and 2.8 Hz), 6.81 (1H, d, *J* = 8.9 Hz), 7.06 (1H, d, *J* = 8.8 Hz), 7.10 (1H, d, *J* = 8.8 Hz); ^{13}C NMR (100 MHz,

$CDCl_3$) δ 55.33, 56.33, 57.63, 58.91, 66.55, 110.80, 111.10, 114.00, 123.53, 126.15, 127.30, 128.23, 140.55, 142.01, 151.40, 156.15; HRMS (EI^+) *m/z* calcd for $C_{17}H_{17}ClN_2O_2$ $[M]^+$ 316.0979, observed 316.0963.

Bromination of 4,10-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine (3). Starting with **3** (200 mg, 0.8 mmol), the mixture was stirred for 24 h and the crude material was chromatographed (silica gel, dichloromethane) to afford **11** (190 mg, 58%) as a white solid, mp 197-199 °C (lit.[41] 195.5-196.5 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (6H, s), 3.90 (2H, d, *J* = 16.9 Hz), 4.24 (2H, s), 4.52 (2H, d, *J* = 16.9 Hz), 6.88-6.92 (2H, m), 7.14-7.20 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.79, 54.57, 67.22, 116.81, 127.06, 129.82, 131.76, 135.30, 144.70. The data are in agreement with those reported in the literature.[41]

Chlorination of 4,10-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine (3). Starting with **3** (200 mg, 0.8 mmol), the mixture was stirred for 24 h and the crude material was chromatographed (silica gel, dichloromethane) to afford **12** (29 mg, 11%) as a white solid, mp 180-182 °C (lit.[41] 182-183 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (6H, s), 3.89 (2H, d, *J* = 17.0 Hz), 4.25 (2H, s), 4.51 (2H, d, *J* = 17.0 Hz), 6.75 (2H, d, *J* = 1.8 Hz), 7.03 (2H, d, *J* = 1.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.87, 54.77, 67.35, 124.10, 128.91, 129.39, 134.95, 144.32. The data are in agreement with those reported in the literature.[36] Subsequently, **13** (148 mg, 65%) was eluted from the column as a white solid, mp 145-146 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (3H, s), 2.41 (3H, s), 3.95 (2H, d, *J* = 16.8 Hz), 3.96 (1H, d, *J* = 16.8 Hz), 4.23-4.35 (2H, m), 4.48-4.62 (2H, m), 6.74-6.80 (2H, m), 6.94 (1H, app. t, *J* = 7.5 Hz), 7.03 (1H, d, *J* = 1.7 Hz), 7.07 (1H, d, *J* = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.89, 17.06, 54.76, 54.97, 67.37, 123.88, 124.09, 124.36, 127.69, 128.67, 128.70, 129.02, 129.71, 132.88, 134.92, 144.57, 145.65; Anal. Calcd. for $C_{17}H_{17}ClN_2$: C 71.70; H 6.02; N 9.84. Found C 71.54; H 6.02; N 9.80 %.

Bromination of 6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine (4). Starting with **4** (400 mg, 1.8 mmol), the mixture was stirred at for 7 days and the crude material was chromatographed (silica gel, ethyl acetate:dichloromethane 1:4) to afford **14** (500 mg, 73%) as a white solid, mp 165-166 °C (lit.[41] 164-165 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.09 (2H, d, *J* = 16.9 Hz), 4.25 (2H, s), 4.63 (2H, d, *J* = 16.9 Hz), 7.00 (2H, d, *J* = 8.6 Hz), 7.04 (2H, d, *J* = 2.2 Hz), 7.27 (2H, dd, *J* = 8.6 Hz and 2.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.25, 66.58, 116.82, 126.68, 129.56, 129.67, 130.60, 146.61 The data are in agreement with those reported in the literature.[41] Subsequently, **15** (123 mg, 23%) was eluted from the column as a white solid, mp 123-125 °C (lit.[35] 119-121 °C, lit.[26] 123.5-125 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (1H, d, *J* = 16.6 Hz), 4.15 (1H, d, *J* = 16.6 Hz), 4.23-4.35 (2H, m), 4.61-4.73 (2H, m), 6.88-6.93 (1H, m), 6.96-7.06 (3H, m), 7.11-7.14 (1H, m), 7.14-7.21 (1H, m), 7.24-7.28 (1H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.34, 58.66, 66.71, 116.52, 124.18, 125.03, 126.74, 126.92, 127.48, 127.50, 129.70, 129.99, 130.39, 147.16, 147.65; Anal. Calcd. for $C_{15}H_{13}BrN_2$: C 59.82; H 4.35; N 9.30. Found C 59.82; H 4.34; N 9.26 %. The data are in agreement with those reported in the literature.[26]

Chlorination of 6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine (4). Starting with **4** (100 mg, 0.45 mmol), the mixture was stirred for 7 days and the crude material was chromatographed

(silica gel, ethyl acetate:dichloromethane 1:9) to afford **16** (43 mg, 32%) as a pale yellow solid, mp 129-130 °C (lit.[41] 140-141 °C; lit.[46] 129.3 °C): ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.08 (2H, d, *J* = 16.8 Hz), 4.25 (2H, s), 4.63 (2H, d, *J* = 16.8 Hz), 6.90 (2H, d, *J* = 2.3 Hz), 7.05 (2H, d, *J* = 8.6 Hz), 7.13 (2H, dd, *J* = 8.6 Hz and 2.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.43, 66.68, 126.34, 126.71, 127.71, 129.07, 129.14, 146.22. The data are in agreement with those reported in the literature.[41] Subsequently, **17** (11 mg, 10%) was eluted from the column as a white solid, mp 127-128 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (1H, d, *J* = 16.7 Hz), 4.15 (1H, d, *J* = 16.5 Hz), 4.24-4.36 (2H, m), 4.62-4.73 (2H, m), 6.88-6.93 (2H, m), 6.97-7.02 (1H, m), 7.05-7.09 (1H, m), 7.09-7.14 (2H, m), 7.15-7.21 (1H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.43, 58.68, 66.76, 124.26, 125.03, 126.38, 126.72, 126.94, 127.46, 127.53, 127.56, 128.94, 129.43, 146.51, 147.55; Anal. Calcd. for $C_{15}H_{13}ClN_2$: C 70.18; H 5.10; N 10.91. Found C 70.22; H 5.11; N 10.98 %.

Supplementary Information Available

The crystallographic data (excluding structure factors) for compounds **7**, **8** and **12** have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC 648927, 706539 and 706540, respectively. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk or http://www.ccdc.cam.ac.uk).

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