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Synthesis and Property Studies of Cyclotrisazobenzenes

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Azobenzenophanes are fascinating macrocycles, which are of special interest due to their unique photochromic behavior. Cyclotrisazobenzenes **2** (R = H, Br, *t*Bu) were prepared to probe how much strain the photoisomerization of the azobenzene motive can tolerate. The macrocycles were synthesized in an overall yield of 10–20 % from *ortho*-phenylenediamine (**6**). Solid-state structures of cyclotrisazobenzenes **2a** and **2b** were obtained. Irradiation under various conditions did not induce any isomerization.

Introduction

Azo compounds are important and mainly used as dyes and pigments. The interest in their (*E*) → (*Z*) photoisomerization has been growing in recent years.[1] Even though the mechanism of their photochromism is still uncertain,[2] a variety of examples can be found in the literature, where the (*E*) → (*Z*) isomerization of azobenzenes is exploited to induce a structural change in molecules by irradiation.[3]

A particularly interesting class of compounds are azobenzenophanes;[4,5] they are macrocycles containing the azobenzene scaffold at least once (Figure 1, e.g. **1**). (*Z*)-Azobenzenophanes like **1** show a longer lifetime compared to their linear analogues due to their distorted geometry.[5] Even a thermally stable (*Z*) isomer has been reported recently (**1**, *n* = 0). The cavity has the potential to act as a host for cations,[6] similar to crown ethers[7] or calixarenes.[8] Cyclotrisazobenzenes **2** are a special class of azobenzenophanes, in which all azobenzene units are in conjugation. Dreiding and co-workers first synthesized the parent cyclotrisazobenzene in an overall yield of 2.6% from *N*-(l-pyridinio)-2-nitroanilide by pyrolysis as a key step.[9] The precursor for the final oxidative coupling was prepared in higher yield by Skrabal et al.[10] Nevertheless, the overall yield was still low. The fully conjugated macrocycle **2** might also be used as core structure for molecular grippers.[11] Because of these potential photochromic properties we became interested in this class of compounds, especially, if molecules such as **2** still exhibit photochromism. A new efficient strategy to access these molecules was developed, and different derivatives were synthesized.

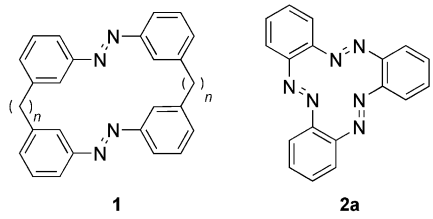

Figure 1. Azobenzenophane **1** and cyclotrisazobenzene **2a**.

Results and Discussion

There are many different methods to prepare symmetrical azobenzenes: Various oxidants have been reported to transform anilines to the corresponding azobenzenes.[12] They can also be obtained by reduction of nitroarenes.[13] However, for the preparation of unsymmetrical azobenzenes and especially oligoazobenzenes, only a few procedures are known,[14] e.g. by a two-step process, involving Pd and Cu catalysis, developed by Cho et al.[14g] One of the most versatile methods to generate unsymmetrical azobenzenes is the condensation of anilines with nitrosoarenes, known as the Mills reaction.[15]

Our synthesis of cyclotrisazobenzene commences with the preparation of 2,2′-diaminoazobenzene (**7**) from *ortho*-phenylenediamine (**6**) by treatment with activated MnO_2 in DCM. However, the use of KO_2 as an oxidant significantly increased the yield[16] (Scheme 1). According to the synthetic plan, the next azo bond should be installed by using the Mills reaction.[15] Interestingly, under the classical conditions in acetic acid only starting material was recovered.[15e] By screening different conditions it was discovered that the reaction proceeded in diluted acetic acid upon heating. First experiments were carried out in a 10:1 solvent mixture of chloroform/acetic acid to yield 42% of bisazo compound **9a**.

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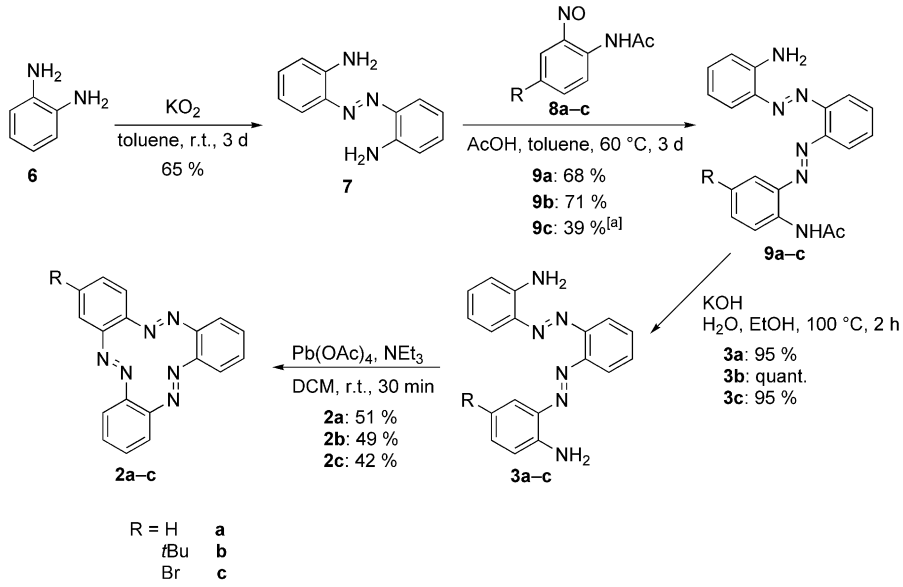


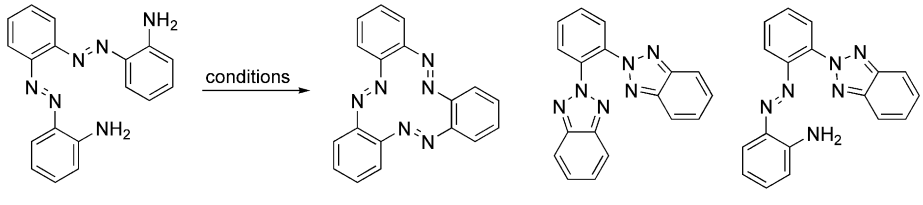
Scheme 1. Preparation of cyclotrisazobenzenes **2a**–**c**. [a] The Mills reaction for the bromo derivative was carried out in chloroform.

The yield was further improved by switching to toluene as a solvent. Under these conditions an isolated yield of 68% of the bisazo compound **9a** was obtained. Polar solvents like methanol and DMSO led to various side products. The subsequent basic hydrolysis of the acetyl-protected diamines **9** smoothly gave the desired free amines **3**. The key step of the synthesis was the oxidative azo coupling with $Pb(OAc)_4$, which was also used in Dreiding's original synthesis. However, under those conditions 2-aminoazobenzenes are usually converted to benzotriazoles.[17] Screening of different conditions revealed that changing the solvent to toluene did not improve the yield of the desired product (Table 1). Conducting the reaction in acetic acid gave exclusively bis(triazole) **4**. From this result was concluded, that the AcOH formed in the reaction is detrimental for the azo bond formation. Therefore, different bases were tested to capture the acid formed; NEt_3 gave the best result (Table 1, Entry 5). Other oxidants such as $PhI(OAc)_2$ did only result in the formation of **4** (Table 1, Entry 7).

With this improved strategy, three derivatives were synthesized in overall yields of 10–20% from *ortho*-phenylenediamine (**6**) (Scheme 1). The preparation of the 2-methoxy derivative failed. The last step produced no macrocyclization product.

The different nitroso compounds **8b**,**c** were prepared according to Scheme 2. The new protocol developed by Priewisch and Rück-Braun (Oxone® in a biphasic system of CH_2Cl_2/H_2O) turned out to be the method of choice to in-

Table 1. Optimization of the oxidative azo coupling of the diamine **3**.

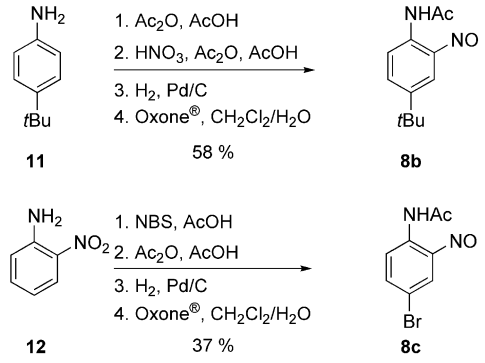


3a **2a** **4** **5**

Entry	Oxidant/additive	Solvent	Ratio **2a/4/5**[a]
1	$Pb(OAc)_4$	CH_2Cl_2	1:2:0
2	$Pb(OAc)_4$	toluene	1:4:0
3	$Pb(OAc)_4$	AcOH	0:1:0
4	$Pb(OAc)_4/K_2CO_3$	CH_2Cl_2	1:2.5:0
5	$Pb(OAc)_4/NEt_3$	CH_2Cl_2	3.9:0:1
6	$Pb(OAc)_4$/DBU	CH_2Cl_2	1:1.3:1.6
7	$PhI(OAc)_2/NEt_3$	CH_2Cl_2	0:1:0

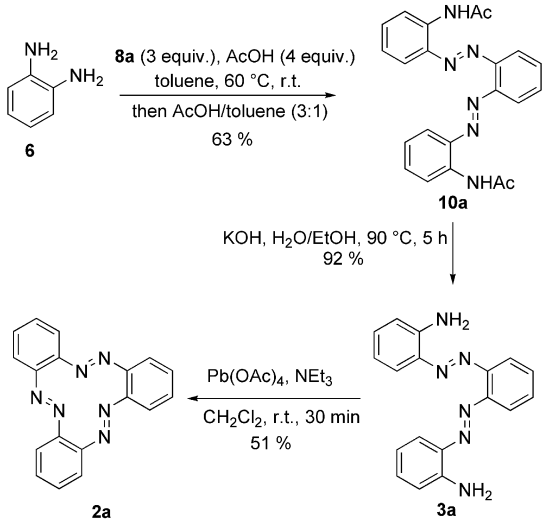
[a] Determined by ^1H NMR spectroscopy.

troduce the nitroso functionality.[18] The unsubstituted derivative **8a** was synthesized according to known literature procedures.[19]



Scheme 2. Synthesis of nitroso compounds **8b** and **8c**.

With the improved Mills reaction described above two of the three azo bonds can also be generated in a single step. This is due to the fact that *ortho*-phenylenediamine (**6**) is inert to classical Mills reaction conditions: in concentrated acetic acid no reaction was observed. As mentioned above, when *ortho*-phenylenediamine (**6**) was treated with 1 equiv. of nitrosobenzene **8a** in toluene with only 4 equiv. of acetic acid, just one coupling took place selectively. Enhancement of the polarity by increasing the amount of acetic acid initiated the second coupling to **10a** in a one-pot procedure. After deprotection and oxidative macrocyclization, cyclotrisazobenzene **2a** was prepared in only three steps with a total yield of 30%, starting from *ortho*-phenylenediamine (**6**) (Scheme 3).



Scheme 3. Improved synthesis of cyclotrisazobenzene **2a**.

Macrocycles **2a**–**c** were subjected to UV irradiation to mediate (*E*) → (*Z*) isomerization of their azo bonds. All compounds show a similar absorption spectrum with one peak at 293 nm (Figure 2). The band exhibits a blueshift compared to the $\pi_1 \rightarrow \pi_1^*$ transition, which normally occurs around 314 nm for most (*E*)-azobenzenes.[20] First isomerization experiments were carried out by irradiating at different wavelengths between 280 and 350 nm with a spectrofluorimeter; but even after prolonged irradiation no change of the absorption spectra was observed. Also, with laser-flash photolysis, no photochromism was detected.

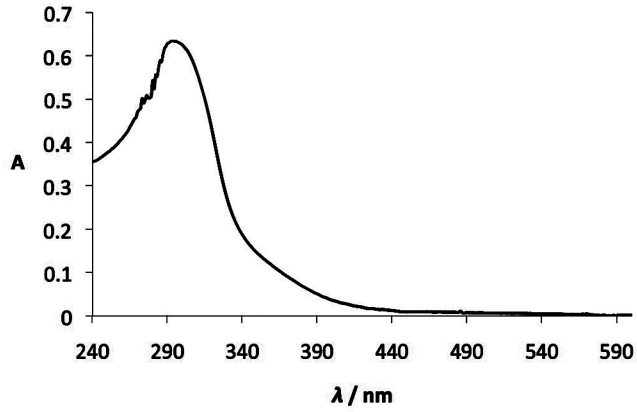


Figure 2. Absorption spectrum of cyclotrisazobenzene **2a** (3.2×10^{-5} M in chloroform).

A possible explanation of the inertness to isomerization could be the high distortion after the first (*E*) → (*Z*) isomerization.

Crystals suitable for X-ray structure analysis of macrocycles **2a** and **2b** were obtained (Figure 3). The solid-state structure of unsubstituted cyclotrisazobenzene has been discussed by Dreiding and co-workers.[9,21] Slow solvent evaporation from a TBME solution gave needle-shaped crystals of *tert*-butylcyclotrisazobenzene **2b** of which the solid-state structure was solved.[22] Both structures, **2a** and **2b**, can only be described properly by a unit of two molecules in each case. The most eye-catching feature is that in the unsubstituted derivative **2a**, π–π-stacking interactions are causing a face-to-face arrangement of the two molecules, whereas these interactions in *tert*-butylcyclotris(azobenzene) **2b** are not possible due to the bulkiness of the *tert*-butyl group. In spite of this difference, there are obvious

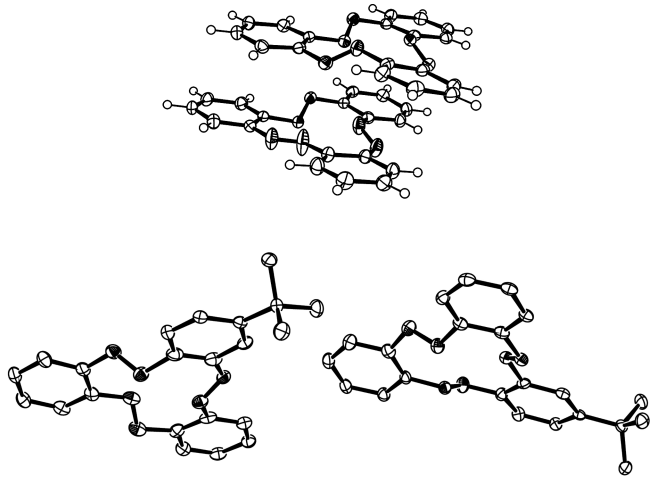


Figure 3. Solid-state structures of **2a** (top) and **2b** (bottom). For **2b** all hydrogen atoms as well as the less populated fragment of the disordered part of the structure have been omitted for clarity.

similarities. Interestingly, in both crystal structures the two molecules exhibit a different symmetry, as one of them shows uniform N=N bond lengths between 1.24 Å and 1.26 Å. The bond and torsion angles between the N=N bond and the phenyl group are unusually high in both cases (up to 54°). The N=N bonds in the second ring are all shorter (1.22–1.24 Å). Due to the distorted geometry, the three phenyl moieties do not lie in a plane but rather are displaced, which is probably caused by repulsion of the electron lone pairs on the nitrogen atoms, which point towards the cavity.

Conclusions

A convenient and simple three-step procedure starting from nitrosoacetanilides for the synthesis of cyclotris(azobenzene)s has been developed, thus allowing large-scale preparation. The introduction of a bromine atom should also allow further functionalization or incorporation of the macrocycle into larger structures by cross-coupling reactions. Current efforts are focusing on the design of related macrocyclic azobenzenes to tune photoisomerization behavior.

Experimental Section

4-*tert*-Butyl-2-nitrosoacetanilide (8b): A solution of 2-amino-4-*tert*-butylacetanilide (3.00 g, 14.5 mmol, 1.00 equiv.) in CH_2Cl_2 (65 mL) was treated with Oxone® (13.4 g, 21.8 mmol, 1.50 equiv.), dissolved in water (260 mL). The mixture was stirred for 30 min. The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2 (100 mL). The organic phase was washed with 1 M aq. HCl, satd. aq. $NaHCO_3$ and water (100 mL each). Drying with $MgSO_4$ and removal of the solvent gave a black residue, which was purified by flash column chromatography (silica gel; hexanes/EtOAc, 5:1). A green oil was obtained, which crystallized while standing at room temperature for several hours to yield green crystals (2.57 g, 81%); m.p. 88–89 °C. IR: $\tilde{\nu}$ = 3238, 2955, 1664, 1591, 1475 cm^{-1}. ^1H NMR (400 MHz, $CHCl_3$): δ = 10.69 (s, 1 H, NH), 8.74 (d, $^3J_{HH}$ = 8.9 Hz, 1 H, 6-H), 7.78 (d, $^3J_{HH}$ = 8.9 Hz, 1 H, 5-H), 7.35 (br. s, 1 H, 3-H), 2.33 [s, 3 H, NHC(O)CH_3], 1.33 [s, 9 H, C(CH_3)$_3$] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 169.9 [*C*(O)NHCH$_3$], 156.7, 146.2, 137.4, 133.9 (C-2), 121.3, 115.8, 34.8 [*C*(CH_3)$_3$], 31.4 [C(*C*H$_3$)$_3$], 25.5 [NHC(O)*C*H$_3$] ppm. MS (EI, 70 eV): *m*/*z* (%) = 220 (51) [M^+], 163 (100). $C_{12}H_{16}N_2O_2$ (220.27): calcd. C 65.43, H 7.32, N 12.72; found C 65.55, H 7.18, N 12.68.

2-Acetamino-5-bromonitrosobenzene (8c): Iron powder (4.20 g, 75.2 mmol, 3.25 equiv.) was suspended in H_2O (15 mL) and glacial acetic acid (0.4 mL). The mixture was heated to 70 °C, and 2-acetamino-5-bromonitrobenzene (6.00 g, 23.3 mmol, 1.00 equiv.) was added in small portions over 30 min. The temperature was raised to 80 °C, and the mixture was stirred for an additional 10 min. It was filtered through a Celite® pad, and the filter cake was washed with boiling ethanol (250 mL). The ethanol was removed under vacuum and water (200 mL) was added. The precipitate was collected by filtration. The solid was treated with ethanol (50 mL) and again filtered. Drying of the filtrate with $MgSO_4$ and removal of the solvent yielded 2.77 g of a pale brown solid, which was suspended in CH_2Cl_2 (60 mL). Oxone® (11.1 g, 18.0 mL, 0.78 equiv.), dissolved in water (300 mL), was added. The mixture was stirred for 2 h. The organic phase was separated, washed with 1 M HCl, saturated aqueous $NaHCO_3$, and water (each 50 mL). After drying with $MgSO_4$ and removal of the solvent, the crude product was purified by flash column chromatography (silica gel; hexanes/EtOAc, 3:1) to yield green crystals (2.50 g, 44%); m.p. 137–139 °C. IR: $\tilde{\nu}$ = 3322, 1674, 1581, 1418 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 10.66 (s, 1 H, NH), 8.83 (d, $^3J_{HH}$ = 9.1 Hz, 1 H, 6-H), 7.79 (d, $^3J_{HH}$ = 9.1 Hz, 1 H, 5-H), 7.11 (s, 1 H, 3-H), 2.36 [s, 3 H, NHC(O)CH_3] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 169.6 [*C*(O)NHCH$_3$], 155.2, 141.2, 137.2, 123.4, 116.9, 116.4; 25.8 [NHC(O)*C*H$_3$] ppm. MS (EI, 70 eV): *m*/*z* (%) = 244 (41), 242 (42) [M^+], 43 (100). $C_8H_7BrN_2O_2$ (243.06): calcd. C 39.53, H 2.90, N 11.53; found C 39.53, H 2.78, N 11.48.

Amino-acetaminobisazobenzene 9a: A solution of 2,2′-diaminoazobenzene (**7**) (1.20 g, 5.70 mmol, 1.00 equiv.) in toluene was degassed with an argon stream for 15 min. Then, 2-nitrosoacetanilide (**8a**) (0.93 g, 5.70 mmol, 1.00 equiv.) and acetic acid (2.60 mL) were added. The mixture was stirred under argon at 60 °C. After 3 d, the solvent was evaporated under reduced pressure, and the residue was purified by flash column chromatography (silica gel; hexanes/EtOAc, 2:1) to yield red crystals (1.38 g, 68%); m.p. 168–170 °C (ref.[10] 164–165 °C). ^1H NMR (400 MHz, $CDCl_3$): δ = 10.12 [s, 1 H, N*H*C(O)CH$_3$], 8.68 (d, $^3J_{HH}$ = 7.8 Hz, 1 H), 7.88 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.85 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.81 (d, $^3J_{HH}$ = 7.8 Hz, 1 H), 7.72 (d, $^3J_{HH}$ = 7.8 Hz, 1 H), 7.62–7.44 (m, 3 H), 7.25–7.15 (m, 2 H), 6.84 (dd, $^3J_{HH}$ = 8.2, $^3J_{HH}$ = 8.2 Hz, 1 H), 6.74 (d, $^3J_{HH}$ = 8.2 Hz, 1 H), 6.31 (br. s, 2 H, NH_2), 2.00 [s, 3 H, NHC(O)CH_3] ppm.

Amino-acetamino-*tert*-butylbisazobenzene 9b: A solution of 2,2′-diaminoazobenzene (**7**) (1.00 g, 4.71 mmol, 1.00 equiv.) was dissolved in toluene and degassed with an argon stream for 15 min. 4-*tert*-Butyl-2-nitrosoacetanilide (**8b**) (1.14 g, 5.18 mmol, 1.10 equiv.) and acetic acid (2.6 mL) was added. The mixture was stirred under argon at 60 °C. After 3 d, the solvent was evaporated under reduced pressure, and the residue was purified by flash column chromatography (silica gel; hexanes/EtOAc, 2:1) to yield red crystals (1.38 g, 71%); m.p. >270 °C. IR: $\tilde{\nu}$ = 2918, 1757, 1373, 1203, 1009 cm^{-1}. ^1H NMR (400 MHz, $CHCl_3$): δ = 10.18 [s, 1 H, N*H*C(O)CH$_3$], 8.59 (d, $^3J_{HH}$ = 8.8 Hz, 1 H), 7.91 (s, 1 H), 7.88 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.80 (d, $^3J_{HH}$ = 7.3 Hz, 1 H), 7.73 (d, $^3J_{HH}$ = 7.5 Hz, 1 H), 7.61–7.51 (m, 3 H), 7.22 (dd, $^3J_{HH}$ = 8.4, $^3J_{HH}$ = 8.4 Hz, 1 H), 6.83 (dd, $^3J_{HH}$ = 8.0, $^3J_{HH}$ = 8.0 Hz, 1 H), 6.73 (d, $^3J_{HH}$ = 8.3 Hz, 1 H), 6.24 (br. s, 2 H, NH_2), 1.97 [s, 3 H, NHC(O)CH_3], 1.37 [s, 9 H, C(CH_3)$_3$] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 169.5 [*C*(O)NHCH$_3$], 148.0, 148.0, 146.8, 142.5, 139.6, 138.1, 133.6, 133.2, 131.8, 131.1, 130.9, 130.6, 120.7, 119.7, 118.9, 117.8, 117.7, 117.6, 35.0 [*C*(CH_3)$_3$], 31.7 [C(*C*H$_3$)$_3$], 25.5 [NHC(O)*C*H$_3$] ppm. MS (EI, 70 eV): *m*/*z* (%) = 414 (32) [M^+], 267 (100). $C_{24}H_{26}N_6O$ (414.50): calcd. C 69.54, H 6.32, N 20.28; found C 69.42, H 6.29, N 20.31.

Amino-acetamino-bromobisazobenzene 9c: To a solution of 2,2′-diaminoazobenzene (**7**) (1.00 g, 4.71 mmol, 1.00 equiv.) and 1-acetamino-4-bromo-2-nitrosobenzene (**8c**) (1.26 g, 5.18 mmol, 1.10 equiv.) in $CHCl_3$ (27 mL), acetic acid (2.7 mL) was added. The mixture was stirred under reflux for 2 d. Then it was diluted with CH_2Cl_2 (150 mL), washed with water (2× 200 mL), dried with Na_2SO_4, and concentrated. Flash column chromatography of the residue (silica gel; hexanes/EtOAc, 1:1) yielded the product (810 mg, 39%); m.p. 221–224 °C. IR: $\tilde{\nu}$ = 3365, 1677, 1613, 1494, 758 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 9.70 [s, 1 H, N*H*C(O)CH$_3$], 8.60 (d, $^3J_{HH}$ = 9.0 Hz, 1 H), 7.95 (s, 1 H), 7.88 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.82 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.72 (d, $^3J_{HH}$ = 7.9 Hz, 1 H), 7.64–7.52 (m, 3 H), 7.23 (t, $^3J_{HH}$ = 7.7 Hz, 1 H), 6.84 (t, $^3J_{HH}$

= 7.6 Hz, 1 H), 6.76 (d, $^3J_{HH}$ = 8.3 Hz, 1 H), 6.39 (br. s, 2 H, NH_2), 2.01 [s, 3 H, NHC(O)CH_3] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 168.8, 147.6, 147.2, 142.0, 140.1, 137.7, 135.6, 135.4, 132.9, 132.2, 131.3, 130.1, 122.7, 122.0, 118.8, 117.3 (2 C), 117.3, 116.4, 25.8 ppm. MS (EI, 70 eV): *m*/*z* (%) = 438 (11), 436 (11) [M^+], 106 (100). $C_{20}H_{17}BrN_6O$ (437.29): calcd. C 54.93, H 3.92, N 19.22; found C 54.95, H 3.91, N 19.20.

Diaminobisazobenzene 3a: A solution of **9a** (790 mg, 2.20 mmol, 1.00 equiv.) in ethanol (80 mL) was treated with a solution of KOH (7.10 g, 0.127 mol, 57.7 equiv.) in ethanol (46 mL) and water (18 mL). The mixture was heated to 90 °C. After 1 h, the mixture was poured onto of ice (300 g), extracted with CH_2Cl_2 (3 × 50 mL), dried with Na_2SO_4 and concentrated to yield a red oil (660 mg), which crystallized in the refridgerator overnight (95%); m.p. 94–96 °C (ref.[10] 96–97 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.89 (dd, $^3J_{HH}$ = 8.1, $^4J_{HH}$ = 1.5 Hz, 2 H), 7.81–7.75 (m, 2 H), 7.52–7.46 (m, 2 H), 7.21 (ddd, $^3J_{HH}$ = 8.4, $^3J_{HH}$ = 7.1 , $^4J_{HH}$ = 1.6 Hz, 2 H), 6.84 (ddd, $^3J_{HH}$ = 8.2, $^3J_{HH}$ = 7.1, $^4J_{HH}$ = 1.2 Hz, 2 H), 6.72 (dd, $^3J_{HH}$ = 8.2, $^4J_{HH}$ = 1.1 Hz, 2 H), 6.27 (br. s, 4 H, NH_2) ppm.

Diamino-*tert*-butylbisazobenzene 3b: To a solution of **9b** (1.23 g, 2.97 mmol, 1.00 equiv.) in ethanol (75 mL) was added KOH (3.77 g, 67.2 mmol, 22.7 equiv.), dissolved in a mixture of ethanol (50 mL) and water (20 mL). The reaction mixture was stirred at 100 °C for 2 h. The mixture was allowed to cool to room temperature and diluted with water. After extraction with CH_2Cl_2, washing four times with water and drying with Na_2SO_4, the solvent was removed under reduced pressure to yield a red solid (1.13 g, 100%); m.p. 103–105 °C. IR: $\tilde{\nu}$ = 3456, 2957, 1614, 1385, 1157, 1139 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.91 (d, $^4J_{HH}$ = 8.8 Hz, 1 H), 7.89 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.80–7.76 (m, 2 H), 7.51–7.46 (m, 2 H), 7.29 (dd, $^3J_{HH}$ = 8.6, $^4J_{HH}$ = 2.4 Hz, 1 H), 7.24–7.18 (m, 1 H), 6.86–6.81 (m, 1 H), 6.73 (d, $^3J_{HH}$ = 8.5 Hz, 1 H), 6.71 (d, $^3J_{HH}$ = 8.6 Hz, 1 H), 5.95 (br. s, 4 H, NH_2), 1.34 [s, 9 H, $C(CH_3)_3$] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 148.5, 148.2, 142.4, 140.6, 140.1, 138.2, 137.9, 132.7, 131.8, 130.8, 130.7, 130.6, 127.1, 124.7, 117.6, 117.5, 117.3, 117.1, 34.4 [*C*$(CH_3)_3$], 31.8 [C(*C*$H_3)_3$] ppm. MS (EI, 70 eV): *m*/*z* (%) = 372 (96) [M^+], 162 (100). $C_{22}H_{24}N_6$ (372.46): calcd. C 70.94, H 6.49, N 22.56; found C 70.85, H 6.55, N 22.70.

Diamino-bromobisazobenzene 3c: A solution of **9c** (720 mg, 1.65 mmol, 1.00 equiv.) in ethanol (40 mL) was prepared and treated with KOH (2.09 g, 37.2 mmol, 22.5 equiv.), dissolved in ethanol (7 mL) and H_2O (7 mL). The mixture was heated to 100 °C for 1 h, and then poured onto of crushed ice (130 g). It was extracted with CH_2Cl_2 (3 × 100 mL) and dried with Na_2SO_4. Evaporation of the solvent yielded the product (620 mg, 95%); m.p. 118–119 °C. IR: $\tilde{\nu}$ = 3438, 1602, 1482, 1393, 1159, 811 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.98 (s, 1 H), 7.87 (d, $^3J_{HH}$ = 8.1 Hz, 1 H), 7.82–7.73 (m, 2 H), 7.56–7.45 (m, 2 H), 7.28 (d, $^3J_{HH}$ = 8.7 Hz, 1 H), 7.22 (t, $^3J_{HH}$ = 7.7 Hz, 1 H), 6.84 (t, $^3J_{HH}$ = 8.7 Hz, 1 H), 6.76 (d, $^3J_{HH}$ = 7.2 Hz, 1 H), 6.65 (d, $^3J_{HH}$ = 8.7 Hz, 1 H), 6.30 (s, 2 H, NH_2), 6.08 (s, 2 H, NH_2) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 148.2, 147.5, 142.2, 141.8, 138.4, 137.9, 134.7, 132.5, 131.1, 130.4, 130.3, 130.2, 118.6, 117.3, 117.2, 116.7, 116.4, 108.8 ppm. MS (EI, 70 eV): *m*/*z* (%) = 396 (31), 394 (33) [M^+], 106 (100). $C_{18}H_{15}BrN_6$ (395.26): calcd. C 54.70, H 3.82, N 21.26; found C 54.58, H 3.80, N 21.05.

Cyclotrisazobenzene (2a): Triethylamine (1.32 mL, 9.50 mmol, 10.0 equiv.) was added to a solution of **3a** (0.30 g, 0.95 mmol, 1.00 equiv.) in CH_2Cl_2 (100 mL). $Pb(OAc)_4$ (0.96 g, 2.20 mmol, 2.30 equiv.), dissolved in CH_2Cl_2 (12 mL), was added dropwise. After complete addition, the mixture was stirred for 40 min. The solvent was removed under reduced pressure, and the residue was purified by flash column chromatography (neutral alox; hexanes/EtOAc, 5:1) to yield golden brown crystals (151 mg, 51%); m.p. 180–182 °C (ref.[9] 169–176 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.72–7.66 (m, 6 H), 7.59–7.53 (m, 6 H) ppm.

3-*tert*-Butylcyclotrisazobenzene (2b): Triethylamine (0.75 mL, 5.37 mmol, 10.0 equiv.) was added to a solution of **3b** (200 mg, 0.54 mmol, 1.00 equiv.) in CH_2Cl_2 (65 mL). $Pb(OAc)_4$ (541 mg, 1.22 mmol, 2.26 mmol), dissolved in of CH_2Cl_2 (7 mL), was added dropwise. After complete addition, the mixture was stirred for 30 min. The solvent was removed under reduced pressure, and the residue was purified by flash column chromatography (neutral alox; TBME/hexane, 1:7). A red-brown oil was obtained, which crystallized after a few days to give brown crystals (97.0 mg, 49%); m.p. 128–132 °C. IR: $\tilde{\nu}$ = 2952, 1456, 1360, 825, 758 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.73–7.52 (m, 11 H), 1.43 [s, 9 H, $C(CH_3)_3$] ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 154.4, 147.0, 146.9, 146.8, 146.7, 146.7, 144.4, 130.5, 130.4, 130.4, 130.4, 127.6, 122.8, 122.7, 122.0, 121.8, 121.8, 119.7, 37.6 [*C*$(CH_3)_3$], 31.7 [C(*C*$H_3)_3$] ppm. MS (EI, 70 eV): *m*/*z* (%) = 368 (12) [M^+], 353 (100). $C_{22}H_{20}N_6$ (368.43): calcd. C 71.72, H 5.47, N 22.81; found C 71.55, H 5.61, N 22.49.

3-Bromocyclotrisazobenzene (2c): Triethylamine (1.75 mL, 12.6 mmol, 10.0 equiv.) was added to a stirred solution of **3c** (500 mg, 1.26 mmol, 1.00 equiv.) in CH_2Cl_2 (150 mL). $Pb(OAc)_4$ (1.27 g, 2.87 mmol, 2.28 equiv.), dissolved in CH_2Cl_2 (10 mL), was added dropwise. After stirring for 30 min, the solvent was removed under reduced pressure. The residue was purified by flash column chromatography (neutral alox; hexanes/EtOAc, 10:1) to yield the product (208 mg, 42%); m.p. 140–142 °C. IR: $\tilde{\nu}$ = 3054, 1757, 1373, 1203, 1009, 690 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.79 (d, $^4J_{HH}$ = 2.0 Hz, 1 H), 7.74–7.52 (m, 10 H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ = 147.0, 146.74, 142.65, 146.2, 145.9, 145.6, 133.0, 130.7 (2 C), 130.4, 130.3, 124.5, 124.4, 124.0, 123.1, 123.0, 121.4 (2 C) ppm. MS (EI, 70 eV): *m*/*z* (%) = 392 (100), 390 (86) [M^+]. $C_{18}H_{11}BrN_6$ (391.22): calcd. C 55.26, H 2.83, N 21.48; found C 55.34, H 2.87, N 21.25.

Supporting Information (see also the footnote on the first page of this article): Full experimental data for **7**, **8a**, **13**, **14**, **15**, **16**, **17**, **10a** and ^{1}H and ^{13}C NMR spectra for **2b**, **2c**, **3b**, **3c**, **8b**, **8c**, **9b**, **9c**, **10a**.

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[22] Crystal data for **2b**: $C_{22}H_{20}N_6$ (368.44), $F(000)$ = 776.000, crystal size $0.04 \times 0.19 \times 0.29$ mm, monoclinic, space group $P2_1$, Z = 4, a = 6.2341(3), b = 14.0454(5), c = 21.1540(8) Å, β = 90.686(2)°, V = 1852.12(13) Å^3, $D_{calcd.}$ = 1.321 Mg m^{-3}. The crystal was measured with a KappaAPEX2 diffractometer at 123 K by using graphite-monochromated Mo-K_α radiation with λ = 0.71073 Å, Θ_{max} = 29.017°. Minimal/maximal transmission 0.98/1.00, μ = 0.083 mm^{-1}. The APEX software package (*Apex2*, Version 2, User Manual, M86-E01078, Bruker Analytical X-ray Systems, Inc., Madison, WI, **2006**) was used for data collection and integration. From a total of 28498 reflections, 5100 were independent (merging r = 0.038). From these, 4575 were considered as observed [$I > 2.0\sigma(I)$] and were used to refine 579 parameters. The structure was solved by direct methods using the program SIR92 (A. Altomare, G. Cascarano, G. Giacovazzo, A. Guagliardi, M. C. Burla, G. Polidori, M. Camalli, *J. Appl. Crystallogr.* **1994**, *27*, 435). Least-squares refinement against F was carried out on all non-hydrogen atoms by using the program CRYSTALS (P. W. Betteridge, J. R. Carruthers, R. I. Cooper, K. Prout, D. J. Watkin, *J. Appl. Crystallogr.* **2003**, *36*, 1487). R = 0.0489 (observed data), wR = 0.0673 (all data), GOF = 1.0853. Minimal/maximal residual electron density: –0.23/0.56 e Å^{-3}. Chebychev polynomial weights (D. J. Watkin, *Acta Crystallogr., Sect. A* **1994**, *50*, 411; E. Prince, *Mathematical Techniques in Crystallography and Materials Science*, Springer-Verlag, New York, **1982**) were used to complete the refinement. One of the molecules shows disorder, which was modeled by using appropriate restraints. Plots were produced by using ORTEP3 for Windows (L. J. Farrugia, *J. Appl. Crystallogr.* **1997**, *30*, 565). CCDC-730161 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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