Refined Synthesis of *meso*-Substituted *trans*-A_2B-Corroles Bearing Electron-Withdrawing Groups

Daniel T. Gryko,* Beata Koszarna

Institute of Organic Chemistry of the Polish Academy of Sciences, Kasprzaka 44/52, 01-224 Warsaw, Poland
Fax +48(22)6326681; E-mail: daniel@icho.edu.pl

Received 3 May 2004; revised 26 May 2004

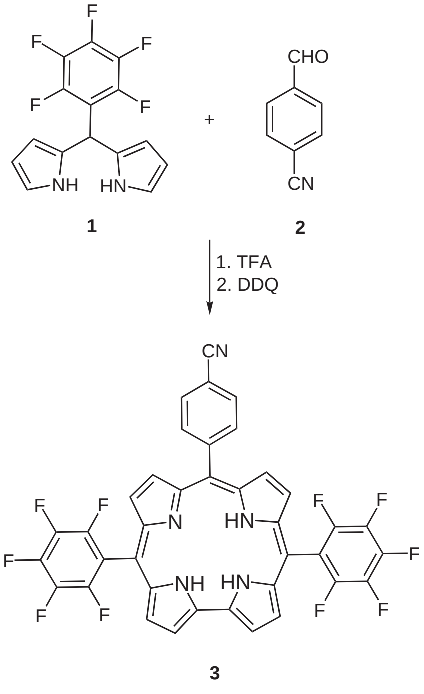
Abstract: We have refined a one-pot synthesis of *trans*-A_2B-corroles via the condensation of 5-(pentafluorophenyl)dipyrromethane with aldehydes followed by macrocyclization mediated by DDQ. After thorough examination of reaction parameters and thanks to the identification of key factors influencing the formation of bilanes and the efficiency of their conversion to corroles, we were able to improve yields from ca. 6 to ca. 20% for a broad range of aldehydes. We proved that these conditions work well also for dipyrromethanes possessing cyano and nitro groups. *meso*-Substituted alkyl aryl corrole has been obtained for the first time using this procedure.

Key words: aldehydes, corroles, macrocycles, oxidations, pyrroles

Corroles[1] have for some time been the object of intense study, both because of their fascinating architecture, and because they may have useful properties as catalysts,[2] anti-cancer agents[3] and sensors.[4] Since the discovery of corroles four decades ago,[5] much attention has focused on broadening the scope of their physicochemical investigations and practical applications.[6] However, to achieve this aim we need powerful methods for the synthesis of corroles, and while there has been dramatic progress in the past six years,[7] we still have much to learn. We report herein an efficient approach to *trans*-A_2B-corroles bearing electron-withdrawing substituents, developed from the detailed analysis of the reaction parameters.

The stability issue plays a much more important role in the corrole family than in porphyrins.[8] Our extensive research proved that handling of corroles bearing substituents with electron-donating groups is troublesome, mainly because of their oxidative decomposition. These compounds are only partially stable in solutions and consequently they undergo decomposition during chromatography[7d] and further synthetic transformations. While working on projects aimed to develop more sophisticated corrole architectures for the molecular magnetism phenomenon and electron transfer systems studies, we encountered tremendous problems with the stability of our building blocks (e.g. *trans*-A_2B-corroles bearing two mesityl substituents) during derivatization and/or complexation.[7d] We thought that the replacement of two mesityl substituents with strongly electron-withdrawing groups would decrease the electron density on the macrocyclic ring and thereby would improve the overall stability. The pentafluorphenyl group appeared to be the best choice due to the strong electron-withdrawing effect and susceptibility to further transformations.[9] One example of such a corrole has been prepared but the yield was only 6%.[7d] The necessity to ensure reasonable quantities of stable corrolic building blocks for our studies prompted us to develop better reaction conditions for their synthesis.

We have chosen the reaction of (pentafluorophenyl)dipyrromethane **1** with 4-cyanobenzaldehyde (**2**) as a model system (Scheme 1). The respective corrole **3** has been obtained before[7d] using the conditions characterized by very low acid concentration, developed for condensation of unhindered dipyrromethanes (DPMs) with aldehydes (Table 1, entry 1).



Scheme 1

As the most promising starting point of our optimization study we turned to the conditions refined for the synthesis of *trans*-A_2B-corroles from sterically hindered dipyrromethanes and aldehydes.[10] Disappointingly, a decrease in the yield to 4% was observed (Table 1, entry 2). Dipyrromethane (DPM) **1** has two striking features. Firstly, the strong electron-withdrawing character of the pentafluo-

SYNTHESIS 2004, No. 13, pp 2205–2209
Advanced online publication: 27.07.2004
DOI: 10.1055/s-2004-829179; Art ID: Z08604SS

Table 1 Optimization of Conditions for the Reaction of Dipyrromethane **1** with Aldehyde **2**[a]

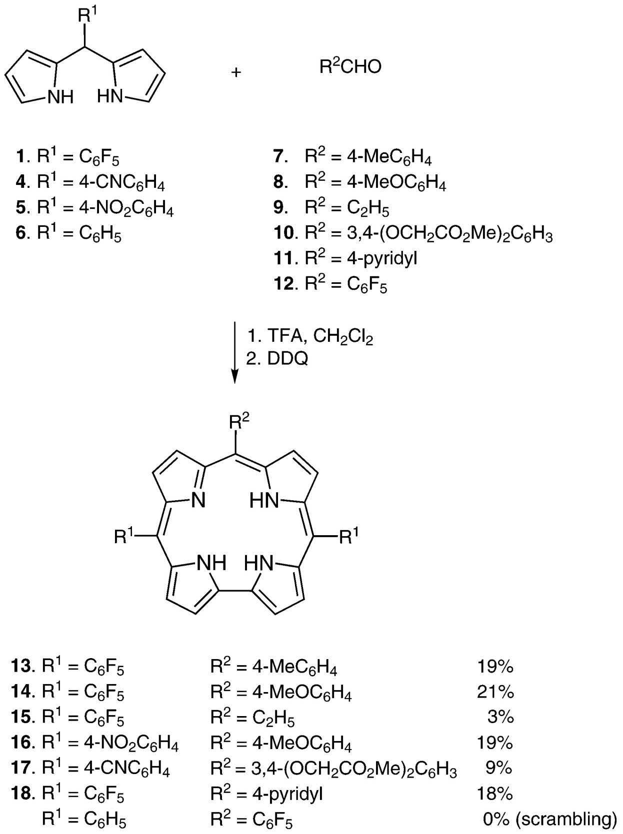
Entry	TFA (mM)	Time of acid-catalysed step	DPM (**1**) (mM)	Ratio DDQ:**1**	x-fold dilution[b]	Yield of corrole **3** (%)[c]
1	0.3	5 h	33	1	–	6[d]
2	1.3	5 h	133	1.3	100	4
3	13	10 min	133	1.3	–	9
4	13	20 min	133	1.3	–	10
5	13	5 h	133	1.3	–	14
6	13	20 min	133	1.3	100	21
7	13	5 h	133	1.3	100	19
8	22	20 min	133	1.3	100	21
9	43	20 min	133	1.3	–	11

[a] All reactions were performed under the following constant conditions: (i) CH_2Cl_2, DPM (**1**)–aldehyde **2** = 2:1, r.t.; (ii) r.t.
[b] Where x indicates how many times the reaction mixture was diluted before an addition of DDQ.
[c] Isolated yields.
[d] Ref.[7d]

rophenyl substituent slightly deactivates pyrrole rings against electrophilic aromatic substitution. It suggests that a higher concentration of TFA should be used in this reaction. Secondly, a key concern upon exposure of dipyrromethanes to acidic media is the occurrence of acidolysis yielding fragments that can recombine to form products with an undesired substitution pattern (i.e. scrambling).[11] The pentafluorophenyl substituent can cause higher stability of DPM **1** against acidolysis. It is known that the analogous CF_3 group deactivates pyrromethanes toward α-carbocation formation,[12a] which allowed the use of a high concentration of acid in the condensation of the respective dipyrromethane with aldehydes leading to porphyrins with the absence of scrambling.[12b] According to the fundamental work of Lindsey et al.,[11a] the TFA concentration which can be safely used in the condensation of unhindered dipyrromethanes with aldehydes is very low. However, a higher concentration of TFA was used when dipyrromethanes possessing NO_2 or CN groups were employed in such syntheses.[13]

This consideration prompted us to use an increased concentration of TFA in the next experiments. A 10-fold increase in TFA concentration combined with the decrease in the reaction time and with an increased amount of DDQ[10] furnished corrole **3** in 9% yield (entry 3). Prolongation of the reaction time to 20 min did not improve the outcome of the process significantly (entry 4). A further increase in reaction time to 5 h resulted in a substantial increase in the yield (14%, entry 5). The idea of diluting the reaction mixture before DDQ addition was inspired by the mechanistic hypotheses[14] (DDQ mediated cyclization) and by our earlier results[15] and gave an additional gain (21% yield, entry 6). Combining both effects did not affect the yield of corrole **3** (entry 7). While an increase in the concentration of TFA in first step to 22 mM (entry 8) gave essentially the same yield (21%, entry 8), further increase but without the dilution of the reaction mixture before the second DDQ-mediated step decreased the yield (entry 9). The latter result strongly indicates the important role of the concentration of bilanes during the DDQ addition on the yield of macrocyclization. It is noteworthy that, judging from TLC and ESI, MS scrambling was absent under all these conditions.

Large volumes of solvents are required for the preparative-scale synthesis if 100-fold dilution precedes the DDQ addition. To eliminate this disadvantage while at the same time maintaining high dilution conditions, simultaneous addition of the reaction mixture (after 1st step) and DDQ solution to the small amount of vigorously stirred CH_2Cl_2 had been previously developed[10] and was successfully used for all subsequent reactions described here. The optimized procedure (first step: CH_2Cl_2, [DPM] = 133 mM, [aldehyde] = 66 mM, [TFA] = 13 mM, 20 min, r.t.; second step: simultaneous addition of the reaction mixture dissolved in CH_2Cl_2 and DDQ solution to CH_2Cl_2, 1.3 equiv of DDQ) was subsequently used in the preparation of various corroles. DPM (**1**) was reacted with 4-methylbenzaldehyde (**7**) and with 4-methoxybenzaldehyde (**8**) (Scheme 2). Reactions gave rise to *trans*-A_2B-corroles **13** and **14** in almost identical yields (19 and 21%), regardless of the electronic nature of substituents in the starting aldehyde. We had always been eager to employ also aliphatic aldehydes in dipyrromethane condensation leading to *trans*-A_2B-corroles. Although mesityldipyrromethane reacted with propionaldehyde, the resulting corrole was exceptionally unstable and did not survive any purification procedure. Having now in hand the superior reaction conditions for the introduction of strongly electron-withdrawing group, we attempted to synthesize the analogous corrole **15**. The reaction of DPM (**1**) with propionaldehyde gave corrole **15** by far more stable than that one bearing mesityl groups. This compound could be purified using chromatography, but unfortunately the overall yield was only 3% (Scheme 2). It is noteworthy that this is the first example of a corrole bearing a simple alkyl substituent at the *meso* position.[16]



Scheme 2

Subsequently, we expanded the scope of substrates by using dipyrromethanes **4** and **5** with weaker electron-withdrawing groups as well as simple phenyldipyrromethane. Reactions of DPMs **4** and **5** with less reactive aldehydes (bearing electron-donating groups) **8** and **10** gave rise to corroles **16** and **17** in 19% (compared to 6% under previous conditions)[7d] and 9% yield, respectively. Unfortunately, the reaction of phenyldipyrromethane (**6**) with pentafluorobenzaldehyde (**12**) under the optimized conditions led to the extensive scrambling (Level 3 according to Lindsey's classification).[11a] Finally, encouraged by these results confirming the high acidolytic stability of dipyrromethanes bearing electron-withdrawing groups, we decided to examine the behavior of pentafluorophenyldipyrromethane **1** under conditions optimized for the condensation of sterically hindered DPMs with aldehydes bearing basic nitrogen atom.[16] Generally such syntheses require significantly higher TFA concentrations due to the influence of a base. We had found that unhindered dipyrromethanes need much lower acid concentrations to eliminate scrambling and thereby gave lower yields of corroles than sterically hindered DPMs.[16] Now we found that the reaction of pyridine-4-carboxaldehyde (**11**) with DPM **1** in the presence of 3 equiv of TFA leads to the corrole **18** in 18% yield with no scrambling (Scheme 2).

In conclusion, we have developed the refined and versatile procedure for the preparation of pure *trans*-A_2B-corroles bearing two electron-withdrawing substituents at *meso* positions from readily available dipyrromethanes. By identifying the issue of the higher stability of such dipyrromethanes versus acids and by tailoring the reaction conditions accordingly, yields of a broad range of corroles have been improved by a factor of 3. The most notable findings are as follows. Firstly, the dilution of the reaction mixture after the first acid-catalyzed step significantly improves the yields of corroles. Such a phenomenon has been already recognized in other cases,[16] but seems to depend strongly on specific substituents. Secondly, one alkyl group can be introduced at the *meso* position of corroles provided that the remaining two substituent have strong electron-withdrawing character. Finally, dipyrromethanes bearing NO_2 and CN groups can be employed in this condensation as well as even less reactive aldehydes, without noticeable scrambling. We believe that this new procedure will allow exploration of these more stable corroles for the construction of more sophisticated systems and in physicochemical studies.

All chemicals were used as received unless otherwise noted. Reagent grade solvents (CH_2Cl_2, hexanes, cyclohexane) were distilled prior to use. All reported ^1H NMR and ^{13}C NMR spectra were recorded on Bruker AM 500 MHz or Varian 400 MHz spectrometers. Chemical shifts (δ) were determined with TMS as the internal reference; *J* values are given in Hz. UV-Vis spectra were recorded in toluene (Cary). Chromatography was performed on silica (Kieselgel 60, 200–400 mesh), or dry column vacuum chromatography[17] was performed on preparative thin layer chromatography silica (Merck 107747). Mass spectra were obtained via electrospray MS (ESI-MS). Elemental analyses were performed by the staff of the microanalytical laboratory of our institute. The purity of all new corroles was established based on ^1H NMR spectra and ESI-MS spectra and elemental analysis (for most compounds). Dipyrromethanes **1**,[18] **4**[19] and **5**[19] were prepared as described in the literature.

Methyl 2-{2-[(Methoxycarbonyl)methoxy]-4-(formyl)phenoxy}acetate (10)

3,4-Dihydroxybenzaldehyde (2.76 g, 0.02 mol) and $BrCH_2CO_2Me$ (3.68 mL, 0.04 mol) were dissolved in acetonitrile (100 mL), and K_2CO_3 (10g, 72 mmol) was added in one portion. The whole mixture was kept at 70 °C for 16 h while stirring. Then the suspension was cooled to r.t. and filtered. The solvent was evaporated and the resulting oil was distilled under reduced pressure (Kugelrohr, 7 mbar, 200 °C) to obtain the aldehyde contaminated with a few unidentified compounds. The residue was crystallized from EtOAc to obtain colorless crystals (2.6 g, 46%).

Mp 93–94°C.

^1H NMR (400 MHz, $CDCl_3$): δ = 3.82 (s, 6 H, CH_3), 4.79 (s, 2 H, CH_2), 4.83 (s, 2 H, CH_2), 6.94 (d, *J* = 8.3 Hz, 1 H, ArH), 7.38 (d, *J* = 1.9 Hz, 1 H, ArH), 7.49 (dd, *J* = 1.9 Hz, 1 H, ArH), 9.85 (s, 1 H, CHO).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 52.3, 52.4, 65.9, 112.7, 113.4, 126.9, 131.0, 148.1, 152.9, 168.5, 168.7, 190.4

HRMS (EI): *m/z* calcd for $C_{13}H_{14}O_7$: 282.0740; found: 282.0738.

Anal. Calcd for $C_{13}H_{14}O_7$: C, 55.32; H, 5.00. Found: C, 55.36; H, 5.17.

trans-A_2B-Corrole Starting Dipyrromethanes Bearing Electron Withdrawing Groups and Aldehydes; General Procedure

Samples of a dipyrromethane (0.40 mmol) and an aldehyde (0.20 mmol) were dissolved in a pre-prepared solution (3 mL) of TFA (10 μL, 0.13 mmol) in CH_2Cl_2 (10 mL). After 20 min at r.t., the reaction mixture was dissolved in CH_2Cl_2 (300 mL) and a solution of DDQ (118 mg, 0.52 mmol) in toluene (2 mL) was added, and the reaction mixture was stirred at r.t. for a further 5 min. Alternatively, the reaction mixture was diluted to 10 mL with CH_2Cl_2 and added to vigorously stirred CH_2Cl_2 (40 mL) simultaneously with the solution of DDQ (118 mg, 0.52 mmol) in THF (10 mL) over 10 min, and the reaction was stirred at r.t. for a further 5 min. Then the reaction mixture was purified as described below.

5,15-Bis(pentafluorophenyl)-10-(4-cyanophenyl)corrole (3)

The reaction mixture was evaporated and chromatographed (silica; acetone–hexanes, 1:9, then 1:4). All fractions containing contaminated corrole were combined and evaporated. Subsequent dry column vacuum chromatography (silica; toluene–hexanes, 1:9, then 2:3 and 1:1) afforded pure corrole (32 mg, 21%). Spectral and physical properties concur with published data.[7d]

5,15-Bis(pentafluorophenyl)-10-(4-methylphenyl)corrole (13)

After evaporation to dryness, the reaction mixture was redissolved (toluene–hexanes, 1:3) and passed over a chromatography column (silica; toluene–hexanes, 1:3) to give corrole contaminated with porphyrin. Subsequent chromatography (silica; CH_2Cl_2–hexanes, 1:3) afforded pure corrole (27 mg, 19%), which was crystallized (CH_2Cl_2–hexanes) to give dark crystals.

R_f = 0.64 (silica, CH_2Cl_2–hexanes, 2:3)

^{1}H NMR (500 MHz, $CDCl_3$): δ = –2.70 (br s, 3 H, NH), 2.69 (s, 3 H, CH_3), 7.57, 8.06 (AA′BB′, *J* = 7.7 Hz, 4 H, MeC_6H_4), 8.56 (d, *J* = 3.6 Hz, 2 H, β-H), 8.69 (d, *J* = 4.7 Hz, 2 H, β-H), 8.72 (d, *J* = 4.7 Hz, 2H, β-H), 9.09 (d, *J* = 4.2 Hz, 2 H, β-H).

HRMS (ESI): calcd for $C_{38}H_{19}F_{10}N_4$ [M + H$^+$]: 721.1445; found: 721.1474.

Anal. Calcd for $C_{38}H_{18}F_{10}N_4$ + H_2O: C, 62.56; H, 2.62; N, 7.68. Found: C, 62.86; H, 2.02; N, 7.42.

UV-Vis (toluene): λ_{max} ($\varepsilon \times 10^{-3}$) = 419 (95), 524 (6.8), 563 (15), 617 (9.0), 638 (7.2) nm.

5,15-Bis(pentafluorophenyl)-10-(4-methoxyphenyl)corrole (14)

After evaporation to dryness, the reaction mixture was redissolved in CH_2Cl_2–hexanes (1:3) and passed over a chromatography column (silica; CH_2Cl_2–hexanes, 1:3). All fractions containing corrole were combined and evaporated. The dark green residue was dissolved in hot hexanes, and cooled in the freezer. After filtration solid was recrystallized from cyclohexane afforded pure corrole (31 mg, 21%).

R_f = 0.47 (silica; CH_2Cl_2–hexanes, 2:3)

^{1}H NMR (500 MHz, $CDCl_3$): δ = –2.66 (br s, 3 H, NH), 4.08 (s, 3 H, CH_3), 7.29, 8.09 (AA′BB′, *J* = 8.5 Hz, 4 H, $MeOC_6H_4$), 8.56 (d, *J* = 3.9 Hz, 2 H, β-H), 8.69 (d, *J* = 4.7 Hz, 2 H, β-H), 8.72 (d, *J* = 4.8 Hz, 2 H, β-H), 9.10 (d, *J* = 4.2 Hz, 2 H, β-H).

HRMS (ESI): calcd for $C_{38}H_{19}F_{10}N_4O$ [M + H$^+$]: 737.1394; found: 737.1412.

UV-Vis (toluene): λ_{max} ($\varepsilon \times 10^{-3}$) = 418 (114), 523 (7.8), 564 (17), 617 (10), 638 nm (8.5).

Anal. Calcd for $C_{38}H_{18}F_{10}N_4O$: C, 61.96; H, 2.46; N, 7.61. Found: C, 61.67; H, 2.11; N, 7.37.

5,15-Bis(pentafluorophenyl)-10-ethylcorrole (15)

The reaction mixture was evaporated with silica and put on the top of a chromatography column (silica; CH_2Cl_2–hexanes, 1:3). All fractions containing contaminated corrole were combined and evaporated. Subsequent dry column vacuum chromatography (silica; CH_2Cl_2–cyclohexane, 1:9) afforded pure corrole (4.7 mg, 3.2%).

R_f = 0.54 (silica; CH_2Cl_2–hexanes, 2:3)

^{1}H NMR (500 MHz, $CDCl_3$): δ = –2.71 (br s, 3 H, NH), 2.08 (t, *J* = 7.6 Hz, 3 H, CH_3), 4.88 (q, *J* = 7.6 Hz, 2 H, CH_2), 8.52 (d, *J* = 3.5 Hz, 2 H, β-H), 8.78 (d, *J* = 4.7 Hz, 2 H, β-H), 9.06 (d, *J* = 4.2 Hz, 2 H, β-H), 9.29 (d, *J* = 4.8 Hz, 2 H, β-H).

HRMS (ESI): calcd for $C_{33}H_{17}F_{10}N_4$ [M + H$^+$]: 659.1288; found: 659.1305.

UV-Vis (toluene): λ_{max} ($\varepsilon \times 10^{-3}$) = 418 (94), 523 (5.8), 562 (15), 621 (10), 638 nm (7.4).

5,15-Bis(4-nitrophenyl)-10-(4-methoxyphenyl)corrole (16)

The reaction mixture was evaporated to half of the volume and passed over a chromatography column (silica; CH_2Cl_2–hexanes, 3:2) to give corrole contaminated with a few unidentified compounds. After evaporation, hexanes–acetone (4:1) was added to the dark crystals, and the suspension was filtered. Then the compound was recrystallized from THF–CH_2Cl_2–hexanes to afford pure corrole (51 mg, 19%). Spectral and physical properties concur with published data.[7d]

5,15-Bis(4-cyanophenyl)-10-(3,4-dimethoxycarbonylphenyl)corrole (17)

The reaction mixture was concentrated to half of the volume and passed over a chromatography column (silica; CH_2Cl_2 then CH_2Cl_2–EtOAc, 95:5). All fractions containing corrole were combined and evaporated. Subsequent crystallization (CH_2Cl_2–hexanes) gave dark crystals (26 mg, 9%).

R_f = 0.64 (silica; CH_2Cl_2–EtOAc, 9:1).

^{1}H NMR (200 MHz, THF): δ = 3.73 (s, 3 H, CH_3), 3.84 (s, 3 H, CH_3), 4.95 (s, 2 H, CH_2), 5.02 (s, 2 H, CH_2), 7.38 (d, *J* = 8.4 Hz, 1 H, ArH), 7.72 (d, *J* = 8.0 Hz, 1 H, ArH), 7.83 (s, 1 H, ArH), 8.18 (AA′BB′, *J* = 8.0 Hz, 4 H, Ar), 8.53–8.63 (m, 8 H, β-H + AA′BB′), 8.83 (d, *J* = 4.2 Hz, 2 H, β-H), 9.01 (d, *J* = 2.8 Hz, 2 H, β-H).

HRMS(ESI): calcd for $C_{45}H_{33}N_6O_6$: [M + H$^+$] 753.2456; found: 753.2480.

UV-Vis (toluene): λ_{max} ($\varepsilon \times 10^{-3}$) = 432 (108), 576 (17), 632 (13), 656 nm (13).

Anal. Calcd for $C_{45}H_{32}N_6O_6$ + H_2O: C, 70.12; H, 4.45; N, 10.90. Found: C, 70.44; H, 4.49; N, 10.65.

5,15-Bis(pentafluorophenyl)-10-(4-pyridylphenyl)corrole (18)

5-(Pentafluorophenyl)dipyrromethane (125 mg, 0.40 mmol) and the pyridine-4-carboxaldehyde (19 μL, 0.20 mmol) were dissolved in CH_2Cl_2 (12 mL) and then TFA (46 μL, 0.6 mmol) was added. After 1 h at r.t., the reaction mixture was dissolved in CH_2Cl_2 (300 mL), neutralized with Et_3N (84 μL, 0.6 mmol) and then a solution of DDQ (118 mg, 0.52 mmol) in toluene (2 mL) was added. The reaction mixture was stirred at r.t. for an additional 5 min. Then the reaction mixture was evaporated to half of the volume and passed over a chromatography column (silica; CH_2Cl_2) to give corrole contaminated with a few unidentified compounds. After evaporation, subsequent dry column vacuum chromatography (silica; CH_2Cl_2 then CH_2Cl_2–EtOAc, 95:5) afforded pure corrole (26 mg, 18%) which was crystallized ($CHCl_3$–cyclohexane) to give dark crystals.

$R_f = 0.45$ (silica, CH_2Cl_2–acetone, 9:1).

^{1}H NMR (500 MHz, $CDCl_3$): $\delta = -2.45$ (br s, 3 H, NH), 8.20 (br s, 2 H, Py), 8.59 (br s, 2 H, β-H), 8.63 (d, $J = 4.5$ Hz, 2 H, β-H), 8.76 (d, $J = 4.0$ Hz, 2 H, β-H), 8.85 (br s, 2 H, Py), 9.13 (br s, 2 H, β-H).

HRMS(ESI): calcd for $C_{36}H_{16}F_{10}N_5$ [M + H$^+$]: 708.1241; found: 708.1276.

UV-Vis (toluene): λ_{max} ($\varepsilon \times 10^{-3}$) 418 (81), 524 (5.9), 565 (14), 612 (7.9), 638 nm (4.3).

Anal. Calcd for $C_{36}H_{15}F_{10}N_5$: C, 61.11; H, 2.14; N, 9.90. Found: C, 61.02; H, 1.86; N, 9.94.

Acknowledgment

This work was funded by the State Committee for Scientific Research (project 7 T09A 00521). We thank Volkswagen Foundation and Pawel Juszczynski for logistic support.

References

(1) (a) Paolesse, R. In *The Porphyrin Handbook*, Vol. 2; Kadish, K. M.; Smith, K. M.; Guilard, R., Eds.; Academic Press: New-York, **2000**, 201–232. (b) Montforts, F.-P.; Glasenapp-Breiling, M.; Kusch, D. In *Houben-Weyl Methods of Organic Chemistry*, Vol E9d; Schaumann, E., Ed.; Thieme: Stuttgart-New York, **1998**, 665–672.
(c) Gryko, D. T. *Eur. J. Org. Chem.* **2002**, 1735.
(d) Guilard, R.; Barbe, J.-M.; Stern, C.; Kadish, K. M. In *The Porphyrin Handbook*, Vol 18; Kadish, K. M.; Smith, K. M.; Guilard, R., Eds.; Elsevier Science: Amsterdam, **2003**, 303–351. (e) Gryko, D. T.; Fox, J. P.; Goldebrg, D. P. *J. Porphyrins Phthalocyanines* **2004**, *8*, in press.

(2) (a) Simkhovich, L.; Mahammed, A.; Goldberg, I.; Gross, Z. *Chem.–Eur. J.* **2001**, *7*, 1041. (b) Golubkov, G.; Bendix, J.; Gray, H. G.; Mahammed, A.; Goldberg, I.; DiBilio, A. J.; Gross, Z. *Angew. Chem. Int. Ed.* **2001**, *40*, 2132. (c) Gross, Z.; Gray, H. B. *Adv. Synth. Catal.* **2004**, *346*, 165.

(3) Aviezer, D.; Cotton, S.; David, M.; Segev, A.; Khasalav, N.; Galili, N.; Gross, Z.; Yayon, A. *Cancer Res.* **2000**, *60*, 2973.

(4) (a) DiNatale, C.; Salimbeni, D.; Paolesse, R.; Macagnano, A.; D'Amico, A. *Sens. Actuators, B* **2000**, *65*, 220.
(b) Barbe, J.-M.; Canard, G.; Brandès, S.; Jérôme, F.; Dubois, G.; Guilard, R. *Dalton Trans.* **2004**, 1208.

(5) Johnson, A. W.; Kay, I. T. *J. Chem. Soc.* **1965**, 1620.

(6) Jérôme, F.; Dubois, G.; Brandès, S.; Canard, G.; Barbe, J.-M.; Guilard, R.; Roux-Fouillet, B.; Ledon, H. WO Patent 0311865, **2003**.

(7) (a) Paolesse, R.; Nardis, S.; Sagone, F.; Khoury, R. G. *J. Org. Chem.* **2001**, *66*, 550. (b) Gross, Z.; Galili, N.; Saltsman, I. *Angew. Chem. Int. Ed.* **1999**, *38*, 1427.
(c) Briñas, R. P.; Brückner, C. *Synlett* **2001**, 442.
(d) Gryko, D. T.; Jadach, K. *J. Org. Chem.* **2001**, *66*, 4267.
(e) Ramdhanie, B.; Stern, C. L.; Goldberg, D. P. *J. Am. Chem. Soc.* **2001**, *123*, 9447. (f) Guilard, R.; Gryko, D. T.; Canard, G.; Barbe, J.-M.; Koszarna, B.; Brandes, S.; Tasior, M. *Org. Lett.* **2002**, *4*, 4491. (g) Barbe, J.-M.; Burdet, F.; Espinoza, E.; Gros, C. P.; Guilard, R. *J. Porphyrins Phthalocyanines* **2003**, *7*, 365.

(8) Tardieux, C.; Gros, C. P.; Guilard, R. *J. Heterocycl. Chem.* **1998**, *35*, 965.

(9) (a) Shaw, S. J.; Edwards, C.; Boyle, R. W. *Tetrahedron Lett.* **1999**, *40*, 7585. (b) Weiss, R.; Pühlhofer, F.; Jux, N.; Merz, K. *Angew. Chem. Int. Ed.* **2002**, *41*, 3815.

(10) Gryko, D. T.; Koszarna, B. *Org. Biomol. Chem.* **2003**, *1*, 350.

(11) (a) Littler, B. J.; Ciringh, Y.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 2864. (b) Geier, G. R. III; Littler, B. J.; Lindsey, J. S. *J. Chem. Soc., Perkin Trans. 2* **2001**, 701.

(12) (a) Allen, A. D.; Kwong-Chip, J.-M.; Lin, W. C.; Nguyen, P.; Tidwell, T. T. *Can. J. Chem.* **1990**, *68*, 1709.
(b) Nishino, N.; Wagner, R. W.; Lindsey, J. S. *J. Org. Chem.* **1996**, *61*, 7534.

(13) (a) Krebs, F. C.; Hagemann, O.; Spanggaard, H. *J. Org. Chem.* **2003**, *68*, 2463. (b) Frixo, C.; Mahon, M. F.; Thompson, A. F.; Threadgill, M. D. *Org. Biomol. Chem.* **2003**, *1*, 306.

(14) Ka, J.-W.; Cho, W.-S.; Lee, C.-H. *Tetrahedron Lett.* **2000**, *41*, 8121.

(15) Gryko, D. T.; Piechota, K. E. *J. Porphyrins Phthalocyanines* **2002**, *6*, 81.

(16) For the synthesis of corroles possessing perfluoroalkyl groups at *meso* positions see: (a) Tse, M. K.; Zhang, Z.; Mak, T. C. W.; Chan, K. S. *Chem. Commun.* **1998**, 1199.
(b) Simkhovich, L.; Goldberg, I.; Gross, Z. *J. Inorg. Biochem.* **2000**, *80*, 235.

(17) Pedersen, D. S.; Rosenbohm, C. *Synthesis* **2001**, 2431.

(18) Laha, J. K.; Dhanalekshmi, S.; Taniguchi, M.; Ambroise, A.; Lindsey, J. S. *Org. Proc. Res. Dev.* **2003**, *7*, 799.

(19) Littler, B. J.; Miller, M. A.; Hung, C. H.; Wagner, R. W.; O'Shea, D. F.; Boyle, P. D.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 1391.