Fluoroalkylation of Porphyrins: A Facile Synthesis of Trifluoromethylated Porphyrins by a Palladium-Catalyzed Cross-Coupling Reaction

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Various trifluoromethylated porphyrins can be conveniently synthesized in high yields by the reaction of brominated porphyrins with FSO_2CF_2COOMe/CuI in the presence of catalytic amounts of $Pd_2(dba)_3{\cdot}CHCl_3/AsPh_3$.

Introduction

Porphyrins have widespread application in various scientific fields, such as biomimetic models for photosynthesis, catalysis, supramolecular chemistry, and medical applications such as photodynamic therapy.[1] Electronically and sterically modified porphyrins incorporating strongly electron-withdrawing substituents at the pyrrolic β- and/or *meso*-positions form a class of so-called "electron-deficient porphyrins".[1] Many such kinds of electron-deficient porphyrins have been reported with a focus on their catalytic oxidation in order to mimic and improve their cytochrome-P450-like activity.[2–4] Of the numerous electron-withdrawing groups, perfluoroalkyl groups are unique because they are inert and strongly σ-electron-withdrawing, but do not function as π-electron donors. Accordingly, perfluoalkyl groups effectively stabilize the HOMO of the porphyrin macrocycle,[5] improve its solubility in a wide range of solvents,[6,7] and may be useful as catalysts in certain media.[8,9]

Among (perfluoroalkyl)porphyrins,[10] the trifluoromethylated porphyrins are the simplest and most attractive. However, to the best of our knowledge, there are only a few methods for synthesizing trifluoromethylated porphyrins.[11] A general approach for the preparation of β-trifluoromethyl-*meso*-tetraphenylporphyrins has been demonstrated by Terazono and Dolphin based on the most widely available starting material, i.e. *meso*-tetraphenylporphyrin (TPP).[11a] This method involves the nucleophilic trifluoromethylation of (β-tetrabromo-*meso*-tetraphenylporphyrin)-metal complexes with a mixture of $Cd(CF_3)_2$ and CF_3CdBr in HMPA. Thus, β-mono-, -bis-, -tris-, and -tetrakis(trifluoromethyl)TPPs have been prepared successfully. However, this method suffers from the difficult preparation of the trifluoromethylating agent, lower yield, and a difficult purification. In connection with our continuing interest in the trifluoromethylation of organic halides[12] with methyl difluoro(fluorosulfonyl)acetate (FSO_2CF_2COOMe), we envisioned that brominated porphyrins might be trifluoromethylated with this reagent. We present the results here.

Results and Discussion

As mentioned above, the most straightforward route for the preparation trifluoromethylated porphyrins is the substitution of brominated prophyrins, like normal aromatic halides, with trifluoromethylating agents.

We have previously used FSO_2CF_2COOMe to smoothly trifluoromethylate aromatic, vinyl, and allylic halides, and even *trans*-1,2-diiodoalkenes, in the presence of CuI.[13] Although the generation of active $[CF_3Cu]$ species in situ from FSO_2CF_2COOMe is the same as that from $Cd(CF_3)_2$/CF_3CdBr, our reagent is readily available[14,15] as its precursor, FSO_2CF_2COF, is one of the starting materials for producing the commercial ion-exchange resins Nafion-H®.[16] Various brominated porphyrins, such as $H_2TPP(Br)$ (**2**),[17] $H_2TPP(Br)_4$ (**4**),[18] $H_2TPP(Br)_8$ (**6**),[19] $H_2DPP(Br)$ (**11**),[20] and $H_2DPP(Br)_2$ (**13**),[21] can be conveniently prepared by the controlled bromination of H_2TPP either by treatment of the free porphyrin with NBS or the porphyrin copper complex (CuTPP, **Cu1**) with Br_2, according to literature procedures (Scheme 1).

With the trifluoromethylating agent and brominated porphyrins in hand, we carried out the trifluoromethylation reaction of [Zn{TPP(Br)}] (**Zn2**), a readily available brominated porphyrin, with FSO_2CF_2COOMe/CuI under our standard conditions,[13a] i.e., **Zn2**/FSO_2CF_2COOMe/CuI = 1:10:10 at 100 °C in DMF for 16 h, and, rather than the desired product [Zn{TPP(CF_3)}] (**Zn3**), the transmetalated product [Cu{TPP(Br)}] (**Cu2**) was obtained (Scheme 2).

It is known that the trifluoromethylation reaction can be accelerated and improved greatly by the addition of cata-

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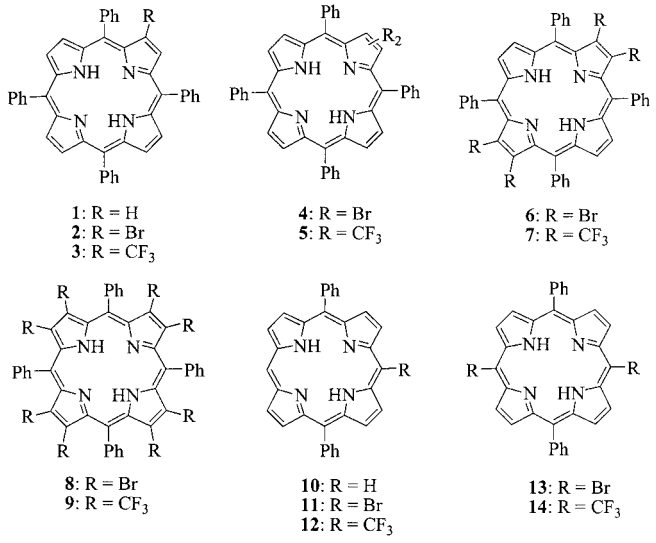
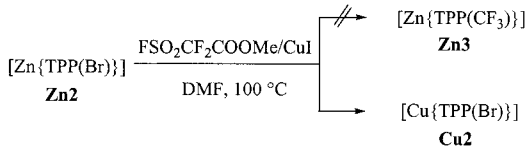


Scheme 1.



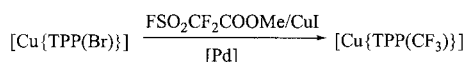
Scheme 2.

lytic amounts of $PdCl_2$.[22] We therefore decided to add $[Pd(PPh_3)_4]$ to the reaction. We found that [Cu{TPP(Br)}] (**Cu2**) or [Zn{TPP(Br)}] (**Zn2**) could be converted into the expected [Cu{TPP(CF_3)}] (**Cu3**) under identical conditions. Representative results for the model substrate [Cu{TPP(Br)}] (**Cu2**) are shown in Table 1, where it can be seen that 10 mol-% Pd is sufficient for the reaction. The yield improved only slightly when $[Pd(PPh_3)_4]$ or $[PdCl_2(PPh_3)_2]$ were used (Entries 2 and 3). Although $[PdCl_2(dppf)]$ [dppf = 1,1′-bis(diphenylphosphanyl)ferrocene] might play a significant role (Entry 4), $Pd_2(dba)_3{\cdot}CHCl_3/AsPh_3$ (dba = dibenzylideneacetone) was found to be the most efficient catalyst (Entry 5).The amounts of FSO_2CF_2COOMe/CuI used also influence the reaction, 5–10 equiv. being most suitable.

In order to explore the reaction scope, a number of related systems were tested; the results are summarized in Table 2. All the brominated porphyrins underwent smooth trifluoromethylation in high yields. The trifluoromethylated porphyrins formed were unambiguously assigned by ^1H and ^{19}F NMR spectroscopy, mass spectrometry and HRMS or elemental analysis, as well as X-ray crystallography for [Cu{TPP(CF_3)$_4$}] (**Cu7**) and [Ni{TPP(CF_3)$_8$}] (**Ni9**), both of which exhibit strongly saddled conformations (Figure 1).

Notably, the data in Table 2 indicate that trifluoromethylation of [Cu{TPP(Br)$_8$}] (**Cu8**) is much faster than that of [Cu{TPP(Br)}] (**Cu2**) and [Cu{TPP(Br)$_4$}] (**Cu6**) (Entries 1–3). The reactivity at the β-position of the porphyrin was also found to be higher than that at the *meso*-position (Entry 1 vs. 7). All these results can be ascribed to: (1) the Pd-catalyzed cross-coupling of brominated porphyrins, like

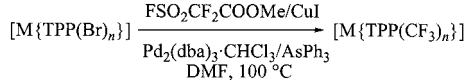
Table 1. Trifluororomethylation of [Cu{TPP(Br)}] (**Cu2**).[a,b]



Entry	[Pd] (10 mol-%)	FSO_2CF_2COOMe/CuI [equiv.]	*t* [h]	Yield [%][c]
1	–	10/10	24	–
2	$[Pd(PPh_3)_4]$	10/10	16	20
3	$[PdCl_2(PPh_3)_2]$	10/10	16	25
4	$[PdCl_2(dppf)]$	10/10	8	50
5	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	10/10	12	65
6	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	1/1	24	trace
7	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	10/1	16	<10
8	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	1/5	16	trace
9	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	5/5	16	68
10	$Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$	10/5	16	70

[a] Reaction conditions: [Cu{TPP(Br)}] (**Cu2**) (50 mg), 100 °C, 10 mL of DMF. [b] A trace amount of [Cu{TPP(CF_3)$_2$}] (**Cu5**) was also isolated, which probably generated from the reaction of [Cu{TPP(Br)$_2$}] (**Cu4**) in the starting material.[21] [c] Isolated yields.

Table 2. Trifluoromethylation of various brominated porphyrins.[a]



Entry	Reactant	Product	*t* [h][b]	Yield [%][c]
1	[Cu{TPP(Br)}] (**Cu2**)	[Cu{TPP(CF_3)}] (**Cu3**)	16	68
2	[Cu{TPP(Br)$_4$}] (**Cu6**)	[Cu{TPP(CF_3)$_4$}] (**Cu7**)	6	95
3	[Cu{TPP(Br)$_8$}] (**Cu8**)	[Cu{TPP(CF_3)$_8$}] (**Cu9**)	2	85
4	[Ni{TPP(Br)}] (**Ni2**)	[Ni{TPP(CF_3)}] (**Ni3**)	12	65
5	[Ni{TPP(Br)$_4$}] (**Ni6**)	[Ni{TPP(CF_3)$_4$}] (**Ni7**)	4	95
6	[Ni{TPP(Br)$_8$}] (**Ni8**)	[Ni{TPP(CF_3)$_8$}] (**Ni9**)	2	90
7	[Cu{DPP(Br)}] (**Cu11**)	[Cu{DPP(CF_3)}] (**Cu12**)	48	45[d] [e]
8	[Cu{DPP(Br)$_2$}] (**Cu13**)	[Cu{DPP(CF_3)$_2$}] (**Cu14**)	24	65[f]
9	[Ni{DPP(Br)}] (**Ni11**)	[Ni{DPP(CF_3)}] (**Ni12**)	48	40[d] [g]
10	[Ni{DPP(Br)$_2$}] (**Ni13**)	[Ni{DPP(CF_3)$_2$}] (**Ni14**)	24	70[f]

[a] Reaction conditions: porphyrin (50 mg), $Pd_2(dba)_3{\cdot}CHCl_3$/$AsPh_3$ (5 mol-%/40 mol-%), FSO_2CF_2COOMe/CuI (5 equiv./5 equiv. per Br), 100 °C. [b] Time required for consumption of the starting material, as monitored by TLC. [c] Isolated yield. [d] FSO_2CF_2COOMe/CuI (20 equiv.:10 equiv.). [e] Around 15% of [Cu{TPP(CF_3)$_2$}] (**Cu14**) was also isolated. [f] FSO_2CF_2COOMe/CuI (40 equiv.:20 equiv.). [g] Around 10% of [Ni{TPP(CF_3)$_2$}] (**Ni14**) was also isolated.

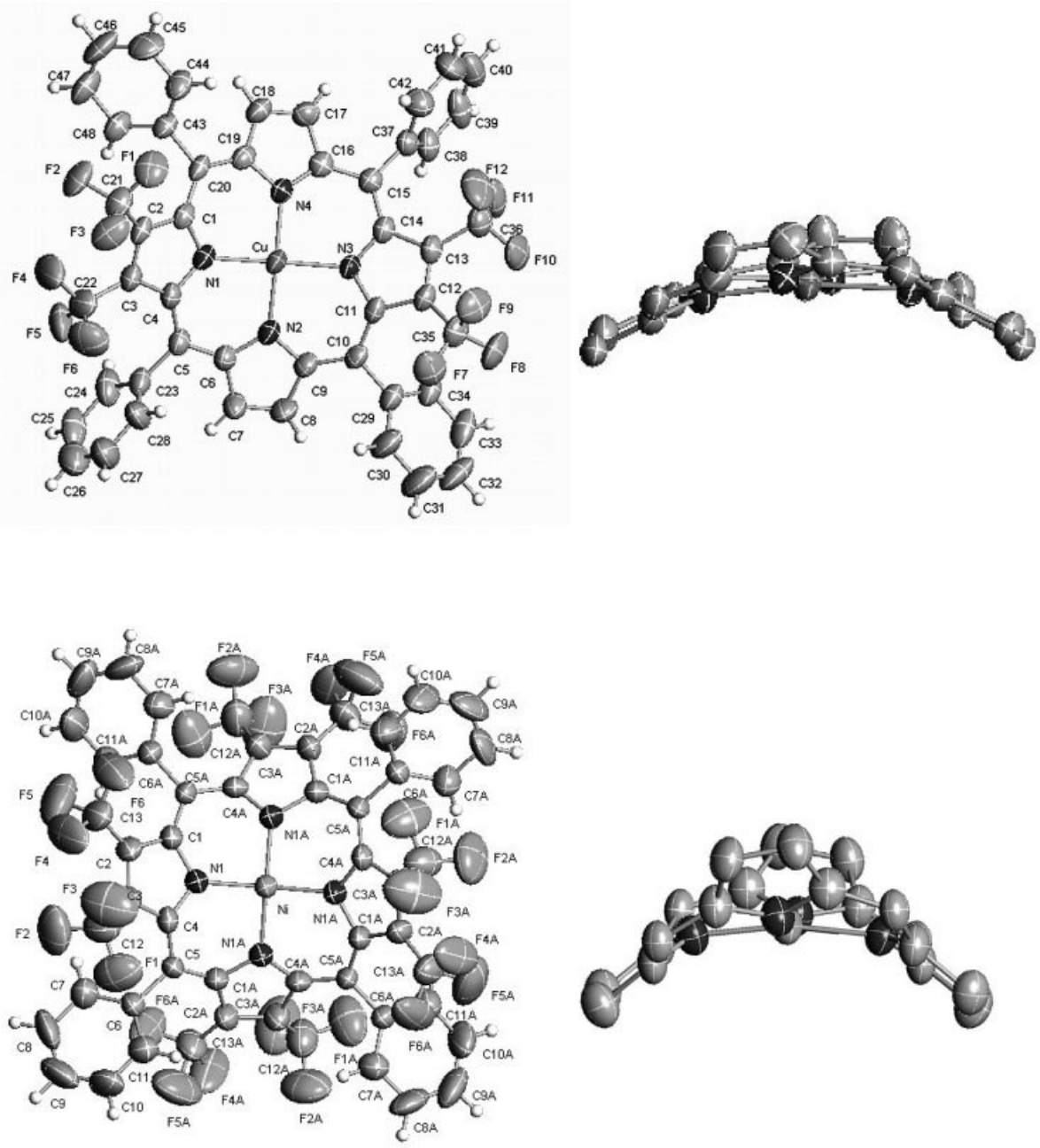
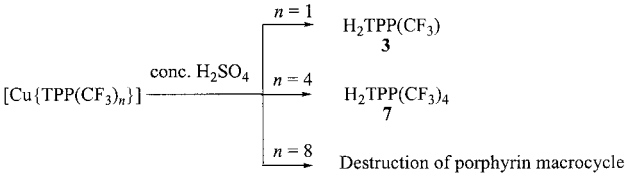


Figure 1. X-ray crystal structures and side views of [Cu{TPP(CF_3)$_4$}] (**Cu7**) and [Ni{TPP(CF_3)$_8$}] (**Ni9**). The *meso*-phenyl groups, β-trifluoromethyl groups and hydrogen atoms have been omitted for clarity.

simple aromatic halides,[23–27] is accelerated by the presence of electron-withdrawing substituents, and (2) the electron density of porphyrin methyne carbon atoms is higher than pyrrolic ones.[28,29] Different from brominated (porphyrin)-zinc complexes, brominated (porphyrin)nickel complexes can be trifluoromethylated without changing into the corresponding (trifluoromethylated porphyrin)copper complexes.

Demetalation of [Cu{TPP(CF_3)}] (**Cu3**) and [Cu{TPP(CF_3)$_4$}] (**Cu7**) was accomplished smoothly by treatment with conc. H_2SO_4 in CH_2Cl_2 at room temperature for 1–2 h to give the corresponding free-base porphyrins H_2TPP(CF_3) (**3**) and H_2TPP(CF_3)$_4$ (**7**), whereas treatment of [Cu{TPP(CF_3)$_8$}] (**Cu9**) under similar conditions resulted in the destruction of the porphyrin macrocycle (UV/Vis detection; see Scheme 3).



Scheme 3. Demetalation of various trifluoromethylated (porphyrin)-copper complexes.

As expected, introduction of trifluoromethyl groups to the β-positions of the porphyrin causes severe distortion to

the ring and, as a consequence, the Soret absorption bands and the Q bands are strongly shifted to lower energy relative to those of the brominated porphyrins (Table 3 and Figure 2). This is indicative of a narrower HOMO–LUMO gap.

Table 3. UV/Vis data for β-trifluoromethylated porphyrins in CH_2Cl_2 at 20 °C.

Porphyrins	B bands	Q bands	
[Cu{TPP(Br)}] (**Cu2**)	417	540	576
[Cu{TPP(Br)$_4$}] (**Cu6**)	426	553	593
[Cu{TPP(Br)$_8$}] (**Cu8**)	364, 446(sh), 464	580	624
[Cu{TPP(CF$_3$)}] (**Cu3**)	418	544	577
[Cu{TPP(CF$_3$)$_4$}] (**Cu7**)	439, 467(sh)	666	–
[Cu{TPP(CF$_3$)$_8$}] (**Cu9**)	371, 454 (sh), 495	721	–
[Ni{TPP(CF$_3$)}] (**Ni3**)	419	534	608
[Ni{TPP(CF$_3$)$_4$}] (**Ni7**)	365, 441	578	630
[Ni{TPP(CF$_3$)$_8$}] (**Ni9**)	462	580	639

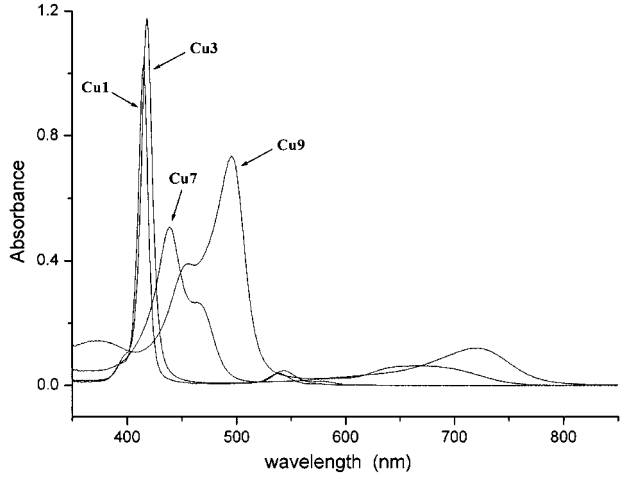
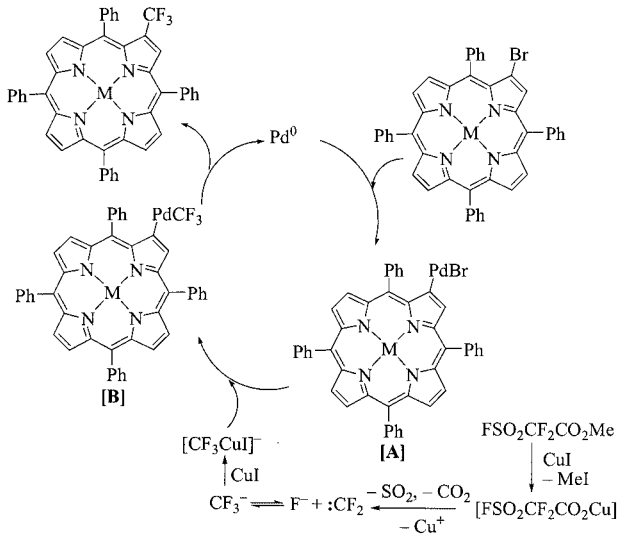


Figure 2. UV/Vis spectra of [CuTPP] (**Cu1**), [Cu{TPP(CF$_3$)}] (**Cu3**), [Cu{TPP(CF$_3$)$_4$}] (**Cu7**) and [Cu{TPP(CF$_3$)$_8$}] (**Cu9**) in CH_2Cl_2 at 20 °C.

Originally, the trifluoromethylation mechanism of organic halides with FSO_2CF_2COOMe/CuI was expected to be involved in the nucleophilic attack of $(CF_3CuI)^-$ on the aryl halide.[12e] However, the inertness of $(CF_3CuI)^-$ toward brominated porphyrins was observed under the standard conditions unless a catalytic amount of Pd was added. Based on the above results and known organometallic chemistry, a plausible mechanism can be proposed to account for the formation of the products. As shown in Scheme 4, oxidative addition of Pd^0 active species generated under the reaction conditions with the brominated porphyrins provides the (porphyrin)Pd^{II} complex **A**, which undergoes transmetalation with the $(CF_3CuI)^-$ generated from FSO_2CF_2COOMe/CuI to form the (trifluoromethylated porphyrin)Pd^{II} complex **B**. Reductive elimination of **B** results in the formation of the desired product and the regeneration of the Pd^0 active species, which continues the catalytic cycle.



Scheme 4. Proposed mechanism for the trifluoromethylation of brominated porphyrins.

Conclusions

In summary, we have developed a facile and general method for the synthesis of various trifluoromethylated porphyrins with commercially available FSO_2CF_2COOMe/CuI in the presence of catalytic amounts of $Pd_2(dba)_3$·$CHCl_3$/$AsPh_3$. This trifluoromethylation reaction is general and can be applied to a variety of brominated porphyrins in good to excellent yields. These trifluoromethylated porphyrins might be useful for applications in many important areas such as catalysis, materials, biomimetics and medicine. Detailed studies of the properties of the trifluoromethylated porphyrins are now in progress.

Experimental Section

Materials and Instrumentation: ^1H (300 MHz) and ^{19}F (282 MHz) NMR spectra were recorded with a Bruker AM-300 spectrometer. Chemical shifts are reported in ppm relative to TMS as an internal standard (δ_{TMS} = 0 ppm) for ^1H NMR spectra and $CFCl_3$ as an external standard (negative for upfield) for ^{19}F NMR spectra. The solvent for NMR measurement was $CDCl_3$ (Aldrich). MS and HRMS were recorded with a Hewlett–Packard HP-5989A spectrometer and a Finnigan MAT-8483 mass spectrometer. UV/Vis spectra were measured with a Varian Cary 100 spectrophotometer. FSO_2CF_2COOMe can be purchased from Aldrich, SynQuest Lab., FLUOROTECH, or prepared by the reaction of commercially available FSO_2CF_2COF with methanol according to the literature.[14,15] DMF for trifluoromethylation was distilled from CaH_2. All the other solvents and chemicals were reagent grade, purchased commercially, and used without further purification unless noted otherwise. Flash chromatography was performed with 300–400 mesh silica gel.

(5-Bromo-10,20-diphenylporphyrin)copper (Cu11): 5-Bromo-10,20-diphenylporphyrin (100 mg, 0.186 mmol) was suspended in DMF (10 mL) containing $Cu(OAc)_2$·H_2O (186 mg, 0.93 mmol). The mixture was heated under reflux for 2 h and then poured into distilled water. The precipitated purple solid was filtered through a fine fritted disk, washed with water and methanol, and dried in vacuo to

yield 106 mg (95%) of a reddish purple solid. MS (MALDI): *m*/*z* = 601.0 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 411 (826), 536 (34.3), 592 (1.0). $C_{32}H_{19}BrCuN_4$ (601.0): calcd. C 63.74, H 3.18, N 9.29; found C 63.77, H 3.33, N 9.34.

(5,15-Dibromo-10,20-diphenylporphyrin)copper (Cu13): The insertion of copper into 5,15-dibromo-10,20-diphenylporphyrin was similar to that of **Cu11**, with 95% yield. MS (MALDI): *m*/*z* = 678.9 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 416 (319.6), 544 (15.0), 594 (1.0). HRMS (MALDI): calcd. for $[C_{32}H_{18}Br_2CuN_4]^+$ 586.0883; found 586.09098.

General Procedure for the Preparation of Various Trifluoromethylated Porphyrins: FSO_2CF_2COOMe (5 equiv. per Br) was added at room temperature to a mixture of porphyrin (50 mg), $Pd_2(dba)_3$·$CHCl_3$/$AsPh_3$ (5 mol-%:40 mol-%) and CuI (5 equiv. per Br) in dry DMF (10 mL), and the reaction mixture was stirred at 100 °C under nitrogen for 2–48 h. After cooling, the reaction mixture was diluted with CH_2Cl_2 and filtered. The filtrate was washed three times with water and the organic layer was dried with Na_2SO_4 and the solvents were evaporated to dryness. The resulting solid was dissolved in CH_2Cl_2 and purified by flash chromatography to yield the desired product in good yield. An analytical sample was recrystallized from CH_2Cl_2/MeOH. The results are shown in Table 2.

(5,10,15,20-Tetraphenyl-2-trifluoromethylporphyrin)copper (Cu3): Yield: 33 mg (68%). MS (ESI): *m*/*z* = 744.2 [M$^+$ + 1]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 418 (24.5), 544 (1.0), 577 (1.0). $C_{45}H_{27}CuF_3N_4$ (744.2): calcd. C 72.62, H 3.66, N 7.53; found C 72.18, H 3.65, N, 7.39.

[5,10,15,20-Tetraphenyl-β,β′-bis(trifluoromethyl)porphyrin]copper (Cu5): MS (ESI): *m*/*z* = 812.2 [M$^+$ + 1]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 419 (60.1), 546 (2.5), 583 (1.0). HRMS (MALDI): calcd. for $[C_{46}H_{27}CuF_6N_4]^+$ 812.1413; found 812.14304.

[5,10,15,20-Tetraphenyl-2,3,12,13-tetrakis(trifluoromethyl)porphyrin]copper (Cu7): Yield: 45 mg (95%). MS (ESI): *m*/*z* = 948.1 [M$^+$ + 1]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 439 (8.0), 467 (4.2), 666 (1.0). $C_{48}H_{24}CuF_{12}N_4$ (948.1): calcd. C 60.80, H 2.55, N 5.91; found C 60.32, H 2.82, N 5.56.

[5,10,15,20-Tetraphenyl-2,3,7,8,12,13,17,18-octakis(trifluoromethyl)porphyrin]copper (Cu9): Yield: 40 mg (85%). MS (ESI): *m*/*z* =1220.4 [M$^+$ + 1]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 374 (1.2), 454 (3.3), 495 (6.1), 721 (1.0). $C_{52}H_{20}CuF_{24}N_4$·2MeOH (1283.1): calcd. C 50.50, H 2.20, N 4.36; found C 50.98, H 2.63, N 4.15.

(5,10,15,20-Tetraphenyl-2-trifluoromethylporphyrin)nickel (Ni3): Yield: 32 mg (65%). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.55–7.72 (m, 12 H, Ph-H), 7.89–7.99 (m, 8 H, Ph-H), 8.63–8.73 (m, 6 H, β-H), 9.13 (s, 1 H, β-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –52.44 (s, 3 F) ppm. MS (MALDI): *m*/*z* = 738.1 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 419 (125.5), 534 (8.2), 608 (1.0). $C_{45}H_{27}F_3N_4Ni$·H_2O (756.2): calcd. C 71.36, H 3.86, N 7.40; found C 71.84, H 3.77, N 7.29.

[5,10,15,20-Tetraphenyl-β,β′-bis(trifluoromethyl)porphyrin]nickel (Ni5): ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.54–7.72 (m, 12 H, Ph-H), 7.84–8.01 (m, 8 H, Ph-H), 8.57–8.73 (m, 5 H), 9.07 (s, 1 H, β-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –52.81 (s, 6 F) ppm. MS (MALDI): *m*/*z* = 806.1 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 422 (30.0), 539 (1.9), 584 (1.0). HRMS (MALDI): calcd for $[C_{46}H_{27}F_6N_4Ni]^+$ 806.1413; found 806.14096.

[5,10,15,20-Tetraphenyl-2,3,12,13-tetrakis(trifluoromethyl)porphyrin]nickel (Ni7): Yield: 45 mg (95%). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.61–7.71 (m, 12 H, Ph-H), 7.87–7.97 (m, 8 H, Ph-H), 8.13(s, 4 H, β-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –49.01 (s, 12 F, CF_3) ppm. MS (MALDI): *m*/*z* = 942.1 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 365 (1.9), 441 (21.7), 578 (1.0), 630 (3.2). $C_{48}H_{24}F_{12}N_4Ni$·$2H_2O$ (978.1): calcd. C 58.86, H 2.88, N 5.72; found C 58.73, H 2.75, N 5.55.

[5,10,15,20-Tetraphenyl-2,3,7,8,12,13,17,18-octakis(trifluoromethyl)porphyrin]nickel (Ni9): Yield: 42 mg (90%). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.67–7.75 (m, 12 H, Ph-H), 7.90–7.98 (m, 8 H, Ph-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –50.85 (m, 24 F, CF_3) ppm. MS (MALDI): *m*/*z* = 1214.2 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 462 (15.1), 580 (1.0), 639 (1.5). $C_{52}H_{20}F_{24}N_4Ni$·$3H_2O$ (1268.1): calcd. C 49.20, H 2.06, N 4.41; found C 48.99, H 1.93, N 4.62.

(10,20-Diphenyl-5-trifluoromethylporphyrin)copper (Cu12): Yield: 22 mg (45%). MS (MALDI): *m*/*z* = 591.0 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 415 (34.9), 543 (1.5), 578 (1.0). HRMS (MALDI): calcd for $[C_{33}H_{19}CuF_3N_4]^+$ 591.0880; found 591.08523.

[10,20-Diphenyl-5,15-bis(trifluoromethyl)porphyrin]copper (Cu14): Yield: 31 mg (65%). MS (MALDI): *m*/*z* = 659.1 [M$^+$]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 410 (27.8), 547 (1.0), 587 (2.0). $C_{34}H_{18}CuF_6N_4$·1.5MeOH (707.1): calcd. C 60.21, H 3.42, N 7.91; found C 60.57, H 3.39, N 7.42.

(10,20-Diphenyl-5-trifluoromethylporphyrin)nickel (Ni12): Yield: 20 mg (40%). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.69–7.74

Table 4. Crystal data and structure refinement for [Cu{TPP(CF_3)$_4$}] (**Cu7**) and [Ni{TPP(CF_3)$_8$}] (**Ni9**).

	[Cu{TPP(CF_3)$_4$}] (**Cu7**)	[Ni{TPP(CF_3)$_8$}] (**Ni9**)
Empirical formula	$C_{48}H_{24}CuF_{12}N_4$	$C_{56}H_{24}Cl_2F_{24}N_4Ni$
Formula mass	948.25	1338.40
Dimensions [mm]	0.516×0.164×0.143	0.237×0.215×0.087
Crystal system	orthorhombic	tetragonal
a [Å]	17.9989(10)	21.286(2)
b [Å]	13.0050(7)	21.286(2)
c [Å]	34.2462(19)	11.2033(15)
V [Å^3]	8016.2(8)	5076.1(10)
Space group	*Pbca*	*I*4$_1$/*a*
Z	8	4
μ(Mo-K_α) [mm^{-1}]	0.643	0.622
R_1	0.0674	0.1088
Reflections measured	45364	13045
$2\theta_{max}$ [°]	54.00	50.98
T [K]	293(2)	293(2)

(m, 6 H, Ph-H), 7.96 (d, J = 7.2 Hz, 4 H, Ph-H), 8.76 (d, J = 4.8 Hz, 2 H, β-H), 8.85 (d, J = 5.4 Hz, 2 H, β-H), 9.06 (d, J = 4.5 Hz, 2 H, β-H), 9.44 (s, 2 H, β-H), 9.70 (s, 1 H, *meso*-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –38.78 (s, 6 F, CF_3) ppm. MS (MALDI): m/z = 586.1 [M^+]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 415 (34.9), 543 (1.5), 578 (1.0). HRMS (MALDI): calcd for $[C_{33}H_{19}F_3N_4Ni]^+$ 586.0883; found 586.09098.

[10,20-Diphenyl-5,15-bis(trifluoromethyl)porphyrin]nickel (Ni14): Yield: 34 mg (70%). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = 7.66–7.75 (m, 6 H, Ph-H), 7.89–7.95 (m, 4 H, Ph-H), 8.75 (d, J = 5.1 Hz, 4 H, β-H), 9.35–9.38 (m, 4 H, β-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –39.97 (s, 6 F, CF_3) ppm. MS (MALDI): m/z = 654.1 [M^+]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 411 (21), 543 (1.0), 588 (2.0). HRMS (MALDI): calcd for $[C_{34}H_{18}F_6N_4Ni]^+$ 654.0752; found 654.07836. $C_{34}H_{18}F_6N_4Ni$·MeOH (686.1): calcd. C 61.17, H 3.23, N 8.15; found C 61.40, H 3.49, N 7.28.

General Procedure for the Demetalation of (Trifluoromethylated porphyrin)copper Complexes: The (trifluoromethylated porphyrin)copper complex (20 mg) was dissolved in CH_2Cl_2 (20 mL), then conc. H_2SO_4 (2 mL) was added slowly. The mixture was vigorously stirred at room temperature for 1–2 h. The mixture was then shaken with 1 M sodium hydroxide and the product from the CH_2Cl_2 layer was chromatographed to give the pure, base-free porphyrin in high yield.

5,10,15,20-Tetraphenyl-2-trifluoromethylporphyrin (3): ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C): δ = –2.70 (s, 2 H, N–H), 7.64–7.83 (m, 12 H, Ph-H), 8.15–8.23 (m, 8 H, Ph-H), 8.65–8.82 (m, 4 H, β-H), 8.91 (s, 2 H, β-H), 9.15 (s, 1 H, β-H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, 25 °C): δ = –52.25 (s, 3 F, CF_3) ppm. MS (MALDI): m/z = 683.3 [M^+ + 1]. UV/Vis (CH_2Cl_2): λ_{max} (relative intensity) = 420 (94.8), 518 (3.9), 554 (1.2), 596 (1.0), 652 (1.6). $C_{45}H_{29}F_3N_4$ (682.3): calcd. C 79.16, H 4.28, N 8.21; found C 78.63, H 4.07, N 8.16.

5,10,15,20-Tetraphenyl-2,3,12,13-tetrakis(trifluoromethyl)porphyrin (7): ^{1}H NMR (300 MHz, 25 °C): δ = –1.33 (s, 2 H, N–H), 7.25 (m, 12 H, Ph-H), 8.12(s, 4 H, β-H), 8.21–8.24 (m, 8 H, Ph-H) ppm. ^{19}F NMR (282 MHz, C_6D_6, 25 °C): δ = –49.41 (s, 12 F, CF_3) ppm. MS (MALDI): m/z = 887.1 [M^+ + 1]. UV/Vis (CH_2Cl_2): λ_{max} = 444, 465 (sh), 581, 825.

X-ray Crystallographic Studies: Crystals for the X-ray analyses were obtained as described previously. Suitable crystals were mounted on glass fibres or sealed in thin-walled glass capillaries. X-ray intensity data of [Cu{TPP(CF_3)$_4$}] (**Cu7**) and [Ni{TPP(CF_3)$_8$}] (**Ni9**) were collected with a SMART APEX diffractometer employing Mo-K_α radiation (λ = 0.71073 Å) and using the ω-2θ scan technique. The intensity data were corrected for Lorentz and polarization effects. Refinement was by full-matrix least-squares techniques based on F to minimize the quantity $\Sigma w(|F_o| - |F_c|)^2$ with $w = 1/\sigma^2(F)$. Non-hydrogen atoms were refined anisotropically, and hydrogen atoms were refined isotropically. Crystal data and data collection parameters are summarized in Table 4. CCDC-259946 (**Cu7**) and -259947 (**Ni9**) contain 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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[1] *The Porphyrin Handbook* (Eds.: K. M. Kadishi, K. M. Smith, R. Guilard), Academic Press, San Diego, **2000–2003**, vol. 1–20.
[2] D. Dolphin, T. G. Traylor, L. Y. Xie, *Acc. Chem. Res.* **1997**, *30*, 251–259 and references cited therein.
[3] F. Montanari, L. Casella, *Metalloporphrin Catalyzed Oxidations*, Kluwer Academic Publishers, Dordrecht, The Netherlands, **1994**.
[4] R. A. Sheldon, *Metalloporphyrins in Catalytic Oxidations*, Marcel Dekker, New York, **1994**.
[5] P. G. Gassman, A. Ghosh, J. Almlöf, *J. Am. Chem. Soc.* **1992**, *114*, 9990–10000.
[6] J. G. Goll, K. T. Moore, A. Ghosh, M. J. Therien, *J. Am. Chem. Soc.* **1996**, *118*, 8344–8354.
[7] S. G. DiMagno, R. A. Williams, M. J. Therien, *J. Org. Chem.* **1994**, *59*, 6943–6948.
[8] I. T. Horváth, J. Rábai, *Science* **1994**, *266*, 72–75.
[9] G. Pozzi, F. Montanari, S. Uici, *Chem. Commun.* **1997**, 69–70.
[10] For selected recent reports on (perfluoroalkyl)porphyrins, see: a) Z. Zeng, C. Liu, L. M. Jin, C. C. Guo, Q. Y. Chen, *Eur. J. Org. Chem.* **2005**, 306–316; b) L. M. Jin, Z. Zeng, C. C. Guo, Q. Y. Chen, *J. Org. Chem.* **2003**, *68*, 3912–3917; c) T. P. Wijesekera, *Can. J. Chem.* **1996**, *74*, 1868–1871; d) J. G. Goll, K. T. Moore, A. Ghosh, M. J. Therien, *J. Am. Chem. Soc.* **1996**, *118*, 8344–8354; e) S. G. DiMagno, R. A. Williams, M. J. Therine, *J. Org. Chem.* **1994**, *59*, 6943–6948; f) H. Michihide, A. Katsuhiro, A. Yasuhiro, O. Hisanobu, *Tetrahedron Lett.* **1983**, *24*, 4343–4346; g) W. K. Ralph, E. LeGoff, *J. Org. Chem.* **1982**, *47*, 5243–5246; h) I. Kumalaki, A. Ando, M. Omile, *J. Fluorine Chem.* **2001**, *109*, 67–81; i) I. Kumalaki, A. Ando, *J. Fluorine Chem.* **1999**, *100*, 135–146.
[11] a) Y. Terazono, D. Dolphin, *J. Org. Chem.* **2003**, *68*, 1892–1900; b) N. Ono, H. Kawamura, K. Maruyama, *Bull. Chem. Soc. Jpn.* **1989**, *62*, 3386–3388; c) H. Tamiaki, Y. Nagata, S. Tsudzuki, *Eur. J. Org. Chem.* **1999**, 2471–2473; d) J. C. P. Grancho, M. M. Pereira, M. Da G. Miguel, A. M. Rocha Gonsalves, H. D. Burrows, *Photochem. Photobiol.* **2002**, *75*, 249–256; e) Y. Yamamoto, S. Nagao, Y. Hirai, T. Inose, N. Terui, H. Mita, A. Suzuki, *J. Biol. Inorg. Chem.* **2004**, *9*, 152–160.
[12] For reviews on trifluoromethylation see: a) J. A. Ma, D. Cahard, *Chem. Rev.* **2004**, *104*, 6119–6146; b) B. R. Langlois, T. Billard, *Synthesis* **2003**, *2*, 185–194; c) G. K. S. Prakash, M. Mandal, *J. Fluorine Chem.* **2001**, *112*, 123–131; d) R. P. Singh, J. M. Shreeve, *Tetrahedron* **2000**, *56*, 7613–7632; e) Q. Y. Chen, *J. Fluorine Chem.* **1995**, *72*, 241–246; f) M. A. McClinton, D. A. McClinton, *Tetrahedron* **1992**, *48*, 6555–6666.
[13] a) Q. Y. Chen, S. W. Wu, *J. Chem. Soc., Chem. Commun.* **1989**, 705–706; b) J. X. Duan, D. B. Su, J. P. Wu, Q. Y. Chen, *J. Fluorine Chem.* **1994**, *66*, 167–169; c) J. X. Duan, W. D. Dolbier Jr., Q. Y. Chen, *J. Org. Chem.* **1998**, *63*, 9486–9489; d) X. S. Fei, W. S. Tian, Q. Y. Chen, *Bioorg. Med. Chem. Lett.* **1997**, *7*, 3113–3118; e) X. S. Fei, W. S. Tian, Q. Y. Chen, *J. Chem. Soc., Perkin Trans. 1* **1998**, *1*, 1139–1142; f) W. Xu, Q. Y. Chen, *J. Org. Chem.* **2002**, *67*, 9421–9427.
[14] D. C. England, M. A. Dietrich, R. V. Lindsey Jr., *J. Am. Chem. Soc.* **1960**, *82*, 6181–6188.
[15] M. A. Dimitriev, G. A. Sokol'skii, I. L. Knunyants, *Izvest. Akad. Nauk SSSR, Otdel. Khim. Nauk* **1960**, 1227–1230; *Chem. Abstr.* **1961**, *55*, 2544a.
[16] G. A. Olah, P. S. Tyer, P. Surya, *Synthesis* **1986**, 513–531.
[17] H. J. Callot, *Bull. Soc. Chim. Fr.* **1974**, 1492–1496.
[18] D. K. Kumar, P. Bhyrappa, B. Varghese, *Tetrahedron Lett.* **2003**, *44*, 4849–4851.
[19] P. Bhyrappa, V. Krishnan, *Inorg. Chem.* **1991**, *30*, 239–245.
[20] D. P. Arnold, R. C. Bott, H. Eldridge, F. M. Elms, G. Smith, M. Zojaji, *Aust. J. Chem.* **1997**, *50*, 495–503.
[21] S. G. DiMagno, V. S. Y. Lin, M. J. Therien, *J. Org. Chem.* **1993**, *58*, 5983–5993.
[22] A. J. Roche, Jr., W. R. Dolbier, *J. Org. Chem.* **2000**, *65*, 5282–5290.

[23] J. L. Sessler, M. R. Johnson, T. Y. Lin, *Tetrahedron* **1989**, *45*, 4767–4784.
[24] J. L. Sessler, V. L. Capuano, *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 1134–1137.
[25] J. Rodriguez, D. Kirmaier, M. R. Johnson, R. A. Friesner, D. Holten, J. L. Sessler, *J. Am. Chem. Soc.* **1991**, *113*, 1652–1659.
[26] D. Milstein, J. K. Stille, *J. Am. Chem. Soc.* **1979**, *101*, 4992–4998.
[27] T. Hayashi, M. Konishi, Y. Kobori, M. Kumada, T. Higuchi, K. Hirotsu, *J. Am. Chem. Soc.* **1984**, *106*, 158–163.
[28] L. R. Nudy, H. G. Hutchinson, C. Schieber, F. R. Longo, *Tetrahedron* **1984**, *40*, 2359–2363 and references cited therein.
[29] M. Gourerman, *The Porphyrins* (Ed.: D. Dolphin), Academic Press, London, **1978**, vol. III, p. 1–165.

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