New Enzyme Models of Chloroperoxidase: Improved Stability and Catalytic Efficiency of Iron Porphyrinates Containing a Thiolato Ligand

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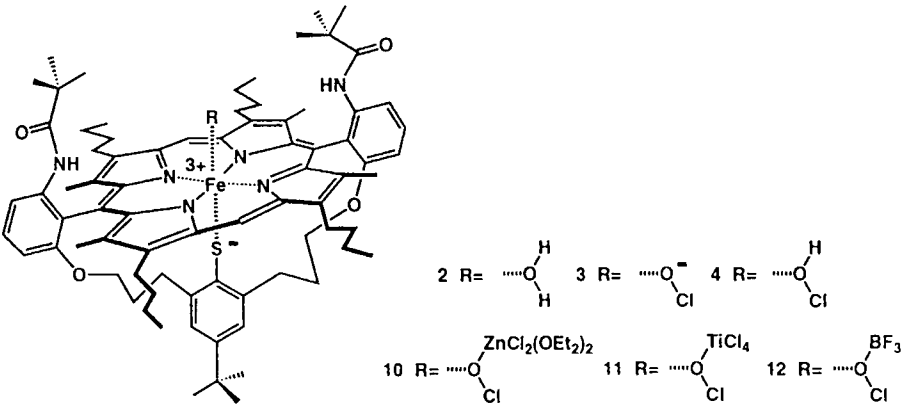
The heme-thiolate protein chloroperoxidase (CPO) catalyzes the chlorination of activated C–H bonds. A reaction mechanism is proposed for this enzymatic transformation (*Scheme 1*), and a new iron(III) porphyrinate complex **13** is synthesized containing pentafluorophenyl groups at two *meso*-positions and a thiophenolato ligand coordinating to the Fe-atom (*Schemes 2* and *3*). Due to the presence of the electron-withdrawing substituents, the catalyst **13** is appreciably resistant to oxidants (HOCl) and chlorinates, *e.g.*, monochlorodimedone (**5**), with turnover numbers up to 1530. The redox potential of **13**, $E_0 = -134$ mV, and the *Soret* band (λ_{max} 448 nm) of the CO adduct of the reduced state of **13** are close to the corresponding values of the enzyme CPO.

Introduction. – The heme-thiolate proteins comprise a large number of different enzymes, such as chloroperoxidase (CPO) [1], cytochrome P450 [2], and nitric-oxide synthase [3]. The inherent reactivity of these enzymes is attributed to an (protoporphyrinato IX) iron(III) complex located in the active site, which is bound to the protein by H-bridges of the two propanoato side chains of the heme, and, most significantly, by a thiolato ligand coordinated to the Fe-center. This ligand is delivered by a cysteine residue in a highly conserved area of all heme-thiolate proteins and is located at the face of the porphyrin opposite to the substrate and O-binding site. Due to its electron-donating character, the thiolato ligand plays an important role in the reactivity of the prosthetic heme group [4], and triggers the redox potential of these enzymes [5].

CPO, first isolated from the mold *Caldariomyces fumago* [6], is the most versatile of the heme-thiolate enzymes catalyzing the chlorination of activated C–H bonds employing H_2O_2 and Cl^- at pH 2.7, and reactions reminiscent of peroxidases, catalase, and cytochrome P450 [1]. Except for the participation of 'compound I' (**1**) [7], the high-valent oxoiron intermediate of the catalytic cycle of cytochrome P450 [8], the reaction mechanism of chlorinations catalyzed by CPO was not elucidated. It was suggested that 'compound I' (**1**) oxidizes Cl^- and releases HOCl into solution which, in turn, reacts with activated substrates RH in a nonenzymatic way [9]. A lack of stereospecificity in the halogenation reactions catalyzed by CPO [10] was seemingly in agreement with the participation of an 'enzyme-free' halogenating species. In contrast, however, the CPO-catalyzed addition of HOBr (KBr, H_2O_2, pH 2.7) to steroid derivatives [11] or a highly substituted glycal [12] occured stereospecifically. Despite numerous investigations of the enzyme [13], the identification of significant reactive intermediates remained elusive.

Recently, we reported the synthesis of **2**, a new enzyme model of CPO. It was shown that this thiolato-coordinating iron(III) porphyrinate forms stable $^-$OCl and HOCl adducts, **3** and **4**, respectively, under strictly defined conditions [14], and it was further demonstrated that only **4** is catalytically active to chlorinate monochlorodimedone (**5**), the substrate of the standard assay of CPO [15], yielding dichlorodimedone (**6**).



It is important to note that **3**, and subsequently **4**, was produced from **2** by two independent reaction pathways, namely using (benzyl)(triethyl)ammonium hypochlorite [14], or H_2O_2 together with (benzyl)(triethyl)ammonium chloride. In particular, the latter, enzyme-like conditions suggested that **3** and **4** are kinetically competent analogues of intermediates of the catalytic cycle of the enzyme CPO. Consequently, the spectroscopic parameters of the active-site analogues **3** and **4** were employed to search for these until then elusive intermediates of CPO's reaction sequence.

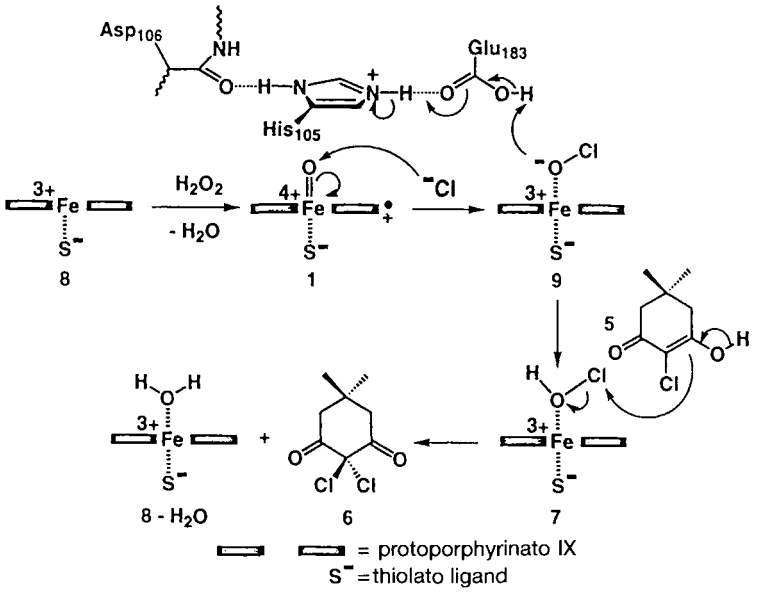
UV/VIS Spectroscopy of CPO from *Caldariomyces fumago* in the presence of NaOCl in a pH range of 3–9 revealed that, only at pH 4.4, a new compound was detected [16]. This complex was identified as the HOCl adduct **7** of the active-site's iron(III) porphyrinate due to its split *Soret* band (λ_{max} 376 and 434 nm) corresponding to the model complex **4** (λ_{max} 390 and 412 nm) (see *Scheme 1*).

The recently published X-ray crystal-structure analysis of CPO's resting state **8** from *Caldariomyces fumago* led to the identification of three amino-acid residues Glu^{183}, His^{105}, and Asp^{106} above the porphyrin face opposite to the thiolato coordination site [17]. It seems very plausible that these amino acids participate in catalysis as a proton-delivery system *i*) by assisting the H_2O_2 cleavage, leading to 'compound I' (**1**) and *ii*) by protonation of the adduct **9** (see *Scheme 1*). Thus, we assumed that the ^-OCl adduct **9** would be observable only if the proton supply is inactivated. This was accomplished by covalent modification of His^{105} using diethyl pyrocarbonate [18], which blocks the catalytic activity of CPO completely [19].

In fact, using the 'CPO derivative', the ^-OCl adduct **9** of the heme thiolate cofactor was detected exhibiting a single *Soret* band (λ_{max} 406 nm) [16] close to the absorption of the corresponding complex **3** derived from the enzyme model **2**.

Iron(III) porphyrinates **2**–**3** served as a decisive guide to trace intermediates of the catalytic cycle of CPO. These complexes have, however, a certain limitation concerning stability and turnover when used in catalytic chlorinations, in particular when the proton in **4** was replaced by *Lewis* acids (see **10**–**12**). We wish to report here on the synthesis, stability, and catalytic reactivity of a new tetraarylporphyrinate **13** as an improved active-site analogue of CPO.

Scheme 1. *Mechanism of the Chlorination of Monochlorodimedone* (**5**) *Catalyzed by Chloroperoxidase*. The essential proton for the chlorination is provided by a proton-supply system containing Glu^{183} and His^{105}



Results and Discussion. – X-Ray crystal-structure determinations of chloroperoxidase [17] and of different forms of cytochrome P450 [20] revealed that the thiolato ligand is H-bonded to two peptide amide groups shifting the redox potential of the heme group of, *e.g.*, CPO to $E_0 = -140$ mV at pH 6.9 [21]. New porphyrinate models prepared by *Nakamura* and co-workers aimed to mimic this situation using noncovalently attached thiophenolato ligands, which provide amide protons as H-bond donors to the S-atom [22]. It was shown that the redox potential changes from $E_0 = -680$ mV of the corresponding porphyrinate without NH–S^- H-bonding to $E_0 = -350$ mV for the iron porphyrinate that has two NH–S^- bonds. This anodic shift is a consequence of the reduced charge density at the thiolato ligand and is in agreement with our results using 4-nitrobenzenethiolato ligands [23].

In principle, however, a positive change of the redox potential of iron (metal) porphyrinates, concomitant stabilization of the iron(II) oxidation state and increased electrophilicity of the corresponding oxoiron(IV) state ('compound I'), can be achieved attaching electron-withdrawing substituents in the periphery of the porphyrinato ligand in the so-called β-pyrrole positions or at the Ph groups of tetraphenylporphyrinato ligands. There is ample precedence for the latter approach in drug-metabolism studies [24] and, more general, in oxidation of alkenes [25]. Concerning a CPO model, a less basic porphyrinato ligand is expected to be more reactive with respect to the Cl^+ release from the HOCl bound to the Fe-center.

The design of iron(III) porphyrinate **13** takes into account structural increments important to the heme-thiolate proteins such as the thiolato ligand tightly coordinating to the Fe-center. Regarding the synthesis and stability of the complex, the porphyrinate **13** is *face-protected* against μ-oxo-dimer formations by both the bridge carrying the

proximal thiophenolato ligand, and two pivalamido (= (2,2-dimethyl-1-oxopropyl)-amino) residues [26] on the distal site. All four *meso*-positions are aryl-substituted to prevent oxidative degradation at these most vulnerable C-atoms of the porphyrinates. Last but not least, two opposite phenyl groups are F-substituted to lower the electron-donating character of the porphyrin macrocycle.

The synthesis of the porphyrinate **13** started with the condensation of the *N*-(2-formylphenyl)pivalamide **14** [27] with 2 equiv. of 1*H*-pyrrole (**15**) under acid catalysis (*Scheme 2*) [28]. The resulting dihydrodipyrrin derivative **16** was condensed with 2,3,4,5,6-pentafluorobenzaldehyde (**17**) in the presence of CF_3COOH [28]. The mixture of porphyrins and chlorins was oxidized with DDQ (4,5-dichloro-3,6-dioxocyclohexa-1,4-diene-1,2-dicarbonitrile) [29], and subsequently Zn^{II} was inserted to facilitate the chromatographic purification of the desired porphyrin in the form of its Zn^{II} complex [4][29]. Thus, **18** was obtained as separable mixture of α,α- (shown in *Scheme 2*) and α,β-atropisomers in 9% overall yield from **16** (α,α: both pivalamido moieties on the same side of the macrocycle reference plane). An alternative route using **17** led, *via* **19**, also to **18**, however, with less satisfactory yields.

Removal of the zinc ion from porphyrinate **18** with conc. HCl solution [30] yielded **20**, and cleavage of the methyl aryl ether with $AlCl_3$ in ethanethiol [31] furnished the porphyrin **21**.

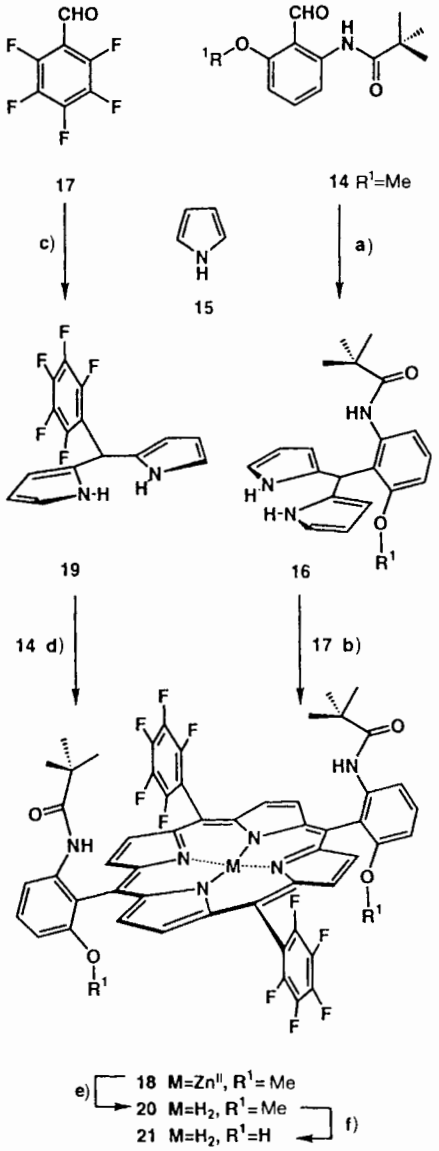
The mixture of α,α- and α,β-porphyrin **21** was condensed [4] with the dimesylate **22** [32] under isomerizing conditions at 65° to yield the bridged, but still *S*-protected porphyrin **23** (see *Scheme 3*). Subsequent removal of the protecting group at the thiophenol moiety [4][32] gave the porphyrin **24**, and Fe insertion [33] completed the preparation of **13**.

The complex **13** is a high-spin (g = 6.318, g = 2.019) iron(III) porphyrinate displaying a *Soret* band in UV/VIS spectrum at λ_{max} 420 nm. In comparison to the porphyrinate **2** [14], the *Soret* band of **13** is red-shifted by 12 nm due to the presence of the electron-withdrawing pentafluorophenyl residues. The ^{1}H-NMR spectrum of **13** showed one broad characteristic downfield-shifted signal of the β-pyrrole protons (82 ppm). On treatment with 30% HBr in CH_2Cl_2 [4], the thiolato ligand of **13** could be protonated yielding **13** · HBr with a *Soret* band at λ_{max} 452 nm. Reduction of **13** with $NaBH_4$ in THF quantitatively provided the corresponding Fe^{II} complex **25** with λ_{max} 426 nm, which, on addition of CO, furnished **26** displaying the expected bathochromic shift to λ_{max} 448 nm, characteristic of a heme-thiolate system.

Cyclic voltammetry of the active-site analog **2** revealed a redox potential $E_0 = -630$ mV (*vs.* SCE); this value is well within the range determined for other iron porphyrinates carrying a thiolate ligand [4][23][32]. The electron-withdrawing effect of the two pentafluorophenyl groups in porphyrinate **13** shifts the potential anodically to $E_0 = -134$ mV (*Fig. 1*). CPO itself displays a redox potential of −140 mV at pH 6.9 and +150 mV at pH 2.7 [21], the pH optimum of CPO for chlorination reactions.

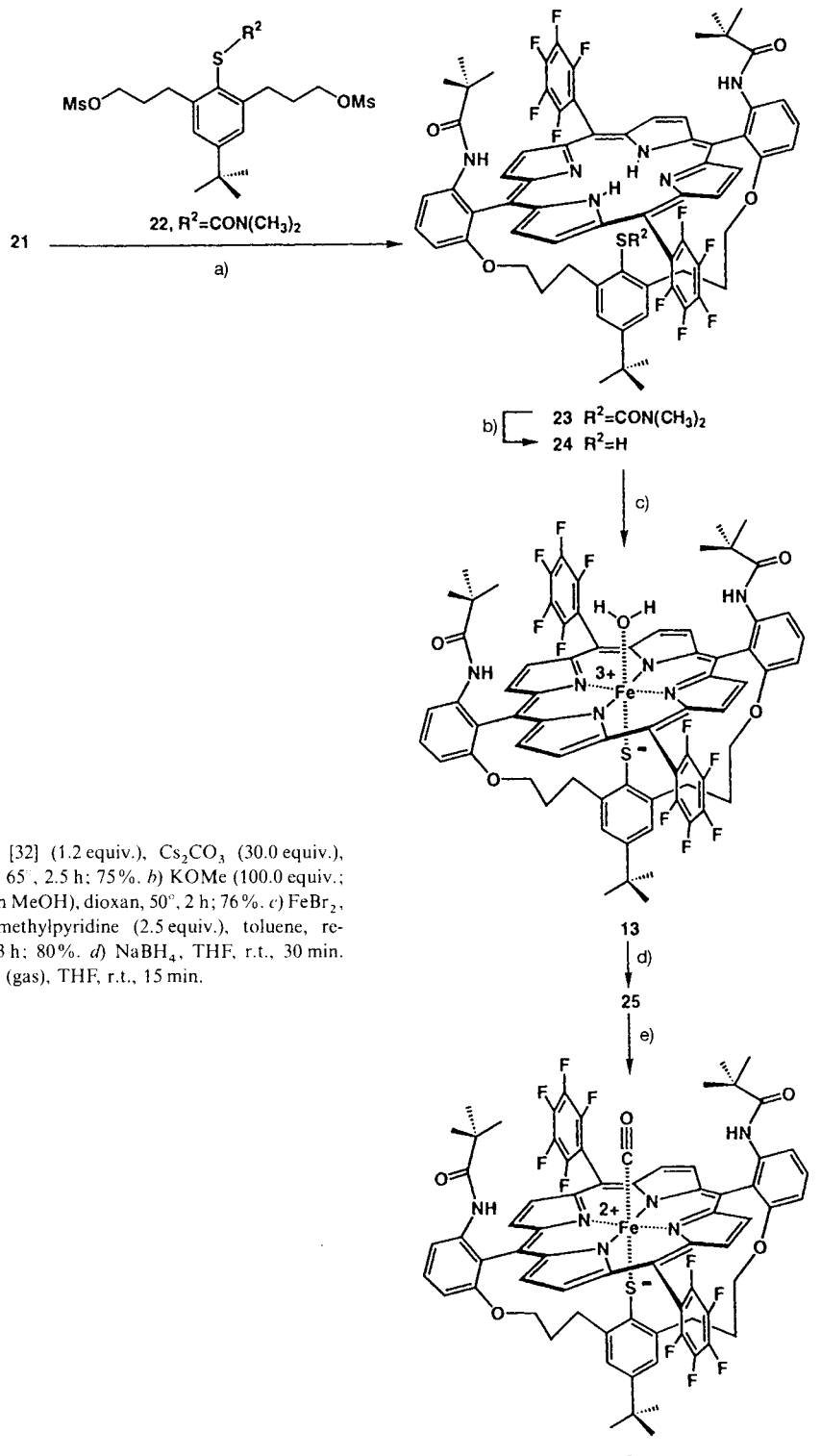
Thus, regarding spectroscopy and electrochemistry, the complex **13** is a suitable model to mimic different features of heme-thiolate proteins. Concerning chemical reactivity and stability, it was important to investigate whether **13** is resistant to degradation in the presence of strong oxidants. Thus, **13** was treated with (benzyl)(triethyl)ammonium hypochlorite [14] or H_2O_2, and the change of absorbance of its *Soret* band at 420 nm was

Scheme 2. *Synthesis of* **21**



a) CF_3COOH (0.1 equiv.), CH_2Cl_2, r.t., 3 h; 75%. *b*) 1) **17** (1.0 equiv.), CF_3COOH (1.0 equiv.), CH_2Cl_2, r.t., 20 min; 2) DDQ (2.0 equiv.), CH_2Cl_2/THF 10:1, reflux, 2 h; 3) $Zn(OAc)_2$ (5.0 equiv.), CH_2Cl_2/MeOH 5:1, reflux, 2 h; 9%. *c*) CF_3COOH (0.1 equiv.), CH_2Cl_2, r.t., 3 h; 91%. *d*) 1) **14** [27] (1.0 equiv.), CF_3COOH (1.0 equiv.), CH_2Cl_2, r.t., 15 min; 2) DDQ (2.0 equiv.), CH_2Cl_2/THF 10:1, reflux, 2 h; 3) $Zn(OAc)_2$ (5 equiv.), CH_2Cl_2/MeOH 5:1, reflux, 2 h; 6%. *e*) Conc. HCl soln., CH_2Cl_2, r.t., 15 min; 95%. *f*) $AlCl_3$ (78.0 equiv.), CH_2Cl_2/EtSH 3:2, r.t., 15 h; 98%.

Scheme 3. *Synthesis of* **13**



a) **22** [32] (1.2 equiv.), Cs_2CO_3 (30.0 equiv.), DMF, 65°, 2.5 h; 75%. *b*) KOMe (100.0 equiv.; 3.5M in MeOH), dioxan, 50°, 2 h; 76%. *c*) $FeBr_2$, 2,6-dimethylpyridine (2.5 equiv.), toluene, reflux, 3 h; 80%. *d*) $NaBH_4$, THF, r.t., 30 min. *e*) CO (gas), THF, r.t., 15 min.

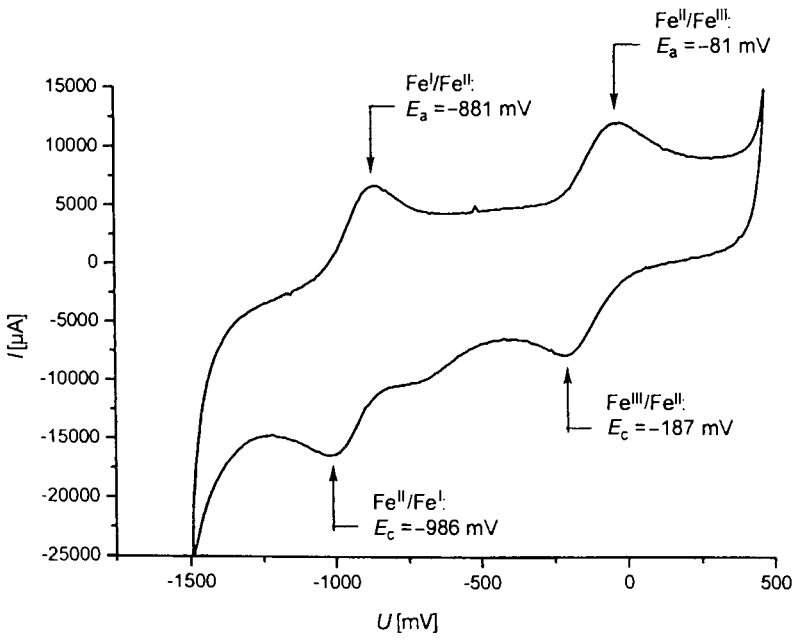


Fig. 1. *Cyclic voltammetry of the iron porphyrinate* **13** (3.0 mM in 0.1M $LiClO_4$ in DMF (saturated with LiBr); 400 mV/s; E_a: anodic potential; E_c: cathodic potential; potentials are given *vs.* SCE)

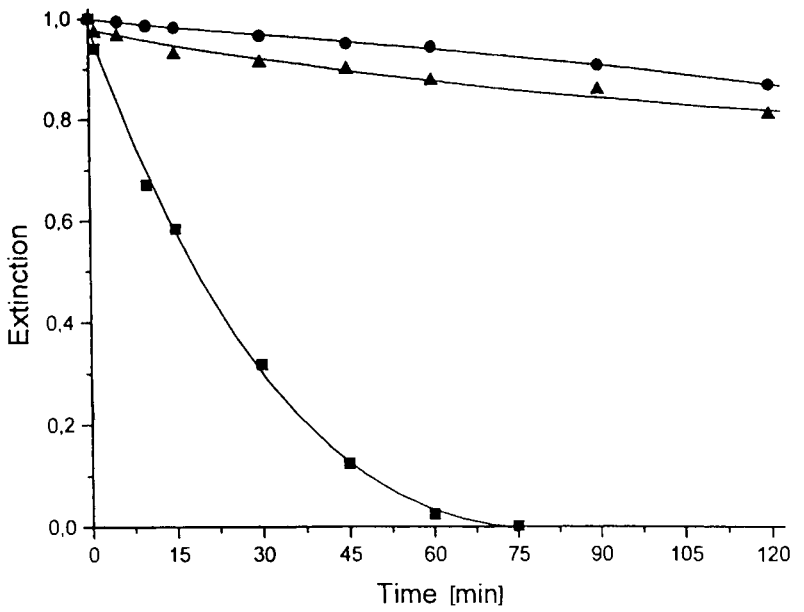


Fig. 2. *Change of absorbance of the iron(III) porhyrinates* **2** *and* **13** *in the presence of (benzyl)(triethyl)ammonium hypochlorite* (BTAH) [14]. ■: **4** (λ_{max} 390 nm) + 80 equiv. of BTAH and AcOH; ●: **13** (λ_{max} 420 nm) + 80 equiv. of BTAH and AcOH; ▲: **13** (λ_{max} 420 nm) + 1500 equiv. of BTAH and AcOH.

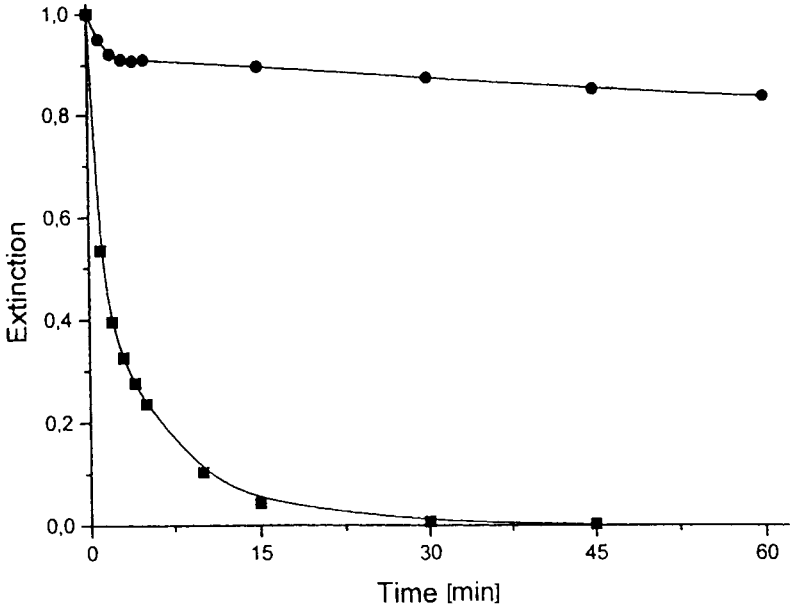


Fig. 3. *Change of absorbance of the iron(III) porhyrinates* **2** *and* **13** *in the presence of* H_2O_2. ■: **2** (λ_{max} 398 nm) + 230 equiv. of H_2O_2; ●: **13** (λ_{max} 420 nm) + 230 equiv. of H_2O_2.

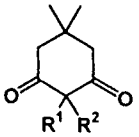
used as a measure of degradation and compared with the corresponding absorbance behavior of complex **4** (*Soret* band at 390 nm). As shown in *Figs. 2* and *3*, the catalyst **13** retained *ca.* 85% of its activity, whereas the iron porphyrinates **2** and **4**, respectively, are completely oxidized within 1 h.

Brominations and chlorinations of activated C–H bonds of the substrates **5**, **27**–**30**, and **32** using various catalysts derived from **13** are reported in *Tables 1–3*. One can see that only very low concentrations of the catalyst, such as 0.05–0.09 mol-%, are required to approach a turnover number of 1030 (bromination of **5**; see *Table 1*, *Entry 4*), 1530 (chlorination of **5**; see *Table 2*, *Entry 4*), and 970 (chlorination of anisole (**27**); *Table 3*, *Entry 4*).

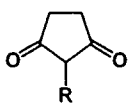
These experiments reveal that employing *Lewis* acids as co-catalysts is advantageous, because Cl^+ donation to the substrate is facilitated, and turnovers become significantly higher. Even substrates like cyclohexanone (**28**) and toluene (**29**), which are not highly activated, are chlorinated using **13** and $BF_3 \cdot OEt_2$ with turnover numbers of 50 (*Table 2*,

Table 1. *Catalytic Halogenation of Monochlorodimedone* (**5**) *Using* H_2O_2/Cl^- *or* H_2O_2/Br^- *to Yield Dichlorodimedone* (**6**) *or Bromochlorodimedone* (**31**), *Respectively*

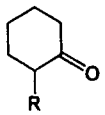
Entry	Catalyst	[mol-%]	Reagents	Turnover number	Product	Yield [%]
1 [14]	**2**	0.7	H_2O_2, $(BnEt_3N)Cl$, AcOH	20	**6**	81
2	**2**	0.7	H_2O_2, $(Bu_4N)Br$, AcOH	100	**31**	73
3	**13**	0.09	H_2O_2, $(BnEt_3N)Cl$, AcOH	270	**6**	68
4	**13**	0.09	H_2O_2, $(Bu_4N)Br$, AcOH	1030	**31**	86



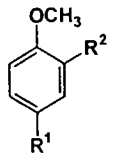
30 R^1 = H, R^2 = H
5 R^1 = Cl, R^2 = H
31 R^1 = Br, R^2 = H
6 R^1 = Cl, R^2 = Cl



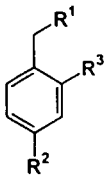
32 R = H
33 R = Cl



28 R = H
34 R = Cl



27 R^1 = H, R^2 = H
35 R^1 = Cl, R^2 = H
36 R^1 = H, R^2 = Cl



29 R^1 = H, R^2 = H, R^3 = H
37 R^1 = Cl, R^2 = H, R^3 = H
38 R^1 = H, R^2 = Cl, R^3 = H
39 R^1 = H, R^2 = H, R^3 = Cl

Table 2. *Catalytic Chlorination of the Ketones* **5**, **28**, **30**, *and* **32** *with Various Iron(III) Porphyrinate Adducts*

Entry	Substrate	Catalyst	[mol-%]	Reagents[a])	Turnover number	Product	Yield [%]
1 [14]	**5**	**2**	1.3	BTAH, AcOH	37	**6**	52
2	**5**	**13**	0.07	BTAH, AcOH	420	**6**	71
3 [14]	**5**	**2**	0.7	BTAH, $ZnCl_2 \cdot (OEt_2)_x$	97	**6**	83
4	**5**	**13**	0.05	BTAH, $ZnCl_2 \cdot (OEt_2)_x$	1530	**6**	55
5 [14]	**5**	**2**	0.7	BTAH, $BF_3 \cdot OEt_2$	87	**6**	87
6	**5**	**13**	0.05	BTAH, $BF_3 \cdot OEt_2$	1260	**6**	73
7	**30**	**2**	1.0	BTAH, AcOH	[b])		
8	**30**	**13**	0.38	BTAH, AcOH	30	**5**	53
						6	–
9	**30**	**2**	1.0	BTAH, $ZnCl_2 \cdot (OEt_2)_x$	37	**5**	74
						6	20
10	**30**	**13**	0.43	BTAH, $ZnCl_2 \cdot (OEt_2)_x$	130	**5**	40
						6	14
11	**30**	**2**	1.0	BTAH, $BF_3 \cdot OEt_2$	10	**5**	95
						6	[c])
12	**30**	**13**	0.22	BTAH, $BF_3 \cdot OEt_2$	250	**5**	150
						6	50
13	**32**	**2**	0.7	BTAH, $BF_3 \cdot OEt_2$	[b])		
14	**32**	**13**	0.60	BTAH, $BF_3 \cdot OEt_2$	50	**33**	74
15	**28**	**2**	0.7	BTAH, $BF_3 \cdot OEt_2$	[b])		
16	**28**	**13**	0.44	BTAH, $BF_3 \cdot OEt_2$	50	**34**	51

[a]) BTAH: (benzyl)(triethyl)ammonium hypochlorite [14]. [b]) No reaction. [c]) Not detectable.

Table 3. *Catalytic Chlorination of Anisole* (**27**) *and Toluene* (**29**) *Using Various Iron(III) Porphyrin Adducts*

Entry	Substrate	Catalyst	[mol-%]	Reagents[a])	Turnover number	Product	Yield [%]
1 [14]	**27**	**2**	10.4	BTAH, $TiCl_4$	103	**35**	50
						36	38
2	**27**	**13**	0.08	BTAH, $TiCl_4$	930	**35**	35
						36	29
3 [14]	**27**	**2**	0.4	BTAH, $BF_3 \cdot OEt_2$	134	**35**	57
						36	9
4	**27**	**13**	0.05	BTAH, $BF_3 \cdot OEt_2$	970	**35**	52
5	**29**	**2**	0.5	BTAH, $BF_3 \cdot OEt_2$	[b])		
6	**29**	**13**	0.29	BTAH, $BF_3 \cdot OEt_2$	50	**37**	38
						38	14
						39	11

[a]) BTAH = (Benzyl)(triethyl)ammonium hypochlorite. [b]) No reaction.

Entry 16, and *Table 3, Entry 6*). With porphyrinate **2** as catalyst, no conversion of **28** and **29** was detectable (*Table 2, Entry 15*, and *Table 3, Entry 5*).

The synthetic *face-protected* tetraarylporphyrinate **13** is a new active-site analogue of chloroperoxidase which perfectly mimics the electron-deficient character of the heme-thiolate cofactor of CPO. Clearly, **13** is more stable than **2** in the presence of strong oxidants, *e.g.*, H_2O_2 or ^-OCl, and shows an appreciable reactivity towards monochlorodimedone (**5**) and anisole (**27**), substrates commonly used for the enzyme CPO. Finally, turnover numbers accomplished with derivatives of **13** surpass those achieved with corresponding adducts of **2** by a factor of 10.

Experimental Part

General. All reactions were performed in freshly distilled solvents under Ar. The insertion of the iron(III) into the porphyrin ligand was carried out in a 'glove box' with distilled solvents which had been degassed prior to use. M.p.: *Mettler FP52* apparatus; uncorrected. TLC: 0.2-mm *Merck* silica gel *60* F_{254} plates. Flash chromatography (FC): *Merck 60* silica gel (40–63 μm). UV/VIS Spectra: *Hewlett-Packard 8452A* diode-array spectrophotometer. IR Spectra: *Perkin-Elmer FTIR* 1600; $\tilde{\nu}$ in cm^{-1}. NMR Spectra: *Varian Gemini* (300 MHz) or *Bruker AC-250* (250 MHz) spectrometer; at r.t.; δ in ppm downfield rel. to Me_4Si as internal standard (^1H) or (trifluoromethyl)benzene as external standard (^{19}F); C-atom numbering according to [4]; because of high coupling constants, the δ values of C-atoms connected to F-atoms are not reported in ^{13}C-NMR spectra. EPR Spectra: *Bruker-ESP-300* spectrometer with a TE_{102} cavity. Cyclic voltammetry: *Amel-443* polarograph; 3 mM porphyrinate in 0.1M $LiClO_4$ in dry and degassed DMF; to prevent ligand exchange, the soln. was saturated with LiBr. EI-MS: *Varian-MAT-112S* spectrometer; ionization potential of 70 eV; *m/z* (rel. %). LDI-TOF- or MALDI-TOF-MS (α-cyano-4-hydroxycinnamic acid as matrix): *Voyager-Vestec-Biospectrometry* workstation. Elemental analysis: *Perkin-Elmer-240* analyzer.

N-*{3-Methoxy-2-[di(1H-pyrrol-2-yl)methyl]phenyl}-2,2-dimethylpropanamide* (**16**). To a soln. of the N-*(3-methoxy-2-formylphenyl)propanamide* (**14**) [27] (2.00 g, 8.50 mmol) in 1*H*-pyrrole (**15**; 47.2 ml, 45.62 g, 0.68 mol), CF_3COOH (65.0 μl, 97.0 mg, 0.85 mmol) was added. The mixture was stirred under Ar at r.t. for 3 h in the dark, neutralized with sat. aq. $NaHCO_3$ soln. (100 ml), and extracted with CH_2Cl_2 (3 × 30 ml). The combined org. extracts were dried (Na_2SO_4) and evaporated. Purification by FC (CH_2Cl_2 + 1% Et_3N) gave 2.25 g (75%) of **16**. Yellow solid. M.p. 52–58°. TLC (CH_2Cl_2 + 1% Et_3N): R_f 0.32. UV/VIS (CH_2Cl_2): 286 (100). IR (KBr): 3360*s*, 3100*m*, 2960*s*, 2870*m*, 2840*m*, 1670*s*, 1590*s*, 1560*m*, 1510*s*, 1470*s*, 1430*s*, 1370*m*, 1330*m*, 1280*s*, 1250*s*, 1170*s*, 1120*s*, 1080*s*, 1030*s*, 970*m*, 950*m*, 890*m*, 850*m*, 810*m*, 770*s*, 720*s*, 560*m*, 500*m*, 460*w*. ^1H-NMR (300 MHz, $CDCl_3$): 8.32 (br., 2 NH (pyr)); 7.37 (*d*, *J* = 8.0, H–C(6′)); 7.28 (*t*, *J* = 8.0, H–C(5′)); 6.81 (*d*, H–C(4′)); 6.65 (*d*, *J* = 3.0, 2 H–C(3) (pyr)); 6.24 (br., 1 CONH); 6.16 (*t*, *J* = 3.0, 2 H–C(4) (pyr)); 6.06 (*t*, *J* = 2.7, 2 H–C(5) (pyr)); 3.77

(*s*, MeO–C(3')); 1.58 (*s*, CH–C(2')); 0.97 (*s*, $Me_3C(2)$). ^{13}C-NMR (75 MHz, $CDCl_3$): 178.0 (NHCO); 157.7; 130.2; 128.5; 119.4; 117.1; 117.0; 109.0; 108.9; 108.7; 106.1; 56.4 (MeO); 39.3 (Me_3C); 33.1 (CH–C(2')); 27.0 (Me_3C). EI-MS: 353 (5), 352 (23), 351 (62, M^+), 350 (8), 294 (5), 280 (5), 268 (5), 267 (30), 266 (100), 251 (7), 250 (10), 249 (7), 235 (9), 227 (7), 223 (5), 222 (6), 211 (5), 199 (8), 185 (5), 184 (7), 145 (9), 144 (8), 91 (5), 80 (9), 57 (20), 41 (11). Anal. calc. for $C_{21}H_{25}N_3O_2$ (351.48): C 71.77, H 7.17, N 11.96, O 9.11; found: C 71.60, H 7.38, N 11.78, O 8.92.

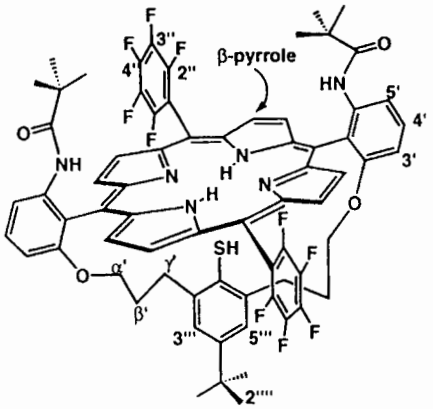
{N,N'-{[10,20-Bis(2,3,4,5,6-pentafluorophenyl)-21H,23H-porphyrin-5,15-diyl-κN^{21},κN^{22},κN^{23},κN^{24}]bis-(6-methoxy-2,1-phenylene)}bis[2,2-dimethylpropanamidato](2–)}zinc(II) (**18**). To a soln. of **16** (2.25 g, 6.41 mmol) and **17** (1.28 g, 6.41 mmol) in dry CH_2Cl_2 (180 ml), CF_3COOH (0.49 ml, 0.73 g, 6.41 mmol) was added. The mixture was stirred for 20 min at r.t. and quenched with sat. aq. $NaHCO_3$ soln. (150 ml). The aq. phase was extracted with CH_2Cl_2 (2 × 50 ml), and the combined org. phase dried (Na_2SO_4) and evaporated. To a soln. of the residue in CH_2Cl_2 (100 ml), a soln. of DDQ (2.91 g, 12.83 mmol) in THF (50 ml) was added. The mixture was stirred for 2 h under reflux and then evaporated. The residue in CH_2Cl_2 was filtered through silica gel and the filtrate evaporated. To a soln. of the residue in CH_2Cl_2 (200 ml), a soln. of $Zn(OAc)_2$ (5.88 g, 32.1 mmol) in MeOH (40 ml) was added. The mixture was stirred for 2 h under reflux and quenched with sat. aq. $NaHCO_3$ soln. The org. layer was filtered through *Celite* and evaporated. FC of the residue (hexane/AcOEt 4:1) yielded 288 mg (9%) of **18** as an atropisomer mixture which was separated by FC.

The same procedure was used for the synthesis of **18** starting with **19** (100 mg, 0.32 mmol) and **14** [27] (75 mg, 0.32 mmol), using the same dilutions and same mol-equiv. as described above: 103 mg (6%) of **18** as an atropisomer mixture. The two isolated compounds were assigned to the atropisomers according to *Stäubli et al.* [4].

Data of α,β-**18**: Red-pink solid. M.p. > 250°. TLC (hexane/AcOEt 1:1 + 1% Et_3N): R_f 0.65. UV/VIS (CH_2Cl_2): 418 (100), 546 (6). IR (KBr): 3430*s*, 2930*m*, 1690*m*, 1650*m*, 1590*s*, 1520*s*, 1500*s*, 1470*s*, 1430*s*, 1390*s*, 1260*s*, 1180*s*, 1080*m*, 1040*m*, 990*s*, 940*m*, 840*w*, 800*m*, 760*m*, 650*m*, 580*w*, 520*w*, 420*w*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 8.98 (*d*, *J* = 4.7, 4 H–C(β) (pyr)); 8.86 (*d*, 4 H–C(β) (pyr)); 8.40 (*d*, *J* = 8.4, 2 H–C(5')); 7.83 (*t*, *J* = 8.4, 2 H–C(4')); 7.18 (*d*, 2 H–C(3')); 6.89 (*s*, 2 CONH); 3.60 (*s*, 2 MeO–C(2')); 0.00 (*s*, 2 *t*-Bu). ^{13}C-NMR (75 MHz, $CDCl_3$)[1]): 176.3 (CONH); 159.3; 151.1; 149.9; 140.1; 132.8 (C(β) (pyr)); 131.5 (C(β) (pyr)); 130.8 (C(4')); 128.8; 120.3; 114.1 (C(5')); 112.3; 106.8 (C(3')); 56.1 (MeO); 26.3 (Me_3C); 1.1 (Me_3C). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): –4.1 (*dd*, *J* = 23.9, 7.9, F–C(2''), F–C(6'')); –19,1 (*t*, *J* = 20.5, F–C(4'')); –28.7 (*m*, F–C(3''), F–C(5'')). LDI-TOF-MS: 1115 ([*M* – 3]$^+$, [$C_{56}H_{42}F_{10}N_6O_4Zn$ – 3]$^+$; calc. 1115.40).

Data of α,α-**18**: Red-pink solid. M.p. > 250°. TLC (hexane/AcOEt 1:1 + 1% Et_3N): R_f 0.60. UV/VIS (CH_2Cl_2): 420 (100), 548 (6). IR (Br): 3430*s*, 2930*m*, 1650*m*, 1520*s*, 1470*s*, 1430*m*, 1400*m*, 1340*w*, 1260*s*, 1180*m*, 1080*m*, 1040*m*, 990*s*, 940*m*, 840*w*, 760*m*, 710*w*, 650*m*, 580*w*, 520*w*, 410*w*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 8.90 (*d*, *J* = 4.7, 4 H–C(β) (pyr)); 8.85 (*d*, 4 H–C(β) (pyr)); 8.37 (*d*, *J* = 8.4, 2 H–C(5')); 7.81 (*t*, *J* = 8.4, 2 H–C(4')); 7.13 (*d*, 2 H–C(3')); 7.03 (*s*, 2 CONH); 3.48 (*s*, 2 MeO–C(2')); 0.06 (*s*, 2 *t*-Bu). ^{13}C-NMR (75 MHz, $CDCl_3$)[1]): 176.3 (CONH); 159.4; 151.1; 149.9; 140.1; 132.9 (C(β) (pyr)); 131.4 (C(β) (pyr)); 130.8 (C(4')); 128.8; 120.3; 114.1

[1]) For numbering, *cf.* **24**.



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(C(5')); 112.3; 107.0 (C(3')); 56.0 (MeO); 26.3 (Me_3C); 1.1 (Me_3C). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −3.9 (*dd*, *J* = 23.8, 8.0, F−C(2''), F−C(6'')); −18.9 (*t*, *J* = 20.5, F−C(4'')); −28.5 (*m*, F−C(3''), F−C(5'')). LDI-TOF-MS: 1116 ([*M* − 2]$^+$, [$C_{56}H_{42}F_{10}N_6Zn$ − 2]$^+$; calc. 1116.40).

2,2'-[(2,3,4,5,6-Pentafluorophenyl)methylene]bis[1H-pyrrole] (**19**). To a soln. of **17** (0.50 g, 2.55 mmol) in 1*H*-pyrrole (**15**) (14.2 ml, 13.7 g, 0.204 mol), CF_3COOH (19.5 µl, 97.0 mg, 0.85 mmol) was added. The mixture was stirred for 3 h under Ar at r.t. in the dark, neutralized with sat. aq. $NaHCO_3$ soln. (20 ml), and extracted with CH_2Cl_2 (3 × 10 ml). The combined org. extract was dried (Na_2SO_4) and evaporated. Purification by FC (CH_2Cl_2 + 1% Et_3N) gave 721 mg (91%) of **19**. Grey solid. M.p. 76–79°. TLC (CH_2Cl_2 + 1% Et_3N): R_f 0.34. UV/VIS (CH_2Cl_2): 246 (100). IR (KBr): 3360*w*, 3100*w*, 2970*w*, 1660*m*, 1500*s*, 1420*m*, 1320*m*, 1260*w*, 1180*w*, 1120*s*, 1030*m*, 980*s*, 930*m*, 880*w*, 710*m*, 730*s*, 630*w*, 560*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 8.12 (br., 2 NH); 6.82 (*dd*, *J* = 4.4, 2.2, H−C(3)); 6.72 (*dd*, *J* = 6.0, 2.7, H−C(3')); 6.26 (*dd*, *J* = 2.2, H−C(4)); 6.16 (*dd*, *J* = 2.7, H−C(4')); 6.02 (br., H−C(5)); 5.89 (br., H−C(5')); 5.80 (*s*, C_6F_6CH). ^{13}C-NMR (75 MHz, $CDCl_3$): 118.1; 117.7; 108.7; 108.2 (C(1)); 107.6. ^{19}F-NMR (282 MHz, $CDCl_3$): −8.3 (*d*, *J* = 17.1, F−C(2''), F−C(6'')); −22.5 (*t*, *J* = 21.1, F−C(4'')); −28.0 (*m*, F−C(3''), F−C(5'')). EI-MS: 313 (28), 312 (100, *M*$^+$), 311 (42), 296 (8), 292 (7), 291 (18), 285 (6), 284 (16), 283 (9), 264 (6), 263 (5), 247 (12), 246 (52), 245 (18), 244 (8), 237 (6), 226 (17), 225 (6), 218 (7), 193 (6), 192 (8), 173 (7), 169 (10), 167 (5), 156 (11), 146 (17), 145 (22), 144 (7), 143 (15), 123 (7), 119 (10), 117 (14), 116 (5), 104 (5), 95 (7), 92 (86), 91 (9), 89 (5), 78 (11), 73 (79), 72 (85), 68 (5), 67 (42), 65 (6), 63 (5), 52 (86), 51 (8), 41 (10), 40 (8), 39 (18), 38 (7). Anal. calc. for $C_{15}H_9F_5N_2$ (312.25): C 57.70, H 2.91, N 8.97; found: C 57.88, H 3.04, N 9.12.

N,N'-{[10,20-Bis(2,3,4,5,6-pentafluorophenyl)-21H,23H-porphyrin-5,15-diyl]bis(6-methoxy-2,1-phenylene)}-bis[2,2-dimethylpropanamide] (**20**). To a soln. of **18** (mixture of atropisomers; 279 mg, 0.25 mmol) in CH_2Cl_2 (200 ml), conc. HCl soln. (20 ml) was added at 0°. The mixture was stirred vigorously for 15 min. After separation, the org. layer was neutralized with sat. aq. $NaHCO_3$ soln. (200 ml), dried (Na_2SO_4), and evaporated. FC (hexane/AcOEt 3:1 + 1% Et_3N) yielded 228 mg (95%) of **20** as a non-separable mixture of both atropisomers. Violet solid. M.p. > 250°. TLC (hexane/AcOEt 1:1 + 1% Et_3N): R_f 0.62. UV/VIS (CH_2Cl_2): 412 (100), 510 (14), 542 (3), 586 (5). IR (KBr): 3430*s*, 2960*m*, 2930*m*, 1690*s*, 1650*m*, 1590*s*, 1520*s*, 1500*s*, 1470*s*, 1430*s*, 1400*m*, 1340*m*, 1290*m*, 1260*s*, 1160*m*, 1080*s*, 1040*m*, 990*s*, 950*w*, 920*m*, 870*w*, 800*m*, 780*w*, 760*m*, 650*w*, 570*w*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 8.89 (*d*, *J* = 4.6, 4 H−C(β) (pyr)); 8.78 (*d*, 4 H−C(β) (pyr)); 8.39 (*d*, *J* = 8.4, H−C(5')); 8.36 (*d*, *J* = 8.4, H−C(5')); 7.85 (*t*, *J* = 8.4, H−C(4')); 7.82 (*t*, *J* = 8.4, H−C(4')); 7.18 (*d*, H−C(3')); 7.16 (*d*, H−C(3')); 6.96 (*s*, CONH); 6.85 (*s*, CONH); 3.60 (*s*, MeO−C(2')); 3.51 (*s*, MeO−C(2')); 0.08 (*s*, *t*-Bu); 0.04 (*s*, *t*-Bu); −2.67 (br., 2 NH (pyr)). ^{13}C-NMR (75 MHz, $CDCl_3$)[1]): 176.4 (CONH); 159.4; 140.0 (C(β) (pyr)); 139.7 (C(β)); 132.7; 132.2; 132.1; 132.0; 131.8; 131.3; 130.8; 130.7 (C(4')); 130.6; 130.5; 130.4; 119.9; 119.6; 116.0; 114.3; 114.2 (C(5')); 111.8; 111.7; 106.8 (C(3')); 102.4; 56.0 (MeO); 26.3 (Me_3C); 1.01 (Me_3C). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −3.9 (*dd*, *J* = 23.6, 7.8, F−C(2''), F−C(6'')); −18.7 (*t*, *J* = 21.0, F−C(4'')); −28.4 (*m*, F−C(3''), F−C(5'')). LDI-TOF-MS: 1055 (*M*$^+$, $C_{56}H_{44}F_{10}N_6O_4^+$; calc. 1055.03).

N,N'-{[10,20-Bis(2,3,4,5,6-pentafluorophenyl)-21H,23H-porphyrin-5,15-diyl](6-hydroxy-2,1-phenylene)}-bis[2,2-dimethylpropanamide] (**21**). To a soln. of **20** (mixture of atropisomers; 228 mg, 0.22 mmol) in dry CH_2Cl_2 (30 ml) and dry EtSH (20 ml), $AlCl_3$ (2.19 g, 16.4 mmol) was added. The mixture was stirred for 24 h and neutralized with sat. aq. $NaHCO_3$ soln. (100 ml). The aq. layer was extracted with CH_2Cl_2 (3 × 20 ml), and the combined org. extract dried (Na_2SO_4) and evaporated. FC (CH_2Cl_2/MeOH 96:4) yielded 220 mg (97%) of **21**. The atropisomers were separated by FC.

*Data of α,β-***21**: Violet solid. M.p. > 250°. TLC (CH_2Cl_2/MeOH 95:5 + 1% Et_3N): R_f 0.34. UV/VIS (CH_2Cl_2): 416 (100), 510 (8), 584 (5), 652 (1). IR (KBr): 3430*s*, 2960*m*, 1690*s*, 1600*m*, 1520*s*, 1500*s*, 1460*s*, 1400*m*, 1340*m*, 1260*m*, 1150*m*, 1030*m*, 990*m*, 920*m*, 800*m*, 780*m*, 760*m*, 730*m*, 570*w*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 9,00 (*d*, *J* = 4.9, 4 H−C(β) (pyr)); 8.85 (*d*, 4 H−C(β) (pyr)); 8.30 (*d*, *J* = 8.3, 2 H−C(5')); 7.75 (*t*, *J* = 8.3, 2 H−C(4')); 7.16 (*d*, 2 H−C(3')); 6.80 (*s*, 2 CONH); 5.29 (br., 2 OH−C(2')); 0.06 (*s*, 2 *t*-Bu); −2.74 (br., 2 NH (pyr)). ^{13}C-NMR (75 MHz, $CDCl_3$)[1]): 176.5 (CONH); 155.9 (C(β) (pyr)); 148.0; 144.7; 139.4; 139.2 (C(β) (pyr)); 135.8; 132.2 (C(4')); 132.0; 131.7; 131.3; 131.1; 130.7; 118.3; 115.5; 114.1; 112.1 (C(5')); 110.1 (C(3')); 102.8; 87.3; 26.2 (Me_3C); 14.2 (Me_3C). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −4.2 (*dd*, *J* = 23.4, 7.3, F−C(2''), F−C(6'')); −18.2 (*t*, *J* = 20.9, F−C(4'')); −28.2 (*m*, F−C(3''), F−C(5'')). LDI-TOF-MS: 1024 ([*M* − 3]$^+$, [$C_{54}H_{40}F_{10}N_6O_4$ − 3]$^+$; calc. 1023.97).

*Data of α,α-***21**: Violet solid. M.p. > 250°. TLC (CH_2Cl_2/MeOH 95:5 + 1% Et_3N): R_f 0.30. UV/VIS (CH_2Cl_2): 416 (100), 50 (8), 584 (4), 656 (4). IR (KBr): 3420*s*, 2960*m*, 1690*s*, 1600*m*, 1470*s*, 1390*m*, 1260*m*, 1150*m*, 1040*m*, 980*m*, 920*m*, 750*m*, 570*w*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 9.00 (*d*, *J* = 5.0, 4 H−C(β) (pyr)); 8.84 (*d*, 4 H−C(β) (pyr)); 8.27 (*d*, *J* = 8.3, 2 H−C(5')); 7.75 (*t*, *J* = 8.3, 2 H−C(4')); 7.23 (*d*, 2 H−C(3')); 6.84 (*s*, 2 CONH); 5.29 (br., 2 HO−C(2')); 0.07 (*s*, 2 *t*-Bu); −2.74 (br., 2 NH (pyr)). ^{13}C-NMR (75 MHz, $CDCl_3$)[1]):

176.5 (CONH); 155.9 (C(β) (pyr)); 148.0; 144.7; 139.4; 139.2 (C(β) (pyr)); 135.8; 132.2 (C(4')); 132.0; 131.7; 131.3; 131.1; 130.7; 118.3; 155.5; 114.1; 112.1 (C(5')); 110.1 (C(3')); 102.8; 87.3; 26.2 (Me_3C); 142 (Me_3C). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −5.0 (*dd*, *J* = 20.8, 5.8, F−C(2''), F−C(6'')); −17.8 (*t*, *J* = 23.2, F−C(4'')); −27.7 (*m*, F−C(3''), F−C(5'')). LDI-TOF-MS: 1025 ($[M-2]^+$, $[C_{54}H_{40}F_{10}N_6O_4-2]^+$; calc. 1024.97).

N,N'-{10,20-Bis(2,3,4,5,6-pentafluorophenyl)-5,15-{[1,2]benzenoxypropano{[2]{[dimethylamino)carbonyl]-thio}[5](1,1-dimethylethyl)[1,3]benzeno}propanoxy[1,2]benzeno}-21H,23H-porphyrin-30,47-diyl}bis[2,2-dimethylpropanamide] (**23**). To a soln. of **21** (mixture of atropisomers; 127 mg, 0.12 mmol) in dry DMF (50 ml), Cs_2CO_3 (1.21 g, 3.71 mmol) was added. The mixture was stirred for 30 min at 65° under Ar. A soln. of **22** [32] (76 mg, 0.15 mmol) in dry DMF (30 ml) was added during 90 min at 65° using an infusion pump. The mixture was stirred for 30 min at 65°, quenched with 10% aq. HCl soln. (50 ml), and extracted with CH_2Cl_2 (3 × 50 ml). The combined org. extracts were dried (Na_2SO_4) and evaporated. Purification by FC (CH_2Cl_2/MeOH 97:3) yielded 125 mg (75%) of **23**. Violet solid. M.p. > 250°. TLC (CH_2Cl_2/MeOH 95:5): R_f 0.23. UV/VIS (CH_2Cl_2): 420 (100), 512 (10), 588 (4), 654 (3). IR (KBr): 3430*s*, 2960*m*, 1660*s*, 1580*m*, 1490*s*, 1350*s*, 1260*m*, 1170*s*, 1100*s*, 980*s*, 920*s*, 800*m*, 760*m*, 730*m*, 530*m*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 8.91–8.86 (*m*, 8 H−C(β) (pyr), 2 H−C(5')); 7.99 (*s*, H−C(3'''), H−C(5''')); 7.71 (*t*, *J* = 9.0, 2 H−C(4')); 7.53 (*d*, 2 H−C(3')); 7.26 (*s*, 2 CONH); 3.76–3.51 (*m*, 4 H−C(α')); 2.94 (br., MeN); 2.87 (br., MeN); 2.34–2.29 (*m*, 4 H−C(β')); 2.31 (*s*, 9 H−C(2''')); 2.04–1.67 (*m*, 4 H−C(β')); 0.07 (*s*, 2 *t*-Bu); −2.68 (br., 2 NH (pyr)). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −5.9 (*m*, F−C(2''), F−C(6'')); −18.2 (*m*, F−C(4'')); −28.2 (*m*, F−C(3''), F−C(5'')). MALDI-TOF-MS: 1343 ($[M-1]^+$, $[C_{73}H_{67}F_{10}N_7O_5S-1]^+$; calc. 1343.49).

N,N'-{10,20-Bis(2,3,4,5,6-pentafluorophenyl)-5,15-{[1,2]benzenoxypropano{[5](1,1-dimethylethyl)[2]mercapto[1,3]benzeno}propanoxy[1,2]benzeno}-21H,23H-porphyrin-30,47-diyl}bis[2,2-dimethylpropanamide] (**24**). To a soln. of **23** (125 mg, 0.093 mol) in degassed dry dioxane (125 ml), 3.5M KOMe in MeOH (2.66 ml, 9.3 mmol) was added. The green soln. was stirred at 50° under Ar, quenched with sat. aq. NH_4Cl soln., and extracted with CH_2Cl_2 (3 × 50 ml). The combined org. extracts were dried (Na_2SO_4) and evaporated. FC (CH_2Cl_2/MeOH 97:3) yielded 91 mg (76%) of **24**. Violet solid. M.p. > 250°. TLC (CH_2Cl_2/MeOH 95:5): R_f 0.21. UV/VIS (CH_2Cl_2): 420 (100), 514 (8), 588 (2), 654 (3). IR (KBr): 3430*s*, 2930*s*, 2850*m*, 1670*m*, 1580*m*, 1540*w*, 1460*s*, 1400*m*, 1260*m*, 1080*m*, 990*m*, 920*m*, 800*w*, 760*w*, 570*w*, 400*m*. ^{1}H-NMR (300 MHz, $CDCl_3$)[1]): 8.96–8.88 (*m*, 8 H−C(β) (pyr)); 8.33–8.30 (*m*, 2 H−C(5')); 7.78–7.75 (*m*, 2 H−C(4')); 7.24–7.22 (*m*, 2 H−C(3')); 7.01–6.81 (*m*, 2 CONH, H−C(3'''), H−C(5''')); 4.42–4.30 (*m*, 4 H−C(α')); 1.34–1.18 (*m*, 4 H−C(β')); 1.25 (*s*, 9 H−C(2''')); 0.91–0.84 (*m*, 4 H−C(γ')); 0.06 (*s*, 2 *t*-Bu); −2.69 (br., 2 NH (pyr)). ^{19}F-NMR (282 MHz, $CDCl_3$)[1]): −5.8 (*m*, F−C(2''), F−C(6'')); −18.3 (*m*, F−C(4'')); −29.2 (*m*, F−C(3''), F−C(5'')). MALDI-TOF-MS: 1273 (M^+, $C_{70}H_{62}F_{10}N_6O_4S^+$; calc. 1273.41).

Aqua{N,N'-{10,20-bis(2,3,4,5,6-pentafluorophenyl)-5,15-{[1,2]benzenoxypropano{[5](1,1-dimethylethyl)-[2](mercapto-κS)[1,3]benzeno}propanoxy[1,2]benzeno}-21H,23H-porphyrin-30,47-diyl-κN^{21},κN^{22},κN^{23},κN^{24}}-bis[2,2-dimethylpropanamidato](3−)}iron(III) (**13**). To a soln. of **24** (91 mg, 0.071 mmol) in refluxing toluene (30 ml), 2,6-dimethylpyridine (0.5 ml) was added. The soln. was saturated with $FeBr_2$. The mixture was stirred 2 h under reflux, filtered through *Celite*, and evaporated. FC yielded 76 mg (80%) of **13**. Brown solid. M.p. > 250°. R_f 0.21 (CH_2Cl_2/MeOH 95:5). UV/VIS (CH_2Cl_2): 420 (100), 510 (11), 580 (7), 656 (3). ^{1}H-NMR (250 MHz, (D_8)toluene)[1]): 82.0 (br., 8 H−C(β) (pyr)); 11.5 (br., H−C(3'''), H−C(5''')); 8.4 (br.); 8.1 (br., 2 H−C(3'), 2 H−C(5')); 7.5 (br., 2 H−C(4')); 7.2 (br., 4 H−C(γ')); 6.7 (br., 2 CONH); 4.3 (br., 9 H−C(2''')); 4.1 (br., 4 H−C(β')); 3.0 (br., 4 H−C(α')); −0.2 (br., 2 *t*-Bu). MALDI-TOF-MS: 1345 ($[M+H_2O]^+$), 1324 (M^+, $C_{70}H_{57}F_{10}FeN_6O_4S^+$; calc. 1324.21). EPR (toluene, 100 K, 20 mW): 6.318, 2.019.

Reaction of **13** *with HBr*. To a UV/VIS soln. of **13** in CH_2Cl_2 with an extinction between 1 and 2, 50 µl of 30% HBr in AcOH were added. The soln. was stirred for 2 h at r.t. under Ar: corresponding bromoiron(III) complex **13** · HBr. Violet soln. UV/VIS (CH_2Cl_2): 452 (100), 516 (29), 588 (13), 644 (15).

Preparation of Complexes **25** *and* **26**. A UV/VIS soln. of **13** in dry THF with an extinction between 1 and 2 was saturated with $NaBH_4$. The suspension was stirred for 30 min at r.t. under Ar to yield the corresponding aquaferrate(1−) **25**. Through the soln. CO gas was bubbled for 15 min at r.t. to yield the corresponding carbonylferrate (1−).

Data of **25**: Red soln. UV/VIS (THF): 366 (sh, 65), 426 (100), 486 (19), 538 (17), 656 (4).

Data of **26**: Bright-red soln. UV/VIS (CH_2Cl_2; difference spectrum to that of **25**): 448.

Chlorination Experiments: General Procedure. (Benzyl)(triethyl)ammonium chloride (200 mg, 0.44 mmol) was dissolved in CH_2Cl_2 (200 ml) and stirred with in the presence of conc. aq. NaOCl soln. (*Sigma*, 5% Cl; 3.2 ml) for 30 min. The org. layer was dried (Na_2SO_4) and directly used for the chlorination experiments. The substrate (**5**: 100 mg, 0.573 mmol; **27**: 40 mg, 0.370 mmol; **28**: 20 mg, 0.204 mmol; **29**: 20 mg, 0.217 mmol; **30**: 20 mg, 0.143 mmol; **32**: 20 mg, 0.204 mmol) was dissolved in CH_2Cl_2 (5 ml). The iron(III) porphyrinate **13** (for equiv.

amount, see *Tables 1–3*) and AcOH (1.2 equiv. rel. to substrate), or *Lewis* acid ($ZnCl_2 \cdot (OEt_2)_x$: 0.1 equiv.; $SnCl_4$: 0.1 equiv.; $TiCl_4$: 0.1 equiv.; $BF_3 \cdot OEt_2$: 0.02 equiv.), were added. Using an infusion pump, a freshly prepared (35 mM) soln. of (benzyl)(triethyl)ammonium hypochlorite (or a mixture of (benzyl)(triethyl)ammonium chloride and H_2O_2) [14] in CH_2Cl_2 (1.2 equiv. rel. to substrate) was added during 15 min. The soln. was concentrated *in vacuo* at r.t. to 1 ml. In case of **5**, **30**, and **32**, the products were purified by FC (hexan/AcOEt/AcOH 20:20:1) and analyzed by ^{1}H-NMR and by EI-MS. In case of **27**–**29**, the soln. was filtered through silica gel (CH_2Cl_2) and analyzed by ^{1}H-NMR (**27**) or GC/MS using standard curves (**28** and **29**). All experiments were repeated in the absence of the iron(III) porphyrinate **13** under otherwise identical conditions. Substrates **5**, **28**–**30**, and **32** were recovered unchanged in all cases; in contrast, **27** was chlorinated in the presence of *Lewis* acids. Accordingly, the corresponding values (*Table 3*) are corrected for these 'background reactions'.

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