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Synthesis of a novel porphyrin bearing chloro*per*-fluoropolyether moieties with very high solubility in supercritical CO_2

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Abstract—A new porphyrin bearing chloro*per*-fluoropolyether substituents at the *meso* positions was prepared in five steps starting from chloro*per*-fluoropolyether carboxylic acid. Metallation of this porphyrin was accomplished with cobalt and zinc. Both the free base and its complex with zinc are highly soluble in supercritical CO_2 under very mild conditions (40°C and 20 MPa) thus allowing, in principle, homogeneous catalytic processes to be performed in this non-conventional reaction medium.

Supercritical carbon dioxide ($scCO_2$) is an interesting reaction medium for industrial processes because of some properties which make it an environmentally and economically profitable solvent.[1,2] In particular, being carbon dioxide fully oxidized and stable under any oxidative conditions, $scCO_2$ is ideally suited as a reaction medium for oxidation reactions and applications in both homogeneous and heterogeneous catalytic processes. Moreover, employing molecular oxygen as primary oxidant, one may take advantage of the much larger concentrations that can be achieved in the supercritical than in conventional liquid solvents.

However, only a limited number of transition metal complexes are sufficiently soluble in $scCO_2$ to perform catalytic homogeneous oxidations. For instance, olefin epoxidations by hydroperoxides in $scCO_2$ using $Mo(CO)_6$ as catalyst have been tested independently by various groups[3–6] stimulated by the reasonable solubility of molybdenum hexacarbonyl in that phase.[7] Solubility is also a main hindrance in the case of oxidations catalyzed by metalloporphyrins in $scCO_2$. Koda reported the oxidation of cyclohexane with O_2 catalyzed by iron 5,10,15,20-tetrakis(pentafluorophenyl)-porphyrinate that was assumed to be reasonably dispersible in supercritical phase due to the presence of perfluorophenyl groups on the porphyrin ring.[8] However, the complex solubility in $scCO_2$ at 70°C and 8 MPa turned out to be quite poor. Tumas and his co-workers published a study on the cyclohexene oxidation with O_2 catalyzed by two halogenated iron porphyrins in $scCO_2$.[9] From this study, the authors estimated that the solubility of the catalysts employed, namely the iron complex 5,10,15,20-tetrakis(pentafluorophenyl)porphyrinate and the complex β-octabromo-5,10,15,20-tetrakis (pentafluorophenyl)porphyrinate, are 18 and 10 μM at 40°C and 34 MPa.

Recently, we reported a study on the oxidation of thioethers with monopersulfate catalyzed by various manganese porphyrins in $scCO_2$ at 40°C and 20 MPa.[10] Among the various catalysts tested, only the manganese 5,10,15,20-tetrakis(heptafluoropropyl)porphyrinate showed a slight solubility in the supercritical phase under the experimental conditions adopted. Therefore, the oxidizing system had a definite heterogeneous character, both oxidant and catalyst were virtually insoluble in $scCO_2$. Nevertheless, the oxidative process was found to take place, under proper conditions, to yield the corresponding sulfoxides and sulfones. These encouraging results prompted us to realize the synthesis of a porphyrin ligand soluble in high concentrations in $scCO_2$ even under very mild conditions. To this aim, we addressed our attention to the synthesis of novel porphyrins bearing, at the *meso* positions, substituents which were highly soluble in $scCO_2$. From previous experiments, we found that simple *per*-fluoroalkyl chains are poorly effective as solubilizing agents for a porphyrin ring. So we turned our attention to a porphyrin bearing (*per*)-fluoropolyether chains (PFPE). In

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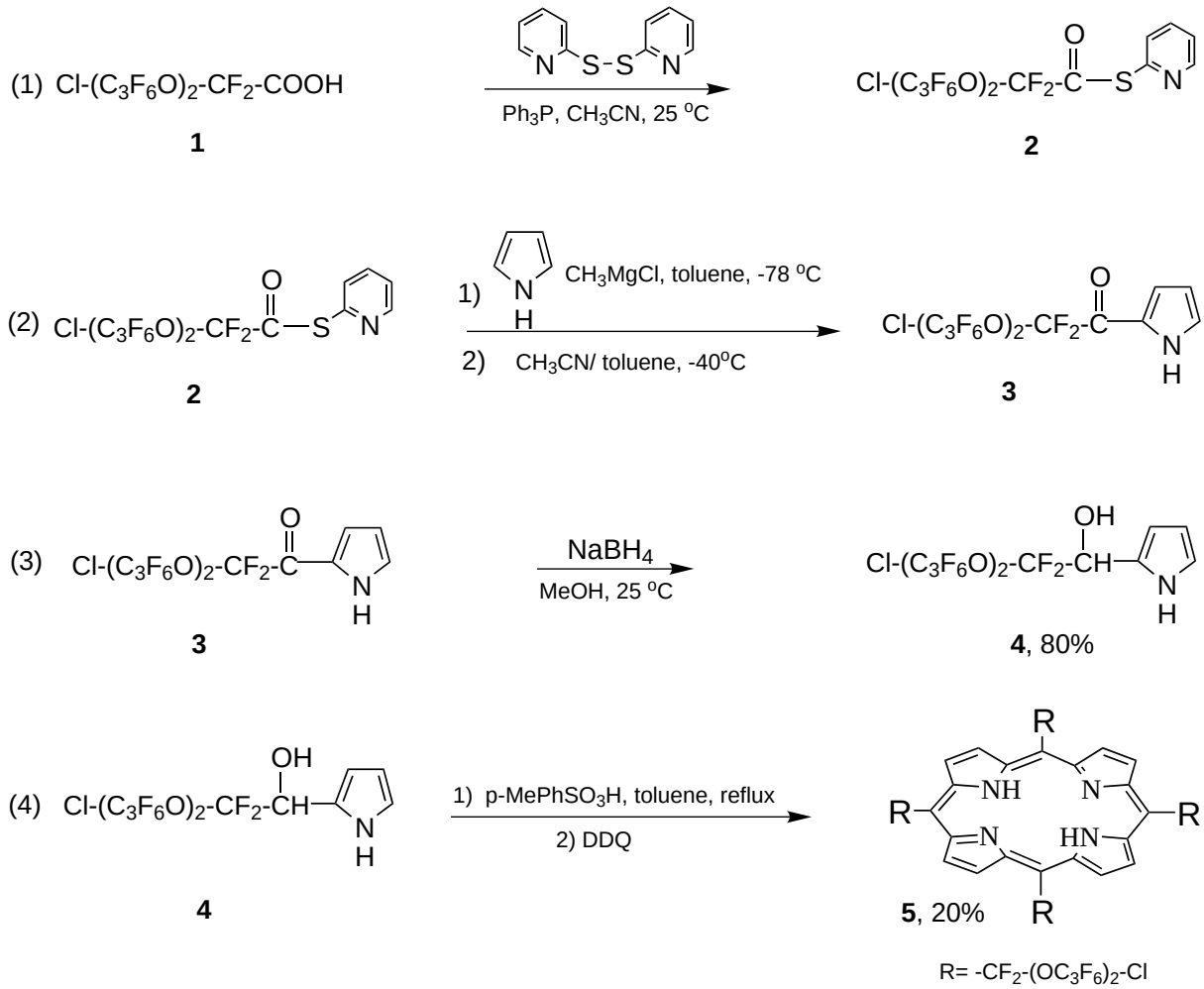
fact, the noticeable solubility in $scCO_2$ of *per*-fluoropolyethers derivatives such as ammonium carboxylate *per*-fluoropolyether (NH_4^+ $^-$OOCPFPE), which is even capable of forming stable reverse micelles,[11] has been recently demonstrated. We report here the synthetic route for a class of porphyrins bearing four (*per*)-fluoropolyethers chains at the *meso* positions following the main reaction steps outlined in Scheme 1.

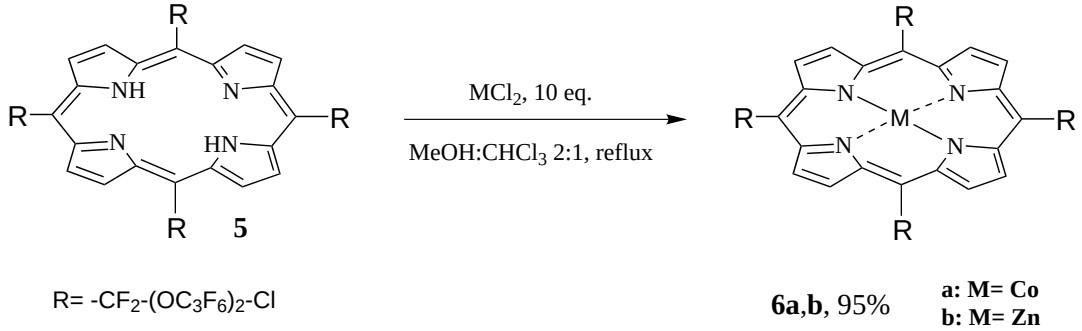
Conventional porphyrin synthetic methodologies are unfit for the preparation of highly electron-deficient porphyrin rings.

Therefore, the synthesis strategy adopted for porphyrin **5** is that reported by DiMagno for the preparation of *meso*-perfluoroalkylporphyrins.[12] This synthetic route requires the acid-catalyzed condensation of 2[(PFPE)]hydroxymethyl] pyrrole (**4**) and PFPE carboxylic acids as precursors. This class of compounds has general formula $X(C_3F_6O)_n$–$(C_2F_4O)_m$–$(CF_2O)_p$–CF_2COOH, where X can be F, Cl, H or a C1–C3 perfluoroalkyl end-group. A series of PFPE acids with X = Cl has been prepared[13] in pure form, on laboratory scale, by Ausimont who kindly supplied us with experimental samples of the terms with $n = 2,3,4$ and m and p very close to zero. The compound with $n = 2$, here schematically indicated as (Cl-PFPE)COOH (**1**), was utilized in this synthetic work as starting material. We tried at first to synthesize (Cl-PFPE)-2-ketopyrrole (**3**) by reacting the pyrrole with the acyl chloride prepared in situ from compound **1** with ossalyl chloride and/or thionile chloride in both, neat and in THF as solvent. However, this synthetic route gave no result in our hands. Conversely, **3** was successfully prepared through steps 1 and 2 of Scheme 1. (Cl-PFPE)-2-pyridil thiolesters (**2**) were synthesized by the general procedure reported by Mukaiyama with some essential adaptations.[14]

In fact, the yields of reaction 1 of Scheme 1 range from 0 to 85% depending on the solvent and reactant concentrations. In particular, the only suitable solvent found is acetonitrile, but reasonable yields were obtained only by using the minimum amount of solvent needed to homogenize the reactants mixture (1.0 M). Compound **2** was converted into **3** at −78°C in a mixture of acetonitrile/toluene with pyrrylmagnesium chloride (2.5 equiv.), prepared in situ from methylmagnesium chloride and pyrrole at −40°C in toluene under a nitrogen atmosphere.[15] Reduction of **3** to **4** was accomplished



Scheme 1. Synthesis of the free base porphyrin **5**.



Scheme 2. Metallation of **5** with cobalt and zinc.

with an excess of $NaBH_4$ in a mixture of toluene/acetonitrile/methanol at 25°C. Product **4**, once purified by chromatography on silica gel (eluent: *n*-hexane: diethylether 70:30), was obtained with an 80% yield relative to the starting material (**1**). Finally, the porphyrin free base **5** was obtained in 20% yield by acid-catalyzed condensation of **4** in a diluted (10^{-3} M) solution of dry refluxing toluene. ^{1}H NMR (**5**) ($CDCl_3$): δ 9.49 (s 8H), δ −1.78 (s 2H).

Metallation of the free base turned out to be not a straightforward process since the conventional method, using metal acetate salts in refluxing DMF, led to the destruction of the porphyrin ring. Successful (95% yield) metallation of (**5**) with zinc and cobalt has been obtained with the chloride metal salt in a refluxing 2:1 mixture of methanol and chloroform (see Scheme 2). ^{1}H NMR (**6a**) ($CDCl_3$): δ 9.38 (s 8H); (**6b**) ($CDCl_3$): δ 9.44 (s 8H).

The electronic absorption spectra of porphyrins **5** and **6a–b** in dichloromethane solutions are shown in Fig. 1.

The Soret band of free porphyrin base appears at 408 nm together with four I–IV bands, respectively, at 653, 597, 548 and 513 nm. The corresponding Zn(II) derivatives exhibit a Soret adsorption at 418 nm with a red shift of 10 nm and two Q bands at 563 and 602 nm. Co(II) derivatives show a Soret band at 397 nm with an 11 nm blue shift relative to the free ligand and two Q bands at 546 and 578 nm.

Positive-ion ESI-TOF mass spectrometry unequivocally confirmed the structure of the porphyrin ring synthesized. In the case of Cobalt derivatives an isotopic ion cluster corresponding to the radical cation T(Cl-PFPE)PCo$^{+\bullet}$ is observed: ID (exp%, calcd%) = 2031 (74, 70); 2032 (46, 38); 2033 (100, 100); 2034 (54, 51); 2035 (79, 57); 2036 (41, 27); 2037 (10, 16).

These new porphyrin derivatives show the following solubility order in some conventional liquid solvents: *n*-pentane>dichloromethane≫methanol. Quite relevant, at least for semi-quantitative experiments, these porphyrins are highly soluble in $scCO_2$ under relatively mild conditions. In fact, an open Pyrex ampoule was loaded with T(Cl-PFPE)PH_2 (100 mg) or T(Cl-PFPE)PZn (50 mg) and placed into the reactor (10 mL volume) at 40°C and 20 MPa for several hours; after venting the reactor, the ampoule was recovered completely empty indicating a lower solubility limit for the free base porphyrin and for the zinc derivatives of 5 and 2.5×10^{-3} M, respectively. These solubility levels are well beyond those usually required for operating an homogeneous catalysis and this is a promising property for exploring the efficacy of the new catalysts in oxidation processes in supercritical carbon dioxide.

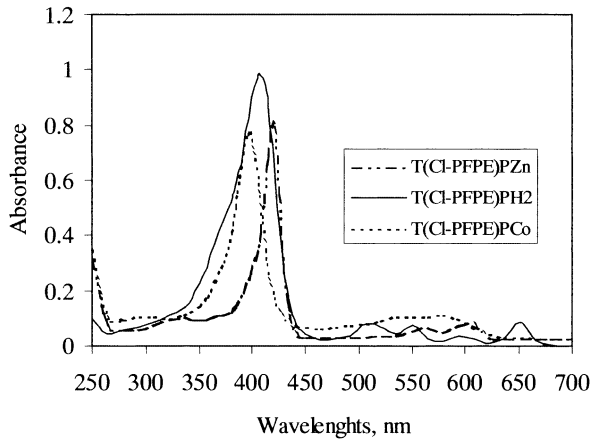


Figure 1. UV–vis spectra of **5** and of its Zn(II) and Co(II) derivatives in dichloromethane solution.

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References

1. *Chemical Synthesis Using Supercritical Fluids*; Jessop, P. G.; Leitner, W., Eds.; Wiley-VCH, 1999.
2. *Green Chemistry—Designing Chemistry for the Environment*; Anastas, P. T.; Williamson, T. C., Eds.; American Chemical Society, 1996.
3. Jessop, P. G. *Top. Catal.* **1998**, *5*, 95.

4. Kreher, U.; Schebesta, S.; Walther, D. *Z. Anorg. Allg. Chem.* **1998**, *624*, 602.
5. Pesisi, D. R.; Morita, D. K.; Glaze, W.; Tumas, W. *Chem. Commun.* **1998**, 1015.
6. Haas, G. R.; Kolis, J. W. *Organometallics* **1998**, *17*, 4454.
7. Palo, D. R.; Erkey, C. *J. Chem. Eng. Data* **1998**, *43*, 47.
8. Wu, X.-W.; Oshima, Y.; Koda, S. *Chem. Lett.* **1997**, 1045.
9. Birnbaum, E. R.; Le Lacheur, R. M.; Horton, A. C.; Tumas, W. *J. Mol. Catal. A* **1999**, *139*, 11.
10. Campestrini, S.; Tonellato, U. *J. Mol. Catal. A* **2000**, *164*, 263.
11. Clarke, M. J.; Harrison, K. L.; Johnston, K. P.; Howdle, S. M. *J. Am. Chem. Soc.* **1997**, *119*, 6399.
12. DiMagno, S. G.; Williams, R. A.; Therien, M. J. *J. Org. Chem.* **1994**, *59*, 6943.
13. G. Marchionni, A. M. Staccione (Ausimont SpA) US Pat. **1992** 5.143.589.
14. Endo, T.; Ikenaga, S.; Mukaiyama, T. *Bull. Chem. Soc. Jpn.* **1970**, *43*, 2632.
15. Nicolaou, K. C.; Claremon, D. A.; Papahatjis, D. P. *Tetrahedron Lett.* **1981**, *22*, 4647.