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Unusual Fluoroalkenylation of Porphyrins: A Highly Stereoselective Synthesis of 10,20-Diaryl-5-[(*E*)-fluoroalkenyl]-15-(fluoroalkyl)porphyrins

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A series of 10,20-diaryl-5-[(*E*)-fluoroalkenyl]-15-(fluoroalkyl)porphyrins has been synthesized by the reaction of free-base 5,15-diarylporphyrins with fluoroalkyl iodides in the presence of $Na_2S_2O_4$. Subsequent intramolecular cyclization of the corresponding (fluoroalkenyl)porphyrins occurs smoothly in refluxing toluene/H_2O.

Introduction

Fluorine-containing olefins are versatile synthetic building blocks in organofluorine chemistry and they are also used as potential enzyme inhibitors with cytotoxic activity.[1,2] Porphyrins possess a core structure similar to some important enzymes and their hybrids, i.e., β-(fluorovinyl)porphyrins, are potentially useful for cancer diagnosis and therapy.[3] However, to the best of our knowledge, no report has been published of a method for the introduction of fluoroalkenyl groups into the *meso* position of porphyrins. Therefore, the synthesis of (fluorovinyl)porphyrins, especially in a stereoselective fashion, is important from both chemical and biological points of view. The addition of fluoroalkyl radicals ($R_f^{\cdot}$), generated in situ in an R_fX (X = I, Br, Cl)/$Na_2S_2O_4$/DMSO system (modified sulfinatodehalogenation reaction), to unsaturated compounds has been widely applied to the fluoroalkylation of alkenes, dienes, allenes, alkynes, and aromatic compounds.[4] Recently, we successfully extended this method to the fluoroalkylation of porphyrins.[5] For example, 10,20-diaryl-5-(fluoroalkyl)porphyrins were obtained by the reaction of 1.1 equiv. of R_fI with 5,15-diarylporphyrinzinc(II) compounds in the presence of $Na_2S_2O_4$/DMSO.[5e] However, when free-base 5,15-diarylporphyrins were fluoroalkylated with excess fluoroalkyl iodide (R_fI), it was found that the structures of the resulting porphyrins were heavily dependent on the reaction conditions, and fluoroalkenylation of porphyrins occurred unexpectedly. We present these results here.

Results and Discussion

After treating 5,15-diphenylporphyrin (**1a**)[6] with 3 equiv. of perfluorohexyl iodide (**2c**)and 6 equiv. of $Na_2S_2O_4$ in DMSO/CH_2Cl_2/H_2O (20:20:1) at 50 °C for 1 h, a dark-blue mixture was formed. Acidification of the mixture with aqueous HCl solution (37%, w/w) for 1 h gave **3ac** (Ar = Ph, R_f = *n*-C_6F_{13}, 40%) and **4ac** (Ar = Ph, R_f = *n*-C_6F_{13}, R_f' = *n*-C_5F_{11}, 10%). Notably, the use of 2% water (v/v) as a co-solvent was necessary, otherwise only a trace amount of products was detected, even after 24 h. Similar results were obtained with other fluoroalkyl iodides (Scheme 1).

Interestingly, treating the same reaction mixture of **1a** and **2c** with triethylamine (TEA) rather than acidifying with aqueous HCl solution gave the (*E*) isomer **5ac** ($^3J_{F,F}$ = 154 Hz) in 50% yield (Scheme 2).

The structures of porphyrins **3**, **4** and **5** were unambiguously established by their UV, ^1H and ^{19}F NMR, IR spectroscopic, and mass spectrometric data. In addition, the reaction mixture could be treated with other bases, such as $NaHCO_3$, K_2CO_3, or pyridine, although the yield of **5** was slightly lower. This novel fluoroalkenylation method could be extended to different 5,15-disubstituted porphyrins and various fluoroalkyl iodides. The results are summarized in Table 1.

The fact that the reaction of 5-(4-chlorooctafluorobutyl)-10,20-diphenylporphyrin (**1d**)[5e] with *n*-$C_6F_{13}I$ (**2c**) afforded exclusively the [(*E*)-fluoroalkenyl]porphyrin **5dc** (Table 1, Entry 10), whereas the reaction of 5,10,15-triphenylporphyrin (**1e**)[7] gave none of the fluoroalkenylated products (Table 1, Entry 11),[5d] seems to indicate that the presence of the fluoroalkyl group at the *meso* position is crucial to

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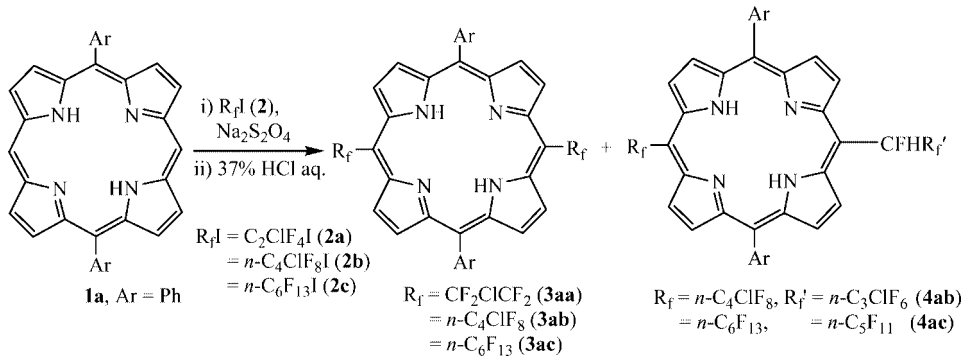
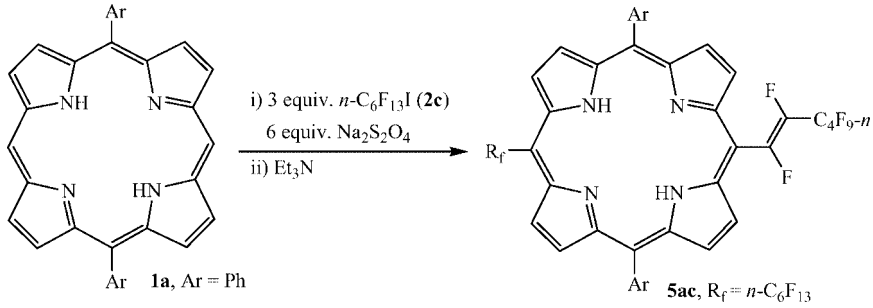
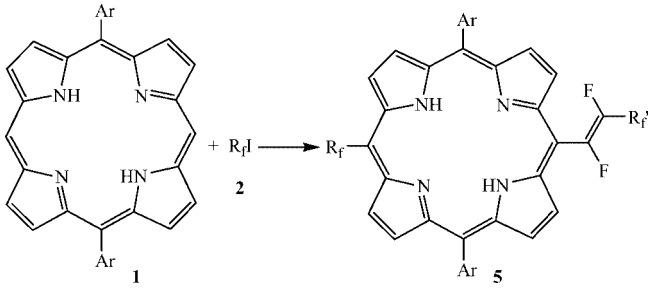


Scheme 1.



Scheme 2.

Table 1. Synthesis of [(*E*)-fluoroalkenyl]porphyrins **5**.[a]



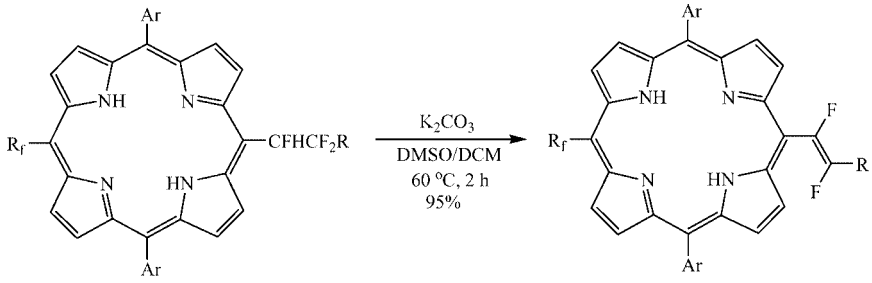
Entry	**1** (Ar =)	**2** (R_f =)	**5** (R_f' =)	Yield [%]
1	Ph (**a**)	$CClF_2CF_2$ (**a**)	F (**aa**)	25[b]
2	Ph	$n\text{-}C_4ClF_8$ (**b**)	$CClF_2CF_2$ (**ab**)	60
3	Ph	$n\text{-}C_6F_{13}$ (**c**)	$n\text{-}C_4F_9$ (**ac**)	50
4	Ph	$n\text{-}C_8F_{17}$ (**d**)	$n\text{-}C_6F_{13}$ (**ad**)	45
5	$m\text{-}FC_6H_4$ (**b**)	$n\text{-}C_4ClF_8$	$CClF_2CF_2$ (**bb**)	65
6	$m\text{-}FC_6H_4$	$n\text{-}C_6F_{13}$	$n\text{-}C_4F_9$ (**bc**)	60
7	$m\text{-}MeC_6H_4$ (**c**)	$CClF_2CF_2$	F (**ca**)	20[c]
8	$m\text{-}MeC_6H_4$	$n\text{-}C_4ClF_8$	$CClF_2CF_2$ (**cb**)	55
9	$m\text{-}MeC_6H_4$	$n\text{-}C_6F_{13}$	$n\text{-}C_4F_9$ (**cc**)	50
10	**1d**[d]	$n\text{-}C_6F_{13}$	$n\text{-}C_4F_9$ (**dc**)	60
11	**1e**[e]	$n\text{-}C_6F_{13}$	–	–

[a] The reaction of **1** (0.1 mmol), **2** (0.3 mmol), and $Na_2S_2O_4$ (0.6 mmol) was carried out in a mixture of solvents [DMSO (10 mL), CH_2Cl_2 (10 mL), and H_2O (0.5 mL)] at 50 °C for 1 h, followed by treatment with TEA (0.6 mmol) for another 1 h. [b] Together with the formation of 20% of **3aa**. [c] Together with the formation of 20% of **3ca**. [d] 5-(4-Chlorooctafluorobutyl)-10,20-diphenylporphyrin (**1d**) was used as the starting porphyrin. [e] 5,10,15-Triphenylporphyrin (**1e**) was used as the starting porphyrin and only *meso*- and β-fluoroalkylated products were obtained. See also ref.[5d]

the following olefin formation. On the other hand, the (fluorohydroalkyl)porphyrins **4**, formed from acid treatment, might be precursors of the olefin **5**. Indeed, porphyrins **4** were quickly converted into the corresponding olefins **5** upon treatment with K_2CO_3 (Scheme 3). The excellent (*E*) selectivity of the reaction was explained by a conformational analysis (Figure 1A and B). Conformation A, which leads to the (*E*) isomer, has much less steric hindrance between the bulky porphyrin unit and the R_f ($R_f = CClF_2CF_2$, $n\text{-}C_4F_9$, $n\text{-}C_6F_{13}$) group than conformation B, which leads to the (*Z*) isomer.

According to our previous results for the fluoroalkylation of porphyrins, it is easy to understand that the formation of **3** occurs by addition of the fluoroalkyl radical ($R_f^{\cdot}$) to 5,15-diarylporphyrins **1** in a normal free radical aromatic substitution.[8] The fact that an attempt to convert porphyrin **3ab** into **4ab** in the presence of $Na_2S_2O_4$/DMSO resulted in only recovery of the starting porphyrin indicates that the formation of the (fluorohydroalkyl)porphyrin **4** does not occur via the corresponding (fluoroalkyl)porphyrin **3** by electron-transfer reduction.[9] The problem is whether the hydrogen atom in the fluorohydroalkyl group comes only from H_2O. In order to gain deeper insight into the formation of **4**, some deuterium-labeling reactions were carried out (Scheme 4).

Firstly, the reaction of **1a** with **2b** in DMSO/CH_2Cl_2/D_2O gave the completely labeled product **D-4ab** after being acidified with aqueous HCl solution (Scheme 4, i). This result indicates that the corresponding anion intermediate might be involved in the formation of **4**. Secondly, the reaction of the deuterated porphyrin **D-1d**, prepared by the reaction of **1d** with neat deuteriosulfuric acid, with **2b** gave no deuterium-labeled product other than **4ab**, which further



Scheme 3.

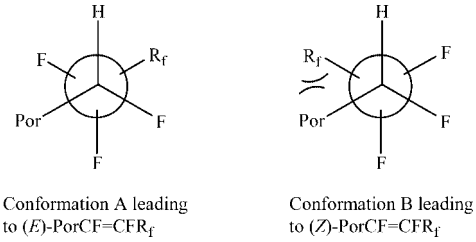
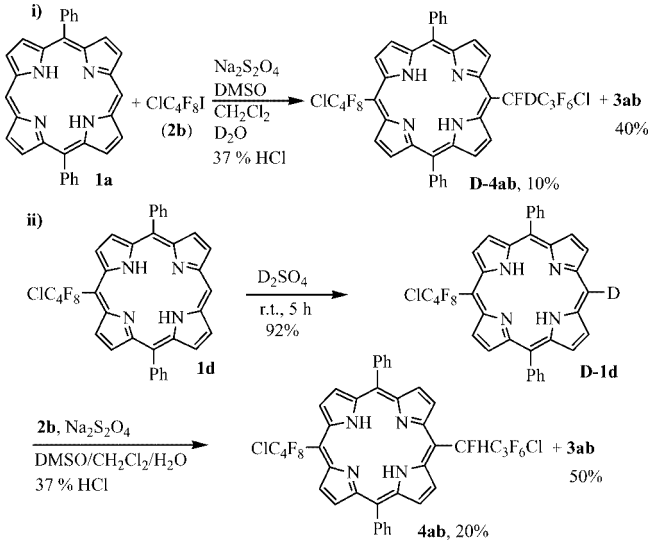


Figure 1. (*E*) selectivity in the dehydrofluorination of PorCHFCF$_2$R$_f$ [**4**; Por = 10,20-diaryl-5-(fluoroalkyl)porphyrin].



Scheme 4.

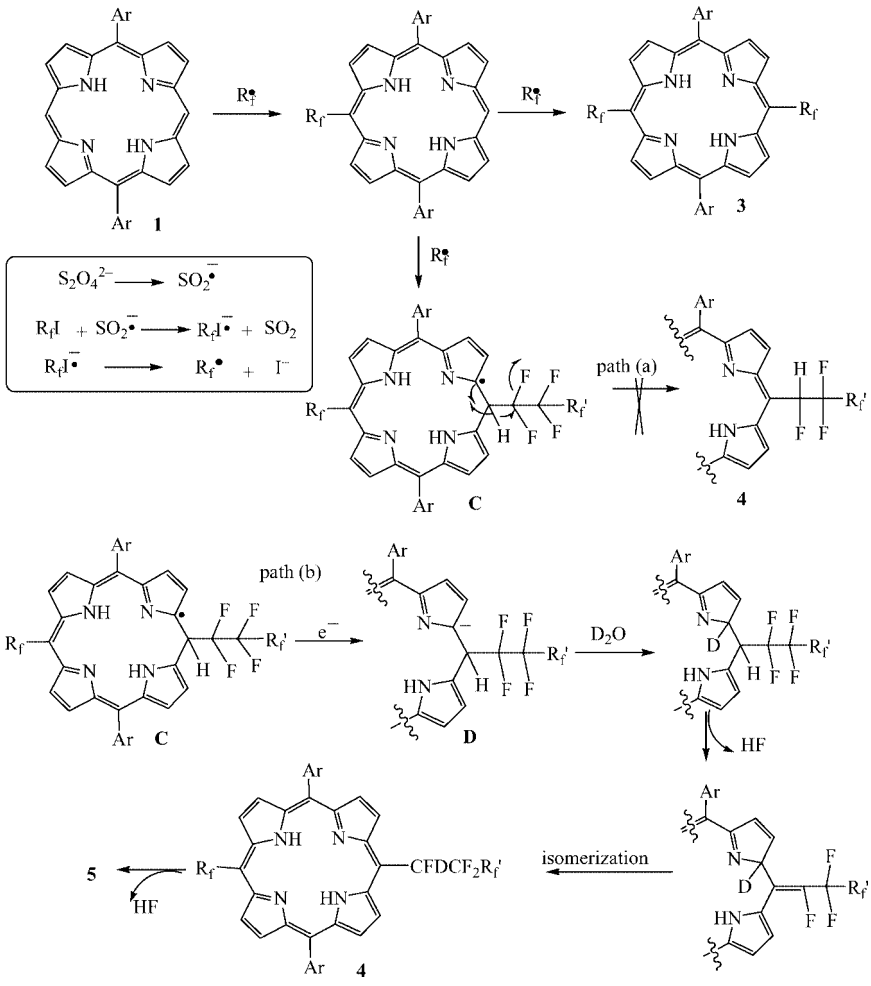
confirms that the hydrogen atom in the fluorohydroalkyl group comes from the solution rather than by any intramolecular hydrogen transfer (Scheme 4, ii).

On the basis of these deuterations and the well-documented chemistry of fluoroalkylations, we can propose a feasible mechanism that explains all the products (Scheme 5). Generation of the fluoroalkyl radical ($R_f^{\cdot}$) occurs by a process in which the fluoroalkyl iodide (R_fI) accepts one electron from the radical anion of sulfur dioxide, which is produced by decomposition of $Na_2S_2O_4$, and then dissociates to give $R_f^{\cdot}$ and I^-.[4] The intermediate **C**, formed by the addition of $R_f^{\cdot}$ to 5,15-diarylporphyrins **1**, is a key intermediate for the formation of **3** and **4**. As mentioned above, intermediate **C** gives **3** after elimination of a hydrogen atom. On the other hand, the formation of **4** does not occur by intramolecular hydrogen transfer [Scheme 5, path (a)] but most probably by picking up another electron to form anion **D** [Scheme 5, path (b)]. This anion, after abstraction of a proton from the solution, elimination of HF, and intramolecular isomerization, affords **4**, which is readily converted into the olefin product **5** by elimination of HF under basic conditions. Notably, all attempts to convert 5,15-bis(fluoroalkyl)porphyrin **3ab** into **4ab** or bis(fluoroalkenyl)porphyrin in the presence of $Na_2S_2O_4$/DMSO resulted in complete recovery of the starting porphyrin, thereby confirming that the formation of the (fluoroalkenyl)porphyrin does not occur via the corresponding 10,20-diaryl-5,15-bis(fluoroalkyl)porphyrin **3** by electron-transfer reduction.

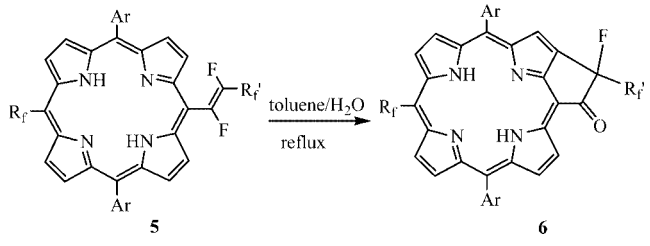
With the (fluoroalkenyl)porphyrins in hand, we attempted to couple them by [2+2] cycloaddition because fluoroethylenes are prone to cyclodimerization.[10] According to Normant's procedure, heating of **5** in refluxing toluene for 24 h afforded only a trace amount of the intramolecular cyclization product **6** instead of the expected cyclic dimer. Further investigation showed that the addition of 5% H_2O (v/v) could significantly enhance the conversion of **5**. Thus, heating of **5aa** or **5ab** in refluxing toluene/H_2O for 24 h afforded **6a** (Ar = Ph, R_f = C_2ClF_4, R_f' = F) and **6b** (Ar = Ph, R_f = C_4ClF_8, R_f' = C_2ClF_4) in 80% and 70% yields, respectively (Scheme 6). The structure of **6** was unambiguously established from its NMR, IR spectroscopic, and mass spectrometric data.

For example, the ^{1}H NMR spectroscopic data for **6b** are in full agreement with the proposed structure: seven different sets of β-hydrogen resonance are observed between δ = 8.0 and 10.0 ppm, and the split N–H proton signals (δ = –2.19, –2.92 ppm) are again diagnostic for the proposed fused structure.[5d] Additionally, the fact that the signals of the fluoroalkenyl group disappear from the ^{19}F NMR spectra, the IR spectrum shows a strong carbonyl absorption at 1726 cm^{-1}, and the MALDI mass spectrum gives the formula weight of the fused carbonyl product (calcd. for $C_{40}H_{19}Cl_2F_{13}N_4O{\cdot}H^+$: 889.0801; found 889.0830) confirm the proposed structure.

The UV/Vis spectra of **6b**, **3ac**, **4ac**, and **5ac** are shown in Figure 2. The spectra of **3ac**, **4ac**, and **5ac** have very similar absorption bands in the Soret and Q regions, while the So-



Scheme 5. Possible mechanism for the formation of **3**, **4**, and **5**.



Scheme 6.

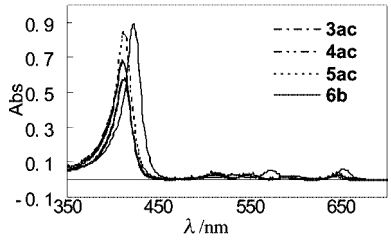


Figure 2. UV/Vis spectra of **3ac**, **4ac**, **5ac**, and **6b** in CH_2Cl_2 solution (about 2 μM) at room temperature.

ret band of **6b** is red-shifted by almost 12 nm and the corresponding Q bands display a longer wavelength than those observed for **3ac**, **4ac**, and **5ac**. The exact mechanism for the formation of the fused carbonyl products is not clear yet. However, the oxygen atom in the carbonyl group might come from water, based on the following facts: the addition of water significantly enhances the conversion of the starting material as mentioned above, while the same reaction does not occur under O_2. The process might involve a thermally allowed (antarafacial) 20-electron electrocyclic reaction followed by addition of water and oxidation.

Conclusion

We have presented a facile method of the synthesis of *meso*-(fluoroalkenyl)porphyrins with high (*E*) selectivity from readily available porphyrins and fluoroalkyl iodides by a modified sulfinatodehalogenation method. The corresponding fused (fluoroalkyl)porphyrins are readily obtained from the (fluoroalkenyl)porphyrins and water by intramolecular cyclization. Further studies on the scope and applications of the chemistry reported herein are underway in our laboratories.

Experimental Section

General Procedure for the Synthesis of (Fluoroalkyl)porphyrin 3 and (Fluorohydroalkyl)porphyrin 4: A sample of 5,15-diphenylporphyrin (**1a**, 0.1 mmol), fluoroalkyl iodide (**2**, 0.3 mmol), and $Na_2S_2O_4$ (0.6 mmol) was dissolved in a mixture of 10 mL of DMSO, 10 mL of CH_2Cl_2, and 0.5 mL of H_2O. After stirring the reaction mixture at 50 °C to yield a blue solution (1–1.5 h), HCl (37% w/w, 0.5 mL) was added and the mixture was stirred for another 1 h. CH_2Cl_2 (50 mL) was then added and the mixture was washed with water several times. The organic layer was dried with anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (silica gel, hexanes/CH_2Cl_2, 30:1). The first band gave product **3** and the second band gave **4**. Both products were crystallized from CH_2Cl_2/MeOH to give purple crystals.

5,15-Bis(4-chlorooctafluorobutyl)-10,20-diphenylporphyrin (3ab): Yield: 37 mg (40%) ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.47–9.45 (m, 4 H), 8.90 (d, J = 4.8 Hz, 4 H), 8.16–8.14 (m, 4 H), 7.83–7.73 (m, 6 H), –2.52 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.44 (t, J = 14.6 Hz, 4 F), –81.14 to –81.28 (m, 4 F), –114.5 to –114.6 (m, 4 F), –119.0 to –119.1 (m, 4 F) ppm. MS (MALDI): m/z = 931.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 409 (19), 512 (0.8), 549 (1), 592 (0.3), 645 (1). HRMS (MALDI): m/z calcd. for $C_{40}H_{21}Cl_2F_{16}N_4$: 931.0882 [$MH^+$]; found 931.0901. $C_{40}H_{20}Cl_2F_{16}N_4 \cdot 1.5H_2O$ (957.1): calcd. C 50.15, H 2.40, F 31.77, N 5.85; found C 49.99, H 2.44, F 31.82, N 5.18.

15-(4-Chloroheptafluorohydrobutyl)-5-(4-chlorooctafluorobutyl)-10,20-diphenylporphyrin (4ab): Yield: 9 mg (10%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.41 (m, 4 H), 8.87 (d, J = 5.1 Hz, 4 H), 8.44 (dd, J = 21, 43 Hz, 1 H), 8.11 (d, J = 6.6 Hz, 4 H), 7.77–7.68 (m, 6 H), –2.72 (s, 1 H), –2.75 (s, 1 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.2 to –67.5 (m, 4 F), –80.26 to –80.36 (m, 2 F), –112.0 to –122.0 (m, 8 F), –176.7 to –177.0 (m, 1 F) ppm. MS (MALDI): m/z = 912.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (28), 512 (1.5), 547 (1.2), 589 (0.6), 643 (1). $C_{40}H_{21}Cl_2F_{15}N_4$ (912.1): calcd. C 52.59, H 2.32, N 6.13; found C 52.14, H 2.28, N 5.71.

5,15-Bis(perfluorohexyl)-10,20-diphenylporphyrin (3ac): Yield: 43 mg (40%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.48–9.43 (m, 4 H), 8.91–8.90 (m, 4 H), 8.19–8.13 (m, 4 H), 7.84–7.73 (m, 6 H), –2.50 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –80.59 (m, 6 F), –81.26 (m, 4 F), –115.21 (m, 4 F), –121.00 (m, 4 F), –122.29 (m, 4 F), –125.80 (m, 4 F) ppm. MS (MALDI): m/z = 1099.25. UV/Vis (CH_2Cl_2): λ_{max} (%) = 410 (20), 512 (1.0), 547 (1.1), 591 (0.4), 645 (1). $C_{44}H_{20}F_{26}N_4$ (1098.1): calcd. C 48.10, H 1.83, N 5.10; found C 47.97, H 2.21, N 4.82.

15-(Dodecafluorohydrohexyl)-5-(perfluorohexyl)-10,20-diphenylporphyrin (4ac): Yield: 10 mg (10%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.46 (m, 4 H), 8.93 (d, J = 5.1 Hz, 4 H), 8.51 (dd, J = 20, 44 Hz, 1 H), 8.17 (d, J = 6.6 Hz, 4 H), 7.86–7.72 (m, 6 H), –2.65 (s, 1 H), –2.68 (s, 1 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –80.2 to –80.5 (m, 2 F), –80.5 to –80.7 (m, 6 F), –112.4 to –126.3 (m, 16 F), –176.1 to –177.0 (m, 1 F) ppm. MS (MALDI): m/z = 1081.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (26), 511 (1.5), 546 (1.2), 589 (0.6), 642 (1). $C_{44}H_{21}F_{25}N_4 \cdot 1.5H_2O$ (1107.1): calcd. C 47.71, H 2.18, N 5.06; found C 47.53, H 1.99, N 4.99.

Similarly, **3aa** (43 mg, 60%) was obtained from **1a** and **2a** as the sole product.[5e]

5,15-Bis(2-chlorotetrafluoroethyl)-10,20-diphenylporphyrin (3aa): ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.52 (m, 4 H), 8.90 (m, 4 H), 8.18 (d, J = 7.1 Hz, 4 H), 7.81(m, 6 H), –2.46 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –64.52 (s, 2 F), –80.11 (s, 2 F). MS (MALDI): m/z = 731.15 [M + H]$^+$. UV/Vis (CH_2Cl_2): λ_{max} (%) = 410 (20), 511 (1), 549 (1.1), 592 (0.4), 646 (1). $C_{36}H_{20}Cl_2F_8N_4 \cdot 2H_2O$ (766.1): calcd. C 56.32, H 3.13, N, 7.30; found C 56.14, H 2.77, N 7.09.

General Procedure for the Synthesis of (Fluoroalkenyl)porphyrin 5: A sample of 5,15-diarylporphyrin (**1**, 0.1 mmol), fluoroalkyl iodide (**2**, 0.3 mmol), and $Na_2S_2O_4$ (0.6 mmol) was dissolved in a mixture of 10 mL of DMSO, 10 mL of CH_2Cl_2, and 0.5 mL of H_2O. After stirring the reaction mixture at 50 °C to yield a blue solution (1–1.5 h), TEA (0.6 mmol) was added and the mixture was stirred for another 1 h to give a purple-red solution. CH_2Cl_2 (50 mL) was then added and the mixture was washed with water several times. The organic layer was dried with anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (silica gel, hexanes/CH_2Cl_2, 30:1) to give **5** as a purple solid from CH_2Cl_2/MeOH.

15-(4-Chlorooctafluorobutyl)-5-[(*E*)-4-chloro-1,2,3,3,4,4-hexafluorobut-1-enyl]-10,20-diphenylporphyrin (5ab): Yield: 53 mg (60%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.51 (m, 2 H), 9.31 (d, J = 4.0 Hz, 2 H), 8.97 (d, J = 5.1 Hz, 4 H), 8.17 (d, J = 6.0 Hz, 4 H), 7.83–7.75 (m, 6 H), –2.87 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.4 (t, J = 14.5 Hz, 2 F), –70.66 (quint, 2 F), –79.08 to –79.16 (m, 2 F), –98.9 (dt, J = 146, 27 Hz, 1 F), –114.20 to –114.3 (m, 2 F), –115.1 to –115.3 (m, 2 F), –118.9 to –119.0 (m, 2 F), –156.9 (dm, J = 147 Hz, 1 F) ppm. MS (MALDI): m/z = 893.2. IR (KBr): $\tilde{\nu}$ = 1715 (FC=CF). UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (25), 512 (1.3), 549 (1.2), 591 (0.5), 646 (1). $C_{40}H_{20}Cl_2F_{14}N_4 \cdot 1.5H_2O$ (919.1): calcd. C 52.19, H 2.53, N 6.09; found C 52.09, H 2.35, N 5.79.

15-(Perfluorohexyl)-10,20-diphenyl-5-[(*E*)-1,2,3,3,4,4,5,5,6,6,6-undecafluorohex-1-enyl]porphyrin (5ac): Yield: 53 mg (50%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.51 (m, 2 H), 9.30 (d, J = 4.5 Hz, 2 H), 8.97 (d, J = 5.1 Hz, 4 H), 8.18–8.16 (m, 4 H), 7.82–7.74 (m, 6 H), –2.87 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –79.19 (m, 2 F), –80.55 to –80.72 (m, 6 H), –99.0 (dt, J = 147, 26 Hz, 1 F), –114.94 (m, 2 F), –116.07 to –116.28 (m, 2 F), –120.91 (m, 2 F), –122.26 (m, 2 F), –123.55 (m, 2 F), –125.73 to –126.01 (m, 4 F), –157.85 (dm, J = 147 Hz, 1 F). MS (MALDI): m/z = 1061.3. UV/Vis (CH_2Cl_2). λ_{max} (%) = 411 (27), 512 (1.4), 549 (1.2), 591 (0.6), 645 (1). $C_{44}H_{20}F_{24}N_4 \cdot 1.5H_2O$ (1087.1): calcd. C 48.59, H 2.13, N 5.15; found C 48.56, H 1.94, N 4.45.

15-(Perfluorooctyl)-10,20-diphenyl-5-[(*E*)-1,2,3,3,4,4,5,5,6,6,7,7,8,8,8-quindecafluorooct-1-enyl]porphyrin (5ad): Yield: 56 mg (45%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.51 (m, 2 H), 9.29 (d, J = 4.8 Hz, 2 H), 8.97 (d, J = 5.4 Hz, 4 H), 8.18 (m, 4 H), 7.84–7.75 (m, 6 H), –2.89 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –79.1 to –79.3 (m, 2 F), –80.61 to –80.68 (m, 6 F), –99.0 (dm, J = 147 Hz, 1 F), –114.90 to –114.97 (m, 2 F), –115.88 to –116.09 (m, 2 F), –120.7 to –120.8 (m, 2 F), –121.2 to –121.4 (m, 2 F), –121.6 to –121.7 (m, 6 F), –122.6 (m, 4 F), –125.92 to –125.98 (m, 4 F), –157.8 (dm, J = 151 Hz, 1 F) ppm. MS (MALDI): m/z = 1260.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (28), 512 (1.4), 548 (1.2), 591 (0.6), 645 (1). $C_{48}H_{20}F_{32}N_4$ (1260.1): calcd. C 45.73, H 1.60, N 4.44; found C 45.30, H 1.95, N 4.04.

15-(4-Chlorooctafluorobutyl)-10,20-bis(3-fluorophenyl)-5-[(*E*)-4-chloro-1,2,3,3,4,4-hexafluorobut-1-enyl]porphyrin (5bb): Yield: 60 mg (65%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.54 (m, 2 H), 9.33 (d, J = 4.2 Hz, 2 H), 8.97 (d, J = 4.8 Hz, 4 H), 7.98–7.90 (m, 4 H), 7.79–7.71 (m, 2 H), 7.60–7.54 (m, 2 H), –2.94 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.43 (t, J =

13.9 Hz, 2 H), –70.7 (quint, 2 F), –79.2 (m, 2 F), –99.1 (dm, J = 151 Hz, 1 F), –114.3 (m, 2 F), –114.5 (m, 2 F), –115.19 to –115.37 (m, 2 F), –119.01 to –119.10 (m, 2 F), –156.7 (dm, J = 146 Hz, 1 F) ppm. MS (MALDI): m/z = 928.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (27), 511 (1.5), 546 (1.3), 589 (0.6), 643 (1). $C_{40}H_{18}Cl_2F_{16}N_4 \cdot H_2O$ (946.1): calcd. C 50.71, H 2.13, N 5.91; found C 50.99, H 2.09, N 5.53.

10,20-Bis(3-fluorophenyl)-15-(perfluorohexyl)-5-[(*E*)-1,2,3,3,4,4,5,5,6,6,6-undecafluorohex-1-enyl]porphyrin (5bc): Yield: 65 mg (60%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.57–9.56 (m, 2 H), 9.35 (d, J = 4.5 Hz, 2 H), 9.01 (d, J = 5.4 Hz, 4 H), 8.02–7.93 (m, 4 H), 7.82–7.74 (m, 2 H), 7.64–7.57 (m, 2 H), –2.89 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –79.2 to –79.3 (m, 2 F), –80.5 to –80.7 (m, 6 F), –90.3 (dm, J = 147 Hz, 1 F), –114.50 to –114.55 (m, 2 F), –114.9 to –115.0 (m, 2 F), –116.1 to –116.3 (m, 2 F), –120.8 to –121.0 (m, 2 F), –122.2 to –122.3 (m, 2 F), –123.5 to –123.6 (m, 2 F), –125.7 to –125.9 (m, 4 F), –157.7 (dm, J = 150 Hz, 1 F) ppm. MS (MALDI): m/z = 1096.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 411 (27), 511 (1.5), 547 (1.2), 589 (0.6), 643 (1). HPLC: 97% pure, t_R = 4.0 min, eluted with *n*-hexane, column: 4.6 × 250 mm. $C_{44}H_{18}F_{26}N_4$ (1096.1): calcd. C 48.19, H 1.65, N 5.11; found C 48.49, H 1.79, N 4.60.

15-(4-Chlorooctafluorobutyl)-5-[(*E*)-4-chloro-1,2,3,3,4,4-hexafluorobut-1-enyl]-10,20-bis(3-methylphenyl)porphyrin (5cb): Yield: 50 mg (55%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.51 (m, 2 H), 9.30 (d, J = 4.5 Hz, 2 H), 8.99 (d, J = 5.1 Hz, 4 H), 7.99 (m, 4 H), 7.7–7.6 (m, 4 H), 2.66 (s, 6 H), –2.89 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.40 (t, J = 12.9 Hz, 2 H), –70.61 to –70.72 (m, 2 F), –79.11 (m, 2 F), –98.9 (dt, J = 149, 25 Hz, 1 F), –114.30 (m, 2 F), –115.17 to –115.35 (m, 2 F), –119.01 to –119.11 (m, 2 F), –157.0 (dm, J = 148 Hz, 1 F) ppm. MS (MALDI): m/z = 920.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 412 (26), 512 (1.3), 550 (1.2), 592 (0.5), 646 (1). $C_{42}H_{24}Cl_2F_{14}N_4 \cdot H_2O$ (938.1): calcd. C 53.69, H 2.79, N 5.96; found C 53.90, H 2.76, N 5.46.

10,20-Bis(3-methylphenyl)-15-(perfluorohexyl)-5-[(*E*)-1,2,3,3,4,4,5,5,6,6,6-undecafluorohex-1-enyl]porphyrin (5cc): Yield: 50 mg (50%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.55–9.53(m, 2 H), 9.33–9.31 (m, 2 H), 9.03 (d, J = 4.5 Hz, 4 H), 8.02–8.00 (m, 4 H), 7.69–7.67 (m, 4 H), 2.70 (s, 6 H), –2.85 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –79.5 to –79.7 (m, 2 F), –81.5 to –81.6 (m, 6 F), –99.5 (dm, J = 148.9 Hz, 1 F), –115.7 to –115.8 (m, 2 F), –116.9 to –117.2 (m, 2 F), –121.6 to –121.8 (m, 2 F), –123.0 to –123.2 (m, 2 F), –124.3 to –124.5 (m, 2 F), –126.6 to –126.8 (m, 4 F), –159.2 (dm, J = 150.7 Hz, 1 F) ppm. MS (MALDI): m/z = 997.5 [M – C_7H_7]. UV/Vis (CH_2Cl_2): λ_{max} (%) = 412 (25), 512 (1.3), 549 (1.2), 592 (0.5), 646 (1). HPLC: 95% pure, t_R = 3.65 min, eluted with *n*-hexane, column: 4.6 × 250 mm. $C_{46}H_{24}F_{24}N_4$ (1088.1): calcd. C 50.75, H 2.22, N 5.15; found C 50.77, H 2.65, N 4.68.

Similarly, **5dc** was prepared in 60% yield from **1d** and **2c**.

15-(4-Chlorooctafluorobutyl)-10,20-diphenyl-5-[(*E*)-1,2,3,3,4,4,5,5,6,6,6-undecafluorohex-1-enyl]porphyrin (5dc): ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.52–9.50 (m, 2 H), 9.31–9.28 (m, 2 H), 8.97 (m, J = 4.5 Hz, 4 H), 8.19–8.15 (m, 4 H), 7.83–7.76 (m, 6 H), –2.89 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –67.3 to –67.4 (m, 2 F), –79.1 to –79.2 (m, 2 F), –80.5 to –80.7 (m, 3 F), –99.02 (dm, J = 152 Hz, 1 F), –114.3 to –126.1 (m, 10 F), –157.4 (dm, J = 148 Hz, 1 F). MS (MALDI): m/z = 976.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 410 (26), 512 (1.5), 546 (1.3), 590 (0.6), 643 (1). HRMS (MALDI): m/z calcd. for $C_{42}H_{20}ClF_{19}N_4 \cdot H^+$: 977.1146; found 977.1131.

Similarly, compounds **3aa** (14 mg, 20%) and **5aa** were formed by the reaction of **1a** with ClC_2F_4I (**2a**). The spectroscopic data of **3aa** are listed above.

15-(2-Chlorotetrafluoroethyl)-10,20-diphenyl-5-(1,2,2-trifluorovinyl)-porphyrin (5aa): Yield: 17 mg (25%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.55–9.53 (m, 2 H), 9.37 (9.38–9.36; m, 2 H), 8.94 (t, J = 4.8 Hz, 4 H), 8.18 (d, J = 6.6 Hz, 4 H), 7.86–7.75 (m, 6 H), –2.85 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –64.19 (s, 2 F), –77.85 (s, 2 F), –97.8 (dd, J = 27, 69 Hz, 1 F), –114.6 (dd, J = 70, 120 Hz, 1 F), –135.1 (dd, J = 29, 122 Hz, 1 F) ppm. MS (MALDI): m/z = 677.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 412 (28), 512 (1.5), 549 (1.2), 589 (0.6), 646 (1). HRMS (MALDI): m/z calcd. for $C_{36}H_{20}ClF_7N_4 \cdot H^+$: 677.1337; found 677.1330.

Similarly, compounds **3ca** and **5ca** were formed by the reaction of **1c** with ClC_2F_4I (**2a**).

5,15-Bis(2-chlorotetrafluoroethyl)-10,20-bis(3-methylphenyl)porphyrin (3ca): Yield: 15 mg (20%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.48 (m, 4 H), 8.90 (d, J = 5.4 Hz, 4 H), 7.96–7.94 (m, 4 H), 7.66–7.63 (m, 4 H), 2.67 (s, 6 H), –2.49 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –64.19 (s, 4 F), –79.78 (s, 4 F) ppm. MS (MALDI): m/z = 758.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 410 (18), 512 (0.9), 549 (1.1), 592 (0.4), 645 (1). $C_{38}H_{24}Cl_2F_8N_4 \cdot 1.5H_2O$ (785.1): calcd. C 58.75, H 3.74, N 6.94; found C 58.92, H 3.51, N 6.40.

15-(2-Chlorotetrafluoroethyl)-10,20-bis(3-methylphenyl)-5-(1,2,2-trifluorovinyl)porphyrin (5ca): Yield: 14 mg (20%). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 9.57 (m, 2 H), 9.41 (d, J = 4.8 Hz, 2 H), 8.90 (t, J = 5.1 Hz, 4 H), 8.03–8.01 (m, 4 H), 7.73–7.67 (m, 4 H), 2.70 (s, 6 H), –2.81 (s, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –63.78 (s, 2 F), –77.66 (s, 2 F), –97.1 (dd, J = 28.4, 69.1 Hz, 1 F), –114.0 (dd, J = 68.3, 120.2 Hz, 1 F), –134.6 (dd, J = 28.2, 121 Hz, 1 F) ppm. MS (MALDI): m/z = 704.2. UV/Vis (CH_2Cl_2): λ_{max} (%) = 413 (29), 512 (1.5), 548 (1.2), 591 (0.6), 645 (1). HRMS (MALDI): m/z calcd. for $C_{38}H_{24}ClF_7N_4 \cdot H^+$: 705.1650; found 705.1628.

Typical Procedure for the Synthesis of 6: A sample of **5aa** (20 mg, 0.03 mmol) was stirred in a mixture of refluxing toluene (10 mL) and H_2O (0.5 mL) for 24 h. After cooling to room temperature, the mixture was concentrated in vacuo. The residue was chromatographed on silica gel (hexanes/CH_2Cl_2, 10:1) and the blue band was collected to give **6a** (14 mg, 70%) as purple crystals from CH_2Cl_2/MeOH. ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 10.21–10.19 (m, 1 H), 9.82–9.81 (m, 1 H), 9.50–9.49 (m, 1 H), 9.28–9.19 (m, 3 H), 8.91 (d, J = 5.1 Hz, 1 H), 8.29–8.20 (m, 4 H), 7.90–7.81 (m, 6 H), –2.31 (s, 1 H), –3.02 (s, 1 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –63.12 (s, 2 F), –74.52 (m, 2 F), –93.54 (m, 2 F) ppm. MS (MALDI): m/z = 672.1. UV/Vis (CH_2Cl_2): λ_{max} (%) = 422 (14), 530 (0.6), 572 (0.9), 596 (0.5), 651 (1). HRMS (MALDI): m/z calcd. for $C_{36}H_{20}ClF_6N_4O$: 673.1224; found 673.1241. Compound **6b** was prepared in 80% yield according to the same procedure, starting from **5ab**. ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ = 10.22–10.19 (m, 1 H), 9.81–9.76 (m, 1 H), 9.46–9.44 (m, 1 H), 9.27–9.20 (m, 3 H), 8.93 (d, J = 5.1 Hz, 1 H), 8.36–8.16 (m, 4 H), 7.96–7.81 (m, 6 H), –2.18 (s, 1 H), –2.91 (s, 1 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$, F11): δ = –65.1 to –65.25 (2 dd, 2 F), –67.42 (t, J = 13.3 Hz, 2 F), –76.44 (m, 2 F), –113.49 to –116.71 (4 dd, 2 F), –113.7 (m, 2 F), –119.13 (m, 2 F), –148.41 (m, 1 F) ppm. MS (MALDI): m/z = 889.0. IR (KBr): $\tilde{\nu}$ = 1726 (s, C=O). UV/Vis (CH_2Cl_2): λ_{max} (%) = 423 (14), 532 (0.5), 573 (0.9), 598 (0.4), 653 (1). HRMS (MALDI): m/z calcd. for $C_{40}H_{20}Cl_2F_{13}N_4O$: 889.0801; found 889.0830.

Supporting Information (see footnote on the first page of this article): Selected characterization data (^{1}H and ^{19}F NMR spectra) for **5aa**, **5cb**, **6a**, and **6b**; deuterium-labeling experiments.

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