

Site-Selective *N*-Methylation of 5,15-Diazaporphyrins: Reactive Cationic Porphyrinoids that Provide Isoporphyrin Analogues

Wen Xi Chia,^[a] Mayu Nishijo,^[a] Seongsoo Kang,^[b] Juwon Oh,^[b] Tsubasa Nishimura,^[a] Hiroto Omori,^[a] Jean-François Longevial,^[a] Yoshihiro Miyake,^[a] Dongho Kim,^[b] and Hiroshi Shinokubo^{*[a]}

Abstract: *N*-Alkylation significantly changes the electronic and optical properties as well as the reactivity of nitrogen-containing π -conjugated molecules. In this study, we found that treating 5,15-diazaporphyrins with methyl triflate selectively affords the corresponding *N*-methyl-5,15-diazaporphyrinium cations in good yield. *N*-Methylation substantially alters the electronic properties and the reactivity of diazaporphyrins. The electron-accepting properties of the *N*-methyl-5,15-diazaporphyrinium cations are enhanced due to their lowered LUMO level. The stabilization of the LUMO energy enables regio- and stereoselective Diels–Alder reactions of the cationic diazaporphyrin with cyclopentadiene. *N*-Methylation also enhances the acidity of the inner NH protons, thus allowing facile deprotonation to provide nitrogen-substituted isoporphyrin analogues with only one NH group in the central cavity.

Introduction

The properties of nitrogen-containing π -conjugated systems can be drastically changed by *N*-alkylation of pyridine-type sp^2 -hybridized nitrogen atoms, which induces a positive charge on the molecule to enhance its electron-deficient nature. For example, *N*-methylation of 4,4'-bipyridyls provides methyl viologens, which are often used as effective electron-acceptor units.^[1] *N*-Alkylation of pyridine derivatives also affects their reactivity owing to a significant enhancement of the electrophilicity.^[2] The ionic nature and high polarity resulting from *N*-alkylation are essential to control biological activity such as antimicrobial properties and biopermeability.^[3]

Moreover, the fine-tuning of the electronic properties of porphyrins is essential to effectively generate catalytically active porphyrin-metal complexes.^[4] To access highly electron-deficient porphyrins, the creation of cationic porphyrins via the introduction of three or four alkyl groups on the core nitrogen atoms should be an effective strategy (Figure 1).^[5] However, multi-alkylation of porphyrins usually severely distorts their framework. More importantly, tri- or tetraalkylation of the porphyrin core preclude

the use of *N*-multi-methylated porphyrin cations as ligands for the coordination of metals.

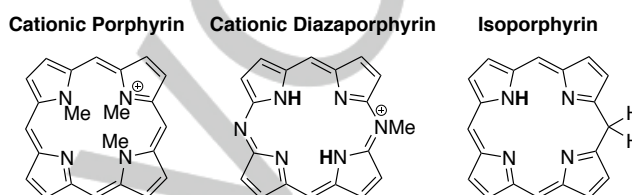


Figure 1. Core structures of cationic porphyrins, cationic 5,15-diazaporphyrins, and isoporphyrins.

Recently, 5,15-diazaporphyrins that bear two sp^2 -hybridized nitrogen atoms at the *meso*-positions of the porphyrin skeleton have emerged as a hybrid between porphyrins and phthalocyanines.^[6] The presence of the *meso*-nitrogen atoms renders the redox properties of the 5,15-diazaporphyrins flexible, which enabled the isolation of stable 18π , 19π , and 20π species.^[7] In addition, cationic 5,15-diazaporphyrin Ni(II) complexes with aryl groups at the *meso*-nitrogen atom have been prepared through one-electron oxidation of 19π diazaporphyrin radicals.^[7c]

We anticipated that *N*-methylation of 5,15-diazaporphyrins could occur selectively at the outer *meso*-nitrogen atoms on account of the steric congestion around the inner nitrogen atoms.^[8] Such selective *N*-methylation of one of the *meso*-nitrogen atoms not only affords cationic species by introducing only one methyl group, but also allows introducing various metals in the cationic diazaporphyrin ligand (Figure 1). Here, we disclose a highly site-selective monomethylation of 5,15-diazaporphyrins to provide *N*-methyl-5,15-diazaporphyrinium cations, and we also report their properties and reactivity. *N*-Methyldiazaporphyrinium cations exhibit a substantially electron-deficient nature. Furthermore, a free-base *N*-methyldiazaporphyrinium cation is susceptible to highly regio- and stereoselective Diels–Alder reactions with cyclopentadiene and to facile deprotonation of its inner NH protons, which yielded an isoporphyrin-type diazaporphyrin that contains only one NH proton in the cavity.

Results and Discussion

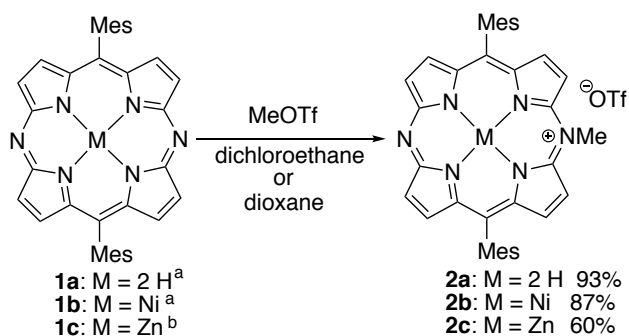
The synthesis of *N*-methyl-5,15-diazaporphyrinium cations **2a–2c** was accomplished by treatment of 5,15-diazaporphyrins **1a–1c** with methyl triflate (4.0 equiv) as the methylating agent. In the case of free-base **2a** and nickel complex **2b**, the reaction was conducted in 1,2-dichloroethane as the solvent. Although the *N*-

[a] W. X. Chia, M. Nishijo, T. Nishimura, Dr. H. Omori, Dr. J.-F. Longevial, Prof. Dr. Y. Miyake, Prof. Dr. H. Shinokubo
Department of Molecular and Macromolecular Chemistry, Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603 (Japan)
E-mail: hshino@chembio.nagoya-u.ac.jp

[b] S. Kang, Dr. J. Oh, Prof. Dr. D. Kim
Spectroscopy Laboratory for Functional π -Electronic Systems and Department of Chemistry, Yonsei University, Seoul 03722 (Korea)

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methylation of **1c** was sluggish, due to its low solubility in 1,2-dichloroethane, the use of 1,4-dioxane significantly improved the yield of **2c** (60%). Even in the presence of an excess (16.0 equiv) of methyl triflate, the *N,N*-dimethylated dication were not detected in the reaction mixture. It is also important to note that the inner nitrogen atoms were not methylated.



Scheme 1. Synthesis of *N*-methyl-5,15-diazaporphyrinium cations. Reaction conditions: a) methyl triflate (4.0 equiv), 1,2-dichloroethane, RT, 24 h. b) Methyl triflate (4.0 equiv), 1,4-dioxane, RT, 24 h.

The ¹H NMR spectrum of **2a** exhibits four sets of doublet peaks for the pyrrole β protons in the downfield region (δ = 8.7–9.6 ppm), confirming its less symmetric nature relative to **1a** on account of the methylation of only one *meso*-nitrogen atom. The signal of the inner two NH protons appears as a broad peak at δ = −1.26 ppm, which indicates that the methylation selectively occurs only at one of the peripheral nitrogen atoms. The pyrrole β protons of **2b** and **2c** also appear in the aromatic region. The chemical shifts of pyrrole β and the inner NH protons support the notion that the distinct aromatic character of the diazaphthalene is preserved after the *N*-methylation.

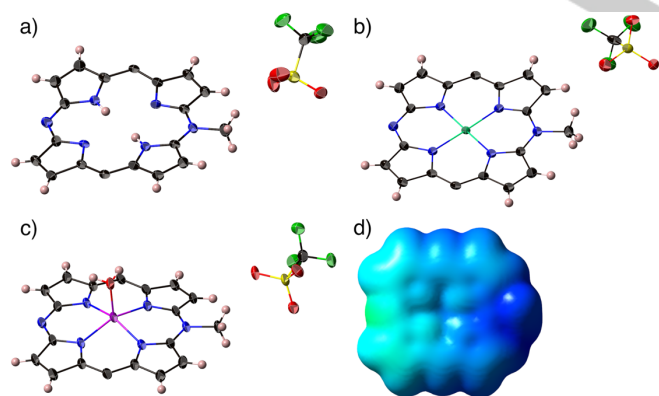


Figure 2. X-ray crystal structures of a) **2a**, b) **2b**, and c) **2c** with atomic displacement parameters at 50% probability; mesityl groups are omitted for clarity. d) Electrostatic potential map of **2a** calculated at the B3LYP/6-31G(d) level of theory; mesityl substituents were replaced with hydrogen atoms and the triflate anion was not included for the calculation.

The structures of the *N*-methyl-5,15-diazaporphyrinium cations **2a–2c** were unambiguously determined by X-ray

diffraction analyses (Figure 2). The presence of one triflate counter ion confirmed the monocationic nature of **2a–2c**. The diazaphthalene core maintains its planar conformation, although the *N*-methylation induces a slight distortion of the π -system. The mean deviation from planarity in **2a–2c** is 0.097, 0.046, and 0.084 Å, respectively.^[9] In the crystal packing of **2a–2c**, the triflate anion is located near to the *N*-methyl group, indicating hydrogen-bonding interactions between the methyl protons and the anion. The electrostatic potential map of **2a**, calculated at the B3LYP/6-31G(d) level of theory, suggests that the positive charge is effectively delocalized over the entire macrocyclic skeleton, albeit that the *N*-methyl protons are considerably positively charged (Figure 2d). In contrast, a significant interaction between the counter anion and the inner NH protons is not observed in **2a**.

Figure 3a displays the UV/vis absorption spectra of **2a–2c** in dichloromethane. Diazaporphyrinium cations **2a** and **2c** exhibit intensified and red-shifted Q-bands as well as broadened Soret bands compared to those of neutral 5,15-diazaphthalenes **1a** and **1c**, respectively. The Q-bands of **2b** are substantially broadened by the *N*-methylation. In accordance with the absorption spectral features, the fluorescence emission of **2a** and **2c** is bathochromically shifted compared to **1a** and **1c** (Figure 3b). Moreover, the fluorescence quantum yields of **2a** (Φ_F = 7.6%) and **2c** (Φ_F = 5.3%) in 1,2-dichlorobenzene are higher than those of **1a** (Φ_F = 3.8%) and **1c** (Φ_F = 1.5%).^[6c] The radiative rate of decay and the singlet-excited-state lifetime of **1a**, **1c**, **2a**, and **2c** were determined by a time-resolved fluorescence decay analysis, and the obtained results highlighted the effect of the symmetry-lowering by *N*-methylation (Table 1 and Figure S15). *N*-Methylation perturbs the four frontier orbitals of **1a** and splits the energies of the HOMO and HOMO−1 as well as those of the LUMO and LUMO+1 (Figure S16). This change in the electronic structure reduces the degree of degeneracy in the four frontier orbitals of **2a** to mitigate the forbidden nature of the S_1 – S_0 transition.

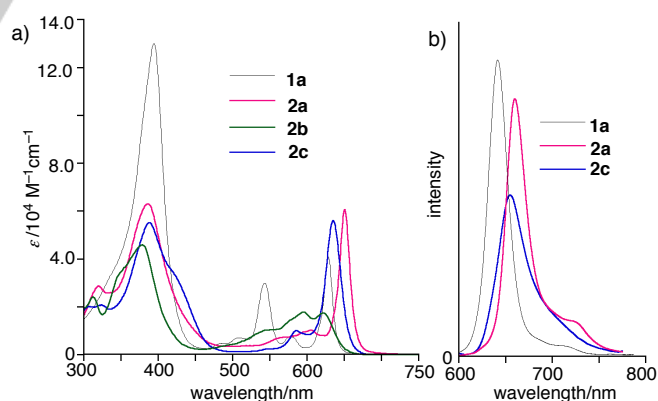
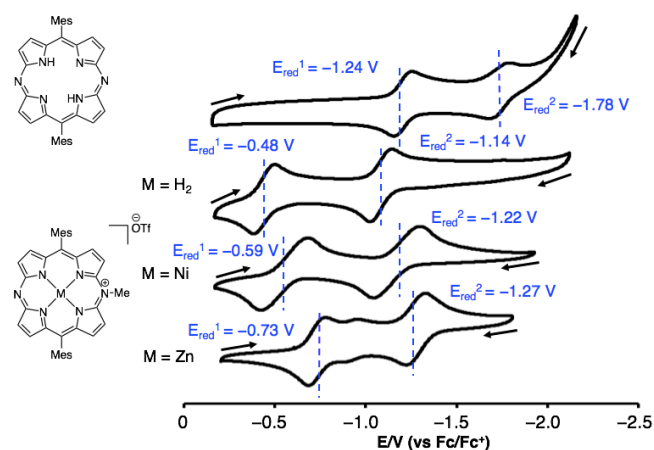


Figure 3. a) UV/vis absorption spectra of **1a**, **2a**, **2b**, and **2c**. b) Fluorescence spectra of **1a**, **2a**, and **2c**.

Table 1. Summary of photophysical data measured in 1,2-dichlorobenzene.

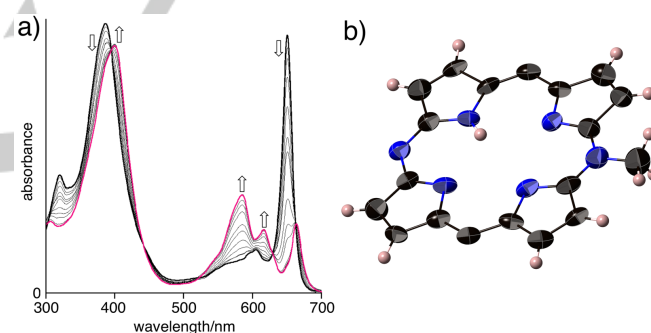
	1a	2a	1c	2c
quantum yield (%)	3.8	7.6	1.5	5.3
k_r (s ⁻¹)	1.65×10^7	3.04×10^7	3.13×10^7	5.30×10^7
k_{nr} (s ⁻¹)	4.18×10^8	3.70×10^8	2.05×10^9	9.47×10^8
singlet lifetime (ns)	2.3	2.5	0.48	1.0

Subsequently, we conducted an electrochemical analysis of the *N*-methyldiazaporphyrinium cations by cyclic voltammetry (Figure 4 and Table 2). The first reduction potentials of **2a** (−0.48 V vs ferrocene/ferrocenium), **2b** (−0.59 V), and **2c** (−0.73 V) are significantly higher than that of **1a** (−1.24 V). This result confirms the substantial enhancement of the electron-accepting nature of the diazaporphyrins upon *N*-methylation. The experimental results were supported by density functional theory (DFT) calculations at the B3LYP/6-31G(d) level of theory (Figure S16). *N*-Methylation stabilizes the LUMO more than the HOMO, given that in **2a**, the former exhibits large MO coefficients at the *meso*-nitrogen atoms, whereas the latter exhibits nodal positions there.

**Figure 4.** Cyclic voltammograms (100 mV s⁻¹) of **1a**, **2a**, **2b**, and **2c** in CH₂Cl₂ (0.1 M TBAPF₆). Working electrode: Glassy carbon, counter electrode: Pt, reference electrode: Ag/AgClO₄.**Table 2.** Summary of electrochemical data.

Compound	E_{red}^1	E_{red}^2
1a	−1.24	−1.78
2a	−0.48	−1.14
2b	−0.59	−1.22
2c	−0.73	−1.27

The positive charge on the diazaporphyrin skeleton should moreover enhance the acidity of the inner NH protons. Accordingly, we then investigated the deprotonation behavior of **2a** using bases. A titration experiment of **2a** with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) monitored by UV/vis absorption spectroscopy clearly indicated the formation of the new species **3** (Figure 5a), which was readily isolated in 86% yield by passing **2a** through amino-functionalized silica gel (Scheme 2). The structure of **3** was eventually confirmed by a single-crystal X-ray diffraction analysis (Figure 5b). Although the number of hydrogen-bonding interactions in the core is decreased relative to **2a**, the framework of **3** maintains a planar conformation. The mean plane deviation in **3** is 0.016 Å. The ¹H NMR spectrum of **3** exhibits only one NH proton at δ = 0.52 ppm, which suggests that **3** contains one amine-type NH and three imine-type nitrogen atoms in its cavity. This situation is reminiscent of free-base isoporphyrin, which is difficult to isolate due to its instability.^[10] In this regard, **3** may be considered a *N*-methylated diazaisoporphyrin. The pyrrole β proton signals appear as four doublet peaks from δ = 8.3–8.8 ppm, indicating a distinctly aromatic nature of **3**.

**Figure 5.** a) Changes of the UV/vis absorption spectra of **2a** in dichloromethane upon gradual addition of DBU (0–1.5 equiv). b) X-ray crystal structure of **3** with atomic displacement parameters at 50% probability; mesityl groups are omitted for clarity.**Scheme 2.** Deprotonation of *N*-methyl-5,15-diazaporphyrinium cation **2a**.

We then investigated the NH tautomerism of **2a** and **3** via variable-temperature ¹H NMR analysis. Although tautomerization of porphyrins has been extensively investigated,^[11] an isoporphyrin-type central cavity with only one NH proton is rare. Upon decreasing the temperature, the NH proton signal of **2a** in CD₂Cl₂ gradually broadened and finally split into two peaks

(Figure 6a). Below $-80\text{ }^{\circ}\text{C}$, **2a** clearly displays eight pyrrole β proton signals, indicating that the NH proton migration is frozen at that temperature (coalescence temperature: $-45\text{ }^{\circ}\text{C}$). The activation energy of the inner-proton exchange of **2a** was determined to be $10.7\text{ kcal mol}^{-1}$. In contrast, no such splitting of the inner NH and pyrrole β protons was observed in the ^1H NMR spectrum of **3** (Figure 6b). Proton migration of one NH proton in **2a** would probably be subject to steric repulsion due to the second NH proton in the cavity, which would most likely retard the tautomerization process. On the other hand, the comparatively lower steric congestion in the inner cavity of **3** should allow faster proton migration.

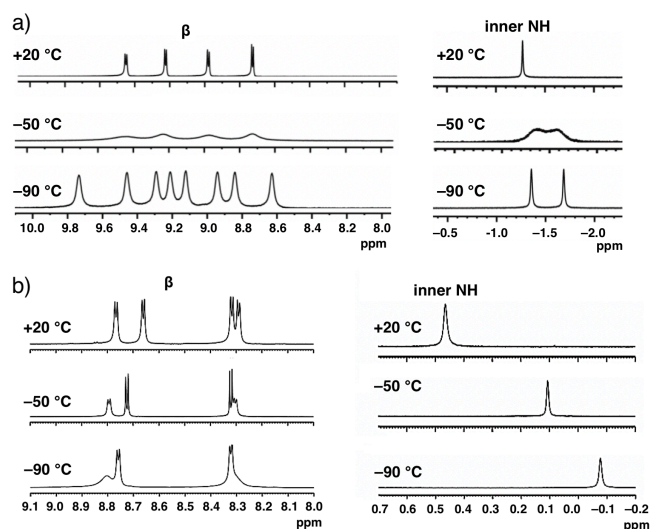
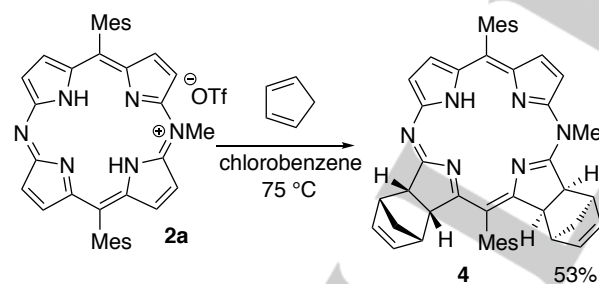


Figure 6. Variable-temperature ^1H NMR spectra of a) **2a** and b) **3** in CD_2Cl_2 .



Scheme 3. Diels–Alder reaction of **2a** with cyclopentadiene.

The results of the electrochemical analysis and DFT calculations clearly demonstrate that *N*-methylation substantially lowers the LUMO energy of diazaporphyrins. Such a drastic change should also affect the reactivity of the diazaporphyrinium cation. In order to examine this hypothesis, we chose the Diels–Alder reaction of **2a** to investigate the effect of *N*-methylation. Porphyrins act as dienophiles only with highly reactive dienes such as *o*-quinodimethane and isobenzofuran, while they are inert toward cyclopentadiene.^[12,13] Treatment of **2a** in the presence of 50 equiv of cyclopentadiene in chlorobenzene at $75\text{ }^{\circ}\text{C}$ afforded

bis-adduct **4** in 53% yield as a single isomer out of possible 28 isomers (Scheme 3). In sharp contrast, a Diels–Alder reaction between **1a** and cyclopentadiene did not proceed under the same reaction conditions. This result indicates that *N*-methylation facilitates the cycloaddition due to better energy matching of the HOMO of cyclopentadiene with the LUMO of **2a**.

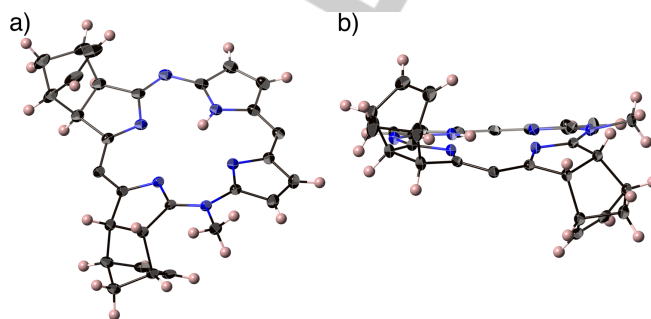


Figure 7. X-ray crystal structure of a) diagonal view and b) side view of **4** with atomic displacement parameters at 50% probability; mesityl groups are omitted for clarity.

The isoporphyrin-type structure of **4** was revealed by a single-crystal X-ray diffraction analysis, which indicated that the two-fold cycloaddition occurs in an *anti* fashion at two off-diagonal pyrrole sites (Figure 7a), and that each of the cycloadditions proceeds selectively in an *endo* mode (Figure 7b). A counter ion was not detected in the X-ray crystal structure, confirming the neutral state of **4**. The introduction of two fused bicyclic rings induced a slight distortion in the framework of **4**, i.e., the mean deviation from the plane is 0.178 Å . The ^1H NMR spectrum of **4** exhibited one NH proton peak, which supports the isoporphyrin-like cavity of **4**. The C–N bond lengths around the methylated nitrogen atom are longer than those of **2a**, which is indicative of an increased single-bond character.

Conclusions

We have synthesized *N*-methyl-5,15-diazaporphyrinium cations through the selective methylation of 5,15-diazaporphyrins and examined their intriguing properties and reactivity. *N*-Methylation of 5,15-diazaporphyrins considerably enhances their electron-accepting properties. The increased acidity of the inner NH protons of **2a** results in facile deprotonation, which yields *N*-methyl-5,15-diazaporphyrin **3** with only one NH group in the central cavity. The stabilized LUMO level of **2a** by *N*-methylation facilitates highly regio- and stereoselective double Diels–Alder reactions of **2a** with cyclopentadiene.

Experimental Section

Instrumentation and materials: ^1H NMR (500 MHz), ^{13}C NMR (126 MHz), and ^{19}F NMR (470 MHz) spectra were recorded on a Bruker AVANCE III HD spectrometer. Chemical shifts were reported as the delta scale in ppm relative to CDCl_3 ($\delta = 7.26\text{ ppm}$) and CD_3OD ($\delta = 3.31\text{ ppm}$) for ^1H NMR,

CDCl_3 ($\delta = 77.16$ ppm) and CD_3OD ($\delta = 49.00$ ppm) for ^{13}C NMR, and hexafluorobenzene ($\delta = -162.9$ ppm) for ^{19}F NMR. UV/vis absorption spectra were recorded on a Shimadzu UV-2550 spectrometer. Emission spectra were measured in 1 cm quartz cell on a JASCO FP-6500 spectrometer and absolute fluorescence quantum yields were determined by photon-counting method using an integration sphere. Mass spectra were recorded on a Bruker microTOF using APCI-TOF method. X-ray crystallographic data of **2a**, **2b**, **2c**, and **3** were taken on a Rigaku CCD diffractometer (Saturn 724 with MicroMax-007) with Varimax Mo optics using graphite monochromated Mo-K α radiation ($\lambda = 0.71075$ Å). X-ray crystallographic data of **4** was obtained using a Bruker D8 QUEST X-ray diffractometer with an I μ S microfocus X-ray source and a large area (10 cm \times 10 cm) CMOS detector (PHOTON 100). Unless otherwise noted, materials obtained from commercial suppliers were used without further purification.

Synthesis of N-methyl-10,20-dimesityl-5,15-diazaporphyrinium triflate 2a: A Schlenk tube containing 10,20-dimesityl-5,15-diazaporphyrin (**1a**, 16.46 mg, 0.030 mmol) was evacuated and then refilled with argon. To the flask, methyl triflate (4.0 equiv) and 1,2-dichloroethane (8 mL) were added. The bluish-green mixture was stirred for 24 h at the room temperature. The progress of the reaction was monitored by TLC analysis. After the reaction was completed, 1,2-dichloroethane was removed under reduced pressure. The residue was then recrystallized from CH_2Cl_2 /hexane to yield **2a** as a purple solid (19.99 mg, 93%). ^1H NMR (500 MHz, CDCl_3): δ 9.58 (d, $J = 5.1$ Hz, 2H, β -H), 9.20 (d, $J = 4.8$ Hz, 2H, β -H), 8.96 (d, $J = 5.2$ Hz, 2H, β -H), 8.72 (d, $J = 4.7$ Hz, 2H, β -H), 7.32 (s, 4H, Mes-*meta*), 6.35 (s, 3H, N-methyl), 2.64 (s, 6H, Mes-*para*), 1.83 (s, 12H, Mes-*ortho*), -1.26 (br s, 2H, inner NH) ppm; ^{13}C NMR (500 MHz, CDCl_3 , 318.15 K): δ 140.20, 138.97, 137.49, 135.93, 134.12, 134.05, 129.56, 128.77, 125.07, 29.86, 21.71, 21.56 ppm; ^{19}F NMR (500 MHz, CDCl_3): δ -81.40 ppm; UV/vis (CH_2Cl_2): λ_{max} (ϵ [$\text{M}^{-1}\text{cm}^{-1}$]) = 320 (28700), 386 (63000), 651 (60550), and 605 (10325) nm; HR-MS (APCI-MS): $m/z = 563.2908$, calcd for $(\text{C}_{37}\text{H}_{35}\text{N}_6)^+ = 563.2917$ [(M) $^+$].

Synthesis of Ni(II) N-methyl-10,20-dimesityl-5,15-diazaporphyrinium triflate 2b: A Schlenk tube containing Ni(II) 10,20-dimesityl-5,15-diazaporphyrin (**1b**, 54.48 mg, 0.090 mmol) was evacuated and then refilled with argon. To the flask, methyl triflate (4.0 equiv) and 1,2-dichloroethane (23 mL) were added. The blue mixture was stirred for 24 h at the room temperature. The progress of the reaction was monitored by TLC analysis. After the reaction was completed, 1,2-dichloroethane was removed under reduced pressure. The residue was then recrystallized from CH_2Cl_2 /hexane to yield **2b** as a dark purple solid (60.54 mg, 87%). ^1H NMR (500 MHz, CDCl_3): δ 9.57 (d, $J = 5.5$ Hz, 2H, β -H), 9.16 (d, $J = 5.0$ Hz, 2H, β -H), 8.92 (d, $J = 5.0$ Hz, 2H, β -H), 8.72 (d, $J = 5.0$ Hz, 2H, β -H), 7.28 (s, 4H, Mes-*meta*), 6.24 (s, 3H, N-methyl), 2.60 (s, 6H, Mes-*para*), 1.79 (s, 12H, Mes-*ortho*) ppm; ^{13}C NMR (500 MHz, CDCl_3): δ 152.30, 148.17, 146.52, 144.21, 140.04, 138.63, 138.61, 137.91, 135.61, 133.10, 128.71, 127.57, 126.27, 46.61, 21.60, 21.56 ppm; UV/vis (CH_2Cl_2): λ_{max} (ϵ [$\text{M}^{-1}\text{cm}^{-1}$]) = 314 (24255), 388 (46000), 628 (17877), and 658 (17459) nm; HR-MS (APCI-MS): $m/z = 619.2098$, calcd for $(\text{C}_{37}\text{H}_{33}\text{N}_6\text{Ni})^+ = 619.2115$ [(M) $^+$].

Synthesis of Zn(II) N-methyl-10,20-dimesityl-5,15-diazaporphyrinium triflate 2c: A Schlenk tube containing Zn(II) 10,20-dimesityl-5,15-diazaporphyrin (**1c**, 24.25 mg, 0.040 mmol) was evacuated and then refilled with argon. To the flask, methyl triflate (4.0 equiv) and 1,4-dioxane (10 mL) were added. The green mixture was stirred for 24 h at the room temperature. The progress of the reaction was monitored by TLC analysis. After the reaction was completed, 1,4-dioxane was removed under reduced pressure. The residue was subjected on silica gel column chromatography (MeOH/EtOAc = 1/20 as an eluent) and was then recrystallized from CH_2Cl_2 /hexane to yield **2c** as a purple solid (18.54 mg,

60%). ^1H NMR (500 MHz, CD_3OD): δ 9.10 (d, $J = 4.5$ Hz, 2H, β -H), 9.01 (d, $J = 4.5$ Hz, 2H, β -H), 8.81 (d, $J = 5.0$ Hz, 2H, β -H), 8.58 (d, $J = 4.5$ Hz, 2H, β -H), 7.27 (s, 4H, Mes-*meta*), 6.04 (s, 3H, N-methyl), 2.62 (s, 6H, Mes-*para*), 1.87 (s, 12H, Mes-*ortho*) ppm; ^{13}C NMR (500 MHz, CD_3OD): δ 160.08, 156.50, 155.54, 151.61, 140.69, 140.01, 137.96, 137.93, 137.15, 136.62, 135.41, 129.28, 126.25, 45.27, 21.87, 21.52 ppm; UV/vis (CH_2Cl_2): λ_{max} (ϵ [$\text{M}^{-1}\text{cm}^{-1}$]) = 324 (20863), 388 (55146), 586 (10005), and 635 (56000) nm; HR-MS (APCI-MS): $m/z = 625.2031$, calcd for $(\text{C}_{37}\text{H}_{33}\text{N}_6\text{Zn})^+ = 625.2053$ [(M) $^+$].

Synthesis of N-methyl-5,15-diazaisoporphyrin 3: N-Methyl-10,20-dimesityl-5,15-diazaporphyrinium triflate **2a** was subjected on amino functionalized silica gel chromatography (MeOH as an eluent) to yield **3** in 86% yield as a purple solid. ^1H NMR (500 MHz, CDCl_3): δ 8.80 (d, $J = 4.5$ Hz, 2H, β -H), 8.62 (d, $J = 5.0$ Hz, 2H, β -H), 8.38 (d, $J = 4.5$ Hz, 2H, β -H), 8.31 (d, $J = 4.5$ Hz, 2H, β -H), 7.22 (s, 4H, Mes-*meta*), 5.76 (s, 3H, N-methyl), 2.58 (s, 6H, Mes-*para*), 1.90 (s, 12H, Mes-*ortho*), 0.52 (br s, 1H, inner NH) ppm; ^{13}C NMR (500 MHz, CDCl_3): δ 156.54, 139.30, 138.15, 137.30, 136.84, 127.96, 124.55, 29.50, 22.27, 21.52 ppm; UV/vis (CH_2Cl_2): λ_{max} (ϵ [$\text{M}^{-1}\text{cm}^{-1}$]) = 400 (60400), 585 (24839), 616 (16282), 663 (17614) nm; HR-MS (APCI-MS): $m/z = 563.2913$, calcd for $(\text{C}_{37}\text{H}_{35}\text{N}_6)^+ = 563.2918$ [($M + H$) $^+$].

Synthesis of Diels–Alder Adduct 4: A Schlenk tube containing **2a** (21.0 mg, 0.03 mmol) was evacuated and then refilled with argon. To the flask, cyclopentadiene (50 equiv) and chlorobenzene (3 mL) were added. The mixture was heated to 75 °C and stirred for 6 h. The progress of the reaction was monitored by TLC analysis. After the reaction was completed, chlorobenzene was removed under reduced pressure. The solid residue was subjected on silica gel column chromatography (MeOH as an eluent) to yield **4** (11.0 mg, 53%). ^1H NMR (500 MHz, CDCl_3): δ 7.44 (d, $J = 4.4$ Hz, 1H, β -H), 7.37 (d, $J = 2.9$ Hz, 1H, β -H), 7.36 (d, $J = 3.0$ Hz, 1H, β -H), 7.28 (d, $J = 4.4$ Hz, 1H, β -H), 7.17 (s, 1H, Mes-*meta*), 7.15 (s, 1H, Mes-*meta*), 7.03 (s, 2H, Mes-*meta*), 5.81 (br s, 1H, inner NH), 5.73 (dd, $J_1 = 5.6$, $J_2 = 2.7$ Hz, 1H, sp^3 β -H), 5.67 (dd, $J_1 = 5.6$, $J_2 = 2.8$ Hz, 1H, sp^3 β -H), 5.61 (dd, $J_1 = 5.6$, $J_2 = 2.9$ Hz, 1H, sp^3 β -H), 5.48 (dd, $J_1 = 5.6$, $J_2 = 2.7$ Hz, 1H, sp^3 β -H), 4.68 (s, 3H, N-methyl), 4.53 (dd, $J_1 = 7.0$, $J_2 = 4.3$ Hz, 1H), 4.32 (dd, $J_1 = 7.2$, $J_2 = 4.9$ Hz, 1H), 4.09 (dd, $J_1 = 7.1$, $J_2 = 4.2$ Hz, 1H), 3.91 (dd, $J_1 = 7.2$, $J_2 = 4.3$ Hz, 1H), 3.70 (s, 1H), 3.65 (s, 1H), 2.62 (s, 1H), 2.5 (s, 1H), 2.47 (s, 3H, Mes-*para*), 2.46 (s, 3H, Mes-*para*), 2.31 (s, 3H, Mes-*ortho*), 2.22 (s, 3H, Mes-*ortho*), 1.95 (s, 3H, Mes-*ortho*), 1.93 (s, 3H, Mes-*ortho*), 1.60 (d, $J = 8.1$ Hz, 1H), 1.55 (d, $J = 8.3$ Hz, 1H), 1.50 (d, $J = 7.9$ Hz, 1H), 1.46 (d, $J = 8.0$ Hz, 1H) ppm; ^{13}C NMR (500 MHz, CDCl_3): δ 182.74, 175.10, 172.63, 170.94, 155.09, 146.84, 143.54, 138.65, 138.46, 138.16, 137.90, 137.66, 137.27, 137.21, 136.24, 136.17, 136.07, 133.74, 133.50, 132.87, 132.28, 129.53, 129.28, 129.15, 127.62, 125.07, 115.82, 115.75, 114.89, 55.65, 54.27, 53.19, 51.74, 51.46, 51.40, 47.30, 46.88, 46.79, 46.61, 41.58, 21.43, 21.40, 21.13, 20.90, 20.81, 20.65 ppm; UV/vis (CH_2Cl_2): λ_{max} (ϵ [$\text{M}^{-1}\text{cm}^{-1}$]) = 385 (72000), 539 (10226), 578 (14800) nm; HR-MS (APCI-MS): $m/z = 695.3881$, calcd for $(\text{C}_{47}\text{H}_{46}\text{N}_6)^+ = 695.3857$ [($M + H$) $^+$].

Crystallographic data for 2a (CCDC-1962797): Single crystals were obtained by vapor diffusion of hexane into a chloroform solution of **2a**. $\text{C}_{39}\text{H}_{36}\text{Cl}_3\text{F}_3\text{N}_6\text{O}_3\text{S}$, $M_w = 712.24$, triclinic, space group $P-1$, $a = 8.525(3)$, $b = 18.511(6)$, $c = 25.137(4)$ Å, $\alpha = 102.926(6)$, $\beta = 90.757(4)$, $\gamma = 91.873(5)^\circ$, $V = 3863(2)$ Å 3 , $Z = 4$, $D_{\text{calc}} = 1.431$ g/cm 3 , $T = 123$ K, $R = 0.0722$ ($I > 2.0 \sigma(I)$), $R_w = 0.1929$ (all data), GOF = 1.065.

Crystallographic data for 2b (CCDC-1962798): Single crystals were obtained by vapor diffusion of heptane into a toluene solution of **2b**. $\text{C}_{45}\text{H}_{41}\text{F}_3\text{N}_6\text{NiO}_3\text{S}$, $M_w = 768.16$, monoclinic, space group $P2_1/c$, $a = 13.5284(4)$, $b = 17.4810(4)$, $c = 16.6553(3)$ Å, $\beta = 91.099(2)^\circ$, $V =$

3938.09(16) Å³, $Z = 4$, $D_{\text{calc}} = 1.453 \text{ g/cm}^3$, $T = 93 \text{ K}$, $R = 0.0460$ ($I > 2.0 \sigma(I)$), $R_w = 0.1289$ (all data), GOF = 1.053.

Crystallographic data for 2c (CCDC-1962799): Single crystals were obtained by vapor diffusion of hexane into a chloroform solution of **2c**. $\text{C}_{38}\text{H}_{35}\text{F}_3\text{N}_6\text{O}_4\text{SZn}$, $M_w = 774.16$, triclinic, space group $P\bar{1}$, $a = 11.6465(4)$, $b = 16.1710(5)$, $c = 21.2708(5) \text{ Å}$, $\alpha = 79.631(2)$, $\beta = 75.325(3)$, $\gamma = 72.317(3)^\circ$, $V = 3669.1(2) \text{ Å}^3$, $Z = 4$, $D_{\text{calc}} = 1.438 \text{ g/cm}^3$, $T = 93 \text{ K}$, $R = 0.0667$ ($I > 2.0 \sigma(I)$), $R_w = 0.1701$ (all data), GOF = 1.032.

Crystallographic data for 3 (CCDC-1962800): Single crystals were obtained by evaporation of a chloroform solution of **3**. $\text{C}_{39}\text{H}_{38}\text{Cl}_4\text{N}_6$, $M_w = 732.55$, orthorhombic, space group $Pca2_1$, $a = 15.8025(6)$, $b = 15.4549(4)$, $c = 14.6721(4) \text{ Å}$, $V = 3583.31(19) \text{ Å}^3$, $Z = 4$, $D_{\text{calc}} = 1.358 \text{ g/cm}^3$, $T = 93 \text{ K}$, $R = 0.0518$ ($I > 2.0 \sigma(I)$), $R_w = 0.1333$ (all data), GOF = 1.059.

Crystallographic data for 4 (CCDC-1962801): Single crystals were obtained by vapor diffusion of octane into a toluene solution of **4**. $\text{C}_{61}\text{H}_{62}\text{N}_6$, $M_w = 879.16$, monoclinic, space group $P2_1/n$, $a = 14.7329(9)$, $b = 11.1590(7)$, $c = 29.8131(19) \text{ Å}$, $\beta = 92.574(2)^\circ$, $V = 4896.5(5) \text{ Å}^3$, $Z = 4$, $D_{\text{calc}} = 1.193 \text{ g/cm}^3$, $T = 107 \text{ K}$, $R = 0.0470$ ($I > 2.0 \sigma(I)$), $R_w = 0.1198$ (all data), GOF = 1.025.

Electrochemical analysis: Cyclic voltammograms of **1a**, **2a**, **2b**, and **2c** were recorded using an ALS electrochemical analyzer 612C. Measurements were performed in freshly distilled CH_2Cl_2 with tetrabutylammonium hexafluorophosphate as the electrolyte. A three-electrode system was used. The system consisted of a platinum working electrode, a platinum wire, and Ag/AgClO_4 as the reference electrode. The scan rate was 100 mV s^{-1} . The measurement was performed under nitrogen atmosphere. All potentials are referenced to the potential of ferrocene/ferrocenium cation couple.

Picosecond time-resolved fluorescence measurements: A time-correlated single-photon-counting (TCSPC) system was used for measurements of spontaneous fluorescence decay. As an excitation light source, we used a mode-locked Ti:sapphire laser (Spectra Physics, MaiTai BB) which provides ultrashort pulse (center wavelength of 800 nm with 80 fs at the full width at half maximum) with high repetition rate (80 MHz). This high repetition rate was reduced to 800 kHz by using homemade pulse-picker. The pulse-picked output was frequency doubled by a 1-mm-thick BBO crystal (type-I, $\theta = 29.2^\circ$, EKSMA). The fluorescence was collected by a microchannel plate photomultiplier (MCP-PMT, Hamamatsu, R3809U51) with a thermoelectric cooler (Hamamatsu, C4878) connected to a TCSPC board (Becker & Hickel SPC-130). The overall instrumental response function was about 25 ps. A vertically polarized pump pulse by a Glan-laser polarizer was irradiated to samples, and a sheet polarizer set at an angle complementary to the magic angle (54.7°), was placed in the fluorescence collection path to obtain polarization-independent fluorescence decays.

Theoretical calculations: All calculations were performed using the Gaussian 09 program.^[14] Geometries of **1a** and **2a** were obtained from their X-ray crystal structures but the *meso*-mesityl substituents were replaced with hydrogen atoms. Their structures were fully optimized without any symmetry restriction at the Becke's three-parameter hybrid exchange functional and the Lee–Yang–Parr correlation functional (B3LYP)^[15,16] and 6-31G(d) basis sets.

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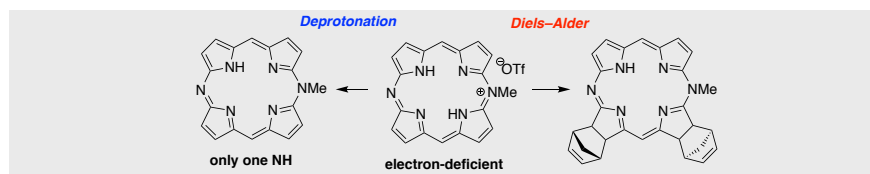
Keywords: porphyrinoid • aromaticity • Diels–Alder reaction • onium salt

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FULL PAPER



Treatment of 5,15-diazaporphyrins with methyl triflate selectively provides *N*-methyl diazaporphyrinium cations, which exhibit strong electron-deficiency and increased reactivity. The former manifests in facile deprotonations that afforded a nitrogen-substituted isoporphyrin analogue. The latter is reflected in a highly regio- and stereoselective Diels–Alder reaction with cyclopentadiene, which proceeds due to the effective lowering of the LUMO level by *N*-methylation.

W. X. Chia, M. Nishijo, S. Kang, J. Oh, T. Nishimura, H. Omori, J.-F. Longevial, Y. Miyake, D. Kim, and H. Shinokubo*

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Site-Selective N-Methylation of 5,15-Diazaporphyrins: Reactive Cationic Porphyrinoids that Provide Isoporphyrin Analogues