Pergamon

Tetrahedron Letters 41 (2000) 3583–3587

TETRAHEDRON
LETTERS

Coplanar conjugated β-nitroporphyrins and some aspects of nitration of porphyrins with N_2O_4

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Received 8 February 2000; accepted 7 March 2000

Abstract

Sterically controlled N_2O_4 nitration of a *meso*-2,3-unsubstituted porphyrin or a bis-α-unsubstituted pyrroloporphyrin affords coplanar conjugated β-nitroporphyrins displaying strong electronic interactions.

Keywords: aromaticity; nitration; nitro compounds; porphyrins; substitution.

The versatility of β-nitroporphyrins in porphyrin chemistry has been well-recognized. They serve as Michael acceptors and react with a wide range of nucleophiles to give 2,3-disubstituted porphyrins, chlorins and pyrroloporphyrins or undergo various nucleophilic aromatic substitutions.[1] They have also been investigated as biomimetic oxidation catalysts[2] and as potential nonlinear optical materials.[3] INDO/SCI calculations showed that large red solvatochromic shifts could be expected for porphyrins bearing a β-nitro group lying in the plane (or nearly so) of the porphyrin ring.[4] However, the visible spectra of metal free and Cu(2-NO_2TPP) were unaffected by a change in the solvent polarity which suggested a similar electron distribution in the ground and the first excited states due to a near 90° dihedral angle between the nitro group and the porphyrin ring.

A few *meso*-unsubstituted β-nitroporphyrins[5] and a 2,3-dinitroporphyrazine[6] have been prepared, but the nitro groups were sterically prevented from becoming coplanar with the porphyrin ring. One remaining challenge, therefore, was to develop porphyrins bearing nitro substituents free of steric hindrance from abutting *meso*- or β-substituents, potentially leading to new molecules possessing strongly perturbed absorption spectra. Peripheral functionalization of a tetra-*meso*-arylporphyrin by a series of olefin-bridged electron acceptor groups has recently been shown to yield porphyrins with remarkable electronic interactions[7] and prompted us to report our concurrent investigation of π-conjugated coplanar nitroporphyrins. Furthermore, N_2O_4 nitration studies reported herein shed light on a possible ionic mechanistic pathway that has been previously overlooked in favor of the formation of π-cation radical intermediates (vide infra).[8,9]

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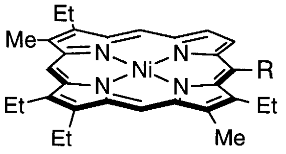
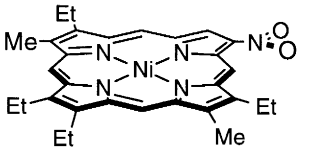
0040-4039/00/$ - see front matter
PII: S0040-4039(00)00468-8

Reactions at the periphery of metalloporphyrins occur preferentially on the *meso*-positions; exceptions (e.g. bromination, formylation) can be explained as arising from significant steric impediment to such attack. However, nitration reactions of metal free or metalloporphyrins afforded exclusively products which are functionalized at the *meso*-position rather than the β-positions when both types of positions are available for reaction. Nitration of deuteroporphyrin IX (e.g. a *meso*-unsubstituted 3,8-di-unsubstituted porphyrin) occurred at the *meso*- (5 or/and 20) positions (IUPAC nomenclature).[10] Nitration of porphyrin[11] or 5,15-diphenylporphyrins[12] afforded also some mono- or di-*meso*-nitrated products. While the N_2O_4 nitration of 5,10,15,20-tetraphenylporphyrin (TPP) was directed to the beta position by coordination with electronegative metals such as nickel(II) and copper(II), the aryl-substituent did not prevent attack at the *meso*-position in the magnesium(II) or zinc(II) chelates, underlining that the nitration reaction was under electronic rather than steric control.[9]

We prepared nickel(II) 2,7,8,13-tetraethyl-3,12-dimethylporphyrin **1** (bearing two adjacent unhindered β-unsubstituted positions but where the *meso*-positions have at least one abutting β-substituent)[13] in order to determine if the predominant electronic effect leading to *meso*-nitration could be overridden by careful use of steric effects. Treatment of a solution of **1** in CH_2Cl_2 with a solution of N_2O_4 in petroleum ether afforded the red *meso*-nitroporphyrin **2** and the green β-nitroporphyrin **3** in 32 and 20% yield, respectively.[14] By using iodine/silver nitrite in CH_2Cl_2/CH_3CN,[15] **2** and **3** were obtained after chromatography on silica gel in 10 and 52% yield. This is the first example where β-nitration has been shown to compete with *meso*-nitration.



1: R = H
2: R = NO_2



3

UV–vis absorption spectra of **2** and **3** are shown in Fig. 1. The *meso*-nitro group in **2**, sterically forced out of planarity, cannot conjugate effectively with the macrocycle. Indeed, 5-nitroporphyrin **2** possessed a typical optical spectrum, slightly red shifted compared with **1**, as expected for introduction of a *meso*-nitro group.[15] The absorption spectrum of **3** displayed split Soret bands at 371 and 426 nm and one intense Q-band absorption at 602 nm, the signature of an effective intramolecular charge transfer.[16] Theoretical calculations on 2-nitroporphyrins have shown that a coplanar nitro group would result in a splitting of the Soret band by 15–45 nm.[4] Such perturbed UV–vis spectra were observed for a series of nickel(II) tetra-*meso*-(*p*-isopropylphenyl)porphyrins β-conjugated with an electronic acceptor through an olefinic bridge.[7] The UV–vis spectra of **3** was found to be somewhat insensitive to change in the dielectric constant of the medium, experiencing shifts no larger than 10 nm (from toluene to acetonitrile as solvents).

In **3**, the magnetic anisotropy of a coplanar β-nitro group places the abutting β-proton in a region of strong negative shielding (β-H observed at 9.68 ppm), whereas the shielding of the four *meso*-protons (8.41–8.81 ppm) stems from a strongly reduced aromatic ring current. Indeed, the nitro group acts as a powerful electron-withdrawing group by resonance effects, those being sterically accessible. In the IR spectra of **2**, peaks at 1523 and 1365 cm^{-1} were attributed, respectively, to the asymmetric and symmetric stretching modes of NO_2.[17] For **3**, these peaks, found at 1457 and 1327 cm^{-1}, support the conjugation of the nitro group with the π-system leading to a decrease in both frequencies. In summary, our data point to a β-nitro group lying in the plane of the porphyrin macrocycle.[18]

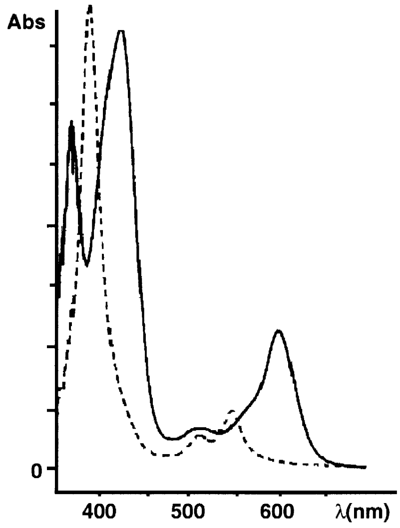
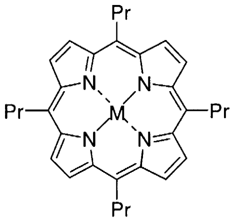
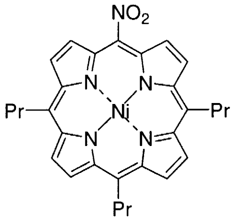


Fig. 1. UV–vis spectra (CH_2Cl_2) of **2** (dotted line) and **3** (full) in at 20°C



4: M = Cu
5: M = Ni



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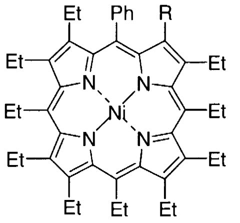
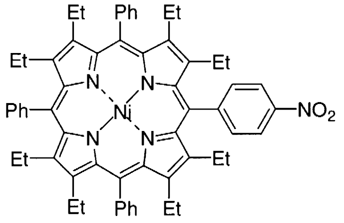


7: R = Et
8: R = NO_2



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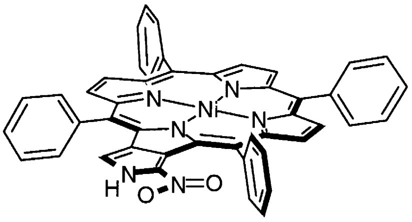
In electron-rich tetra-*meso*-propylporphyrin **4**–**5**, electronegative metals did not prevent electrophilic attack at the *meso*-positions. N_2O_4 [or $Cu(NO_3)_2$][19] nitration of **4** led to ring opening, blue bilinone formation, and decomposition. Careful and rapid nitration of the nickel(II) complex **5** with N_2O_4 produced the 5-nitroporphyrin **6** in 36% yield instead of the expected β-nitroporphyrin. Nitration (N_2O_4 or $AgNO_2/I_2$) of nickel(II) octaethyl-tetra-*meso*-phenylporphyrin **7** led, among other non-characterized compounds, to the substitution of one β-ethyl group affording the green β-nitroporphyrin **8** and to the formation of the more polar brown *p*-nitrophenylporphyrin **9**. By analogy with the nitration proposed for the NO_2/N_2O_4 nitration of Ni(TPP),[9] the reactions affording **6** and **8** could be interpreted as proceeding by an initial oxidation of the porphyrin followed by radical combination of the porphyrin π-cation radical with $NO_2^{\cdot}$. They could also involve direct attack of a nitronium ion and subsequent re-aromatization (in both homolytic or ionic pathways) via carbonium ion ($CH_3CH_2^+$ or $C_2H_5CH_2^+$) loss. Electrophilic dealkylative nitrations with nitronium ions (carried out with NO_2BF_4) are known for secondary or tertiary alkylbenzenes; however no cleavage was observed for *n*-propylbenzenes.[20] Eberson and Radner stressed that the $NO_2^{\cdot}$ nitration of porphyrins might be identical with a nitrous acid catalyzed nitration.[21] Hydrolysis of N_2O_4 to HONO and $HONO_2$ is promoted by solvents with dielectric constants of the order or higher than CH_2Cl_2, catalyzed by water and acids, and inhibited by non-nucleophilic bases.[22] The N_2O_4 nitration of Ni(TPP) did not proceed in CH_2Cl_2 in the presence of 2,4,6-collidine, pointing to an ionic pathway.

We decided to investigate the nitration of nickel(II) pyrrolo[3,4-*b*]-tetra-*meso*-phenylporphyrin as a mechanistic probe for further distinguishing between radical and ionic nitration pathways. These fused porphyrins undergo typical pyrrole chemistry;[23] therefore, an aromatic electrophilic substitution taking place at the α-unsubstituted positions of the pyrrole could indicate an ionic-based mechanism. N_2O_4 nitration of nickel(II) pyrrolo[3,4-*b*]-5,10,15,20-tetraphenylporphyrin in CH_2Cl_2 gave α-nitropyrroloporphyrin **10** in 70% yield.[14] Such regioselectivity could be expected from an electrophilic attack of NO_2^+ on an electron-rich pyrrole. When the nitration was carried out on a 'deactivated' nickel(II) α-carbethoxypyrroloporphyrin,[23] a non-regioselective substitution occurred on the porphyrin ring. The absorption spectra of **10** is shown in Fig. 2 and displayed split and broadened Soret and Q-bands. Again, the strong π-acceptor properties of the nitro group strongly alter the photophysical properties of the chromophore.



10

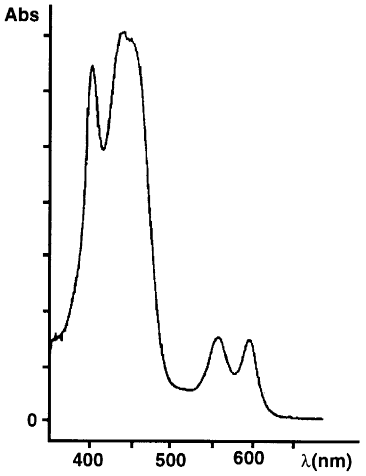


Fig. 2. UV–vis spectrum of **10** (CH_2Cl_2) at 20°C

We have demonstrated that β-nitration of porphyrins could compete with *meso*-nitration and, due to the strong π-acceptor properties of the nitro group, leads to strong interactions with the porphyrin π-system.

Acknowledgements

We thank the National Institutes of Health (HL 22252) and the National Science Foundation (CHE-99-04076) for support of this research.

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14. Selected data for **3**: λ_{max} (CH_2Cl_2), nm (ε) 371 (50 000), 426 (65 500), 510 (6000), 520 (6000), 602 (21 500); ^{1}H NMR ($CDCl_3$) δ 1.40–1.80 (m, 12H), 3.04, 3.06 (each s, 3H), 3.26, 3.38 (each q, 2H), 3.62 (m, 4H), 8.41 (s, 1H), 8.73 (s, 1H), 8.81 (s, 1H), 8.88 (s, 1H), 9.68 (s, 1H). For **10**: λ_{max} (CH_2Cl_2), nm (ε) 408 (60 500), 444 (73 000), 460 (71 500), 560 (12 500), 598 (17 500); ^{1}H NMR (DMSO-d_6) δ 6.00 (s, 1H), 7.60–8.10 (m, 20H), 8.13 (d, 1H), 8.50 (d, 1H), 8.60 (m, 3H), 8.73 (d, 1H).
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