Diporphyrinyl Derivatives of 1,10-Phenanthroline and 2,2′-Bipyridyl

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The title derivatives were synthesized containing two meso-tri-*p*-tolylpheneleneporphyrin units attached *via* amide bridges to 4,7- and 4,4′ positions of the respective heteroaromatic spacers.

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Attaching two porphyrin units, P to an azaheteroaromatic molecule like 1,10-phenanthroline, PN or 2,2′-bipyridyl, BP (which are able to form bis- and tris-chelate metal complexes), gives one the chance to synthesize $(P_2\text{-}PN)M(PN)_{2,3}$, $(P_2\text{-}PN)_2M(PN)_{0,1}$ and $(P_2\text{-}PN)_3M$ porphyrinyl systems and the respective complexes containing BP instead of PN. Those of them containing four or six porphyrin or metalloporphyrin rings could be called "antenna" porphyrins because of their location in an antenna-like fashion around the central complexing metal. It is reasonable to expect that these systems will reveal interesting physicochemical properties, some of them originating from the particular 3D architecture and the presence of multimetallic centers, those in the porphyrin rings having the potential of different axial ligation, *e.g.* of nucleobases [1], or cross-ligation. The structures also might spark biochemical interest, for instance some P, $M(PN)_{2,3}$ or $M(BP)_{2,3}$ structural units are capable of interaction with DNA [2-4]. When complexating only one molecule by the metal center, *e.g.*, $(P_2\text{-}PN)Cu(II)Cl_2$, the resulting diporphyrins might act as potential restriction enzyme models [4] or be involved in interaction with nucleoside monophosphates [5] resulting in, yet not known, porphyrin-nucleoside mixed ligand complexes.

Continuing our interest in the meso-(aza)arylporphyrins [6-8] we now report two new systems, each containing two porphyrin units attached *via* an amide bridge to the 4,7 positions of 1,10-phenanthroline and 4,4′-positions of 2,2′-bipyridyl, Figure 1. They represent, respectively, the *N*,*N*′-di(5-*p*-phenylene-10,15,20-tri-*p*-tolylporphyrin)-1,10-

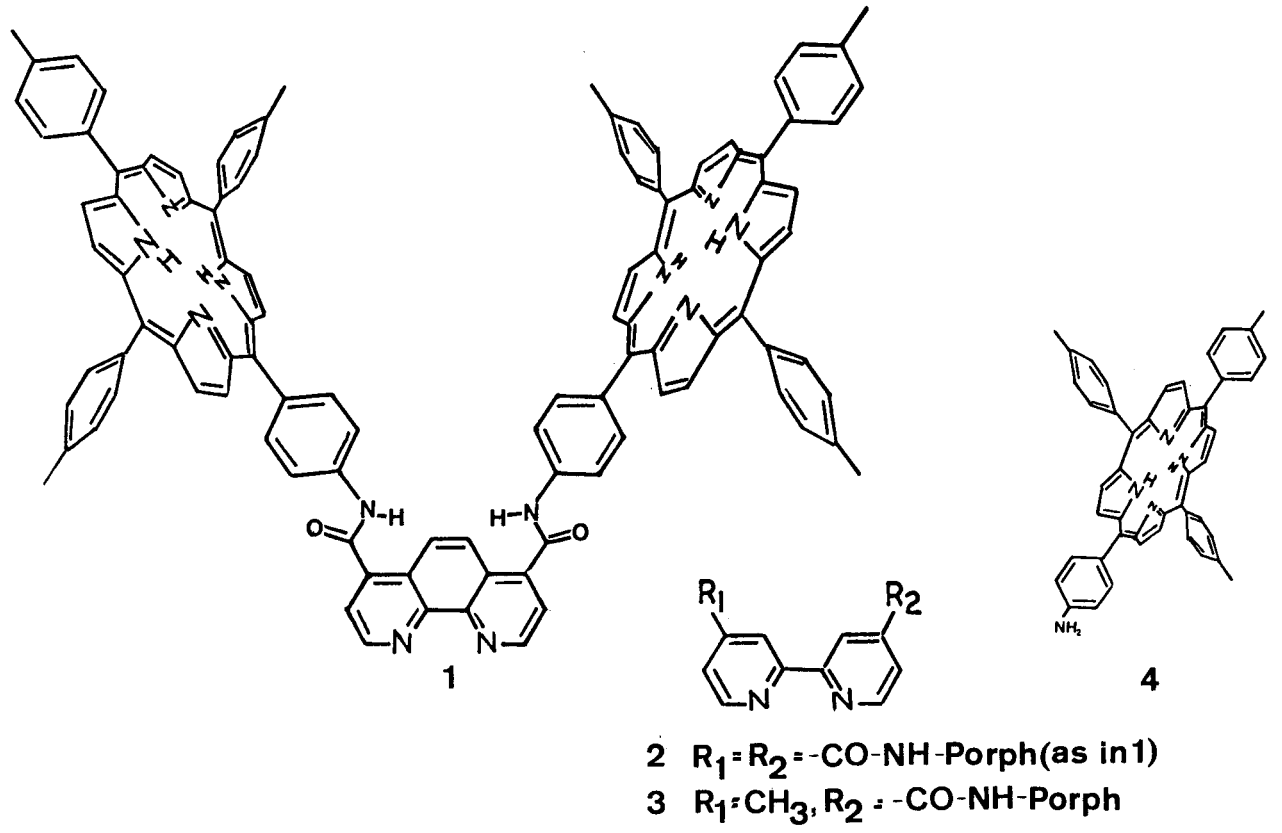

Figure 1. The porphyrins under consideration.

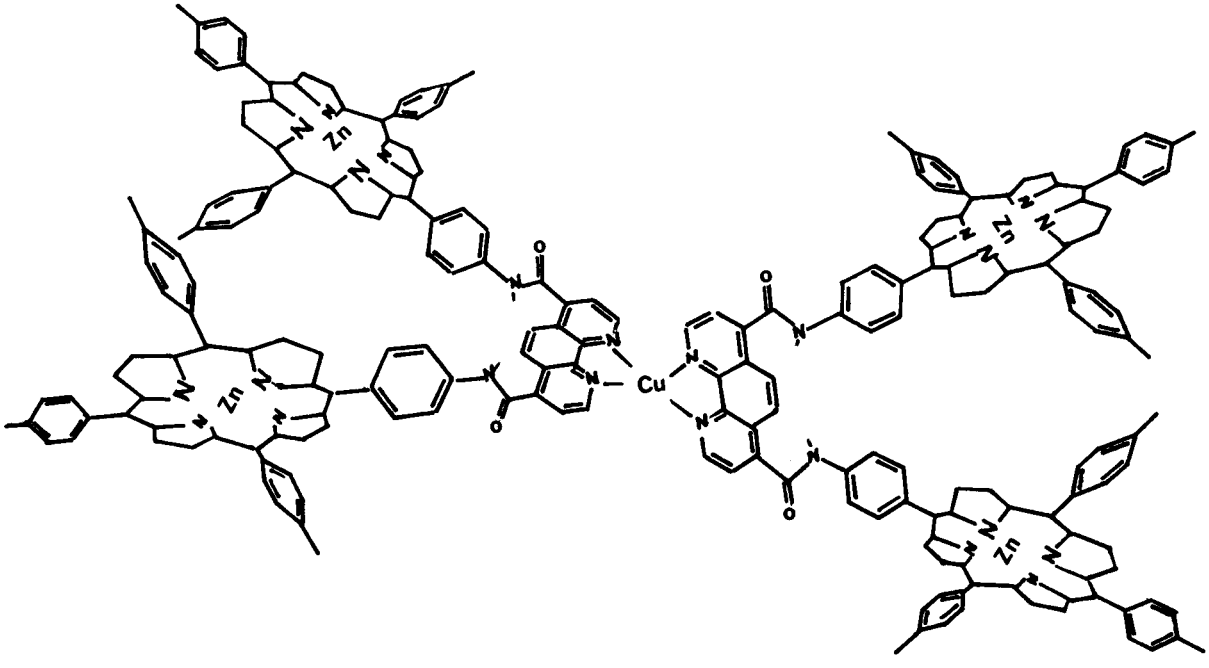

Figure 2. An example of the antenna porphyrins: Cu(I) (**2**-Zn)$_2$.

phenanthroline-4,7-diamide, **1** and *N,N'*-di(5-*p*-phenylene-10,15,20-tri-*p*-tolylporphyrin)-2,2'-bipyridyl-4,4'-diamide, **2**. Both form the building blocks of the mentioned complex porphyrin systems, among them the antenna porphyrins. In addition, the 4-methyl-2,2'-bipyridyl-*N'*-(5-*p*-phenylene-10,15,20-tri-*p*-tolyl)-4'-amide, **3** was obtained, representing the monoporphyrinyl analog of **2**.

The porphyrinyl derivatives of 2,2'-bipyridyl, already described in the literature, contain only one porphyrin unit attached by a non-amide-type bridge [9,10] while the known diporphyrinyl derivatives of 1,10-phenanthroline differ from **1** in the type and positions of attachment [11,12], which would not allow them to form the multiporphyrinyl systems described above.

The presence in **1** and **2** of two porphyrin units attached to the phenanthroline or bipyridyl spacer would allow, among other effects, investigation of possible interaction between the porphyrin rings which might differ for **1** and **2**. This difference can originate from the fact that phenanthroline is planar while 2,2'-bipyridyl is non-planar as a free base. Also, the zinc derivatives of the diporphyrinyl **1** and **2** systems are described, **1**-Zn and **2**-Zn. They can be useful as the building blocks of the multiporphyrinyl complexes because the only centers left in them for further complexation with the metal [13] are those present in phenanthroline or bipyridyl, Figure 2.

The diporphyrinyl phenanthroline **1** was obtained starting with 4,7-dimethyl-1,10-phenanthroline which was oxidized by selenium oxide to 1,10-phenanthroline-4,7-dicarboxaldehyde [14], and then by further oxidation with nitric acid to the dicarboxylic acid (compare [15]). The final step was the convertion to the respective acid chloride. The latter reacting with meso-*p*-aminophenyl-tri-*p*-tolyl porphyrin, **4** gave **1**. The diporphyrinyl bipyridyl **2** was obtained in a similar way as **1**, the reaction starting from 2,2'-bipyridyl-4,4'-dicarboxylic acid [16]. The monoporphyrinyl bipyridyl **3** was obtained starting with 4,4'-dimethyl-2,2'-bipyridyl. Its partial oxidation by aqueous potassium permanganate gave the mixture of mono- and diacid which were converted to respective acid chlorides, and separated by fractional crystallization. The monoacid chloride was then reacted as described above for **1**. The aminoporphyrin **4** used in the synthesis of **1**, **2** and **3** was the meso-5-*p*-aminophenyl-10,15,20-tri-*p*-tolylporphyrin obtained by hydrolysis [17] of the respective acetamidophenylporphyrin, the latter formed in the reaction of *p*-tolualdehyde, *p*-acetamidoaldehyde (3:1) and pyrrole in propionic acid [18]. The di-zinc derivatives **1**-Zn and **2**-Zn were obtained from the respective diacid chlorides and aminoporphyrin **4**, the latter previously metallated with zinc acetate in chloroform-methanol solution.

The difference between the effects exhibited by two porphyrinyl units attached to phenanthroline and bipyridyl was revealed by the nmr spectroscopy. The ^{1}H nmr (300 MHz) spectra of **1** and **1**-Zn showed greater shielding of

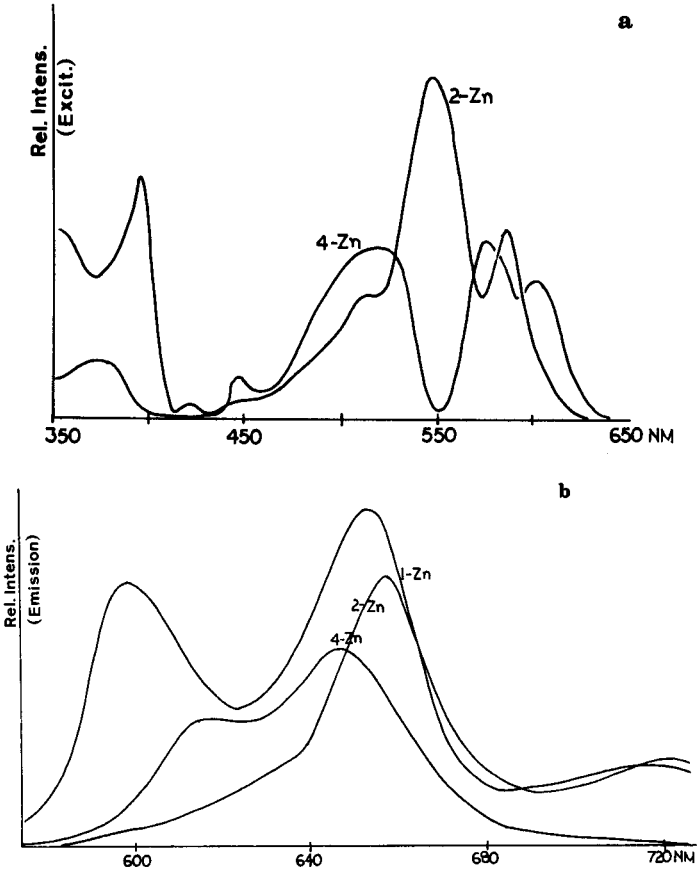

Figure 3. The fluorescence excitation spectra (a) and emission spectra (b) of porphyrin zinc derivatives in chloroform.

the methyl and phenylene protons in two tolyl substituents of each porphyrin unit compared to the third tolyl. This phenomenon did not appear in the spectra of **2** and **2**-Zn. One can assume that the planarity of the phenanthroline spacer cause that the wagging of both porphyrin units expose the "horizontal", h tolyl substituents to the ring current of the opposite porphyrin ring, while the "vertical", v tolyls do not experience such an exposure. As the result, the differences in chemical shifts $CH_{3(h)}$-$CH_{3(v)}$, 0.12, and $H_{ar(h)}$-$H_{ar(v)}$, 0.15/0.20 ppm, appear.

The visible absorption spectra of the diporphyrinylphenanthroline (bipyridyl) systems **1** and **2** were virtually the same as the porphyrinyl unit alone, the latter represented by aminophenyl-tri-*p*-tolylporphyrin **4**. The same appeared for the respective zinc derivatives. However, the emission spectra of the latter showed substantial difference which became even more apparent in the fluorescence excitation spectra, see Figure 3. These phenomena deserve prompt theoretical explanation.

EXPERIMENTAL

Mass spectrometry was performed on a fast atom bombardment Micromass 70/70 mass spectrometer model V6 with an 11/250 data system, 3-nitrobenzyl alcohol applied as a matrix. The ^1H nmr spectra were recorded on a Bruker-IBM AF (300 MHz) Fourier transform spectrometer. Electronic absorption spectra were recorded on a Perkin-Elmer Lambda 4C uv-vis spectrometer model C 688-0002, the fluorescence excitation and emission spectra were measured on a Perkin-Elmer fluorescence spectrometer model MPF-66 with the series 7000 professional computer.

4,7-Dimethyl-1,10-phenanthroline, 4,4'-dimethyl-2,2'-bipyridyl, 2,2'-bipyridyl-4,4'-dicarboxylic acid, *p*-acetamidobenzaldehyde, *p*-tolualdehyde, thionyl chloride, propionic acid and the applied solvents (all from Aldrich) were used as received. Pyrrole, 99% (Aldrich) was freshly distilled. Selenium oxide was obtained from selenium powder, 99.5% (Aldrich), and concentrated nitric acid. Celite 521 (Aldrich) was used as a filter agent in the procedure of oxidation with selenium dioxide. For column chromatography Florisil 60/200 mesh (Applied Science Laboratories) and silica gel 70-230 mesh, 60 Å (Aldrich) were used.

N,N-Di(5-*p*-phenylene-10,15,20-tri-*p*-tolylporphyrin)-1,10-phenanthroline-4,4'-diamide (**1**).

4,7-Dimethyl-1,10-phenanthroline was oxidized to dicarboxaldehyde by selenium oxide [8,14,15]. The dialdehyde (800 mg) was refluxed with 80% nitric acid (20 ml) for 3 hours, poured onto ice and left overnight. The crystals were washed several times with methanol. The obtained 1,10-phenanthroline-4,7-dicarboxylic acid (300 mg) was then refluxed with thionyl chloride (20 ml) for 4.5 hours and the mixture evaporated to dryness on a rotavap. The syrup-like substance which solidified was extracted with benzene from which the orange fine-crystalline 1,10-phenanthroline-4,7-dicarbonyl chloride precipitated (290 mg). This was directly used in the condensation reaction with the meso-*p*-aminophenyl-tri-*p*-tolylporphyrin **4**. This porphyrin (135 mg, 0.2 mmole), 1,10-phenanthroline-4,7-dicarbonyl chloride (30 mg, 0.1 mmole), three drops of pyridine and methylene chloride (100 ml) were mixed at room temperature for 22 hours. The obtained solution was washed with 5% aqueous sodium hydroxide, then with the solution of sodium chloride, finally with water, and dried with sodium sulfate. After removing the solvent on a rotavap, the residue was chromatographed on the silica gel column. First chloroform was used as eluent to remove the unreacted porphyrin **4**, then the elution was carried on with chloroform/methanol 9:1. The crude product was rechromatographed on the silica gel column with chloroform/methanol 10:1 as eluent, yield of **1** 18% based on phenanthroline-dicarbonyl chloride; fabms: 1575 $(M+1)^+$; ^1H nmr (deuteriochloroform): δ 9.50 (bs, 2H, CONH), 9.21 (bs, 2H, phenanthroline, PN), 8.83 (m, 16H, pyrrole), 8.32 (bs, 8H, C_6H_4), 8.16 (bs, 2H, PN), 8.07 and 7.53 (dd, 7.8 Hz, 8H, tolyl), 7.92 and 7.35 (dd, 7.4 Hz, 16H, tolyl), 2.68 (s, 6H, CH_3)), 2.56 (s, 12H, CH_3), -2.78 (s, 4H, NH porphyrin); uv vis (chloroform): abs, λ max nm 649, 592, 552, 517, 420 Soret.

Anal. Calcd. for $C_{108}H_{78}N_{12}O_2$ (1574): C, 82.34; H, 4.95; N, 10.67; O, 2.03. Found: C, 82.19; H, 4.85; N, 10.81.

N,N'-Di(5-*p*-phenylene-tri-*p*-tolylporphyrin)-2,2'-bipyridyl-4,4'-diamide (**2**).

2,2'-Bipyridyl-4,4'-dicarboxylic acid (244 mg, 0.1 mmole) and thionyl chloride (15 ml) were refluxed for 18 hours, evaporated to dryness and the residue used in the reaction with porphyrin **4**. The latter porphyrin (155 mg, 0.22 mmole) was mixed with one

drop of pyridine and 2,2'-bipyridyl-4,4'-dicarbonyl chloride (30 mg, 0.1 mmole) for 3.5 hours at room temperature. The solution was washed with 5% aqueous ammonia, then water and chromatographed on the silica gel column. After the unreacted porphyrin **4** was eluted with chloroform, the elution was continued with chloroform/methanol 20:1. The to crude product was rechromatographed using at the beginning chloroform which eluted the impurities, then with chloroform/methanol 40:1. The collected fraction was rechromatographed again, first with chloroform as eluent, and then with chloroform/methanol 100:1, yield of pure **2** 22% based on bipyridyldicarbonyl chloride; fab-ms: 1551 $(M+1)^+$; ^1H nmr (deuteriochloroform): δ 9.05 (d, 2H, bipyridyl-BP), 8.86 (d, 16H, pyrrole), 8.26 (m, 2H, BP), 8.09 and 7.55 (dd, 8.0 Hz, 32H, C_6H_4 and tolyl), 7.58 (s, 2H, BP), 2.70 (s, 18H, CH_3), -2.78 (s, 4H, NH porph.); uv vis (chloroform) abs, λ max nm 648, 591, 553, 517, 420 Soret.

Anal. Calcd. for $C_{106}H_{78}N_{12}O_2$ (1550): C, 82.06; H, 5.03; N, 10.84; O, 2.06. Found: C, 81.80; H, 5.00; N, 11.13.

4-Methyl-2,2'-bipyridyl-*N*-(5-*p*-phenylene-10,15,20-tri-*p*-tolylporphyrin)-4'-amide (**3**).

This was obtained in the same way as its diporphyrinyl analog **2**, however, with the application of 4-methyl-2,2'-bipyridyl-4'-carbonyl chloride. The latter was obtained in a mixture with 2,2'-bipyridyl-4,4'-dicarbonyl chloride by the action of thionyl chloride on the mixture of the respective mono- and dicarboxylic acid obtained as the result of oxidation of 4,4'-dimethyl-2,2'-bipyridyl [19], also compare comments in [20]. The monocarbonyl chloride was separated from dicarbonyl chloride by fractional crystallization; yield of **3** 28% based on porphyrin **4**; fab-ms: 868 $(M+1)^+$; ^1H nmr (deuteriochloroform): δ 8.86 (m, 8H, pyrrole), 8.59 (m, 2H, BP), 8.34 (m, 2H, BP), 8.23 (m, 2H, BP), 8.08 and 7.53 (dd, 8.0 Hz, 16H), 2.68 (s, 9H, CH_3), 2.48 (s, 3H, CH_3-BP), -2.78 (s, 2H, NH porphyrin); uv vis (chloroform): abs, λ max nm 649, 592, 553, 517, 420 Soret.

Anal. Calcd. for $C_{59}H_{45}N_7O$ (867): C, 81.66; H, 5.19; N, 11.30; O, 1.84. Found: C, 81.79; H, 5.02; N, 11.43.

Meso-*p*-aminophenyl-tri-*p*-tolylprophyrin (**4**).

First, meso-*p*-acetamidophenyl-tri-*p*-tolylporphyrin was obtained from *p*-acetamidobenzaldehyde, *p*-tolualdehyde and pyrrole in propionic acid [18]. After distilling off propionic acid from the reaction mixture, the residue was dissolved in methylene chloride and chromatographed on the Florisil column, chloroform/ether 9:1 as eluent. After removing the eluent, the residue was dissolved in chloroform and chromatographed on the silica gel column with chloroform. The first fraction containing meso-tetra-*p*-tolylphorphyrin was discarded while the second fraction containing meso-*p*-acetamidophenyl-tri-*p*-tolylporphyrin was deacetylated after removing the solvent. Thus, the acetylated porphyrin (420 mg, 0.6 mmole) was heated with trifluoroacetic acid (42 ml) and concentrated hydrochloric acid (45 ml) at 80° for 22 hours and after cooling, poured into water (200 ml). The insoluble green reaction product and the water layer were extracted twice with methylene chloride, and the combined extracts washed with water, then with 10% aqueous sodium carbonate and dried with sodium sulfate. The solution was chromatographed on the silica gel column with chloroform/methanol 95:5 as eluent; 310 mg of pure **4** was obtained. Yield of deacetylation 79%; fab-ms: 672 $(M+1)^+$; ^1H nmr (deuteriochloroform): δ 8.82 (m, 8H, pyrrole), 8.07 and 7.53 (dd, 7.8 Hz, 12H, tolyl), 7.97 and 7.04 (dd, 8.4 Hz, 4H, C_6H_4), 3.97 (bs, 2H, NH_2), 2.69 (s, 9H, CH_3), -2.78 (s, 2H, NH porphyrin); uv vis (chloroform): abs, λ max nm 649, 593, 518, 421 Soret.

Anal. Calcd. for $C_{47}H_{37}N_5$ (671): C, 84.05; H, 5.51; N, 10.42. Found: C, 83.76; H, 5.33; N, 10.70.

Zinc Derivatives **1**-Zn, **2**-Zn, and **4**-Zn.

The metallodiporphyrinyl-phenanthroline and -bipyridyl were obtained in the same way as the free-base porphyrins **1** and **2**, however using in condensation with the respective dicarbonyl chloride the meso-*p*-aminophenyl-tri-*p*-tolylporphyrin-zinc(II), **4**-Zn. The latter was prepared by refluxing for 4 hours porphyrin **4** (670 mg, 1 mmole) dissolved in chloroform (150 ml) with the saturated methanol solution of zinc acetate dihydrate (10 ml). After removing the solvent by distillation, the dry residue was added with methanol (70 ml) and filtered. The solid on the filter was dissolved in methylene chloride and chromatographed on the silica gel column with chloroform as eluent; elution was monitored by the vis absorption spectra and tlc, yield of metallation 89%; **1**-Zn; ^1H nmr (deuteriochloroform): δ ppm 8.95 (m, 16H, pyrrole), 8.82 (bs, 2H, PN), 8.76 and 8.63 (dd, 6.0 Hz, 8H, C_6H_4), 8.16 and 7.54 (dd, 8H, tolyl), 8.01 and 7.34 (dd, 16H, tolyl), 7.40 (s, 2H, PN), 7.37 (s, 2H, PN), 2.69 (s, 6H, CH_3), 2.58 (s, 12H, CH_3); uv vis (chloroform): abs, λ max nm 601, 553, 421 Soret; emission (chloroform): nm 715, 653, 597; exitation (chloroform): nm 586, 549, 515, 434, 409, 349; **2**-Zn, ^1H nmr (deuteriochloroform): ppm 8.94 (b, 16H, pyrrole), 8.10 (m, 2H, BP), 7.92 and 6.83 (dd, 8.6 Hz, 32H, C_6H_4 and tolyl), 7.52 (m, 2H, BP), 7.32 (m, 2H, BP), 2.69 (s, 18H, CH_3); uv vis (chloroform) abs, max nm 597, 556, 424 Soret; emission (chloroform): nm 517, 659; excitation (chloroform): nm 586, 549, 515, 396, 347. **4**-Zn, uv vis (chloroform) abs, λ max nm 600, 558, 422 Soret; emission (chloroform): nm 647, 617; excitation (chloroform): nm 597, 577, 519, 447, 372.

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