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Synthesis of β-Substituted Porphyrins Using Palladium Catalysed Reactions

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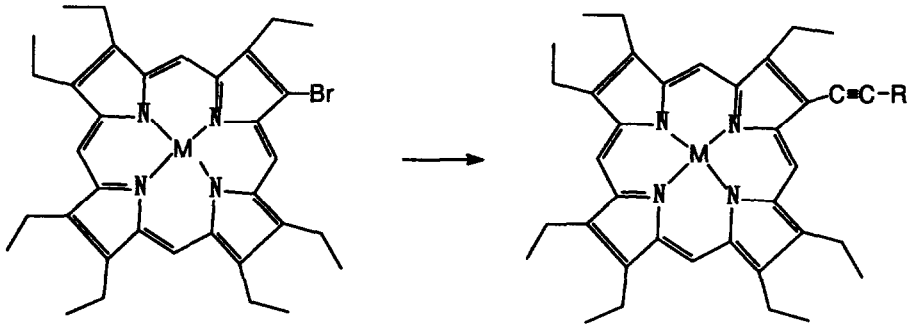
Abstract: *The palladium(II)-catalysed carbon-carbon-coupling reaction (Heck reaction) between a variety of metalated β-monohalosubstituted porphyrins (2-bromotetraphenylporphyrin, 2-bromo-3,7,8,12,13,17,18-heptaethylporphyrin, and 3(8)monoiodo-deuteroporphyrin IX dimethyl ester) and a series of terminally substituted acetylenic derivatives, is reported. A few disubstituted porphyrin analogs were also synthesized using the corresponding β-dihalogenated porphyrin precursors.*

Porphyrin synthesis impacts on a large and continually growing number of research endeavors in physical, biological, organic and inorganic chemistry. Our own studies on photodynamically active antitumor and antiviral agents, led us to synthesize porphyrin and phthalocyanine derivatives[1]. The reactions of substituted porphyrins are of considerable chemical interest since the fundamental properties of the porphyrin macrocycle can be altered by small changes in selected substituents. Attachment of unusual organic moieties to the porphyrin periphery often involves elaborate synthetic strategies and tedious product separation procedures[2]. Typical routes to porphyrins that possess one or more differing *meso*- or β-substituents involve condensation of an appropriate aldehyde(s) with various monopyrroles[3] and substituted dipyrryl methanes[4]. In addition to the purification problem, other restraining factors of the porphyrin cyclization step are steric and electronic features of substituents at the methine and the pyrrolic position, and incompatibility of the reactants with the condensation condition[5] (*i.e.* protic or Lewis acid catalyst or high temperature). Thus there exists a continuing need for more efficient methods to synthesize modified porphyrins. The palladium catalysed coupling of terminal alkynes and aryl halides (Heck condition)[6] is a well tested and efficient process and we applied this chemistry to the synthesis of various β-substituted porphyrins. This approach greatly simplifies the fabrication of such molecules and dramatically amplifies the type of porphyrins which can be obtained. During the course of this study, other reports on the application of metal-mediated cross-coupling methodologies to porphyrinic systems have also appeared[7].

Readily accessible halogenated porphyrins were chosen to explore the applicability of the palladium catalysed cross-coupling methodology to porphyrin syntheses. The previously reported β-halogenated porphyrin template, 2-bromo-3,7,8,12,13,17,18-heptaethylporphyrin nickel (**1**) was prepared either by the method of Bonnett *et al.*[8] or a new method[9]. In addition to **1**, a less polar component, eluting first from the

silica gel column, was obtained and identified as 2,12(13)dibromohexaethylporphyrin nickel(II) (**11**). The compound **1** was dissolved in a mixture of triethylamine and DMF. An excess of the 1-hexyne was added followed by bis(triphenylphosphine)palladium(II) chloride and copper(I) iodide whereafter the mixture was heated at 80-85 °C for 48 h. After about 10 h, the optical spectrum of the reaction mixture changed, and two



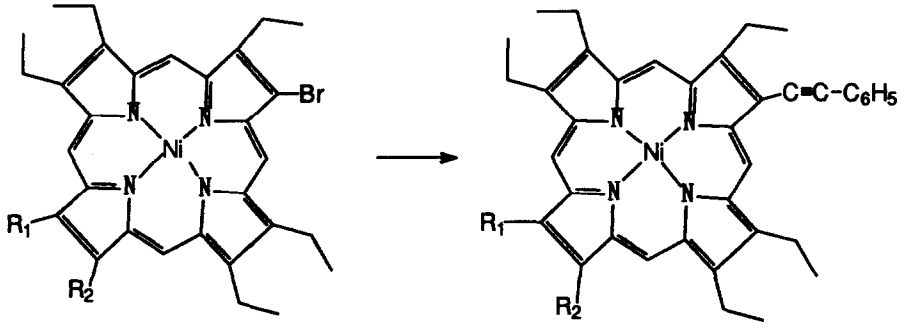
M	
1: Ni	
2: Cu	

M	R
3: Ni	$(CH_2)_3CH_3$
4: Ni	$(CH_2)_9CH_3$
5: Ni	C_6H_5
6: Ni	CH_2CH_2OH
7: Ni	$(CH_2)_4OH$
8: Ni	$(CH_2)_4CN$
9: Cu	C_6H_5
10: Cu	CH_2CH_2OH

Soret bands were observed. About 30-40% starting material was converted to a new compound (monitored by TLC) which after work-up and chromatographic purification was isolated in 60-80% yield (based on the starting material consumed). The product was characterized by mass spectroscopy which revealed a cluster (due to the various abundances of the natural nickel isotopes) of molecular ions around the major *m/z* 642 ion (M^+, ^{58}Ni) corresponding to the coupling product **3**. The reaction of **1** with 1-dodecyne also gave the corresponding coupling product **4**, which was characterized by its molecular ion at *m/z* 726 (M^+, ^{58}Ni). ^1H NMR revealed that all four *meso*-protons were separated and appeared as singlets, and that one *meso*-proton was shifted more downfield from the others. Similarly, one of the protons of the $-CH_2-$ (quartet) and CH_3- (triplet) of the ethyl group was also shifted downfield. This is due to the anisotropy of the -C≡C-R group, which affects particularly the adjacent carbon protons. The optical spectrum is consistent with a porphyrin molecule, revealing two visible bands between 500 and 600 nm and an intense Soret band around 400 nm. The lowest energy Q band is less intense as compared to the high energy Q band. In acetylenic substituted products, a pronounced shift in the Soret band was observed relative to the parent molecule, *i.e.* octaethylporphyrin nickel (λ_{max} 553, 518, 393 nm). Utilizing the same protocol developed for the open chain acetylenic derivatives as described above, we were able to prepare phenylacetylenic substituted products by reacting **1** with phenylacetylene. As compared to the open chain acetylenic substituted products, the

phenylacetylene derivatives exhibited a greater red shift of Soret and Q bands. The ^{1}H NMR of **5** clearly shows the presence of the aromatic protons as a multiplet at δ 7.26. The reaction of functionalized acetylenic reagents was also investigated. Thus the reaction of **1** with 3-butyn-1-ol, 5-hexyn-1-ol or 5-hexyn-1-nitrile gave the corresponding coupling products **6**, **7** and **8** respectively. The formation of these products is evident from the HRMS which indicates the insertion of an oxygen atom in **6** and **7** and a nitrogen atom in compound **8**. ^{1}H NMR of **6** and **7** gave triplets at δ 3.22 and δ 3.72 which were assigned to the two protons of -CH_2-OH. Attempts to couple **1** via 1,7-octadiyne to yield porphyrin dimers were unsuccessful. Likewise, coupling of **1** with ethyl propiolate and (N-propargyloxy)phthalimide failed to afford any appropriate coupling product. Substitution of the nickel for copper in **1** did not affect the course of the reaction. Thus, from the reaction of 2-bromo-3,7,8,12,13,17,18-heptaethylporphyrin copper(II) (**2**) with phenylacetylene and 3-butyn-1-ol we isolated the corresponding coupling products **9** and **10**, which were characterized via their HRMS and UV-Vis spectroscopic data. Due to the presence of the copper ion no satisfactory ^{1}H NMR spectrum was obtained.

The reaction of **11** with phenylacetylene under the above mentioned condition gave two products. The first, less polar, minor component was identified as monobromo-monophenyethynylhexaethylporphyrin nickel(II) based on the HRMS and visible spectral data. The second, more polar, major product gave a peak at *m/z* 734 (M^+, ^{58}Ni) in the mass spectrum which corresponds to the molecular ion of the coupling product of **11** and two phenylacetylenic groups. The presence of two distinct sets of *meso*-proton in the characteristic downfield region of the ^{1}H NMR spectrum confirmed that the latter product consists of a mixture of two isomeric porphyrins. The finger print in the ^{1}H NMR spectrum derived from the *meso*-protons suggest a mixture of **12a** and **12b** in a 3:1 ratio. Attempts to separate these isomeric products by usual chromatographic procedures failed. Consistent with a porphyrin bearing two moderately electron withdrawing side groups, the Soret band in the visible spectrum showed a pronounced red shift, directly proportional to the number of phenylacetylene groups present. Thus, for each added phenylethynyl group, the Soret and one of the Q bands show a bathochromic shift of about 7 and 10 nm, respectively.

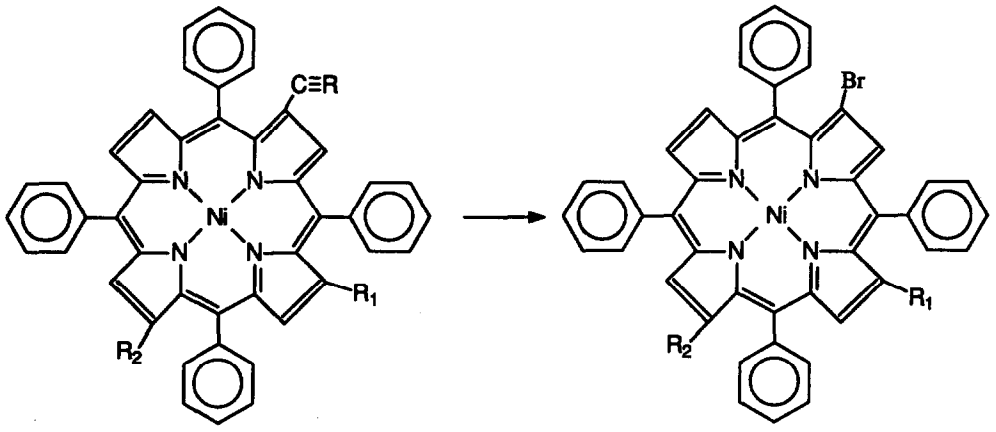


	R_1	R_2
11a:	**Br**	**H**
11b:	**H**	**Br**

	R_1	R_2
12a:	**C≡C-C_6H_5**	**H**
12b:	**H**	**C≡C-C_6H_5**

The most readily available porphyrin bearing a halogen at a β–position of,TPPNi, *i.e.* 2-bromotetraphenyl porphyrin nickel (BTPPNi) (**13**) and 2,7(12)-dibromotetraphenylporphyrin nickel (**14**) were synthesized by the

reaction of NBS with TPP in chloroform as previously reported[10]. The resulting mixture was purified by silica gel column chromatography. The reaction of **13** with 1-dodecyne, phenylacetylene, 3-butyn-1-ol, 5-hexyn-1-ol or 5-hexyn-1-nitrile proceeded smoothly under the above condition and gave **15**, **16**, **17**, **18** or **19**, respectively. However in this series, using identical condition as for porphyrin **1**, the reaction attained 100% conversion in 6-8 h (isolated yield 80-90%). The high reactivity of **13** as compared to **1** could reflect steric interference from the ethyl group adjacent to the reactive bromo group in **1**.



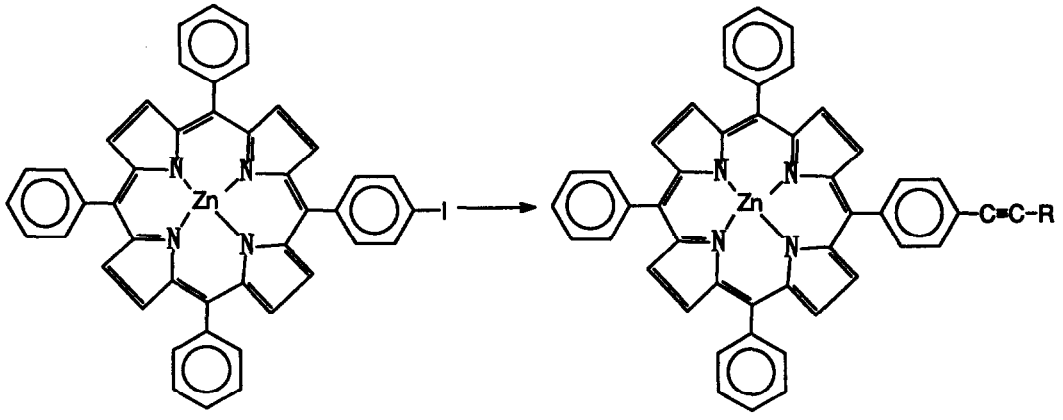
	R_1	R_2
13:	H	H
14:	H	Br
	Br	H

	R	R_1	R_2
15:	$(CH_2)_9CH_3$	H	H
16:	C_6H_5	H	H
17:	CH_2CH_2OH	H	H
18:	$(CH_2)_4OH$	H	H
19:	CH_2CH_2CN	H	H
20:	C_6H_5	$C{\equiv}C\text{-}C_6H_5$	H
	C_6H_5	H	$C{\equiv}C\text{-}C_6H_5$
21:	$(CH_2)_2OH$	$C{\equiv}C(CH_2)_2OH$	H
	$(CH_2)_2OH$	H	$C{\equiv}C(CH_2)_2OH$

All coupling products gave the expected molecular ion peak and a satisfactory HRMS for the molecular composition. In all the cases the ^1H NMR signal of the β-proton at carbon 3 adjacent to the C≡C-R is downfield from the remaining β-protons reflecting the anisotropy of the molecule due to these substituents. The bis(phenylacetylene) and bis(3-butyn-1-ol) derivatives of TPPNi (**20** and **21**) were obtained by the treatment of 2,7(12)dibromoTPPNi (**14**) with phenylacetylene and 3-butyn-1-ol. The UV-Vis spectrum revealed a red shift of both Soret and Q bands as compared to the parent molecule (TPPNi, λ_{max} 528, 416 nm). The shift is more pronounced for the phenylacetylene substituted products and is attributed to the extended conjugation of the porphyrin system.

As a further extension of this reaction, modifications of the 5-*p*-phenyl group were also investigated. The 5-(*p*-iodo)-5,10,15,20-TPPZn (**22**) was obtained from the corresponding free base 5-(*p*-amino)-5,10,15,20-TPP derivative[11] using diazotization conditions followed by metalation with zinc acetate. The coupling

reaction of **22** with phenylacetylene and 3-butyn-1-ol was very fast and quantitative, even at room temperature, in 2-4 h to yield the corresponding products **23** and **24**. The coupling products were characterized from their molecular ion peak in the mass spectra and optical and ^{1}H NMR spectral data.



22

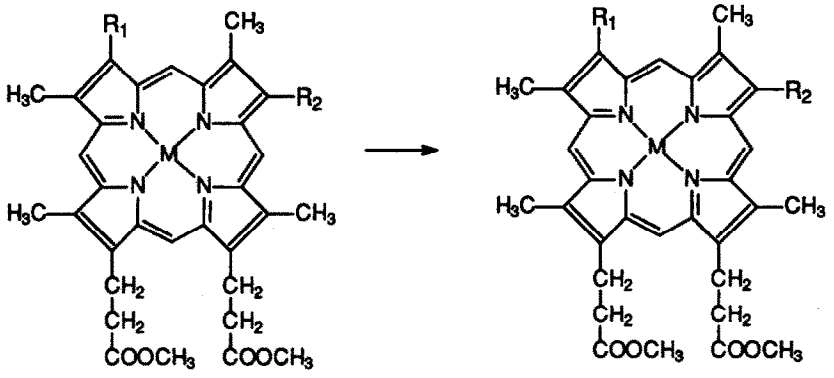
R

23: C_6H_5

24: CH_2CH_2OH

Finally, we also coupled an alkyne with an iododeuteroporphyrin IX dimethyl ester. Smith and collaborators[7e-g] used palladium catalysed coupling of 2,4-bismercurated- and 2,4-dibromo deutereoporphyrin IX dimethyl ester to form alkenyl and styryl substituted products using both Heck[6] as well as Stille methods[12], but they were unable to introduce alkynes via these methods. The free base 3(8)-monoiododeuteroporphyrin IX dimethyl esters were synthesized by the iodination of the deuteroporphyrin IX dimethyl ester using iodine in *o*-dichloro-benzene and subsequent metalation with an appropriate metal salt. Contrary to a report by Bonnet *et al.*[8], claiming the formation of a single diiodo substituted product, we obtained an isomeric mixture of 3- and 8-monoiodinated products in addition to the 3,8-diiodinated product. Prolonging the reaction time or increasing the amount of the iodine in the reaction mixture did not furnish the pure 3,8-diiodinated product. The mixture did not separate on TLC or on a silica gel column, however analytical HPLC allowed for the resolution of the products. Due to this purification problem the mixture was used as such for the coupling reaction. These halogenated porphyrin derivatives served as template for the functionalization of porphyrins via β-substitution. Since free base porphyrins are metalated with the copper catalyst during the reaction, the use of metalated porphyrins was desirable. Several considerations guided our choice for the central metal atom, including the ease of metal insertion, stability of the complex and the absence of interference in the ^{1}H NMR spectrum. The choice of the reagent and the substrate was governed by their ability to couple easily and efficiently at ambient temperature without affecting porphyrin stability. Reaction of **25** with 1-hexyne, 1-dodecyne, phenylacetylene or 3-butyn-1-ol was complete at room temperature in 8-12 h providing the coupling products in 60-70% yield. Similarly, the reaction of free base with 3-butyn-1-ol afforded a coupling product, however the UV-Vis and the HRMS data suggested that copper insertion occurred during the course

of the reaction. Since the presence of Zn often enhances photodynamic properties[1], attempts were also made to couple **30** with 3-butyn-1-ol. The reaction proceeded smoothly and all the spectroscopic data suggest the coupling product is **31**.



M	R_1	R_2
25: Ni	**I**	**H**
Ni	**H**	**I**
30: Zn	**I**	**H**
Zn	**H**	**I**

M	R_1	R_2
26: Ni	**C≡C-$(CH_2)_3CH_3$**	**H**
Ni	**H**	**C≡C-$(CH_2)_3CH_3$**
27: Ni	**C≡C-$(CH_2)_9CH_3$**	**H**
Ni	**H**	**C≡C-$(CH_2)_9CH_3$**
28: Ni	**C≡C-C_6H_5**	**H**
Ni	**H**	**C≡C-C_6H_5**
29: Ni	**C≡C-$(CH_2)_2OH$**	**H**
Ni	**H**	**C≡C-$(CH_2)_2OH$**
31: Zn	**C=C-$(CH_2)_2OH$**	**H**
Zn	**H**	**C≡C-$(CH_2)_2OH$**

The metal-mediated cross-coupling methodology, using alkyne derivatives and halogenated porphyrins, allows for the high-yield coupling of sensitive (heat or acid) organic substrates to target molecules which are not readily accessible through conventional condensation procedures. Particularly the cross-coupling onto porphyrin templates opens up a route to the fabrication of porphyrins possessing unusual optical and interesting biological properties.

EXPERIMENTAL

General

Reagents and solvents used for the synthesis were obtained commercially (Aldrich or Fisher) and were of the highest chemical grade available. Thin layer chromatography (TLC) was carried out on pre-coated silica plates containing fluorescent indicator (UV 254 nm). Crude reaction mixtures were purified by column chromatography on 60-200 mesh silica gel. High performance liquid chromatography (HPLC) was conducted on a 25 cm x 0.94 cm i.d. column packed with 5 μm silica particles (CSC, Montreal) operated at 2 ml/min with mixtures of hexanes and chloroform. Porphyrins were detected by their absorption at 400 nm. ^{1}H NMR Spectra were recorded on a Bruker AC 300 (300 MHz) in $CDCl_3$ solution, using the solvent signal as internal reference (^{1}H, 7.25 ppm). Visible absorption spectra were recorded in chloroform on a Hitachi U-2000 spectrophotometer. High and low-resolution mass spectra (HRMS, MS) were determined with a VG micromas model ZAB-1F apparatus at 70 eV ionization voltage.

General procedure for coupling of acetylenic derivatives with halogenated porphyrins:

The halogenated porphyrin (20-30 mg) was dissolved in dry triethylamine (30-40 ml). Then bis(triphenylphosphine) palladium(II)chloride (5-10 mg), alkyne (2-3 molar excess) and cuprous iodide (5 mg) were added, stirred and heated as required. The course of the reaction was monitored by TLC. If the halide was not sufficiently soluble in triethylamine, an appropriate amount of dimethylformamide was also added. The solution was heated for 48 h in the case of **1**, **2** and **11**, 6-8 h for **13** and **14** and 4-6 h room temperature for **22**, **25 and 30**. Upon completion of the reaction, solvent was evaporated under reduced pressure. The residue was extracted with chloroform, washed with water, dried (anh. Na_2SO_4) and filtered. The organic solvent was removed under reduced pressured and the residue chromatographed over silica gel. All coupling reactions were carried out under nitrogen.

[2-(1'-Hexynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (3). 15 mg (70%); Eluted with 10% chlorofrom in hexane; recrystallized from methanol m.p. 150 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 8 min; UV-Vis λ_{max} (relative intensity) 563(3.2), 521(1), 398(22.4) nm; ^{1}H NMR δ: 10.06 (s, 1H, *meso* 20-H), 9.82 (s, 1H, *meso* 5-H), 9.78 (s, 1H, *meso* 15-H), 9.76 (s, 1H, *meso* 10-H), 4.08 (q, 2H, CH_2 of 3-Et), 3.96 (q, 12H, CH_2 of Et), 2.98 (t, 2H, -C≡C-CH_2-), 1.98 (t, J = 7 Hz, 3H, CH_3 of 3-Et), 1.96, 1.90, 1.86,1.84 (t, overlapping each other 18H, CH_3 of Et), 1.26 (m, 4H, -C≡C-CH_2-CH_2-CH_2-CH_3), 1.23 (t, 3H, 6'-CH_3); HRMS *m/z* 642.3232 calcd. for $C_{40}H_{48}N_4{}^{58}Ni$: 642.3224. Anal. cald for $C_{40}H_{48}N_4Ni$: C, 74.66; H, 7.52, N, 8.71. Found C, 74.48; H, 7.93; N, 8.04.

[2-(1'-Dodecynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (4). 10 mg (60%); Eluted with 10% chlorofrom in hexane; recrystallized from methanol m.p. 150 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 8 min; UV-Vis λ_{max} (relative intensity) 563(3.1), 521.5(1), 398.5(20.5) nm; ^{1}H NMR δ: 10.06 (s, 1H, *meso* 20-H), 9.90 (s, 1H, *meso* 5-H), 9.82 (s, 1H, *meso* 15-H), 9.84 (s, 1H, *meso* 10-H), 4.12 (q, 2H, CH_2 of 3-Et), 3.85 (q, 12H, -CH_2 of Et), 2.95 (t, 2H, -C≡C-CH_2-), 1.88 (t, J = 7 Hz, 2H, CH_3 of 3-Et), 1.82, 1.84 (t,

overlapping each other 18H, -CH_3 of Et), 1.2 (m, 16H, CH_2 of dodecynyl group), 0.9 (t, 3H, J = 7 Hz, 12'-CH_3); HRMS *m/z* 726.4171 calcd. for $C_{46}H_{60}N_4{}^{58}Ni$: 726.4164.

[2-(Phenylethynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (5). 18 mg (65%); Eluted with 5-10% toluene in hexane; recrystallized from ethanol, m.p. 195 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 15 min; UV-Vis λ_{max} (relative intensity) 569.5(3.4), 525(1), 402.5(20.1) nm; ^1H NMR δ: 10.13 (s, 1H, *meso* 20-H), 9.82 (s, 1H, *meso* 5-H), 9.75 (s, 1H, *meso* 15-H), 9.74 (s, 1H, *meso* 10-H), 7.26 (m, 5H, aromatic protons), 4.17 (q, 2H, CH_2 of 3-Et), 3.92 (q, 12H,CH_2 of 3-Et), 1.95 (t, J = 7.4 Hz, 3H, 3-CH_3 of Et), 1.83, 1.83 (t, overlapping each other, 18H, CH_3 of Et); HRMS *m/z* 662.2919 calcd. for $C_{42}H_{44}N_4{}^{58}Ni$: 662.2907. Anal. cald for $C_{42}H_{44}N_4Ni$: C, 76.1; H, 6.70, N, 7.46. Found C, 76.26; H, 6.72; N, 7.91.

[2-(4'-Hydroxybutynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (6). 15 mg (75%); Eluted with 75% chloroform in hexane; recrystallized from methanol, m.p. 175 °C; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 19 min; UV-Vis λ_{max} (relative intensity) 563.5(2.6), 522(1), 398.5(17.9) nm; ^1H NMR δ: 9.99 (s, 1H, *meso* 20-H), 9.79 (s, 1H, *meso* 5-H), 9.75 (s, 1H, *meso* 15-H), 9.74 (s, 1H, *meso* 10-H), 4.32 (q, 2H, CH_2 of 3-Et), 4.18 (q, 2H, CH_2 of 18-Et), 4.05 (q, 2H, CH_2 of Et), 3.91 (q, 8H, CH_2 of Et), 3.22 (t, 2H, J = 6.3 Hz, -CH_2-OH), 2.70 (t, 2H, J = 6.3 Hz, -C≡C-CH_2-CH_2OH), 1.87 (t, J = 7.4 Hz, CH_3 of 3-Et), 1.82, 1.81, 1.80 (t, overlapping each other 18H, CH_3 of Et); HRMS *m/z* 630.2869 calcd. for $C_{38}H_{44}N_4O^{58}Ni$: 630.2854.

[2-(6'-Hydroxyhexynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (7). 10 mg (75%); eluted with chloroform; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 32 min; UV-Vis λ_{max} (relative intensity) 563.5(3.3), 522(1), 398.5(25.3) nm; ^1H NMR δ: 10.02 (s, 1H, *meso* 20-H), 9.96 (s, 1H, *meso* 5-H), 9.92 (s, 1H, *meso* 15-H), 9.90 (s, 1H, *meso* 10-H), 4.05 (q, 2H, CH_2 of 3-Et), 3.88 (q, 12H, CH_2 of Et), 3.72 (t, 2H, J = 6.3 Hz, -CH_2-OH), 2.45 (t, 2H, J = 6.3 Hz, -C≡C-CH_2-CH_2OH), 2.28 (t, J = 7 Hz, 3H, 3-CH_3 of Et), 1.84 (t, J = 7 Hz, 3H, 18-CH_3 of Et), 1.84, 1.82, 1.80 (t, overlapping each other 15H, CH_3 of Et), 1.6 (m, 4H, -C≡C-CH_2-CH_2-CH_2CH_2OH); HRMS *m/z* 658.3181 calcd. for $C_{40}H_{48}N_4O^{58}Ni$: 658.3159.

[2-(5'-Cyanohexynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] nickel(II) (8). 15 mg (60%); Eluted with 50%-100% chloroform in hexane; recrystallized from ethanol; m.p. 170 °C; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 9 min; UV-Vis λ_{max} (relative intensity) 564.5(3.2), 522(1), 398.5(21) nm; ^1H NMR δ: 9.94 (s, 1H, *meso* 20-H), 9.78 (s, 1H, *meso* 5-H), 9.74 (s, 1H, *meso* 15-H), 9.73 (s, 1H, *meso* 10-H), 4.02 (q, 2H, CH_2 of 3-Et), 3.89 (q, 12H, -CH_2 of Et), 2.56 (t, 2H, J = 7 Hz, CH_2-CN), 2.30 (t, 2H, -C≡C-CH_2), 1.91, 1.86, 1.82, 1.80 (t, overlapping each other 21H, CH_3 of Et); 1.3(m, 2H, -C≡C-CH_2-CH_2-CH_2CN); HRMS *m/z* 653.3028 calcd. for $C_{40}H_{45}N_5{}^{58}Ni$: 653.3021. Anal. cald for $C_{40}H_{45}N_5Ni$: C, 73.4; H, 6.93, N, 10.7. Found C, 73.68; H, 6.45; N, 9.98.

[2-(Phenylethynyl)-3,7,8,12,13,17,18-heptaethylporphyrin] copper(II) (9). 15 mg (60%); Eluted with 20% dichloromethane in hexane; recrystallized from hexane; m.p. 250 °C; HPLC (10:90 $CHCl_3$/Hexanes) t_R = 15 min; UV-Vis λ_{max} (relative intensity) 578.5(3.1), 534.5(1), 407.5(29) nm; HRMS *m/z* 667.2862 calcd. for $C_{42}H_{44}N_4{}^{63}Cu$: 667.2856. Anal. cald for $C_{42}H_{44}N_4Cu$: C, 75.47; H, 6.64, N, 8.38. Found C, 75.38; H, 6.33; N, 8.14.

[2-(4'-Hydroxybutynyl)3,7,8,12,13,17,18-heptaethylporphyrin] copper(II) (10). 15 mg (60%); Eluted with 40-50% chloroform in hexane; recrystallized from hexane; m.p. 235 °C; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 20 min; UV-Vis λ_{max} (relative intensity) 573.5(2.8), 531(1), 404.5(42.2) nm; HRMS *m/z* 635.2811 calcd. for $C_{38}H_{44}N_4O^{63}Cu$: 635.2784.

[2,12(13)-Bis(Phenylethynyl)-3,7,8,12(13),17,18-hexaethylporphyrin] nickel(II) (12). 15 mg (60%); Eluted with 10% dichloromethane in hexane; recrystallized from ethanol; m.p. 208-210 °C; HPLC (10:90 $CHCl_3$/Hexanes) t_R = 18 min; UV-Vis λ_{max} (relative intensity) 569.5(3.5), 531(1), 411.5(17.8) nm; ^1H NMR δ: 10.08, 10.03, 10.02, 10.01, 9.69 (s, 1H each, *meso*-H), 9.70 (s, 2H, *meso*-H), 7.96 (m, 5H, aromatic protons), 7.54 (m, 5H, aromatic protons), 4.08 (q, CH_2 of Et next to phenylethynyl substituents), 3.7-3.95 (m, CH_2 of Et), 1.98, 1.96 (t, CH_3 of Et next to phenylethynyl substituents), 1.90, 1.86, 1.64 (t, overlapping each other, CH_3 of Et); HRMS *m/z* 734.2919 calcd. for $C_{48}H_{44}N_4{}^{58}Ni$: 734.2919. Anal. cald for $C_{48}H_{44}N_4Ni$: C, 78.38; H, 6.03, N, 7.62. Found C, 78.38; H, 6.93; N, 6.62.

[2-(1'-Dodecynyl)5,10,15,20-tetraphenylporphinato] nickel(II) (15). Eluted with 10% toluene in hexane; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 8 min; UV-Vis λ_{max} (relative intensity) 572(1), 536(1.7), 422.5(23.3); ^1H NMR δ: 8.84 (s, 1H, β-H on C-3), 8.72 (d, J = 2.2 Hz, 4H), 8.68 (d, J = 4.8 Hz, 2H), 7.93-8.01 (m, 8H, H_o), 7.61-7.70 (m, 12H, H_m, H_p), 2.16 (t, 2H, J = 7Hz, -C≡C-CH_2-), 1.28 (m, 16H), 0.89 (t, J = 7 Hz, 12'-CH_3); HRMS *m/z* 834.3232 calcd. for $C_{56}H_{48}N_4{}^{58}Ni$: 834.3226.

[2-(Phenylethynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (16). Eluted with 10% toluene in hexane; recrystallized from methanol; m.p. 125 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 10 min; UV-Vis λ_{max} (relative intensity) 572(1), 538(2.2), 426(33.7); ^1H NMR δ: 9.01 (s, 1H, β-H on C-3), 8.73 (s, 4H, β-H), 8.69 (s, 2H, β-H), 8.0-8.04 (m, 8H, H_o), 7.69-7.72 (m, 12H, H_m, H_p), 7.31 (m, 5H, phenylethynyl protons); HRMS *m/z* 770.1980 calcd. for $C_{52}H_{32}N_4{}^{58}Ni$: 770.1971. Anal. cald for $C_{52}H_{32}N_4Ni$: C, 80.95; H, 4.18, N, 7.26. Found C, 80.71; H, 4.85; N, 7.66.

[2-(4'-Hydroxybutynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (17). 20 mg (80%); Eluted with dichloromethane; recrystallized from methanol; m.p. 275 °C; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 15 min; UV-Vis λ_{max} (relative intensity) 572(s), 536(1), 422.5(16.2); ^1H NMR δ: 8.86 (s, 1H, β-H on C-3), 8.72 (s, 2H, β–H), 8.72 (s, 2H, β–H) 8.68, 8.67 (s, each 1H, β–H), 7.93-8.01 (m, 8H, H_o), 7.63-7.70 (m, 12H, H_m, H_p), 3.63 (t, 2H, J = 6.2 Hz, -CH_2-OH), 2.48 (t, 2H, J = 6.2 Hz, -C≡C-CH_2-CH_2OH); HRMS *m/z* 738.1929 calcd. for $C_{48}H_{34}N_4O^{58}Ni$: 738.1923. Anal. cald for $C_{48}H_{34}N_4ONi$: C, 77.75; H, 4.62, N, 7.56. Found C, 77.58; H, 4.66; N, 7.19.

[2-(6'-Hydroxyhexynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (18). 15 mg (80%); Eluted with dichloromethane; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 22 min; UV-Vis λ_{max} (relative intensity) 572(s), 536(1), 422.5(16.3); ^1H NMR δ: 8.80 (s, 1H, β-H on C-3), 8.66 (m, 6H, β–H), 7.95-7.99 (m, 2H, H_o of 20-phenyl group), 7.69-7.73 (m, 6H, H_o), 7.60-7.67 (m, 3H, 20-phenyl H_m, H_p), 7.51-7.54 (m, 9H, H_m, H_p), 4.29 (t, J =

7 Hz, CH_2-OH), 2.22 (t, 2H, J = 7 Hz, -C≡C-CH_2-CH_2OH), 1.6 (m, 4H, -C≡C-CH_2-CH_2-CH_2-CH_2OH); HRMS *m/z* 766.2242 calcd. for $C_{50}H_{36}N_4O^{58}Ni$: 766.2236.

[2-(5'-Cyanohexynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (19). 20 mg (75%); Eluted with dichloromethane; recrystallized from hexane, m.p. 268 °C; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 8 min; UV-Vis λ_{max} (relative intensity) 574(s), 536(1), 423(14.8); ^{1}H NMR δ: 8.84 (s, 1H, β–H on C-3), 8.73-8.69 (m, 6H, β–H), 7.93-8.02 (m, 2H, H_o of 20-phenyl), 7.93-8.02 (m, 6H, H_o), 7.53-7.70 (m, 12H, H_m, H_p), 2.43 (t, 2H, J = 7.3 Hz, -CH_2CN), 2.36 (t, 2H, J = 7.3 Hz, -C≡C-CH_2), 1.79 (m, 2H, -C≡C-CH_2-CH_2CH_2CN); HRMS *m/z* 761.2089 calcd. for $C_{50}H_{33}N_5{}^{58}Ni$: 761.2085. Anal. cald for $C_{50}H_{33}N_5Ni$: C, 78.76; H, 4.36, N, 9.18. Found C, 78.99; H, 4.31; H, 8.75.

[2,7(12)-Bis(phenylethynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (20). 18 mg (85%); Eluted with 10-15% toluene in hexane; recrystallized from ethanol: hexane; m.p. 170 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 10 min; UV-Vis λ_{max} (relative intensity) 587(1), 548(1.1), 435(14.4); ^{1}H NMR δ: 8.95 (s, 2H, 3 and 8 β-H), 8.94 (s, 2H, 3 and 13 β-H), 8.61-8.72 (m, 6H, β-H), 7.96-8.01 (m, 6H, H_o), 7.64-7.70 (m, 12H, H_m, H_p), 7.30 (m, 5H, phenylethynyl protons), 7.29 (m, 5H, phenylethynyl protons); HRMS *m/z* 870.2293 calcd. for $C_{60}H_{37}N_4{}^{58}Ni$: 870.2286. Anal. cald for $C_{60}H_{37}N_4Ni$: C,82.58; H, 4.27. Found C, 82.08; H, 4.61.

[2,7(12)-Bis(4'-hydroxybutynyl)-5,10,15,20-tetraphenylporphinato] nickel(II) (21). 12 mg (80%); Eluted with dichloromethane; HPLC (50:50 $CHCl_3$/Hexanes) t_R = 40 min; UV-Vis λ_{max} (relative intensity) 578(1), 543(1.3), 430(21.7); ^{1}H NMR δ: 8.81 (s, 1H, β-H), 8.80 (s, 1H, β–H), 8.54-8.73 (m, 6H, β–H), 7.89-8.01 (m, 8H, H_o), 7.53-7.70 (m, 12H, H_m, H_p), 3.85 (t, 2H, J = 6.3 Hz, -CH_2-CH_2OH), 3.74 (t, 2H, J = 6.1 Hz, -CH_2-OH), 2.61 (t, 2H, J = 6.1 Hz, -C≡C-CH_2-CH_2OH), 2.46 (t, J = 6.2 Hz, -C≡C-CH_2-CH_2OH); HRMS *m/z* 806.2192 calcd. for $C_{52}H_{37}N_4O_2{}^{58}Ni$: 806.2193.

[5-(p-Phenylethynyl)-5,10,15,20-tetraphenylporphinato] zinc(II) (23). 15 mg (85%); Eluted with 30% toluene in hexane; m.p. >300 °C; HPLC (5:95 $CHCl_3$/Hexanes) t_R = 24 min; UV-Vis λ_{max} (relative intensity) 594.5(s), 552(1), 424(36); ^{1}H NMR δ: 8.98 (s, 4H, β-H), 8.96 (s, 4H, β–H), 8.25 (AA'BB' J = 1.4 and 7 Hz, 4H, 5-phenylene protons), 7.96 (AA'BB' J = 1.4 and 8 Hz, 4H, 5-phenylene), 7.92 (d, J = 8 Hz, 1H H_o of phenylethyne), 7.72-7.86 (m, 6H, H_o), 7.68 (m, 3H, H_m, H_p of phenylethyne), 7.3-7.6 (m, 9H, H_m, H_p of phenylene); HRMS *m/z* 776.1918 calcd. for $C_{52}H_{32}N_4{}^{64}Zn$: 776.1924. Anal. cald for $C_{52}H_{32}N_4Ni$: C, 80.95; H, 4.36; N, 9.18. Found C, 78.99; H, 4.36; N, 8.75.

[5-(p-4'-Hydroxybutynyl)-5,10,15,20-tetraphenylporphinato] zinc(II) (24). 10 mg (85%); Eluted with 50% dichloromethane in hexane; UV-Vis λ_{max} (relative intensity) 593(1), 553(2.1), 424.5(34); ^{1}H NMR δ: 8.88 (d, 1H, β-H), 8.83 (s, 6H, β–H), 8.78 (d, 1H, β–H), 7.4-7.7 (m, 24H, aromatic protons), 3.08 (t, 2H, -CH_2-OH), 2.35 (t, 2H, J = 7 Hz, -C≡C-CH_2-CH_2OH) .

[3(8)-(1'-Hexynyl)-deuteroporphyrin IX Dimethylester] nickel(II) (26). 10 mg (60%); Eluted with dichloromethane; UV-Vis λ_{max} (relative intensity) 550(2.5), 516(1), 392(17.8); ^{1}H NMR δ: 9.78, 9.70, 9.42,

9.38 (s, 1H each, *meso*-H), 8.62 and 8.68 (s, 1H, β-H), 4.02 (m, 4H, $-CH_2-CH_2CO_2CH_3$), 3.67, 3.68 (s, 3H each, $-OCH_3$), 3.69, 3.65 (s, 3H each, ring CH_3), 3.38, 3.24 (s, 3H each, ring CH_3), 3.18 (m, 4H, $-CH_2-CH_2CO_2CH_3$), 2.42 (t, 2H, $-C\equiv C-CH_2-$), 1.98-2.1 (m, 4H, $-C\equiv C-CH_2-CH_2CH_2CH_3$), 0.98 (t, 3H, 6'-$CH_3$); HRMS *m/z* 674.2403 calcd. for $C_{38}H_{41}N_4O_4{}^{58}Ni$: 674.2406.

[3(8)-(1'-Dodecynyl)-deuteroporphyrin IX Dimethylester] nickel(II) (27). 15 mg (70%); Eluted with 5% acetonitrile in dichloromethane; recrystallized from hexane; m.p. 98 °C; UV-Vis λ_{max} (relative intensity) 561(2.6), 521(1), 399(15.3); ^1H NMR δ: 9.65, 9.38, 9.36, 9.34 (s, 1H each, *meso*-H), 8.62 and 8.68 (s, 1H each, β-H), 4.02- 4.20 (m, 4H, $CH_2-CH_2CO_2CH_3$), 3.68, 3.67, 3.66, 3.65 (s, 3H each, $-OCH_3$), 3.51, 3.46, 3.45, 3.40, 3.39, 3.38, 3.37, 3.34 (s, 3H each, ring CH_3), 3.2 (m, 4H, $CH_2-CH_2CO_2CH_3$), 2.98 (q, 2H, $-C\equiv C-CH_2-$), 1.33-1.26 (m, 16H, CH_2 of dodecyl group), 0.90 (t, 3H, J = 7 Hz, 12'-CH_3); HRMS *m/z* 758.3342 calcd. for $C_{44}H_{52}N_4O_4{}^{58}Ni$: 758.3359. Anal. cald for $C_{44}H_{52}N_4O_4Ni$: C, 69.57; H, 6.90, N, 7.38: Found C, 70.07; H, 7.23, N, 7.19.

[3(8)-(1'-Phenylethynyl)-deuteroporphyrin IX Dimethylester] nickel(II) (28). 10 mg (70%); Eluted with dichloromethane; UV-Vis λ_{max} (relative intensity) 567(2.2), 525.5(1), 404.5(10); ^1H NMR δ: 9.48, 9.46, 9.20, 9.18 (s, 1H each, *meso*-H), 7.4-7.6 (m, aromatic protons), 3.98 (m, 4H, $CH_2-CH_2CO_2CH_3$), 3.62, 3.63, 3.64, 3.65 (s, 3H each, OCH_3), 3.22, 3.24, 3.42, 3.46 (s, 3H each, ring CH_3), 3.20 (m, 4H, $CH_2-CH_2CO_2CH_3$); HRMS *m/z* 694.2090 calcd. for $C_{40}H_{36}N_4O_4{}^{58}Ni$: 694.2077.

3(8)-(4'-Hydroxybutynyl)-deuteroporphyrin IX Dimethylester] nickel(II) (29). Eluted with 5% acetonitrile in dichloromethane; recrystallized from methanol; m.p. 225-228 °C HPLC (5:55:45 $CH_3CN/CHCl_3$/Hexanes) R_t = 23 min; UV-Vis λ_{max} (relative intensity) 562(2.1), 526(1), 403(20.5); ^1H NMR δ: 9.8, 9.6, 9.46, 9.4 (s, 1H each, *meso*-H), 8.76 (s, 1H, β-H), 4.32 (t, J = 5.3, 2H, $-CH_2-OH$), 4.29 (m, 4H, $CH_2-CH_2CO_2CH_3$), 3.67, 3.66 (s, 3H each, $-OCH_3$), 3.55, 3.48, 3.38, 3.27 (s, 3H each, ring CH_3), 3.08 (m, 4H, $CH_2CH_2CO_2CH_3$), 2.58 (t, 2H, $-C\equiv C-CH_2$); HRMS *m/z* 662.2039 calcd. for $C_{36}H_{36}N_4O_5Ni$: 662.2070. C, Anal. cald for $C_{36}H_{36}N_4O_5Ni$: C, 65.18; H, 5.47; N, 8.4. Found C, 65.68; H, 5.88; H, 8.04.

[8(3)-(4'-Hydroxybutynyl)-deuteroporphyrin IX Dimethylester] nickel(II) (29). HPLC (5:55:45 $CH_3CN/CHCl_3$/Hexanes) R_t = 27 min; UV-Vis λ_{max} (relative intensity) 561(1.96), 523(1), 402.5(16.4); ^1H NMR δ: 9.88, 9.82, 9.58, 9.52 (s, 1H each, *meso*-H), 8.52 (s, 1H, β-H), 4.22 (t, J = 5.3, 2H, $-CH_2-OH$), 3.95 (m, 4H, $CH_2-CH_2CO_2CH_3$), 3.73, 3.70 (s, 3H each, $-OCH_3$), 3.72, 3.71, 3.72, 3.69 (s, 3H each, ring CH_3), 3.30 (m, 4H, $CH_2CH_2CO_2CH_3$), 2.5 (t, 2H, $-C\equiv C-CH_2$); HRMS *m/z* 662.2039 calcd. for $C_{36}H_{36}N_4O_5{}^{58}Ni$: 662.2070. Anal. cald for $C_{36}H_{36}N_4O_4Ni$: C, 65.18; H, 5.47; Found C, 65.18; H, 6.06.

[8(3)-(4'-Hydroxybutynyl)-deuteroporphyrin IX Dimethylester] zinc(II) (31). Eluted with dichloromethane, HPLC (5:55:45 $CH_3CN/CHCl_3$/Hexanes) R_t = 15 min; UV-Vis λ_{max} (relative intensity) 578(1.2), 540.5(1), 412.5(15.7); ^1H NMR δ: 9.56, 9.12, 9.08, 8.95 (s, 1H each, *meso*-H), 8.45 (s, 1H, β-H), 4.25 (t, 2H, $-CH_2-OH$), 4.06 (m, 4H, $-CH_2CH_2CO_2CH_3$), 3.65, 3.62 (s, 3H each, $-OCH_3$), 3.49, 3.42, 3.40, 3.29 (s, 3H each, ring CH_3), 2.98 (m, 4H, $CH_2CH_2CO_2CH_3$); 2.46 (t, 2H,$-C\equiv C-CH_2-$) HRMS *m/z* 668.1977 calcd. for $C_{36}H_{36}N_4O_5{}^{64}Zn$: 668.1960.

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