

# Syntheses and characterization of phthalonitriles and phthalocyanines substituted with adamantane moieties<sup>1</sup>

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**Abstract:** The reaction of 3,4,5,6-tetrafluorophthalonitrile with 1-adamantanol, 1-adamantylamine, 1-adamantanemethanol, and 1-adamantaneethanol gave 4,5-di-(1-adamantyl-1-oxy)-3,6-difluorophthalonitrile, 4,5-di-(1-adamantylamino)-3,6-difluorophthalonitrile, 4-(1-adamantylamino)-3,5,6-trifluorophthalonitrile, 3,4,5,6-tetra-(1-adamantylmethoxy)phthalonitrile, and 3,4,5,6-tetra-(1-adamantylethoxy)phthalonitrile, respectively. The conversion of these tetrasubstituted phthalonitriles to magnesium, nickel, and metal-free phthalocyanines was demonstrated. These highly hindered phthalocyanines exhibited interesting red shifts in their UV-vis spectra.

*Key words:* highly hindered adamantane phthalocyanines, adamantylphthalonitriles.

**Résumé :** La réaction du 3,4,5,6-tétrafluorophthalonitrile avec l'adamantan-1-ol, l'adamantyl-1-amine, l'adamantane-1-méthanol et l'adamantane-1-éthanol conduit à la formation des 4,5-di-(adamantanyl-1-oxy)-3,6-difluorophthalonitrile, 4,5-di-(adamantanyl-1-amino)-3,6-difluorophthalonitrile, 4-(adamantanyl-1-amino)-3,5,6-trifluorophthalonitrile, 3,4,5,6-tétra-(adamantanyl-1-méthoxy)phthalonitrile, 3,4,5,6-tétra-(adamantanyl-1-éthoxy)phthalonitrile respectivement. On a démontré qu'il est possible de transformer ces phthalonitriles tétrasubstitués en phthalocyanines libre ou complexées avec du nickel ou du magnésium. Les spectres UV-visible de ces phthalocyanines fortement empêchées présentent des déplacements intéressants vers le rouge.

*Mots clés :* phthalocyanines de l'adamantane fortement empêchées, adamantylphthalonitriles.

[Traduit par la Rédaction]

## Introduction

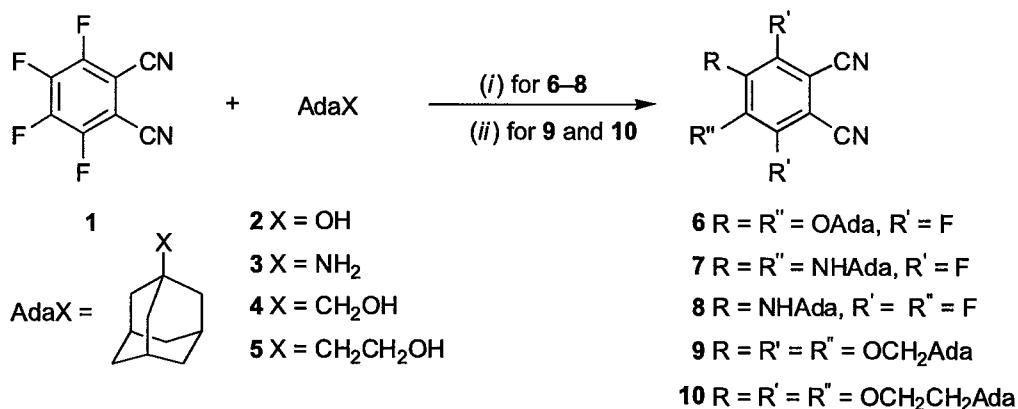
Phthalocyanines (Pcs) are brilliantly coloured purple, blue, or green macrocyclic compounds that have been extensively studied, initially because of their extensive use as dyes (1), but more recently because of their interesting photochemistry (2), potential applications as chemical sensors (3), nonlinear optics (4), and as medicinal agents in photodynamic therapy (PDT) (5). Recently, red-coloured manganese Pcs for analogs, substituted with highly hindered, bulky hexadecaalkoxyl functional groups, have been reported (6, 7), while other red phthalocyanines bearing alkylthio (8) and phenyl groups (9) have been described. These analogs represent Pcs exhibiting pronounced red shifts. Previously, some highly red-shifted analogs of some Pcs had been prepared with some difficulty owing to insolubility (10) and decomposition problems (11).

A significant bathochromic red shift of the Pc chromophore has long been associated with analogs bearing electron-donating substituents at the 1, 4, 8, 11, 15, 18, 22, and 25 positions (nonperipheral), while less pronounced red shifts of the Q band are associated with substitution on the

2, 3, 9, 10, 16, 17, 23, and 24 positions (peripheral) (12, 13). For analogs fully substituted at both the peripheral and nonperipheral positions with alkoxy moieties, enhanced red shifts of the Q band have also been reported (14). It has been postulated that sterically bulky substituents at the peripheral positions around the Pc exert influence upon the nonperipheral positions, thereby effectively increasing the steric bulk of the nonperipheral substituents and further promoting a shifting of the Q band. Various metallated and nonmetallated Pcs bearing sterically bulky alkoxy moieties have been reported, including both neopentoxy and cyclohexylmethoxy groups (6, 7). In addition to the effect that these substitutions appear to have on the absorption spectra of the resulting Pcs, a disruption of the  $\pi$  stacking among the aromatic macrocycles increases the solubility of the molecule, even in nonpolar solvents.

One particular bulky alkyl moiety that has interested our research group is adamantane. In particular, amine-substituted adamantanes have been approved for treatment as an antiviral agent against influenza A (15) and adamantyl moieties have been investigated for their potential use as carrier groups for anticonvulsant (16) and anticancer drugs

**Scheme 1.** Reagents and conditions: (i) *n*-BuLi, THF, 25 °C, 1 h; (ii) K<sub>2</sub>CO<sub>3</sub>, DMF, 140 °C, 4 days.



(17). However, it is their more general physicochemical characteristics associated with large steric bulk and their close steric relationship to our favorite bulky group, the neopentoxy group, that have piqued our interest as related to the potential for substitution onto the Pc framework.

The synthesis of substituted Pcs can be accomplished through two distinct approaches, each involving nucleophilic aromatic substitution. A recent approach employed in our research group has focused upon directly reacting metallated hexadecafluorophthalocyanines with various heteroatom nucleophiles (18). A limit to this synthetic approach is the distribution of substituents replacing the fluorine atoms resulting in a range of products that are difficult to separate by flash chromatography. Furthermore, complete replacement of all 16 fluorine atoms is limited to sterically small, strong nucleophiles. Alternatively, tetrasubstituted phthalonitriles bearing functionalities, such as the neopentoxy group, can be readily produced by nucleophilic aromatic substitution reactions on 3,4,5,6-tetrafluorophthalonitrile (**1**) despite the steric bulk of the substituents (19).

The general synthetic strategy employed for the synthesis of adamantyl-substituted Pcs follows the production and isolation of substituted phthalonitriles. Subsequent condensation of the adamantyl-substituted phthalonitriles gives the required phthalocyanines. In this research we were interested in systematically varying the bulk of the substituents so as to produce a series of hexadecasubstituted phthalocyanines and examining their spectroscopic properties.

## Results and discussion

A novel series of phthalocyanine compounds were designed and synthesized bearing bulky adamantane-based substituents. Commercially available 3,4,5,6-tetrafluorophthalonitrile (**1**) was reacted with 1-adamantanol (**2**), 1-adamantylamine (**3**), 1-adamantanemethanol (**4**), or 2-(1-adamantanyloxy)ethanol (**5**) in the presence of a base to generate 4,5-di-(1-adamantanyloxy)-3,6-difluorophthalonitrile (**6**), 4,5-di-(1-adamantylamino)-3,6-difluorophthalonitrile (**7**), 4-(1-adamantylamino)-3,5,6-trifluorophthalonitrile (**8**), 3,4,5,6-tetra-(1-adamantylmethoxy)phthalonitrile (**9**), or 3,4,5,6-tetra-[2-(1-adamantyl)ethoxy]phthalonitrile (**10**). For the synthesis of fully substituted adamantylmethoxyl and adamantylethoxyl (Scheme 1) derivatives, a previously re-

ported synthetic approach was followed in which an excess of alkyl alcohol was combined with 3,4,5,6-tetrafluorophthalonitrile (**1**) in *N,N*-dimethylformamide (DMF) at 140 °C in the presence of potassium carbonate (19). Both tetrasubstituted crude products, purified by flash silica gel column chromatography, were eluted with dichloromethane-methanol and reduced to an amber-coloured oil under reduced pressure. These oils solidified under a stream of air yielding the desired final products, which were confirmed by EI mass spectra NMR and IR spectroscopic analysis and microanalyses.

Despite repeated attempts to synthesize the tetrasubstituted analog from 1-adamantanol and **1** using this synthetic approach, the reaction was not successful. Therefore, an alternative synthetic approach for the aromatic nucleophilic substitution of the phthalonitrile fluorine was implemented, in which *n*-butyllithium in tetrahydrofuran (THF) was used to deprotonate **2** (or **3**) to create the desired nucleophile. Although this modified approach did result in fluorine substitution, complete tetrasubstitution was not achieved, presumably because of the high degree of steric bulk associated with the adamantanyl cage. This steric hindrance is not so severe in the adamantanemethanol and adamantaneethanol homologs, thereby enabling complete substitution. An obvious colour change was noted immediately upon addition of 3,4,5,6-tetrafluorophthalonitrile to the activated adamantyl-oxide nucleophile, and despite allowing the reaction to continue for up to 72 h, substitution of more than two fluorine moieties was not observed (Scheme 1). TLC of the reaction mixture did reveal an additional spot that was presumed to be the monosubstituted analog, although isolation of this species was not achieved. As usual, a sharp intense absorbance at 2239 cm<sup>-1</sup> was observed in the IR spectra and was attributed to CN stretching. Furthermore, EI mass spectroscopy and microanalysis confirmed that the product from this reaction is a disubstituted phthalonitrile. The <sup>1</sup>H NMR spectra for this compound revealed the expected resonances for the adamantyl protons between δ 1.68 and 2.24 ppm, while the <sup>19</sup>F NMR exhibited a singlet at δ -114.9 ppm. The singlet suggests that the two adamantyloxy substituents are positioned at the peripheral position.

The synthesis of derivatives substituted with nitrogen-containing adamantane analogs was accomplished through an approach similar to adamantanol involving the in situ

generation of an adamantamide anion from **3**, followed by subsequent addition of **1**. The desired disubstituted product was separated by flash silica gel column chromatography, yielding an amber-coloured oil that solidified under air. EI mass spectroscopy and elemental analysis confirmed the product, while fluorine NMR spectra for the species showed a singlet at  $\delta \sim -119$  ppm.

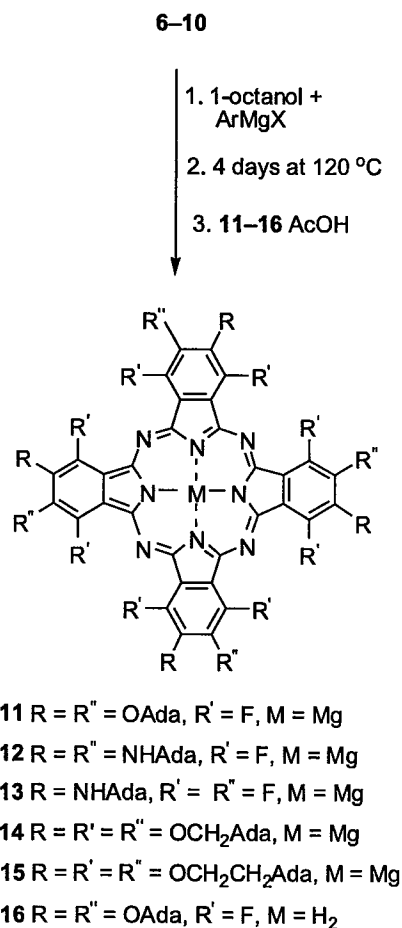
Subsequently, the reaction was repeated with 1 equiv. of adamantylamine (**3**) and **1** to generate the monosubstituted analog, **8**. Three distinct resonances ( $\delta -118.7, -129.7,$  and  $-136.8$ ) were identified in the  $^{19}\text{F}$  NMR, corresponding to the three inequivalent fluorines from the monosubstituted phthalonitrile. Further characterization by EI mass spectroscopy, FT-IR spectroscopy, and elemental analysis confirm the synthesis of the monosubstituted adamantylamine-substituted analog.

Each of the above phthalonitriles (**6–10**) was condensed with 1-octanol and phenyl or 4-methoxyphenylmagnesium bromide to yield the corresponding magnesium phthalocyanine, as outlined in Scheme 2. The formed Pcs were all purified by flash silica gel column chromatography, eluting with a solvent mixture of hexane – ethyl acetate, and subsequently characterized by MALDI mass spectroscopy (MALDI-MS), elemental analyses, UV–vis spectrophotometry, and NMR analyses. The mass spectra of all magnesium phthalocyanines gave the expected parent ion clusters. In addition, daughter ion clusters corresponding to the loss of the adamantanyl fragments cleaved at the alkyl–heteroatom bond were also detected.

The  $^1\text{H}$  NMR spectra for all magnesium phthalocyanines exhibited resonances for the adamantanyl protons between 1.6 and 2.3 ppm. In the  $\text{OCH}_2$  region for the hexadecaadamantylmethoxysubstituted analog **14**, a broad singlet was observed. A similar nickel phthalocyanine bearing hexadecacyclohexylmethoxyl moieties revealed temperature-dependant separation of the peripherally and nonperipherally substituted methylene protons and that at room temperature the two chemically different proton pairs appeared as a broad singlet (19). The peripheral and nonperipheral  $\text{OCH}_2$  protons for the hexadecaadamantylethoxyphthalocyanine **15** are chemically inequivalent and appeared as distinct triplets at 4.27 and 4.16 ppm, respectively. As expected, the  $^{19}\text{F}$  NMR for the hexadecasubstituted analogs showed no fluorine resonances, while the octaadamantyl octafluoro Pcs **11** and **12** exhibited singlets at approximately  $-120$  ppm. However, the  $^{19}\text{F}$  NMR for the tetrasubstituted analog **13**, which consists of a mixture of isomers, revealed multiple fluorine resonances corresponding to the multitude of inequivalent fluorines formed during the phthalocyanine condensation reaction.

A comparison of the UV–vis spectra for the Mg Pcs exhibits the expected red shifts owing to the substitution onto the macrocyclic aromatic ring, as shown in Table 1. Each of the hexadecasubstituted compounds exhibited a pronounced red shift of the Q band, with  $\lambda_{\text{max}}$  values similar to those reported in the literature for magnesium hexadecaneopentoxophthalocyanine (754 nm) (6, 7). The tetrasubstituted derivative **13** was not red-shifted as greatly as the octaadamantylamine derivative, further supporting the association between large, sterically bulky substituents and the red shift of the corresponding UV–vis spectra. As compared

Scheme 2.



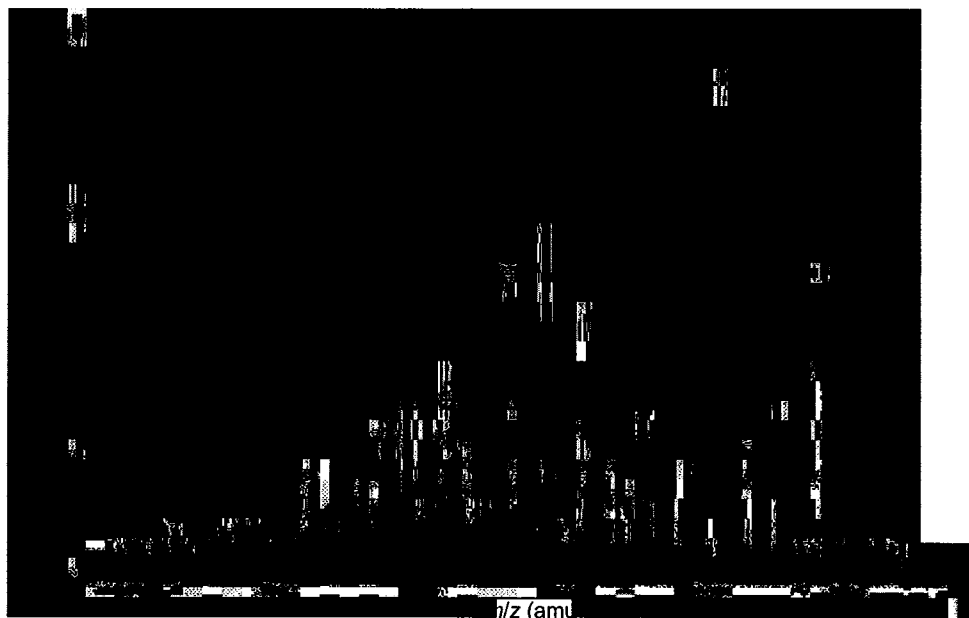
**Table 1.** Summary of the UV–vis spectra for the adamantane-substituted magnesium phthalocyanines.

Mg Pc	$\lambda_{\text{max}}$ (log $\epsilon$ )
<b>11</b>	708 (4.83)
<b>12</b>	794 (4.57)
<b>13</b>	714 (4.63)
<b>14</b>	752 (4.91)
<b>15</b>	744 (4.93)

with the tetrasubstituted analog, the octaadamantylamine-substituted derivative exhibited a red shift of 80 nm. It is possible that these bulky adamantylamino groups, even at the peripheral positions, distort the planar Pc ring, causing this red shift. Not surprisingly, a small decrease in the  $\lambda_{\text{max}}$  was detected upon insertion of a methylene unit for the hexadecasubstituted analogs **15**, as compared with **14**, as the extra methylene group in **15** will position the bulky adamantyl group further from the core of the Pc.

Metal-free Pcs are useful intermediates for transmetallating synthetically challenging complexes. A metal-free phthalocyanine analog **16** was synthesized after refluxing the magnesium derivative **11** in acetic acid. Purification was achieved by flash silica gel column chromatogra-

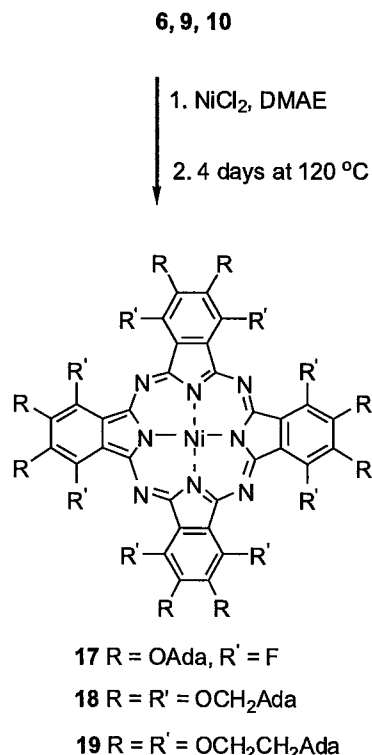
**Fig. 1.** MALDI-MS spectra for **19** showing parent ion cluster  $[M + H]^+$  at 3418, along with daughter ion clusters separated by 163 amu ( $C_{12}H_{19}$ ).



phy with hexane – ethyl acetate used as the mobile phase. This compound was characterized by MALDI-MS and again revealed the expected parent ion cluster at 1883 amu. A series of daughter ion clusters were observed separated by 135 amu, corresponding to the loss of an adamantanyl unit ( $C_{10}H_{15}$ ). The complex was further characterized by NMR spectroscopy, elemental analysis, and UV-vis spectrophotometry, with the  $\lambda_{max}$  of the Q band red-shifted by 26–764 nm with respect to the magnesium derivative. Following the isolation and characterization of the metal-free derivative, repeated attempts to introduce manganese into the core of the phthalocyanine were unsuccessful.

Due to the difficulty associated with forming the metal-free phthalocyanines incorporating adamantane-based substituents, a multistep synthesis for transmetalating Pcs was not viable. Therefore, direct condensation of precursor phthalonitriles with nickel as the core metal ion was pursued. As previously described (19), the general synthetic approach is outlined in Scheme 3 in which **6**, **9**, or **10** was heated with  $NiCl_2$  in *N,N*-dimethylaminoethanol (DMAE) for 4 days at 120 °C to give the nickel phthalocyanines **17–19**, respectively. Again, MALDI-MS revealed the expected parent ion clusters, in addition to daughter ion clusters corresponding to fragmentation between the alkyl substituents and oxygen. For the octaadamantyl octafluoro-nickel Pc **17**, the daughter ions were separated by 135 amu, while the daughter ion clusters for the hexadecaadamantylmethoxy-nickel Pc **18** were separated by 149 amu and the daughter ion peaks corresponding to hexadecaadamantylethoxy-substituted analog were separated by 163 amu, as shown in Fig. 1. Similar to the magnesium Pc analogs, the  $OCH_2$  resonances for the adamantylmethoxyphthalocyanine **18** appeared as a broad signal at 4.21 ppm representing both the peripheral and nonperipheral substituents, while two clearly distinct triplet resonances at 4.78 and 4.53 ppm were ob-

**Scheme 3.**



served for the peripheral and nonperipheral  $OCH_2$  protons, respectively, of the adamantylethoxy Pc **19**. UV-vis spectra were recorded for the three nickel phthalocyanines (summarized in Table 2), although the Q bands are not as red-shifted as the corresponding magnesium phthalocyanines. The most sterically congested nickel Pc (**18**) exhibited the greatest red

**Table 2.** Summary of the UV-vis spectra for the adamantane-substituted nickel phthalocyanines.

Ni Pc	$\lambda_{\max}$ (log $\epsilon$ )
<b>17</b>	708 (4.91), 636 (4.23)
<b>18</b>	750 (4.93), 672 (4.43)
<b>19</b>	736 (4.88), 660 (4.25)

shift, while the octadamantylxy-octafluorophthalocyanine **17** was the least red-shifted nickel complex. Perhaps some aggregation in **17–19** resulted in somewhat lower log  $\epsilon$  values than usual. This reinforces the association between large sterically hindered substitutions onto the aromatic macrocycle and the red shifting of the Q band for phthalocyanines, although the  $\lambda_{\max}$  for **18** was slightly less red-shifted as compared with hexadecaneopentoxypthalocyaninato nickel (750 vs. 758 nm) (**19**).

## Experimental

### General methods

Inert atmosphere conditions were maintained using Air Liquide prepurified argon. Magnetic stirring methods were utilized during all reactions. Flash chromatography was performed using silica gel of particle size 40–63  $\mu\text{m}$ , with eluting solvents mixtures as described. Nuclear magnetic resonance (NMR) spectroscopy for proton and fluorine was performed using a Bruker 300 spectrometer at room temperature and was processed using XWIN-NMR 3.5 software. Chemical shifts are reported in parts per million ( $\delta$ ). Infrared (IR) spectra were recorded on a Mattson 3000 FT-IR spectrometer using KBr discs. UV-vis were recorded on a Hewlett-Packard HP8452A diode array spectrophotometer. For all phthalonitriles, low-resolution mass spectra (MS) were recorded in electron ionization (70 eV) mode on a Micromass/Waters GCT time-of-flight instrument. For all phthalocyanines, low-resolution MS were recorded using laser desorption ionization (LDI) on a PE Sciex Q-STAR XL or PerSeptive Biosystems Voyager – DE STR spectrometer. Microanalyses were performed by Guelph Chemical Laboratory Ltd., Guelph, Ontario.

### Synthesis of 4,5-di-(1-adamantylxy)-3,6-difluorophthalonitrile (**6**)

1-Adamantanol (**2**, 1.50 g, 9.85 mmol, 2 equiv.) was dissolved in 10 mL of THF and the solution was stirred under an argon atmosphere at room temperature. To this solution was added *n*-butyllithium in hexanes (4.94 mL, 2 mol/L, 2 equiv.). The reaction mixture initially turned cloudy and a fine white precipitate was observed. The mixture was stirred for 1 h before a solution of 3,4,5,6-tetrafluorophthalonitrile (**1**, 0.986 g, 4.93 mmol, 1 equiv.) in THF was added dropwise under argon. The reaction mixture turned reddish-purple and was stirred at room temperature for 4 h. After this period, 100 mL of water was added to the reaction mixture and the mixture was extracted with diethyl ether (3  $\times$  50 mL). After drying over sodium sulfate, the solvent was removed under reduced pressure, resulting in an amber-coloured oil. The oil was then dissolved in a minimum of toluene and was passed through a flash silica gel column using

toluene as eluant. The first fraction was collected and the solvent was removed under reduced pressure, yielding an oil that solidified upon sitting under a stream of air overnight. Yield: 76% (1.74 g); mp 196–198 °C. TLC (toluene):  $R_f$  0.63. IR (KBr,  $\text{cm}^{-1}$ ) v: 2911, 2846, 2239 (CN), 1454, 1354, 1295, 1113, 1042.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 2.24 (br m, 6H, bridgehead C-H), 1.93 (m, 12H,  $\text{CH}_2$ ), 1.68 (br m, 12H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -114.9 (s). EI-MS  $m/z$  (rel. intensity):  $\text{M}^+$  464 (64). Anal. calcd. for  $\text{C}_{28}\text{H}_{30}\text{O}_2\text{N}_2\text{F}_2$ : C 72.39, H 6.51, N 6.03; found: C 72.42, H 6.34, N, 6.11.

### Synthesis of 4,5-di-(1-adamantylamino)-3,6-difluorophthalonitrile (**7**)

1-Adamantylamine (**3**, 1.52 g, 10.1 mmol, 2 equiv.) was dissolved in 15 mL of THF and the solution was stirred under an argon atmosphere at room temperature. To this was added *n*-butyllithium in hexanes (4.0 mL, 2.5 mol/L, 2 equiv.). The reaction mixture initially turned cloudy and a fine white precipitate was observed. The mixture was stirred for 1 h before a solution of 3,4,5,6-tetrafluorophthalonitrile (**1**, 0.986 g, 4.93 mmol, 1 equiv.) in THF was added dropwise under argon. The reaction mixture turned dark red and was stirred at room temperature for 4 h. After this period, 100 mL of water was added to the reaction mixture and was extracted with diethyl ether (3  $\times$  50 mL). After drying over sodium sulfate, the solvent was removed under reduced pressure, resulting in an amber-coloured oil. The oil was then dissolved in a minimum of toluene and was passed through a flash silica gel column using toluene for elution. The first fraction was collected and the solvent was removed under reduced pressure, yielding an oil that solidified upon sitting under a stream of air overnight. Yield: 52% (1.12 g); mp 184–186 °C. TLC (toluene):  $R_f$  0.61. IR (KBr,  $\text{cm}^{-1}$ ) v: 3377, 2910, 2850, 2225 (CN), 1594, 1515, 1453, 1384, 1359, 1306.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 4.05 (br s, 2H, N-H), 2.20 (br s, 6H, bridgehead C-H), 1.94 (m, 6H,  $\text{CH}_2$ ), 1.85 (m, 6H,  $\text{CH}_2$ ), 1.70 (m, 12H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -119.6. EI-MS  $m/z$  (rel. intensity):  $\text{M}^+$  462 (100). Anal. calcd. for  $\text{C}_{28}\text{H}_{32}\text{N}_4\text{F}_2$ : C 72.70, H 6.97, N 12.11; found: C 72.89, H 7.20, N 12.16.

### Synthesis of 4-(1-adamantylamino)-3,5,6-trifluorophthalonitrile (**8**)

1-Adamantylamine (**3**, 0.76 g, 5.0 mmol, 1 equiv.) was dissolved in 15 mL of THF and the solution was stirred under an argon atmosphere at room temperature. To this solution was added *n*-butyllithium in hexanes (2.0 mL, 2.5 mol/L, 1 equiv.). The reaction mixture initially turned cloudy and a fine white precipitate was observed. The reaction was stirred for 1 h before a solution of 3,4,5,6-tetrafluorophthalonitrile (**1**, 0.986 g, 4.93 mmol, 1 equiv.) in THF was added dropwise under argon. It was then stirred at room temperature for 4 h and worked up as for **7**. IR (KBr,  $\text{cm}^{-1}$ ) v: 3418, 3382, 2912, 2854, 2231 (CN), 1566, 1452, 1382, 1108. Yield: 58% (0.95 g); mp 135–137 °C. TLC (toluene):  $R_f$  0.65.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 3.42 (br s, 1H, N-H), 2.19 (br s, 3H, bridgehead C-H), 1.93 (br s, 6H,  $\text{CH}_2$ ), 1.71 (br s, 6H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -118.7 (m), -129.7 (m), -136.8 (m). EI-MS  $m/z$  (rel. intensity):  $\text{M}^+$  331 (47). Anal. calcd. for  $\text{C}_{18}\text{H}_{16}\text{N}_3\text{F}_3$ : C 65.25, H 4.87, N 12.68; found: C 65.03, H 4.85, N 12.78.

### Synthesis of 3,4,5,6-tetra-(1-adamantylmethoxy)phthalonitrile (9)

1-Adamantanemethanol (4, 5.0 g, 30.1 mmol, 24 equiv.), potassium carbonate (5 g, 36 mmol, 30 equiv.), and 3,4,5,6-tetrafluorophthalonitrile (1, 1.0 g, 5 mmol, 1 eq.) were dissolved in 12 mL DMF and the reaction mixture was heated to 120 °C for 4 days. After this period, 100 mL of water was added to the reaction mixture, which was subsequently extracted with diethyl ether (3 × 75 mL). After drying over sodium sulfate, the solvent was removed under reduced pressure, yielding an amber-coloured oil. The oil was dissolved in a minimum of dichloromethane and was passed through a flash silica gel column using dichloromethane-methanol (20:1) as eluant. The first fraction was collected and the solvent was removed under reduced pressure, yielding an amber oil that solidified to an off-white solid under a stream of air overnight. Yield: 78% (3.07 g); mp 173–176 °C. TLC (toluene):  $R_f$  0.66. IR (KBr,  $\text{cm}^{-1}$ ): 2943, 2917, 2230 (CN), 1558, 1489, 1358, 1101.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 3.69 (s, 4H,  $\text{CH}_2$ ), 3.68 (s, 4H,  $\text{CH}_2$ ), 2.04 (m, 12H, bridgehead C-H), 1.71 (m, 24H,  $\text{CH}_2$ ), 1.67 (m, 24H,  $\text{CH}_2$ ). EI-MS  $m/z$  (rel. intensity):  $\text{M}^+$  784 (41). Anal. calcd. for  $\text{C}_{52}\text{H}_{68}\text{O}_4\text{N}_2$ : C 79.55, H 8.73, N 3.57; found: C 79.14, H 9.07, N 3.59.

### Synthesis of 3,4,5,6-tetra-(1-adamantylethoxy)phthalonitrile (10)

1-Adamantaneethanol (5, 5.0 g, 27.8 mmol, 8 equiv.), potassium carbonate (4.3 g, 32 mmol, 8 equiv.), and 3,4,5,6-tetrafluorophthalonitrile (1, 0.7 g, 3.5 mmol, 1 equiv.) were added to 12 mL of DMF and the reaction mixture was heated to 120 °C for 4 days. The work-up proceeded as for 9, but dichloromethane-methanol (10:1) was used as eluant. Yield: 81% (2.39 g); mp 166–168 °C. TLC (toluene):  $R_f$  0.68. IR (KBr,  $\text{cm}^{-1}$ ): 2935, 2846, 2231 (CN), 1559, 1448, 1382, 1371, 1244, 1106.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 4.19 (m, 8H,  $\text{OCH}_2$ ), 1.98 (br s, 12H, bridgehead C-H), 1.67 (m, 24H,  $\text{CH}_2$ ), 1.56 (m, 32H,  $\text{OCH}_2\text{CH}_2$  and adamantyl  $\text{CH}_2$ ). EI-MS  $m/z$  (rel. intensity):  $\text{M}^+$  840 (51). Anal. calcd. for  $\text{C}_{56}\text{H}_{76}\text{O}_4\text{N}_2$ : C 79.96, H 9.11, N 3.33; found: C 79.60, H 9.35, N 3.32.

### Synthesis of magnesium 2,3,9,10,16,17,23,24-octa-(1-adamantylxy)-1,4,8,11,15,18,22,25-octafluorophthalocyanine (11)

4-Methoxyphenylmagnesium bromide (2 mL, 0.5 mol/L in THF) was added to 3 mL of 1-octanol and the mixture was stirred for 0.5 h under argon at room temperature. To this was added 4,5-di-(1-adamantylxy)-3,6-difluorophthalonitrile (6) (0.250 g, 0.53 mmol) and the mixture was heated under argon to 120 °C. Upon heating, the clear, colourless mixture turned green. After heating for 24 h, 50 mL of methanol was added and a green solid precipitated out of solution. The solid was collected by centrifugation and was washed with water and methanol. The crude product was then passed through a flash silica gel column eluting with hexane – ethyl acetate (9:1). The first fraction was collected and the solvent was removed under reduced pressure, yielding a dark green solid. Yield: 34% (0.085 g); mp >300 °C. TLC (hexane – ethyl acetate, 5:1):  $R_f$  0.72. UV-vis (dichloromethane)  $\lambda_{\text{max}}$  (log  $\epsilon$ ) (nm): 708 (4.83), 636 (4.06), 364 (4.43), 318 (4.37).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 2.50 (br s, 24H,

bridgehead C-H), 2.31 (m, 48H,  $\text{CH}_2$ ), 2.22 (m, 48H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -119.2. MALDI-MS  $m/z$  (rel. intensity): 1883 [ $\text{M}$ ] $^+$  (10), 1748 [ $\text{M} - \text{C}_{10}\text{H}_{15}$ ] $^+$  (21), 1613 [ $\text{M} - 2(\text{C}_{10}\text{H}_{15})$ ] $^+$  (25), 1478 [ $\text{M} - 3(\text{C}_{10}\text{H}_{15})$ ] $^+$ . Anal. calcd. for  $\text{C}_{112}\text{H}_{120}\text{O}_8\text{N}_8\text{F}_8\text{Mg}$ : C 71.46, H 6.43, N 5.95; found: C 71.48, H 6.44, N, 6.11

### Synthesis of magnesium 2,3,9,10,16,17,23,24-octa-(1-adamantylamino)-1,4,8,11,15,18,22,25-octafluorophthalocyanine (12)

4-Methoxyphenylmagnesium bromide (2 mL, 0.5 mol/L in THF) was added to 3 mL of 1-octanol and the mixture was stirred for 0.5 h under argon at room temperature. To this was added 4,5-di-(1-adamantylamino)-3,6-difluorophthalonitrile (7, 0.250 g, 0.53 mmol) and the mixture was heated under argon to 120 °C. Upon heating, the clear, colourless mixture turned red and was worked up as for 11, yielding a dark green solid. Yield: 17% (0.042 g); mp >300 °C. TLC (hexane – ethyl acetate, 5:1):  $R_f$  0.72. UV-vis (dichloromethane)  $\lambda_{\text{max}}$  (log  $\epsilon$ ) (nm): 794 (4.57), 708 (4.09), 478 (4.04), 358 (4.34), 322 (4.34).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 2.11 (m, 24H, bridgehead C-H), 1.87 (m, 48H,  $\text{CH}_2$ ), 1.68 (m, 48H,  $\text{CH}_2$ ). MALDI-MS  $m/z$  (rel. intensity): 1872 [ $\text{M}$ ] $^+$  100. Anal. calcd. for  $\text{C}_{112}\text{H}_{128}\text{N}_{16}\text{F}_8\text{Mg}$ : C 71.76, H 6.88, N 11.95; found: C 71.87, H 7.27, N 11.24.

### Synthesis of magnesium 2,9,16,23-tetra-(1-adamantylamino)-1,3,4,8,10,11,15,17,18,22,24,25-dodecafluorophthalocyanine (13)

4-Methoxyphenylmagnesium bromide (2 mL, 0.5 mol/L in THF) was added to 3 mL of 1-octanol and the mixture was stirred for 0.5 h under argon at room temperature. To this was added 4-(1-adamantylamino)-3,5,6-trifluorophthalonitrile (8, 0.250 g, 0.75 mmol) and the mixture was heated under argon to 120 °C. Upon heating, the clear, colourless mixture turned green. After heating for 24 h, 50 mL of methanol was added and a green solid precipitated out of solution and was worked up as for 11, yielding a dark green solid. Yield: 21% (0.053 g); mp >300 °C. TLC (hexane – ethyl acetate, 9:1):  $R_f$  0.62. UV-vis (dichloromethane)  $\lambda_{\text{max}}$  (log  $\epsilon$ ) (nm): 714 (4.63), 646 (4.07), 362 (4.37).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 3.82 (br s, 4H, NH), 2.18 (m, 12H, bridgehead C-H), 1.71–1.96 (m, 24H,  $\text{CH}_2$ ), 1.58 (br s, 24H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -128 (m), -138 (m). MALDI-MS  $m/z$  (rel. intensity): 1348 [ $\text{M}$ ] $^+$  (100), 1213 [ $\text{M} - \text{C}_{10}\text{H}_{15}$ ] $^+$  (63), 1078 [ $\text{M} - 2(\text{C}_{10}\text{H}_{15})$ ] $^+$  (53), 943 [ $\text{M} - 4(\text{C}_{10}\text{H}_{15})$ ] $^+$  (24). Anal. calcd. for  $\text{C}_{72}\text{H}_{64}\text{N}_{12}\text{F}_{12}\text{Mg}$ : C 64.07, H 4.78, N 12.45; found: C 64.44, H 4.94, N 12.78

### Synthesis of magnesium 1,2,3,4,8,9,10,11,15,16,17,18,22,23,24,25-hexadeca-(1-adamantylmethoxy)phthalocyanine (14)

4-Methoxyphenylmagnesium bromide was added (2 mL, 0.5 mol/L in THF) to 3 mL of 1-octanol and the mixture was stirred for 0.5 h under argon at room temperature. To this was added 3,4,5,6-tetraadamantylmethoxyphthalonitrile (9, 0.250 g, 0.32 mmol) and the mixture was heated under argon to 120 °C. Upon heating, the clear, colourless mixture turned green. After heating for 24 h, 50 mL of methanol was added and a green solid precipitated out of solution and was worked up as for 11, yielding a dark green solid. Yield: 15%

(0.039 g); mp >300 °C. TLC (hexane – ethyl acetate, 15:1):  $R_f$  0.52. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 752 (4.91), 672 (4.12), 364 (4.19).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 3.49 (br s, 32H,  $\text{OCH}_2$ ), 2.00 (m, 48H, bridgehead C-H), 1.70–1.90 (m, 192H,  $\text{CH}_2$ ). MALDI-MS  $m/z$  (rel. intensity): 3160  $[\text{M}]^+$  (49), 3011  $[\text{M} - \text{C}_{11}\text{H}_{17}]^+$  (57), 2862  $[\text{M} - 2(\text{C}_{11}\text{H}_{17})]^+$  (100), 2713  $[\text{M} - 3(\text{C}_{11}\text{H}_{17})]^+$  (96). Anal. calcd. for  $\text{C}_{208}\text{H}_{272}\text{O}_{16}\text{N}_8\text{Mg}$ : C 78.94, H 8.66, N 3.54; found: C 78.50, H 8.47, N, 3.28.

#### Synthesis of magnesium 1,2,3,4,8,9,10,11,15,16,17,18, 22,23,24,25-hexadeca-(1-adamantaneethoxy)phthalocyanine (15)

4-Methoxyphenylmagnesium bromide (2 mL, 0.5 mol/L in THF) was added to 3 mL of 1-octanol and the mixture was stirred for 0.5 h under argon at room temperature. To this was added 3,4,5,6-tetra-(1-adamantylethoxy)phthalonitrile (**10**, 0.250 g, 0.30 mmol) and the mixture was heated under argon to 120 °C. Upon heating, the clear, colourless mixture turned green. After heating for 24 h, 50 mL of methanol was added and a green solid precipitated out of solution. The solid was collected by centrifugation and was washed with water and methanol. The crude product was then passed through a flash silica gel column eluting with hexane – ethyl acetate (9:1). The first fraction was collected and the solvent was removed under reduced pressure, yielding a dark green solid. Yield: 20% (0.051 g); mp >300 °C. TLC (hexane – ethyl acetate, 15:1):  $R_f$  0.49. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 744 (4.93), 668 (4.09), 328 (4.10).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 4.27 (t, 16H,  $J = 9.0$  Hz,  $\text{OCH}_2$ ), 4.16 (t, 16H,  $J = 9.0$  Hz,  $\text{OCH}_2$ ), 1.99 (br s, 48H, bridgehead C-H), 1.76 (m, 96H,  $\text{CH}_2$ ), 1.61 (m, 128H,  $\text{OCH}_2\text{OCH}_2$ - and  $\text{CH}_2$ ). MALDI-MS  $m/z$  (rel. intensity): 3384  $[\text{M}]^+$  (68), 3221  $[\text{M} - \text{C}_{12}\text{H}_{19}]^+$  (71), 3058  $[\text{M} - 2(\text{C}_{12}\text{H}_{19})]^+$  (95), 2895  $[\text{M} - 3(\text{C}_{12}\text{H}_{19})]^+$  (89), 2732  $[\text{M} - 4(\text{C}_{12}\text{H}_{19})]^+$  (83), 2569  $[\text{M} - 5(\text{C}_{12}\text{H}_{19})]^+$  (83), 2406  $[\text{M} - 6(\text{C}_{12}\text{H}_{19})]^+$  (100). Anal. calcd. for  $\text{C}_{224}\text{H}_{304}\text{O}_{16}\text{N}_8\text{Mg}$ : C 79.38, H 9.04, N 3.31; found: C 78.77, H 9.41, N 3.78

#### Synthesis of metal-free 2,3,9,10,16,17,23,24-octa-(1-adamantyloxy)-1,4,8,11,15,18,22,25-octafluorophthalocyanine (16)

Magnesium 2,3,9,10,16,17,23,24-octa-(1-adamantyloxy)-1,4,8,11,15,18,22,25-octafluorophthalocyanine (**11**, 0.502 g, 0.27 mmol) was dissolved in glacial acetic acid (5 mL) and the mixture was refluxed under air. After 4 days, the crude product was precipitated out of solution following the addition of absolute ethanol (50 mL). The dark green precipitate was washed with ethanol (2  $\times$  30 mL) and methanol (1  $\times$  30 mL). The crude product was purified by flash silica gel column chromatography using hexane – ethyl acetate (4:1) as eluant. The first fraction was collected and the solvent was removed under reduced pressure. Yield: 11% (55 mg); mp >300 °C. TLC (hexane – ethyl acetate, 4:1):  $R_f$  0.80. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 734 (4.02), 704 (4.01), 670 (3.51), 636 (3.40), 358 (3.63).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 2.25 (m, 24H, bridgehead C-H), 1.52–1.98 (m, 96H,  $\text{CH}_2$ ).  $^{19}\text{F}$  ( $\text{CDCl}_3$ )  $\delta$ : -119.2. IR (KBr,  $\text{cm}^{-1}$ )  $\nu$ : 3275, 2915, 2853, 1732, 1653, 1456, 1300, 1281, 1048, 967. MALDI-MS  $m/z$  (rel. intensity): 1858  $[\text{M}]^+$  (28), 1723  $[\text{M} - \text{C}_{10}\text{H}_{15}]^+$  (51), 1588  $[\text{M} - 2(\text{C}_{10}\text{H}_{15})]^+$  (87), 1453  $[\text{M} -$

$3(\text{C}_{10}\text{H}_{15})]^+$  (100). Anal. calcd. for  $\text{C}_{112}\text{H}_{122}\text{O}_8\text{N}_8\text{F}_8$ : C 72.31, H 6.61, N 6.02; found: C 71.90, H 6.75, N 5.96.

#### Synthesis of nickel 2,3,9,10,16,17,23,24-octa-(1-adamantyloxy)-1,4,8,11,15,18,22,25-octafluorophthalocyanine (17)

4,5-Di-(1-adamantyloxy)-3,6-difluorophthalonitrile (**6**, 0.306 g, 0.65 mmol) and nickel(II) chloride (90 mg, 0.7 mmol) were added to 4 mL of *N,N*-dimethylaminoethanol (DMEA). The mixture was heated to 145 °C and stirred under argon. After stirring for 24 h, a green solid was precipitated following the addition of 40 mL of water. The precipitate was collected by centrifugation. The crude product was purified by flash silica gel column chromatography with hexane – ethyl acetate (4:1) as eluant. The first fraction was collected and the solvent was removed under reduced pressure. Yield: 24% (0.076 g); mp >300 °C. TLC (hexane – ethyl acetate, 2:1):  $R_f$  0.81. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 708 (4.91), 636 (4.23), 342 (4.34), 304 (4.47).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 2.41 (br s, 24H, bridgehead C-H), 2.36 (br m, 48H,  $\text{CH}_2$ ), 1.74 (m, 48H,  $\text{CH}_2$ ).  $^{19}\text{F}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : -126.1. MALDI-MS  $m/z$  (rel. intensity): 1914  $[\text{M}]^+$  (10), 1779  $[\text{M} - \text{C}_{10}\text{H}_{15}]^+$  (23), 1644  $[\text{M} - 2(\text{C}_{10}\text{H}_{15})]^+$  (42), 1509  $[\text{M} - 2(\text{C}_{10}\text{H}_{15})]^+$  (67), 1374  $[\text{M} - 4(\text{C}_{10}\text{H}_{15})]^+$  (91). Anal. calcd. for  $\text{C}_{112}\text{H}_{120}\text{O}_8\text{N}_8\text{F}_8\text{Ni}$ : C 70.18, H 6.31, N 5.85; found: C 69.91, H 6.78, N 5.74.

#### Synthesis of nickel 1,2,3,4,8,9,10,11,15,16,17,18, 22,23,24,25-hexadeca-(1-adamantylmethoxy)phthalocyanine (18)

3,4,5,6-Tetra-(1-adamantylmethoxy)phthalonitrile (**9**, 0.202 g, 0.26 mmol) and nickel(II) chloride (36 mg, 0.28 mmol) were added to 4 mL of DMEA. The mixture was heated to 145 °C and allowed to stir under argon. After stirring for 24 h, a green solid was precipitated following the addition of 40 mL of water and was worked up as for **17**. Yield: 14% (29 mg); mp >300 °C. TLC (hexane – ethyl acetate, 9:1):  $R_f$  0.71. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 750 (4.93), 672 (4.43), 386 (4.55), 314 (4.77).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 4.21 (br m, 32H,  $\text{OCH}_2$ ), 2.10 (br m, 24H, bridgehead CH), 1.98 (br m, 24H, bridgehead CH), 1.61–1.88 (m, 192H,  $\text{CH}_2$ ). MALDI-MS  $m/z$  (rel. intensity): 3214  $[\text{M} + \text{H}_2\text{O}]^+$  (38), 3065  $[\text{M} + \text{H}_2\text{O} - \text{C}_{11}\text{H}_{17}]^+$  (52), 2916  $[\text{M} + \text{H}_2\text{O} - 2(\text{C}_{11}\text{H}_{17})]^+$  (53), 2769  $[\text{M} + \text{H}_2\text{O} - 3(\text{C}_{11}\text{H}_{17})]^+$  (94). Anal. calcd. for  $\text{C}_{208}\text{H}_{272}\text{O}_{16}\text{N}_8\text{Ni}$ : C 77.65, H 8.58, N 3.48; found: C 77.48, H 9.03 N, 3.61.

#### Synthesis of nickel 1,2,3,4,8,9,10,11,15,16,17,18, 22,23,24,25-hexadeca-(1-adamantaneethoxy)phthalocyanine (19)

3,4,5,6-Tetra-(1-adamantaneethoxy)phthalonitrile (**10**, 0.260 g, 0.31 mmol) and nickel(II) chloride (40 mg, 0.31 mmol) were added to 4 mL of DMEA. The mixture was heated to 145 °C and allowed to stir under argon. After stirring for 24 h, a green solid was precipitated following the addition of 40 mL of water and was worked up as for **17**. Yield: 32% (85 mg); mp >300 °C. TLC (hexane – ethyl acetate, 9:1):  $R_f$  0.73. UV-vis (dichloromethane)  $\lambda_{\max}$  (log  $\epsilon$ ) (nm): 736 (4.85), 660 (4.25), 372 (4.40), 340 (4.48), 312 (4.61).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$ : 4.78 (t, 16H,  $J = 7.1$  Hz,  $\text{OCH}_2\text{CH}_2$ ), 4.53 (t, 16H,  $J = 7.1$  Hz,  $\text{OCH}_2\text{CH}_2$ ), 2.12 (t, 16H,  $J = 7.1$  Hz,

OCH<sub>2</sub>CH<sub>2</sub>), 2.05 (two br m, 48H, bridgehead CH), 1.94 (t, 16H,  $J = 7.1$  Hz, OCH<sub>2</sub>CH<sub>2</sub>), 1.62–1.85 (m, 192H, adamantyl-CH<sub>2</sub>). MALDI-MS  $m/z$  (rel. intensity): 3418 [M + H]<sup>+</sup> (83), 3256 [M + H - C<sub>12</sub>H<sub>19</sub>]<sup>+</sup> (72), 3094 [M + H - 2(C<sub>12</sub>H<sub>19</sub>)]<sup>+</sup> (100), 2930 [M + H - 3(C<sub>12</sub>H<sub>19</sub>)]<sup>+</sup> (85). Anal. calcd. for C<sub>224</sub>H<sub>304</sub>O<sub>16</sub>N<sub>8</sub>Ni: C 78.59, H 8.95, N 3.27; found: C 78.07, H 9.29, N 3.64.

## Conclusions

Phthalocyanines bearing large bulky substituents have previously shown interesting physicochemical properties, including a red shifting of the Q band. A series of metallated and nonmetallated Pcs have been synthesized incorporating large bulky substituents based upon analogs of adamantane. These complexes exhibit interesting characteristics, notably pronounced red shifting of the Q band.

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