Synthesis and spectroscopic properties of new unsymmetrically substituted phthalocyanines

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Unsymmetrically substituted monophthalocyanine complexes containing a free phthalodinitrile unit were synthesised with the use of microwave irradiation for the first time. The possibility of synthesising phthalocyanine heterodimers starting from unsymmetrically substituted monophthalocyanine **3a** was demonstrated for the first time.

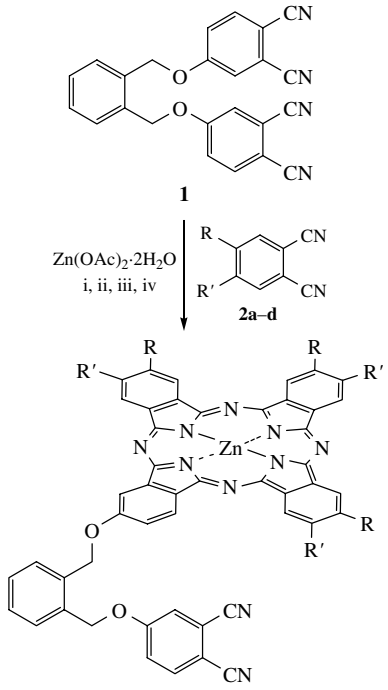
It is well known that unsymmetrically substituted monophthalocyanines exhibit unique optical, spectroscopic and catalytic properties.[1] It was found that they can be used in the photodynamic therapy of cancer[2] and in non-linear optics.[3]

The use of unsymmetrically substituted monophthalocyanines with functional substituents in the syntheses of bi-,[4] tri-[5] and polynuclear phthtalocyanines[5,6] is a problem of current interest.

In this context, the aim of this work was to optimise the single-stage synthesis of unsymmetrically substituted monophthalocyanines containing free phthalodinitrile units.

The starting compounds – 1,2-bis(3,4-dicyanophenoxymethyl)-benzene **1**,[7] 4,5-dipropyloxy-,[8] 4,5-dibutyl-[9] and 4,5-diethyl-phthalodinitrile[10] – were synthesised in accordance with published procedures, whereas phthalocyanines **3a–d** were synthesised in accordance with Scheme 1.†

With the use of phthalocyanine **3a** as an example, we studied a number of synthetic approaches to the preparation of compounds **3a–d**. Initially, the synthesis of **3a** was performed on boiling initial reagents in a stoichiometric ratio in *o*-dichlorobenzene in the presence of isoamyl alcohol and 1,8-diazabicyclo-[5.4.0]undec-7-ene (DBU) in catalytic amounts. Compound **3a** was obtained only in trace amounts; because of this, we studied other approaches to the preparation of the test complexes and the effect of the ratio between initial reagents on the yields of target products.



a R = R′ = OPr **c** R = R′ = *n*-Bu
b R = Bu^t, R′ = H **d** R = R′ = Et

Scheme 1 *Reagents and conditions*: i, *o*-$C_6H_4Cl_2$, DBU, Am^{i}OH, boiling, 1.5–2 h; ii, $Me_2NCH_2CH_2OH$, boiling, 1–1.5 h; iii, microwave irradiation, 600 W, 8–10 min; iv, fusion, 220–230 °C, 7–10 min.

We found that the ratio between starting phthalodinitriles **1** and **2a** had practically no effect on the yield of target compound **3a**. However, as the amount of **2a** was decreased, the amount of a symmetrical by-product decreased. The amount of zinc acetate significantly affected the yield of compound **3a**. Thus, as the amount of the salt was increased to 2.5 equiv. with respect to compound **1**, the yield of the target product increased. A further increase in the amount of zinc acetate resulted in a dramatic decrease in the yield of **3a**. The concentration of phthalocyanine **3a** in the reaction mixture also decreased upon long boiling. We found that an optimum ratio between starting reagents is **1**:**2a–d**:zinc acetate = 1:6:2.5. The optimum reaction time was 1.5–2 h, and the maximum yield of compounds **3a–d** was 2–3%. With the use of *N*,*N*-dimethylaminoethanol (DMAE) as

† *Synthetic procedure*. A mechanical mixture of compounds **1** (100 mg, 0.256 mmol), **2a** (375 mg, 1.538 mmol) and zinc acetate dihydrate (140 mg, 0.640 mmol) was microwaved at 600 W for 10 min. The reaction mixture was treated with methanol and purified by chromatography (silica gel, 40–63 μm; eluent: benzene–ethyl acetate, 5:1) in order to separate complexes **3a–d** from concomitant symmetrical monophthalocyanines. Compounds **3a–d** were obtained for the first time and characterised by visible and IR spectroscopy and mass spectrometry (chemical ionisation mode).

For **3a**: yield 6.1%. ^{1}H NMR ($CDCl_3$ + [$^2H_5$]Py) δ: 1.3 (t, 18H, Me), 2.1–2.3 (m, 12H, CH_2), 4.5 (t, 12H, CH_2), 5.0 (s, 2H, CH_2), 5.3 (s, 2H, CH_2), 7.3–7.8 (m, 7H), 8.7–9.2 (m, 9H). IR (KBr, ν/cm^{-1}): 2961 (s, aromatic CH), 2230 (w, CN), 1601 (s, C=C). Electronic absorption spectrum [$CHCl_3$, λ_{max}/nm (log ε)]: 354 (4.39), 614 (3.90), 679 (4.63). MS, *m*/*z*: 1186.2 (MH^+), 939.2 [$(PrO)_6PcO^+$].

For **3b**: yield 5.4%. ^{1}H NMR ($CDCl_3$ + [$^2H_5$]Py) δ: 1.7–1.9 (m, 27H, Me), 5.0 (s, 2H, CH_2), 5.2 (s, 2H, CH_2), 7.2–7.9 (m, 7H), 9.2–9.6 (m, 12H). IR (KBr, ν/cm^{-1}): 2990 (s, aromatic CH), 2231 (w, CN), 1600 (s, C=C). Electronic absorption spectrum [$CHCl_3$, λ_{max}/nm (1og ε)]: 350 (4.41), 611 (3.95), 679 (4.94). MS, *m*/*z*: 1008.1 (MH^+), 759.3 ($Bu^t_6PcO^+$).

For **3c**: yield 5.3%. ^{1}H NMR ($CDCl_3$ + [$^2H_5$]Py) δ: 1.2 (t, 18H, Me), 1.6–1.8 (m, 12H, CH_2), 1.8–2.1 (m, 12H, CH_2), 3.2 (t, 12H, CH_2), 5.0 (s, 2H, CH_2), 5.2 (s, 2H, CH_2), 7.1–7.8 (m, 7H), 8.9–9.8 (m, 9H). IR (KBr, ν/cm^{-1}): 2956 (s, aromatic CH), 2230 (w, CN), 1596 (s, C=C). Electronic absorption spectrum [$CHCl_3$, λ_{max}/nm (1og ε)]: 352 (4.62), 617 (3.90), 685 (4.90). MS, *m*/*z*: 1174.4 (MH^+), 929.5 (Bu_6PcO^+).

For **3d**: yield 4.8%. ^{1}H NMR ($CDCl_3$ + [$^2H_5$]Py) δ: 1.3 (t, 6H, Me), 1.6 (t, 12H, Me), 2.6–2.8 (m, 4H, CH_2), 3.7–3.9 (m, 8H, CH_2), 5.0 (s, 2H, CH_2), 5.2 (s, 2H, CH_2), 7.1–7.8 (m, 7H), 8.7–9.4 (m, 9H). IR (KBr, ν/cm^{-1}): 2959 (s, aromatic CH), 2229 (w, CN), 1597 (s, C=C). Electronic absorption spectrum [$CHCl_3$, λ_{max}/nm (log ε)]: 352 (4.61), 616 (4.19), 684 (4.93). MS, *m*/*z*: 1007.2 (MH^+), 758.6 (Et_6PcO^+).

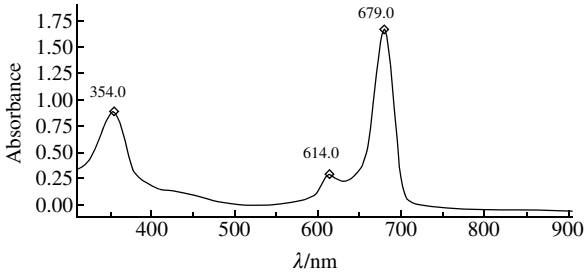


Figure 1 Electronic absorption spectrum of phthalocyanine **3a** ($CHCl_3$).

a solvent, the above behaviour was also observed; however, the yields of compounds **3a–d** were as high as 4–5%, whereas the reaction time was shortened to 1–1.5 h.

Phthalocyanines **3a–d** were also synthesised by fusion and by the microwave irradiation of the starting reagents (the ratio **1**:**3a–d**:zinc acetate was 1:6:2.5). Upon the fusion of the starting reagents, the yields of target products **3a–d** were as high as 6–8%, whereas the reaction time was shortened to 7–10 min. As well as in the previous cases, the yields of compounds **3a–d** decreased as the amount of zinc acetate or the time of fusion was increased. Complexation was observed at 200 °C to result in maximum yields of target products at 220–230 °C. As the temperature was further increased, the yields of **3a–d** decreased.

On the microwave irradiation of the reagents (Samsung M1915NR oven), the reaction time and the yield of phthalocyanine **3a** primarily depended on the radiation power. Thus, as the radiation power was increased from 300 to 1100 W, the reaction time gradually decreased from 25 to 3 min. An optimum radiation power was 600 W, at which the maximum yields of **3a–d** (4–6%) were reached. The reaction time was 8–10 min.

Note that, in the case of unsymmetrically substituted phthalocyanines **3a–d**, maximum yields were obtained in the synthesis by fusion. In addition to the set of statistical products, the main problem of the synthesis of these compounds consists in inevitable oligomerisation due to the presence of a free phthalodinitrile unit. This fact occurs to some extent as the time of boiling, fusion or irradiation of the reagents is increased.

The structures of complexes **3a–d** were confirmed by mass spectrometry and IR spectroscopy. The mass spectra (Finnigan MAT INCOS-50 instrument; chemical ionisation) contained peaks due to $[MH]^+$ molecular ions and $[R_3R'_3PcO]^+$ fragment ions in the positive mass region. All the peaks of observed ions were characterised by isotope splitting that corresponds to the natural abundance of isotopes. The IR spectra (Nicolet Nexus IR Fourier spectrometer) of chromatographically pure compounds **3a–d** exhibited absorption bands due to CN groups at 2229–2231 cm^{-1}. The ^1H NMR spectra of these complexes ($CDCl_3$ + $[^2H_5]$Py) exhibited signals due to aromatic multiplets in the regions 8.8–9.5 and 7.0–7.8 ppm and two singlets due to magnetically non-equivalent benzyl protons in the region 5.0–5.3 ppm (2H) and due to aliphatic protons in the region 1.1–3.2 ppm, depending on the structure of the compounds.

Phthalocyanines **3a–d** were also characterised by electronic absorption spectra. As an example, Figure 1 demonstrates the electronic absorption spectrum of compound **3a**. The spectra of compounds **3b–d** were similar; however, additional absorption,

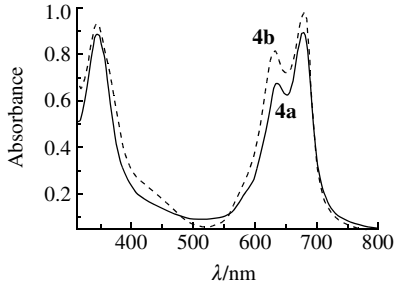
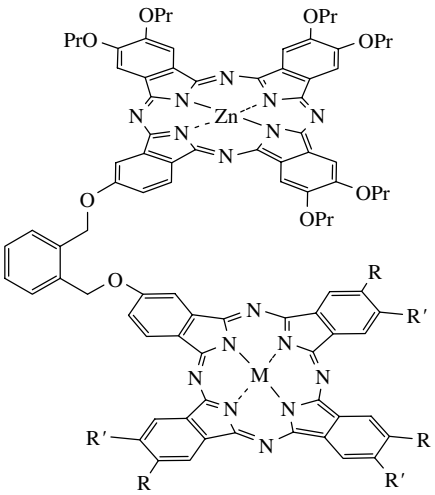


Figure 2 Electronic absorption spectra of binuclear phthalocyanines **4a**,**b** ($CHCl_3$).



4a R = Bu^t, R′ = H, M = Zn
4b R = R′ = OPr, M = Cu

which is typical of alkoxy-substituted phthalocyanines, was not observed in the region 400–450 nm.

The character and position of the Q-band suggest that compounds **3a–d** belong to symmetry group D_{4h}. Vibrational satellites were well resolved. Compound **3c** exhibited the greatest bathochromic shift of the Q-band.

The possibility of preparing unsymmetical mixed-ligand and bimetallic binuclear phthalocyanines was demonstrated using complex **3a** as an example.‡

Figure 2 demonstrates the electronic absorption spectra of phthalocyanines **4a**,**b**. The MALDI-TOF mass spectra of chromatographically individual binuclear complexes **4a**,**b** exhibited peaks due to molecular ions $[MH^+]$ with *m*/*z* 1808 and 1985, respectively.

Note that the single-stage synthesis developed allowed us to obtain phthalocyanines **3a–d** in maximum yields, which are comparable to the yields of related compounds, which were synthesised in six stages.[11] In this case, the reaction time was considerably shortened to 8–10 min. We were the first to use microwave irradiation, which was found promising for the preparation of complexes of this type. The possibility of synthesising unsymmetrical binuclear phthalocyanines based on an unsymmetrically substituted monophthalocyanine was demonstrated for the first time.

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‡ *Synthetic procedure*: $Zn(OAc)_2 \cdot 2H_2O$ (6 mg, 0.025 mmol) was added to a solution of compounds **3a** (15 mg, 0.012 mmol) and **2b** (16 mg, 0.088 mmol) in *n*-hexanol. The mixture was refluxed for 25 min. The solvent was evaporated at a reduced pressure. After separating oligomeric by-products (40–63 μm silica gel; chloroform–THF, 20:1), the subsequent purification was continued on BioBeads SX-l (Biorad, THF) and finished on TLC (Merck Silica Ge1 60 F_{254}; chloroform–THF, 40:1). Compounds **4a**,**b** were prepared for the first time and characterised by electron absorption spectroscopy as well as mass-spectrometric data (MALDI-TOF).

For **4a**: 6.8% yield; electronic absorption spectrum ($CHCl_3$) λ_{max}/nm: 344, 635, 676. MS, *m*/*z*: 1808 (MH^+).

For **4b**: 8.0% yield; electronic absorption spectrum ($CHCl_3$) λ_{max}/nm: 343, 630, 678. MS, *m*/*z*: 1985 (MH^+).

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