Synthesis of Cu(II) and Ni(II) Phthalocyanines Bearing Nitro and 4-(1-Methyl-1-phenylethyl)phenoxy Groups

Serafima A. Znoyko, a, b Anastasia I. Mikhailova, a Olga B. Akopova, b Natalia V. Bumbina, b Nadezhda V. Usol'tseva, b Vladimir E. Maizlish, a and Gennady P. Shaposhnikov a

Dedicated to Oleg A. Golubchikov on the occasion of his 70th anniversary

Research Institute of Macroheterocycles, Ivanovo State University of Chemistry and Technology, 153000 Ivanovo, Russia
Research Institute of Nanomaterials, Ivanovo State University, 153025 Ivanovo, Russia
Corresponding author E-mail: znoykosa@yandex.ru

Bifunctional substituted copper and nickel phthalocyanines were synthesized. These compounds were modified by introduction of sulfonic and sulfonamide groups into aryloxy fragments. Spectral and mesomorphic properties of synthesized compounds were studied.

Keywords: Bifunctional substituted phthalocyanines, synthesis, mesomorphism.
Introduction

The investigation of the liquid crystalline (mesomorphic) state of low-molecular organic compounds has more than a half of century history.[1-2] However, the study of the influence of the structure peculiarities on the thermotropic mesomorphism of disc-like compounds began only in the 80s of the previous century. This study is primarily associated with Prof. S. Chandrasekhar, who was the first to show the possibility of conceptually new supramolecular mesogens of this type packing into columnar ensembles.[3]

The first proof of liquid crystallinity of porphyrin derivatives was obtained in the 1990s and it immediately drew attention to these mesogens in the aspect of studying the influence of the features of their structure on mesomorphic properties and the type of supramolecular organization.[1,4-6]

The steadily increasing interest to the mesomorphism of phthalocyanine derivatives is determined by the unique properties of these compounds: one-dimensional conductivity along the column axis,[7] high thermal and chemical stability,[8] the ability to vitrify,[9,10] photoactivity,[11-13] absorption in the visible and near-IR regions of the spectrum,[14] sensing,[15] and photoconduction[16] which suggest a great potential for their use as nanomaterials.

At the first stages of studying phthalocyanine derivatives, the main attention was paid to the analysis of the effect of aliphatic (and related to them in structure) substituents on homo-substitution in the peripheral and non-peripheral positions of the phthalocyanine macroheterocycle.[1,4,17,18]

It was later shown that the presence of aliphatic substituents was not absolutely necessary for the formation of columnar mesophases.[19] The so-called flying-seeds-like compounds (FSLM) synthesized by Ohta et al.[20-24] unlike classical discotic mesogens, did not contain extended aliphatic substituents in the molecule. Nevertheless, the mesophase was formed due to the filling of free volumes at the periphery of the columns with mobile aromatic substituents.[25] All these compounds had only electron-donating fragments (from 4 to 8). A typical example of the FSLM compound is the 2,9,16,23-tetra[4-(1-methyl-1-phenylethyl)phenoxy]phthalocyanine copper(II) complex.[20] On heating this compound exhibits two different types of mesophases, which exist in an extremely wide temperature range of 480 °C (from the melting point to the decomposition).

As it was shown previously,[26-28] the mix-substituted phthalocyanines without aliphatic substituents but having both donor oxyaryl and acceptor benzotriazolyl functional groups exhibit mesomorphic properties as well as a tendency to vitrify (Figure 1). While the presence of only 1-benzotriazole groups on periphery of homosubstituted phthalocyanines is not accompanied by the appearance of liquid crystalline phases.[24]

Moreover, the introduction of the electron-withdrawing 1-benzotriazole fragment into the mesogenic 2,9,16,23-tetra[4-(1-methyl-1-phenylethyl)phenoxy]phthalocyanine copper(II) complex (1e, Figure 1), studied earlier by Ohta,[20] leads to substantial increase of the melting point (Cr→Mes phase transition temperature of 1e is 131 °C) and narrowing of the mesophase existence temperature range to 43 °C. Further modification of the electron-donor substituent by introducing in it a sulfo group causes an increase the Cr→Mes phase transition temperature to 183 °C. In contrast, the introduction of the octadecylsulfamoyl group leads to a decrease of temperature of the indicated phase transition to 108 °C and to an expansion of the mesophase existence temperature range to 89 °C.[26]

Therefore, our studies showed a significant change of mesomorphic behavior, crystalline phase thermostability and the manifestation of glass state due to variation of the oxyaryl group structure acting as electron donor substituent. At the same time, the influence of the electron-withdrawing group (EWG) nature on the mesomorphic behavior of the studied phthalocyanines has not been investigated.

Figure 1. Structural formula of mix-substituted phthalocyanines and their metal complexes (1a-p) with four peripheral benzotriazolyl and oxyaryl fragments,[26-28] 4-(1-methyl-1-phenylethyl)phenoxy substituent is framed.
All the above mentioned motivated us to analyze the effect of the chemical nature of the electron-withdrawing group on mesomorphic behavior of 4-(1-methyl-1-phenylethyl)phenoxy substituted phthalocyanines (on the example of replacing the benzotriazolyl acceptor group with a nitro group). In this case, modification of phthalocyanines by the variation of EWG structure will allow to establish its effect on the ability to form a mesomorphic state. In addition, the results obtained should contribute to further deepening of the notion of a correlation between the structure of bifunctional-substituted phthalocyanines and the manifestation of LC properties. The latter will contribute to the development of condensation methods in general.

**Experimental**

Spectral studies and elemental analysis were carried out on the equipment of the Center for Collective Use (Ivanovo, ISUCT). UV-Vis spectra of solutions of the synthesized phthalocyanines in DMF, chloroform and sulfuric acid were recorded using a HITACHI U-2001 spectrophotometer at room temperature within the spectral range 325–900 nm. IR spectra of phthalocyanines 2-5 were recorded using a ThermoflashEA-1112 (CHNS-O). Mass spectra (MALDI-TOF) were obtained using a MALDI-TOF mass spectrometer (Axima Confidence, Shimadzu Biotech) in positive ions mode. 2-(4-Hydroxybenzoazo)benzoic acid (2b) was used as the matrix. The samples were prepared by dissolving test solutions of [D6]DMSO and CDCl3, test solutions of 2-5 with internal standard tetramethylsilane (TMS) were recorded by «Bruker DRX-500». Elemental analysis of the synthesized compounds was performed on Thermo FlashEA-1112 (CHNS-O).

Mass spectra (MALDI-TOF) were obtained using a MALDI-TOF mass spectrometer (Axima Confidence, Shimadzu Biotech) in positive ions mode. 2-(4-Hydroxybenzoazo)benzoic acid (2b) was used as the matrix. The samples were prepared by dissolving test solutions of [D6]DMSO and CDCl3, test solutions of 2-5 with internal standard tetramethylsilane (TMS) were recorded by «Bruker DRX-500». Elemental analysis of the synthesized compounds was performed on Thermo FlashEA-1112 (CHNS-O). The method for modeling and prognosing mesomorphism in discotic compounds was carried out using a thermogravimetric-DSC synchronous thermal analyzer (STA 449 F3 Jupiter by NETZSCH, Germany) under oxygen-argon atmosphere, heating rate 5 °C/min, in platinum crucible. Before carrying out the elemental and thermogravimetric analysis, the samples of the investigated compounds were heated at 110 °C for 2 hours.

Phase state of phthalocyanine derivatives 2-5 was studied using the polarization microscopy method (a microscope MIN-8 with a heating table and a camera “Zorkiy” as equipment, heating rate 2 deg/min).

The method for modeling and prognosing mesomorphism in discotic compounds using molecular parameters (MP) of single molecules[26-31] was used. The parameters were calculated in the original CMP ChemCard program, [11] which involves the molecules geometry construction and optimization, using the HyperChem software package. The benefits of this method include ease of use, short operating time and sufficiently high degree of prediction reliability (70–90%). According to the conditions of this method, a significant deviation of at least one of the calculated MP values from the boundary values of the classification series [11] indicates the inability of the compound to the mesophase formation, typical for discotic mesogens (DM). In case of a slight deviation of the calculated MP values a latent mesophase can appear.

4-Bromo-3-nitrophthalonitrile was synthesized according to the well-known method.[10]

4-[4-(1-Methyl-1-phenylethyl)phenoxy]-5-nitrophthalonitrile was synthesized according to known procedure.[11]

**Copper(I) (2a) and nickel(I) (2b) complexes of 2,9,16,23-tetra[4-(1-methyl-1-phenylethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanines. General method 1.** Thoroughly trituated mixture of 0.38 g (1 mmol) of 4-[4-(1-methyl-1-phenylethyl)phenoxy]-5-nitrophthalonitrile, 0.05 g (0.8 mmol) of urea, and 0.34 g (0.2 mmol) of (CH3COO)2Cu·2H2O or 0.97 g (0.2 mmol) of (CH3COO)Ni·4H2O was heated at 155–170 °C for 1.5 h, after which it was dissolved in chloroform and chromatographed on aluminum oxide (elucent – chloroform).

**Copper(II) complexes of 2,9,16,23-tetra[4-(1-methyl-1-phenylethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanines (3a,b).** General method 2. The interaction between compounds 2a (160 mg, 0.1 mmol) or 2b (158 mg, 0.1 mmol) in 2 ml (18 mmol) of mixture of chloroform, water, ammonia, aqueous-alkaline solutions. The precipitate was collected on a Schott filter, then dried in a desiccator above sulfuric acid for 72 h. The obtained salts were distilled off and then boiled with water until complete dissolution. Then the solvent was distilled off. Final purification of 3a,b was carried out using column chromatography: eluent – DMF, sorbent – silica M 60. The products obtained are dark green solid materials soluble in DMF, water, ammonia, aqueous-alkaline solutions.

**Copper(II) complexes of 2,9,16,23-tetra[4-(1-methyl-1-(4-sulphonylphenyl)ethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanines (3a).** Synthesis of metallocomplexes of 2,9,16,23-tetra[4-(1-methyl-1-(4-sulphonylphenyl)ethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanines (4, 5). General method 3. The interaction between compounds 2a,b (0.1 mmol) in 2 ml mixture of chloroform, water, ammonia, aqueous-alkaline solutions. The precipitate was collected on a Schott filter, then dried in a desiccator above sulfuric acid for 72 h. The obtained salts were distilled off and then boiled with water until complete dissolution. Then the solvent was distilled off. Final purification of 4a,b was carried out using column chromatography: eluent – DMF, sorbent – silica M 60. The products obtained are dark green solid materials soluble in DMF, water, ammonia, aqueous-alkaline solutions.
Cu and Ni Phthalocyanines Bearing Nitro and Phenoxy Groups

in acetone and boiled at 60 °C for 1–1.5 h. The process was controlled by the completeness of the reaction mass sample dissolving in chloroform. At the end of the reaction the acetone was distilled off. The products (4, 5) were extracted from the reaction mixture with chloroform. Final purification was carried out using column chromatography: eluent – chloroform, sorbent – silica M 60. The products obtained are dark green solid materials partially soluble in DME, highly soluble in benzene, acetone, chloroform.

**Coppper(II) complex of 2,9,16,23-tetra-(4-[(1-methyl-1-phenylmethyl)phenyl]ethyl)phenoxy)-3,10,17,23-tetrakisnitro-phthalocyanine (4a)** was synthesized according to general method 3 from 160 mg of 2a. (171 mg, 0.08 mmol, 80 % on 2a). Found, %: C 60.15, N 10.16, H 5.02, S 5.82. C_{14}H_{37}CuN_{16}O_{20}S_{4}. Requires, %: C 60.68, N 10.48, H 4.90, S 6.00. m/z (MALDI-TOF) 2326.86 [M+H]^{+}. IR (KBr) ν max cm^{-1}: 3055 (NH), 2954, 2907, 2850 (CH 2, CH 3). 1H NMR (CDCl 3) δ ppm: 8.57 (s, H1, 4H), 7.80 (s, H2, 4H), 7.49 (m, H5, 8H), 7.34 (m, H6, 8H), 7.07 (s, H3, 8H), 7.07 (s, H4, 8H), 3.28 (m, CH 2, 16H), 1.47 (s, CH 3 of N(С2Н5)), 2.4H).

**Nickel(II) complex of 2,9,16,23-tetra-(4-[(1-methyl-1-phenylmethyl)phenyl]ethyl)phenoxy]-3,10,17,23-tetrakisnitro-phthalocyanine (5a)** was synthesized according to general method 3 from 159 mg of 2b. (170 mg, 0.08 mmol, 72 % on 2b). Found, %: C 60.40, N 10.30, H 5.00, S 5.90. C_{14}H_{37}NiN_{16}O_{20}S_{4}. Requires, %: C 60.68, N 10.48, H 4.90, S 6.00. m/z (MALDI-TOF) 2332.82 [M+H]^{+}. IR (KBr) ν max cm^{-1}: 3055 (NH), 2954, 2907, 2850 (CH 2, CH 3). 1H NMR (CDCl 3) δ ppm: 8.57 (s, H1, 4H), 7.80 (s, H2, 4H), 7.49 (m, H5, 8H), 7.34 (m, H6, 8H), 7.14 (s, H3, 8H), 7.04 (s, H4, 8H), 3.16 (m, CH 2, 16H), 1.45 (s, CH 3 of N(С2Н5)), 2.4H).

**Nickel(II) complex of 2,9,16,23-tetra-(4-[(1-methyl-1-phenylmethyl)phenyl]ethyl)phenoxy]-3,10,17,23-tetratetra-

## Results and Discussion

This work consists of several stages. At the first stage, the ability of phthalocyanines 2-5 to form mesophases, typical for discotic mesogens (DM), was predicted. At the second stage, the synthesis of the initial phalanitnitrile with nitro- and 4-(1-methyl-1-phenylethyl)phenoxy groups was carried out, on the basis of which the corresponding copper and nickel phthalocyanine derivatives of different structures were obtained (2-5). At the third stage, the spectral and mesomorphic properties and thermodegradation processes upon the heat of synthesized bifunctional-substituted phthalocyanines were investigated. The predicted results were brought into correlation with the experimentally obtained data.

### Prognosis of mesomorphism of phthalocyanines 2-5

The mesomorphism prognosis of a new series of phthalocyanine derivatives (2a-b, 5a-b) was carried out according to the method of molecular mechanics (MM^+). Then the geometric characteristics required for calculating of the molecular parameters (MP) were extracted from the obtained models and introduced into CMP ChemCard.[26] Samples of optimized models are given in Figure 2. For the compounds of specified structure the prediction of the ability to form columnar and nematic mesomorphism was carried out by analyzing and comparing the calculated MP values with the classification series (I) (Table 1):

\[ K = 2 - 8.5; K = 1 - 2.6; K = 0.2 - 0.7; K = 0.25 - 1.00; M = 0.2 - 0.8; M = 0.15 - 0.80; K = 0.08 - 0.30 \]

Deviations of at least one of the calculated MP values from the limiting values of the reference number shows the inability of the designed compound to exhibit mesomorphism typical for DM.

### Table 1. Calculated MP and data of prognosis for substituted phthalocyanines 2-5.

| Compound | \( E_{opt} \) kcal/mol | \( M_n \) | \( M_w \) | \( K_p \) | \( K \) | \( K_c \) | \( K_{opt} \) | \( \rho_{Cal/X} \) |
|----------|------------------------|--------|--------|--------|--------|--------|--------|--------------|
| 2a       | 91.78                  | 1.04   | 0.34   | 0.72*  | 3.21   | 1.31   | 0.19   | –            |
| 2b       | 90.05                  | 1.04   | 0.34   | 0.61   | 2.38   | 1.00   | 0.21   | –            |
| 3a       | 203.93                 | 0.74   | 0.30   | 0.61   | 3.46   | 1.00   | 0.19   | +            |
| 3b       | 206.36                 | 0.74   | 0.30   | 1.88*  | 3.28   | 1.00   | 0.18   | –            |
| 4a       | 239.34                 | 0.62   | 0.20   | 0.50   | 3.19   | 1.31   | 0.17   | +            |
| 4b       | 247.67                 | 0.62   | 0.20   | 0.43   | 1.77*  | 1.00   | 0.19   | –            |
| 5a       | 169.62                 | 0.44   | 0.15   | 0.20   | 2.23   | 1.31   | 0.07*  | +/–          |
| 5b       | 168.95                 | 0.44   | 0.15   | 0.20   | 3.07   | 1.01   | 0.07*  | +/–          |

*Note: \( E_{opt} \) – optimization energy, \( K = 0.50 \) for all compounds, \( P \) – prognosis of mesomorphism typical for DM.

**MP* value closed to the boundary of classified number (1). MP* value deviated significantly from number (1).**

44 Макрогетероциклы / Macroheterocycles 2018 11(1) 41-51
According to Table 1, the compounds 2a, 2b, 3b can’t exhibit mesomorphism. The prognosis is positive for the compound 3a, and equally probable for 4a and 4b.

The prognosis is probable for the alkylsulfamoyl derivatives 4a, 4b, 5a, 5b and positive for the complexes 3a, 4a.

The data in Table 1 (the last two columns) show that in general there is a correspondence between the results of the prediction and the experiment on the mesomorphism study of this compound series. Thus, the reliability of the prediction is 75%.

Synthesis

On the basis of the previously described method,[33] 4-[4-(1-methyl-1-phenylethyl)phenoxy]-5-nitrophthalonitrile was synthesized by nucleophilic aromatic substitution of the bromine atom for the 4-(1-methyl-1-phenylethyl) phenol residue in 4-bromo-5-nitrophthalonitrile (Scheme 1). The reaction was carried out in aqueous DMF in the presence of potassium carbonate at room temperature for 0.5 hour. At the end of the reaction, the formed precipitate was filtered off, washed with 2-propanol, then with water and winded at 70–80 °C.

Then the corresponding bifunctional-substituted phthalocyanines of copper and nickel (2a, b) were synthesized by heating the phthalonitrile (1) and copper acetate dihydrate or nickel acetate tetrahydrate to 180–190 °C for 2 hours in the presence of urea. Then the corresponding sulfochloride (Scheme 1) was synthesized at room temperature by the reaction of phthalocyanines 2a, b and a mixture of thionyl chloride and chlorosulfonic acid (Scheme), which were then either converted to the corresponding sulfonic acids by hydrolysis or to sulfonamides by interaction with the corresponding amines.

Purification of the synthesized copper and nickel phthalocyanines (2a, b) and alkylsulfamoyl derivatives (3-4) on their basis was carried out by liquid column chromatography.

Figure 2. Samples of optimized models of molecule of compounds 2a (a), 4a (b), 4b (c) and 5a (d).
In the IR spectra of compounds 2a,b-5a,b symmetric (1340–1360 cm⁻¹) and asymmetric (1530–1560 cm⁻¹) stretch of nitro groups were observed. The stretching bands of the C=S (1035–1118 cm⁻¹) bonds, symmetric (1129–1163 cm⁻¹) and asymmetric (1329–1360 cm⁻¹) S=O stretching vibration were recorded in the spectra of compounds 3-5.[14] In the IR spectra of alkylsulfamoyl derivatives (3-4), the stretching bands (1310–1311 cm⁻¹) and bending bands (1630–1640 cm⁻¹) vibrations of secondary amino groups were observed, as well as a band in 3015–3150 cm⁻¹ region indicating the presence of N-H bond.

In the ¹H NMR spectra of compounds 2a,b, the proton signals of the phenoxy substituent (7.05–7.07 ppm) and benzene rings of the phthalocyanine molecule (8.27–8.33 and 7.83–7.88 ppm) were recorded. Their position was not affected by the introduction of sulfo- or alkylsulfamoyl groups. 1-Methyl-1-phenylethyl fragment proton signals were observed at 7.17–7.14 ppm as a multiplet.

As for the compounds with sulfo- and alkylsulfamoyl substituents in the oxyaryl moieties, the proton signal at position 6 was shifted to the weaker field region (7.74 ppm for compounds 3a,b, and 7.29–7.34 ppm for compounds 4a,b-5a,b). This fact confirmed the modification of the compounds 3a,b-4a,b by the para positions of 4-(1-methyl-1-phenylethyl) phenoxy substituent phenyl rings, since the proton signal (pos. 2, Scheme 2) located in the ortho position to the aryloxy fragment (7.80–7.84 ppm in spectra of 3, 4) was observed almost in the same region as in the spectrum of the initial compounds 2a,b (7.83 ppm).

Further, UV-Vis spectra of the synthesized phthalocyanines were studied (Table 2). In DMF and chloroform, 2,9,16,23-tetrakis[4-(1-methyl-1-phenylethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanines (2a,b) were in the associated form (Figure 3), in contrast to benztetrazolyl-substituted analogues.[35] In addition, the substitution of 1-benztetrazole fragments for nitro groups was accompanied by a bathochromic shift of long-wavelength absorption bands.

The passing from copper(II) complexes to nickel(II) complexes was accompanied by a hypsochromic shift of long-wavelength absorption bands in organic solvents (Table 2). Comparing the UV-Vis spectra of phthalocyanines (2a,b) in chloroform with the spectrum of the alkylsulfamoyl derivatives obtained therefrom, it was found that the introduction of diethyl sulfamoyl substituents into the oxyaryl moieties of the compound 2a,b caused a bathochromic shift of the Q-band, and the compound 4a was in the given solvent in non-associated form (Figures 4, 5, Table 2). The introduction of octadecylsulfamoyl substituents (5a) was accompanied by a hypsochromic shift and the increase in the association degree.

In the passing from organic solvents to concentrated sulfuric acid, a bathochromic shift of long-wavelength absorption bands was observed (Table 2). Its value

![Scheme 1](http://example.com/scheme1.png)
Table 2. UV-Vis spectra of compounds 2-4.

| №  | R                  | M   | UV-Vis spectra, λ\text{max}, nm |
|----|--------------------|-----|---------------------------------|
| 2a | ![Image](image1.png) | Cu  | DMF 685 CHCl$_3$ 696 H$_2$SO$_4$ 804 |
| 2b | ![Image](image2.png) | Ni  | DMF 667 CHCl$_3$ 683 H$_2$SO$_4$ 813 |
| 3a | ![Image](image3.png) | Cu  | DMF 651, 690 CHCl$_3$ – H$_2$SO$_4$ 788, 794 |
| 3b | ![Image](image4.png) | Ni  | DMF 649 CHCl$_3$ – H$_2$SO$_4$ 796 |
| 4a | ![Image](image5.png) | Cu  | DMF 693 CHCl$_3$ 698 H$_2$SO$_4$ 782 |
| 4b | ![Image](image6.png) | Ni  | DMF 683 CHCl$_3$ 688 H$_2$SO$_4$ 791 |
| 5a | ![Image](image7.png) | Cu  | DMF 692 CHCl$_3$ 693 H$_2$SO$_4$ 790 |
| 5b | ![Image](image8.png) | Ni  | DMF 689 CHCl$_3$ 677 H$_2$SO$_4$ 792 |

Figure 3. UV-Vis spectra in DMF (C=1.05·10$^{-5}$ mol/l): 1 – (2a); 2 – (2b).

Figure 4. UV-Vis spectra in DMF (C=0.65·10$^{-5}$ mol/l): 1 – (4a); 2 – (5a).

Figure 5. UV-Vis spectra in CHCl$_3$ (C=0.85·10$^{-5}$ mol/l): 1 – (2a); 2 – (4a); 3 – (5a).

in the series of corresponding metal complexes decreases depending on the nature of the substituent introduced to 4-(1-methyl-1-phenylethyl)phenoxy group:

It should be noted that the values of the bathochromic displacement for the corresponding nickel complexes are larger in comparison with copper complexes.

**Study of mesomorphic properties of compounds 2-5**

Synthesized phthalocyanines 2-5 were studied using polarization microscopy method. It was found that compounds 2a,b, 3a,b were not mesomorphic, what was coincided with the prognosis data (Table 1), except compound 3a, for which the prognosis was positive. The sulfo derivative 3a was powdery at room temperature. Its sample passed into isotropic liquid at 158 °C. On cooling, typical crystals grew (Figure 6) starting from needle-like at 155 °C to dendritic at 110 °C.

The diethyl sulfamoyl derivative 4a in heating cycle immediately melted into isotropic liquid at 115 °C (Table 3). On cooling to 98 °C, mesophase appeared with
DM-characteristic flower-like domains (Figure 7), i.e. exhibited a monotropic mesomorphism.

Compound (5a) exhibited enantiotropic mesomorphism. In heating cycle, at 65 °C the substance sample transformed into a mesophase with a small-domain structure in spherulite form. On further heating, the spherulites grew to flower-like formations, along the edges of which a wavy dark rim appeared (Figure 8). At 182 °C the mesophase entered an isotropic state. On cooling, the appearance of mesophase was observed with a slight delay (170 °C).

Finally, 5b, which was in the crystalline state at room temperature, when heated to 110 °C revealed a mesophase that at 167 °C passed into isotropic liquid (Table 3, Figures 10–12). On cooling, the mesophase appeared with a slight delay (supercooling) at 145 °C in the form of large spherulites or spindle-shaped domains, subsequently it was vitrified at 82 °C while maintaining the texture of the mesophase (Figure 12). It was found that, in comparison with the corresponding copper complex (5a), an increase in the temperature of the Cr→Mes phase transition was observed in the nickel complex (5b). The observed textures were very similar to the textures of the compound (5a). Thus, the introduction of Ni atom instead of Cu into the coordination site of the indicated phthalocyanines significantly affected the mesophase existence interval, which narrowed almost twofold due to a decrease in the thermal stability of the mesophase.

In case of the mesogenic copper complex (5c), the substitution of the benzotriazole group for the nitro group (5a) broadened the temperature range of mesophase existence. Perhaps, in that case the introduction of a less voluminous acceptor substituent (NO₂ group) made it possible to improve π-π stacking interaction and make stacking of the columns in the mesophase in a wider temperature range. This was cooperated by long hydrocarbon radicals along the molecule periphery.

For copper complexes 1f and 1h, the substitution of the benzotriazole group for the nitro group, on the contrary, led to a deterioration of the mesophase formation conditions for the compounds 2a, 3a. In this case, the tri...
| №  | Compound | Mesomorphism |
|----|----------|--------------|
| 2a | Cu       | Heating: Cr · 160 °C Iso  
                 Cooling: Iso · 150 G |
| 2b | Ni       | Heating: Cr · 168 °C Iso  
                 Cooling: Iso · 161 G |
| 1f | Cu       | Heating: Cr · 131 °C Mes · 174 °C Iso  
                 Cooling: Iso · 112 °C Mes · 75 °C G |
| 1f | Ni       | Heating: Cr · 151 °C Mes · 184 °C Iso  
                 Cooling: Iso · 175 °C Mes · 114 °C G |
| 3a | Cu       | Heating: Cr · 158 °C Iso  
                 Cooling: Iso · 155 °C Cr |
| 3a | Ni       | Heating: Cr · 165 °C Iso  
                 Cooling: Iso · 157 G |
| 1h | Cu       | Heating: Cr · 183 °C Mes · 227 °C Iso  
                 Cooling: Iso · 209 °C Mes · 164 °C Cr |
| 4a | Cu       | Heating: Cr · 115 °C Iso  
                 Cooling: Iso · 98 °C Mes · 45 °C G |
| 4a | Ni       | Heating: Cr · 120 °C · Iso  
                 Cooling: Iso · 112 Amorphous powder |
| 5a | Cu       | Heating: Cr · 65 °C Mes · 182 °C Iso  
                 Cooling: Iso · 170 °C Mes · 80 °C G |
| 5b | Ni       | Heating: Cr · 110 °C Mes · 167 °C · I  
                 Cooling: Iso · 145 °C Mes · 82 °C G |
| 1g | Cu       | Heating: Cr · 108 °C Mes · 197 °C Iso  
                 Cooling: Iso · 170 °C Mes · 70 °C G |

Azole group played a positive role in mesophase formation, increasing the hydrophobicity of the periphery and decreasing the interaction in the center.

Along with the investigation of the mesomorphic properties of phthalocyanines 2-5, a study on their thermo-oxidative degradation was undertaken, which was important for establishing the thermal and oxidative stability of 2-5 (Table 4). The introduction of sulfo groups into 4-(1-methyl-1-phenylethyl)phenoxy substituents caused a decrease in the temperature of the maximum exoeffect. In addition, the appearance of the endopic at 210–230 °C was observed on the DSC curves of sulfo derivatives (3a,b). It was found that these compounds, being heated at this temperature, practically lost their solubility in water. Apparently, processes involving sulfo groups occurred in this temperature range.

It was found that the process of thermooxidative degradation of 3a began at 229 °C.

Comparison of the nickel 3b phthalocyanine sulfo derivative with previously obtained[35] benzotriazolyl-substituted nickel phthalocyanine showed that the substitution of benzotriazole fragments for nitro groups caused a decrease in the thermal stability of nitro substituted compound 3b (Table 4).

The passing from the sulfo derivative 3b to the corresponding diethylsulfamoyl derivative 4b was accompanied by temperature increase in both the onset of mass loss and the maximum exoeffect. Mesogenic compound 4a retained its structure to 278 °C, whereas the range of its mesophase existence was in the range of 98–45 °C (Table 3). In addition, it was noted that the copper complex 4a was a bit more stable than the corresponding nickel complex 4b.

The substitution of diethylsulfamoyl 4a fragments for more extended octadeylsulfamoyl caused increase in the thermal stability of the corresponding phthalocyanine derivative 5a due to additional shielding of nitro groups and the metal atom in the coordination cavity of the phthalocyanine molecule. An oxidizer-oxygen molecule interacted in these groups, which resulted in thermal destruction of the compounds (Table 4).
Cu and Ni Phthalocyanines Bearing Nitro and Phenoxy Groups

Table 4. Thermogravimetical study of compounds 2-5.

| №  | M  | Compound | T_{exo}, °C | ΔT, °C |
|----|----|----------|-------------|--------|
|    |    |          | I | II            |        |
| 2b | Ni | ![Image](image1.png) | 478 | 619 | 525–665 |
| 3a | Cu | ![Image](image2.png) | 229 | 459 | 380–535 |
| 3b | Ni | ![Image](image3.png) | 204 | 441 | 380–540 |
| 1g | Ni | ![Image](image4.png) | 265 | 486 | 418–498 |
| 4b | Ni | ![Image](image5.png) | 266 | 567 | 480–660 |
| 4a | Cu | ![Image](image6.png) | 284 | 599 | 408–660 |
| 5a | Cu | ![Image](image7.png) | 363 | 497 | 438–580 |

Note: I – 1 exopic, II – 2 exopic

Figure 9. Layers of 5a domains oriented by shear deformation. Cooling cycle, 90 °C, polarizers crossed.

Figure 10. Spindle-shaped domains 5b oriented by shear deformation. Polarizers crossed, 1st heating cycle, 135 °C.

Figure 11. Texture 5b in the 2nd heating cycle. Polarizers crossed, 128 °C.

Figure 12. Texture of vitrified mesophase 5b. Polarizers crossed, 82 °C.
Conclusions

The synthesis of copper and nickel phthalocyanines with 4-(1-methyl-1-phenylethyl)phenoxy and nitro groups was carried out. By introducing alkylsulfamoyl groups into the available oxyaryl moieties, further modification was carried out. Physicochemical, particularly mesomorphic, properties of the synthesized compounds were studied, their comparative analysis was carried out.

It was found that the substitution of benzotriazole fragments of copper 2,9,16,23-tetra[4-(1-benzotriazolyl)-3,10,17,24-tetra[4-(1-methyl-1-phenylethyl)phenoxy]-phthalocyanine for nitro groups led to the inability of this phthalocyanine derivative to form a mesophase. Introduction of 2,9,16,23-tetra[4-(1-methyl-1-phenylethyl)phenoxy]-3,10,17,24-tetranitrophthalocyanine copper diethyl or octadecyl sulfamoyl substituents gave these compounds mesomorphic properties, but led to decreasing the stability to thermal destruction. It was also established that for the mesogenic copper complex 5c, the substitution of the benzotriazole group for the nitro group (5a) broadened the temperature range of mesophase existence.

It was shown that the introduction of Ni atom instead of Cu into the coordination site of the phthalocyanines significantly affected the mesophase existence interval, which narrowed almost twofold due to a decrease in the thermal stability of the mesophase.

The repeatability of the prognosis with the experimental data was 75 %.

Acknowledgements. The work was supported by Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6 (study of synthesized phthalocyanines) and project № 4.1929.2017/4.6 (synthesis of substituted phthalocyanines) for the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6. The work was supported by the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6 (synthesis of substituted phthalocyanines) and project № 16.1037.2017/4.6 (study of synthesized phthalocyanines for the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6). The work was supported by the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6 (synthesis of substituted phthalocyanines) and project № 16.1037.2017/4.6 (study of synthesized phthalocyanines for the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6). The work was supported by the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6 (synthesis of substituted phthalocyanines) and project № 16.1037.2017/4.6 (study of synthesized phthalocyanines for the Ministry of Education and Science of the Russian Federation, agreement № 4.1929.2017/4.6).

References

1. Demus D., Goodby J., Gray G.W., Spiess H.-W., and Waser H. Handbook of Liquid Crystals: Fundamentals. 1. WILEY-VCH Verlag GmbH, 1998.

2. Nanoscience with Liquid Crystals. From Self-Organized Nanostructures to Applications (Li Q., Ed.) Kent: Springer, 2014, 420 p.

3. Chandrasekhar S., Sadashiva B.K., Suresh K.A. Pramana 1977, 9, 471–480.

4. Goody J.W., Robinson P.S., Teo B.K., Cladis P.E. Mol. Cryst. Liq. Cryst. 1980, 56, 303–309.

5. Peking C., Simon J., Skoulios A., Guillon D., Weber P.J. Am. Chem. Soc. 1982, 104, 5245–5247.

6. Li Q., Li L. Photoconducting Discotic Liquid Crystals. In: Thermotropic Liquid Crystal (Ramamorthy A., Ed.) Dordrecht, The Netherlands: Springer, 2007, 297 p.

7. Takita Y., Hasegawa H., Takahashi Y., Harada Y., Kanda A., Hanasaki N., Inabe T. J. Porphyrins Phthalocyanines 2014, 18, 814–818.

8. The Porphyrin Handbook. Vol. 16 (Kadish K.M., Smith K.M., Guilard R., Eds.) San Diego, California: Academic Press, Elsevier Science, 2003, p. 285.

9. Basova T., Hassan A., Durmus M., Gurek A.G., Ahsen V. Coord. Chem. Rev. 2016, 310, 131–153.

10. Tekdas D.A., Gurek A.G., Ahsen V. J. Porphyrins Phthalocyanines 2014, 18, 899–908.

11. Motoyoshi R., Suzuki A., Kikuchi K., Oku T. Synth. Met. 2009, 159, 1345–1348.

12. Zhou X.Q., Wang B., Han X.Z., He C.Y. Applied Mechanics and Materials 2013, 303–306, 45–48.

13. Rodriguez-Morgade M.S., Pelleja L., Torres T., Palomares E. J. Porphyrins Phthalocyanines 2013, 17, 814–820.

14. Makarov V.I., Vasil’chenko S.Yu., Ryabova A.V., Konov V.I., Shevchenko E.N., Lukyanets E.A., Ernmov A.E., Loschensov V.B. Russ. J. Gen. Chem. 2015, 85, 338–342.

15. Sato H., Igarashi K., Yama Y., Ichihara M., Itoh E., Ohta K. J. Porphyrins Phthalocyanines 2012, 16, 1148–1158.

16. Wöhrle D., Schnuppfeil G., Makarov S.G., Kazarin A., Suvarova O.N. Macroheterocycles 2012, 5, 191–202.

17. Smirnova A.I., Usol’tseva N.V., Henrich B., Donnio B. Liq. Cryst. 2018, 45(4), 625–633.

18. Usol’tseva N.V., Smirnova A.I., Kazak A.V., Giricheva N.I., Galanin N.E., Shaposhnikov G.P., Bondarchuk V.Y., Slyboniski S.V. Opto-Electronic Review 2017, 25, 127–136.

19. Kudrik E.V., Zharnikova N.V., Usol’tseva N.V., Bykova V.V., Anan’eva G.A. Liquid Crystals and Their Application, Russ. J. Chem. 2004, 1(8), 80–89.

20. Takagi Y., Ohta K., Shimosugi Sh., Fujii T., Itoh E. J. Mater. Chem. 2012, 22, 14418–14425.

21. Yoshioka M., Ohta K., Yasutake M. RSC Adv. 2015, 5, 13828–13839.

22. Ishikawa A., Ohta K., Yasutake M. J. Porphyrins Phthalocyanines 2015, 19, 639–650.

23. Watarai A., Ohta K., Yasutake M. J. Porphyrins Phthalocyanines 2016, 20, 822–832.

24. Ohta K., Adachi K., Yasutake M. J. Porphyrins Phthalocyanines 2017, 21, 48–58.

25. Tschierski C. J. Mater. Chem. 1998, 8, 1485–1508.

26. Znoiko S.A., Akopova O.B., Bumbina N.V., Maizlish V.E., Shaposhnikov G.P., Usol’tseva N.V. Macroheterocycles 2014, 7, 287–295.

27. Znoiko S.A., Akopova O.B., Bumbina N.V., Usol’tseva N.V., Maizlish V.E., Shaposhnikov G.P., Abramov I.G. Russ. J. Gen. Chem. 2014, 84, 708–714.

28. Znoiko S.A., Maizlish V.E., Shaposhnikov G.P., Bykova V.V., Usol’tseva N.V. Liquid Crystals and Their Application, Russ. J. Chem. 2011, 3(8), 69–79.

29. Akopova O.B., Kovaleva M.I. Liquid Crystals and Their Application, Russ. J. Chem. 2014, 14, 21–57.

30. Akopova O.B., Bulavkova M.G., Gruzdev M.S., Floрова T.V. Russ. J. Gen. Chem. 2011, 81, 714–720.

31. Akopova O.B., Akopov D.A. Computer program «CMP ChemCard» № 2012610165, 10.01.2012. (in Russ.).

32. Shishkina O.V., Maizlish V.E., Shaposhnikov G.P., Abramov I.G. Russ. J. Gen. Chem. 2014, 84, 708–714.

33. Znoiko S.A., Maizlish V.E., Shaposhnikov G.P., Bykova V.V., Usol’tseva N.V. Liquid Crystals and Their Application, Russ. J. Chem. 2015, 3(8), 69–79.

Received 18.01.2018
Accepted 28.02.2018