

Thiadiazole Containing Macrocycles as Core-Modified Analogues of Phthalocyanine<sup>⊗</sup>Elena A. Danilova,<sup>a</sup> Tat'yana V. Melenchuk,<sup>a</sup> Olga N. Trukhina,<sup>a</sup>  
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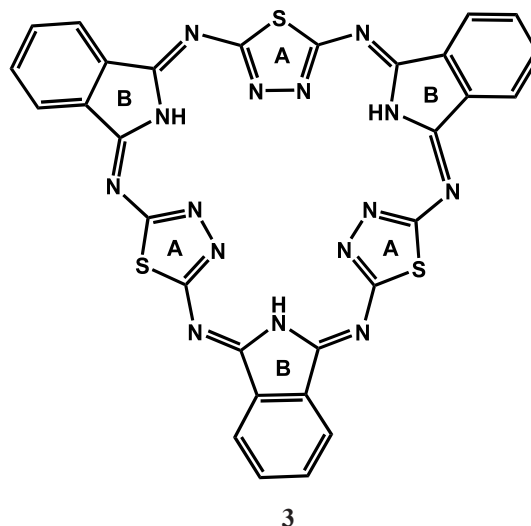
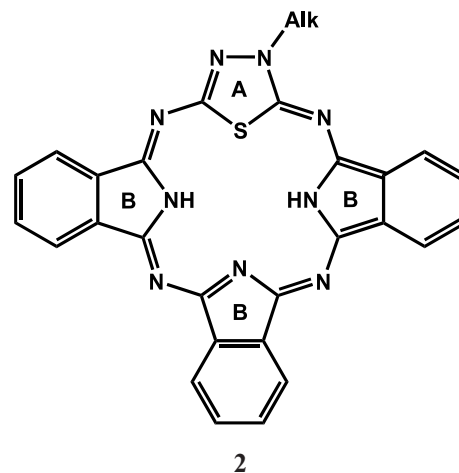
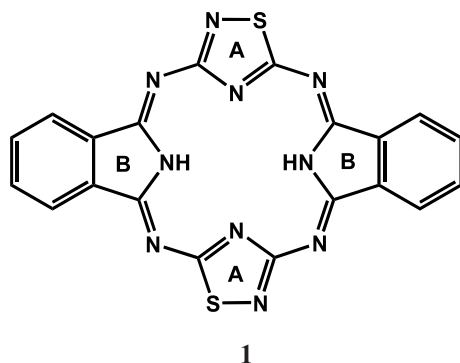
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Macroheterocyclic compounds can be considered as structural analogues of phthalocyanine having one or two opposite isoindole fragments (**B**) replaced by other cyclic subunits (**A**) derived from aromatic diamines. In this short review our attention is focused on recent advances in the chemistry of new representatives of macroheterocyclic compounds of **ABAB**-, **ABBB**- and **ABABAB**-types, where **A** is 1,2,4-thiadiazole, 3-alkyl-1,3,4-thiadiazoline and 1,3,4-thiadiazole subunits, correspondingly. Their structure particularities were studied by both experimental (including MALDI-TOF, gas phase electron diffraction - GED) and theoretical (quantum chemistry calculations at the DFT level using hybrid functional B3LYP with various basis sets from 6-31G(d,p) to cc-pVTZ) methods. Relationships between structure and properties of these macrocycles are under consideration.

**Keywords:** Macroheterocyclic compounds, hemiporphyrazine, thiadiazole, synthesis, structure, gas phase electron diffraction, DFT calculations.

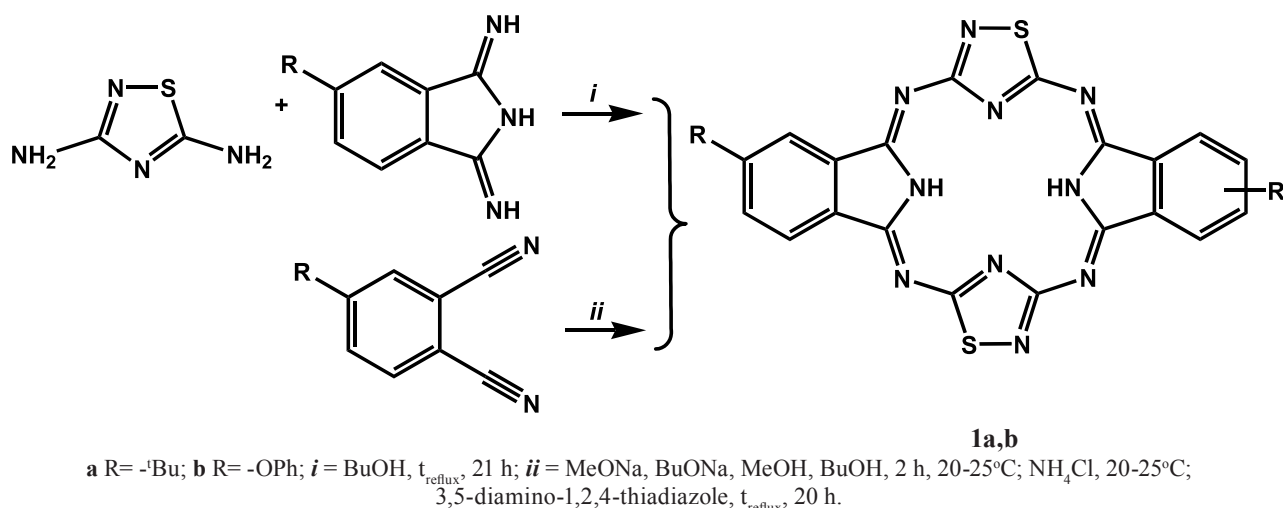
## Introduction

Macroheterocyclic compounds (Mc) can be considered to be structural analogues of phthalocyanine having one or two opposite isoindole fragments (**B**) replaced by other cyclic subunits (**A**) derived from aromatic diamines and called by Campbell *hemiporphyrazines*.<sup>[1-3]</sup> Among them Mc containing thiadiazole rings are of great interest because of their theoretical importance and potential practical applications. For example, 2-imino-4-thiobiurete and 3,5-diamino-1,2,4-thiadiazole, precursors of Mc synthesis, are known as antihypoxantes Amtizole and Gutimine, correspondingly.<sup>[4,5]</sup> Due to their importance for the Mc synthesis, improved methods of their obtaining as well as that of 2,5-diamino-1,3,4-thiadiazole have been developed.<sup>[6,7]</sup> In this paper we focus our attention



⊗ This contribution is dedicated to professor Vasilij Fedorovich Borodkin on the occasion of his 100<sup>th</sup> Anniversary.

⊗ Статья посвящена 100-летию юбилею профессора Василия Фёдоровича Бородинкина.



Scheme 1.

on the recent advances in chemistry of new macroheterocyclic compounds of **ABAB**- (**1**), **ABBB**- (**2**) and **ABABAB**-types (**3**), where **A** is 1,2,4-thiadiazole, 3-alkyl-1,3,4-thiadiazoline and 1,3,4-thiadiazole subunits correspondingly.

## Discussion

The **1a,b** compounds of **ABAB** type were synthesized by interaction of 3,5-diamino-1,2,4-thiadiazole with substituted phthalonitrile or its functional derivatives, such as 1,1-dimethoxy-3-iminoisoindoline or 1,3-diiminoisoindoline (Scheme 1).<sup>[8]</sup> The synthesis and properties of **1a,b** were reported in <sup>[9]</sup>.

The obtained compounds are probably a mixture of regioisomers, which could not be separated under the experimental conditions. In order to find the differences in properties of two possible tautomeric species we carried

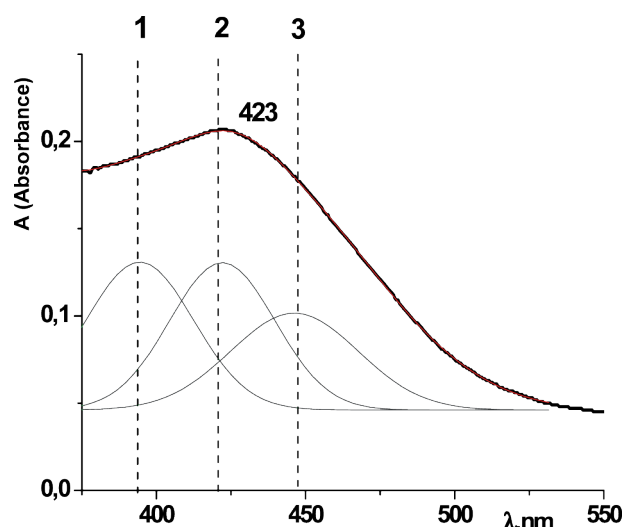
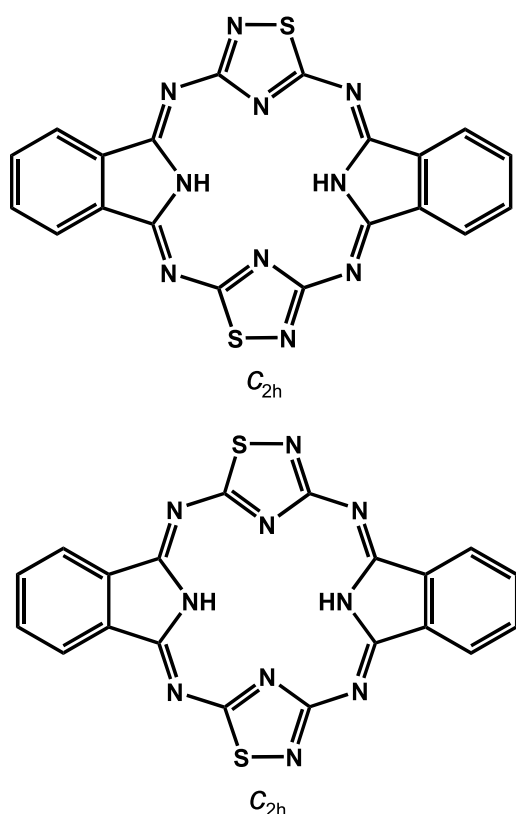
out computations of electronic absorption spectra of the Mc models of the **ABAB**-type of  $C_{2h}$  and  $C_{2v}$  symmetry point groups using the TDDFT method for the configurations optimized at the B3LYP/6-31G(*d,p*)<sup>[10]</sup> level of theory, with full geometry optimization.

The results of TDDFT calculations of the first six singlet-singlet electron transfers are given in Table 1.

**Table 1.** Calculated wavelengths (nm) and oscillator strengths (*f*) of Mc ( $C_{2h}$  and  $C_{2v}$  symmetry).

$C_{2h}$		$C_{2v}$	
$\lambda_{\text{max}}$ , nm	<i>f</i>	$\lambda_{\text{max}}$ , nm	<i>f</i>
505	0.00	562	0.04
<b>401</b>	<b>0.35</b>	390	0.15
351	0.47	386	0.15
340	0.00	360	0.00
334	0.00	346	0.00
329	0.01	335	0.01

An experimental spectrum of **1a** was decomposed down into its Gaussian components (Figure 1 and Table 2). Hence a good correlation between quantum chemistry



**Figure 1.** The experimental UV-vis spectrum of **1a** in MeOH (thick) and the spectrum decomposed into three Gaussian functions (thin).

calculations and the experimental UV-vis spectra of the compound **1a** can be another proof of structure of the **ABAB**-type product.

**Table 2.** Calculated wavelengths (nm), oscillator strengths (*f*) and the decomposition of experimental spectrum into several Gaussian functions.

The decomposition of experimental spectrum into several Gaussian functions		Calculated data (TDDFT)	
$\lambda$ , nm	Height	$\lambda$ , nm	<i>f</i>
394	0.085	401	0.35
422	0.084		
446	0.055		

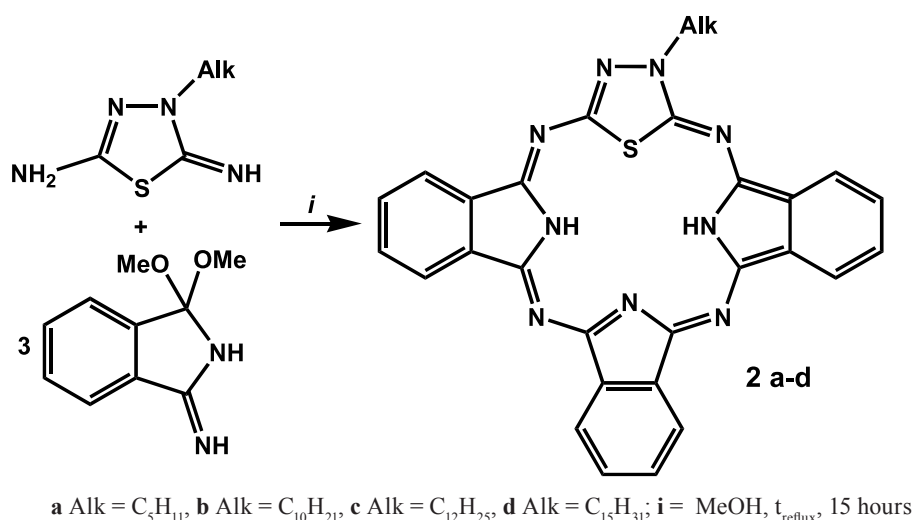
The obtained data demonstrate that the experimental absorption spectrum of the **1a** is in better agreement with the

computed spectrum of the  $C_{2h}$  symmetry molecular model than that of  $C_{2v}$  symmetry. It appears that the  $C_{2h}$  symmetry isomer dominates in the obtained product.

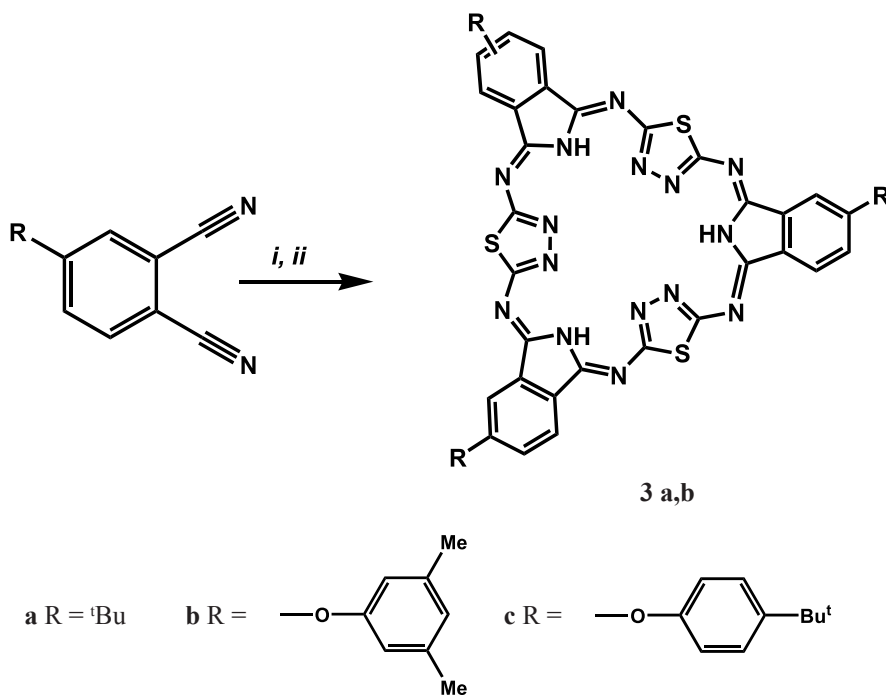
We succeeded in synthesizing a series of 3-alkyl-5-amino-2-imino-1,3,4-thiadiazolines (alkyl= $C_5H_{11}$ ,  $C_{10}H_{21}$ ,  $C_{12}H_{25}$ ,  $C_{15}H_{31}$ ) by direct alkylation of 2,5-diamino-1,3,4-thiadiazole by corresponding alkyl bromides.<sup>[11]</sup> These compounds give rise to a new family of thiadiazoline containing macroheterocyclic compounds of **ABBB**-type, **2a-d** (Scheme 2).

After separation from the reaction mass, the crude products were purified by column chromatography. It has been observed that their solutions in  $CHCl_3$  emit a strong fluorescence in the UV light.<sup>[12]</sup>

The application of 2,5-diamino-1,3,4-thiadiazole for these purposes unexpectedly led to a new type of Mc with expended inner cavity (**ABABAB**) for instance, **3a-c**.<sup>[13,14]</sup> They are representatives of a new class of porphyrinoids

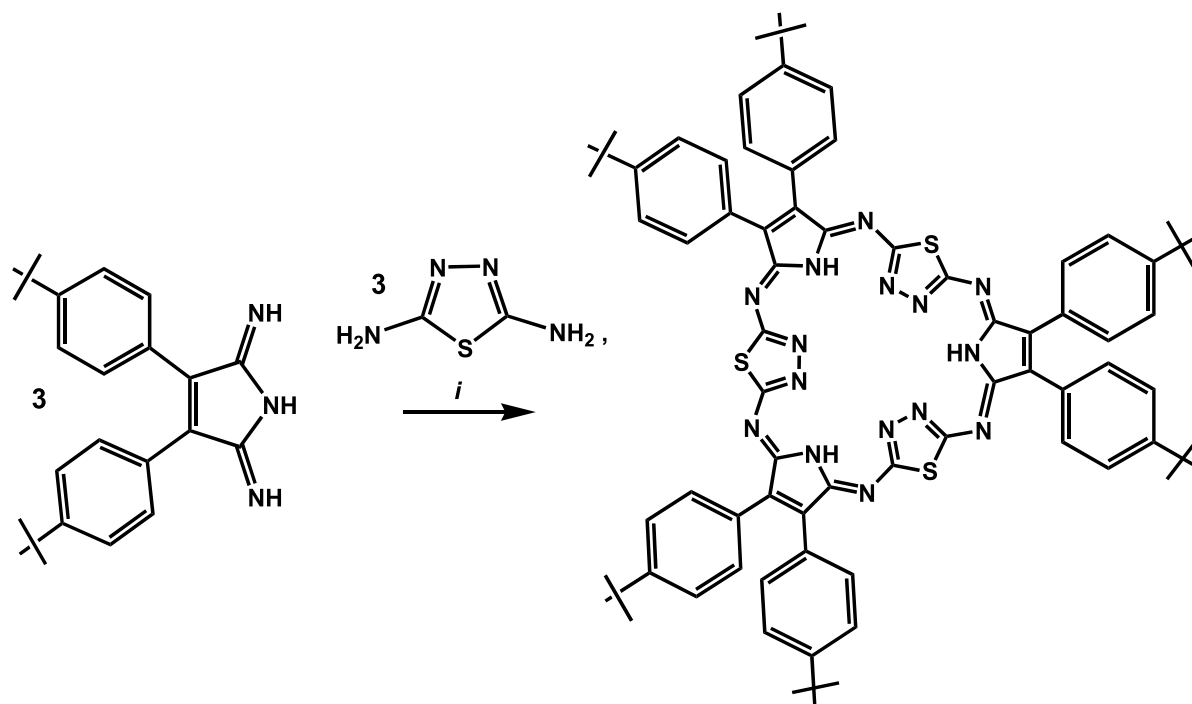


Scheme 2.



i = BuONa, MeOH, BuOH, 7 h, 20-25 °C; ii =  $\text{NH}_4\text{Cl}$ , 3 hours, 20-25 °C; 2,5-diamino-1,3,4-thiadiazole, 33 hours, 120 °C.

Scheme 3.



Scheme 4.

having expanded coordination cavity and can be considered as heteroanalogues of hexaphyrins.<sup>[15]</sup>

For a long period its structure was under discussion<sup>[16-18]</sup> and numerous efforts were made to solve the task. In 2001 the *tert*-butylsubstituted Mc was characterized by mass spectrometry (MALDI, FAB), <sup>1</sup>H and <sup>13</sup>C NMR, infrared and UV-vis spectroscopy, and elemental analysis.<sup>[13]</sup> Finally, in 2008 its structure has been directly characterized. The gas-phase molecular structure of *tert*-butylsubstituted Mc has been studied by a synchronous gas electron diffraction and mass spectrometric experiment and density functional theory calculations using the B3LYP hybrid method and cc-pVTZ basis sets.<sup>[19,20]</sup> Now it is evident that this compound contains three 1,3,4-thiadiazole rings and three 5-*tert*-butylisindole subunits connected to each other *via* azabridges, and is therefore, a macrocyclic system of the **ABABAB**-type. It is also interesting to note that the molecule has a structure with a planar macrocycle and the thiadiazole rings oriented in such a way that the sulfur atoms point outwards from the inner cavity.

The common method of the synthesis of macroheterocyclic compounds **3a-c** is the interaction of 2,5-diamino-1,3,4-thiadiazole with substituted phthalonitriles (Scheme 3).<sup>[13,21]</sup>

The reaction run has been monitored by TLC and UV-vis spectroscopy. The compounds **3a,b** were purified by column chromatography on aluminum oxide using dichloromethane as an eluent. After solvent removal, the orange solids were washed by methanol and dried under vacuum. The compounds were characterized by IR, <sup>1</sup>H NMR and UV-vis spectroscopy, mass-spectrometry, and elemental analysis.<sup>[21]</sup>

Condensation of equimolecular amounts of 3,4-bis(4-*tert*-butylphenyl)pyrroline-2,5-diimine with 2,5-diamino-1,3,4-thiadiazole yielded compound **4** with an increased coordination cavity; the compound incorporates substituted pyrrole fragments into the macrosystem<sup>[22]</sup> (Scheme 4).

The structure of Mc **4** was established using the methods of UV-vis, IR, <sup>1</sup>H and <sup>13</sup>C NMR spectroscopy, as well as mass spectrometry data. Thus, the <sup>1</sup>H NMR spectrum of compound **4** measured in deuterated chloroform, along with signals in the region of 1.40–1.25 ppm, which characterize resonance of protons of *tert*-butyl groups, and signals in the region of 7.94–7.61 ppm, which are evoked by absorption of protons of benzene nuclei of isoindole fragments, yielded a singlet in the region of 12.35 ppm, which vanishes upon addition of deuterated water and can be assigned to the resonance of protons of imino groups. The location of the latter absorption in the weak field indicates the nonaromatic character of the macrocycle.

The spectral curves obtained for solutions of Mc **4** in chloroform have an unusual appearance and are practically the same. Two most intensive absorption bands are observed in the region of 428 and 452 nm, as well as two bands of average intensity respectively at 515 and 552 nm. The presence of the main absorption in a so short-wavelength region (450 nm) indicates the nonaromatic character of the macrocycle.

The first information about the coordinating properties and acid-basic behaviors of Mc of **ABABAB**-type have been published recently.<sup>[23-26]</sup>

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