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Syntheses and Properties of Two Heterocyclically Substituted Hypericin Derivatives: 10,11-Dibenzothiazolyl-10,11-didemethylhypericin and 10,11-Dibenzoxazolyl-10,11-didemethylhypericin

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Summary. The syntheses of the two heterocyclically substituted title hypericin derivatives were achieved starting either from 6-benzothiazolyl-tri-*O*-methyl-6-demethylemodin or 6-benzoxazolyl-tri-*O*-methyl-6-demethylemodin. The use of microwave assisted synthesis for the preparation of these anthraquinone synthons and the chemical as well as photochemical properties of the corresponding unique hypericin derivatives, which might constitute new photodynamic therapy agents, are reported. The tautomeric and stereochemical aspects of these hypericin derivatives were investigated by means of semiempirical calculations (AM1).

Keywords. Anthraquinones; Microwave assisted synthesis; Phenanthroperylenequinones; Photodynamic therapy; Semiempirical calculations.

Introduction

The recently synthesized 10,11-dibenzimidazolyl-10,11-didemethylhypericin (**1**) constitutes the first representative of a new class of modified hypercin derivatives [1]. It might be valuable as a lead structure for applications in photodynamic therapy (PDT) [2, 3]. Since the naturally occurring phenanthroperylenequinone hypericin (**2**) is one of the most powerful photosensitizing compounds found in nature, intensive research has been undertaken to optimize this natural product by synthetic modifications concerning its applicability in PDT. In addition, **2** is known for its broad anticancer and antiviral activity [4], which makes it extraordinarily

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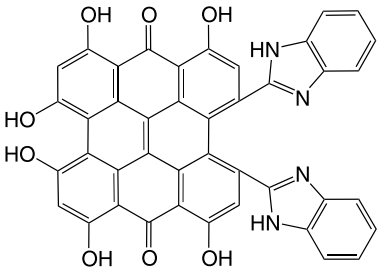
interesting for a variety of biological and medicinal applications. Besides an improved solubility under physiological conditions and an enhanced ability to generate singlet oxygen and/or reactive oxygen species, the shifting of the long wavelength absorption band of **2** into the emission wavelength range of medicinal lasers ($\lambda_{max} \geq 620\,nm$) is one of the main targets.



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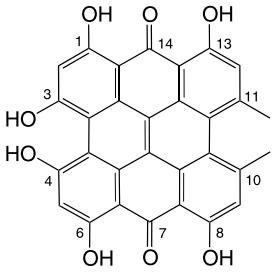


2

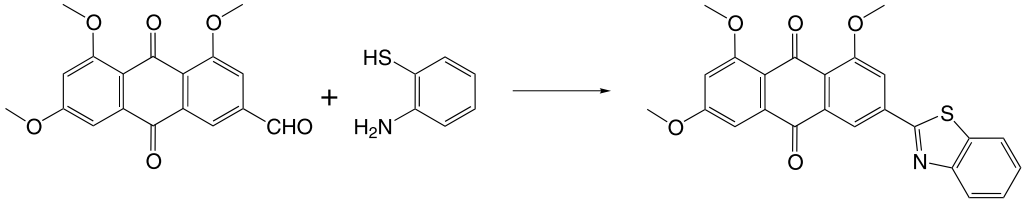
The heterocyclically appended hypericin derivative **1** has been found to display a pronounced bathochromic shift [1] as compared to the parent system **2**. Thus, there is a potential of **1** for its application in PDT together with its ability to generate singlet oxygen and/or reactive oxygen species upon irradiation [1]. However, drawbacks of the highly complicated structural system of **1** given by the benzimidazolyl moieties lead to a decreased extinction coefficient of the long wavelength band and a rather limited solubility in aqueous solvents as compared to **2** [1]. Therefore, the syntheses of the corresponding S- and O-analogs were targeted to complete this series of heterocyclic hypericin derivatives and to possibly overcome the disadvantages of **1**.

Herein, we report the microwave assisted syntheses of 6-heterocyclically appended tri-*O*-methyl protected 6-demethylemodin derivatives as an alternative route to the recently developed conventional syntheses [5] to obtain these interesting synthons for the preparation of the corresponding substituted hypericin derivatives in general. These synthons are then used to prepare and investigate 10,11-dibenzothiazolyl-10,11-didemethylhypericin (**13**) and 10,11-dibenzoxazolyl-10,11-didemethylhypericin (**14**).

Results and Discussion

Microwave Assisted Syntheses of Anthraquinone Derivatives

The syntheses of the dibenzothiazolyl didemethyl hypericin **13** and dibenzoxazolyl didemethyl hypericin **14** were performed in three steps starting from the corresponding 6-heterocyclically appended tri-*O*-methyl protected 6-demethylemodin derivatives **5** and **8**. For the syntheses of 6-benzothiazolyl-tri-*O*-methyl-6-demethylemodin (**5**), the intermediate *Schiff* base **7** and 6-benzoxazolyl-tri-*O*-methyl-6-demethylemodin (**8**), which necessitates rather long reaction times and



3 **4** **5**

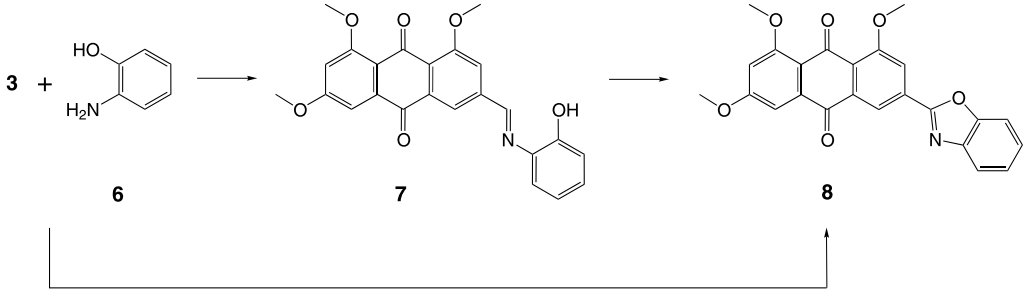
Scheme 1

elevated temperatures [5], microwave assisted synthesis [6, 7] was applied, which allowed access to this type of heterocyclic synthons *via* convenient, high yield protocols.

Starting from tri-*O*-methylemodin aldehyde (**3**) the benzothiazole **5** was synthesized *via* microwave assisted solid phase synthesis with *o*-aminothiophenol (**4**) in 82% yield after 1 h heating at 600 W ($t = 91°C$) (Scheme 1). It should be mentioned that microwave assisted syntheses of **5** according to literature procedures for analogous heterocylces under solid phase conditions using Montmorillonite K10 [6], or under liquid phase conditions using toluene [7], end up in much lower yields than in the procedure described above. By use of microwave assisted synthesis, which is known for its contribution to ''green chemistry'', the reaction time in this case could be decreased to 1 h under solid phase/microwave conditions. Furthermore, the yield could be increased from 70 [5] to 82%.

It should be mentioned also that under microwave conditions the reaction time may vary depending on the scale, the homogenization of the reactants under solid phase conditions, the heat distribution in the reaction flask as well as the shape of the flask, and has therefore to be controlled by TLC. Main advantages of the application of microwave assisted solid phase synthesis for the preparation of 6-benzothiazolyl-tri-*O*-methyl-6-demethylemodin (**5**) are the absence of nitrobenzene as an inconvenient, high boiling solvent as well as a decreased reaction time and increased yield.

Following one-step microwave assisted synthesis of benzoxazole derivatives according to Ref. [7], a refluxing mixture of tri-*O*-methylemodin aldehyde (**3**) and *o*-aminophenol (**6**) in toluene for 15 min at 800 W led exclusively to the intermediate *Schiff* base **7** in 97% yield (Scheme 2). It is noteworthy that microwave



6 **7** **8**

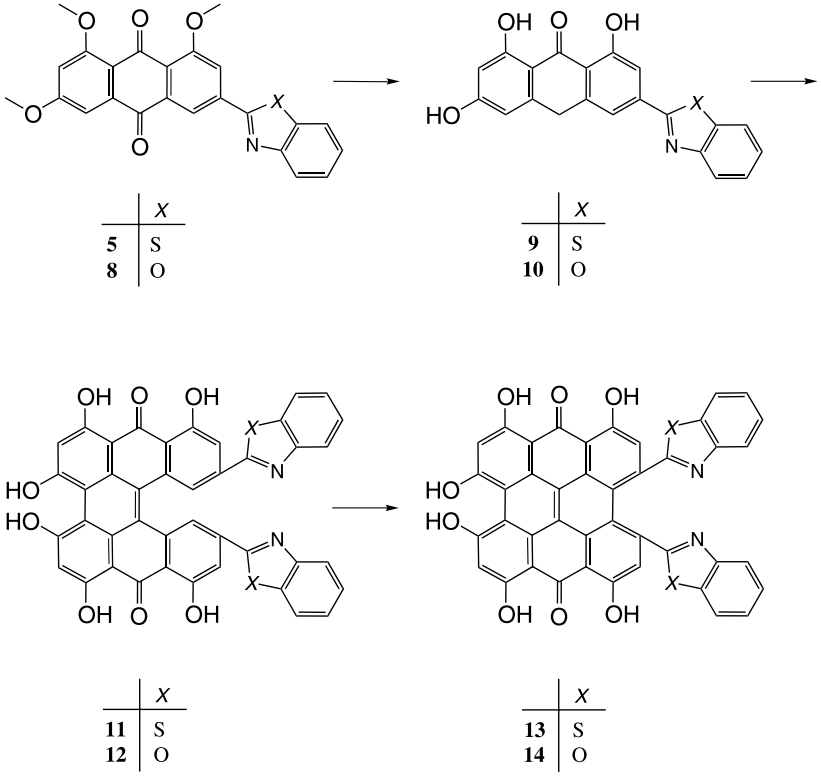
Scheme 2

assisted solid phase synthesis of the benzoxazole **8** failed and provided a mixture of starting aldehyde **3** and *Schiff* base **7**. Applying microwave assisted synthesis for the conversion of *Schiff* base **7** to **8**, lead tetraacetate [5] was used in a solid phase synthesis. Beside a series of side products the target benzoxazole **8** was isolated in insufficient yield (<50%). The cyclization of **7** to **8** was therefore performed under optimized conditions following Ref. [5] by using a molar ratio of *Schiff* base to lead tetraacetate of 1:1.2 in acetic acid at 80°C for 30 min to afford **8** in 92% yield (Scheme 2).

Finally, the one-step conversion of aldehyde **3** to the target benzoxazole **8** was possible under microwave conditions by using nitrobenzene under liquid phase conditions. For this purpose, a mixture of tri-*O*-methylemodin aldehyde (**3**) and aminophenol (**6**) was refluxed in nitrobenzene for 3 h at 800 W to afford **8** in almost 63% yield (Scheme 2). The application of microwave assisted synthesis, either under solid phase or liquid phase conditions, thus provides a powerful tool for convenient short time syntheses of these heterocyclically appended tri-*O*-methyl protected 6-demethylemodin derivatives in good to excellent yields.

Syntheses of Heterocyclically Substituted Hypericin Derivatives

Starting from 6-benzothiazolyl-tri-*O*-methyl-6-demethylemodin (**5**) or 6-benzoxazolyl-tri-*O*-methyl-6-demethylemodin (**8**), which both display an adequate



	X
5	S
8	O

	X
9	S
10	O

	X
11	S
12	O

	X
13	S
14	O

Scheme 3

bathochromic shift ($\Delta\lambda_{max} \sim 7$ nm) of the long wavelength absorption band in comparison to its parent compound, tri-*O*-methylemodin ($\lambda_{max} \sim 401$ nm), the syntheses of dibenzothiazolyl-didemethyl-hypericin **13** and dibenzoxazolyl-didemethyl-hypericin **14** were performed in three steps (Scheme 3). Thus, reduction/deprotection of **5** to the corresponding anthrone **9** by refluxing a mixture of **5**, $SnCl_2 \cdot 2H_2O$, and HBr in glacial acetic acid in analogy to Ref. [8] for 1 h under Ar provided **9** in 97% yield. Dimerization of **9** was carried out in the conventional way [9] using a stirred solution of **9**, $FeSO_4 \cdot 7H_2O$, pyridine-*N*-oxide, piperidine, and pyridine under Ar and light protection. Heating at 115°C for 1 h yielded 89% of the light sensitive protohypericin derivative **11**. Cyclization of **11** upon irradiation afforded the desired hypericin derivative **13**, which was isolated as a dark green solid in 55% yield (47% overall yield based on **5**, Scheme 3).

The synthesis of the corresponding O-analog was performed similarily to the S-analog mentioned above. Thus, reduction/deprotection of **8** afforded the corresponding anthrone **10** in 97% yield followed by dimerization of **10** to the light sensitive protohypericin derivative **12** in 91% yield. Finally, photocyclization of **12** afforded the desired O-analogous hypericin derivative **14** in 73% yield as a dark green solid (64% overall yield based on **8**, Scheme 3).

*Chemical and Photochemical Properties of **13** and **14***

Modified hypericin derivatives as potential new drugs in photodynamic therapy have to fulfill three main properties, which are the bathochromic shifting of the long wavelength absorption band towards the emission wavelength of medicinal lasers, the ability of generating singlet oxygen and/or reactive oxygen species, and a sufficient solubility under physiological conditions. Thus, a series of investigations were undertaken for the determination of the chemical and photochemical behaviour of these unique heterocyclically substituted hypericin derivatives **13** and **14**.

Despite a small observable shift of the long wavelength absorption band of the tri-*O*-methyl protected benzothiazole **5** and benzoxazole **8** ($\Delta\lambda_{max} < 10$ nm in comparison to 1,3,8-trimethoxy-6-methyl-9,10-anthraquinone [5]), the bathochromic shifts of the corresponding S- and O-analogous hypericin derivatives **13** ($\Delta\lambda_{max} \sim 21$–$23$ nm, in a series of solvents) and **14** ($\Delta\lambda_{max} \sim 16$–$18$ nm) in comparison to **2** were satisfying. Especially the S-analogous hypericin derivative **13** ($\lambda_{max} = 610$–624 nm) showed in comparison to hypericin (**2**) ($\lambda_{max} = 592$–602 nm) a sufficient bathochromic shift, which reaches precisely the intended wavelength ($\lambda_{max} \geq 620$ nm). The corresponding O-derivative **14** ($\lambda_{max} = 605$–619 nm) showed a long wavelength absorption, which was shifted slightly below the mark of $\lambda_{max} \geq 620$ nm. However, one of the main targets, which is the shifting of the long wavelength absorption band of hypericin (**2**) towards the emission wavelength range of medicinal lasers ($\lambda_{max} \geq 620$ nm) was achieved by the syntheses of **13** and **14**. Regarding the solubility of **13** and **14** it should be stressed that these hypericin derivatives are very well soluble (>2 mg·cm^{-3}!) in all common polar and nonpolar organic solvents (acetone, acetonitrile, *DMF*, *DMSO*, 80% aqueous ethanol, ethanol, ethyl acetate, methanol, pyridine, and *THF*) either comparable to hypericin (**2**) or even better than **2**, which is of particular interest

for a proper solubility of these hypericin derivatives under physiological conditions. The molar extinction coefficients of the long wavelength absorption band of **13** and **14** in these common organic solvents are in the range of $\varepsilon \sim 13000$–$19000\,dm^3 \cdot mol^{-1} \cdot cm^{-1}$, which amounts approximately to one third of that observed for hypericin (**2**) itself.

The modification of hypericin (**2**) by the two benzothiazolyl- or benzoxazolyl substituents is predestined for a complex protonation and deprotonation behaviour of **13** and **14**. However, in comparison to the complexity of this behaviour observed for the dibenzimidazolyl didemethyl hypericin **1**, the benzothiazolyl analog **13** and the benzoxazolyl analog **14** seem to be less complicated. The basic benzothiazole or oxazole itself can act as a weak proton acceptor with $pK_a \sim 1.2$ [10] or $pK_a \sim 0.8$ [11]. Since the *bay*-hydroxyl groups of hypericin (**2**) are acidic ($pK_a \sim 2$ [12]), it is obvious that **13** and **14** with their basic benzothiazolyl- and benzoxazolyl-substituents have the possibility of forming a zwitterion *via* deprotonation of the *bay*-hydroxyl group involving the benzothiazolyl- or benzoxazolyl nitrogen. Nevertheless, the range of these zwitterionic species of **13** and **14** will be smaller than that observed for the benzimidazolyl analog **1** [1] due to the similarity of the pK_a's of benzothiazole, -oxazole, and hypericin (**2**). The results of the spectrophotometric titration of **13** and **14** in 80% aqueous ethanol are shown in Figs. 1 and 2 and describe the protonation and deprotonation behaviour of **13** and **14**. It became evident that, depending on the *pH*-values of the 80% aqueous ethanol solutions, a certain species dominated below $pH \sim 1$, another one prevailed within the *pH*-range of 3 and 7, followed by a third species predominant above $pH \sim 7$, and finally, a fourth one became prominent above $pH \sim 12.5$.

It was not possible to find direct evidence for the existence of a zwitterion of **13** and **14**, but it could be unequivocally established by means of electrospray mass experiments [13], that the species predominant within the *pH*-range of 7–12.5 are the monodeprotonated species $\mathbf{13}^{(-)}$ and $\mathbf{14}^{(-)}$ characterized by

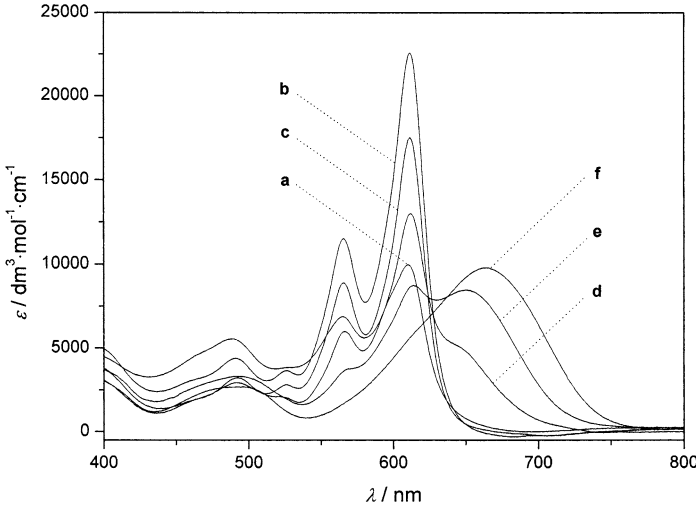


Fig. 1. Absorption spectra of **13** in 80% aqueous ethanol at $pH = 1.0$ (a), 3.0 (b), 8.4 (c), 11.4 (d), 12.4 (e), and 13.4 (f) (titration with H_2SO_4 and *TBAH*)

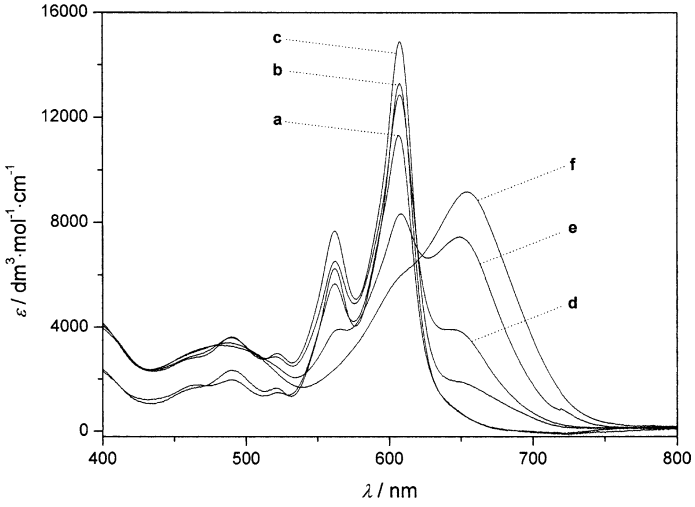


Fig. 2. Absorption spectra of **14** in 80% aqueous ethanol at $pH = 1.0$ (a), 3.0 (b), 8.4 (c), 11.4 (d), 12.4 (e), and 13.4 (f) (titration with H_2SO_4 and *TBAH*)

$m/z = 741$ ($[M–H]^-$) and $m/z = 709$ ($[M–H]^-$). At *pH*-ranges below 3 the masses of the monoprotonated species **13**·H^+ and **14**·H^+ are observed, whereas between $pH \sim 3$ and 7 no signal could be detected originating from the existence of the zwitterion of **13** and **14**. Thus, the "delayed" appearance of the $\mathbf{13}^{(-)}$ as well as $\mathbf{14}^{(-)}$ ions above $pH \sim 7$ in comparison with that of $\mathbf{2}^{(-)}$ might also constitute an evidence for the existence of the zwitterion between $pH \sim 3$ and 7. Finally, the dideprotonated forms $\mathbf{13}^{(2-)}$ and $\mathbf{14}^{(2-)}$ may be inferred at $pH > 12.5$, as can be derived from the titration experiments (Figs. 1 and 2). Apart from the possibility of **13** and **14** to form an internal salt it is also conceivable that tautomerism as well as rotational phenomena of the benzothiazolyl- and benzoxazolyl-substituents within the systems of **13** and **14** may play a role in the chemical behaviour of these compounds.

The structural assignments of **13** and **14** were performed *via* their characteristic IR absorption bands and mass spectra. However, the presence of tautomerism, internal salt formation, association, rotational phenomena, and protonation/deprotonation behaviour prohibited to assign ^{1}H NMR signals to a certain species of **13** or **14**. The ^{1}H NMR spectra of **13** and **14** did not show such a complex pattern as observed for the benzimidazolyl derivative **1** [1]. However, it is even for the benzothiazolyl derivative **13** as well as for the benzoxazolyl derivative **14** not possible to identify a single species by means of ^{1}H NMR temperature variation experiments. In *DMSO* at 30°C signal broadening as well as the appearance of more signals than could be assigned to one single species of **13** or **14** could be observed. The fact that the signals coalesced and became sharper at elevated temperatures (60 and 90°C in *DMSO*) is an indication of rotational phenomena of the two benzothiazolyl- or benzoxazolyl-substituents of **13** or **14**. It should be stressed, that the strong acidity of the *bay*-phenolic proton observed in the titration experiments is in agreement with the hypericinoide and not an isohypericinoide [12, 13] constitution of **13** and **14**.

The recently synthesized dibenzimidazolyl didemethyl hypericin **1** [1] showed the ability to generate singlet oxygen and/or reactive oxygen species to a some-

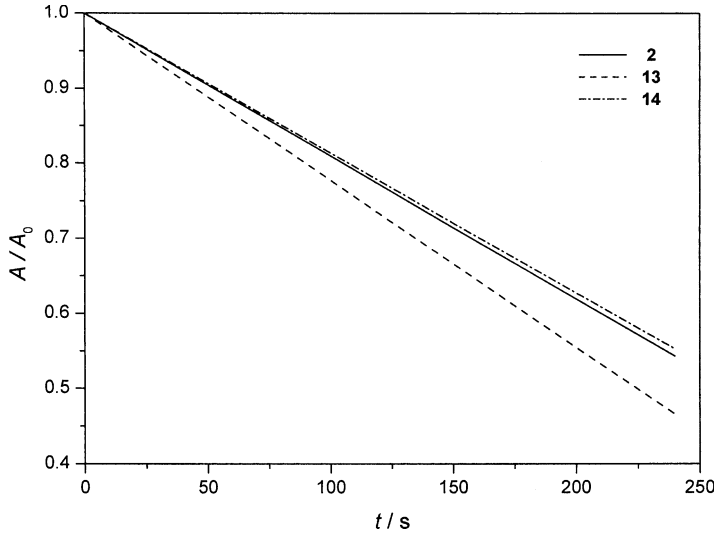


Fig. 3. Hypericin derivative sensitized photooxidation of bilirubin IXα: normalized absorption (A/A_0) *vs.* time curves of solutions of disodium bilirubinate IXα together with either sodium hypericinate ($^{-3}$**2**), the sodium salt of dibenzothiazolyl hypericin ($^{-3}$**13**), or the sodium salt of dibenzoxazolyl hypericin ($^{-3}$**14**) in aereated 80% aqueous ethanol upon irradiation at $\lambda > 570$ nm

what lesser extent as hypericin (**2**) itself. However, in contrast to other nitrogen containing hypericin derivatives [8], which did not show any photosensitizing ability, this fact is of importance for the potential application of this series of nitrogen containing hypericin derivatives in PDT. The two heterocyclically appended hypericin derivatives **13** and **14** were indeed highly effective in the hypericin sensitized destruction of bilirubin, which has been established as a rapid means to assess sensitized production of singlet oxygen and/or reactive oxygen species [4a, 14]. As can be derived from Fig. 3, hypericin (**2**) and the dibenzoxazolyl didemethyl hypericin **14** are quite effective, comparable singlet oxygen and/or reactive oxygen species sensitizers. The corresponding S-analogous dibenzothiazolyl didemethyl hypericin **13** is even a more effective sensitizer than hypericin (**2**) itself which makes **13** in particular besides **14** an extraordinarily interesting compound for the potential application in photodynamic therapy. The rather small quantum yields of fluorescence of **13** and **14**, which amount only about one tenth of that of **2** [2], correlates with their observed sensitizing properties.

Semiempirical Calculations

To clarify the role of tautomerism in the behavior of **13** and **14** they were investigated by means of semiempirical calculations (AM1 [15]). According to previous calculations by a variety of methods on hypericin (**2**) it is known that ten different tautomers are possible for **2**, where the $\boldsymbol{Q}^{7,14}$ tautomer ($\boldsymbol{Q}^{m,n}$ denotes the type of tautomer by indicating the carbonyl positions in superscripts) represents the most stable one [16–18]. For each tautomer of **2** two conformers, namely the ''propeller'' and ''butterfly'' conformer, might exist.

Calculations for the dibenzothiazolyl didemethyl hypericin **13** and dibenzoxazolyl didemethyl hypericin **14** showed similar results as for the dibenzimidazolyl didemethyl hypericin **1** [1]. Calculations were executed on the propeller conformers only because the butterfly conformers proved to be of higher energy in selected cases. In principle, there are two, three, or four carbonyl groups possible in the structure of **13** and **14**. Thus, there are ten different tautomers of the $\boldsymbol{Q}^{m,n}$ type for **13** and **14**, with four possible conformers depending on the orientation of the benzothiazolyl- or the benzoxazolyl-substituents (*anti* or *syn*, denotes the relative orientations of the two heterocycles to each other) for any of these species (Fig. 4).

Tautomers with symmetric positions of their carbonyl groups have identical conformers of the *anti*,*syn*-type. Accordingly, overall there are 36 conformers of the type $\boldsymbol{Q}^{m,n}$ possible. For each $\boldsymbol{Q}^{m,n,o}$ type of **13** and **14**, 15 tautomers may exist as 60 conformers (Fig. 5), whereas the three tautomers of $\boldsymbol{Q}^{m,n,o,p}$ type display two or four conformers each, depending on the symmetry of the position of the carbonyl groups (Fig. 6).

As a summary, Fig. 7 presents the heats of formation of the conformers of hypericin (**2**), benzothiazolyl didemethyl hypericin **13**, and benzoxazolyl didemethyl hypericin **14**, which are possible in principle. As observed for a variety

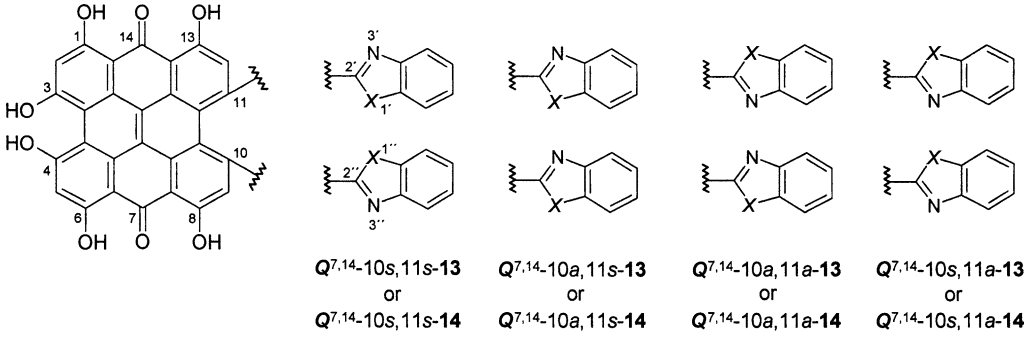


Fig. 4. Four possible conformers of the tautomers of type $\boldsymbol{Q}^{m,n}$ of **13** ($X = S$) and **14** ($X = O$), depending on the orientation of the benzothiazolyl- and benzoxazolyl-substituents (*a* . . . *anti*, *s* . . . *syn*)

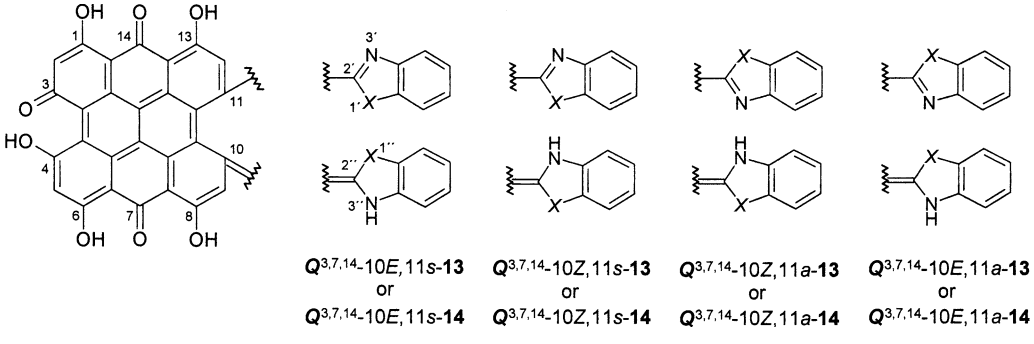


Fig. 5. Four possible conformers of the tautomers of type $\boldsymbol{Q}^{m,n,o}$ of **13** ($X = S$) and **14** ($X = O$), depending on the orientation of the benzothiazolyl- and benzoxazolyl-substituents (*a* . . . *anti*, *s* . . . *syn*)

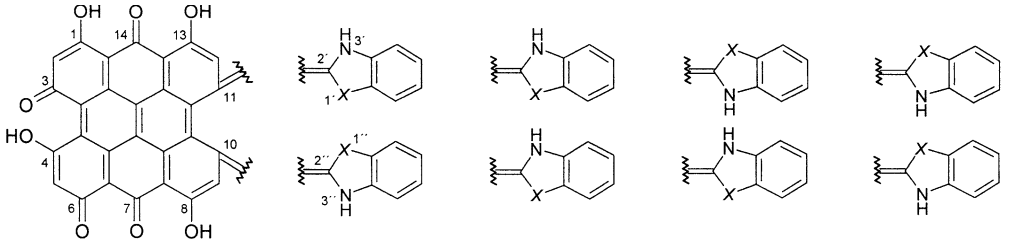


Fig. 6. Four possible conformers of the tautomers of type $Q^{m,n,o,p}$ of **13** ($X = S$) and **14** ($X = O$), depending on the orientation of the benzothiazolyl- and benzoxazolyl-substituents

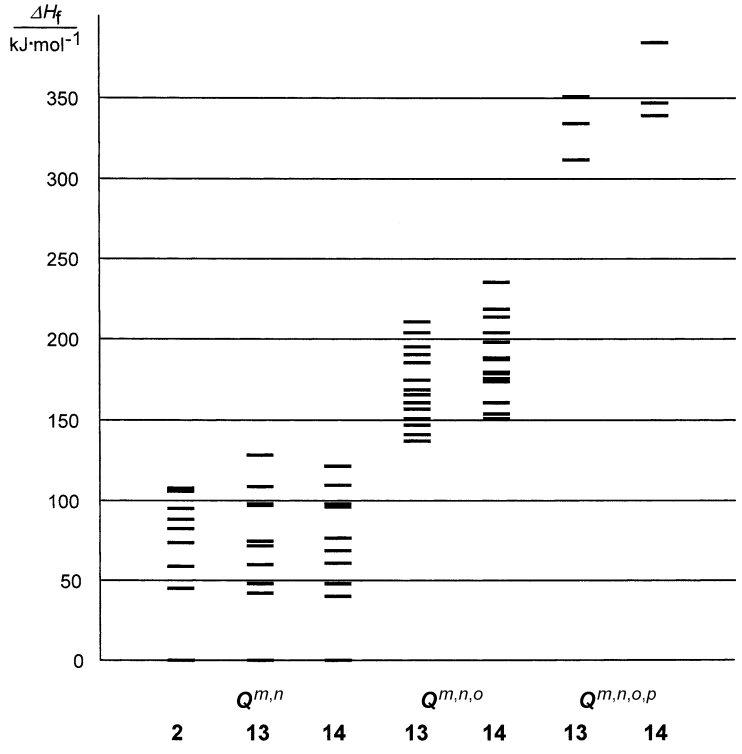


Fig. 7. The differences of heats of formation of $Q^{7,14}$-**2** are included as a reference for the species of **13** and **14**; the $Q^{7,14}$-type tautomer of **2**, **13**, and **14** is the standard for all other tautomers of **2**, **13**, and **14**; the bars represent the most stable conformer of each tautomer; the relative stability of tautomers in descending order is for **13**: $Q^{m,n}$: $Q^{7,14}$, $Q^{7,13}$, $Q^{1,7}$, $Q^{3,7}$, $Q^{8,13}$, $Q^{1,6}$, $Q^{1,4}$, $Q^{1,8}$, $Q^{3,8}$, $Q^{3,4}$; $Q^{m,n,o}$: $Q^{7,8,14}$, $Q^{3,7,13}$, $Q^{3,7,14}$, $Q^{1,4,8}$, $Q^{1,7,13}$, $Q^{1,4,7}$, $Q^{1,7,8}$, $Q^{1,6,8}$, $Q^{3,4,8}$, $Q^{1,4,13}$, $Q^{3,7,8}$, $Q^{3,4,7}$, $Q^{1,6,7}$, $Q^{1,7,14}$, $Q^{1,4,14}$; $Q^{m,n,o,p}$: $Q^{3,4,7,14}$, $Q^{1,4,7,14}$, $Q^{1,6,7,14}$; and for **14**: $Q^{m,n}$: $Q^{7,14}$, $Q^{7,13}$, $Q^{1,7}$, $Q^{3,7}$, $Q^{8,13}$, $Q^{1,6}$, $Q^{1,8}$, $Q^{1,4}$, $Q^{3,8}$, $Q^{3,4}$; $Q^{m,n,o}$: $Q^{7,8,14}$, $Q^{3,7,13}$, $Q^{3,7,14}$, $Q^{1,4,8}$, $Q^{1,7,13}$, $Q^{1,4,7}$, $Q^{1,6,8}$, $Q^{3,4,8}$, $Q^{1,7,8}$, $Q^{1,4,13}$, $Q^{3,7,8}$, $Q^{3,4,7}$, $Q^{1,7,14}$, $Q^{1,6,7}$, $Q^{1,4,14}$; $Q^{m,n,o,p}$: $Q^{3,4,7,14}$, $Q^{1,4,7,14}$, $Q^{1,6,7,14}$

of substituted hypericin derivatives [17] the 7,14-tautomers of **13** and **14** are by far ($\sim$40 kJ·mol^{-1}) the most stable ones. This has been proven for hypericin (**2**) also by experimental means [16], which are, however, not directly applicable to the

cases of **13** and **14**. Tautomers $\boldsymbol{Q}^{7,14}$–**13** and $\boldsymbol{Q}^{7,14}$–**14** appear to be stabilized by about 40 kJ·mol^{-1} compared to $\boldsymbol{Q}^{7,13}$–**13** and $\boldsymbol{Q}^{7,13}$–**14**. All other tautomers are even less stable. The *Born-Oppenheimer* hypersurface appears to be rather flat with many local minima since minor modifications of the structure of conformers resulted in changes in the order of stability of conformers.

To obtain a value for the highest rotation barrier of the benzothiazolyl- and benzoxazolyl-substituent these subsituents were rotated into the position with highest steric hindrance and a 1-SCF cycle was calculated to obtain an energy for these conformers. Thus, a rotation barrrier of 90 kJ·mol^{-1} for the dibenzothiazolyl didemethyl hypericin **13** and 55 kJ·mol^{-1} for the dibenzoxazolyl didemethyl hypericin **14** could be estimated.

Comparison of the heats of formation of those tautomers showed that the most important influence on stability is the degree of aromaticity, which is optimal in case of the $\boldsymbol{Q}^{m,n}$ tautomers, especially in $\boldsymbol{Q}^{7,14}$. As the number of quinoid rings increases, the heat of formation increases concomitantly. Thus, it seems unlikely that other tautomers than $\boldsymbol{Q}^{7,14}$ are stable enough to be present in solutions of **13** and **14**. Accordingly, the NMR signal behaviour of **13** and **14** should be due to equilibria between conformers rather than tautomers.

Experimental

Solvents were of p.a. quality. *DMF* was freshly distilled prior to use. Melting points were measured on a *Kofler* melting point microscope (*Reichert*, Vienna). ^{1}H NMR spectra were recorded on a Bruker Avance DRX 500 MHz spectrometer using a TXI cryoprobe with *z*-gradient coil. Standard temperature for NMR experiments in *DMSO*-d_6 and $CDCl_3$ was 30°C. ^{1}H NMR temperature variation experiments of **13** and **14** were performed on a Bruker Avance DPX 200 MHz instrument in *DMSO*-d_6 up to 60 and 90°C. 2D NMR experiments were performed on the 500 MHz spectrometer using standard pulse sequences as provided by the manufacturer. Typical 90° hard pulse durations were 8.2 μs (^{1}H) and 16.6 μs (^{13}C), 90° pulses in decoupling experiments were set to 67 μs. HSQC and HMBC experiments were optimized for coupling constants of 145 Hz for single quantum correlations and 10 Hz for multibond correlations. N*O*ESY mixing time was set to 400 ms. IR, UV/Vis, fluorescence, and mass spectra were recorded using the Bruker Tensor 27, Varian Cary 100 Bio UV/Vis, Hitachi 4010F, and Hewlett Packard 5989 quadrupole instruments. Microwave assisted syntheses were performed on a MLS-ETHOS 1600 microwave unit with Terminal 320 from MLS-Milestone. Hypericin sensitized photooxidation of bilirubinate IXα was executed according to Ref. [14]. Spectrophotometric titrations of **13** and **14** were carried out in 80% aqueous ethanol using H_2SO_4 and tetrabutylammonium hydroxide (*TBAH*) as acid and base [12]. For mass spectroscopic experiments [13] the *pH*-values were adjusted by means of buffered aqueous solutions (*e.g.* $HCOO^-NH_4^+$/HCOOH, KCl/HCl, Na_2CO_3/NaOH, as well as HCl and NaOH) instead of distilled H_2O. Semiempirical calculations were performed at the SGI Origin 3800 of the ZID at the Johannes Kepler University of Linz with AM1 [15] using geometry inputs from MM3 [19]. Tri-*O*-methylemodin aldehyde (**3**) was prepared according to Ref. [20]. The starting material for the synthesis of **3**, 1,3,8-trimethoxy-6-methyl-9,10-anthraquinone (tri-*O*-methylemodin), was now prepared by means of microwave assisted synthesis: A mixture of 0.125 g (0.46 mmol) 1,3,8-trihydroxy-6-methyl-9,10-anthraquinone (emodin), 1.26 g (9.12 mmol) dried potassium carbonate, 0.7 g (5.55 mmol) dimethyl sulfate, and 15 mg (0.05 mmol) tetrabutylammoniumbromide was suspended in 5 cm^3 dry CH_2Cl_2, homogenized, followed by evaporation of CH_2Cl_2 to dryness. The solid was heated up in the microwave unit in a round bottomed flask under Ar for 20 min at 600 W ($t = 75$°C). After cooling, the yellow solid was extracted with $CHCl_3/H_2O$. The combined organic layers were dried over Na_2SO_4 to yield 0.142 g (98%) tri-*O*-methylemodin. The mp, TLC, IR, MS, and NMR spectra of tri-*O*-methylemodin were identical to Ref. [21]. All

novel compounds were judged to be pure (>97%) by means of their ^{1}H NMR spectra and chromatography.

6-(1,3-Benzothiazol-2-yl)-1,3,8-trimethoxy-9,10-anthraquinone (**5**)

A mixture of 12 mg (0.037 mmol) **3** and 4.6 mg (0.037 mmol, 3.9 mm^3) *o*-aminothiophenol (**4**) was suspended in 1 cm^3 acetonitrile and stirred for 5 min at room temperature for homogenisation followed by evaporation of acetonitrile to dryness. The solid was heated up in a round bottomed flask in the microwave unit under Ar for 1 h at 600 W ($t = 91$°C) and the reaction was controlled *via* TLC. After cooling, the crude product was chromatographed using $CHCl_3$:ethyl acetate (4:1) and dried under vacuum over P_2O_5 to afford 13 mg (82%) **5** as a yellow solid. The mp, TLC, IR, MS, and NMR spectra (in *DMSO*-d_6) of **5** were identical to the reference compound [5]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.39$ (d, $J = 1.3$ Hz, ar-H5), 8.18 (d, $J = 1.3$ Hz, ar-H7), 8.14 (d, $J = 8.3$ Hz, ar-H4′), 7.97 (d, $J = 8.3$ Hz, ar-H7′), 7.57–7.54 (m, ar-H5′), 7.48–7.45 (m, ar-H6′), 7.38 (d, $J = 2.4$ Hz, ar-H4), 6.81 (d, $J = 2.4$ Hz, ar-H2), 4.17 (s, 8-OCH_3), 4.00 (s, 1-OCH_3), 3.99 (s, 3-OCH_3) ppm; N*O*ESY ($CDCl_3$): 1-OC*H*$_3$ ↔ ar-*H*2, 3-OC*H*$_3$ ↔ ar-*H*2 and ar-*H*4, 8-OC*H*$_3$ ↔ ar-*H*7, ar-*H*4′ ↔ ar-*H*5′, ar-*H*5′ ↔ ar-*H*6′, ar-*H*6′ ↔ ar-*H*7′; ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 183.7$ (C10), 181.4 (C9), 166.0 (C=N), 164.3 (C3), 162.1 (C1), 160.5 (C8), 154.2 (C3a′), 138.3 (C10a), 136.5 (C4a), 135.8 (C6 or C7a′), 135.6 (C7a′ or C6), 127.0 (C5′), 126.2 (C6′), 125.4 (C8a), 124.0 (C4′), 122.1 (C7′), 118.7 (C9a), 118.4 (C5), 116.0 (C7), 105.7 (C2), 102.5 (C4), 57.13 (8-OCH_3), 56.76 (1-OCH_3), 56.17 (3-OCH_3) ppm; HSQC ($CDCl_3$): ar-*H*2 ↔ *C*2, ar-*H*4 ↔ *C*4, ar-*H*5 ↔ *C*5, ar-*H*7 ↔ *C*7, 1-OC*H*$_3$ ↔ 1-O*C*H$_3$, 3-OC*H*$_3$ ↔ 3-O*C*H$_3$, 8-OC*H*$_3$ ↔ 8-O*C*H$_3$, ar-*H*4′ ↔ *C*4′, ar-*H*5′ ↔ *C*5′, ar-*H*6′ ↔ *C*6′, ar-*H*7′ ↔ *C*7′; HMBC ($CDCl_3$): *C*1 → 1-OC*H*$_3$ and ar-*H*2, *C*2 → ar-*H*4, 1-OC*H*$_3$, and 3-OC*H*$_3$, *C*3 → 3-OC*H*$_3$, ar-*H*2, and ar-*H*4, *C*4 → ar-*H*2, *C*5 → ar-*H*7, *C*6 → ar-*H*7, *C*7 → ar-*H*5, *C*8 → 8-OC*H*$_3$ and ar-*H*7, *C*9 → ar-*H*2 and ar-*H*7, *C*10 → ar-*H*4 and ar-*H*5, *C*4a → ar-*H*4, *C*8a → ar-*H*5 and ar-*H*7, *C*9a → ar-*H*2 and ar-*H*4, *C*10a → ar-*H*5, *C*2′ → ar-*H*5 and ar-*H*7, *C*3a′ → ar-*H*4′, ar-*H*5′, and ar-*H*7′, *C*4′ → ar-*H*5′ and ar-*H*6′, *C*5′ → ar-*H*6′ and ar-*H*7′, *C*6′ → ar-*H*4′ and ar-*H*5′, *C*7′ → ar-*H*5′ and ar-*H*6′, *C*7a′ → ar-*H*4′, ar-*H*5′, and ar-*H*6′.

6-(2-Hydroxyphenylimino)-methyl-1,3,8-trimethoxy 9,10-anthraquinone (**7**)

A mixture of 41 mg (0.126 mmol) **3** and 16.5 mg (0.151 mmol) *o*-aminophenol (**6**) was suspended in 3 cm^3 toluene in a round bottomed flask and refluxed ($t = 111$°C) under Ar and stirring in the microwave unit for 15 min at 800 W. The reaction was controlled by TLC. After cooling, the solvent was evaporated and the crude product was purified *via* centrifugation with ethanol and dried under vacuum to afford 51 mg (97%) **7** as a yellow solid. The mp, TLC, IR, MS, and NMR spectra (in *DMSO*-d_6) of **7** were identical to the reference compound [5]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.78$ (s, –CH=N), 8.25 (d, $J = 1.2$ Hz, ar-H5), 7.88 (d, $J = 1.2$ Hz, ar-H7), 7.37 (d, $J = 2.5$ Hz, ar-H4), 7.36 (d, $J = 7.7$ Hz, ar-H6′), 7.28–7.25 (m, ar-H5′), 7.18 (s, 2′-OH), 7.06 (d, $J = 7.7$ Hz, ar-H3′), 6.97–6.94 (m, ar-H4′), 6.80 (d, $J = 2.5$ Hz, ar-H2), 4.11 (s, 8-OCH_3), 3.99 (s, 1-OCH_3), 3.98 (s, 3-OCH_3) ppm; N*O*ESY ($CDCl_3$): 1-OC*H*$_3$ ↔ ar-*H*2, 3-OC*H*$_3$ ↔ ar-*H*2 and ar-*H*4, 8-OC*H*$_3$ ↔ ar-*H*7, 2′-O*H* ↔ ar-*H*3′, ar-*H*4′ ↔ ar-*H*3′ and ar-*H*5′, ar-*H*6′ ↔ –C*H*=N and ar-*H*5′; ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 183.9$ (C10), 181.5 (C9), 164.3 (C3), 162.1 (C1), 160.4 (C8), 155.1 (C=N), 153.0 (C2′), 140.3 (C6), 136.5 (C4a), 135.5 (C1′), 135.0 (C10a), 130.3 (C5′), 126.0 (C8a), 120.6 (C5 or C4′), 120.5 (C4′ or C5), 118.7 (C9a), 116.3 (C7 or C3′), 116.1 (C3′ or C7), 115.7 (C6′), 105.7 (C2), 102.4 (C4), 57.01 (3-OCH_3), 56.75 (8-OCH_3), 56.16 (1-OCH_3) ppm; HSQC ($CDCl_3$): ar-*H*2 ↔ *C*2, ar-*H*4 ↔ *C*4, ar-*H*5 ↔ *C*5, ar-*H*7 ↔ *C*7, 1-OC*H*$_3$ ↔ 1-O*C*H$_3$, 3-OC*H*$_3$ ↔ 3-O*C*H$_3$, 8-OC*H*$_3$ ↔ 8-O*C*H$_3$, 6-C*H*=N ↔ 6-*C*H=N, ar-*H*3′ ↔ *C*3′, ar-*H*4′ ↔ *C*4′, ar-*H*5′ ↔ *C*5′, ar-*H*6′ ↔ *C*6′; HMBC ($CDCl_3$): *C*1 → 1-OC*H*$_3$ and ar-*H*2, *C*2 → ar-*H*4, *C*3 → 3-OC*H*$_3$, ar-*H*2, and ar-*H*4, *C*4 → ar-*H*2, *C*5 → ar-*H*7 and 6-C*H*=N, *C*6 → ar-*H*7 and 6-C*H*=N, *C*7 → ar-*H*5 and 6-C*H*=N, *C*8 → 8-OC*H*$_3$ and ar-*H*7, *C*10 → ar-*H*4 and ar-*H*5,

*C*4a → ar-*H*4, *C*8a → ar-*H*5 and ar-*H*7, *C*9a → ar-*H*2 and ar-*H*4, *C*10a → ar-*H*5, *C*1′ → 6-C*H*=N, *C*2′ → ar-*H*3′, ar-*H*4′, and ar-*H*6′, *C*3′ → 2′-OH and ar-*H*5′, *C*4′ → ar-*H*6′, *C*5′ → ar-*H*3′, *C*6′ → ar-*H*4′ and 2′-OH.

6-(1,3-Benzoxazol-2-yl)-1,3,8-trimethoxy-9,10-anthraquinone (**8**)

A mixture of 25 mg (0.077 mmol) **3** and 9 mg (0.082 mmol) *o*-aminophenol (**6**) in 2 cm^3 nitrobenzene was stirred and refluxed ($t = 210°C$) in the microwave unit under Ar for 3 h at 800 W. The reaction was controlled *via* TLC. After cooling, the crude product was washed with ethanol and dried under vacuum over P_2O_5 to afford 20 mg (63%) **8** as a yellow solid. The mp, TLC, IR, MS, and NMR spectra of **8** were identical to the reference compound [5].

6-(1,3-Benzothiazol-2-yl)-1,3,8-trihydroxy-10H-anthracen-9-one (**9**, $C_{21}H_{13}NO_4S$)

To a refluxing solution of 240 mg (0.556 mmol) **5** in 46 cm^3 glacial acetic acid under Ar, 996 mg (4.414 mmol) $SnCl_2{\cdot}2H_2O$ in 20.7 cm^3 HBr (47% aq) were added. The resulting mixture was refluxed for 1 h, cooled, poured onto ice/H_2O, and centrifuged. The residue was washed three times with distilled H_2O, dried under vacuum over P_2O_5 and triturated with $CHCl_3$ to yield 202 mg (97%) **9** as a brown solid. mp 240°C (decomp.); TLC: $R_f = 0.86$ (*n*-C_4H_9OH:CH_3COOH:H_2O = 5:1:4), $R_f = 0.59$ ($CHCl_3$:CH_3OH = 9:1); ^1H NMR (500 MHz, *DMSO*-d_6): $\delta = 12.45$ (s, 8-OH), 12.27 (s, 1-OH), 10.95 (s, 3-OH), 8.21 (d, $J = 7.1$ Hz, ar-H4′ or ar-H7′), 8.13 (d, $J = 8.1$ Hz, ar-H7′ or ar-H4′), 7.69 (d, $J = 1.5$ Hz, ar-H5), 7.60 (d/d, $J = 7.1$, 8.1 Hz, ar-H5′ or ar-H6′), 7.52 (d/d, $J = 8.1$, 7.1 Hz, ar-H6′ or ar-H5′), 7.50 (d, $J = 1.5$ Hz, ar-H7), 6.48 (d, $J = 2.0$ Hz, ar-H4), 6.28 (d, $J = 2.0$ Hz, ar-H2), 4.52 (s, –CH_2–) ppm; N*O*ESY (*DMSO*-d_6): 1-O*H* ↔ ar-*H*2, 3-O*H* ↔ ar-*H*2 and ar-*H*4, 8-O*H* ↔ ar-*H*7, 10-CH_2 ↔ ar-*H*4 and ar-*H*5, ar-*H*4′/ar-*H*7′ ↔ ar-*H*5′/ar-*H*6′; ^{13}C NMR (125 MHz, *DMSO*-d_6): $\delta = 190.6$ (C9), 165.6 (C=N), 165.5 (C3), 164.8 (C1), 161.8 (C8), 153.4 (C3a′), 145.1 (C4a), 143.4 (C10a), 138.4 (C6), 134.9 (C7a′), 126.9 (C5′ or C6′), 126.2 (C6′ or C5′), 123.3 (C4′ or C7′), 122.5 (C7′ or C4′), 117.3 (C5), 116.8 (C8a), 112.7 (C7), 108.6 (C9a), 107.5 (C4), 101.1 (C2), 32.47 (C10) ppm; HSQC (*DMSO*-d_6): ar-*H*2 ↔ *C*2, ar-*H*4 ↔ *C*4, ar-*H*5 ↔ *C*5, ar-*H*7 ↔ *C*7, 10-CH_2 ↔ 10-*C*H_2, ar-*H*4′/ar-*H*7′ ↔ *C*4′/*C*7′, ar-*H*5′/ar-*H*6′ ↔ *C*5′/*C*6′; HMBC (*DMSO*-d_6): *C*1 → 1-O*H* and ar-*H*2, *C*2 → 1-O*H*, 3-O*H*, and ar-*H*4, *C*3 → 3-O*H*, ar-*H*2, ar-*H*4, and 10-CH_2-, *C*4 → ar-*H*2, 3-O*H*, and 10-CH_2-, *C*5 → ar-*H*7 and 10-CH_2-, *C*6 → 8-O*H* and 10-CH_2-, *C*7 → ar-*H*5 and 8-O*H*, *C*8 → 8-O*H* and ar-*H*7, *C*10 → ar-*H*4 and ar-*H*5, C4a → ar-*H*4, ar-*H*5, and 10-CH_2-, *C*8a → ar-*H*5, ar-*H*7, 8-O*H*, and 10-CH_2-, *C*9a → ar-*H*2, ar-*H*4, 1-O*H*, and 10-CH_2-, *C*10a → ar-*H*4, ar-*H*5, and 10-CH_2-, 6-*C*=N → ar-*H*5, ar-*H*7, and 10-CH_2-, *C*3a′ → ar-*H*4′, ar-*H*5′, ar-*H*6′, and ar-*H*7′, *C*4′ → ar-*H*5′, ar-*H*6′, and ar-*H*7′, *C*5′ → ar-*H*4′, ar-*H*6′, and ar-*H*7′, *C*6′ → ar-*H*4′, ar-*H*5′, and ar-*H*7′, *C*7′ → ar-*H*4′, ar-*H*5′, and ar-*H*6′, *C*7a′ → ar-*H*4′, ar-*H*5′, ar-*H*6′, and ar-*H*7′; ESI-MS (CH_3OH:*DMSO* = 3:2 + 1% NH_3, $\gamma \sim 1$ mg·cm^{-3}, negative ion mode): $m/z = 374$ ($[M–H]^-$); IR (KBr): $\bar{\nu} = 3425$, 3084, 3023, 1622, 1600, 1557, 1498, 1482, 1458, 1421, 1385, 1334, 1290, 1257, 1184, 1166, 1064, 1028, 925, 804, 748, 725 cm^{-1}; UV-Vis (CH_3OH, $c = 1.10{\cdot}10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 226$ (25953), 375 (15488) nm ($dm^3{\cdot}mol^{-1}{\cdot}cm^{-1}$); UV-Vis ($CH_3COOC_2H_5$, $c = 1.10{\cdot}10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 252$ (7041), 267 (7391), 375 (14978) nm ($dm^3{\cdot}mol^{-1}{\cdot}cm^{-1}$).

6-(1,3-Benzoxazol-2-yl)-1,3,8-trihydroxy-10H-anthracen-9-one (**10**, $C_{21}H_{13}NO_5$)

To a refluxing solution of 20 mg (0.048 mmol) **8** in 5 cm^3 glacial acetic acid under Ar, 86.9 mg (0.385 mmol) $SnCl_2{\cdot}2H_2O$ in 1.87 cm^3 HBr (47% aq) were added. The resulting mixture was refluxed for 1 h, cooled, poured onto ice/H_2O, and adjusted to $pH = 5.5$ with 4 *N* NaOH. The precipitate was centrifuged, washed once with distilled H_2O, and dried under vacuum over P_2O_5. The crude product

was washed three times with $CHCl_3$:CH_3OH = 10:1 and the collected filtrates after centrifugation were evaporated to dryness to yield 16.8 mg (97%) **10** as an ochre solid. mp 246°C (decomp.); TLC: R_f = 0.88 ($CHCl_3$:CH_3OH = 1:1), R_f = 0.72 ($CHCl_3$:CH_3OH = 10:1); ^{1}H NMR (500 MHz, *DMSO*-d_6): δ = 12.46 (s, 8-OH), 12.24 (s, 1-OH), 10.97 (s, 3-OH), 7.86 (d, J = 7.8 Hz, ar-H4′), 7.83 (d, J = 8.1 Hz, ar-H7′), 7.76 (s, ar-H5), 7.55 (s, ar-H7), 7.49 (t, J = 8.1 Hz, ar-H5′), 7.45 (t, J = 7.8 Hz, ar-H6′), 6.48 (d, J = 2.0 Hz, ar-H4), 6.27 (d, J = 2.0 Hz, ar-H2), 4.51 (s, –CH_2–) ppm; N*O*ESY (*DMSO*-d_6): 1-O*H* ↔ ar-*H*2, 3-O*H* ↔ ar-*H*2 and ar-*H*4, 8-O*H* ↔ ar-*H*7, 10-CH_2 ↔ ar-*H*4 and ar-*H*5, ar-*H*4′/ar-*H*7′ ↔ ar-*H*5′/ar-*H*6′; ^{13}C NMR (125 MHz, *DMSO*-d_6): δ = 190.6 (C9), 165.5 (C3), 164.8 (C1), 161.7 (C8), 160.8 (C=N), 150.3 (C3a′), 145.0 (C4a), 143.3 (C10a), 141.3 (C7a′), 131.9 (C6), 126.3 (C5′), 125.2 (C6′), 120.2 (C4′), 117.2 (C5 and C8a), 112.8 (C7), 111.1 (C7′), 108.7 (C9a), 107.5 (C4), 101.1 (C2), 32.44 (C10) ppm; HSQC (*DMSO*-d_6): ar-*H*2 ↔ *C*2, ar-*H*4 ↔ *C*4, ar-*H*5 ↔ *C*5, ar-*H*7 ↔ *C*7, 10-CH_2- ↔ 10-*C*H_2-, ar-*H*4′ ↔ *C*4′, ar-*H*5′ ↔ *C*5′, ar-*H*6′ ↔ *C*6′, ar-*H*7′ ↔ *C*7′; HMBC (*DMSO*-d_6): *C*1 → 1-O*H* and ar-*H*2, *C*2 → 1-O*H* and ar-*H*4, *C*3 → 3-O*H*, ar-*H*2, ar-*H*4, and 10-CH_2-, *C*4 → ar-*H*2 and 10-CH_2-, *C*5 → ar-*H*7 and 10-CH_2-, *C*6 → 8-O*H* and 10-CH_2-, *C*7 → ar-*H*5 and 8-O*H*, *C*8 → 8-O*H* and ar-*H*7, *C*10 → ar-*H*4 and ar-*H*5, C4a → ar-*H*4, ar-*H*5 and 10-CH_2-, *C*8a → ar-*H*5, ar-*H*7, 8-O*H*, and 10-CH_2-, *C*9a → ar-*H*2, ar-*H*4, 1-O*H*, and 10-CH_2-, *C*10a → ar-*H*5, ar-*H*7, and 10-CH_2-, 6-*C*=N → ar-*H*5, ar-*H*7, and 10-CH_2-, *C*3a′ → ar-*H*4′, ar-*H*5′, ar-*H*6′, and ar-*H*7′, *C*4′ → ar-*H*5′, ar-*H*6′, and ar-*H*7′, *C*5′ → ar-*H*4′, ar-*H*6′, and ar-*H*7′, *C*6′ → ar-*H*4′, ar-*H*5′, and ar-*H*7′, *C*7′ → ar-*H*4′, ar-*H*5′, and ar-*H*6′, *C*7a′ → ar-*H*4′, ar-*H*5′, ar-*H*6′, and ar-*H*7′; ESI-MS (CH_3OH:*DMSO* = 4:1 + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): m/z = 358 ([M–H]$^-$); IR (KBr): $\bar{\nu}$ = 3087, 3027, 2925, 1644, 1623, 1600, 1560, 1541, 1490, 1456, 1421, 1421, 1383, 1361, 1329, 1288, 1245, 1210, 1167, 1056, 967, 921, 896, 887, 795, 759, 741, 670, 650 cm^{-1}; UV-Vis ($CH_3COOC_2H_5$, $c = 1.04 \cdot 10^{-5}$ $mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon)$ = 272 (9036), 311 (12614), 333 (13185), 373 (17996) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (acetone, $c = 1.04 \cdot 10^{-5}$ $mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon)$ = 327 (16874), 386 (12070) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$).

10,13-Bis-(1,3-benzothiazol-2-yl)-1,3,4,6,8,15-hexahydroxydibenzo[ao]perylene-7,16-dione (**11**, $C_{42}H_{20}N_2O_8S_2$)

A mixture of 199 mg (0.530 mmol) **9**, 9.4 mg (0.034 mmol) $FeSO_4 \cdot 7H_2O$, and 274 mg (2.881 mmol) pyridine-*N*-oxide in 2.88 cm^3 dry pyridine and 260 mm^3 dry piperidine was stirred under Ar with protection from light at 115°C for 1 h. After cooling to room temperature the reaction mixture was poured into 8 cm^3 2 *M* HCl and stirred for 30 min at room temperature in the dark. After centrifugation the residue was washed with 3% HCl (3×), distilled H_2O (3×), and dried under vacuum over P_2O_5 to yield 175 mg (89%) **11** as a black solid. mp > 350°C; ESI-MS (CH_3OH + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): m/z = 743 ([M–H]$^-$); IR (KBr): $\bar{\nu}$ = 3448, 3062, 2943, 1616, 1586, 1508, 1473, 1425, 1348, 1314, 1273, 1187, 1107, 1038, 931, 849, 759, 728 cm^{-1}; UV-Vis (acetone): λ_{max}(rel. int.) = 328 (100), 395 (56), 570 (34), 612 (28) nm.

10,13-Bis-(1,3-benzoxazol-2-yl)-1,3,4,6,8,15-hexahydroxydibenzo[ao]perylene-7,16-dione (**12**, $C_{42}H_{20}N_2O_{10}$)

A mixture of 138 mg (0.384 mmol) **10**, 5.3 mg (0.019 mmol) $FeSO_4 \cdot 7H_2O$, and 200.9 mg (2.113 mmol) pyridine-*N*-oxide in 3 cm^3 dry pyridine and 273 mm^3 dry piperidine was stirred under Ar with protection from light at 115°C for 1 h. After cooling to room temperature the reaction mixture was poured into 6 cm^3 2 *M* HCl and stirred for 30 min at room temperature in the dark. After centrifugation the residue was washed with 3% HCl (3×), distilled H_2O (3×), and dried under vacuum over P_2O_5 to yield 124.8 mg (91%) **12** as a black solid. mp > 350°C; ESI-MS (CH_3OH + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): m/z = 711 ([M–H]$^-$); IR (KBr): $\bar{\nu}$ = 3423, 3065, 2951, 1630, 1595, 1556, 1486, 1452, 1424, 1374, 1273, 1211, 1107, 1003, 924, 845, 747, 680 cm^{-1}; UV-Vis (acetone): λ_{max}(rel. int.) = 328 (100), 389 (58), 583 (41), 617 (43) nm.

10,11-Bis-(1,3-benzothiazol-2-yl)-1,3,4,6,8,13-hexahydroxy-phenanthro[1,10,9,8-opqra]perylene-7,14-dione (**13**, $C_{42}H_{18}N_2O_8S_2$)

A solution of 170 mg (0.228 mmol) **11** in 3500 cm^3 acetone was irradiated for 30 min by means of a 700 W Hg high pressure lamp with fluorescence screen (Philips) under stirring and air admission. After evaporation of the solvent the resulting solid was chromatographed with *THF*:petrol ether:CH_3OH (7:1:1) to yield 92.4 mg **13** (55%) as a dark green solid. mp > 350°C; TLC: $R_f = 0.78$ (*THF*:CH_3OH:petrol ether = 7:1:1), $R_f = 0.15$ ($CHCl_3$:CH_3OH = 9:1); ESI-MS (CH_3OH:*DMSO* = 3:1 + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): $m/z = 741$ ($[M–H]^-$); ESI-MS (CH_3OH + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): $m/z = 741$ ($[M–H]^-$); ESI-MS (ethanol:buffer ($pH = 10.0$) = 4:1, $\gamma \sim 0.1\ mg \cdot cm^{-3}$, negative ion mode): $m/z = 741$ ($[M–H]^-$); IR (KBr): $\bar{\nu} = 3420$, 2956, 2925, 2857, 1719, 1583, 1551, 1507, 1459, 1432, 1282, 1259, 1191, 1164, 1117, 1026, 974, 849, 759, 726, 669 cm^{-1}; UV-Vis (acetone, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 335$ (15973), 499 (2778), 530 (2836), 570 (9679), 618 (19347) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (acetonitrile, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 274$ (31105), 330 (16908), 496 (2356), 528 (2127), 569 (8139), 615 (16809) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*DMF*, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 503$ (2603), 527 (2167), 573 (6563), 620 (14144) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*DMSO*, $c = 1.29 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 331$ (19229), 500 (2841), 534 (2661), 574 (8724), 621 (17737) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethanol, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 274$ (28283), 332 (15189), 493 (2543), 527 (2120), 567 (8459), 612 (17515) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethanol:$H_2O$ = 4:1, $c = 2.09 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 270$ (20580), 331 (14345), 491 (2603), 527 (2368), 566 (7469), 611 (14192) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethyl acetate, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 275$ (28286), 298 (18674), 332 (15357), 496 (2569), 529 (2301), 568 (8752), 615 (17731) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (methanol, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 219$ (45970), 270 (26136), 330 (16309), 491 (2417), 564 (9028), 610 (17636) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (pyridine, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 338$ (15224), 502 (2883), 534 (2310), 577 (8434), 624 (17573) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*THF*, $c = 1.07 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 335$ (14589), 502 (3005), 533 (2627), 575 (9176), 623 (19002) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); fluorescence (acetone, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 632 (100), 675 (32) nm, $\Phi_f = 0.02$; fluorescence (acetonitrile, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 629 (100), 678 (34) nm; fluorescence (*DMF*, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 601 (30), 634 (100), 681 (41) nm; fluorescence (*DMSO*, $c = 1.03 \cdot 10^{-6}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 602 (28), 635 (100), 685 (44) nm; fluorescence (ethanol, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 627 (100), 673 (31) nm, $\Phi_f = 0.03$; fluorescence (ethyl acetate, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 631 (100), 679 (29) nm; fluorescence (methanol, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 625 (100), 670 (34) nm; fluorescence (pyridine, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 638 (100), 687 (30) nm; fluorescence (*THF*, $c = 8.59 \cdot 10^{-7}\ mol \cdot dm^{-3}$, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 634 (100), 682 (26) nm.

10,11-Bis-(1,3-benzoxazol-2-yl)-1,3,4,6,8,13-hexahydroxy-phenanthro[1,10,9,8-opqra]perylene-7,14-dione (**14**, $C_{42}H_{18}N_2O_{10}$)

A solution of 118.9 mg (0.167 mmol) **12** in 3500 cm^3 acetone was irradiated for 60 min by means of a 700 W Hg high pressure lamp with fluorescence screen (Philips) under stirring and air admission. After evaporation of the solvent the resulting solid was chromatographed with $CHCl_3$:CH_3OH (2:1) to yield 86.3 mg **14** (73%) as a dark green solid. mp > 350°C; TLC: $R_f = 0.83$ (*THF*:CH_3OH:petrol ether = 7:1:1), $R_f = 0.79$ ($CHCl_3$:CH_3OH = 2:1); ESI-MS (CH_3OH + 1% NH_3, $\gamma \sim 1\ mg \cdot cm^{-3}$, negative ion mode): $m/z = 709$ ($[M–H]^-$); ESI-MS (ethanol:buffer ($pH = 10.0$) = 4:1, $\gamma \sim 0.1\ mg \cdot cm^{-3}$, negative ion mode): $m/z = 709$ ($[M–H]^-$); IR (KBr): $\bar{\nu} = 3422$, 2926, 2854, 1589, 1454, 1429, 1385, 1274, 1235, 1183, 1121, 1023, 967, 835, 801, 762, 748 cm^{-1}; UV-Vis (acetone, $c = 1.10 \cdot 10^{-5}\ mol \cdot dm^{-3}$): $\lambda_{max}(\varepsilon) = 327$ (18511), 495 (6363), 525 (5738), 566 (9715), 612 (15804) nm

($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (acetonitrile, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 265$ (24064), 332 (17231), 492 (5489), 523 (4643), 564 (8900), 610 (15642) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*DMF*, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 272$ (23481), 333 (15413), 495 (5226), 569 (7625), 616 (13685) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*DMSO*, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 266$ (29843), 333 (19492), 494 (6293), 569 (8832), 616 (15437) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethanol, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 263$ (24681), 330 (17723), 490 (5647), 522 (4638), 562 (9253), 608 (16714) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethanol:$H_2O$ = 4:1, $c = 1.40 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 262$ (21611), 328 (13429), 492 (1246), 522 (866), 563 (5755), 608 (13028) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (ethyl acetate, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 264$ (19000), 297 (16319), 334 (15121), 495 (5439), 521 (4925), 564 (8264), 610 (13602) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (methanol, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 213$ (31403), 270 (29279), 330 (18928), 487 (7335), 519 (6190), 560 (10507), 605 (17277) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (pyridine, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 337$ (18013), 498 (5914), 529 (4702), 572 (9251), 619 (17097) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); UV-Vis (*THF*, $c = 1.10 \cdot 10^{-5}$ mol·dm^{-3}): $\lambda_{max}(\varepsilon) = 334$ (15648), 466 (4787), 499 (5067), 527 (4169), 570 (8277), 617 (15232) nm ($dm^3 \cdot mol^{-1} \cdot cm^{-1}$); fluorescence (acetone, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 624 (100), 667 (34) nm, $\Phi_f = 0.01$; fluorescence (acetonitrile, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 623 (100), 668 (40) nm; fluorescence (*DMF*, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 628 (100), 673 (39) nm; fluorescence (*DMSO*, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 629 (100), 678 (47) nm; fluorescence (ethanol, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 620 (100), 664 (33) nm, $\Phi_f = 0.02$; fluorescence (ethyl acetate, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 621 (100), 667 (33) nm; fluorescence (methanol, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 619 (100), 661 (41) nm; fluorescence (pyridine, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 630 (100), 679 (32) nm; fluorescence (*THF*, $c = 8.82 \cdot 10^{-7}$ mol·dm^{-3}, $\lambda_{ex} = 550$ nm): λ_{em}(rel. int.) = 627 (100), 674 (29) nm.

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