Convenient and Multistep Preparation of Oligopyridines Bearing Multiple Dansyl and Nitroxide Radicals

Raymond Ziessel,* Christophe Stroh

Laboratoire de Chimie Moléculaire, Associé au CNRS, Ecole de Chimie, Polymères Matériaux de Strasbourg (ECPM), 25 rue Becquerel, 67087 Strasbourg, Cedex 02, France
Fax +33(3)90242689; E-mail: ziessel@chimie.u-strasbg.fr
Received 26 May 2003; revised 2 July 2003

Abstract: A series of pyridine and bipyridine molecules combining dual fluorescent (dansyl) and magnetic (free radical) probes has been prepared by a linear multistep protocol from the corresponding monodansylated derivatives. The grafting of the flexible aliphatic radical is realized by the use of a chloromethylnitronyl nitroxide derivative under basic conditions and with KI as a mediator. The synthetic potential of 2-[(5-dimethylamino-1-naphthalenesulfonamide)methyl]-6-formylpyridine is assessed by the construction, in a first step, of an aliphatic nitroxide radical and subsequently of an additional aromatic radical. The synthetic methods reported herein provide a practical approach to the rational design of ligands bearing various kinds of functionalities such as chromogenic and spin-labeled fragments. A significant merit of this method is that it allows the introduction of the fluorescent substituent onto the pyridine or bipyridine framework at the beginning of the synthetic protocol.

Key words: pyridine, bipyridine, dansyl, nitroxide radicals, absorption spectrum

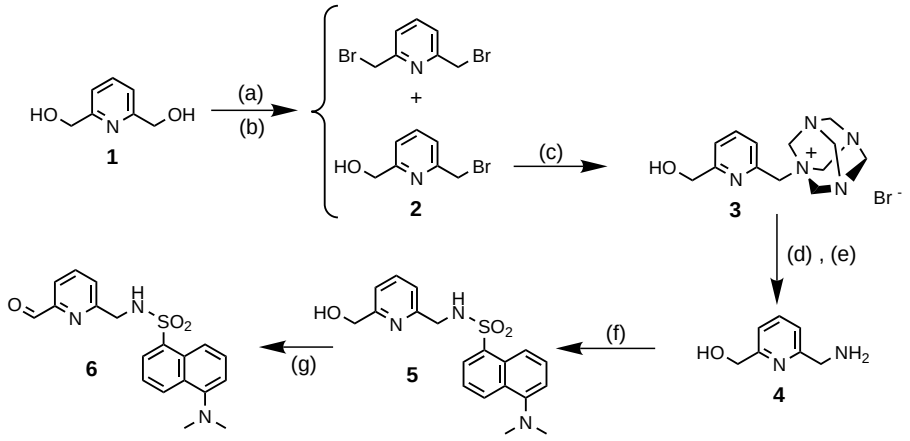
The engineering of molecules bearing chelating centers, fluorescent and paramagnetic probes offers a wealth of possibilities for the construction of sophisticated scaffoldings with predesigned optical and magnetic properties.[1] The realization of this potential required a detailed understanding of the chemistry and also of the intrinsic features of the individual building blocks to allow prediction and design of novel systems.[2] To gain insight into the development of new class of material and to integrate them in new devices such as chemiosensors we have to embrace different measurement techniques including UV-visible absorption, EPR, photoluminescence, measurement of the excited states of lifetime in a time resolved mode in dilute solution and/or in solid-state films. The objectives to this research program is to synthesize and characterize a novel series of spin-labeled molecules bearing a singlet reporter (dansyl fragment) and an electron-donor (radical moieties) in order to tune the luminescence characteristics in the presence of adventitious cations or other substrates.[3] The investigation of their spectroscopic, electrochemical, photophysical, structure-property relationship and optimization will be performed in a second step.

Dansyl moieties have been successfully employed as fluorogenic probes in several cases which include N-protected α-amino acids,[4] nitroxides,[5] aminotroponimiate rings,[6] tripodal complexants,[7] a variety of macrocyclic platforms such as calix[4]arenes,[8] α-cyclodextrin,[9] 1,4,7,10-tetraazacyclododecane,[10] and poly(propyleneamine) dendrimers.[11] Dansyl fragments are also very popular as auxiliaries for fluorescence switch in optical sensors.[12]

Interest in nitroxide free radicals stems in part from their use as spin-labeled probes[13] but also as paramagnetic building blocks for the assemblage of multidimensional arrays, some of them exhibit very interesting cooperative magnetic properties.[14,15] Nevertheless, in comparison with these separated field of research, the synthesis of hybrid derivatives bearing dual dansyl and free radicals is less extensive than one might expect. This shortcoming is due largely to difficulties in synthesizing the prerequisite starting materials. A notable advance was previously reported by Hideg and co-workers, who have shown that the dansylation of aniline substituted nitroxide radicals is feasible.[16] Depending on the structure of the molecule, modulation of the fluorescence of the dansyl reporter is effective depending on the nature of the radical species [nitronyl-nitroxide (NIT) versus an imino-nitroxide (IM)].[16]

Since few years we have been interested in the synthesis and properties of nitroxide radicals containing chelating centers.[17] For this purpose we have developed a synthetic strategy based on the construction of molecules bearing aldehyde as well as reactive halide functions in order to involve them in palladium/copper-promoted cross coupling reactions with terminal alkynes reagents.[18] As we were particularly interested in the behavior of these scaffolds in magneto-optical properties, we decided to investigate the synthesis of novel molecules bearing a stable and very efficient organic fluorophore. As a model reaction we first studied the conversion of 2-aminomethyl-6-hydroxymethylpyridine (**4**) into the corresponding N-substituted dansylated derivative **5** as sketched in Scheme 1. After some experimentation it became evident that this reaction is regioselective affording the selective alkylation of the amino fragment in 75%. The synthetic route to this interesting derivative **5** employs straightforward reactions that are easily accomplished on a large scale. The preparation of the starting material **4**[19] was realized in three steps from the commercially available 2,6-bis(hydroxymethyl)pyridine (**1**) as shown in Scheme 1.

SYNTHESIS 2003, No. 14, pp 2145–2154
Advanced online publication: 24.09.2003
DOI: 10.1055/s-2003-42083; Art ID: Z06903SS.pdf



Scheme 1 (a) HBr (37%), reflux; (b) aq NaOH 40%; (c) hexamethylenetetramine, CH_2Cl_2, reflux; (d) HCl (36%), EtOH, reflux; (e) 2 N aq NaOH; (f) DANS–Cl (1 equiv), MeCN, Et_3N, r.t.; (g) MnO_2, CH_2Cl_2, r.t.

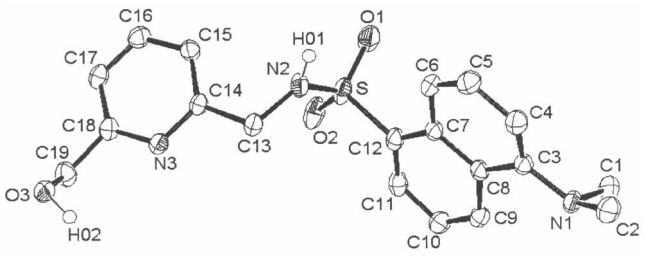


Figure 1 ORTEP view of compound **5**.

The dansylated alcohol **5** crystallizes in the P-1 space group and an ORTEP view is given in Figure 1. The bond distances around the pyridine ring are in conformity keeping with related X-ray molecular structures. It is of interest to note that the sulfonamide fragment is located in an *anti* position versus the pyridine ring (N3–C14–C13–N2 torsion angle = 171.0°). Furthermore, the hydroxymethyl fragment adopt an eclipsed conformation versus one of the hydrogen atom of the methylene bridge (N3–C18–C19–O3 torsion angle = 67.8°). This interesting arrangement of the atoms is auspicious for intermolecular hydrogen bonding in the solid state (vide infra). Additionally, the nitrogen atom of the sulfonamide fragment is almost planar, as evidenced by the fact that the sum of the angles provided by all the substituents is 359.2°. Furthermore, the plane formed by these fragments is quasi orthogonal to the plane formed by the pyridine cycle (H01–N2–C13–C14 torsion angle = 91.2°). As expected one of the sp^3 sulfur–oxygen bond lies in a *trans* position versus the pyridine CN bond (C13–N2–S–O1 torsion angle = 162.4°). Finally, it is of interest to note that the naphthyl group deviates slightly from the mean plane formed by the tertiary amine (tilt angle ca. 110°). Close examination of the packing of these molecules in the solid state reveal two interesting features. The packing is essentially governed by a hydrogen bonding network as well as by π-π stacking of the naphthyl rings as shown in Figure 2. The shortest hydrogen bond is observed between the hydrogen of the alcohol of one molecule and the sulfonamide group of a neighboring molecule (O3–H01 distance ca. 1.86 Å). Two

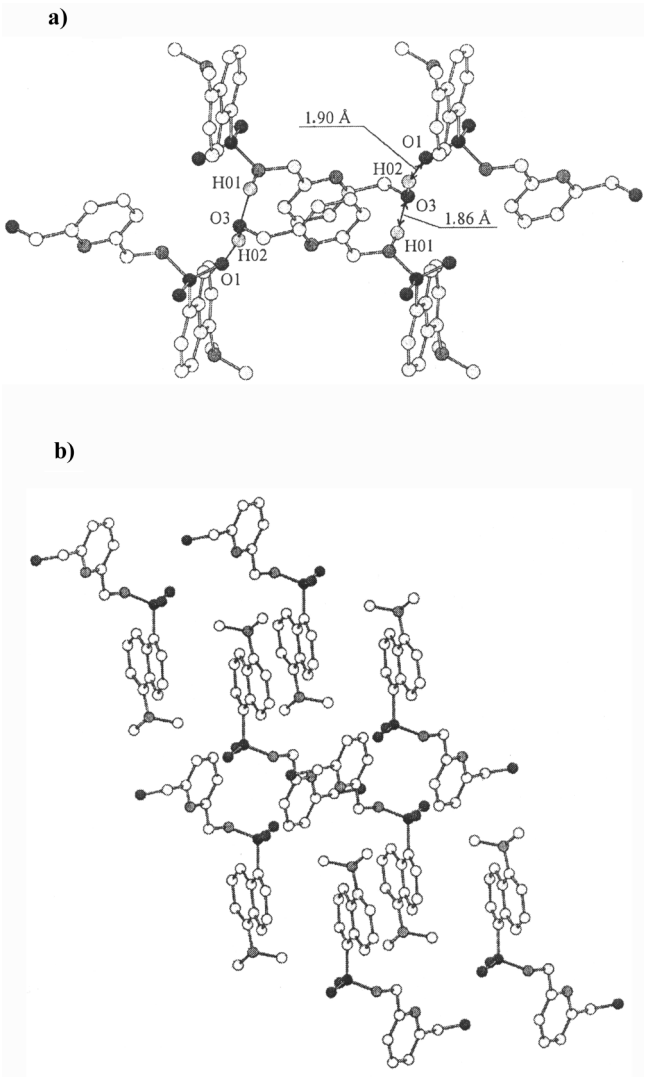
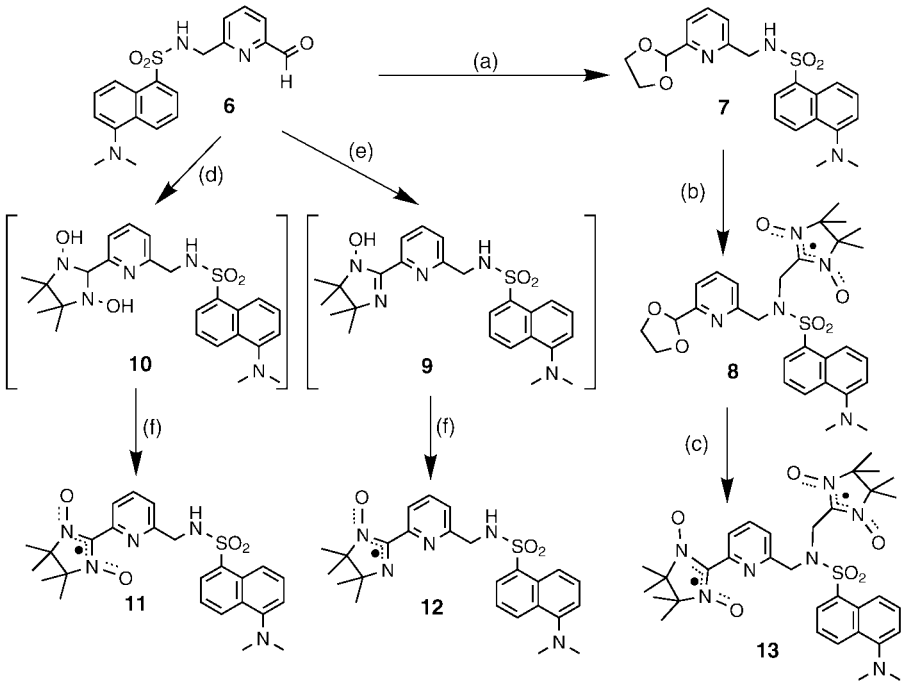


Figure 2 a) Intermolecular hydrogen bonding between molecules of **5**: shortest distances 1.86 and 1.96 Å; b) π-π stacking interaction between neighboring molecules of **5**, shortest distances 3.52 Å.

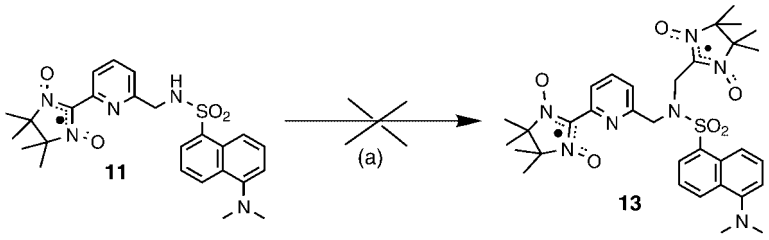
types of hydrogen bonds are evidenced by the X-ray molecular structure determination. Two molecules of **5** are arranged in a head-to tail fashion to form a dimer (Figure 2a), in which a second hydrogen bond is observed between the oxygen atom of the sulfonamide function and the hydrogen atom of the primary alcohol (O1–H02 distance ca. 1.90 Å) forming an infinite chain of dimeric units. Finally, a second type of stabilizing interaction is due to a favorable π–π overlapping (average distance ca. 3.52 Å) between two neighboring naphthyl subunits (Figure 2b).

Additional studies on the chemical reactivity of compound **5** shows that the primary alcohol is readily oxidized under mild conditions with MnO_2 to the corresponding formyl compound **6** in 75% (Scheme 1). This molecule is of special interest because it has the potential for the construction of two different kind of spin carries such as, one radical on the formyl site (aromatic nitroxide) and a second radical on the sulfonamide site (aliphatic nitroxide). In the first case, condensation of **6** with 2,3-bis(hydroxyamino)-2,3-dimethylbutane afforded the intermediate dihydroxyimidazolidine **10** which by phase-transfer oxidation with aqueous sodium periodate gave the deep blue radical **11** in fair yield (Scheme 2). The presence of trace amounts of SeO_2[20] during the condensation step allowed the intermediate formation of the monohydroxyimidazolidine **9** which similarly provided after phase-transfer oxidation the expected orange monoradical **12** in good yield. Direct alkylation of the remaining sulfonamide function with chloromethylnitronyl nitroxide failed providing intractable mixture of compounds (Scheme 3). This is probably due to electron-transfer processes between the electron rich aliphatic radical and the more electron demanding aromatic radical. A nice solution came out, when we discovered that protection of the aldehyde function with an oxolane leading to compound **7** allowed the smooth alkylation of the sulfonamide to provide the desired derivative **8**. This reaction required the presence of catalytic amounts of KI favoring the in situ exchange of the halide and the presence of a base, which quenched the nascent acid (Scheme 2). During this reaction, we found only traces of the alkylation of the pyridine fragment leading, as expected, to polar derivatives. It is worth pointing out that a single step was required to synthesize the target bisradical **13**. The use of the sulfate salt of 2,3-bis(hydroxyamino)-2,3-dimethylbutane favors the in situ deprotection of the aldehyde and the in situ condensation to the intermediate five-membered ring. Such a simultaneous and one-pot deprotection of the aldehyde and condensation step has been previously exploited with instable aldehydes.[21] Phase-transfer oxidation is straightforward and produced the bisradical **13** in acceptable yield (Scheme 2).

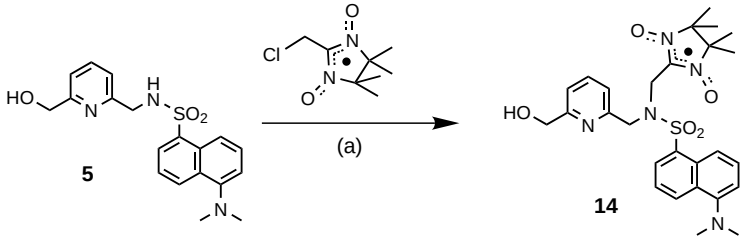
In order to check the generality of the regioselective alkylation reaction with chloromethylnitronyl nitroxide, we attempted the reaction with derivative **5**. It was soon established that, with KI the reaction is completely regiospecific and no pyridine or NMe_2 alkylation was observed (Scheme 4). This is probably due to the relatively low pK value of the sulfonamide and the mild experimental conditions.[22] However, the yield is significantly lower compared to the alkylation of derivative **7**. In this case the O-alkylation of the benzylic function could not be excluded, despite the fact that the ether derivative could



Scheme 2 (a) $HOCH_2CH_2OH$, *p*-TsOH, benzene; (b) chloromethylnitronyl nitroxide, K_2CO_3, KI (10 mol%), MeCN, 60 °C; (c) 2,3-bis(hydroxyamino)-2,3-dimethylbutane sulfate salt, MeOH, r.t.; (d) 2,3-bis(hydroxyamino)-2,3-dimethylbutane, MeOH, r.t.; (e) 2,3-bis(hydroxyamino)-2,3-dimethylbutane, SeO_2, r.t., MeOH; (f) $NaIO_4$, CH_2Cl_2, H_2O, r.t.



Scheme 3 (a) chloromethylnitronyl nitroxide (1 equiv), K_2CO_3, KI (10 mol%), MeCN, 30–60 °C

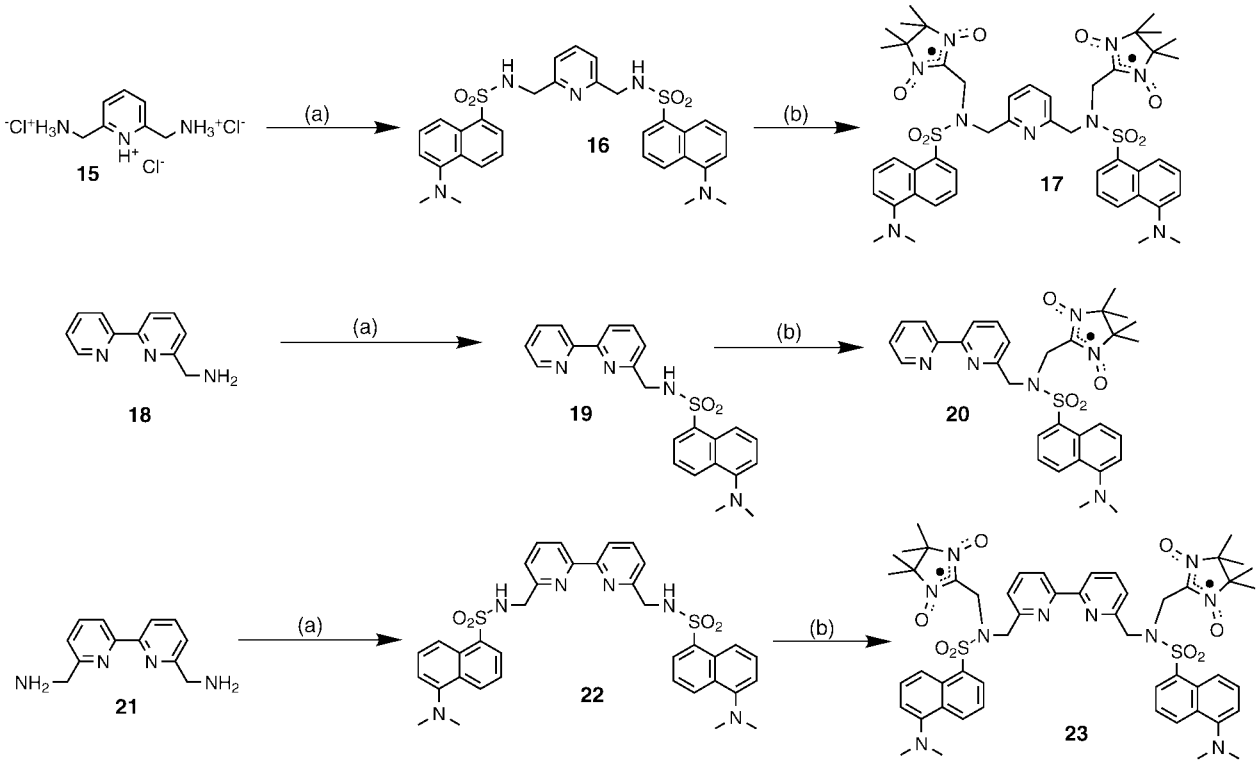


Scheme 4 (a) chloromethylnitronyl nitroxide (1 equiv), K_2CO_3, KI (10 mol%), MeCN, 60 °C

not be properly isolated possibly due to its inherent instability.

As the former functionalization of compounds **5** and **7** gave satisfactory results, we were encouraged to extend this reaction to additional mono- or didansylated pyridine or bipyridine frameworks (Scheme 5). Here the highly luminescent molecules **16**, **19** and **22** were prepared in excellent yield from the corresponding mono- and diaminomethyl derivatives under similar conditions previously formulated for the preparation of compound **5**. The selective alkylation of the sulfonamide is effective and the prior difficulties are circumvented by the absence of the benzylic alcohol function. The dialkylation of derivatives **16** and **22** is driven by the stoichiometry of starting reagents.

Preliminary studies on the chemical stability, of these molecules in dilute solution, is provided by EPR studies (Figure 4). As a matter of fact such studies have been only



Scheme 5 (a) DANS-Cl (2 equiv) for **15** and **21** and (1 equiv) with **18**, MeCN, Et_3N, r.t.; (b) chloromethylnitronyl nitroxide (2 equiv) for **16** and **22** and (1 equiv) with **19**, K_2CO_3, KI (10 mol%), MeCN, 60 °C

scarcely performed.[23] We checked by EPR that the thermal stability of monoradicals **11** and **12** is excellent in polar and apolar solvents at 10^{-5} M. No loss of the signal intensity and the shape of the spectra were found when dilute solutions were allowed to stand in the dark or in sunlight over 60 hours. The stability of these hybrid molecules is as good as the one found for classical nitroxide radicals previously prepared in our laboratory (Figure 3).

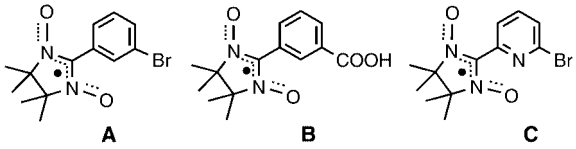


Figure 3 Structures of some known classical nitroxide radicals **A**–**C**.

However, the steady state irradiation with more powerful light sources (e.g. 100 W, Olympus Xe lamp without cut-off filter) shows major modification of the EPR spectrum over irradiation time. The typical five lines spectrum characteristic of the nitronyl nitroxide radical **11** (g = 2.0066) is progressively transformed into a seven line spectrum characteristic of an imino nitroxide radical (Figure 4a). It is surmised that during the irradiation selective deoxygenation of the radical **11** to the radical **12** is achieved. It is interesting to note that at the early stage of the photolysis process a transient species is observed. In order to check that this species is due to the presence of the pendent dansyl fragment or pyridine ring, the photolysis of derivatives **A**, **B**, **C** (Figure 3) was undertaken in different solvents (Figure 4b). During the photolysis of compounds **A** and **B** no transient species was observed in three different solvents. However, it appears clearly that a very similar intermediate species is present during photolysis of the pyridine based derivative **C**.

This observation excludes a major contribution of the dansyl fragment but strengthened the fact that the pyridine moiety plays a major role during the photochemical event. In this case also it appears that the photoconversion of the nitronyl nitroxide to the imino nitroxide species is very effective and does not depend on the nature and polarity of the solvent. At the present stage of our investigations the nature of this transient species is not known but might result from the stabilization (or trapping) of a very reactive radical by the pyridine ring possibly in the form of a pyridine *N*-oxide radical. Photolysis experiments at cryogenic temperature would provide some useful information about the chemical nature of this very reactive intermediate. Previous studies on the direct and photosensitized photochemistry of stable free radicals in aprotic solvent have revealed similar deoxygenation processes but involving the reactivity of the aliphatic side chain.[24,25]

Figure 5 illustrates the absorption spectra of dansylated pyridine and bipyridine ligands and their nitronyl nitroxide counterparts. Comparison with the spectra of the individual fragments allows assignment of the various

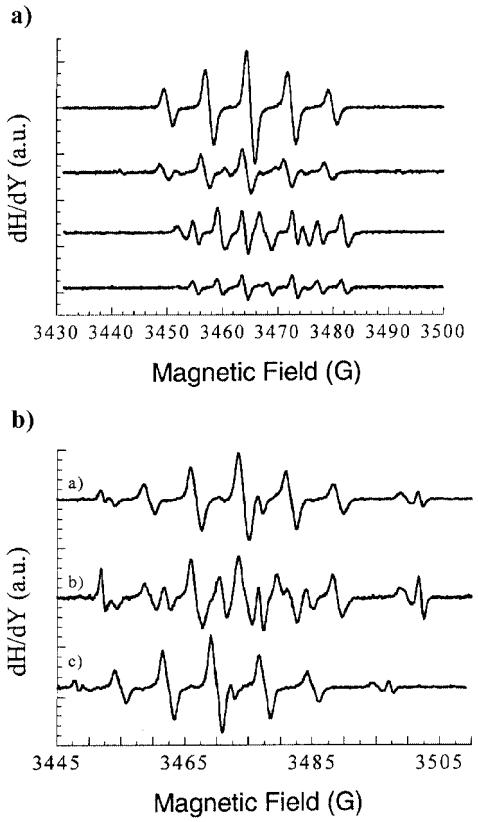


Figure 4 a) Evolution of the EPR spectrum of derivative **11** as a function of irradiation time, in CH_2Cl_2 at 10^{-5} M. Top trace: before irradiation, and successive irradiation of 10 min slots. Bottom trace: after 30 min irradiation. b) Irradiation of compound C at 10^{-5} M for 15 min a) in CH_2Cl_2; b) acetone; c) MeOH.

absorption bands to transitions localized on the ancillary pyridine or bipyridine π-π^* transitions in the UV at approximately 250 to 280 nm,[26] to the dansyl singlet state transitions in the near UV around 340 nm[27] and $n\rightarrow\pi^*$ transition of the nitroxide radical around 550 nm (Figure 5b).[28,29] As expected the latter transition is absent in the spectrum of related diamagnetic species (Figure 5a). Finally, it appears that no significant modification of the absorption spectrum of the diamagnetic and paramagnetic derivatives was observed in dilute solution when the samples are stored in the absence of direct light over at least two days.

Taken as a whole, the results presented here provide a rational approach for the synthesis of hybrid molecules bearing dansyl and free radical subunits. All reactions are effective under mild and well controlled reaction conditions and cleanly gives the desired molecules. Symmetrically substituted ligands were prepared in two steps from the corresponding aminomethyl starting materials. Asymmetrically substituted pyridines were synthesized in three and five steps from the hydroxymethyl compound leading respectively to molecules with one and two free radicals. This finding expands the synthetic scope of dansylated molecules carrying free radicals and makes readily accessible a class of previously rare ligands. The

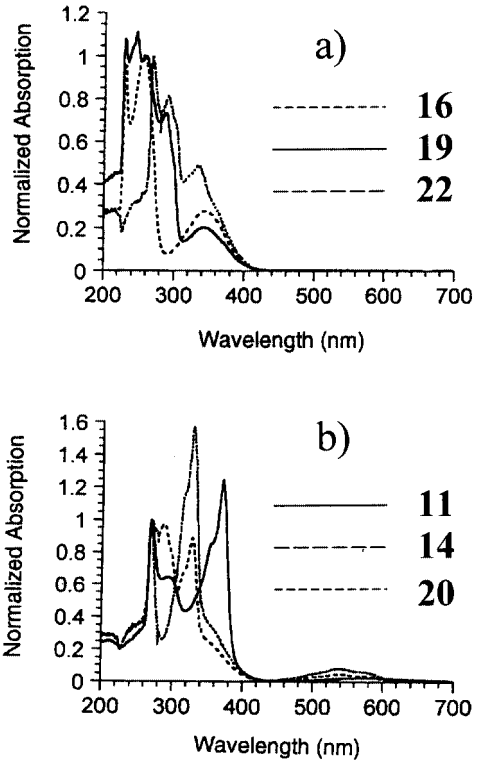


Figure 5 a) Normalized absorption spectrum in CH_2Cl_2 solution of a series of mono- and didansylated compounds; b) normalized absorption spectrum in CH_2Cl_2 solution of a series of radicals bearing a single dansyl fragment.

demonstrated ability of these molecules to be robust in dilute solutions and in the solid state augurs well for immediate and long term advances in the field of sensors.

The 200.1 (^{1}H) and 50.3 MHz (^{13}C) NMR spectra were recorded at r.t. on a Bruker AC 200 spectrometer in $CDCl_3$ Residual $CHCl_3$ in $CDCl_3$ (δ_H = 7.26 and δ_C = 77.3) were used as internal standards. In order to avoid acidic traces, the deuterated solvent was passed through a cartouche of basic alumina. FT-IR spectra were recorded as KBr pellets on a Nicolet 210 spectrometer. High Resolution Mass Spectral Analysis (HRMS) were performed using a Mariner ESI-Tof instrument from Applied Bio-System/Perking Elmer. Fast-atom bombardement (FAB, positive mode) mass spectra were recorded with a ZAB-HF-VB-analytical apparatus in *m*-nitrobenzyl alcohol (*m*-NBA) as matrix. Chromatographic purification was conducted using 0.063–0.200 mm silica gel or aluminum oxide 90 (Merck). TLC was performed on silica gel or aluminum oxide plates (Merck) coated with fluorescent indicator. All mixtures of solvents are given in v/v ratio.

2,6-Bis(aminomethyl)pyridinium trichloride (**15**),[30] 6-aminomethyl-2,2′-bipyridine (**18**),[31] 6,6′-aminomethyl-2,2′-bipyridine (**21**),[32] chloromethylnitronyl nitroxide,[33] and 2,3-bis(hydroxyamino)-2,3-dimethylbutane[34] were prepared according to literature procedures. CH_2Cl_2 was distilled from CaH_2. Et_3N was dried over KOH prior to distillation. MeCN was filtered over aluminum oxide (Merck, Act III) and distilled over P_2O_5. Dansyl chloride, MnO_2, $NaIO_4$ were used as purchased.

2-Bromomethyl-6-hydroxymethylpyridine (2)
A mixture of 2,6-bis(hydroxymethyl)pyridine (**1**; 5 g, 35.9 mmol) and HBr (37%, 50 mL) was refluxed for 1 h. The crude yellow mixture was cooled down to 0 °C and neutralized (pH 6.9) with aq 40% NaOH. H_2O (200 mL) was added and the white precipitate was extracted with CH_2Cl_2 (5 × 100 mL). The combined organic layers were evaporated to dryness and the solid was purified by flash chromatography (silica gel) using CH_2Cl_2 as eluent to separate first the dibromo adduct (11%), followed by elution with Et_2O providing the desired product **2**; yield: 2.8 g (39%).

IR (KBr): 3213, 3054, 2975, 2840, 1593, 1568, 1456, 1348, 1218, 1201, 1148, 1090, 1064, 1000, 800, 755, 736, 636, 616, 569, 506 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 7.66 (t, 1 H, ^3J = 7.6 Hz, H-4), 7.30 (d, 1 H, ^3J = 7.6 Hz, H-3), 7.19 (d, 1 H, ^3J = 8.0 Hz, H-5), 4.72 (d, 2 H, ^3J = 4.4 Hz, CH_2O), 4.50 (s, 2 H, CH_2Br), 4.26 (br, 1 H, OH).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 159.2, 155.8, 137.8, 122.1, 119.9, 64.0 (CH_2O), 33.5 (CH_2Br).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 268 (4900), 229 nm (4300).

Anal. Calcd for C_7H_8BrNO (202.05): C, 41.61; H, 3.99; N, 6.93. Found: C, 41.45; H, 3.89; N, 6.79.

2-[(Hexamethylenetetrammonium)methyl]-6-hydroxymethylpyridine Bromide (3)
2-Bromomethyl-6-hydroxymethylpyridine (**2**; 0.5 g, 2.47 mmol) and hexamethylenetetramine (0.42 g, 2.96 mmol) in CH_2Cl_2 (20 mL) were refluxed for 4 h. The white precipitate was filtered and washed with Et_2O (3 × 50 mL) to afford 0.840 g (98%) of **3**.

IR (KBr): 3347, 2972, 2941, 2894, 1591, 1571, 1464, 1436, 1303, 1269, 1254, 1237, 1200, 1111, 1046, 1005, 991, 934, 825, 812, 785, 652, 571, 501 cm^{-1}.

2-Aminomethyl-6-hydroxymethylpyridine (4)
A mixtutre of **3** (0.796 g, 0.435 mmol), HCl (37%, 4.4 mL) and EtOH (20 mL) was heated at 100 °C. After 17 h, the clear solution was cooled down to r.t., then Et_2O (150 mL) was added and the resulting white precipitate was filtered off. The solid was dissolved in H_2O (4 mL) and the solution was basified with 6 N aq NaOH to pH 14. The product was extracted with CH_2Cl_2 (4 × 100 mL). After drying ($MgSO_4$), the solvent was evaporated to give **4**; yield: 0.307 g (97%).

IR (KBr) = 3365, 2977, 1597, 1577, 1459, 1382, 1319, 1049, 616 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 7.64 (t, 1 H, ^3J = 7.6 Hz), 7.18 (d, 1 H, ^3J = 7.6 Hz), 7.10 (d, 1 H, ^3J = 7.6 Hz), 4.74 (s, 2 H, CH_2O), 3.98 (s, 2 H, CH_2N), 2.26 (br, OH, NH_2, H_2O).

MALDI-TOF: *m/z* (%) = 139.1 ([M + H]$^+$, 100%).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 272 nm (4400).

2-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-6-hydroxymethylpyridine (5)
To a solution of **4** (0.260 g, 1.88 mmol) and dansyl chloride (0.507 g, 1.88 mmol) in anhyd

MeCN (10 mL) was added slowly anhyd Et_3N (1 mL). The yellow precipitate disappeared instantaneously, to yield a yellow-greenish solution. After stirring for 64 h at r.t., the reaction mixture was evaporated to dryness. The residual oil was dissolved in CH_2Cl_2 (50 mL) and vigourously washed with H_2O (3 × 25 mL). The organic phase was dried ($MgSO_4$) and evaporated to dryness. The remaining oil was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to afford **5** (0.526 g, 75%).

IR (KBr): 3433, 3147, 2962, 2924, 2876, 2838, 1588, 1573, 1456, 1420, 1398, 1384, 1324 (SO_2N), 1262, 1231, 1158 (SO_2N), 1140, 1121, 1092, 1047, 1017, 961, 851, 784 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.42 (d, 1 H, J = 8.4 Hz), 8.29 (d, 1 H, ^3J = 8.4 Hz), 8.19 (dd, 1 H, ^3J = 7.4 Hz, ^4J = 1.0 Hz), 7.55–7.33 (m, 3 H), 7.13 (d, 1 H, ^3J = 7.2 Hz), 6.91 (d, 1 H, ^3J = 7.6 Hz), 6.84 (d, 1 H, ^3J = 7.6 Hz), 6.25 (t, 1 H, ^3J = 5.6 Hz, NH), 4.44 (s, 2 H, CH_2OH), 4.19 (d, 2 H, ^3J = 5.2 Hz, CH_2NH), 3.41 (br, 1 H, OH), 2.84 (s, 6 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 158.9, 154.2, 152.0, 137.1, 134.7, 130.4, 129.8, 129.7, 129.6, 128.4, 123.2, 120.5, 119.2, 118.9, 115.2, 64.1, 47.8, 45.5.

FAB$^+$ (*m*-NBA): *m*/*z* (%): 372.2 ([M + H]$^+$, 100), 123.2 ([M – DANS + H], 20).

UV-Vis (CH_2Cl_2): λ, (ε, $M^{-1}cm^{-1}$) = 270 (5900), 343 nm (3100).

Anal. Calcd for $C_{19}H_{21}N_3O_3S$ (371.46): C, 61.44; H, 5.70; N, 11.31. Found: C, 61.21; H, 5.51; N, 11.01.

2-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-6-formylpyridine (6)

To a solution of **5** (0.297 g, 0.80 mmol) in CH_2Cl_2 (50 mL) was added MnO_2 (2.12 g, 30 equiv). The suspension was stirred for 45 h. After filtration over Celite, the solvent was evaporated and the product was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to give the desired product **6** (0.209 g); yield: 71%.

IR (KBr): 3256, 1697 (C=O), 1588, 1445, 1339, 1320 (SO_2N), 1162 (SO_2N), 1146, 1091, 1069, 856, 789 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 9.57 (s, 1 H, CHO), 8.34 (t, 2 H, ^3J = 8.4 Hz), 8.18 (d, 1 H, ^3J = 7.2 Hz), 7.58–7.50 (m, 3 H), 7.39 (t, 1 H, ^3J = 7.8 Hz), 7.13–7.08 (m, 2 H), 6.13 (t, 1 H, ^3J = 5.4 Hz, NH), 4.32 (d, 2 H, ^3J = 6.0 Hz, CH_2), 2.82 (s, 6 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 192.6, 155.6, 152.0, 151.6, 137.2, 134.6, 130.5, 129.7, 129.6, 128.4, 125.7, 123.1, 120.0, 119.0, 115.5, 47.6, 45.4.

FAB$^+$ (*m*-NBA): *m*/*z* (%): 370.5 ([M + H]$^+$, 100), 121.5 ([M – DANS], 30).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 269 (3100), 345 nm (1200).

Anal. Calcd for $C_{19}H_{19}N_3O_3S$ (369.44): C, 61.77, H, 5.18, N, 11.37. Found: C, 61.41, H, 4.78, N, 10.91.

2-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-6-(1,3-dioxolan-2-yl)pyridine (7)

A mixture of **6** (0.200 g, 0.540 mmol), ethylene glycol (5 mL) and *p*-toluenesulfonic acid (0.005 g) in benzene (20 mL) was refluxed in a Dean–Stark apparatus overnight. The solvent was evaporated under vacuum and brine was added, and the aqueous phase was extracted with CH_2Cl_2 (5 × 50 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed under vacuum. The protected aldehyde was purified by chromatography (silica gel, flash chromatography, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to give **7**; yield: 0.213 g (95%).

IR (KBr): 3256, 3000, 2880, 1590, 1450, 1336, 1322 (SO_2N), 1165 (SO_2N), 1146, 1075, 865 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.3 (t, 2 H, ^3J = 8.3 Hz), 8.22 (d, 1 H, ^3J = 7.1 Hz), 7.58–7.52 (m, 3 H), 7.40 (t, 1 H, ^3J = 7.8 Hz), 7.15–7.10 (m, 2 H), 6.15 (t, 1 H, ^3J = 5.3 Hz, NH), 5.76 (s, 1 H, OCHO), 4.32 (d, 2 H, ^3J = 6.0 Hz, CH_2), 3.99 (s, 4 H, OCH_2CH_2O, 4 H), 2.82 (s, 6 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 158.6, 154.0, 152.4, 138.5, 133.9, 131.5, 130.5, 130.2, 129.3, 124.7, 123.5, 121.4, 120.2, 116.3, 113.9, 73.8, 47.4, 46.7.

FAB$^+$ (*m*-NBA): *m*/*z* (%): 414.1 ([M + H]$^+$, 100), 167.3 ([M – DANS + H]$^+$, 30).

UV-Vis (CH_2Cl_2), λ, (ε, $M^{-1}cm^{-1}$) = 270 (3500), 347 nm (1500).

Anal. Calcd for $C_{21}H_{23}N_3O_4S$ (413.49): C, 61.00; H, 5.61; N, 10.16. Found: C, 60.79; H, 5.43; N, 9.93.

2-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}-6-(1,3-dioxolan-2-yl)pyridine (8)

A mixture of **7** (0.200 g, 0.484 mmol), K_2CO_3 (0.337 g, 2.420 mmol), KI (0.008 g, 10 mol%) and chloromethylnitronyl nitroxide (0.120 g, 0.580 mmol) in MeCN (20 mL) was heated at 60 °C in the dark for 2 h. Then the reaction was quenched with H_2O (20 mL) and extracted with CH_2Cl_2 (2 × 100 mL). The combined organic layers were dried ($MgSO_4$) and evaporated to dryness; yield: 78%. An analyticaly pure sample **8** (0.220 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 1% MeOH).

IR (KBr): 3520, 290, 1617, 1586, 1563, 1457, 1402, 1355 (NO), 1324 (SO_2N), 1146 (SO_2N), 1098, 824 cm^{-1}.

ESI-TOF: *m*/*z* (%) = 605.3 ([M + Na]$^+$, 10), 568.3 ([M – O + 2 H + e$^-$], 100), 552.3 ([M – 2 O + 2 H + e$^-$], 10).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 545 (900), 330 (16500), 270 nm (10200).

Anal. Calcd for $C_{29}H_{36}N_5O_6S$ (582.69): C, 59.78; H, 6.23; N, 12.02. Found: C, 59.44; H, 5.98; N, 11.81.

2-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-6-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-yl)pyridine (11)

Compound **6** (0.105 g, 0.284 mmol), and 2,3-bis(hydroxyamino)-2,3-dimethylbutane (0.130 g, 0.877 mmol) were dissolved in MeOH (10 mL). After stirring for 5 h at r.t. and in the dark, the solution was evaporated to dryness. The residual solid was oxidized with $NaIO_4$ (0.090 g, 0.421 mmol) in a biphasic mixture of H_2O–CH_2Cl_2 (200 mL, 1:1) for 1 h. The product was extracted with CH_2Cl_2 and the organic phase was dried ($MgSO_4$) and evaporated. The pure radical **11** (0.051 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 0.2% MeOH); yield: 36%. IR (KBr): 3429, 2928, 1612, 1588, 1573, 1454, 1396, 1367 (NO), 1325 (SO_2N), 1144 (SO_2N), 1074, 791 cm^{-1}.

MS (ES$^+$): *m*/*z* = 497.2 [M + H]$^+$, 482.3 [M – O + 2H], 466.3 [M – 2O + 2H].

UV-Vis (CH_2Cl_2), λ ,ε ($M^{-1}cm^{-1}$) = 580 (300), 370 (13900), 355 (9550), 294 (7200), 270 nm (11160).

Anal. Calcd for $C_{25}H_{30}N_5O_4S$ (496.60): C, 60.46; H, 6.09; N, 14.10. Found: C, 60,19; H, 5.84; N, 13.75.

2-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-6-(1-oxyl-4,4,5,5-tetramethylimidazolin-2-yl)pyridine (12)

Compound **6** (0.114 g, 0.309 mmol), 2,3-bis(hydroxyamino)-2,3-dimethylbutane (0.130 g, 0.877 mmol) were dissolved in MeOH (20 mL). After stirring for 9 h at r.t. and in the dark, the solution was evaporated. The solid was oxidized with $NaIO_4$ (0.090 g, 0.421 mmol) in a biphasic mixture of H_2O–CH_2Cl_2 (200 mL, 1:1) for 45 min. The product was extracted with CH_2Cl_2 and the organic phases were dried ($MgSO_4$) and evaporated. The radical **12** (0.015 g) was obtained after chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 0.2% MeOH); yield: 10%.

IR (KBr): 3434, 2925, 2853, 1588, 1574, 1451, 1384 (NO), 1326 (SO_2N), 1161 (SO_2N), 1145, 1073, 791 cm^{-1}.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 481.2 ([M + H]$^+$, 100), 232.4 ([M – DANS], 20.

UV-Vis (CH_2Cl_2): λ, (ε, $M^{-1}cm^{-1}$) = 420 (700), 368 (12900), 360 (9500), 294 (8000), 268 nm (12000).

Anal. Calcd for $C_{25}H_{30}N_5O_3S$ (480.60): C, 62.48; H, 6.29; N, 14.57. Found: C, 62.23; H, 5.91; N, 14.29.

2-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}-6-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-yl)pyridine (13)

Compound **8** (0.200 g, 0.343 mmol), 2,3-bis(hydroxyamino)-2,3-dimethylbutane sulfate salt (0.127 g, 0.514 mmol) were dissolved in MeOH (10 mL). After stirring for 5 h at r.t. and in the dark, the solution was evaporated to dryness. The residual solid was oxidized with $NaIO_4$ (0.075 g, 0.350 mmol) in a biphasic mixture of H_2O–CH_2Cl_2 (200 mL, 1:1) for 1 h. The product was extracted with CH_2Cl_2 and the organic phase was dried ($MgSO_4$) and evaporated. The pure radical **13** (0.174 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 0.2% MeOH); yield: 76%.

IR (KBr): 3450, 2930, 1615, 1584, 1570, 1453, 1398, 1370 (NO), 1323 (SO_2N), 1141 (SO_2N), 1075, 802 cm^{-1}.

ESI-TOF: *m*/*z* (%) = 688.2 ([M + Na]$^+$, 30), 666.2 ([M + H], 100), 635.3 ([M – 2 O + 2 H + e$^-$], 10), 385.3 ([M – 2 O – DANS], <10).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 585 (1100), 375 (16500), 355 (10500), 330 (17000), 296 (10200), 270 nm (14000).

Anal. Calcd for $C_{33}H_{43}N_7O_6S$ (665.80): C, 59.53; H, 6.51; N, 14.73. Found: C, 59.27; H, 6.31; N, 14.40.

2-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}-6-(hydroxymethyl)pyridine (14)

Compound **5** (0.099 g, 0.269 mmol), K_2CO_3 (0.075 g, 0.538 mmol), KI (0.0045 g, 10 mol%) and chloromethylnitronyl nitroxide (0.061 g, 0.296 mmol) were dissolved in MeCN (20 mL) and heated at 60 °C in the dark for 2 h. Then, the reaction was quenched with H_2O (20 mL) and extracted with CH_2Cl_2 (2 × 100 mL). The organic layer was dried ($MgSO_4$) and evaporated to dryness; yield: 28%. An analytically pure sample **14** (0.041 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 1% MeOH).

IR (KBr): 3293, 2936, 2852, 1573, 1453, 1432, 1415, 1323 (SO_2N), 1160 (SO_2N), 1143, 1091, 1065, 789, 771 cm^{-1}.

ESI-TOF: *m*/*z* (%) = 563.3 ([M + Na]$^+$, 10), 526.3 ([M – O + 2 H + e$^-$], 100), 510.3 ([M – 2 O+ 2 H + e$^-$], 10).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 540 (800), 328 (15200), 269 nm (9600).

Anal. Calcd for $C_{27}H_{34}N_5O_5S$ (540.66): C, 59.98; H, 6.34; N, 12.95. Found: C, 59.65; H, 6.21; N, 12.75.

2,6-Bis-[(5-dimethylamino-1-naphthalenesulfonamide)methyl]pyridine (16)

To a solution of **15** (0.683 g, 0.277 mmol) and dansyl chloride (0.152 g, 0.563 mmol) in anhyd MeCN (10 mL) was added dropwise anhyd Et_3N (3.5 mL). After keeping for 5 d at r.t., H_2O (50 mL) was added. The mixture was basified with 2 N aq NaOH to pH 9 and extracted with CH_2Cl_2 (2 × 150 mL). The combined organic layers were dried ($MgSO_4$) and evaporated to dryness. The residual solid was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to give, after recrystallisation from a mixture of CH_2Cl_2–hexane, the desired compound **16**; yield: 0.827 g (49%).

IR (KBr): 3302, 2941, 2869, 1588, 1575, 1455, 1408, 1325 (SO_2N), 1161 (SO_2N), 1145, 1073, 1048, 791 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.40 (d, 1 H, ^3J = 8.4 Hz), 8.15 (dd, 1 H, ^3J = 7.4 Hz, ^4J = 1.0 Hz), 8.07 (d, 1 H, ^3J = 8.4 Hz), 7.44–7.29 (m, 6 H), 7.08 (d, 2 H, ^3J = 7.6 Hz), 6.81 (d, 2 H, ^3J = 7.6 Hz), 6.46 (d, 2 H, ^3J = 7.2 Hz), 5.61 (t, 2 H, ^3J = 5.6 Hz, NH), 3.83 (d, 4 H, ^3J = 5.6 Hz, C*H*$_2$NH), 2.82 (s, 12 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 154.2, 152.0, 136.4, 134.7, 130.4, 129.7, 129.5, 128.3, 123.2, 120.1, 118.6, 115.4, 47.5, 45.4.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 604.5 ([M + H]$^+$, 100), 355.3 ([M – DANS], 25).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 229 (13300), 256 (13900), 344 nm (3900).

Anal. Calcd for $C_{31}H_{33}N_5O_4S_2$ (603.76): C, 61.67; H, 5.51; N, 11.60. Found: C, 61.40; H, 5.49; N, 11.41.

2,6-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}pyridine (17)

A mixture of **16** (0.200 g, 0.331 mmol), K_2CO_3 (0.150 g, 1.076 mmol), KI (0.0055 g, 10 mol%) and chloromethylnitronyl nitroxide (0.150 g, 0.728 mmol) in MeCN (50 mL) was heated at 50 °C in the dark for 3 h. The reaction was quenched with H_2O (50 mL) and the organic phase was extracted with CH_2Cl_2 (3 × 50 mL). The combined organic layers were dried ($MgSO_4$) and evaporated to dryness; yield: 79%. An analyticaly pure sample **17** (0.246 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 5% MeOH).

IR (KBr): 3298, 2939, 2857, 1585, 1456, 1436, 1412, 1324 (SO_2N), 1162 (SO_2N), 1146, 1093, 1070, 790, 775 cm^{-1}.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 942.1 ([M + H]$^+$, 100), 926.1 ([M – O + H], 70), 678.2 ([M – O – DANS], 30), 414.2 ([M – 2 DANS – 2 O], <10).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 545 (1200), 345 (5600), 260 (17600), 248 (20200), 230 nm (21000).

Anal. Calcd for $C_{47}H_{59}N_9O_8S_2$ (942.16): C, 59.92; H, 6.31; N, 13.38. Found: C, 59.6; H, 5.99; N, 13.12.

6-[(5-Dimethylamino-1-naphthalenesulfonamide)methyl]-2,2′-bipyridine (19)

To a solution of **18** (0.937 g, 0.59 mmol) and dansyl chloride (0.159 g, 0.59 mmol) in distilled MeCN (10 mL) was added anhyd Et_3N (1 mL) in portions and the mixture was stirred at r.t. for 40 h. H_2O (75 mL) was added and the mixture was acidified with 10% aq HCl to pH 1 and extracted with Et_2O (3 × 75 mL). The aqueous phase was basified with aq KOH to pH 8 and extracted with CH_2Cl_2 (3 × 100 mL). The combined organic layers were dried ($MgSO_4$), evaporated to dryness, and the crude solid was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to give the desired product **19**; yield: 0.206 g (83%).

IR (KBr): 3292, 2939, 2831, 1581, 1456, 1431, 1407, 1324 (SO_2N), 1162 (SO_2N), 1144, 1091, 1072, 790, 775 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.58 (d, 1 H, ^3J = 4.8 Hz), 8.36 (d, 2 H, ^3J = 8.4 Hz), 8.22 (d, 1 H, ^3J = 7.2 Hz), 8.05 (t, 2 H, ^3J = 7.8 Hz), 7.72 (dt, 1 H, ^3J = 7.6 Hz, ^4J = 1.7 Hz), 7.50–7.34 (m, 3 H), 7.28–7.22 (m, 1 H), 6.92 (t, 2 H, ^3J = 7.8 Hz), 6.41 (t, 1 H, ^3J = 5.4 Hz, NH), 4.27 (d, 2 H, ^3J = 5.2 Hz, CH_2), 2.74 (s, 6 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 155.2, 155.1, 153.9, 151.9, 149.1, 137.3, 136.8, 134.6, 130.4, 129.8, 129.6, 128.4, 123.9, 123.1, 121.7, 121.1, 119.6, 118.8, 115.1, 47.9, 45.3.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 419.3 ([M + H]$^+$, 100), 170.3 ([M – DANS], 10).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 344 (3700), 288 (12900), 259 (17600), 246 (19600) 229 nm (19000).

Anal. Calcd for $C_{23}H_{22}N_4O_2S + H_2O$ (418.51 + 18.02): C, 63.28; H, 5.54; N, 12.83. Found: C, 63.32; H, 5.62; N, 12.89.

6-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}-2,2′-bipyridine (20)

A mixture of **19** (0.050 g, 0.119 mmol), K_2CO_3 (0.058 g, 0.357 mmol), KI (0.002 g, 10 mol%), and chloromethylnitronyl nitroxide

(0.027 g, 0.139 mmol) in MeCN (20 mL) was heated at 60 °C in the dark for 2.5 h. After 2 h, K_2CO_3 (0.050 g, 0.357 mmol) was added and the suspension was heated at 60 °C for 2 additional h. The reaction was quenched with H_2O (20 mL) and extracted with CH_2Cl_2 (100 mL). The organic layer was dried ($MgSO_4$) and evaporated to dryness under vacuum; yield: 73%. An analytically pure sample (0.051 g) was obtained by chromatography (Al_2O_3, eluent: CH_2Cl_2 with a gradient of 0.1% MeOH) and recrystallized from a mixture CH_2Cl_2–hexane.

IR (KBr): 3296, 2931, 2856, 1582, 1453, 1433, 1415, 1324 (SO_2N), 1162 (SO_2N), 1148, 1089, 1068, 793, 775 cm^{-1}.

ESI-TOF: *m*/*z* (%) = 610.2 ([M + Na]$^+$, 100), 588.3 ([M + H], 80).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 540 (600), 327 (11500), 288 (12700), 270 nm (13000).

Anal. Calcd for $C_{31}H_{35}N_6O_4S$ (587.24): C, 63.35; H, 6.00; N, 14.30. Found: C, 63.27; H, 5.92; N, 13.99.

6,6′-Bis-[(5-dimethylamino-1-naphthalenesulfonamide)methyl]-2,2′-bipyridine (22)

To a solution of **21** (0.178 g, 0.83 mmol) and dansyl chloride (0.448 g, 1.66 mmol) in distilled MeCN (20 mL) was added anhyd Et_3N (1.5 mL) in portions and the mixture was stirred at r.t. for 23 h. H_2O (50 mL) was added and the mixture was extracted with CH_2Cl_2 (3 × 100 mL). The combined organic layers were dried ($MgSO_4$), evaporated to dryness, and the crude solid was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of 1% MeOH) to give the desired product **22** (0.380 g), after recrystallisation from a mixture of CH_2Cl_2–hexane; yield: 67%.

IR (KBr): 3301, 2943, 2835, 1580, 1458, 1432, 1325 (SO_2N), 1162 (SO_2N), 1146, 1098, 1078, 800 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.42–8.22 (m, 6 H), 7.85 (d, 2 H, ^3J = 7.6 Hz), 7.58–7.35 (m, 6 H), 6.98 (d, 4 H, ^3J = 7.6 Hz), 6.17 (t, 2 H, ^3J = 5.2 Hz, NH), 4.26 (d, 4 H, ^3J = 5.2 Hz, CH_2), 2.77 (s, 12 H, CH_3).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 154.2, 153.8, 152.0, 137.3, 134.4, 130.5, 129.7, 128.0, 123.1, 121.9, 119.7, 118.7, 115.0, 47.7, 45.4.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 681.1 ([M + H]$^+$, 100), 433.2.3 ([M – DANS], 20), 185.2 ([M – 2 DANS], <5).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 344 (7500), 291 (19300), 269 nm (23800).

Anal Calcd for $C_{36}H_{36}N_6O_4S_2$ (680.84): C, 63.51; H, 5.33; N, 12.34. Found: C, 63.37; H, 5.12; N, 12.02.

6,6′-{[5-Dimethylamino-1-naphthalenesulfonamide-*N*-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-methyl-2-yl)]methyl}-2,2′-bipyridine (23)

Compound **22** (0.0937 g, 0.59 mmol) and dansyl chloride (0.159 g, 0.590 mmol) were dissolved in distilled MeCN (10 mL). Anhyd Et_3N (1 mL) was added and the mixture was stirred at r.t. for 40 h. After this period, H_2O (75 mL) was added. The mixture was acidified with 10% aq HCl to pH 1 and extracted with Et_2O (3 × 75 mL). The aqueous phase was basified with aq KOH to pH 8 and extracted with CH_2Cl_2 (3 × 100 mL). The combined organic layers were dried ($MgSO_4$), evaporated to dryness, and the crude solid was purified by flash chromatography (silica gel, eluent: CH_2Cl_2 with a gradient of ?% MeOH) to give the desired product **23** (0.206 g); yield: 83%.

IR (KBr): 3292, 2939, 2831, 1581, 1456, 1431, 1407, 1324 (SO_2N), 1162 (SO_2N), 1144, 1091, 1072, 790, 775 cm^{-1}.

FAB$^+$ (*m*-NBA): *m*/*z* (%) = 1019.2 ([M + H]$^+$, 100), 986.2 ([M – 2 O], 50), 738.4 ([M – 2 O – DANS], 30).

UV-Vis (CH_2Cl_2): λ (ε, $M^{-1}cm^{-1}$) = 344 (3700), 288 (12900), 259 (17600), 246 (19600) 229 nm (19000).

Anal. Calcd for $C_{52}H_{62}N_{10}O_8S_2$ (1019.24): C, 61.28; H, 6.13; N, 13.74. Found: C, 61.05; H, 5.91; N, 13.58.

References

(1) (a) *Molecular Fluorescence, Principles and Applications*; Valeur, B., Ed.; Wiley-VCH: Weinheim Germany, **2002**. (b) *Inorganic Materials*; Bruce, D. M.; O'Hare, D., Eds.; Wiley: Chichester, **1996**. (c) *Magnetism: Molecules to Materials: Models and Experiments*; Miller, J. S.; Drillon, M., Eds.; Wiley-VCH: Weinheim Germany, **2001**.
(2) Ziessel, R. *Synthesis* **1999**, 1839.
(3) Lozinsky, E.; Martin, V. V.; Berezina, T. A.; Shames, A. I.; Weis, A. L.; Likhtenshtein, G. I. J. *Biochem. Biophys. Methods* **1999**, *38*, 29.
(4) Battistuzzi, G. G.; Grandi, G.; Menabue, L.; Pellacani, G. C.; Sola, M. *J. Chem. Soc., Dalton Trans.* **1985**, 2363.
(5) Blough, N. V.; Simpson, D. J. *J. Am. Chem. Soc.* **1988**, *110*, 1915.
(6) Fanz, K. J.; Singh, N.; Lippard, S. J. *Angew. Chem. Int. Ed.* **2000**, *39*, 2120.
(7) Prodi, L.; Bolletta, F.; Montalti, M.; Zaccheroni, N. *Eur. J. Inorg. Chem.* **1999**, 455.
(8) Talanova, G. G.; Elkarim, N. S. A.; Talanov, V. S.; Bartsch, R. A. *Anal. Chem.* **1999**, *71*, 3106.
(9) Tamura, M.; Ueno, A. *Chem. Lett.* **1998**, 369.
(10) Aoki, S.; Kawatani, H.; Goto, T.; Kimura, E.; Shiro, M. *J. Am. Chem. Soc.* **2001**, *123*, 1123.
(11) Vögtle, F.; Gestermann, S. N.; C, ; Ceroni, P.; Vicinelli, V.; Balzani, V. *J. Am. Chem. Soc.* **2000**, *122*, 10398.
(12) Herbelin, S. E.; Blough, N. V. *J. Phys. Chem. B* **1998**, *102*, 8170.
(13) *Synthetic Chemistry of Stable Nitroxides*; Volodarsky, L. B.; Reznikov, V. A.; Ovcharenko, V. I., Eds.; CRC Press: Boca Raton Florida, **1994**.
(14) Inoue, K.; Hayamizu, T.; Iwamura, H.; Hashizume, D.; Ohashi, Y. *J. Am. Chem. Soc.* **1996**, *118*, 1803.
(15) Inoue, K.; Iwamura, H. *J. Am. Chem. Soc.* **1994**, *116*, 3173.
(16) Kalai, T.; Jekö, J.; Szabo, Z.; Parkanyi, L.; Hideg, K. *Synthesis* **1997**, 1049.
(17) (a) Ziessel, R. *Mol. Cryst. Liq. Cryst.* **1995**, *273*, 101. (b) Ulrich, G.; Stroh, C.; Ziessel, R. *C. R. Acad. Sci. Paris* **2001**, *4*, 113.
(18) Ziessel, R.; El-ghayoury, *Synthesis* **2000**, 2137.
(19) (a) Fornasier, R.; Milani, D.; Scrimin, P.; Tonellato, U. *J. Chem. Soc., Perkin Trans. 2* **1986**, 233. (b) Fornasier, R.; Scrimimin, P.; Tecilla, P.; Tonellato, U. *J. Am. Chem. Soc.* **1989**, *111*, 224.
(20) Ulrich, G.; Ziessel, R. *Tetrahedron Lett.* **1994**, *35*, 1215.
(21) Stroh, C.; Turek, P.; Ziessel, R. *Chem. Commun.* **1998**, 2337.
(22) Métivier, R.; Leray, I.; Valeur, B. *Chem. Commun.* **2003**, 996.
(23) (a) Keana, J. F. W.; Baitis, F. *Tetrahedron Lett.* **1968**, 365. (b) Keana, J. F. W.; Dinerstein, R. J.; Baitis, F. *J. Org. Chem.* **1971**, *36*, 209.
(24) Ullman, E. F.; Call, L.; Tseng, S. S. *J. Am. Chem. Soc.* **1973**, *95*, 1677.
(25) Call, L.; Ullman, E. F. *Tetrahedron Lett.* **1973**, 961.
(26) De Armond, M. K.; Carlin, C. M. *Coord. Chem. Rev.* **1981**, *36*, 325.
(27) (a) Koike, T.; Watanabe, T.; Aoki, S.; Kimura, E.; Shiro, M. *J. Am. Chem. Soc.* **1996**, *118*, 12696. (b) Hill, R. R.; Richenburg, C. W.; Roberts, D. R. *J. Photochem. Photobiol.* **1969**, *97*, 109.

(28) (a) Osiecki, J. H.; Ullman, E. F. *J. Am. Chem. Soc.* **1968**, *90*, 1078. (b) Ullman, E. F.; Osiecki, J. H.; Boocock, D. G. B.; Darcy, R. *J. Am. Chem. Soc.* **1972**, *94*, 7049.
(29) Ullman, E. F.; Call, L.; Osiecki, J. H. *J. Org. Chem.* **1970**, *35*, 3623.
(30) Lee, G.; Oka, M.; Takemura, H.; Miyahara, Y.; Shimizu, N.; Inazu, T. *J. Org. Chem.* **1996**, *61*, 8304.
(31) Ziessel, R.; Lehn, J.-M. *Helv. Chim. Acta* **1990**, *73*, 1149.
(32) Alpha, B.; Anklam, E.; Deschenaux, R.; Lehn, J.-M.; Pietraskiewicz, M. *Helv. Chim. Acta* **1988**, *71*, 1042.
(33) Ulrich, G.; Turek, P.; Ziessel, R. *Tetrahedron Lett.* **1996**, *37*, 8755.
(34) Lamchen, M.; Mittag, T. W. *J. Chem. Soc., C* **1966**, 2300.