Facile, Regioselective Synthesis of Highly Solvatochromic Thiophene-Spaced *N*-Alkylpyridinium Dicyanomethanides for Second-Harmonic Generation

Alessandro Abbotto, Silvia Bradamante, Antonio Facchetti, and Giorgio A. Pagani*

Dipartimento di Chimica Organica e Industriale dell'Università di Milano, and Centro CNR Speciali Sistemi Organici, Via Golgi 19, I-20133 Milano, Italy

Received January 10, 1997 (Revised Manuscript Received May 28, 1997[⊗]*)*

The facile and clean synthesis of a novel class of highly solvatochromic chromophores **1** is reported. Compounds **1** are push−pull systems containing a negatively charged dicyanomethanide as a donor group and a positively charged *N*-alkylpyridinium as an acceptor group. The terminal polar functions are spaced by a thiophene-based moiety containing one or two heterocyclic rings and none, one, or two ethylene bridges. Chromophores **1** have been obtained through a general synthetic scheme involving, as the last step, the 100% regioselective alkylation of the precursor bidentate anions **2**, where two competing nucleophilic sites, one neutral at the pyridic nitrogen and one anionic at the carbanionic carbon of the dicyanomethanide group, are present. The unprecedented highly regioselective attack of the alkylating agent onto the neutral pyridic nitrogen rather than the highly charged carbanionic carbon has been also confirmed in the case of the intermolecular competition. Multinuclear (^{13}C and ^{15}N) NMR spectroscopy has been used to investigate the structure and the extent of intramolecular charge transfer in **1**, which are shown to exist in the ground state as highly charge-separated zwitterionic systems. Experimental results are discussed and compared with semiempirical (PM3) computations. The solvatochromic response of compounds **1**, among the highest ever reported in the literature for similar systems, candidates this class of compounds as very attractive active components of nonlinear optical materials.

Much of the impetus for the study of systems that use light as a carrier of information comes from the search for materials that offer the possibility of extremely high-speed data processing, transmission, and storage.[1] Many of these photonic systems require high-performance nonlinear optical (NLO) materials,[2,3] particularly those that have second and third NLO effects.[4] In the area of electro-optical applications, early attempts included the improvement of electronic biasing strengths by varying classical donor and acceptor groups in push−pull systems,[5] changing the substitution patterns, and varying the extension of the conjugation between donor and acceptor moieties.[6,7] One of the strategies[8] aimed at increasing the first molecular hyperpolarizability β and providing stability involves the insertion of five-membered heteroaromatics in the conjugated backbone. Jen et al. have shown that high β values can be achieved by replacing benzenoid rings with easily delocalizable thiophene moieties.[9] Furthermore, thiophene-derived chromophores have been recently developed with enhanced thermal stability.[10] Within these compounds, particularly large molecular hyperpolarizabilities were found when dicyanovinyl and tricyanovinyl acceptors were present.

Ab initio and semiempirical calculations have predicted extremely large β values for heterocyclic betaines.[11] This class of NLO phores have recently attracted attention due to their zwitterionic nature, which leads to high ground-state dipole moments and large negative solvatochromism.[12,13] In this connection, we have shown[14] that the 4-pyridine moiety is among the highest ranked electron-acceptor groups, showing a charge demand[15] *c*

[⊗] Abstract published in *Advance ACS Abstracts,* July 15, 1997.

(1) Williams, D. J. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 690−703.

(2) Prasad, P. N.; Williams, J. *Introduction to Nonlinear Optical Effects in Molecules and Polymers*; Wiley: New York, 1991.

(3) Marder, S. R.; Sohn, J. E.; Stucky, G. D. *Materials for Nonlinear Optics: Chemical Perspectives*; ACS Symposium Series, Vol. 455; American Chemical Society: Washington, DC, 1991.

(4) (a) Chemla, D. S.; Zyss, J. *Nonlinear Optical Properties of Organic Molecules and Crystals*; Academic Press: New York, 1987. (b) Marder, S. R.; Perry, J. W. *Adv. Mater.* **1993**, *5*, 804−815. (c) Burland, D. M.; Miller, R. D.; Walsh, C. A. *Chem. Rev.* **1994**, *94*, 31. (d) Bredas, J. L.; Adant, C.; Tackx, P.; Persoons, A.; Pierce, B. M. *Chem. Rev.* **1994**, *94*, 243. (e) Dalton, L. R.; Harper, A. W.; Ghosn, R.; Steier, W. H.; Ziari, M.; Fetterman, H.; Shi, Y.; Mustacich, R. V.; Jen, A. K.-Y.; Shea, K. J. *Chem. Mater.* **1995**, *7*, 1060−1081. (f) Drost, K. J.; Jen, A. K.-Y.; Rao, V. P. *CHEMTECH* **1995**, *25*, 16−25

(5) Cheng, L.-T.; Tam, W.; Stevenson, S. H.; Meredith, G. R.; Rikken, G.; Marder, S. R. *J. Phys. Chem.* **1991,** *95*, 10631−10643.

(6) Cheng, L.-T.; Tam, W.; Marder, S. R.; Stiegman, A. E.; Rikken, G.; Spangler, C. W. *J. Phys. Chem.* **1991**, *95*, 10643−10652.

(7) Cabrera, I.; Althoff, O.; Mau, H.-T.; Yoon, H. N. *Adv. Mater.* **1994**, *6*, 43.

(8) Dirk, C.; Katz, H.; Schilling, L. *Chem. Mater.* **1990**, *2*, 700.

(9) (a) Rao, V. P.; Jen, A. K.-Y.; Wong, K. Y.; Drost, K. J. *Tetrahedron Lett.* **1993**, *34*, 1747−1750. (b) Jen, A. K.-Y.; Rao, V. P.; Wong, K. Y.; Drost, K. J. *J. Chem. Soc., Chem. Commun.* **1993**, 90−92. (c) Wong, K. Y.; Jen, A. K.-Y.; Rao, V. P.; Drost, K. J. *J. Chem. Phys.* **1994**, *100*, 6818−6825.

(10) (a) Gilmour, S.; Marder, S. R.; Perry, J. W.; Cheng, L.-T. *Adv. Mater.* **1994**, *6*, 494−496. (b) Jen, A. K-Y.; Rao, V. P.; Drost, K. J.; Wong, K. Y.; Cava, M. P. *J. Chem. Soc., Chem. Commun.* **1994**, 2057−2058. (c) Bedworth, P. V.; Cai, Y.; Jen, A.; Marder, S. R. *J. Org. Chem.* **1996**, *61*, 2242−246. (d) Rao, V. P.; Jen, A. K-Y.; Cai, Y. *J. Chem. Soc., Chem. Commun.* **1996**, 1237−1238. (e) Shu, C.-F.; Tsai, W. J.; Chen, J.-Y.; Jen, A. K.-Y.; Zhang, Y.; Chen, T.-A. *J. Chem. Soc., Chem. Commun.* **1996**, 2279−2280. (f) Shu, C.-F.; Tsai, W.-J.; Jen, A. K-Y. *Tetrahedron Lett.* **1996**, *37*, 7055−7058.

(11) Abe, J.; Shirai, Y. *J. Am. Chem. Soc.* **1996**, *118*, 4705−4706.

(12) Alcade, E. *Adv. Heterocycl. Chem.* **1994**, *60*, 197.

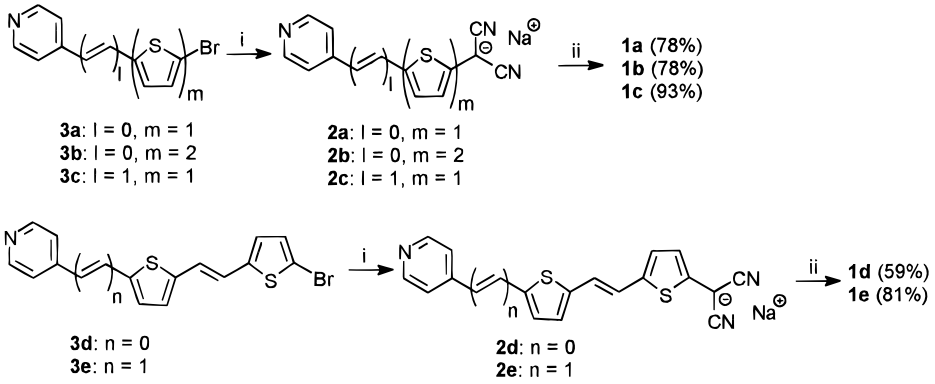
(13) (a) Paley, M. S.; Harris, J. M. *J. Org. Chem.* **1991**, *56*, 568−574. (b) Nemoto, N.; Abe, J.; Miyata, F.; Hasegawa, M.; Shirai, Y.; Nagase, Y. *Chem. Lett.* **1996**, 851−852.

(14) (a) Berlin, A.; Bradamante, S.; Pagani, G. A. *J. Chem. Soc., Perkin Trans. 2* **1988**, 1525−1530. (b) Abbotto, A.; Bradamante, S.; Pagani, G.; Rzepa, H.; Stoppa, F. *Heterocycles* **1994**, *40*, 757−776.

(15) We have previously defined the charge demand c_X of a substituent group X as the fraction of π-charge withdrawn from an adjacent charged trigonal carbon atom and have subsequently used charge demands as a measure of the capacity of group X to delocalize positive or negative charge: (a) Bradamante, S.; Pagani, G. A. *J. Chem. Soc., Perkin Trans. 2* **1986**, 1035−1045. (b) Bradamante, S.; Pagani, G. A. *Pure Appl. Chem.* **1989**, *61*, 709−716. (c) Barchiesi, E.; Bradamante, S.; Ferraccioli, R.; Pagani, G. A. *J. Chem. Soc., Perkin Trans. 2* **1990**, 375−383.

S0022-3263(97)00059-5 CCC: $14.00

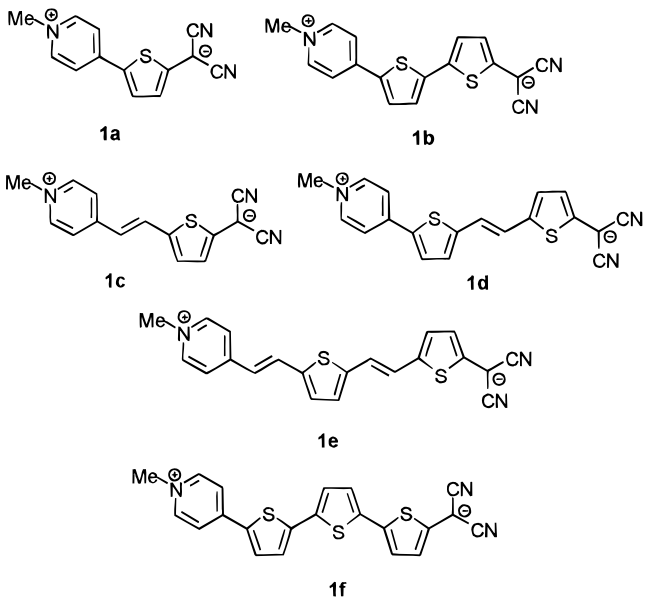
Scheme 1[a]



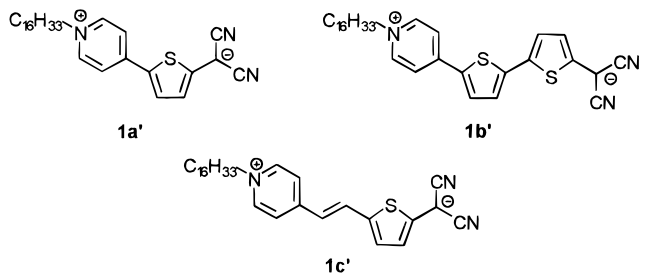
[a] Key: (i) $NaCH(CN)_2$, DME, $Pd(PPh_3)_4$, overnight, rt; (ii) CF_3SO_3Me, acetone, overnight, rt.

that is comparable to that of a methoxycarbonyl group. If the pyridic acceptor is alkylated at the nitrogen atom, the strength of the group can become very high and efficiently promote charge transfer from the donor moiety.

Because of the strict connection between solvatochromism and first hyperpolarizability,[16] the aim of the present work was to combine the various optimization strategies and synthesize highly solvatochromic hybrid molecules consisting of an *N*-alkylpyridinium ring (the acceptor) bonded to a negatively charged dicyanomethanide functionality (the donor) through a π-conjugated spacer group containing the thiophene ring. Compounds **1** responded to these criteria. We considered as a spacer moiety from one to three thiophene rings, containing none or one or two ethylene bridges. Our synthetic interest in push−pull systems[17] based on carbanions[18,19] led us to consider carbanions **2** as the closest precursor to the conjugated zwitterionic push−pull compounds **1**. Since carbanions **2** are ambident nucleophiles, one site being the pyridyl nitrogen and the second the dicyanomethyl carbanion fragment, we were faced with the problem of developing a strategy that could suitably control the regiochemistry of the electrophilic attack of the alkylating agent.



In this paper, we show the highly efficient and clean access to the zwitterionic systems **1a**−**e** and describe the regioselective strategy that we used to achieve it. We also report on the solvatochromic response of compounds **1a**−**e**, which is found to be among the highest reported in the literature for analogous systems. Recently, our group has prepared Langmuir−Blodgett films starting with *N*-cetyl derivatives **1a′**,[20] **1b′**, and **1c′**.[21]



Results

Synthesis of Zwitterionic Dyes 1. The synthesis of compounds **1a**−**e** is reported in Schemes 1 and 2. We were not able to isolate the terthiophene-bridged dye **1f** for the reasons given below. Sodium salts **2** were obtained from bromothiophenes **3** by reaction with malononitrile sodium salt in dimethoxyethane, using tetrakis(triphenylphosphine)palladium (0) as catalyst[22] (Scheme 1). Sodium salts **2** can be easily isolated in a pure form from the reaction mixture and are stable in air. Carbanion **2a** is stable for months in air, but stability decreases on going from **2a** to **2e**. Compounds **2d** and **2e** start to decompose after a few days; they were used for the synthesis of **1** preferably as soon as they were obtained. These salts exhibit a particularly interesting fluorescence in solution; for example, compound **2a** has a strong fluorescence band at $\lambda = 449$ nm when irradiated in acetone at $\lambda = 445$ nm. All the bromo derivatives **3** are new compounds. They were obtained according to

(16) (a) Buckely, A.; Choe, E.; DeMartino, R.; Leslie, T.; Nelson, G.; Starnatoff, J.; Stuetz, D.; Yoon, H. *Polym. Mater. Sci. Eng.* **1986**, *54*, 502. (b) Paley, M. S.; Harris, J. M.; Looser, H.; Baumert, J. C.; Bjorklund, G. C.; Jundt, D.; Twieg, R. J. *J. Org. Chem.* **1989**, *54*, 3774−3778.

(17) (a) Abbotto, A.; Bradamante, S.; Capri, N.; Rzepa, H.; Williams, D. J.; White, A. *J. Org. Chem.* **1996**, *61*, 1770−1778. (b) Bradamante, S.; Facchetti, A.; Pagani, G. A. *J. Phys. Org. Chem.* **1997**, in press.

(18) Abbotto, A.; Bradamante, S.; Pagani, G. A. *J. Org. Chem.* **1993**, *58*, 449−455.

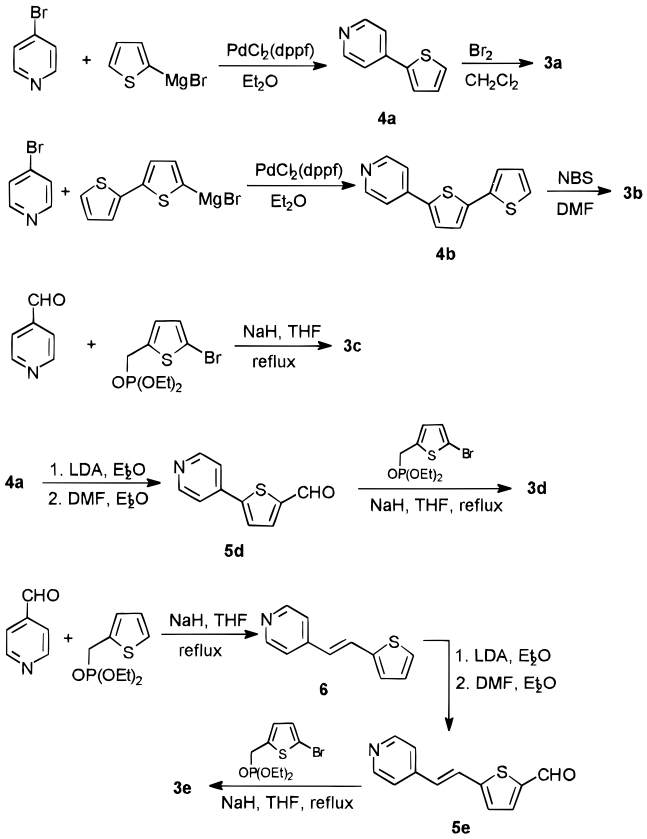
(19) Abbotto, A.; Bradamante, S.; Pagani, G. A. *J. Org. Chem.* **1996**, *61*, 1761−1769.

(20) Ricceri, R.; Abbotto, A.; Facchetti, A.; Gabrielli, G.; Pagani, G. A. *Langmuir* **1997**, *13*, 3434−3437.

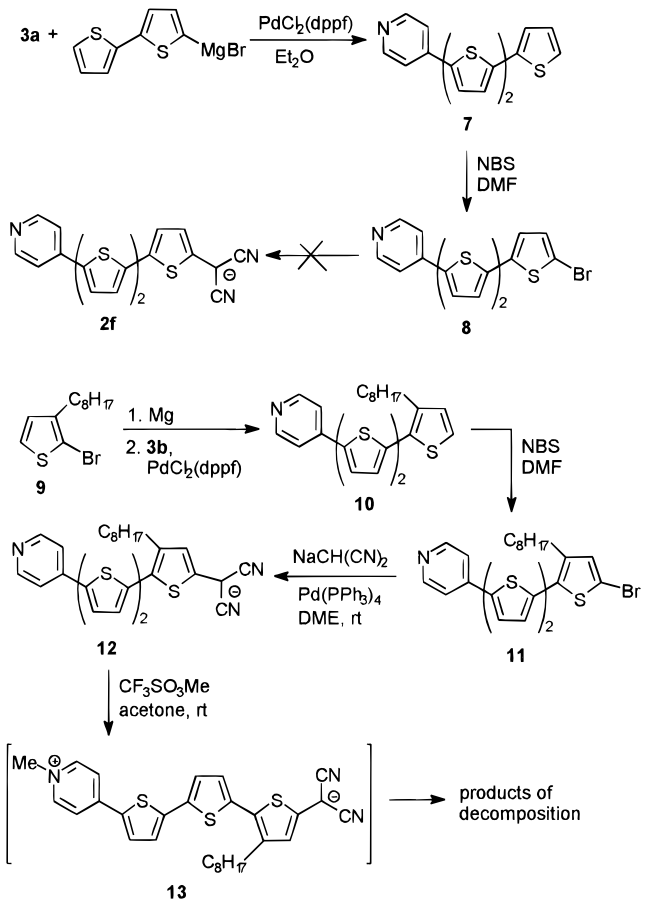
(21) Ricceri, R.; Abbotto, A.; Facchetti, A.; Gabrielli, G.; Pagani, G. A. *Langmuir* **1997**, *13*, 4182−4184.

(22) Yui, K.; Aso, Y.; Otsubo, T.; Ogura, F. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 1539−1546.

Scheme 2



Scheme 3



Scheme 2 either by high-yield bromination of the thienylpyridines **4a** and **4b** or *via* Horner−Wittig condensation between diethyl [(5-bromothien-2-yl)methyl]phosphonate and the proper aldehyde (4-pyridinecarbaldehydes **5d** and **5e** for the synthesis of **3c**, **3d**, and **3e**, respectively). No effective methods were known for the synthesis of 4-(2-thienyl)pyridine (**4a**), with the exception of a coupling between 2-iodothiophene and 4-iodopyridine in the presence of palladium amalgam, which occurred with modest yields.[23] We obtained pure compound **4a** in much more satisfactory yields (84%) via a palladium complex-catalyzed cross-coupling reaction[24] of the Grignard reagent of 2-bromothiophene with 4-bromopyridine. The same method was used for the synthesis of the unknown 4-pyridylbisthiophene derivative **4b**, as well as the new 4-pyridylterthiophene derivatives **7** and **10** (Scheme 3). Deprotonation of **4a** and subsequent quenching with DMF led easily to 4-(5-formylthien-2-yl)pyridine (**5d**) in good yields. Also, the preparation of this compound was previously reported[25] from the coupling between 4-iodopyridine and 2-iodo-5-methylthiophene in the presence of PdHg, followed by oxidation of the methyl group with SeO_2; again, yields were very modest. The unknown aldehyde **5e** was prepared similarly from 1-(4-pyridyl)-2-(2-thienyl)ethylene (**6**), which was obtained from the Horner−Wittig condensation between diethyl [(2-thienyl)methyl]phosphonate and 4-pyridinecarbaldehyde with almost quantitative yields.[26]

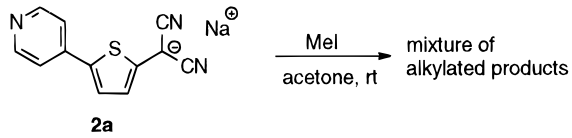
All of the dyes **1** investigated in this study are chemically stable as a solid in the air for months and do not need particular precautions during storage. Solutions of **1** are similarly stable but need to be stored in the dark since stability is somewhat decreased in the presence of light. Details on thermal and photochemical stability, as well as results on decomposition of the dyes, will be presented elsewhere.[27]

We were not able to isolate the terthiophene-bridged chromophore **1f**. The precursor carbanion **2f** could not be prepared from the bromo derivative **8** due to the too scarce solubility of the reagent under the conditions required for the coupling with the sodium salt of malononitrile (Scheme 3). We succeeded in improving the solubility by introducing a C_8-aliphatic chain on the terminal thiophene ring. From the bromo derivative **11**, the sodium salt **12** was successfully obtained and isolated. Unfortunately, the desired chromophore **13** was extremely unstable under the reaction conditions, and only a mixture of decomposition products was recovered.

We planned the regioselective alkylation of the sodium salts **2** on considering the hard and soft properties of the two nucleophilic sites present in the reagent. We envisaged the dicyanomethyl carbanion fragment as a soft nucleophile, while we expected the pyridic one to be a harder one.[28] We therefore anticipated that hard alkylating agents such as alkyl triflates would favor the selective formation of the *N*-alkylated derivative. Indeed, carbanions **2a**−**e** upon treatment with methyl triflates

(23) Nakajima, R.; Iida, H.; Hara, T. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 636−637.
(24) Kumada, M. *Pure Appl. Chem.* **1980**, *52*, 669−679.
(25) Nakajima, R.; Jamamoto, A. Hara, T. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 1968−1972.
(26) During the course of our work, a preparation of **6** was reported from 2-thiophenecarbaldehyde and 4-picoline in acetic anhydride and acetic acid with 66% yield: Pan, H.; Gao, X.; Zhang, Y.; Prasad, P. N.; Reinhardt, B.; Kannan, R. *Chem. Mater.* **1995**, *7*, 816−821.
(27) Abbotto, A.; Bradamante, S.; Facchetti. A.; Pagani, G. A. Results to be published.
(28) Pearson, R. G. In *Advances in Linear Free Energy Relationship*; Chapman, N. B., Shorter, J., Eds.; Plenum Press: London, 1972; p 281.

Scheme 4



2a

afforded exclusively the push−pull systems **1a**−**e**, in the satisfactory yields shown in Scheme 1. Analogously, reaction with cetyl triflate led to the clean obtainment of cetyl derivatives **1a′**−**c′**, which were used for the preparation of Langmuir−Blodgett films.[20,21] In contrast, the reaction of dicyanomethyl carbanion **2a** with the soft methyl iodide afforded a complex, untractable mixture of alkylated products (Scheme 4), where, along with the desired chromophore **1a**, solvatochromic inactive products deriving from alkylation of the carbanionic carbon atom or from polyalkylation are likely to be present.

Although the favored attack to the pyridic nitrogen was predicted by the use of the hard alkyl triflate, the clean and exclusive obtainment of **1** was nevertheless surprising. We wanted to investigate this reaction in more detail. In particular, we were interested in knowing if the exclusive attack to the pyridic nitrogen was due to the intrinsic nature of this electrophilic site or rather promoted by the intramolecular charge transfer from the negatively charged dicyanomethyl carbanionic center to the heterocyclic ring. Consequently, we investigated the intermolecular (vs. intramolecular) competitive alkylation between the two nucleophilic centers present in **2** by planning the model reactions presented in the next paragraph.

Intermolecular Regioselective Alkylation. We conceived the two model molecules 2-thienylpyridine (**4a**) and the sodium salt of phenylmalononitrile (**14**) as the intermolecular equivalent of the two competing nucleophilic sites of **2a**. The sodium salt **14** was obtained by treatment of phenylmalononitrile[29] with MeONa in MeOH and isolated as a solid before running the subsequent competitive alkylation. An equivalent mixture of the two compounds **4a** and **14** was submitted to alkylation either with methyl triflate or methyl iodide in acetone. The results are given in Scheme 5. Both reactions occurred regioselectively with opposite results. The extent of regioselectivity was determined by ^{1}H-NMR. The action of methyl triflate led to the preferential formation (ca. 80%) of the *N*-alkylated derivative **15a**, whereas selective obtainment (70%) of the *C*-alkylated product **16** was observed in the case of the reaction with methyl iodide. Although the degree of regioselectivity is lower than in the case of the intramolecular competitive attack of the two nucleophilic sites of anion **2a**, the direction of the regioselectivity is the same both for intramolecular and intermolecular competition.

With the exception of a very old report with no spectroscopic data,[30] 2-cyano-2-phenylpropiononitrile (**16**) was not previously described in the literature. The *N*-methyl-4-(2-thienyl)pyridinium cation is known as iodide[31] but not as triflate. We prepared the pure products **15a** and **16** by the action of methyl triflate and methyl iodide on **4a** and phenylmalononitrile, respectively.

(29) Suzuki, H.; Kobayashi, T.; Osuka, A. *Chem. Lett.* **1983**, 589−590.

(30) Hessler, J. C. *Am. Chem. J.* **1908**, *39*, 63 (cf. *Beilstein* H, *9*, 872 or *Chem. Abstr.* **1908**, *2*, 1003).

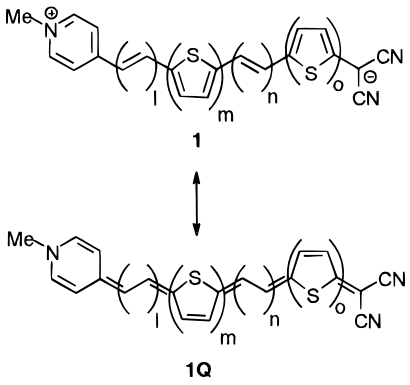
(31) Albers, W. M.; Canters, G. W.; Reedijk, J. *Tetrahedron* **1995**, *51*, 3895−3904.

Table 1. Solvatochromic Data [λ_{max} (nm) of the Charge-Transfer Band] for the Chromophores 1a−1e in Selected Solvents

compd	MeOH	CH_3CN	acetone	THF	$CHCl_3$	$\Delta\lambda_{acetone}^{MeOH}$ [a]	$\Delta\lambda_{THF}^{MeOH}$ [a]
1a	537	546	559	586	600	−22	−49 (−63)[b]
1b	610	627	665	752	*c*	−55	−142
1c	609	623	639	686	702	−30	−77 (−93)[b]
1d	622	643	692	*c*	*c*	−70	
1e	634	649	705	*c*	*c*	−71	

[a] $\Delta\lambda = \lambda_{max}$ (polar solvent) − λ_{max} (nonpolar solvent): positive values $\Delta\lambda$ mean positive solvatochromism. [b] $\Delta\lambda = \lambda_{max}$ (MeOH) − λ_{max} ($CHCl_3$). [c] Compound not soluble.

Solvatochromic Data: Zwitterionic vs. Quinoidic Structure of 1. The description of the bonding in the highly delocalized dipolar *N*-alkylpyridinium dicyanomethanides **1** could involve the quinoidic structures **1Q**, where intermolecular charge transfer (CT) took place from the negatively charged donor to the positively charged heterocyclic acceptor. Both the ground state and the excited state structures of molecules **1** can be described as linear combination, with different coefficients, of the two limit resonance formula **1** and **1Q**.



1

a: l = m = n = 0; o = 1
b: l = n = 0; m = o = 1
c: l = m = 0; n = o = 1
d: l = 0; m = n = o = 1
e: l = m = n = o = 1

1Q

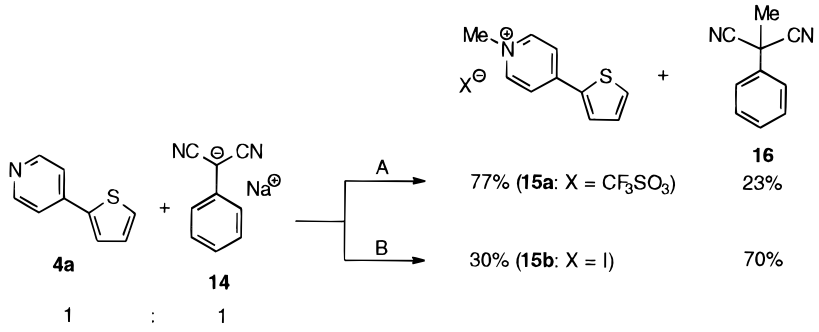
All of the compounds **1a**−**e** present a strong CT band in the visible region of the spectrum. Table 1 collects absorption data relative to the CT band in selected solvents. As an example, Figure 1 shows the absorption spectra of compound **1c** in four solvents of different polarity, and it can be seen that the solvatochromic shift from MeOH (E_T = 55.5) to THF (E_T = 37.4) is about 80 nm toward longer wavelengths. From the spectra recorded in solvents of different polarity, it was determined that compounds **1** show a strong negative solvatochromism with respect to their CT absorption band, that is, the position of the absorption maximum shifts to shorter wavelengths with increasing the solvent polarity. Within the conventional interpretation of solvatochromic interactions,[32] the negative solvatochromism indicates that the value of the dipole moment in the excited state is smaller than in the ground state. Although other factors can affect the sign of solvatochromism (aggregation or different solvent polarizabilities),[33] in the hypothesis that the various solvents here considered do not dramatically affect the electronic nature of the ground and of the excited state, respectively, the result of a negative solvatochromism indicates that the ground state of **1** is better represented by the zwitterionic limit formula **1**.

The analysis of ^{1}H, ^{13}C, and ^{15}N NMR spectra of the chromophore **1a**, and their comparison with spectra of

(32) Reichardt, C. *Solvent Effects in Organic Chemistry*; Verlag Chemie: New York, 1979; Chapter 6.

(33) Chen, C.-T.; Marder, S. R. *Adv. Mater.* **1995**, *7*, 1030−1033.

Scheme 5[a]



[a] Key: (A) CF_3SO_3Me, acetone, rt; (B) MeI, acetone, rt.

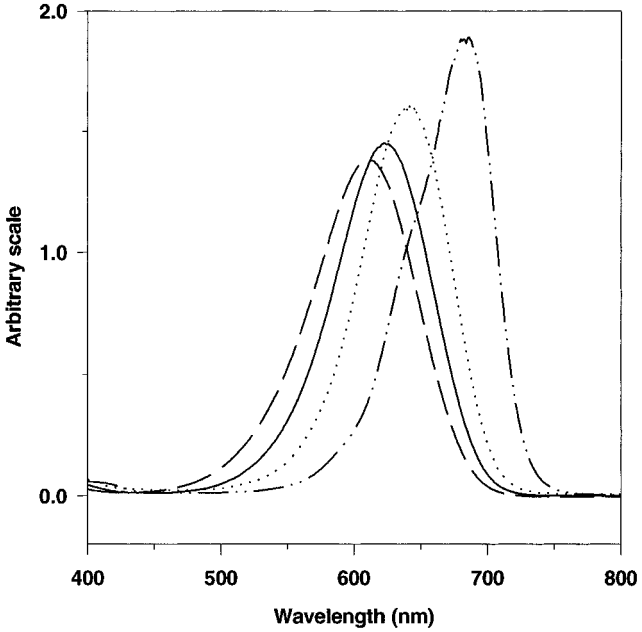


Figure 1. UV−vis spectra of **1c** in different solvents: THF, −••−; acetone, •••; acetonitrile, −; methanol, - - -.

the charged precursor **2a**, 4-(2-thienyl)pyridine (**4a**), and *N*-methyl-4-(2-thienyl)pyridinium triflate (**15a**), provides further information about the ground state structure and, qualitatively, about the extent of the charge transfer from the donor to the heterocyclic acceptor. All of the ^{13}C and ^{15}N chemical shift data are shown in Figure 2.

Discussion

This study reports the easy, clean, and high-yield obtainment of a novel series of highly solvatochromic systems for second-harmonic generation. The synthesis scheme appears to be of general applicability and allows access to a series of a potentially large class of chromophores, with spacers of different structure and length. Whereas the *N*-alkylpyridinium acceptor moiety was already used as an acceptor in a number of chromophores, including cyanine dyes, which are among the most interesting systems for NLO applications,[34,35] the dicyanomethanide carbanion appeared as a donor only in a limited series of benzenoid derivatives investigated by Ashwell for the preparation of Langmuir−Blodgett films.[36] The inclusion of a thiophene-based spacer[9] makes compounds **1** very attractive and promising, as confirmed by the large solvatochromic response.

The use of methyl triflate on the ambident anions **2** led to the *N*-alkylated zwitterionic compounds **1** in a completely regioselective manner. The reported majority of the selective alkylations concern 1,3-ambident nucleophiles only, involving systems centered on enolate, indolyl anions, and the like.[37] Very often, selectivity is obtained, by varying the leaving group of the alkylating agent, the counterion of the negatively charged ambident anion, the solvent, and the temperature as well as adding chelating molecules or inorganic salts[38] (all factors that, more or less directly, affect the nature and the concentration of the monomeric, aggregated and mixed inorganic−organic aggregated species present in solution).[39] Without going into the details of each of these factors, our aim was simply that of having a supporting rationale for the expected, but nonetheless surprising, behavior of **2a** toward electrophiles. For these reasons, we carried out an intermolecular competition reaction exactly under the same conditions (counterion, solvent, temperature, concentration) of the reaction of **2a** with methyl triflate and methyl iodide. Our results are the first examples in which the competing nucleophiles are a carbanionic and a neutral center, respectively, with an unprecedented selectivity for the neutral one: they are a successful experimental application, never treated before, of the HSAB (hard and soft acids and bases) theory[40] to competing nucleophilic centers. The intermolecular confirmation of the direction of the *N* vs *C* alkylation with

(34) Bosshard, C.; Sutter, K.; Prêtre, P.; Hulliger, J.; Flörsheimer, M.; Kaatz, P.; Günter, P. In *Organic Nonlinear Optical Materials* In *Advances in Nonlinear Optics*; Garito, A. F., Kajzar, F., Eds.; Gordon and Breach Publishers: Basel, 1995; Vol. 1.

(35) See also, more recently: (a) Blenkle, M.; Boldt, P.; Bräuchle, C.; Grahn, W.; Ledoux, I.; Nerenz, H.; Stadler, S.; Wichern, J.; Zyss, J. *J. Chem. Soc., Perkin Trans. 2* **1996**, 1377−1384. (b) Alain, V.; Fort, A.; Barzoukas, M.; Chen, C.-T.; Blanchard-Desce, M.; Marder, S. R.; Perry, J. W. *Inorg. Chim. Acta* **1996**, *242*, 43−49. (c) Ashwell, G. J.; Walker, T. W.; Gentle, I. R.; Foran, G. J.; Bahra, G. S.; Brown, C. R. *J. Mater. Chem.* **1996**, *6*, 969−974. (d) Ashwell, G. J.; Jackson, P. D.; Jefferies, G.; Gentle, I. R.; Kennard, C. H. L. *J. Mater. Chem.* **1996**, *6*, 137−141.

(36) (a) Ashwell, G. J.; Dawnay, E. J. C.; Kuczynski, A. P.; Szablewski, M.; Sandy, I. M.; Bryce, M. R.; Grainger, A. M.; Hasan, M. *J. Chem. Soc., Faraday Trans.* **1990**, *86*, 1117−1121. (b) Ashwell, G. J. *Thin Solid Films* **1990**, *187*, 155−165. (c) Ashwell, G. J.; Malhotra, M.; Bryce, M. R.; Grainger, A. M. *Synth. Met.* **1991**, *41−43*, 3173−3176. (d) Ashwell, G. J.; Hargreaves, R. C.; Baldwin, C. E.; Bahra, G. S.; Brown, C. R. *Nature* **1992**, *357*, 393−395.

(37) Reutov, O. A.; Beletskaya, I. P.; Kurts, A. L. *Ambident Anions*; Consultants Bureau: New York, 1983.

(38) See, for instance, the investigation on the C/O alkylation ratio of lithium enolates: (a) Jackman, L. M.; Lange, B. C. *J. Am. Chem. Soc.* **1981**, *103*, 4494. (b) Jackman, L. M.; Dunne, T. S. *J. Am. Chem. Soc.* **1985**, *107*, 2805.

(39) (a) Jackman, L. M.; Rakiewicz, E. F. *J. Am. Chem. Soc.* **1991**, *113*, 1202. (b) Abbotto, A.; Streitwieser, A. *J. Am. Chem. Soc.* **1995**, *117*, 6358−6359. (c) Abu-Hasanayn, F.; Stratakis, M.; Streitwieser, A. *J. Org. Chem.* **1995**, *60*, 4688−4689. (d) Abu-Hasanayn, F.; Streitwieser, A. *J. Am. Chem. Soc.* **1996**, *118*, 8136−8137.

(40) Pearson, R. G. *Hard and Soft Acids and Bases*; Dowden, Hutchinson and Ross: Stroudsville, PA, 1973.

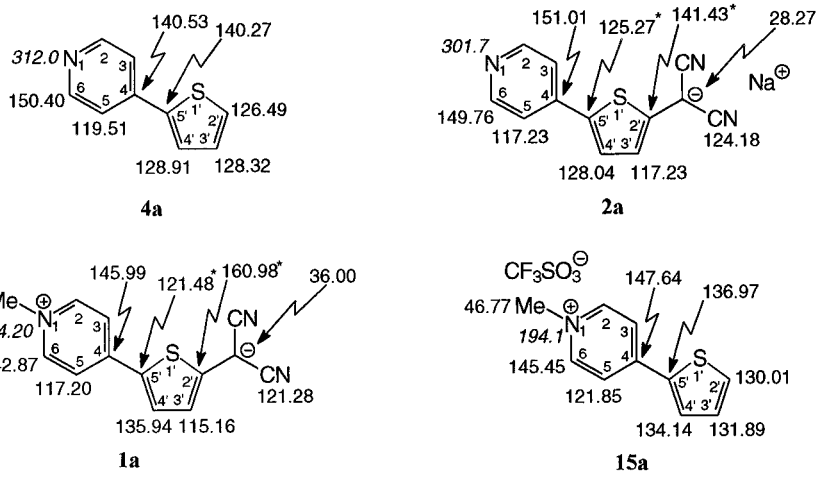
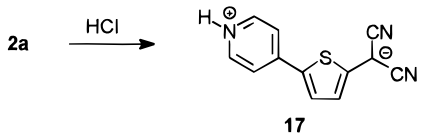


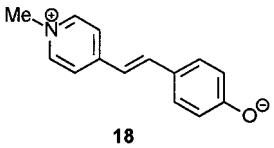
Figure 2. ^{13}C (roman type) and ^{15}N (italic type) NMR data in DMSO at 27 °C for compounds **4a**, **2a**, **1a**, and **15a** (assignments marked with an asterisk are tentative).

Scheme 6



methyl triflate excludes the fact that the origin of the exclusive electrophilic attack to the pyridic nitrogen of **2a** is a possible charge transfer from the dicyanomethanide moiety to the heterocyclic ring. According to the NMR analysis that will be discussed below, the charge transfer in carbanion **2a** is very limited, and the negative charge residing on the pyridic nitrogen is comparable to that of 4-(2-thienyl)pyridine (**4a**). Nevertheless, the results of the intermolecular competition show very clearly that toward methyl triflate the neutral pyridine derivative is much more reactive than the competitive carbanionic nucleophile. To our knowledge, this is the first example where a neutral species is found to be much more reactive than the classical highly nucleophilic cyano-disubstituted carbanion in a reaction with an energetic electrophilic agent. Also, for the first time, a negatively charged carbanionic carbon is not perturbed by the reaction with a strong methylating agent and is found unaltered in the product. This result is even more impressive in view of the fact the negative charge is almost completely localized on the carbanionic carbon of the dicyanomethanide moiety of **2a** and not on the heterocyclic rings (see below) or the cyano groups.[18] Finally, the same complete regioselectivity was found in the reaction with the hard hydronium ion: treatment of **2a** with hydrochloric acid led exclusively to the product **17** protonated at the pyridic nitrogen (Scheme 6).

The analysis of the ^{13}C and ^{15}N NMR of **1a** and their comparison with the synthetic precursors or models **2a**, **15a**, and **4a** gives very useful and detailed insights on its structure and electronic distribution (see Figure 2). We have previously proposed the π-electron density/shift relationships (1)[15a] and (2)[41] for ^{13}C and ^{15}N, respectively, which allow the empirical calculation of the variation of the electron density of a sp^2 carbon or nitrogen atom, respectively, upon variation of the chemical shift. The involved atom must have the same substitution pattern in both compounds associated with the shift variation. The validity of these relationships was assessed by its successful application to a high number of aliphatic, aromatic, and heteroaromatic derivatives.[14,15,18,19,41]



$$\Delta\delta^{13}C = -160\Delta q_C^{\pi} \quad (1)$$

$$\Delta\delta^{13}N = -366.34\Delta q_N^{\pi} \quad (2)$$

Comparison between **4a** and **2a** shows that the introduction of the dicyanomethanide carbanion group does not significantly affect the electronic distribution in **2a**. The ^{15}N shift of **4a** is typical of a substituted pyridine.[42] The pyridic nitrogen experiences a small increase (Δq = 0.028)[43] of π-electron density, whereas the mean increase for the carbon atoms of the two heterocyclic rings is almost zero.[44] We can therefore conclude that more than 90% of the negative charge is localized on the dicyanomethanide moiety. We have previously shown[18] that the charge demand[15] of the cyano groups is very modest. In the sodium salt of malononitrile, where the ^{13}C shift of the carbanionic carbon is −0.25 ppm (DMSO), almost 60% of the negative charge is localized on this atom. A more proper comparison is, however, with the sodium salt of phenylmalononitrile, where the substitution of the carbanionic carbon is closer to that of **2a**. In this anion, the ^{13}C shift of the central carbon atom is 27.11 ppm (DMSO),[18] which corresponds to a negative π-charge of 0.50 electrons (localized on this site). The chemical shift of the corresponding site of **2a** (28.27 ppm) and the above

(41) See ref 18 and: (a) Abbotto, A.; Alanzo, V.; Bradamante, S.; Pagani, G. A. *J. Chem. Soc., Perkin Trans. 2* **1991**, 481−488. (b) Abbotto, A.; Bradamante, S.; Pagani, G. A. *J. Org. Chem.* **1993**, *58*, 444−448. (c) Gatti, C.; Ponti, A.; Gamba, A.; Pagani, G. A. *J. Am. Chem. Soc.* **1992**, *114*, 8634−8644.

(42) Witanowski, M.; Stefaniak, L.; Webb, G. A. In *Annual Reports on NMR Spectroscopy*; Webb, G. A., Ed.; Academic Press: London, 1986; Vol. 18.

(43) A positive value of Δq corresponds to an increase in π-electron density.

(44) The difference between $(\Sigma\delta^{13}C)_{rings}$ going from **4a** to **2a** is only −7.4 ppm, corresponding to a total Δq of 0.05 electrons. Although differently substituted, it is justified to compare C-2′ in **4a** and in **2a** since the shielding contribution of the group $CH(CN)_2$ is almost zero (as can be seen by comparing the ^{13}C chemical shift of benzene with that of C_{ipso} in phenylmalononitrile).[18] Finally, we assume that the sulfur atom does not delocalize any negative charge. This was confirmed in an earlier study of α-thiazolylmethyl carbanions.[19]

considerations led us to conclude that a considerable quantity of negative π-charge is resident on the carbanionic carbon. In view of this result, the regioselectivity of the electrophilic attack appears even more surprising. Similar conclusions can be drawn by comparing the chemical shifts of **1a** and **15a**. The pyridic nitrogen in the former is modestly high-field shifted with respect to **15a**. Its chemical shift, and therefore the corresponding π-electron density, is that typical of a pyridinium salt. On going from **15a** to **1a** there is an increase in the electron density of the nitrogen atom by only 0.05 electrons, which corresponds exactly to the decrease (by 0.05 electrons) experienced by the carbanionic carbon atom on going from **2a** to **1a**. In conclusion, apart from this almost negligible charge transfer, the electronic structure of the sample chromophore **1a** resembles, on the *N*-alkylpyridinium side, that of a simple pyridinium salt, like **15**, and on the dicianomethanide portion, that of a localized carbanion salt, like **2a**. That is, the ground-state electronic structure of **1a** is, at least in DMSO, that of a highly charge-separated zwitterionic system.

There are some additional experimental facts that support this conclusion. Firstly, the absence of hindered rotation for the carbon atoms of the pyridine ring suggests that the quinoidic limit structure **1Q** is not important in the description of the chromophores **1**. In fact, we have previously shown that in correspondence of a charge delocalization on the 4-pyridine ring, the consequent double-bond character of the exocyclic bond has the effect to make the pyridine C-3 and C-5 shifts anisochronous.[41b] Secondly, the value of the $^3J_{H-H}$ coupling constants of the central *trans* carbon−carbon double bond in the chromophore **1c** (15 Hz) is almost identical to that of the anionic precursor **2c** (15.9 Hz) and of the simple ethylene derivative **6** (16.1 Hz), where neither the donor nor the acceptor group are present. Finally, the crystallographic analysis of a 2-pyridine benzenoid analog of our systems **1** showed the zwitterionic nature of the chromophore.[45]

Semiempirical calculations have been carried out using the program MOPAC 6.0[46] with the aim to calculate the dipole moments of the ground and excited state and the first molecular hyperpolarizabilities of compounds **1a**−**e**. Computations have been performed in the gas phase using the keywords PM3, EF, PRECISE, and POLAR for the ground state and PM3 and EXCITED for the excited state. Geometries were fully optimized without any symmetry constraint. All of the structures were quinoidic in the ground state with a high charge transfer from the carbanionic carbon to the pyridic nitrogen. Calculated bond lengths are in accord with the description of the chromophore as the limit formula **1Q**. For compound **1a** the σ-charge and π-charge for the carbanionic carbon of the dicyanomethanide moiety are calculated to be +0.19 and −0.22, respectively. Corresponding values for the nitrogen atom are +0.45 and −0.63, respectively. Calculated charges for the other compounds **1** are similar to that of **1a** and are not reported. The ground state dipole moment ranges from 13.9 to 15.6 D. The excited state dipole moment of **1a** is calculated to be 33.6 D. It is clear that, in terms of contribution of the zwitterionic and quinoidic limit formulas in the ground state structure, computations give an opposite description with respect to experimental evidence. It is possible that the semiempirical theoretical approach is not able to compute adequately the chromophores **1**. If, instead, PM3 calculations are assumed to be sufficiently reliable, we must conclude that the chromophores **1** are intrinsically (semiempirical calculations) better described by the neutral quinoidic structure **1Q** and that the charge-separated zwitterionic formula is more relevant only in solution (experimental data). The latter can be considered a realistic situation since it is likely that polar solvents like DMSO—where NMR analysis was performed[47]—or the ones used in the solvatochromic study (from MeOH to $CHCl_3$) favor the charge-separated form thanks to stabilizing intermolecular interactions. In any case, the calculated β values are not reported due to the inadequacy of computations to describe accurately the situation in solution, where experimental EFISH or hyper-Rayleigh scattering[48] measures are generally performed.

On the basis of the highly zwitterionic ground state structure of **1** and the dipole moment values calculated semiempirically for the neutral and charge-separated forms, it is justified to expect a large difference between the dipole moments of the ground and excited states of **1** in solution. According to the two-state model[49] derived from the perturbation theory, the dyes **1** should exhibit large negative β values. These expectations are experimentally corroborated by the very large solvatochromic response of compounds **1a**−**e**, which is among the largest reported in the literature for similar type of systems. As an example, the merocyanine dye **18**, which shows the extremely large $\beta\mu$ value of 7600×10^{-48} esu,[50] has a solvatochromic response of $\Delta\lambda_{CHCl_3}^{MeOH} = -128$ nm,[51] which is comparable to those recorded in this study.[52]

Conclusions

In this study, we have prepared a novel class of compounds **1** for second-harmonic generation using a high-yield clean procedure of general applicability. In the 100% regioselective alkylation carried out to prepare **1** from the bidentate nucleophilic precursors **2**, for the first time a neutral site has been found to be much more reactive than a highly negatively charged carbanionic center with respect to hard electrophiles. The same surprising result was obtained when competitive intermolecular nucleophilic attacks were investigated. The structure of **1** in solution was determined by multinuclear NMR analysis and other experimental data to be almost exclusively described by the charge-separated zwitterionic limit formula **1**, with highly localized positive and negative charges. Since in the gas phase the structure of **1** is computed to be preferentially quinoidic, it was concluded that the zwitterionic structure is stabilized by solvent−dye intermolecular interactions. The solvatochromic response of **1** was found to be very large, with respect to values reported in the literature for similar compounds. This and other data suggest that large molecular hyperpolarizabilities should be exhibited by these chromophores.[53]

(45) Metzger, R. M.; Heimer, N. E.; Ashwell, G. J. *Mol. Cryst. Liq. Cryst.* **1984**, *107*, 133.
(46) Stewart, J. J. P. *QCPE* **455,** 1990.
(47) Less polar solvents could not be considered due to solubility limits.
(48) See ref 34, p. 117.
(49) Oudar, J. L.; Chemla, D. S. *J. Chem. Phys.* **1977**, *66*, 2664.
(50) Dulcic, A.; Flytzanis, C. *Opt. Commun.* **1978**, *25*, 402.
(51) Benson, H. G.; Murrell, J. N. *J. Chem. Soc., Faraday Trans.2* **1972**, *68*, 137−143.
(52) For instance, for compound **1b** solvatochromism recorded between MeOH and THF is −142 nm (it must be noted that the corresponding data between MeOH and $CHCl_3$ is expected to be larger, as can be seen from Table 1).

Experimental Section

^{1}H NMR spectra were recorded at 300 and 500 MHz. Coupling constants are reported in Hz. Mass spectra were determined at an ionizing voltage of 70 eV. Anhydrous solvents were prepared by continuous distillation over sodium sand, in the presence of benzophenone and under nitrogen or argon, until the blue color of sodium ketyl was permanent. Anhydrous *N*,*N*-dimethylformamide (DMF) was supplied by Fluka. Acetone was dried over Na_2SO_4 for a few days. Diisopropylamine was refluxed over CaH_2 for 4 h and distilled under nitrogen prior to use. Extracts were dried over Na_2SO_4 (4 h). Melting points are uncorrected.

Materials. 4-Pyridinecarbaldehyde and 2-bromothiophene are commercially available (Fluka). The unstable 4-bromopyridine as a free base was obtained from the commercially available hydrochloride (Fluka), by addition to its aqueous solution of an equimolar amount of potassium carbonate at 0 °C. Extraction with diethyl ether, drying of the organic layers, and evaporation of the solvent below 30 °C yielded almost pure 4-bromopyridine. Because of its instability, it was used immediately for further reactions.

4-(2-Thienyl)pyridine (4a). 2-Thienylmagnesium bromide was prepared by adding a solution of 2-bromothiophene (9.27 g, 56.86 mmol) in anhydrous diethyl ether (70 mL) to a suspension of magnesium (1.71 g, 70.34 mmol) in the same solvent (20 mL). This Grignard solution was kept under dry nitrogen atmosphere and added dropwise to a stirred suspension of 4-bromopyridine (8.01 g, 50.70 mmol) and $PdCl_2$(dppf) (0.319 g, 0.43 mmol) in the same solvent (30 mL), maintaining the temperature between −30 and −20 °C. A white precipitate formed immediately. After being stirred for 2 h at 0−5 °C, the reaction mixture was poured into a saturated aqueous ammonium chloride solution (120 mL), and the aqueous layer was extracted with diethyl ether (3 × 60 mL). The combined organic layers were dried, and the solvent was evaporated to give the practically pure compound as a light yellow solid (6.86 g, 42.55 mmol, 84%): mp 87−88 °C (lit.[23] mp 93−94 °C); ^{1}H NMR ($CDCl_3$) δ 8.59 (d, 2 H, J = 4.8), 7.51 (d, 1 H, J = 3.8), 7.49 (d, 2 H, J = 4.8), 7.41 (d, 1 H, J = 5.0), 7.13 (dd, 1 H, J = 5.0, 3.8).

4-(5-Bromothien-2-yl)pyridine (3a). Bromine (13.54 g, 85.06 mmol) was added to a solution of 4-(2-thienyl)pyridine (**4a**) (6.86 g, 42.55 mmol) in methylene chloride (300 mL). After being stirred for 15 min at room temperature, the reaction mixture was poured onto 10% aqueous K_2CO_3 (300 mL), and the aqueous layer was extracted with methylene chloride (2 × 100 mL). The combined organic layers were dried, and the solvent was evaporated to give a brown solid (9.51 g) that, after sublimation, afforded the pure product (8.41 g, 35.02 mmol, 82%): mp 152−153 °C (EtOH); ^{1}H NMR ($CDCl_3$) δ 8.57 (d, 2 H, J = 6.1), 7.36 (d, 2 H, J = 6), 7.24 (d, 1 H, J = 4.0), 7.08 (d, 1 H, J = 4). Anal. Calcd for C_9H_6BrNS: C, 45.02; H, 2.52; N, 5.83. Found: C, 45.20; H, 2.66; N, 6.17.

4-[5-(Dicyanomethanido)thien-2-yl]pyridine Sodium Salt (2a). Malononitrile (5.92 g, 89.94 mmol) was added portionwise to an ice-cooled suspension of sodium hydride (7.19 g, 60% in oil, 179.75 mmol) in 1,2-dimethoxyethane (300 mL), and the mixture was stirred at room temperature for 20 min under nitrogen. 4-(5-Bromothien-2-yl)pyridine (**3a**) (8.85 g, 36.85 mmol) and tetrakis(triphenylphosphine)palladium(0) (4.33 g, 3.75 mmol) were added to the above solution, and the mixture was heated under reflux for 2 h. The resulting precipitate was collected by filtration, washed with benzene (30 mL) to eliminate the catalyst, and then recrystallized from H_2O to give the product as a yellow solid (3.62 g, 13.20 mmol, 36%): mp > 240 °C; ^{1}H NMR (DMSO-d_6) δ 8.31 (d, 2 H, J = 6.3), 7.43 (d, 1 H, J = 3.1), 7.27 (d, 2 H, J = 6.3), 6.11 (d, 1 H, J = 3). Anal. Calcd for $C_{12}H_6N_3NaS$: C, 58.30; H, 2.45; N, 17.01. Found: C, 57.87; H, 2.43; N, 16.59.

2-(4-*N*-Methylpyridinium)-5-(dicyanomethanido)-thiophene (1a). Methyl triflate (1.32 g, 0.88 mL, 8.09 mmol) was added dropwise to a suspension of 4-[5-(dicyanomethanido)thien-2-yl]pyridine sodium salt (**2a**) (2.00 g, 8.09 mmol) in dry acetone (100 mL). The color of the mixture immediately changed from yellow to violet. After being stirred overnight at room temperature, the precipitate was collected and washed with water and then with EtOH to give the analytically pure product (1.51 g, 6.32 mmol, 78%) as a violet solid: mp > 240 °C; ^{1}H NMR (DMSO-d_6) δ 8.26 (d, 2 H, J = 7.0), 7.92 (d, 1 H, J = 4.4), 7.62 (d, 2 H, J = 7.0), 6.41 (d, 1 H, J = 4.4), 3.96 (s, 3 H). Anal. Calcd for $C_{13}H_9N_3S$: C, 65.26; H, 3.79; N, 17.57. Found: C, 65.10; H, 3.81; N, 17.23.

2-(4-*N*-Cetylpyridinium)-5-(dicyanomethanido)-thiophene (1a′). A solution of trifluoromethanesulfonic anhydride (0.62 g, 2.20 mmol) in CH_2Cl_2 (5 mL) was added, in a period of 15 min, to a solution of cetyl alcohol (0.50 g, 2.06 mmol) in the same solvent (8 mL). After being stirred at room temperature for 20 min, the reaction mixture was poured onto ice (20 mL), and then the organic layer was washed with water, dried, and evaporated to leave the crude cetyl triflate (0.64 g, 1.71 mmol, 83.0%). Cetyl triflate (0.64 g, 1.71 mmol) in dry acetone (10 mL) was added dropwise to a suspension of 4-[5-(dicyanomethanido)thien-2-yl]pyridine sodium salt (**2a**) (0.47 g, 1.71 mmol) in the same solvent (10 mL). The color of the mixture immediately changed from yellow to violet. After the mixture was stirred for 12 h at room temperature, the precipitate was collected and washed with H_2O and then with EtOH to give the product (0.25 g, 0.56 mmol, 33%) as a violet solid: mp 207−208 °C (EtOH); ^{1}H NMR (DMSO-d_6) δ 8.31 (d, 2 H, J = 7.8), 7.92 (d, 1 H, J = 4.2), 7.58 (d, 2 H, J = 7.8), 6.41 (d, 1 H, J = 4.2), 4.20 (t, 2 H, J = 7.1), 1.85−1.70 (m , 2 H), 1.40−1.10 (m, 26 H), 0.85 (t, 3 H, J = 7.1); UV−vis (DMF) λ_{max} = 551 nm, ϵ = 75 700 ± 600 M^{-1} cm^{-1}. Anal. Calcd for $C_{28}H_{39}N_3S$: C, 74.79; H, 8.75; N, 9.35. Found: C, 75.17; H, 8.77; N, 9.65.

4-[5-(2-Thienyl)thien-2-yl]pyridine (4b). 5-(2,2′-Bithienyl)magnesium bromide was prepared by adding a solution of 5-bromo-2,2′-bithiophene[54] (1.72 g, 7.01 mmol) in anhydrous diethyl ether (5 mL) to a suspension of magnesium (0.21 g, 8.73 mmol) in the same solvent (10 mL). The reaction mixture was refluxed for 45 min under nitrogen. After cooling, the Grignard solution was added dropwise to a stirred suspension of 4-bromopyridine (0.95 g, 6.01 mmol) and $PdCl_2$(dppf) (0.04 g, 0.05 mmol) in the same solvent (15 mL), maintaining the temperature at −20 °C. After being stirred for 4 h at 0−5 °C and overnight at room temperature, the reaction mixture was poured into a saturated aqueous ammonium chloride solution (30 mL), and the aqueous layer was extracted with methylene chloride (4 × 30 mL). The combined organic layers were washed with H_2O and dried, and the solvent was evaporated to leave a brown solid (1.20 g), which was submitted to flash chromatography (diethyl ether−petroleum ether 1:1) on silica gel. The title product was obtained as a yellow solid (0.88 g, 3.61 mmol, 60%): mp 147−148 °C. A pure analytical sample was obtained by sublimation (110 °C/0.005 mmHg): mp 148 °C; ^{1}H NMR ($CDCl_3$) δ 8.57 (d, 2 H, J = 6.1), 7.44 (d, 2 H, J = 6.1), 7.41 (d, 1 H, J = 3.9), 7.26 (d, 1 H, J = 5.1), 7.23 (d, 1 H, J = 3.7), 7.16 (d, 1 H, J = 3.9), 7.03 (dd, 1 H, J = 5.1, 3.7). Anal. Calcd for $C_{13}H_9NS_2$: C, 64.15; H, 3.74; N, 5.76. Found: C, 64.24; H, 3.68; N, 5.58.

4-[[5-(5-Bromothien-2-yl)]thien-2-yl]pyridine (3b). A solution of *N*-bromosuccinimide (0.40 g, 2.2 mmol) in anhydrous DMF (25 mL) was added dropwise to a solution of 4-[5-(2-thienyl)thien-2-yl]pyridine (**4b**) (0.50 g, 2.0 mmol) in the same solvent (25 mL) under nitrogen in the dark. After being stirred for 2 h at room temperature, keeping the reaction flask removed from light, the mixture was poured onto ice (50 mL) and extracted with methylene chloride (4 × 40 mL). The combined organic layers were washed with H_2O, dried, and evaporated to dryness to give the product as a light brown solid (0.65 g, 2.0 mmol, 100%): mp 153 °C (EtOH); ^{1}H NMR ($CDCl_3$) δ 8.57 (d, 2 H, J = 5.9), 7.42 (d, 2 H, J = 5.9), 7.39 (d, 1 H, J = 3.9), 7.10 (d, 1 H, J = 3.9), 6.99 (d, 1 H, J = 3.9), 6.97 (d, 1 H, J = 3.9). Anal. Calcd for $C_{13}H_8BrNS_2$: C, 48.45; H, 2.51; N, 4.35. Found: C, 48.11; H, 2.71; N, 4.52.

(53) Preliminary EFISH measures for compounds **1a** and **1c** in $CHCl_3$ solutions indicate $\beta\mu$ values of ca. −7000 and −13000 × 10^{-48} esu at λ = 1.9 μm, respectively. Full data of the measures currently in progress will be reported elsewhere.

(54) Rossi, R.; Carpita, A.; Ciofalo, M.; Nouben, J. L. *Gazz. Chim. Ital.* **1985**, *115*, 575.

4-[[5-[5-(Dicyanomethanido)thien-2-yl]]thien-2-yl]pyridine Sodium Salt (2b). Malononitrile (0.32 g, 4.77 mmol) was added to an ice-cooled suspension of sodium hydride (0.38 g, 60% oily, 9.50 mmol) in anhydrous 1,2-dimethoxyethane (30 mL), and under nitrogen atmosphere, the mixture was stirred at room temperature for 30 min. 4-[[5-(5-Bromothien-2-yl)]thien-2-yl]pyridine (**3b**) (0.58 g, 1.80 mmol) and tetrakis(triphenylphosphine)palladium(0) (0.23 g, 0.20 mmol) were added to the above solution, and the mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure, and the resulting solid was taken up with benzene (2 × 10 mL) to eliminate the catalyst and then washed with H_2O (5 mL) to give the product as a red solid (0.52 g, 1.57 mmol, 87%): mp > 240 °C; this was used without further purification in the next step; ^{1}H NMR (DMSO-d_6) δ 8.49 (d, 2 H, J = 6.0), 7.67 (d, 1 H, J = 3.9), 7.53 (d, 2 H, J = 6.0), 7.02 (d, 1 H, J = 3.9), 6.98 (d, 1 H, J = 3.9), 6.03 (d, 1 H, J = 3.9).

2-(4-*N*-Methylpyridinium)-5-[5-(dicyanomethanido)-thien-2-yl]thiene (1b). A procedure similar to that used for the synthesis of 3-(4-*N*-methylpyridinium)-5-(dicyanomethanido)thiophene (**1a**) was employed. From the sodium salt **2b** (0.100 g, 0.33 mmol) and methyl triflate (0.053 g, 0.33 mmol) was obtained the title product as a very dark solid (0.083 g, 0.26 mmol, 78%): mp > 240 °C; ^{1}H NMR (DMSO-d_6) δ 8.65 (d, 2 H, J = 6.7), 8.10 (d, 1 H, J = 4.1), 8.05 (d, 2 H, J = 6.7), 7.27 (d, 1 H, J = 3.9), 7.20 (d, 1 H, J = 3.9), 6.15 (d, 1 H, J = 4.1), 4.15 (s, 3 H). Anal. Calcd for $C_{17}H_{11}N_3S_2$: C, 63.53; H, 3.45; N, 13.07. Found: C, 63.29; H, 3.29; N, 13.12.

2-(4-*N*-Cetylpyridinium)-5-[5-(dicyanomethanido)thien-2-yl]thiophene (1b′). Cetyl triflate (0.114 g, 0.30 mmol) in dry acetone (3 mL) was added dropwise to a suspension of the sodium salt **2b** (0.100 g, 0.30 mmol) in the same solvent (4 mL). After the mixture was stirred for 4 h at room temperature, the precipitate was collected to give the product (0.080 g, 0.15 mmol, 50%) as a dark solid: mp > 240 °C (DMF); ^{1}H NMR (DMSO-d_6) δ 8.67 (d, 2 H, J = 6.4), 8.07 (d, 1 H, J = 3.9), 8.01 (d, 2 H, J = 6.4), 7.24 (d, 1 H, J = 4.3), 7.17 (d, 1 H, J = 4.3), 6.16 (d, 1 H, J = 3.9), 4.35 (t, 2 H, J = 7.0), 1.92−1.80 (m, 2 H), 1.35−1.15 (m, 26 H), 0.82 (t, 3 H, J = 7.1). Anal. Calcd for $C_{32}H_{41}N_3S_2$: C, 72.25; H, 7.78; N, 7.90. Found: C, 72.05; H, 7.83; N, 7.86.

1-(4-Pyridyl)-2-(5-bromothien-2-yl)ethylene (3c). A mixture of 5-bromo-2-(chloromethyl)thiophene[55] (4.60 g, 21.76 mmol) and triethyl phosphite (3.60 g, 21.76 mmol) was refluxed for 6 h at 110 °C. The resulting oil was heated at 200 °C and 1 mmHg in a Kugelrohr apparatus to distill low-boiling components and leave the diethyl [(5-bromothien-2-yl)methyl]phosphonate (6.02 g, 19.22 mmol, 88%) as a lightly red oily residue: this was used for subsequent steps without further purification: ^{1}H NMR ($CDCl_3$) δ 6.88 (d, 1 H, J = 3.7), 6.71 (tt, 1 H, J(PH) = 3.7, J = 1.0), 4.07 (dq, 4 H, J(PH) = 8.22), 3.26 (dd, 2 H, J(PH) = 20.7), 1.28 (t, 6 H, J = 7.1). A suspension of sodium hydride in oil (60% by weight; 0.77 g corresponding to 0.46 g, 19.2 mmol) was thoroughly washed with anhydrous THF and finally suspended in the same solvent (50 mL). A solution of diethyl [(5-bromothien-2-yl)methyl]phosphonate (5.98 g, 19.1 mmol) in anhydrous THF (20 mL) was first added to this suspension kept under nitrogen, followed by the addition of a solution of 4-pyridinecarbaldehyde (2.05 g, 19.1 mmol) in the same solvent (25 mL). The mixture was cautiously heated in an oil bath at 50 °C until the evolution of hydrogen had ceased and then at reflux for 1 h. The mixture was poured onto ice (250 mL) to give a brown solid (3.08 g) that was collected and washed with H_2O. After drying, sublimation afforded the pure product as a light yellow solid (2.72 g, 10.22 mmol, 54%): mp 106−107 °C; ^{1}H NMR ($CDCl_3$) δ 8.54 (d, 2 H, J = 6.1), 7.27 (d, 2 H, J = 6.1), 7.27 (d, 1 H, J = 16.4), 6.97 (d, 1 H, J = 3.9), 6.87 (d, 1 H, J = 3.9), 6.68 (d, 1 H, J = 16.4). Anal. Calcd for $C_{11}H_8BrNS$: C, 49.64; H, 3.03; N, 5.26. Found: C, 49.87; H, 3.29; N, 5.35.

1-(4-Pyridyl)-2-[5-(dicyanomethanido)thien-2-yl]ethylene Sodium Salt (2c). Malononitrile (0.59 g, 9.00 mmol) was added to an ice-cooled suspension of sodium hydride (0.72 g, 60% oily, 18.00 mmol) in anhydrous 1,2-dimethoxyethane (30 mL), and under nitrogen atmosphere, the mixture was stirred at room temperature for 20 min. 1-(4-Pyridyl)-2-(5-bromothien-2-yl)ethylene **(3c)** (1.00 g, 3.76 mmol) and tetrakis(triphenylphosphine)palladium(0) (0.43 g, 0.37 mmol) were added to the above solution, and the mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure, and the resulting solid (2.68 g) was taken up with benzene (2 × 30 mL) and washed with H_2O (40 mL) to give the product as an orange solid (0.95 g, 3.48 mmol, 92%): mp > 240 °C (H_2O); ^{1}H NMR (DMSO-d_6) δ 8.36 (dd, 2 H, J = 6.1, 1.4), 7.50 (d, 1 H, J = 15.9), 7.34 (dd, 2 H, J = 6.1, 1.4), 6.89 (d, 1 H, J = 3.8), 6.24 (d, 1 H, J = 16), 6.02 (d, 1 H, J = 3.8). Anal. Calcd for $C_{14}H_8N_3NaS\cdot H_2O$: C, 57.72; H, 3.46; N, 14.42. Found: C, 57.65; H, 3.66; N, 14.32.

1-(4-*N*-Methylpyridinium)-2-[5-(dicyanomethanido)-thien-2-yl]ethylene (1c). A procedure similar to that used for the synthesis of 2-(4-*N*-methylpyridinium)-5-(dicyanomethanido)thiophene (**1a**) was employed. From the sodium salt **2c** (0.20 g, 0.73 mmol) and methyl triflate (0.12 g, 0.73 mmol) was obtained the title product as a blue solid (0.18 g, 0.68 mmol, 93%): mp > 240 °C; ^{1}H NMR (DMSO-d_6) δ 8.38 (d, 2 H, J = 6.8), 7.96 (d, 1 H, J = 15.2), 7.73 (d, 2 H, J = 6.8), 7.18 (d, 1 H, J = 4.2), 6.32 (d, 1 H, J = 15), 6.25 (d, 1 H, J = 4), 4.00 (s, 3 H). Anal. Calcd for $C_{15}H_{11}N_3S$: C, 67.90; H, 4.18; N, 15.84. Found: C, 67.64; H, 4.32; N, 15.58.

1-(4-*N*-Cetylpyridinium)-2-[5-(dicyanomethanido)thien-2-yl]ethylene (1c′). Cetyl triflate (0.85 g, 2.27 mmol) in dry acetone (13 mL) was added dropwise to a suspension of 1-(4-pyridyl)-2-[5-(dicyanomethanido)thien-2-yl]ethylene sodium salt **(2c)** (0.62 g, 2.27 mmol) in the same solvent (13 mL). The color of the mixture immediately changed from orange to blue. After the mixture was stirred overnight at room temperature, the precipitate was collected and washed with EtOH to give the practically pure product (0.83 g, 1.74 mmol, 77%) as a blue solid: mp 238−239 °C (EtOH); ^{1}H NMR (DMSO-d_6) δ 8.43 (d, 2 H, J = 7.0), 7.96 (d, 1 H, J = 15.1), 7.71 (d, 2 H, J = 7), 7.20 (d, 1 H, J = 4.2), 6.30 (d, 1 H, J = 15), 6.27 (d, 1 H, J = 4), 4.24 (t, 2 H, J = 7.1), 1.85−1.75 (m, 2 H), 1.40−1.10 (m , 26 H), 0.85 (t, 3 H, J = 7.1); UV−vis (DMF) λ_{max} = 629 nm, ϵ = 79 500 ± 400 $M^{-1}cm^{-1}$. Anal. Calcd for $C_{30}H_{41}N_3S$: C, 75.74; H, 8.69; N, 8.83. Found: C, 75.47; H, 8.85; N, 8.69.

4-(5-Formylthien-2-yl)pyridine (5d). A solution of lithium diisopropylamide (LDA) in anhydrous diethyl ether [prepared *in situ* from freshly distilled diisopropylamine (3.16 g, 31.0 mmol) and *n*-BuLi 1.6 M in hexane (19.4 mL, 31.0 mmol) in anhydrous diethyl ether (20 mL) at room temperature under nitrogen] was added dropwise to a solution of 4-(2-thienyl)pyridine (**4a**) (2.50 g, 15.5 mmol) in the same solvent (50 mL) at −10 °C under nitrogen. After the mixture was stirred for 1 h at room temperature, a solution of anhydrous DMF (2.27 g, 31.1 mmol) in anhydrous diethyl ether (10 mL) was added. The reaction mixture was stirred for 3 h at room temperature, poured into a saturated aqueous solution of ammonium chloride (600 mL), and extracted with diethyl ether (4 × 400 mL). The solvent was removed from the dried extracts to give the crude product as a brown solid (2.01 g, 10.6 mmol, 67%): mp 107−109 °C. A sample was purified by recrystallization to give a pale yellow solid: mp 131−132 °C (H_2O) (lit.[25] mp 135−136 °C); ^{1}H NMR ($CDCl_3$) δ 9.95 (s, 1 H), 8.69 (d, 2 H, J = 6.0), 7.79 (d, 1 H, J = 4.0), 7.56 (d, 1 H, J = 4.0), 7.53 (d, 2 H, J = 6.0).

1-[5-(4-Pyridyl)thien-2-yl]-2-(5-bromothien-2-yl)ethylene (3d). A suspension of sodium hydride in oil (60% by weight; 0.29 g corresponding to 0.17 g, 7.2 mmol) was thoroughly washed with anhydrous THF and finally suspended in THF (15 mL). A solution of diethyl [(5-bromothien-2-yl)methyl]phosphonate (2.50 g, 7.99 mmol) (prepared as in the synthesis of **3c**) in THF (10 mL) was first added to this suspension kept under nitrogen, followed after 10 min by the addition of a solution of 4-(5-formylthien-2-yl)pyridine (**5d**) (1.001 g, 5.28 mmol) in the same solvent (7 mL). The mixture was cautiously heated in an oil bath at 50 °C until the evolution of hydrogen had ceased and then at reflux for 2 h. The mixture was allowed to cool to room temperature, poured into a saturated aqueous solution of ammonium chloride (80 mL), and extracted with chloroform (4 × 100 mL). The solvent was removed from the dried extracts to give a brown solid (3.6

(55) Gronowitz, S.; Lilijefors, S. *Chem. Scr.* **1979**, *13*, 39.

g), which was submitted to flash chromatography (AcOEt) on silica gel to provide the product as a yellow solid (1.05 g, 3.02 mmol, 57%): mp 125 °C. An analytical pale yellow sample was obtained by recrystallization: mp 140 °C (AcOEt); ^{1}H NMR ($CDCl_3$) δ 8.58 (d, 2 H, J = 6.0), 7.48 (d, 2 H, J = 6.0), 7.42 (d, 1 H, J = 4.7), 7.05 (d, 1 H, J = 4.7), 6.95 (d, 1 H, J = 3.9), 6.93 (d, 1 H, J = 15.7), 6.88 (d, 1 H, J = 15.7), 6.81 (d, 1 H, J = 3.9). Anal. Calcd for $C_{15}H_{10}BrNS_2$: C, 51.74; H, 2.89; N, 4.02. Found: C, 51.57; H, 2.99; N, 4.28.

1-[5-(4-Pyridyl)thien-2-yl]-2-[5-(dicyanomethanido)-thien-2-yl]ethylene Sodium Salt (2d). A procedure similar to that used for the synthesis of 1-(4-pyridyl)-2-[5-(dicyanomethanido)thien-2-yl]ethylene sodium salt (**2c**) was employed. From 1-[5-(4-pyridyl)thien-2-yl]-2-(5-bromothien-2-yl)ethylene (**3d**) (0.505 g, 1.45 mmol), malononitrile (0.190 g, 2.88 mmol), sodium hydride (0.24 g, 60% oily, 5.9 mmol), and tetrakis(triphenylphosphine)palladium(0) (0.154 g, 0.133 mmol), the product was obtained as a reddish solid (0.50 g, 1.40 mmol, 97%): mp > 240 °C; this was used for the subsequent step without further purification; an analytical sample was obtained after washing with H_2O and EtOH at room temperature: ^{1}H NMR (DMSO-d_6) δ 8.51 (d, 2 H, J = 6.2), 7.68 (d, 1H, J = 3.9), 7.55 (d, 2 H, J = 6.2), 7.07 (d, 1 H, J = 3.9), 7.02 (d, 1 H, J = 14.6), 6.84 (d, 1 H, J = 3.7), 6.53 (d, 1 H, J = 15.6), 6.00 (d, 1 H, J = 3.7). Anal. Calcd for $C_{18}H_{10}N_3S_2Na\cdot 1/3H_2O$: C, 59.82; H, 2.97; N, 11.63. Found: C, 59.97; H, 2.98; N, 11.87.

1-[5-(4-*N*-Methylpyridinium)thien-2-yl]-2-[5-(dicyanomethanido)thien-2-yl]ethylene (1d). A procedure similar to that used for the synthesis of 2-(4-*N*-methylpyridinium)-5-(dicyanomethanido)thiophene (**1a**) was employed. From the sodium salt **2d** (0.518 g, 1.46 mmol) and methyl triflate (0.239 g, 1.457 mmol) was obtained the title product as a dark brown-violet solid (0.301 g, 0.866 mmol, 59%): mp > 240 °C. A pure analytical sample was obtained by recrystallization from EtOH/DMF: ^{1}H NMR (DMSO-d_6) δ 8.68 (d, 2 H, J = 7.5), 8.11 (d, 1 H, J = 3.5), 8.08 (d, 2 H, J = 7.5), 7.24 (d, 1 H, J = 3.5), 7.22 (d, 1 H, J = 16.0), 6.95 (d, 1 H, J = 4.3), 6.58 (d, 1 H, J = 16.1), 6.06 (d, 1 H, J = 4.3), 4.30 (s, 3 H). Anal. Calcd for $C_{19}H_{13}N_3S_2$: C, 65.69; H, 3.77; N, 12.10. Found: C, 66.06; H, 3.70; N, 11.98.

1-(4-Pyridyl)-2-(2-thienyl)ethylene (6). A procedure similar to that used for the synthesis of 1-[5-(4-pyridyl)thien-2-yl]-2-(5-bromothien-2-yl)ethylene (**3d**) was employed. From diethyl (2-thienylmethyl)phosphonate[56] (2.001 g, 8.54 mmol), 4-pyridinecarbaldehyde (1.002 g, 9.35 mmol), and sodium hydride (0.56 g, 60% oily, 14.1 mmol) was obtained the practically pure product as a yellow solid (1.50 g, 8.01 mmol, 94%): mp 143−145 °C. An analytical sample was purified by recrystallization: mp 145−147 °C (benzene) (lit.[26] mp 151−151.5 °C); ^{1}H NMR ($CDCl_3$) δ 8.54 (d, 2 H, J = 5), 7.41 (d, 1 H, J = 16.1), 7.29 (d, 2 H, J = 5), 7.27 (d, 1 H, J = 5.1), 7.14 (d, 1 H, J = 3.7), 7.00 (dd, 1 H, J = 5.0, 3.6), 6.81 (d, 1 H, J = 16.1). Anal. Calcd for $C_{11}H_9NS$: C, 70.6; H, 4.8; N, 7.5. Found: C, 70.8; H, 4.5; N, 7.2.

1-(4-Pyridyl)-2-(5-formylthien-2-yl)ethylene (5e). A procedure similar to that used for the synthesis of 4-(5-formylthien-2-yl)pyridine (**5d**) was employed. From diisopropylamine (0.816 g, 8.01 mmol), *n*-BuLi 1.6 M in hexane (5 mL, 8.0 mmol), 1-(4-pyridyl)-2-(2-thienyl)ethylene (**6**) (0.998 g, 5.33 mmol), and anhydrous DMF (0.816 g, 11.2 mmol) was obtained the crude title product as a brownish solid (0.750 g, 3.48 mmol, 65%): mp 97−98 °C. This was used without further purification in the next step. A pure analytical yellow sample was obtained by recrystallization from *i*-PrOH and sublimation (90 °C/0.01 mmHg): mp 98 °C; ^{1}H NMR ($CDCl_3$) δ 9.90 (s, 1 H), 8.56 (d, 2 H, J = 6.2), 7.67 (d, 1 H, J = 4.0), 7.38 (d, 1 H, J = 16.1), 7.33 (d, 2 H, J = 6.2), 7.22 (d, 1 H, J = 4.0), 7.01 (d, 1 H, J = 16.0). Anal. Calcd for $C_{12}H_9NOS$: C, 66.94; H, 4.21; N, 6.51. Found: C, 66.83; H, 4.16; N, 6.49.

1-[5-[1-(4-Pyridyl)ethen-2-yl]thien-2-yl]-2-(5-bromothien-2-yl)ethylene (3e). A suspension of sodium hydride in oil (0.370 g, 60% oily, 9.25 mmol) was suspended in anhydrous THF (25 mL) under nitrogen. A solution of diethyl [(5-bromothien-2-yl)methyl]phosphonate (2.30 g, 7.35 mmol) in THF (10 mL) was first added to this suspension kept under nitrogen, followed after 10 min by the addition of a solution of 1-(4-pyridyl)-2-(5-formylthien-2-yl)ethylene (**5e**) (1.35 g, 6.27 mmol) in the same solvent (10 mL). The obtained very dark mixture was refluxed for 2 h, cooled to room temperature, and then poured into a saturated aqueous solution of ammonium chloride (120 mL). The brown precipitate was collected to give the product (1.59 g, 4.25 mmol, 68%): mp 135−140 °C. An analytical yellow sample was obtained by recrystallization: mp 142 °C (*i*-PrOH); ^{1}H NMR ($CDCl_3$) δ 8.55 (d, 2 H, J = 6), 7.35 (d, 1 H, J = 16.0), 7.30 (m, 3 H), 7.02 (d, 1 H, J = 3.8), 6.98 (d, 1 H, J = 18.8), 6.95 (d, 1 H, J = 3.8), 6.90 (d, 1 H, J = 5.8), 6.77 (d, 1 H, J = 18.6), 6.76 (d, 1 H, J = 16.0). Anal. Calcd for $C_{17}H_{12}BrNS_2$: C, 54.55; H, 3.23; N, 3.74. Found: C, 54.65; H, 3.47; N, 3.66.

1-[5-[1-(4-Pyridyl)ethen-2-yl]thien-2-yl]-2-[5-(dicyanomethanido)thien-2-yl]ethylene Sodium Salt (2e). A procedure similar to that used for the synthesis of 1-(4-pyridyl)-2-[5-(dicyanomethanide)thien-2-yl]ethylene sodium salt (**2c**) was employed. From 1-[5-[1-(4-pyridyl)ethen-2-yl]thien-2-yl]-2-(5-bromothien-2-yl)ethylene (**3e**) (0.300 g, 0.802 mmol), malononitrile (0.107 g, 1.60 mmol), sodium hydride (0.13 g, 60% oily, 3.3 mmol), and tetrakis(triphenylphosphine)palladium(0) (0.092 g, 0.080 mmol) was obtained the title product as a reddish solid (0.295 g, 0.774 mmol, 97%): mp > 240 °C. This was used for subsequent step without further purification: ^{1}H NMR (DMSO-d_6) δ 8.49 (d, 2 H, J = 5.9), 7.67 (d, 1 H, J = 16.0), 7.49 (d, 2 H, J = 6.1), 7.15 (d, 1 H, J = 3.8), 6.97 (d, 1 H, J = 3.9), 6.95 (d, 1 H, J = 15.5), 6.84 (d, 1 H, J = 3.8), 6.75 (d, 1 H, J = 16.0), 6.51 (d, 1 H, J = 15.6), 5.99 (d, 1 H, J = 3.8).

1-[5-[1-(4-*N*-Methylpyridinium)ethen-2-yl]thien-2-yl]-2-[5-(dicyanomethanido)thien-2-yl]ethylene (1e). A procedure similar to that used for the synthesis of 2-(4-*N*-methylpyridinium)-5-(dicyanomethanido)thiophene (**1a**) was employed. From the sodium salt **2e** (0.416 g, 1.09 mmol) and methyl triflate (0.178 g, 1.09 mmol) was obtained the title product as a brown-reddish solid (0.33 g, 0.88 mmol, 81%): mp > 240 °C; ^{1}H NMR (DMSO-d_6) δ 8.71 (d, 2 H, J = 6.3), 8.11 (d, 1 H, J = 16.3), 8.07 (d, 2 H, J = 6.9), 7.35 (d, 1 H, 3.8), 7.07 (d, 1 H, J = 3.8), 7.06 (d, 1 H, J = 15.4), 6.93 (d, 1 H, J = 16.2), 6.90 (d, 1 H, J = 3.8), 6.55 (d, 1 H, J = 15.5), 6.04 (d, 1 H, J = 3.8), 4.20 (s, 3 H); HRMS m/z calcd for $C_{21}H_{15}N_3S_2$ 373.0707, found 373.0721.

5-(4-Pyridyl)-2,2′:5′,2″-terthiophene (7). A solution of 5-(2,2′-bithienyl)magnesium bromide in anhydrous diethyl ether (25 mL), prepared from 5-bromo-2,2′-bithiophene (1.40 g, 5.81 mmol) and magnesium (0.28 g, 11.5 mmol) as described in the synthesis of 4-[5-(2-thienyl)thien-2-yl]pyridine (**4b**), was added dropwise to a stirred suspension of 4-(5-bromothien-2-yl)pyridine (**3a**) (1.22 g, 5.00 mmol) and $PdCl_2$(dppf) (0.04 g, 0.05 mmol) in the same solvent (25 mL) at room temperature. After being stirred overnight at room temperature, the reaction mixture was poured into a saturated aqueous ammonium chloride solution (100 mL), and the resulting precipitate was collected by filtration and washed with diethyl ether to give the product as a yellow solid (2.48 g, 7.62 mmol, 66%): mp 239 °C (EtOH/DMF); ^{1}H NMR ($CDCl_3$) δ 8.57 (d, 2 H, J = 6.1), 7.46 (d, 2 H, J = 6.1), 7.44 (d, 1 H, J = 3.9), 7.24 (d, 1 H, J = 4.9), 7.19 (d, 1 H, J = 3.6), 7.18 (d, 1 H, J = 3.9), 7.15 (d, 1 H, J = 3.8), 7.10 (d, 1 H, J = 3.8), 7.03 (dd, 1 H, J = 4.9, 3.6). Anal. Calcd for $C_{17}H_{11}NS_3$: C, 62.73; H, 3.41; N, 4.30. Found: C, 62.62; H, 3.25; N, 4.24.

5-(4-Pyridyl)-5″-bromo-2,2′:5′,2″-terthiophene (8). A solution of *N*-bromosuccinimide (0.73 g, 4.1 mmol) in anhydrous DMF (50 mL) was added dropwise to a suspension of 5-(4-pyridyl)-2,2′:5′,2″-terthiophene (**7**) (1.20 g, 3.7 mmol) in the same solvent (70 mL) under nitrogen in the dark. After being stirred overnight at room temperature, keeping the reaction flask removed from light, the mixture was poured onto ice (120 mL) and the resulting precipitate collected by filtration, giving the product as a solid (0.90 g, 2.2 mmol, 61%): mp 240 °C (EtOH/DMF); ^{1}H NMR (DMSO-d_6) δ 8.64−8.52 (m, 2 H), 7.79 (d, 1 H, J = 3.9), 7.67−7.61 (m, 2 H), 7.45 (d, 1 H, J = 3.9), 7.39 (d, 1 H, J = 3.8), 7.31 (d, 1 H, J = 3.8), 7.23 (d, 1 H, J = 3.0), 7.21 (d, 1 H, J = 3.0). Anal. Calcd for

(56) Kellogg, R. M.; Groen, M. B.; Wynberg, H. *J. Org. Chem.* **1967**, *32*, 3093.

$C_{17}H_{10}BrNS_3$: C, 50.49; H, 2.50; N, 3.46. Found: C, 50.22; H, 2.53; N, 3.68.

2-Bromo-3-octylthiophene (9). A solution of *N*-bromosuccinimide (9.06 g, 50.9 mmol) in anhydrous DMF (40 mL) was added dropwise to a solution of 3-octylthiophene[57] (9.00 g, 45.8 mmol) in the same solvent (40 mL) under nitrogen in the dark. After being stirred for 2 h at room temperature, keeping the reaction flask repaired from light, the mixture was poured onto ice (100 mL) and extracted with diethyl ether (3 × 100 mL). The combined organic layers were washed with H_2O, dried, and evaporated to dryness to leave a yellowish oil (11.6 g), which was submitted to flash chromatography (CH_3CN) on RP-18 solid phase. The title product was obtained as a colorless oil[57] (9.99 g, 36.3 mmol, 79%): ^{1}H NMR ($CDCl_3$) δ 7.18 (d, 1 H, J = 5.7), 6.79 (d, 1 H, J = 5.7), 2.56 (t, 2 H, J = 7.5), 1.58−1.50 (m, 2 H), 1.34−1.21 (m, 10 H), 0.89 (t, 3 H, J = 4.5).

5-(4-Pyridyl)-3″-octyl-2,2′:5′,2″-terthiophene (10). A solution of 2-bromo-3-octylthiophene (**9**) (0.95 g, 3.4 mmol) in anhydrous diethyl ether (7 mL) was added dropwise to a suspension of magnesium (0.17 g, 6.9 mmol) and 1,2-dibromoethane (8 μL) in the same solvent (10 mL), while the flask was kept under nitrogen dipped in a ultrasound bath maintained at 30 °C. After 20 min in the ultrasound bath, the obtained Grignard solution was added dropwise to a stirred suspension of 4-[[5-(5-bromothien-2-yl)]thien-2-yl]pyridine (**3b**) (1.00 g, 3.10 mmol) and $PdCl_2$(dppf) (0.02 g, 0.03 mmol) in anhydrous diethyl ether (15 mL) under nitrogen at room temperature. After being stirred for 5 h at room temperature, the reaction mixture was poured into a saturated aqueous ammonium chloride solution (30 mL), and the aqueous layer was extracted with methylene chloride (3 × 30 mL). The combined organic layers were washed with H_2O and dried and the solvent evaporated to leave a solid (1.83 g), which was submitted to flash chromatography (diethyl ether) on silica gel. The title product was obtained as a yellow solid (0.93 g, 2.1 mmol, 68%): mp 88 °C (EtOH); ^{1}H NMR ($CDCl_3$) δ 8.60 (d, 2 H, J = 6.1), 7.45 (d, 2 H, J = 6.1), 7.42 (d, 1 H, J = 3.9), 7.18 (d, 1 H, J = 5.6), 7.12 (d, 1 H, J = 3.9), 7.01 (d, 1 H, J = 3.9), 6.98 (d, 1 H, J = 3.9), 6.79 (d, 1 H, J = 5.6), 2.55 (t, 2 H, J = 7.8), 1.65−1.45 (m, 2 H), 1.40−1.15 (m, 10 H), 0.85 (t, 3 H, J = 7.1). Anal. Calcd for $C_{25}H_{27}NS_3$: C, 68.59; H, 6.23; N, 3.20. Found: C, 68.65; H, 6.05; N, 3.31.

5-(4-Pyridyl)-5″-bromo-3″-octyl-2,2′:5′,2″-terthiophene (11). A solution of *N*-bromosuccinimide (0.339 g, 1.90 mmol) in anhydrous DMF (6 mL) was added dropwise to a stirred suspension of 5-(4-pyridyl)-3″-octyl-2,2′:5′,2″-terthiophene (**10**) (0.750 g, 1.71 mmol) in the same solvent (6 mL) under nitrogen in the dark. After being stirred for 4 h at room temperature, keeping the reaction flask removed from light, the mixture was poured onto ice (12 mL), and the resulting precipitate was collected by filtration to give the product as an orange solid (0.866 g, 1.68 mmol, 98%): mp 170 °C (EtOH); ^{1}H NMR ($CDCl_3$) δ 8.58 (d, 2 H, J = 4.8), 7.61 (d, 2 H, J = 4.8), 7.54 (d, 1 H, J = 3.9), 7.24 (d, 1 H, J = 3.9), 7.22 (d, 1 H, J = 3.8), 7.01 (d, 1 H, J = 3.8), 6.91 (s, 1 H), 2.70 (t, 2 H, J = 7.8), 1.70−1.50 (m, 2 H), 1.45−1.20 (m, 10 H), 0.90 (t, 3 H, J = 7.1). Anal. Calcd for $C_{25}H_{26}BrNS_3$: C, 58.12; H, 5.08; N, 2.71. Found: C, 58.26; H, 4.95; N, 2.55.

5-(4-Pyridyl)-5″-dicyanomethanide-3″-octyl-2,2′:5′,2″-terthiophene Sodium Salt (12). A procedure similar to that used for the synthesis of the sodium salt (**2c**) was employed. From 5-(4-pyridyl)-5″-bromo-3″-octyl-2,2′:5′,2″-terthiophene (**11**) (0.780 g, 1.51 mmol), malononitrile (0.264 g, 3.99 mmol), sodium hydride (0.32 g, 60% oily, 8.0 mmol), and tetrakis(triphenylphosphine)palladium(0) (0.179 g, 0.16 mmol) was obtained the title product as a reddish solid (0.617 g, 1.18 mmol, 78%): mp > 240 °C (EtOH); ^{1}H NMR (DMSO-d_6) δ 8.56 (d, 2 H, J = 6.1), 7.78 (d, 1 H, J = 3.9), 7.62 (d, 2 H, J = 6.1), 7.33 (d, 1 H, J = 3.9), 7.30 (d, 1 H, J = 3.9), 6.82 (d, 1 H, J = 3.9), 5.97 (s, 1 H), 2.55 (t, 2 H, J = 7.8), 1.65−1.48 (m, 2 H), 1.40−1.15 (m, 10 H), 0.82 (t, 3 H, J = 7.1). Anal. Calcd for $C_{28}H_{26}N_3S_3Na$: C, 64.20; H, 5.01; N, 8.02. Found: C, 63.98; H, 5.46; N, 7.63.

(57) McCullough, R. D.; Lowe, R. D.; Jayaraman, M.; Anderson, D. L. *J. Org. Chem.* **1993**, *58*, 904−912.

***N*-Methyl-4-(2-thienyl)pyridinium Triflate (15a).** Methyl triflate (67.8 mL, 0.101 g, 0.62 mmol) was added to a solution of 4-(2-thienyl)pyridine (**4a**) (0.100 g, 0.62 mmol) in dry acetone (1.5 mL) at room temperature. After the mixture was stirred overnight, the solvent was removed under reduced pressure to leave a solid that was taken up with dry diethyl ether (3 mL). The resulting solid was separated by filtration to give the practically pure product as a yellow solid (0.053 g, 0.16 mmol, 26%): mp = 135 °C (*i*-PrOH); ^{1}H NMR (DMSO-d_6) δ 8.85 (d, 2 H, J = 6.8), 8.35 (d, 2 H, J = 6.8), 8.23 (d, 1 H, J = 3.9), 8.01 (d, 1 H, J = 5.0), 7.39 (dd, 1 H, J = 5.0, 3.9), 4.26 (s, 3 H). Anal. Calcd for $C_{11}H_{10}NS_2F_3O_3 \cdot 1/2H_2O$: C, 39.52; H, 3.32; N, 4.19. Found: C, 39.86; H, 3.12; N, 4.60.

2-Cyano-2-phenylpropiononitrile (16). A solution of phenylmalononitrile[29] (0.088 g, 0.62 mmol) in dry acetone (1.5 mL) was added to a suspension of K_2CO_3 in the same solvent (2 mL). After the mixture was stirred for 10 min, methyl iodide (46.3 mL, 0.106 g, 0.74 mmol) was added. After the resulting mixture was stirred overnight at room temperature, K_2CO_3 solid was discarded, and the filtered solution was evaporated to dryness to leave a residue that was taken up with diethyl ether (6 mL). From the filtered solution, the solvent was removed and the residue submitted to distillation under reduced pressure to give the pure product (0.084 g, 0.53 mmol, 87%): bp = 60 °C/0.02 mmHg); ^{1}H NMR (DMSO-d_6) δ 7.69−7.64 (m, 2 H), 7.61−7.50 (m, 3 H), 2.19 (s, 3 H). Anal. Calcd for $C_{10}H_8N_2$: C, 76.90; H, 5.16; N, 17.94. Found: C, 76.58; H, 5.12; N, 17.76.

Intermolecular Competitive Reaction with Methyl Triflate or Methyl Iodide. A solution of MeONa (0.033 g, 0.62 mmol) (freshly prepared from sodium turnings and absolute MeOH) in absolute MeOH (1 mL) was added to a solution of phenylmalononitrile[29] (0.088 g, 0.62 mmol) in the same solvent (1 mL). After the mixture was stirred for 15 min, the solvent was removed under reduced pressure to give phenylmalononitrile sodium salt (**14**) as a light yellow solid: ^{1}H NMR (DMSO-d_6) δ 6.99 (t, 2 H, J = 7.8), 6.70 (d, 2 H, J = 7.9), 6.48 (t, 1 H, J = 7.4). Dry acetone (1 mL) was added to the solid **14** and the obtained solution mixed with a solution of 4-(2-thienyl)pyridine (**4a**) (0.100 g, 0.62 mmol) in dry acetone (1 mL). Methyl triflate (67.8 mL, 0.101 g, 0.62 mmol) was added in five equivalent portions every 15 min at room temperature. After 1 h, a sample was evaporated to dryness and the solid analyzed by ^{1}H NMR (DMSO-d_6). The relative ratio of *N*-methyl-4-(2-thienyl)pyridinium triflate (**15a**) and 2-cyano-2-phenylpropiononitrile (**16**) was determined by comparison with the spectra of the pure compounds. The same procedure and molar quantities were used in the reaction with methyl iodide.

2-(4-1*H*-Pyridinium)-5-(dicyanomethanido)thiophene (17). Aqueous HCl (10%) was added dropwise to a solution of 4-[5-(dicyanomethanido)thien-2-yl]pyridine sodium salt (**2a**) (0.050 g, 0.20 mmol) in H_2O (3 mL) until pH 1 was reached. A violet precipitate was readily obtained. After being stirred for 15 min at room temperature, the precipitate was collected, washed with H_2O (1 mL), and dried under reduced pressure at 60 °C to give the practically pure product (0.026 g, 0.11 mmol, 55%) as a violet solid: mp > 240 °C (DMF); ^{1}H NMR (DMSO-d_6) δ 13.8 (broad, 1 H), 8.25 (d, 2 H, J = 6.8), 7.92 (d, 1 H, J = 4.4), 7.56 (d, 2 H, J = 6.8), 6.39 (d, 1 H, J = 4.4). Anal. Calcd for $C_{12}H_7N_3S$: C, 63.98; H, 3.13; N, 18.65. Found: C, 63.48; H, 3.29; N, 18.38.

Acknowledgment. We are grateful to Prof. Antonio Selva for providing HRMS data.

Supporting Information Available: Copies of the ^{1}H NMR (DMSO-d_6) spectrum (full and aromatic region) of compound **1e** (2 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO970059X