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Merocyanine Dyes Containing Imide Functional Groups: Synthesis and Studies on Hydrogen Bonding to Melamine Receptors

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The condensation of the CH acidic heterocycles 4-alkyl-2,6-dioxo-1,2,5,6-tetrahydropyridine-3-carbonitrile (**5a** and **b**) and barbituric acid (**15**) with electron-rich thiophene aldehydes and benzaldehyde derivatives affords the respective monomethine dyes **10**−**13** and **17**−**19**. The formylation of **5a,b** and **15** with *N*,*N*′-diphenylformamidine or dibutylformamide in acetic anhydride and further reaction with 4-picolinium salts **9a,b** provide the dimethine dyes **14** and **20a,b**. Triple hydrogen bonding of the imide groups of merocyanine dyes **10**−**14** has been investigated by NMR titration experiments with melamine **21**. Despite rather pronounced variations of the charge-transfer properties within the given series of dyes, minor changes of their binding constants have been observed. These results could be rationalized by semiempirical calculations that reveal small changes in the charge density at the oxygen functionalities involved in hydrogen bonding upon variation of the electron-donating carbocyclic or heterocyclic groups at the terminal double bond. Although the binding constants for triple hydrogen bonding between imides and melamines are rather weak in chloroform, they proved to be strong enough to facilitate dissolution of some of these dyes in aliphatic solvents by coordination to amphiphilic melamines and dipolar aggregation. UV−vis spectral changes observed in methylcyclohexane vs chloroform suggest the formation of colloidal assemblies through noncovalent polymerization.

Introduction

Imide functional groups are important structural constituents in pigment dyestuffs (Chart 1) because these functional groups form hydrogen-bonded networks, which contribute to the high lattice energies required to achieve the desired insolubility of pigment particles.[1]

Recently, the dissolution of dyes with imide functional groups has been realized in supramolecular assemblies by means of triple hydrogen bonding to complementary melamines and well-ordered self-assembled monolayers, double rosettes, and mesoscopic and liquid-crystalline materials have been obtained.[2−6] However, these studies have also provided evidence that the triple hydrogen bonds formed between imides and melamines are too weak (binding constant of about 100 M^{-1}) to effect efficient association under dilute conditions in common organic solvents (e.g., chloroform), and additional noncovalent interactions, cooperativity, or weakly polar aliphatic solvents are required to trigger self-assembly.[5] On the other hand, recent work by Rotello et al.[7] and Smith et al.[8] has demonstrated that the binding constants between imides and diacyl diaminopyridines (diacyl diaminopyridines exhibit similar binding constants as melamines for the coordination to imides)[9] increase considerably upon electrochemical reduction of the imide functionality to the anionic state (Scheme 1). Through this electrochemical triggering, binding constants as high as >10 000 M^{-1} could be achieved. Such strong noncovalent bonding should be enough for self-assembly of the related bis receptors (e.g., bisimides and ditopic melamines) to afford extended oligomeric dye assemblies under reasonable experimental conditions, i.e., in the

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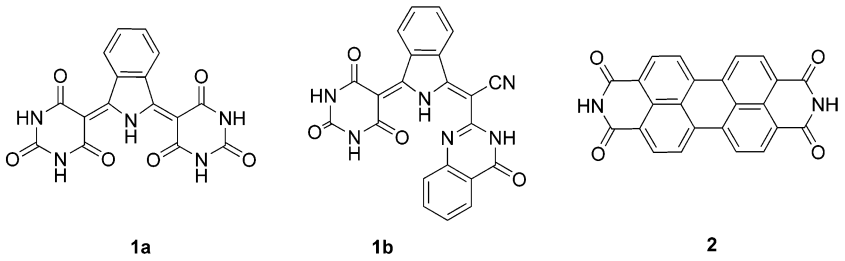
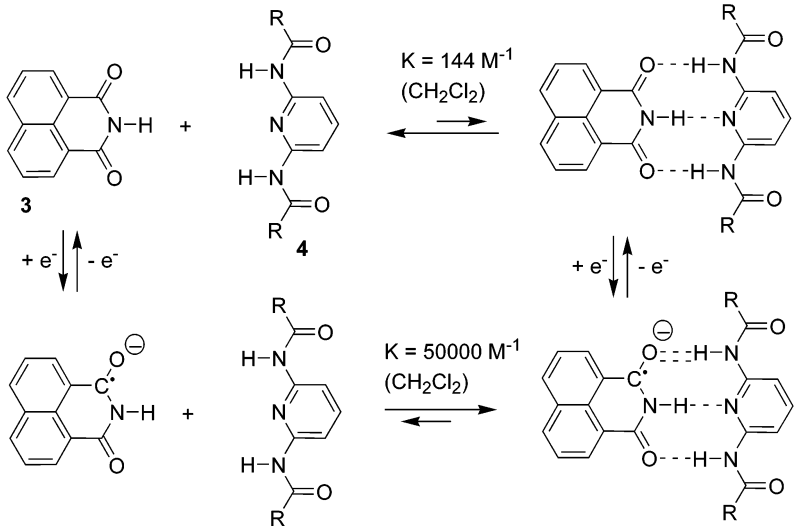
CHART 1. Representative Examples of Pigment Dyestuffs That Contain Hydrogen-Bonded Networks Due to the Imide Functional Groups: Isoindoline Pigments 1a (Pigment Yellow 139) and 1b (Pigment Red 260) and Perylene Pigment 2 (Pigment Violet 29)

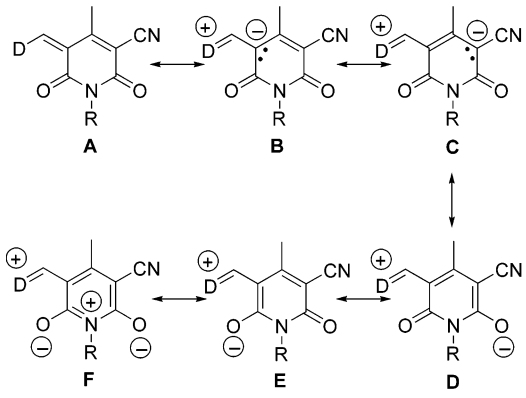


1a **1b** **2**

SCHEME 1. Effect of the Electrochemical Reduction of Imide Functionalities on Binding Constants for Hydrogen Bonding to Diacyl Diaminopyridines According to Ref 8



SCHEME 2. Resonance Structures of Merocyanine Dyes



millimolar regime.[5b] The rationalization for the observed enhancement of hydrogen-bonding propensity of imides upon electrochemical reduction was provided by theoretical studies that assign a major electrostatic contribution to the strength of the hydrogen bond.[10]

During the past years, we have studied merocyanine dyes of the type shown in Scheme 2 (D = electron donor carbo- or heterocycle, R = alkyl) for photorefractive applications and showed that the zwitterionic character of such dyes is highly dependent on the strength of the electron-donor substituent.[11,12] In the case of weak donors such as 4-alkoxyphenyl or 4-dialkylaminophenyl, polyene-type dyes are formed with small ground-state dipole moments and positive solvatochromism, whereas for strong electron donors such as 2-dialkylaminothiophenes or dihydropyridinemethylidene, polymethine-type dyes are formed with large dipole moments and negative solvatochromism. In the simple valence bond description (Scheme 2), the dipolar and the optical properties are explained in terms of charge transfer from the donor carbo- or heterocycle to the acceptor heterocycle suggesting an increase of the electron density at the imide carbonyl groups (resonance structures **D**−**F**) similar to the aforementioned electrochemical reduction. Accordingly, by means of strong electron-donor groups in merocyanine dyes, an increase of their binding strength to melamines seems possible for the dyes with R = H (Scheme 2).

By employment of this strategy, self-assembly of merocyanine dyes and melamine receptors may be achieved

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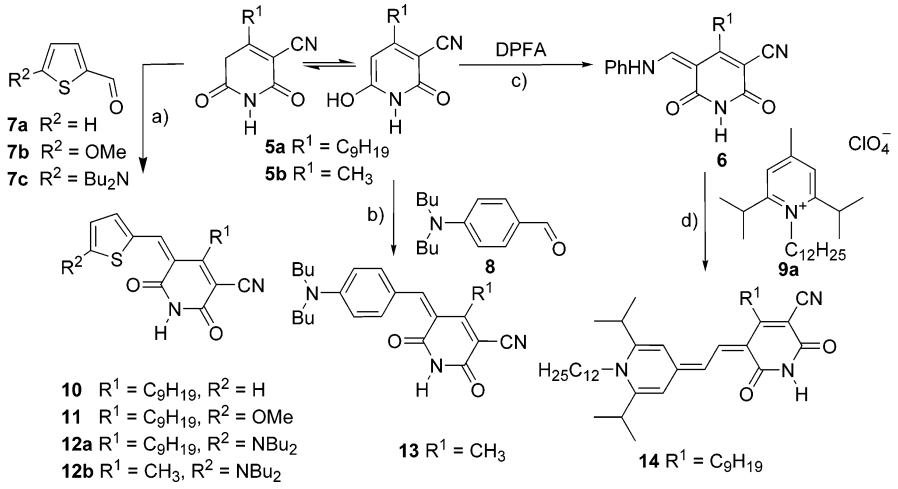
SCHEME 3. Synthesis of Merocyanine Dyes 10−14[a]



[a] (a) Ac_2O, 90 °C, 1.5−2 h, yield 50% of **10**, 48% of **11**, 76% of **12a**, and 74% of **12b**; (b) Ac_2O, 90 °C, 1 h, yield 88%; (c), (d) Ac_2O, room temperature, 0.5 h and 90 °C, 5 min, **9a**, KOAc, 90 °C, 2 h, yield 39% of **14**, (DPFA = *N*,*N*′-diphenylformamidine).

in dilute solutions, and the packing of these dyes in the solid state could be controlled. Here we report our results on the exploration of this strategy, which include the synthesis of properly designed merocyanine dyes with free imide sites (R = H) and the evaluation of their coordination properties to complementary melamine receptors through triple hydrogen bonding.

Results and Discussion

Synthesis. To explore the influence of electron-donating groups on the strength of hydrogen binding, a series of appropriately functionalized merocyanine dyes are required. Thus, the dyes **10**−**13** were synthesized through Knoevenagel condensations of the highly CH-acidic pyridones **5a,b** with thiophen aldehydes **7a**−**c** and benzaldehyde **8**. The dimethine dye **14** was obtained by formylation of pyridone **5a** with *N*,*N*′-diphenylformamidine (DPFA) followed by the reaction with pyridinium salt **9a** according to an earlier reported procedure.[12b,13] In the synthesis of these merocyanine dyes, we have encountered two problems. The first one is related to the low chemical stability of the polyene-type merocyanine dyes.[14] Thus, the derivative corresponding to **13** (Scheme 3) with a 4-butoxyphenyl electron donor group could not be isolated in a pure form and the next more polar dye **14** was so sensitive against bases that its binding to melamine was accompanied by decomposition (probably by retro-Knoevenagel reaction, see ref 2b). The second problem is related to the solubility of merocyanine dyes that decreases significantly with the increasing dipole moment for the present series of dyes. For this reason, solubilizing alkyl groups had to be introduced for the R^1 substituent of the pyridone acceptor heterocycle (**5**) and a dihydropyridine donor with two isopropyl groups has been chosen to obtain a reasonably soluble most polar dye **14**.

A second series of dyes containing barbituric acid acceptor heterocycles was synthesized with the intention to construct polymeric assemblies through coordination of ditopic melamine receptors at both imide groups of the heterocycle. Because of the high CH acidity of barbituric acid (**15**), the same routes were applied as for pyridones **5a,b** to synthesize the dyes **17**−**20** in good yields (Scheme 4).

Binding Studies. To assess the effect of electron-donor carbo- and heterocycles on the binding strength of triple hydrogen bonding of merocyanine dyes to melamines, constant host ^{1}H NMR titration studies[15] were performed in $CDCl_3$. In these experiments the concentrations of the imide dyes were kept constant, while increasing concentrations of the highly soluble complementary melamine **21**[5] were added (Scheme 5, Figure 1). Upon coordination of melamine to imide dyes, the imide proton is deshielded, leading to a strong downfield shift of the signal. This resonance shift was used to calculate the binding constant and the Gibbs binding energy through nonlinear regression analysis, and the data are presented in Table 1.

As shown in Table 1, all binding constants that could be measured with high accuracy are about 120 M^{-1} for the well-soluble dyes with $R^1 = nC_9H_{19}$ (dyes **11**, **12a**, and **14**). Larger values have been measured for the dye **12b** with R^1 = Me and for **10**. However, both of these values are prone to much larger errors because of either low solubility (dye **12b**) or base-catalyzed decomposition (dye **10** upon addition of basic melamine **21**). For dye **13**, this base-mediated decomposition is so fast that the addition of the first drops of melamine solution already caused pronounced destruction of **13**. Despite the fact that merocyanine dyes **11**, **12a**, and **14** exhibit significantly different polarities (as expressed based on the contribution of their zwitterionic resonance structures), their binding constants do not differ accordingly. These results lead to the conclusion that the hydrogen bonding

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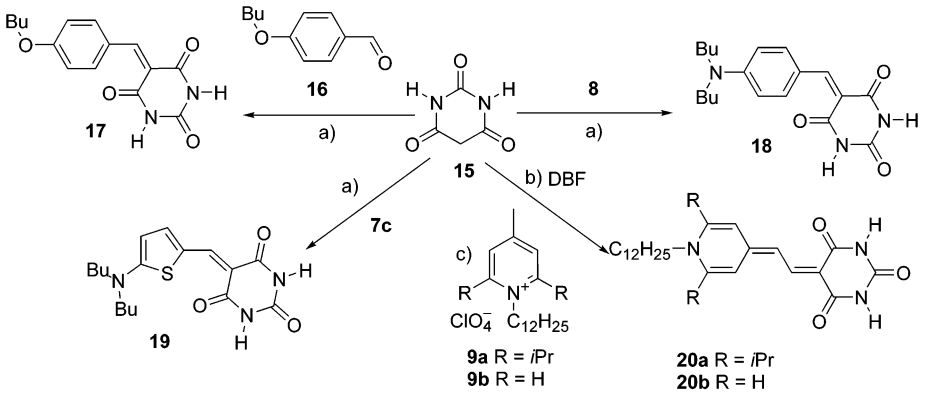
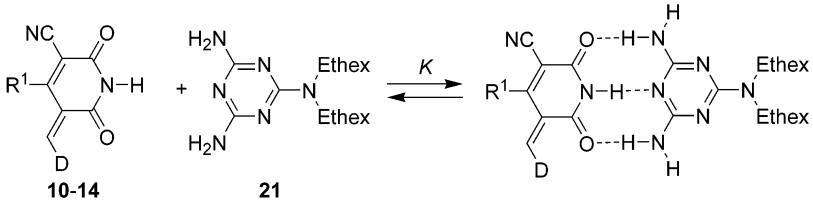
SCHEME 4. Synthesis of Merocyanine Dyes 17−20[a]



[a] (a) Ac_2O, 90 °C, 0.5−2 h, yield 67% of **18**, 39% of **17**, 93% of **19**; (b) Ac_2O, 120 °C, 2 h; (c) Ac_2O, 120 °C, 2 h, yield 66% of **20a,** 29% of **20b** (DBF = dibutylformamide).

SCHEME 5. Formation of Triple Hydrogen-Bonded 1:1 Complexes between Dyes 10−14 and Melamine 21 (R^1 = CH_3 or C_9H_{19}, Ethex = 2-ethylhexyl)



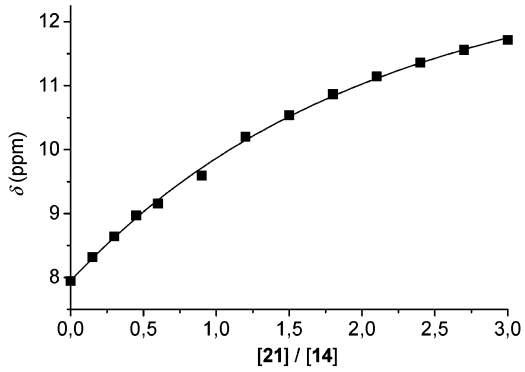


FIGURE 1. Constant host ^1H NMR titration of dye **14** (host) with melamine **21** (guest) in $CDCl_3$ at 300 K and the nonlinear regression curve (—) based on a 1:1 model.[15] The concentration of the dye **14** was kept constant at 5.0 mM.

TABLE 1. Binding Constants of Complexes of Dye 10−14 with Melamine 21 in $CDCl_3$ at 300 K

dye	dipole moment (D)[a]	zwitterionic character (%)[b]	binding constant (M^{-1})	$\Delta G°$ (kJ mol^{-1})
13	10.8	28	*c*	*c*
10	6.6	31	304 ± 21[d]	−14.3[d]
11	8.4	36	117 ± 8	−11.9
12a	14.1	45	123 ± 19	−12.0
12b	14.1	45	170 ± 40	−12.7
14	17.1	60	123 ± 16	−12.0

[a] Determined for related dyes with *n*-butyl substituent at the imide nitrogen and R^1 = Me (ref 11). [b] Calculated based on a two-state model from dipole moments in the ground and the excited state according to ref 11. [c] Binding constant could not be determined because of immediate decomposition of the dye upon addition of melamine. [d] Because of decomposition during the measurements, these values are susceptible to larger errors than those indicated based on the statistical analysis.

strength of merocyanine dyes does not increase with increasing charge transfer from the donor to the acceptor heterocycle.

To rationalize this observation, AM1 calculations were performed. Indeed, these theoretical studies revealed that the charge densities at the imide oxygen atoms did not notably change upon increasing the electron-donor strength from thiophene to dialkylaminothiophene (Figure 2). Instead, the calculation showed that the negative charge is highly delocalized over the whole acceptor heterocycle with the strongest variability at the C5 and C3 centers of the six-membered acceptor heterocycle. Interestingly, these two carbon centers may be regarded as an extension of the polymethine chain. By contrast, the three outer heteroatomic centers (two oxygen atoms and one nitrogen atom of the cyano group) experience a much smaller increase of negative charge. This computational analysis seems to be very reliable because the experimental dipole moment data from Table 1 and the X-ray crystallographic structural data of **12b**[13b] are reproduced well. With regard to the mesomeric formulas in Scheme 2, we have to conclude that structures A, B, and C, with negative charges on the polymethine chain, are most important, whereas D, E, and F, with negative charges on the carbonyl oxygens, are of minor importance. The negligible effect of the increased charge transfer on the hydrogen-bonding strength is in good accordance with this interpretation. On the other hand, further calculations for radical anions derived from molecule **12** have shown that here substantial negative charge accumulates at the imide oxygen atoms, where the SOMO exhibits high coefficients. The same behavior was observed for naphthaline imide **3**. Therefore, the different impact of electrochemical reduction and charge

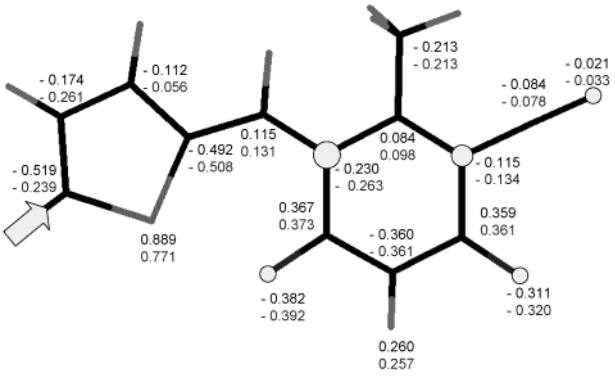


FIGURE 2. Total charge distributions for methine dyes **10** (numbers on top) and **12** (numbers on bottom) with all alkyl groups replaced by methyl groups according to AM1 calculations. The arrow marks the electron donor (hydrogen or dimethylamino), and the circles mark the magnitude of the increase of negative charges at the most influenced atoms.

transfer from electron-donor groups upon hydrogen-bonding strength is well explained by these calculations.

Self-Assembly. For the second series of dyes **17**−**20**, no binding studies could be accomplished owing to their insufficient solubility in solvents where hydrogen bonds exhibit reasonable strength (chloroform or solvents of lower polarity). Notably, even the addition of stoichiometric amounts of melamine receptor **21** or **22** with complementary hydrogen-bonding patterns did not afford an increase of the solubility of these dyes in methylcyclohexane in contrast to the situation for bisimide dyes reported in our earlier work.[5] This low solubility is quite likely related to the planarity of these dyes and the presence of two imide units in one planar dye molecule that can be used to form hydrogen-bonded networks similar to those found in the pigments **1** and **2**.

Therefore, another approach to extended self-assembled hydrogen-bonded merocyanine dye networks was employed, which is based on the combination of hydrogen-bond formation of ditopic melamines with the imide unit of dye **14** and the high dimerization constant of this dye in aliphatic solvents. The latter effect is due to the strong electrostatic interaction of this highly dipolar dye leading to antiparallel dimers with vanishing dipole moment.[12,16]

Figure 3 shows the absorption spectra of a 2:1 mixture of dye **14** with the ditopic melamine **22** in chloroform and in methylcyclohexane. The spectrum recorded in chloroform is identical with that of pure **14** (with $\lambda_{max} = 535$ nm), as melamine **22** and has no absorbance at wavelength $\lambda > 300$ nm. On the other hand, the spectrum in methylcyclohexane is remarkable for two reasons: First, the absorption band of dye **14** is strongly blue shifted (with $\lambda_{max} = 506$ nm), an effect that cannot be related to the formation of hydrogen bonds. Second, the highly polar imide dye **14** is not at all soluble in aliphatic solvents such as methylcyclohexane but only in solvents of high polarity that are able to solvate the dipolar π system ($\mu = 17$ D!) and the hydrogen-bonding imide receptor.

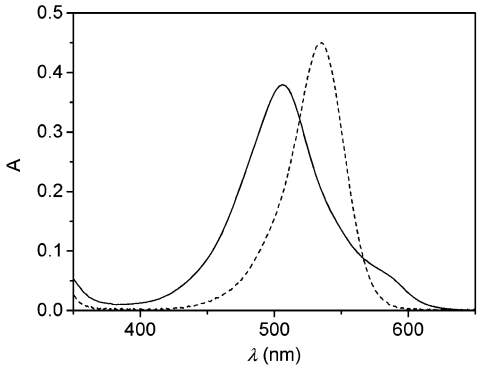


FIGURE 3. UV−vis spetra of dye **14** in the presence of a half equivalent of melamine **22** in chloroform (dotted line, $\lambda_{max} = 535$ nm) and in methylcyclohexane (solid line, $\lambda_{max} = 506$ nm).

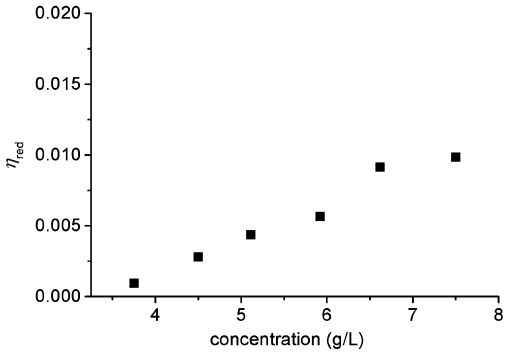


FIGURE 4. Reduced viscosity (in L/g) of a 2:1 mixture of dye **14** and melamine **22** vs concentration in methylcyclohexane at 30 °C.

To address the last point, it seems quite reasonable that upon coordination of melamine **22** by triple hydrogen bonding, the two alkyl groups of the melamine support the dissolution of **14**. But how has the solvation of the dipolar π-system been facilitated? This might be accomplished by dimerization of **14** to dimer aggregates as shown in our earlier work.[16] Such dimers have a vanishing dipole moment which make them surprisingly soluble in weakly polar solvents. As a characteristic feature, these dimers exhibit strongly blue-shifted absorption bands (H aggregate) as observed in Figure 3. Accordingly, the dissolution of dyes **14** upon addition of melamine **22** in methylcyclohexane can be explained in terms of formation of a supramolecular polymer (Scheme 6). In contrast to an earlier reported[17] supramolecular polymer formed by dipolar aggregation of covalently coupled dyes similar to **14**, the present hydrogen-bonded assembly does not lead to a well-ordered aggregate by further hierarchical growth. Therefore, the hypsochromic shift observed for the absorption band of **14** remains quite modest as expected for dimer aggregates and no viscosity increase could be observed by capillary viscosimetry (Figure 4). The latter observation is in accordance with the formation of a rather weakly bound colloid-type assembly in contrast to covalently bonded polymeric chains.

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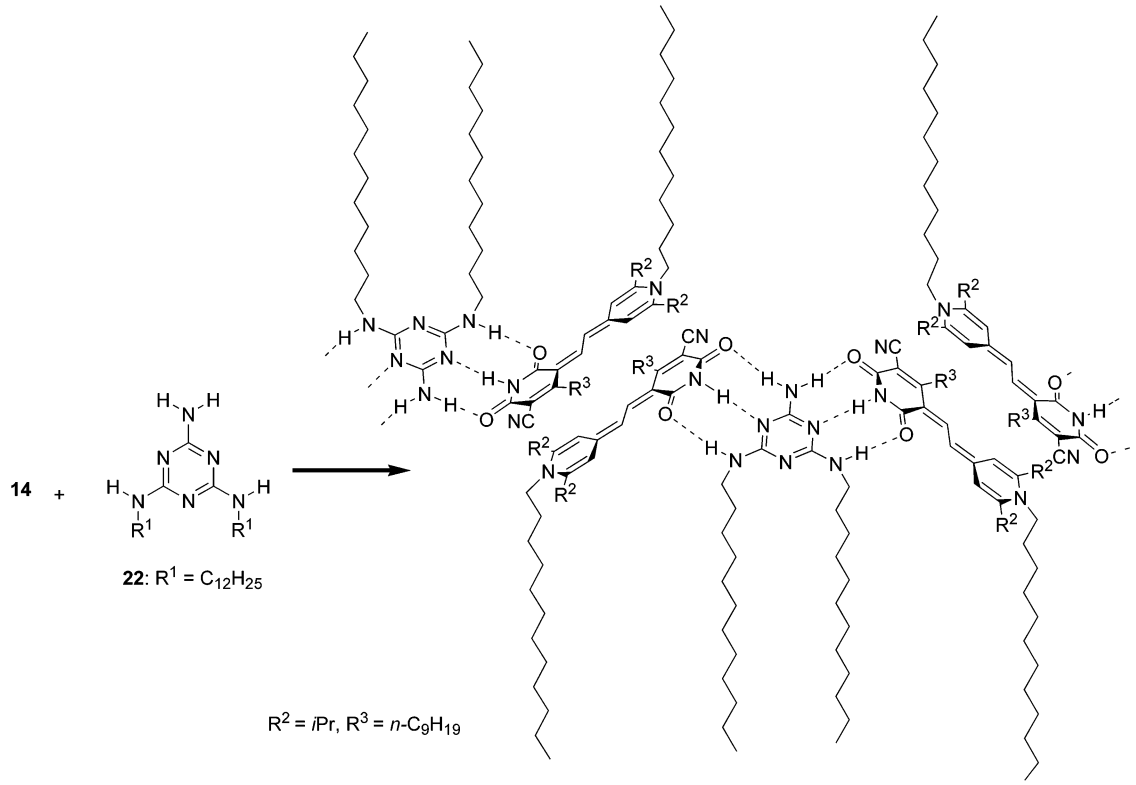
SCHEME 6. Formation of a Supramolecular Polymer from Dye 14 and Melamine 22 through Dimerization of Dipolar Dye 14 and Triple Hydrogen Bonding to Melamine 22



Conclusion

This work has shown for merocyanine dyes with imide-containing acceptor units that the Gibbs energy of imide−melamine triple hydrogen bonding is not influenced by the variation of the electron-donor moiety of the dye. Despite the very diverse charge-transfer character (from polyene- to betaine-type) these dyes are hydrogen bonded to melamine **21** with identical binding constants of $K = 120\ M^{-1}$ in $CDCl_3$. It was demonstrated that the triple hydrogen-bonding coordination to ditopic melamine **22** is useful to dissolve the highly dipolar dye **14** even in the little polar solvent methylcyclohexane. On the basis of the optical properties of the resulting solutions, we conclude that colloidal assemblies have formed by supramolecular polymerization through hydrogen bonding to melamines and dipolar aggregation between the dyes. In contrast to the pyridone-derived dyes **10**−**14**, the barbituric acid-based dyes **17**−**20** retained their pigment-type behavior even in the presence of complementary melamines. Therefore, the dissolution of these dipolar molecules from a strongly hydrogen-bonded crystalline network necessitates a more refined complementary binding partner. For this purpose, more elaborated receptors such as the one introduced by Hamilton[18] seem promising, and such receptors are currently under investigation.

Experimental Section

The characterization of all new compounds was accomplished by ^1H NMR spectroscopy, UV−vis spectroscopy, and elemental analysis. 4-Methyl-2,6-dioxo-1,2,5,6-tetrahydro-pyridine-3-carbonitrile (**5b**) was obtained from commercial sources, and 4-nonyl-2,6-dioxo-1,2,5,6-tetrahydro-pyridine-3-carbonitrile **(5a)** was prepared according to ref 12b. AM1 calculations have been performed with HyperChem 6.03 for Windows from Hypercube, Inc. By comparison of the calculated bond length and dipole moment data with experimental ones from crystal structures and dipole moment measurements (refs 11−13), we consider these calculations as reliable. Solution viscosities were measured at 30 °C with capillary viscometers using an automated viscosity measuring unit to obtain reproducible run times. The effective capillary diameters were 0.47, 0.63, and 1.13 mm. The setup was mounted in a thermostat controlled by circulating a 1:1 mixture of water−ethyleneglycol. The measurements were run from concentrated to diluted solutions. Dilution was achieved by using an automated device.

5-(Thiophene-2-ylmethylene)-4-nonyl-2,6-dioxo-1,2,5,6-tetrahydropyridine-3-carbonitrile (10). Thiophene aldehyde **7a** (0.28 g, 2.5 mmol) and **5a** (0.66 g, 2.25 mmol, 90%) were heated in acetic anhydride (2.5 mL) at 90 °C for 2 h. The mixture was allowed to cool to room temperature with stirring. The slurry formed was filtered by suction, washed with 2-propanol, and dried in vacuo at 60 °C to give 0.40 g (50%) of **10**: mp 202−203 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 8.65 (s, 1H, NH), 8.11 (m, 1H, $H_{thiophene}$), 8.08 (s, 1H, $H_{methine}$), 7.84 (m, 1H, $H_{thiophene}$), 7.34 (m, 1H, $H_{thiophene}$), 3.02 (t, $J = 8.0$ Hz, 2H, CH_2), 1.71 (m, 2H, CH_2), 1.53 (m, 2H, CH_2), 1.37 (m, 2H, CH_2), 1.29 (m, 8H, CH_2), 0.88 (t, $J = 7$ Hz, 3H, CH_3). Anal. Calcd for $C_{21}H_{26}N_2O_3S$ (356.49): C, 67.39; H, 6.79; N, 7.86. Found: C, 67.08; H, 6.71; N, 8.07.

5-(5-Methoxythiophene-2-ylmethylene)-4-nonyl-2,6-dioxo-1,2,5,6-tetrahydropyridine-3-carbonitrile (11). Methoxythiophene aldehyde **7b**[19] (0.51 g, 3.6 mmol) and **5b** (0.85, 3.24 mmol) in acetic anhydride (3 mL) were heated at 90 °C for 2 h. The mixture was allowed to cool to room temperature

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with stirring. The slurry formed was filtered by suction, washed with 2-propanol, and dried in vacuo at 60 °C to give 0.60 g (48%) of **11**: mp 175−176 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 8.98 (s, 1H, NH), 7.67 (s, 1H, $H_{methine}$), 7.61 (d, J = 4.43 Hz, 1H, $H_{thiophene}$), 6.57 (d, J = 4.4 Hz, 1H, $H_{thiophene}$), 4.15 (s, 3H, OCH_3), 2.88 (t, J = 7.4 Hz, 2H, CH_2), 1.62 (m, 2H, CH_2), 1.44 (m, 2H, CH_2), 1.21 (m, 10H, CH_2), 0.81 (t, J = 5.9 Hz, 3H, CH_3). Anal. Calcd for $C_{21}H_{26}N_2O_3S$ (386.52): C, 65.26; H, 6.78; N, 7.25. Found: C, 65.19; H, 6.98; N, 7.35.

5-(5-Dibutylaminothiophene-2-ylmethylene)-4-nonyl-2,6-dioxo-1,2,5,6-tetrahydropyridine-3-carbonitrile (12a). Dibutylaminothiophene aldehyde **7c**[13b] (0.43 g, 1.8 mmol) and **5a** (0.52 g, 1.8 mmol, 90%) in acetic anhydride (2 mL) were heated at 90 °C for 2 h. After the solution cooled, a deep-violet oil was obtained that was purified by column chromatography with CH_2Cl_2/MeOH = 98:2. The solvent was concentrated to 5 mL, and the precipitated dye was filtered by suction and dried in vacuo at 50 °C to give 0.66 g (76%) of **12**: mp 156−158 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 8.81 (s, 1H, NH), 7.53 (s+d, 2H, $H_{thiophene}$ and $H_{methine}$), 6.41 (d, J = 5.41 Hz, 1H, $H_{thiophene}$), 3.56 (t, J = 7.6 Hz, 4H, NCH_2), 2.86 (t, J = 7.9 Hz, 2H, CH_2), 1.81−1.63 (m, 6H, CH_2), 1.52−1.27 (m, 16H, CH_2), 0.99 (t, J = 7.4 Hz, 6H, CH_3), 0.88 (t, J = 6.7 Hz, 3H, CH_3). Anal. Calcd for $C_{28}H_{41}N_3O_2S$ (483.72): C, 69.53; H, 8.54; N, 8.69. Found: C, 69.28; H, 8.36; N, 8.61.

5-(5-Dibutylaminothiophene-2-ylmethylene)-4-methyl-2,6-dioxo-1,2,5,6-tetrahydropyridine-3-carbonitrile (12b). Dibutylaminothiophene aldehyde **7c**[13b] (0.75 g, 5.0 mmol) and **5b** (1.26 g, 5.0 mmol) in acetic anhydride (5 mL) were heated at 90 °C for 1.5 h. The mixture was allowed to cool to room temperature with stirring. The slurry formed was filtered by suction, washed with Ac_2O and 2-propanol, and recrystallized from acetic acid to give 1.38 g (74%) of **1d**: mp 270−272 °C; ^{1}H NMR (200 MHz, [D_6]-DMSO) δ 10.88 (s, 1H, NH), 7.99 (d, J = 5.4 Hz, 1H, $H_{thiophene}$), 7.83 (s, 1H, $H_{methine}$), 6.82 (d, J = 4.9 Hz, 1H, $H_{thiophene}$), 3.57 (t, J = 7.6 Hz, 4H, NCH_2), 2.43 (s, 3H, CH_3), 1.65 (m, 4H, CH_2), 1.33 (m, 4H, CH_2), 0.92 (t, J = 7.4 Hz, 6H, CH_3). Anal. Calcd for $C_{20}H_{25}N_3O_2S$ (371.51): C, 64.66; H, 6.78; N, 11.31. Found: C, 64.78; H, 6.67; N, 11.18.

5-(4-Dibutylaminobenzylidene)-4-methyl-2,6-dioxo-1,-2,5,6-tetrahydropyridine-3-carbonitrile (13). Dibutylaminobenzaldehyde **8** (1.16 g, 5.0 mmol) and **5b** (0.75 g, 5.0 mmol) were heated in acetic anhydride (5 mL) at 90 °C for 1 h. The mixture was allowed to cool to room temperature with stirring. The slurry formed was filtered by suction, washed with Ac_2O and 2-propanol, and recrystallized from acetic acid to give 1.6 g (88%) of **13**: mp 195 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 8.19 (br, 2H, Ar−H), 8.08 (s, 1H, NH), 7.58 (s, 1H, $H_{methine}$), 6.66 (d, J = 9.4 Hz, 2H, Ar−H), 3.44 (t, J = 7.6 Hz, 4H, NCH_2), 2.59 (s, 3H, CH_3), 1.65 (m, 4H, CH_2), 1.38 (m, 4H, CH_2), 0.99 (t, J = 7.1 Hz, 6H, CH_3). Anal. Calcd for $C_{22}H_{27}N_3O_2$ (365.48): C, 72.30; H, 7.45; N, 11.50. Found: C, 72.17; H, 7.35; N, 11.49.

4-Nonyl-2,6-dioxo-5-[2-(1-dodecyl-2,6-diisopropyl-1-hydropyridin-4-ylidene)ethylidene]-1,2,5,6-tetrahydropyridine-3-carbonitrile (14). Pyridone **5a** (0.70 g, 2.7 mmol) and *N*,*N*′-diphenylformamidine (0.58 g, 3.0 mmol) in Ac_2O (3 mL) were stirred at room temperature for 30 min until the mixture solidified. To complete the reaction to **6**, the mixture was heated at 90 °C for another 5 min. After the solution cooled to room temperature, pyridinium perchlorate salt **9a**[11b] (1.78 g, 3.0 mmol, 75%) and potassium acetate (0.3 g, 3.0 mmol) were added and the mixture was heated at 90 °C for 2 h. The resulting solution was concentrated and purified by column chromatography using silica gel and CH_2Cl_2/CH_3OH = 96:4 as eluent. Recrystallization from 2-propanol/hexane afforded 0.60 g (39%) of **14**: mp 165−167 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (s, 1H, NH), 7.77 (d, J = 14.9 Hz, 1H, $H_{methine}$), 7.61 (d, J = 14.9 Hz, 1H, $H_{methine}$), 7.24 (s, 2H, pyridine), 4.16 (t, J = 8.3 Hz, 2H, NCH_2), 3.21 (m, 2H, CH), 2.81 (t, J = 8.0 Hz, 2H, CH_2), 1.78 (m, 2H, CH_2), 1.65 (m, 2H, CH_2), 1.44 (m, 16H, CH_2 and CH_3), 1.27 (m, 26H, CH_2), 0.87 (m, 6H, CH_3). Anal. Calcd for $C_{40}H_{63}N_3O_2$ (617.97): C, 77.75; H, 10.28; N, 6.80. Found: C, 77.36; H, 9.98; N, 6.78.

General Procedure for the Preparation of 5-(4-Substituted-arylidene)pyrimidine-2,4,6-triones 17−19. (Hetero)aromatic aldehyde (2 mmol), 2 mmol of barbituric acid, and 2 mL of Ac_2O were mixed and heated at 90 °C for 2 h. After the solution was cooled, the precipitated dye was filtered off, washed with 2-propanol and hexane, and dried.

5-(4-Butoxylbenzylidene)pyrimidine-2,4,6-trione (17). Recrystallization from ethyl acetate (yield 39%): mp 239−242 °C; ^{1}H NMR (200 MHz, [D_6]-DMSO) δ 11.17 (s, 1H, NH), 11.07 (s, 1H, NH), 8.28 (d, J = 9.0 Hz, 2H, Ar-H), 7.83 (s, 1H, $H_{methine}$), 6.87 (d, J = 8.7 Hz, 2H, Ar-H), 4.00 (t, J = 6.3 Hz, 2H, OCH_2), 1.71 (m, 2H, CH_2), 1.42 (m, 2H, CH_2), 0.90 (t, J = 7.3 Hz, 3H, CH_3). Anal. Calcd for $C_{15}H_{16}N_2O_4$ (288.31): C, 62.49; H, 5.59; N, 9.72. Found: C, 62.05; H, 5.65; N, 9.72.

5-(4-Dibutylaminobenzylidene)pyrimidine-2,4,6-trione (18). Recrystallization from ethyl acetate (yield 67%): mp 214−217 °C; ^{1}H NMR (200 MHz, [D_6]-DMSO) δ 11.04 (s, 1H, NH), 10.91 (s, 1H, NH), 8.42 (d, J = 8.9 Hz, 2H, Ar-H), 8.14 (s, 1H, $H_{methine}$), 6.78 (d, J = 9.1 Hz, 2H, Ar-H), 3.46 (m, 4H, NH_2), 1.57 (m, 4H, CH_2), 1.34 (m, 4H, CH_2), 0.94 (m, 6H, CH_3). Anal. Calcd for $C_{19}H_{25}N_3O_3$ (343.43): C, 66.45; H, 7.34; N, 12.24. Found: C, 66.33; H, 7.46; N, 12.19.

5-(5-Dibutylaminothiophene-2-ylmethylene)pyrimidine-2,4,6-trione (19). Recrystallization from ethyl acetate afforded **19** (yield 93%): mp 289−290 °C; ^{1}H NMR (200 MHz, [D_6]-DMSO) δ 10.61 (s, 1H, NH), 10.53 (s, 1H, NH), 8.06 (s, 1H, $H_{methine}$), 7.89 (d, J = 5.0 Hz, 1H, $H_{thiophene}$), 6.57 (d, J = 5.0 Hz, 1H, $H_{thiophene}$), 3.51 (t, J = 7.3 Hz, 4H, NCH_2), 1.59 (m, 4H, CH_2), 1.31 (m, 4H, CH_2), 0.91 (t, J = 7.3 Hz, 6H, CH_3). Anal. Calcd for $C_{17}H_{23}N_3O_3S$ (349.46): C, 58.43; H, 6.63; N, 12.02. Found: C, 58.20; H, 6.49; N, 11.84.

General Procedure for Preparation of 5-[(Pyridine-4-ylidene)ethylidene]pyrimidine-2,4,6-triones (20a,b). Barbituric acid **15** (1.5 mmol) and *N*,*N*-dibutylformamide (1.5 mmol) in Ac_2O (3 mL) were heated at 120 °C for 2 h. To the clear solution obtained was added pyridinium salt[12b] **9a** or **9b** (1.5 mmol) and potassium acetate (0.15 g, 1.5 mmol), and the mixture was heated at 120 °C for another 2 h. The resulting solution was evaporated in vacuo and the isolated solid was purified by column chromatography using silica gel and CH_2Cl_2/CH_3OH = 95:5 as eluent.

5-[2-(1-Dodecyl-2,6-diisopropyl-pyridine-4-ylidene)-ethylidene]pyrimidine-2,4,6-trione (20a). Recrystallization from CH_2Cl_2/hexane afforded **20a** (yield 66%): mp 223−224 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (d, J = 15.2 Hz, 1H, $H_{methine}$), 7.50 (s, 2H, NH), 7.47 (d, J = 15.4 Hz, 1H, $H_{methine}$), 7.23 (s, 2H, $H_{pyridine}$), 4.04 (t, J = 8.3 Hz, 2H, NCH_2), 3.11 (m, 2H, CH), 1.72 (m, 2H, CH_2), 1.40 (m, 18H, CH_2), 1.27 (m, 15H, CH_2 + CH_3), 0.88 (m, 3H, CH_3). Anal. Calcd for $C_{29}H_{45}N_3O_3 \cdot H_2O$ (501.72): C, 69.42; H, 9.44; N, 8.38. Found: C, 69.42; H, 9.32; N, 8.37.

5-[2-(1-Dodecyl-pyridine-4-ylidene)ethylidene]pyrimidine-2,4,6-trione (20b). Recrystallization from CH_2Cl_2/hexane afforded **20b** (yield 29%): mp 264−265 °C; ^{1}H NMR (400 MHz, [D_6]-DMSO) δ 9.88 (s, 2H, NH), 8.17 (d, J = 7.1 Hz, 2H, $H_{pyridine}$), 8.00 (d, J = 15.2 Hz, 1H, $H_{methine}$), 7.42 (d, J = 6.8 Hz, 2H, $H_{pyridine}$), 7.29 (d, J = 14.9 Hz, 1H, $H_{methine}$), 4.15 (t, J = 7.2 Hz, 2H, NCH_2), 2.51 (s, 3H, CH_3), 1.77 (m, 2H, CH_2), 1.23 (m, 18H, CH_2), 0.85 (t, J = 6.7 Hz, 3H, CH_3). Anal. Calcd for $C_{23}H_{33}N_3O_3 \cdot H_2O$ (417.56): C, 66.15; H, 8.46; N, 10.06. Found: C, 66.07; H, 8.15; N, 9.95.

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