



Synthesis of 1-Formylazulene Derivatives and Absorption Spectra of New Azomethine Dyes Containing an Azulene Ring

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ABSTRACT

Ethyl 1-formyl-2-hydroxyazulene-3-carboxylate (2a) was readily obtained in high yield from ethyl 2-hydroxyazulene-1-carboxylate (1a) using the Vilsmeier reagent. Ethyl 5-isopropyl- and 7-isopropyl-1-formyl-2-hydroxyazulene-3-carboxylate (2b and 2c) were isolated and their structure confirmed by ¹H NMR spectra. Additionally, bromination and nitration of 2a was carried out to introduce a functional group into the seven-membered ring, to give 6-substituted 1-formylazulene derivatives. Absorption spectra of azomethine dyes derived from these 1-formylazulene derivatives were significantly influenced by substituents. PPP-MO (Pariser-Parr-Pople Molecular Orbital) calculations indicated that the origin of these absorption bands was an intramolecular charge-transfer from the azomethine component to the azulene ring.

1 INTRODUCTION

An azulene ring system has been synthesized by the reaction of an activated troponoid with an active methylene compound.¹ However, the azulene

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derivative containing a formyl group could not be directly prepared by this method. Formyl azulene derivatives have been prepared by formylation of the azulene ring.²⁻⁴ Few data pertaining to the introduction of functional groups into the azulene have been reported, particularly in comparison with the naphthalene ring, which also has a 10 π electron system. Limited data on azulene dyes are available,⁵ and no systematic investigation on the colour-constitution relationships in such dyes has been made except for a study of azo dyes containing an azulene ring.⁶ In this paper, we report the synthesis of 1-formylazulene derivatives and the relationship between substituents and the absorption spectra of azomethine dyes containing an azulene ring.

2 RESULTS AND DISCUSSION

2.1 Synthesis of 1-formylazulene derivatives

Ethyl 2-hydroxyazulene-1-carboxylate (**1a**)⁷ was prepared by decarboethoxylation of diethyl 2-hydroxyazulene-1,3-dicarboxylate.⁷ This compound (**1a**) was readily formylated by the Vilsmeier reagent⁸ to give ethyl 1-formyl-2-hydroxyazulene-3-carboxylate (**2a**), together with a trace amount of ethyl 1-formyl-2-chloroazulene-3-carboxylate (**2j**). However, the decarboethoxylation of diethyl 5-isopropyl-2-hydroxyazulene-1,3-dicarboxylate gave two isomers, i.e. ethyl 5-isopropyl- and 7-isopropyl-2-hydroxyazulene-1-

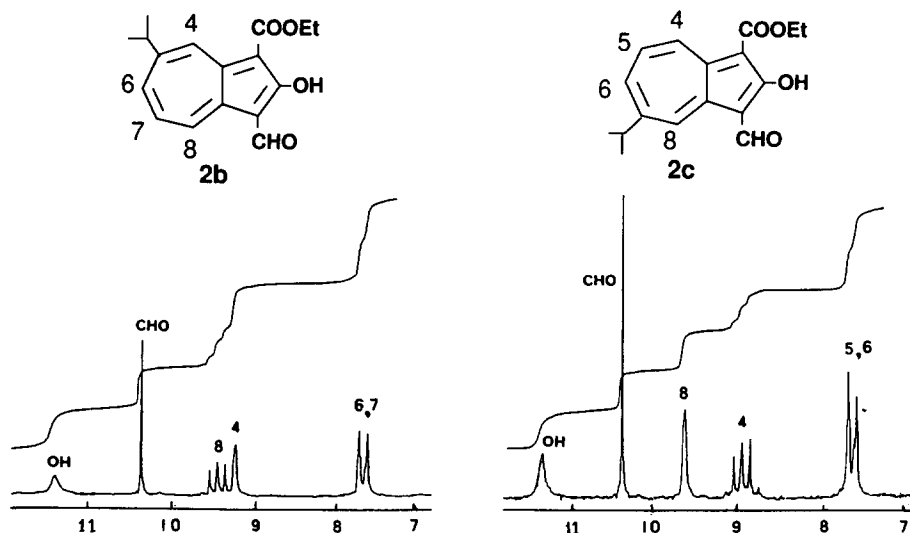
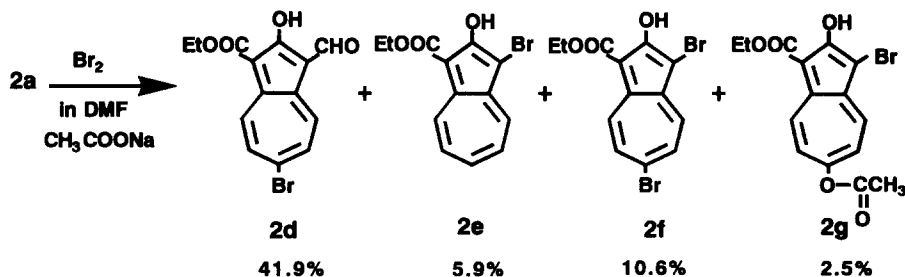


Fig. 1. ¹H NMR spectra of **2b** and **2c** at high magnetic field.

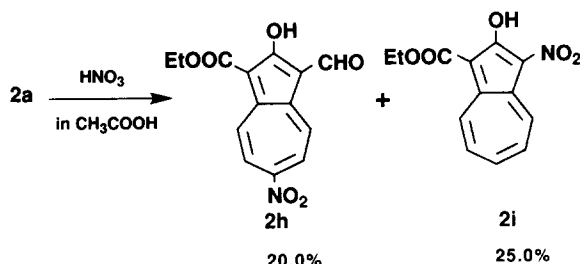
carboxylates (**1b**), which could not be separated by conventional methods, and which were used for the formylation reaction without separation. The ratio of this mixture was estimated to be about 1 : 1 from the integrations for the 3-position in the ^1H NMR spectrum. The formylation of **1b** gave ethyl 5-isopropyl- and 7-isopropyl-1-formyl-2-hydroxyazulene-3-carboxylate (**2b** and **2c**) in 43% and 30% yield, respectively, on separating by column chromatography, together with trace amounts of ethyl 5-isopropyl- and 7-isopropyl-1-formyl-2-chloroazulene-3-carboxylates (**2k** and **2l**). Structural analyses of **2b** and **2c** were carried out using ^1H NMR spectra data for the four protons in the seven-membered ring. Three of the four protons showed an A_2B type signal, and one (the 4-proton of **2b** and the 8-proton of **2c**) showed a broad peak having a long distance spin coupling. Using a simulation program for NMR analysis (Y. Inoue, personal communication), the signals of the 4-proton of **2b** and of the 8-proton of **2c** were assigned at 9.22 and 9.66 ppm, respectively. The signals of the 6,7-protons of **2b** and of the 5,6-protons of **2c** were assigned almost the same value at 7.70 ppm; the 8-proton of **2b** and the 4-proton of **2c** were assigned at 9.44 and 8.99 ppm as pseudo triplet peaks, respectively (Fig. 1).

Bromination and nitration⁹ of **2a** were studied in order to prepare 1-formylazulene derivatives containing a functional group in the seven-membered ring. The bromination of **2a** in *N,N*-dimethylformamide (DMF) in presence of sodium acetate gave ethyl 6-bromo-1-formyl-2-hydroxyazulene-3-carboxylate (**2d**), together with **2a** and by-products (**2e**, **2f** and **2g**) in which the formyl group was replaced with bromine. However, the derivative in which a carboethoxy group was replaced with bromine could not be detected (Scheme 1).

In the case of nitration, ethyl 6-nitro-1-formyl-2-hydroxyazulene-3-carboxylate (**2h**) was also obtained in low yield due to difficulty of the reaction, together with ethyl 1-nitro-2-hydroxyazulene-3-carboxylate (**2i**). Other compounds formed could not be identified (Scheme 2).



Scheme 1. Bromination of **2a**.

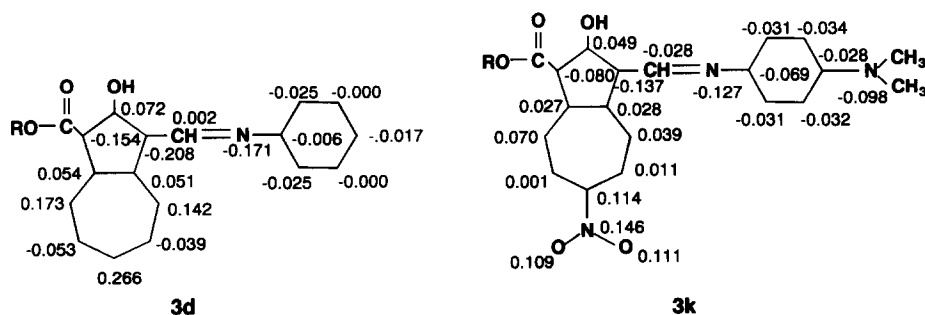


Scheme 2. Nitration of 2a.

2.2 Synthesis and absorption spectra of azomethine dyes

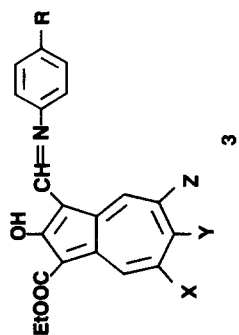
New azomethine dyes containing an azulene ring were readily synthesized by condensation of the formyl azulenes with aromatic amines. Characterization data are shown in Table 1. In general, when the substituent (R) was an electron-donating group, the yields were high.

A new absorption band resultant from the azomethine link appeared within the range 475 to 593 nm, depending on the nature of the substituents (R and Y) (Table 1). The absorption wavelength shifted to longer wavelength as the electron-donating ability of R in the phenyl ring and the electron-withdrawing ability of Y in the seven-membered ring increased. PPP-MO calculations¹⁰ for an unsubstituted azomethine dye indicated that the change of π -electron density accompanying the transition was due to the migration of an electron from the phenyl azomethine residue to the azulene ring (Scheme 3, **3d**). These absorption bands could, therefore, be assigned as an intramolecular charge-transfer absorption. Thus, as the electron-donating ability of R and the electron-withdrawing ability of Y increases, the absorption band shifts to longer wavelength owing to the larger intramolecular charge-transfer (Scheme 3, **3k**).



Scheme 3. Differences of electron densities between the ground and excited state by PPP-MO calculations.

TABLE I
Characteristics and Absorption Spectra of Azomethine Dyes 3



<i>X</i>	<i>Y</i>	<i>Z</i>	<i>R</i>	Yield	<i>M.p.</i> (°C)	λ_{max} (nm) ($\epsilon \times 10^4$) (C_6H_6)	
a	H	H	-N(CH ₃) ₂	63	172-173	410 (1.9)	539 (0.98)
b	H	H	-OCH ₃	79	162-163	394 (2.1)	510 (0.56)
c	H	H	-CH ₃	87	178-180	390 (2.2)	507 (0.4)
d	H	H	-H	45	148-149	388 (1.2)	504 (0.3)
e	H	H	-CN	26	202-203	394 (3.8)	479 (0.8)
f	H	H	-NO ₂	21	205-207	402 (1.1)	475 (0.28)
g	<i>iso</i> -Pro	H	-N(CH ₃) ₂	91	187-188	412 (2.7)	535 (0.84)
h	H	<i>iso</i> -Pro	-N(CH ₃) ₂	82	219-220	411 (2.8)	532 (0.99)
i	H	H	-N(CH ₃) ₂	89	207-209	420 (2.5)	553 (1.1)
j	H	H	H	86	180-182	394 (2.4)	518 (0.51)
k	H	NO ₂	-N(CH ₃) ₂	71	261-263	438 (2.36)	593 (1.41)
l	H	NO ₂	H	51	245-247	386 (1.8)	540 (0.4)

sh, shoulder.

3 EXPERIMENTAL

All melting points are uncorrected. Visible spectra in benzene solution were recorded on a Hitachi EPS-3T spectrophotometer. ^1H NMR spectra were recorded on a Nihon Denshi JNM-FX60Q NMR spectrometer, unless otherwise stated in CDCl_3 solution, with tetramethylsilane as internal reference. Elemental analyses were recorded on a Yanaco CHN recorder MT-2. Column chromatography was carried out on silica gel (Wakogel C-300) using several solvents.

3.1 Material

Diethyl 2-hydroxyazulene-1,3-dicarboxylate and diethyl 5-isopropyl-2-hydroxyazulene-1,3-dicarboxylate were prepared by the previously described method.⁷ Compound **1a** was purified by column chromatography followed by recrystallization from ethanol, but **1b** was a mixture of the 5-isopropyl and 7-isopropyl azulene derivatives, and was liquid at room temperature. Aromatic amines and other reagents were commercial grade and were used without further purification.

3.2 Formylation of **1a**

Phosphorus oxychloride (4.5 g, 30 mmol) was added dropwise to a DMF solution (20 ml) of **1a** (4.2 g, 20 mmol) at 0°C . After 2 h, the reaction mixture was poured into cold water and the suspension extracted with chloroform. The extracted solution was washed with water, dried with anhydrous sodium sulphate, and the extract evaporated to dryness. The products were separated by column chromatography, using benzene as eluent, to give **1a** (100 mg) as the first fraction, ethyl 1-formyl-2-chloroazulene-3-carboxylate (**2j**) (84 mg) as the second fraction, and **2a** (3.93 g, 80.5%) as the final fraction.

3.3 Bromination of **2a**

Bromine (830 mg, 5.2 mmol) was added dropwise to a DMF solution (35 ml) of **2a** (1.0 g, 4.1 mmol) and sodium acetate (425 mg, 5.2 mmol) at room temperature. After 4 h, the reaction mixture was poured into ice-water and the resultant crystals were filtered, dried, and separated by column chromatography (using benzene) to give **2d**, **2e**, **2f** and **2g**, together with recovery of **2a**. The yields of each derivative were 14.5% (**2a**), 41.9% (**2d**), 5.9% (**2e**), 10.6% (**2f**) and 2.5% (**2g**).

3.4 Nitration of **2a**

Concentrated nitric acid (5 ml, 11.2 mmol) was added dropwise to a suspension of **2a** (2 g, 4.1 mmol) in acetic acid (15 ml) at room temperature. When the reaction liquor was heated to 45°C, it became a brownish-red solution. The solution was then cooled to room temperature when crystals appeared. After stirring for 30 min, cold water (3 ml) was added to the reaction mixture and the crystals were filtered and washed with water. They were recrystallized from benzene to give **2h**, 248 mg (20%). Compound **2i** (164 mg) was then obtained by concentrating the recrystallization filtrate. The resultant crystals, after addition of more water (30 ml) to the first aqueous filtrate, were chromatographed using chloroform as eluant to give **2i** (108 mg); the total yield of **2i** was 25%.

3.5 Synthesis of azomethine dyes (general procedure)

A mixture of **2a** (244 mg, 1 mmol) and *N,N*-dimethylaminoaniline (150 mg, 1.1 mmol) was heated at 70–80°C in DMF (20 ml). After stirring for 1 h, the reaction mixture was poured into cold water. The resulting crystals were filtered, chromatographed, and recrystallized from benzene, giving dye **3a** in 63% yield.

3.6 Characterization and identification of products

Compounds **1a** and **2a** are known compounds and were characterized by data described in the literature,⁷ and also by the following.

1a: m.p. 75–76°C; ¹H NMR: 1.51 (t, 3H, CH₃), 4.53 (q, 2H, CH₂), 6.75 (s, 1H, H of five-membered ring), 7.33–7.58 (m, 3H, aromatic), 8.04–8.23 (m, 1H, aromatic), 8.83–9.02 (m, 1H, aromatic), 10.8 (b, 1H, OH).

1b: liquid ¹H NMR: 6.56 and 6.60 (s, 1H, H of five-membered ring); mass 258.

2a: m.p. 158–159°C; ¹H NMR: 1.52 (3H, t, *J* = 7 Hz), 4.56 (2H, q, *J* = 7 Hz), 7.65–7.91 (3H, m), 9.08–9.27 (1H, m), 9.50–9.70 (1H, m), 10.42 (1H, s), 11.35 (1H, b); mass 244 (M⁺).

2b: m.p. 191–192°C; ¹H NMR: 1.41 (6H, d, *J* = 7 Hz), 1.55 (3H, t, *J* = 7 Hz), 3.20 (1H, m), 4.54 (2H, q, *J* = 7 Hz), 7.70 (2H, d, *J* = 6.9 Hz), 9.22 (1H, s), 9.44 (1H, t, *J* = 5.6 Hz), 11.31 (1H, b); mass 286 (M⁺).

2c: m.p. 160–161°C; ¹H NMR: 1.41 (6H, d, *J* = 7 Hz), 1.51 (3H, t, *J* = 7 Hz), 3.23 (1H, m), 4.53 (2H, q, *J* = 7 Hz), 7.70 (2H, d, *J* = 6.1 Hz), 8.99 (1H, t, *J* = 5.6 Hz), 9.66 (1H, s), 11.33 (1H, b); mass 286 (M⁺).

2d: m.p. 185–187°C; ¹H NMR: 1.51 (3H, t, *J* = 7 Hz), 4.56 (2H, q,

TABLE 2
¹H NMR Data for Dyes 3

<i>¹H NMR</i>	
a	1.48 (3H, t, <i>J</i> = 7 Hz), 2.97 (6H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 6.70 (2H, d, <i>J</i> = 9 Hz), 7.14–7.80 (6H, m), 8.47 (1H, s) 9.04 (1H, d, <i>J</i> = 11 Hz)
b	1.48 (3H, t, <i>J</i> = 7 Hz), 3.83 (3H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 6.93 (2H, d, <i>J</i> = 9 Hz), 7.18–7.77 (6H, m), 8.48 (1H, s) 9.07 (1H, d, <i>J</i> = 11 Hz)
c	1.48 (3H, t, <i>J</i> = 7 Hz), 2.37 (3H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 7.21–7.88 (8H, m), 8.52 (1H, s) 9.06 (1H, d, <i>J</i> = 11 Hz)
d	1.48 (3H, t, <i>J</i> = 7 Hz), 3.98 (1H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 7.13–7.81 (8H, m), 8.54 (1H, s) 9.05 (1H, d, <i>J</i> = 11 Hz)
e	1.47 (3H, t, <i>J</i> = 7 Hz), 4.47 (2H, q, <i>J</i> = 7 Hz), 7.54–7.77 (8H, m), 8.50 (1H, s) 9.01 (1H, d, <i>J</i> = 11 Hz)
f	1.47 (3H, t, <i>J</i> = 7 Hz), 4.48 (2H, q, <i>J</i> = 7 Hz), 7.26–7.94 (6H, m), 8.32 (2H, d, <i>J</i> = 9 Hz), 8.53 (1H, s), 9.04 (1H, d, <i>J</i> = 11 Hz)
g	1.35 (6H, d, <i>J</i> = 7 Hz), 1.49 (3H, t, <i>J</i> = 7 Hz), 2.97 (6H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 6.72 (2H, d, <i>J</i> = 9 Hz), 7.21 (2H, d, <i>J</i> = 9 Hz), 7.35–7.55 (3H, m), 8.42 (1H, b), 9.16 (1H, s)
h	1.35 (6H, d, <i>J</i> = 7 Hz), 1.47 (3H, t, <i>J</i> = 7 Hz), 2.97 (6H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 6.71 (2H, d, <i>J</i> = 9 Hz), 7.16–7.39 (4H, m), 7.68 (1H, s), 8.47 (1H, b), 8.95 (1H, dd, <i>J</i> = 10, 2 Hz)
i	1.47 (3H, t, <i>J</i> = 7 Hz), 2.99 (6H, s), 4.47 (2H, <i>J</i> = 7 Hz), 6.65 (2H, d, <i>J</i> = 9 Hz), 7.21 (2H, d, <i>J</i> = 9 Hz), 7.35–7.70 (3H, m), 8.46 (1H, s), 8.78 (1H, d, <i>J</i> = 12 Hz)
j	1.47 (3H, t, <i>J</i> = 7 Hz), 4.47 (2H, q, <i>J</i> = 7 Hz), 7.26–7.72 (8H, m), 8.55 (b, 1H), 8.80 (1H, d, <i>J</i> = 7 Hz)
k	1.48 (3H, t, <i>J</i> = 7 Hz), 3.03 (6H, s), 4.48 (2H, q, <i>J</i> = 7 Hz), 6.73 (2H, d, <i>J</i> = 9 Hz), 7.27 (2H, d, <i>J</i> = 9 Hz), 7.64 (1H, d, <i>J</i> = 11 Hz), 8.25–8.54 (2H, m), 8.65 (1H, b), 8.94 (1H, d, <i>J</i> = 13 Hz)
l	1.49 (3H, t, <i>J</i> = 7 Hz), 4.51 (2H, q, <i>J</i> = 7 Hz), 7.33–7.42 (3H, m), 7.50–7.55 (2H, m), 7.65 (1H, d, <i>J</i> = 11 Hz), 8.34 (1H, d, <i>J</i> = 12 Hz), 8.51 (1H, d, <i>J</i> = 11 Hz), 8.70 (1H, b), 8.96 (1H, d, <i>J</i> = 12 Hz)

J = 7 Hz), 8.03 (2H, d, *J* = 11 Hz), 8.86 (1H, d, *J* = 11 Hz), 9.31 (1H, d, *J* = 11 Hz), 10.4 (1H, s), 11.3 (1H, b); mass 322 (*M*⁺), 324 (*M*⁺ + 2).

2e: m.p. 162–163°C; ¹H NMR: 1.51 (3H, t, *J* = 7 Hz), 4.54 (2H, q, *J* = 7 Hz), 7.52 (3H, m), 8.25 (1H, m), 8.92 (1H, m), 11.1 (1H, s); mass 294 (*M*⁺), 296 (*M*⁺ + 2).

2f: m.p. 167–168°C; ¹H NMR: 1.50 (3H, t, *J* = 7 Hz), 4.54 (2H, q, *J* = 7 Hz), 7.79 (1H, dd, *J* = 2, *J* = 11 Hz), 7.87 (1H, dd, *J* = 2, *J* = 7 Hz), 8.01 (1H, d, *J* = 11 Hz), 8.64 (1H, d, *J* = 11 Hz), 11.0 (1H, s); mass 372 (*M*⁺), 374 (*M*⁺ + 2), 376 (*M*⁺ + 4).

2g: m.p. 114–118°C; ¹H NMR: 1.54 (3H, t, *J* = 7 Hz), 2.30 (3H, s), 4.46 (2H, q, *J* = 7 Hz), 7.19 (2H, d, *J* = 11 Hz), 8.17 (1H, d, *J* = 11 Hz), 8.80 (1H, d, *J* = 11 Hz), 10.9 (1H, s); mass 352 (*M*⁺), 354 (*M*⁺ + 2).

2h: m.p. 215–217°C; ¹H NMR: 1.55 (3H, t, *J* = 7 Hz), 4.61 (2H, q,

TABLE 3
Elementary Analyses of Dyes 3

Molecular formula		Analysis (%)					
		C		H		N	
		Calc.	Found	Calc.	Found	Calc.	Found
a	C ₂₂ H ₂₂ N ₂ O ₃	72.91	73.24	6.12	6.02	7.73	7.13
b	C ₂₁ H ₁₉ NO ₄	72.19	72.51	5.48	5.34	4.01	3.85
c	C ₂₁ H ₁₉ NO ₃	75.66	76.29	5.74	5.61	4.20	4.00
d	C ₂₀ H ₁₇ NO ₃	75.22	75.30	5.37	5.16	4.39	3.92
e	C ₂₁ H ₁₆ N ₂ O ₃	73.24	69.63	4.68	4.91	8.13	7.50
f	C ₂₀ H ₁₆ N ₂ O ₅	65.93	60.60	4.43	4.44	7.69	7.27
g	C ₂₅ H ₂₈ N ₂ O ₃	74.23	74.55	6.98	7.04	6.93	6.53
h	C ₂₅ H ₂₈ N ₂ O ₃	74.23	73.69	6.98	6.93	6.93	6.42
i	C ₂₂ H ₂₁ BrN ₂ O ₃	59.87	59.83	4.80	4.63	6.35	5.86
j	C ₂₀ H ₁₆ BrNO ₃	60.32	59.83	4.05	3.88	3.52	3.32
k	C ₂₂ H ₂₁ N ₃ O ₅	64.86	63.36	5.20	5.07	10.31	10.02
l	C ₂₀ H ₁₆ N ₂ O ₅	65.93	65.13	4.43	4.28	7.69	7.57

$J = 7$ Hz), 8.75 (2H, d, $J = 11$ Hz), 9.22 (1H, d, $J = 11$ Hz), 9.67 (1H, d, $J = 11$ Hz), 10.5 (1H, s), 11.5 (1H, b); mass 289 (M^+).

2i: m.p. 187–189°C; ^1H NMR: 1.51 (3H, t, $J = 7$ Hz), 4.54 (2H, q, $J = 7$ Hz), 7.80–7.95 (3H, m), 9.55–9.73 (2H, m), 12.0 (1H, s); mass 261 (M^+).

2j: m.p. 101–102°C; ^1H NMR: 1.42 (3H, t, $J = 7$ Hz), 4.44 (2H, q, $J = 7$ Hz), 7.64–8.01 (3H, m), 9.51–9.93 (2H, m), 10.44 (1H, s); mass 262 (M^+), 264 ($M^+ + 2$).

2k: m.p. 120–122°C; ^1H NMR: 1.38 (3H, t, $J = 7$ Hz), 1.49 (6H, d, $J = 7$ Hz), 3.27 (1H, h, $J = 7$ Hz), 4.51 (2H, q, $J = 7$ Hz), 7.78–7.92 (2H, m) 9.67–9.85 (2H, m), 10.45 (1H, s); mass 304 (M^+), 306 ($M^+ + 2$).

2l: m.p. 103–106°C; ^1H NMR: 1.38 (3H, t, $J = 7$ Hz), 1.49 (6H, d, $J = 7$ Hz), 3.31 (1H, h, $J = 7$ Hz), 4.49 (2H, q, $J = 7$ Hz), 7.77–7.92 (2H, m) 9.53 (1H, dd, $J = 2$, $J = 7$ Hz), 9.98 (1H, d, $J = 1$ Hz), 10.50 (1H, s); mass 304 (M^+), 306 ($M^+ + 2$).

Relevant data for dyes 3 are given in Tables 2 and 3.

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