

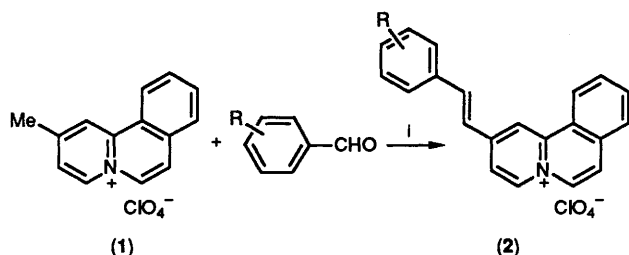
Synthesis of Solvatochromic Cyanine Dyes having a Benzo[*a*]quinolizinium Ring¹

Sadao Arai,* Kimihiko Nagakura, Masanori Ishikawa, and Mitsuhiro Hida*

Department of Industrial Chemistry, Faculty of Technology, Tokyo Metropolitan University, Fukazawa, Setagaya-ku, Tokyo 158, Japan

New stilbazolium cyanine-type dyes were synthesized by the base-catalysed aldol-type condensation of 2-methylbenzo[*a*]quinolizinium perchlorate with hydroxy-substituted benzaldehyde derivatives. The long wavelength absorption band of the deprotonated form of the dyes underwent a remarkable hypsochromic shift as the solvent polarity increased, and the pronounced negative solvatochromism extended over the whole visible region.

Recently we reported the synthesis of (monomethyl)benzo[*a*]quinolizinium perchlorates using photocyclization, cyclodehydration, or oxidative sulphur-extrusion, and discussed their reactivity.² Among the regioisomeric monomethyl derivatives, 2-methylbenzo[*a*]quinolizinium perchlorate (1) reacted with *p*-methoxybenzaldehyde in the presence of piperidine to afford quantitatively the merocyanine-type dye *trans*-2-(*p*-methoxystyryl)benzo[*a*]quinolizinium perchlorate (2; R *p*-OMe), which showed greenish yellow fluorescence in UV light (Scheme 1).



Scheme 1. Conditions: i, piperidine, MeOH, reflux.

Among the merocyanine dyes, stilbazolium betaine-type dyes, in which an electron-accepting group is connected to an hydroxy-substituted moiety, continue to attract attention because of their extreme solvatochromic properties. These betaine dyes have been used to generate an empirical scale of solvent polarity³ and have also been used to characterize the polarity of their immediate environment in micelles, microemulsions, and phospholipid bilayers.⁴ There is currently much interest in the use of stilbazolium chromophores for nonlinear optical applications.⁵ In these dyes, many heterocyclic rings such as pyridinium, quinolinium, and benzothiazolium ions are used as electron-accepting moieties.³ So far, however, no stilbazolium betaine-type dyes, which have a benzoquinolizinium ring as an electron-accepting moiety, have been reported. These results prompted us to use compound (1) for the synthesis of new stilbazolium cyanine dyes. This paper will describe the synthesis and solvatochromic behaviour of new stilbazolium cyanine dyes having a benzo[*a*]quinolizinium ring moiety.

Results and Discussion

When compound (1) was refluxed with various benzaldehyde derivatives in the presence of piperidine in methanol, 2-styrylbenzo[*a*]quinolizinium perchlorates (2) were obtained in good yield (Table 1). The stereochemistry of the double bonds was *E*(*trans*) as indicated by ¹H NMR coupling constants. For

instance, an olefin proton in compound (2e) appeared at δ 7.41 with a coupling constant *J* 16.3 Hz, characteristic of a *trans* configuration. Table 1 shows that the first absorption band of the styryl derivatives (2a-f) is shifted to longer wavelength with increasing electron-donating strength of the *para*-substituent. The absorption maximum of compound (2f) in ethanol showed a large blue shift (from 509 to 395 nm) upon addition of a drop of hydrochloric acid. On the other hand the absorption maximum of compound (2e) in ethanol showed a characteristic red shift (from 430 to 553 nm) when the hydroxy group was deprotonated on the addition of base.

The absorption maximum of the compound (2e) showed a blue shift with increasing solvent polarity (441 nm in 3-methylbutan-1-ol, 430 nm in EtOH, 423 nm in MeOH, and 405 nm in water). On the other hand, the long-wavelength absorption band of the deprotonated form (3) of compound (2e), which was formed on the addition of base, underwent a remarkable hypsochromic shift as the solvent polarity increased. The pronounced negative solvatochromism extended over the whole visible region: the colour of the solution is orange (472 nm) in water, red (520 nm) in methanol, violet (553 nm) in ethanol, blue (588 nm) in 3-methylbutan-1-ol, and green (641 nm) in acetone. The *ortho*-derivative (4c) showed similar behaviour (see Table 3 below). The spectrum of the *meta*-derivative (2g) was, however, little affected by the addition of base. These results can be attributed to the predominant contribution of the polar resonance structure (3a) rather than the quinonoid form (3b) to the ground state of stilbazolium betaines in polar solvents (Scheme 2).³ Thus, with increasing solvent polarity, the energy of the ground state is lowered more than that of the excited state, and this produces a hypsochromic shift (negative solvatochromism).

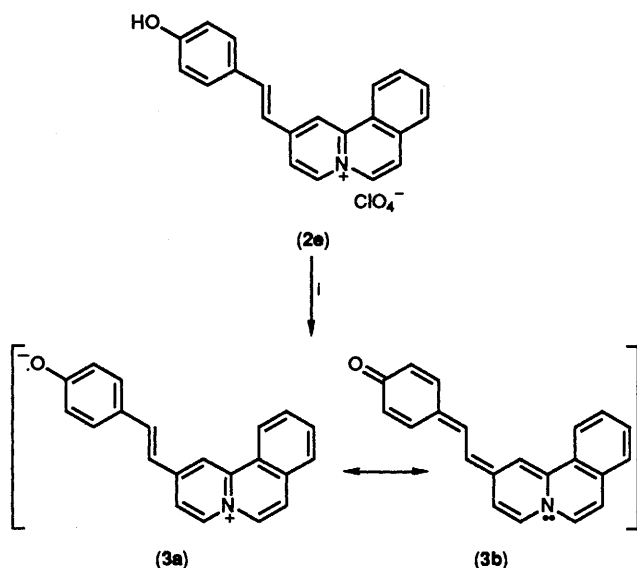
The remarkable colour changes of the deprotonated forms of compounds (2e) and (4c) were comparable to those of Dimroth and Reichardt's pyridinium *N*-phenoxide betaine dye.³ A plot of the transition energy for the longest-wavelength absorption band of the deprotonated form of compound (2e) [the azonia betaine-type dye (3)] against solvent polarity parameter $E_T(30)$ is fairly linear over the range of solvent polarity from acetone to water (see Figure). These results show that the azonia betaine-type dyes can be used as an indicator of solvent polarity. Therefore a series of dyes (4), with a substituent *para* to the hydroxy group and *meta* to the stilbazole bond, was prepared.

The base-catalysed aldol-type condensation of compound (1) with hydroxy-substituted benzaldehyde derivatives in the presence of piperidine afforded the corresponding *trans*-stilbazolium-type dyes (4b-e) in moderate yield (Table 2). Solutions of the dyes were mostly yellow to orange in ethanol.

Table 1. Reaction of compound (1) with benzaldehyde derivatives.

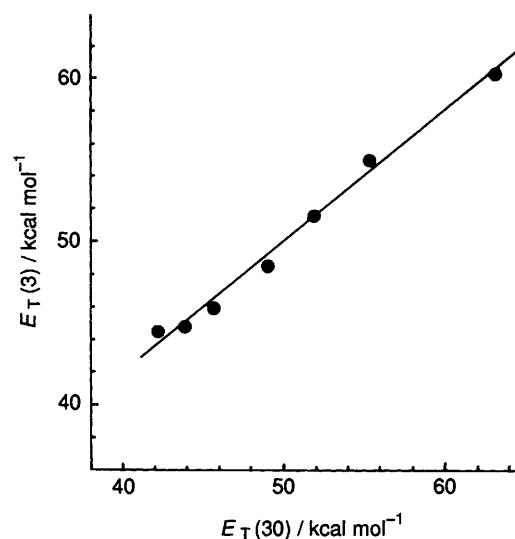
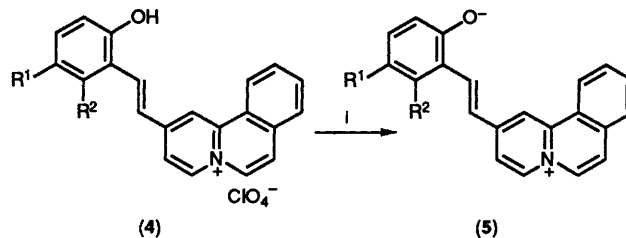
Compound	R	Time (h)	Yield (%)	M.p. (°C)	Found (%) (Required)			λ_{\max}/nm (ϵ) ^b	δ_{H}	$\nu_{\max}(\text{KBr})/\text{cm}^{-1}$
					C	H	N			
(2a)	<i>p</i> -NO ₂	2	71	335.5–336.0	59.3 (59.1)	3.3 (3.5)	6.7 (6.6)	386 (44 800)	7.7–9.6 (15 H, m, ArH and CH=CH)	1 620, 1 515, 1 340, 1 120, 983, 838
(2b)	H	10	85	165.5–167.0	65.8 (66.1)	4.1 (4.2)	3.7 (3.7)	401 (38 400)	7.1–9.6 (16 H, m, ArH and CH=CH)	1 620, 1 477, 1 110, 970, 750, 685
(2c)	<i>p</i> -Me	5	74	327.0–328.0	66.5 (66.8)	4.5 (4.6)	3.7 (3.5)	407 (47 500)	2.33 (3 H, s, CH ₃), 7.1–9.6 (15 H, m, ArH and CH=CH)	1 613, 1 475, 1 178, 1 120, 972, 810
(2d) ^a	<i>p</i> -OMe	5	99	246.0–247.0	64.3 (64.2)	4.3 (4.4)	3.2 (3.4)	420 (48 100)	3.83 (3 H, s, CH ₃), 7.0–9.4 (15 H, m, ArH and CH=CH)	1 620, 1 482, 1 178, 1 125, 980, 838
(2e)	<i>p</i> -OH	3	52	307.0–308.3	63.9 (63.4)	4.1 (4.1)	3.6 (3.5)	430 (44 600)	6.8–9.4 (15 H, m, ArH and CH=CH), 10.1 (1 H, br s, OH)	3 320, 1 590, 1 475, 1 120, 965, 830
(2f) ^c	<i>p</i> -NMe ₂	3	62	265.0–266.0	68.1 (68.2)	5.3 (5.2)	6.9 (6.9)	509 (47 600)	3.00 (6 H, s, CH ₃), 6.6–9.3 (15 H, m, ArH and CH=CH)	1 583, 1 354, 1 183, 943, 820
(2g)	<i>m</i> -OH	4	86	260 (decomp.)	63.3 (63.4)	4.0 (4.1)	3.7 (3.5)	405 (44 800)	6.8–9.6 (15 H, m, ArH and CH=CH), 9.74 (1 H, s, OH)	3 360, 1 615, 1 477, 1 124, 970, 685

^a Ref. 2. ^b In EtOH. ^c Bromide ion.

**Scheme 2.** Conditions: i, base.

The product with 2-hydroxy-5-nitrobenzaldehyde was, however, red in ethanol (503 nm), even in the absence of base. The addition of base to this solution caused little effect on the absorption spectrum. However, on addition of a drop of hydrochloric acid the solution immediately changed colour to pale yellow due to protonation at the phenolic oxygen atom of the dye. Under basic conditions the colour returned to red. The IR spectrum of the product showed no absorption bands corresponding to perchlorate ion. These results, together with analytical data, suggested that the product was not compound (4a) but instead was the betaine form (5a). For all azonia compounds other than (5a), fast-atom bombardment (FAB) mass spectra using *m*-nitrobenzyl alcohol as a matrix showed that the ion at highest *m/z*-values corresponded to the intact cations (C⁺). In the FAB spectrum of the betaine (5a), however, the highest *m/z*-value was (C⁺ + 1).

Table 2 shows that the absorption maxima of the compounds (4b–d) are shifted to longer wavelength with increasing electron-donating strength of the substituents *para* to the hydroxy group. Table 2 also shows that the large bathochromic shift of the dye (4e) to (4c) was observed because of the extended conjugation

**Figure.** Correlation between $E_T(30)$ and the transition energy of the azonia betaine-type dye (3) [$E_T(3)$].**Scheme 3.** Conditions: i, base.

through the naphthalene ring. The solvatochromism of the azonia betaine-type dyes (3) and (5a–e) is shown in Table 3. Table 3 shows that the absorption maxima of dyes (5a)–(5d) is shifted to longer wavelength with increasing the electron-donating strength of the substituent to *para* to the hydroxy group. The solvatochromism of dyes (5a) and (5e) is rather small compared with those of dyes (3) and (5b)–(5d).

The solvatochromic behaviour will be discussed in detail in a future paper.

Table 2. Reaction of compound (1) with hydroxy-substituted benzaldehyde derivatives.

Compound	R ¹	R ²	Time (h)	Yield (%)	M.p. (°C)	Found (%) (Required)			$\lambda_{\max}/\text{nm}^a$	δ_{H}	$\nu_{\max}(\text{KBr})/\text{cm}^{-1}$
						C	H	N			
(5a) ^b	NO ₂	H	2	83	> 300	73.6 (73.7)	4.2 (4.1)	8.0 (8.2)	503	6.17 (d, <i>J</i> 9.7 Hz, 1 H), 7.7–9.3 (m, 13 H, ArH)	1 630, 1 587, 1 480, 1 280, 973, 824
(4b)	Br	H	4	30	272–274	53.2 (52.9)	3.0 (3.2)	3.1 (2.9)	414	6.9–9.5 (m, 14 H, ArH), 10.7 (br s, 1 H, OH)	3 360, 1 612, 1 472, 1 110, 972, 810
(4c)	H	H	3	58	246–247	63.1 (63.4)	4.3 (4.05)	3.2 (3.5)	417	6.9–9.4 (m, ArH)	3 380, 1 617, 1 480, 1 110, 972, 820
(4d)	MeO	H	4	63	245–246	61.6 (61.8)	4.0 (4.2)	3.0 (3.3)	440	3.78 (s, 3 H, CH ₃), 6.9–9.4 (m, 14 H, ArH), 9.95 (s, 1 H, OH)	3 390, 1 608, 1 478, 1 120, 817, 742
(4e)	(CH=CH) ₂		5	57	240–242	67.2 (67.0)	4.1 (4.05)	3.3 (3.1)	450	7.2–9.5 (m, 14 H, ArH), 10.90 (s, 1 H, OH)	3 400, 1 606, 1 478, 1 122, 965, 818

^a In EtOH. ^b Betaine form.**Table 3.** Solvatochromism of azonia betaine-type dyes.

Solvent	λ_{\max}/nm					
	(3)	(5a)	(5b)	(5c)	(5d)	(5e)
Water	472	<i>a</i>	501	<i>b</i>	501	520
MeOH	520	485	516	516	558	582
EtOH	553	503	545	546	594	609
Me ₂ CHCH ₂ CH ₂ OH	588	502	570	571	621	627
MeCN	622	537	616	626	688	648
Me ₂ NCHO	637	545	630	642	702	659
Me ₂ CO	641	556	640	649	701	665

^a Insoluble. ^b Rather unstable.

Experimental

M.p.s. were obtained on a Yamato melting point apparatus MP-21 and are uncorrected. IR spectra were measured on a JASCO IRA-1 spectrometer. UV and visible spectra were obtained with a Hitachi 220A spectrometer. ¹H NMR data were recorded on a JEOL FX90Q (90 MHz) spectrometer as solutions in (CD₃)₂SO. Chemical shifts are reported relative to SiMe₄ as internal standard. Mass spectra (FAB) were obtained with a JEOL JMS-DX 300 spectrometer with *m*-nitrobenzyl alcohol as matrix. Elemental analyses were performed by Mr. Hirokatsu Suzuki at the Department of Chemistry, Tokyo Metropolitan University. All commercial compounds were reagent grade and were used without further purification. All solvents were purified according to the literature procedure.⁶ 2-Methylbenzo[*a*]quinolininium perchlorate (1) was prepared by photocyclization as described in a previous paper.²

Synthesis of the Stilbazolium Cyanine-type Dyes (2a–g), (5a), and (4b–e).—A typical procedure for the reaction of compound (1) with benzaldehyde derivatives is described for the synthesis of *trans*-2-(*o*-hydroxystyryl)benzo[*a*]quinolininium perchlorate (4c). To a mixture of compound (1) (150 mg, 0.51 mmol) and *o*-hydroxybenzaldehyde (75 mg, 0.61 mmol) in methanol (20 ml)

was added piperidine (three drops) and the mixture was refluxed for 3 h. After being cooled to room temperature, the solution was concentrated *in vacuo*. This crude mixture was recrystallized from methanol to afford compound (4c) (118 mg, 58%) as yellow crystals.

Reaction of compound (1) with 2-hydroxy-5-nitrobenzaldehyde afforded a dark red solid, which was filtered off, washed with methanol, and recrystallized from dimethylformamide to give compound (5a) as a dark red powder in 83% yield. The physical properties and analytical data of the stilbazolium cyanine-type dyes are shown in Tables 1 and 2.

UV-Visible Spectral Measurements of the Dyes.—In order to avoid *trans* → *cis* photoisomerization,⁷ the solutions were handled in the dark. After the addition of piperidine (0.05 ml, 1.25%) into a dye solution (4 ml; *ca.* 2 × 10⁻⁵M), the UV and visible spectra of the solvatochromic betaine-type dyes were measured.

References

- 1 Part of this work has been reported in preliminary from: S. Arai, M. Yamazaki, K. Nagakura, M. Ishikawa, and M. Hida, *J. Chem. Soc., Chem. Commun.*, 1983, 1037.
- 2 S. Arai, M. Yamazaki, and M. Hida, *J. Heterocycl. Chem.*, in the press.
- 3 K. Dimroth, C. Reichardt, T. Siepmann, and F. Bohlmann, *Justus Liebigs Ann. Chem.*, 1963, **661**, 1; C. Reichardt, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 98; 'Solvents and Solvent Effects in Organic Chemistry,' VCH, New York, 1988.
- 4 K. A. Zachariasse, N. Van Phuc, and B. Kozankiewicz, *J. Phys. Chem.*, 1981, **85**, 2676.
- 5 D. J. Williams, *Angew. Chem., Int. Ed. Engl.*, 1984, **23**, 690.
- 6 D. D. Perrin and W. L. F. Armarego, 'Purification of Laboratory Chemicals,' Pergamon, Oxford, 1988.
- 7 U. Steiner, M. H. Abdel-Kader, P. Fisher, and H. E. A. Kramer, *J. Am. Chem. Soc.*, 1978, **100**, 3190.

Paper 0/00303D
Received 19th January 1990
Accepted 22nd February 1990