QUINO-4-CYANINES WITH CARBONYL-CONTAINING SUBSTITUENTS

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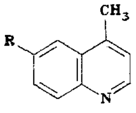
6-Carbonyl-substituted lepidines and their quaternary salts were synthesized. Quino-4-cyanines were obtained from them. The introduction of carbonyl-containing substituents substantially deepens the color of the dyes obtained.

It was shown on the example of cyanine dyes with symmetrical and nonsymmetrical structures, constructed from heterocyclic nuclei of various electron donor properties, that increasing the polarity of the medium leads to an increase in the color, as well as to an increase in the deviations in these properties [1, 2]. These effects are due to a predominant stabilization of the ground state of the dye on account of an increase in the solvation of the positive charge distributed in it with decreasing electron donor capacity of the terminal heterocyclic groups in symmetrical dyes [1] and an increase in the electronic asymmetry in nonsymmetrical dyes [2].

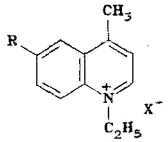
We were interested in following whether the indicated pattern is preserved for dyes in which the electron donor capacity of the terminal groups is changed by the introduction of substituents, which was accomplished in our work on the example of quino-4-cyanines. Such dyes with substituents have received comparatively little study [3]. And yet, the decrease in the basicity of these dyes when electron acceptor substituents (CF_3, CF_3S) are introduced into the 6,6-position increases their effectiveness as spectral sensitizers for photoemulsions [4]. Therefore, a broader investigation in the field of dyes of this type merits attention from this standpoint as well.

We synthesized quinocyanines with diethylaminocarbonyl, methoxy-carbonyl, and acetyl groups, as well as a diethylsulfamide substituent. The base Ia, unusual for synthesis, was produced by ammonolysis of the chloride of lepidine-6-carboxylic acid, Ib by its esterification, and Ic, d by condensation of p-substituted anilines with methyl vinyl ketone, as described for the indicated acid [5].

The bases Ia, d were converted by heating with the ethyl ester of p-toluenesulfonic acid and Ib, c by heating with ethyl iodide to the quaternary salts IIa-d.



Ia-**d**



IIa-**d**

a $R(C_2H_5)_2NC(O)$; b $RH_3COC(O)$; c $RH_3CC(O)$; d $R(H_5C_2)_2NSO_2$

Condensation of these salts with the ethyl ester of o-formic acid, 1-ethyl-4-(2-anilinovinyl)lepidinium chloride, or p-dimethylaminobenzaldehyde was used to synthesize symmetrical 6,6-substituted and nonsymmetrical 6-substituted quino-4-cyanines IIIa-d-IVa-d, respectively, as well as the styryl dyes Va-d (Table 1).

Table 1 compares λ_{max} and log ε of the long-wave absorption bands of the quinocyanines that we synthesized with the corresponding characteristics of their analogs IIIe and Ve, containing no substituents in the quinoline residue.

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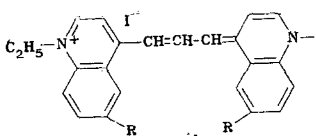
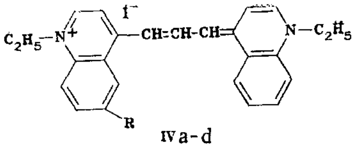
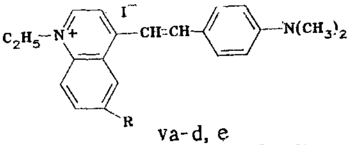
TABLE 1. Absorption Maxima (λ_{max}, nm), Molar Extinction Coefficients ($\varepsilon \cdot 10^{-4}$), and Values of the Deviations (D, nm) of the Synthesized Dyes (III-V)

Compound	III					IV			V					
	$C_6H_4Cl_2$	CH_3OH	$\Delta\lambda$[a]	CH_3CN	$\Delta\lambda$[b]	$C_6H_4Cl_2$	CH_3OH	CH_3CN	$C_6H_4Cl_2$	D	CH_3OH	D	CH_3CN	D
a	740 (22,4)	723 (19,0)	17	720 (19,8)	20	735 (18,0)	718 (16,5)	714 (—)	626 (4,7)	54	572 (4,0)	90	558 (—)	104
b	743 (17,8)	725 (21,5)	18	724 (18,0)	19	734 (17,0)	715 (15,4)	714 (—)	632 (5,4)	49,5	581 (4,2)	82	574 (—)	89,5
c	745 (17,6)	727 (21,4)	18	726 (18,2)	19	737 (17,0)	718 (16,0)	717 (—)	635 (5,0)	47,5	582 (4,2)	83,5	574 (—)	91
d	747 (21,5)	730 (17,7)	17	730 (18,7)	17	732 (15,5)	714 (13,2)	714 (—)	642 (5,7)	41	590 (4,4)	75,5	584 (—)	82,5
e	728	707	21	706	22				600	74	548	106,5	542	112,5

[a] $\Delta\lambda = \lambda_{max}(C_6H_4Cl_2) - \lambda_{max}(CH_3OH)$. [b] $\Delta\lambda = \lambda_{max}(C_6H_4Cl_2) - \lambda_{max}(CH_3CN)$.


IIIa-d, e


IVa-d


Va-d, e

III, Ve R=H

For styryl dyes the values of the deviations D are also given. The spectral characteristics are cited for solutions in relatively nonpolar o-dichlorobenzene and strongly polar methanol and acetonitrile.

As can be seen from the data cited, the electron acceptor substituents under consideration substantially deepen the color of the quinocyanines. Let us note that in the series of trimethylcyanines III of symmetrical structure, approximately the same effect from the introduction of carbonyl-containing substituents, which seem to lengthen the general system of conjugation of the dye, is observed as in the series of 6,6-substituted thiocarbocyanines, where the bathochromic shifts under the influence of the $(C_2H_5)NCO$, CH_3OCO, CH_3CO groups are equal to 15 [6], 17 [6] and 22 nm [7], respectively. At the same time, the influence of fluoro-containing substituents CF_3, CF_3S, CF_3SO_2 in the series of thiacyanines is weaker (by a factor of 2) than in the series of quinocyanines [4].

In all the symmetrical quinocyanines III, just as we should have expected [1, 2], an increase in the polarity of the medium and a decrease in the index of refraction of the solvent cause a hypsochromic shift of the absorption bands. However, a decrease in the electron donor properties of the quinoline residues in the dyes by the introduction of electron acceptor substituents into them does not lead to any increase in the hypsochromic shift in the transition from relatively nonpolar to strongly polar solvents, as should have been expected according to [1], but on the contrary, is accompanied by a certain decrease in it. The cause of such a difference lies in the fact that the principles in [1] were established on polymethine dyes, in which the heterocyclic residues possess low electron donor properties, in pyrylocyanines, their sulfur- and selenium-containing analogs. In cations of such dyes the positive charge is shifted to a substantial degree to the carbon atoms of the polymethine chain, which in turn is subjected to nucleophilic solvation. On the contrary, in quinocyanines the heterocyclic residues possess substantial electron donor capacity, as a result of which evidently not the carbon atoms of the polymethine chain but the heterocyclic residues should be subjected to predominant nucleophilic solvation. The electron acceptor groups in the dyes IIIa-d decrease the electron donor capacity of the heterocyclic residues, which leads to a weakening of the indicated type of solvation, and as a result of this they make the absorption of the dyes less sensitive to an increase in the polarity of the medium than the unsubstituted quinocyanine IIIe.

Close values of λ_{max} in the proton donor methanol and aprotic acetonitrile show that the phenomenon under consideration is rather weakly affected by specific solvation of the substituents.

The introduction of the substituents under consideration into one of the heterocyclic residues of the quinocarbocyanine (compound IV) slightly disturbs the electronic symmetry, so that an appreciable value of the deviation ($D \approx 5$) is observed only in the case of the dye IVd, which contains the most electron acceptor substituent among those under consideration.

On the contrary, in the case of styryl dyes V the influence of substituents has a distinct effect on their electronic asymmetry, which, as is shown by the value of D, decreases in direct correlation to the increase in electron acceptor capacity of the substituent $H < (C_2H_5)NCO < CH_3O$, $CO \approx CH_3CO < (C_2H_5)_2NSO_2$. In these dyes the positive charge is localized on the quinoline ring to a substantially greater degree than in carbocyanines of type III-IV, and the ring has a substantially greater electron donor capacity than the p-dimethylaniline residues; therefore, as follows from [2], their nucleophilic solvation should be greater than for dyes of the type III-IV. Actually, when the relatively nonpolar o-dichlorobenzene is replaced by the highly polar methanol or acetonitrile, the hypsochromic shifts of the absorption bands of the styryls are 4-5 times the corresponding shifts of the parent dyes, which are the corresponding symmetrical quinocarbocyanines of type III and Michler's hydrol for them.*

We should have expected that the introduction of electron acceptor substituents into the quinoline rings of styryls, just as in the corresponding symmetrical dyes III, would lead to a decrease in the shift of the bands into the short-wave region of the spectrum as we go from relatively nonpolar to strongly polar solvents. However, no such dependence is observed. This is probably due to the fact that the absorption bands of styryls represent bell-shaped curves, highly blurred in the region of λ_{max}, especially in polar solvents, which affects the accuracy of the determination of their maxima. Moreover, in dyes with great electronic asymmetry the absorption maxima may be determined by different vibrational transitions depending on the electron donor capacity of the terminal heterocyclic groups and the polarity of the solvent [8]. These circumstances probably do not permit any clear conclusions to be drawn on the influence of the electronic nature of the substituents on the solvatochromism of styryls.

EXPERIMENTAL

The electronic spectra were obtained in SF-4 and SF-8 spectrophotometers.

6-Diethylcarbamidolepidines (Ia). To 5 ml thionyl chloride, 0.01 ml 4-methylquinoline-6-carboxylic acid was added in small portions [5]. The mixture was boiled for 10 min until the evolution of gases ceased. When the solution was cooled, the hydrochloride of the acid chloride crystallized. For a more complete isolation of the product, an equal volume of dry dioxane was added. The mixture was cooled, the crystals filtered off, and washed with dioxane (2 × 10). Yield 70%.

To a solution of 3 ml diethylamine in 10 ml of ether, 2 g of the hydrochloride of the chloride of 4-methylquinoline-6-carboxylic acid was added in portions. After thorough mixing, the reaction mixture was evaporated to dryness and extracted with ether in a Soxhlet apparatus. The ether was evaporated and the residue crystallized from heptane. mp 102-103°C. Yield 83%. Found: C 74.4; H 7.3; N 11.6%. $C_{15}H_{18}N_2O$. Calculated: C 74.4; H 7.5; N 11.56%.

6-Diethylsulfamidolepidine (Id). To a mixture of 0.005 mole 4-diethylsulfamidoaniline hydrochloride, 0.01 mole ferric chloride hexahydrate, and 0.1 g anhydrous zinc chloride in 5 ml of ethanol, 0.005 mole methyl ethyl ketone was added with mixing over a period of 2 h at 60-65°C. The reaction mixture was heated for 4 h at 78°C, then 4 ml of alcohol distilled off, and the mixture neutralized with 10% NaOH. The residue, consisting of ferric hydroxide and 6-diethylsulfamidolepidine, was filtered off, washed well with water, dried, then extracted with chloroform. The chloroform was distilled off and the product crystallized from heptane. mp 125-126°C . Yield 55%. Found: N 11.9; S 9.0%. $C_{18}H_{28}N_3O_2S$. Calculated: N 11.0; S 9.1%.

6-Acetyllepidine (Ic). Produced analogously. Purified by boiling with water, followed by redistillation. bp 135-140°C (0.06 mm). mp 88.5-89.5°C. Yield 49%. Found: C 77.8; H 5.8; N 7.4%. $C_{12}H_{11}NO$. Calculated: C 77.8; H 6.0; N 7.5%.

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*The absorption maxima for Michler's hydrol in o-$C_6H_4Cl_2$, CH_3OH, and CH_3CN are equal to 620, 602, and 604 nm, respectively.

TABLE 2. Characteristics of Compounds III-V

Compound	mp, °C	Found, %		Gross formula	Calculated, %		Yield, %
		I	N		I	N	
IIIa	253	19,3	8,5	$C_{33}H_{43}IN_4O_2$	19,4	8,6	29
IIIb	222	21,2	4,6	$C_{29}H_{29}IN_2O_4$	21,3	4,7	29
IIIc	269	22,4	4,9	$C_{29}H_{29}IN_2O_2$	22,5	5,0	34
IIId	240	16,9	7,2	$C_{33}H_{45}IN_4O_4S_2$	16,5	7,2	67
IVa	182—184	22,6	7,4	$C_{29}H_{35}IN_3O$	22,8	7,6	18
IVb	170—173	23,3	5,1	$C_{27}H_{27}IN_2O_2$	23,4	5,2	72
IVc	170—173	24,3	5,3	$C_{27}H_{27}IN_2O$	24,3	5,4	64
IVd	122—124	20,2	6,9	$C_{29}H_{35}IN_3O_2S$	20,4	6,8	15
Va	213—214	24,3	8,3	$C_{25}H_{32}IN_3O$	24,6	8,1	30
Vb	215—217	25,6	5,8	$C_{23}H_{26}IN_2O_2$	25,8	5,7	42
Vc	216—218	26,5	6,1	$C_{23}H_{26}IN_2O$	26,7	5,9	38
Vd	236—237	22,3	7,4	$C_{25}H_{32}IN_3O_2S$	22,0	7,3	65

1-Ethyl-6-diethylsulfamidolepidinium Tosylate (IId). A mixture of 0.01 mole of the base and 0.015 mole of the ethyl ester of p-toluene-sulfonic acid was fused at 120°C for 6 h. Acetone was added to the slightly solidified melt, the salt was triturated, washed with acetone and ether, and purified by reprecipitation from a mixture of acetone with chloroform and crystallization from acetone. mp 99-101°C. Yield 82%. Found: N 5.9; S 13.3%. $C_{23}H_{30}N_2O_5S_2$. Calculated: N 5.9; S 13.5%.

1-Ethyl-6-acetyllepidinium Iodide (IIc). A mixture of 0.02 mole of the base, 2 ml dimethylformamide, and 3 ml ethyl iodide was heated on an oil bath at 115°C. After 10 min the mass crystallized. Then 5 ml of absolute alcohol was added and boiled for another 30 min. After cooling 10 ml of acetone was added. The precipitate was filtered off and washed with acetone (3 × 3 ml) and with ether. It was crystallized from alcohol. mp 215-217°C. Yield 76%. Found: I 37.4; N 4.0%. $C_{14}H_{16}INO$. Calculated: I 37.4; N 4.1%.

1-Ethyl-6-methoxycarbonyllepidinium Iodide (IIb). Produced analogously. mp 183°C. Yield 83%. Found: I 35.5; N 4.0%. $C_{14}H_{16}INO_2$. Calculated: I 35.5; N 3.9%.

Symmetrical Carbocyanines IIIa-d. A mixture of 0.002 mole of the salt IIa-d (in the case of Ia, after preliminarily melting the base with tosylate, as described for Id) and 0.7 ml of o-formic ester in 2.5 ml of pyridine was boiled for 20 min. Sodium iodide was added to the solidified solution in the case of the dyes I and IV, and the solution was poured out into a mixture of ether and water (50:50 ml). The dye was filtered off, washed with water, with ether, and with boiling benzene (3 × 3 ml). The dye IIIc was additionally washed with acetonitrile (5 ml), methylene chloride (3 ml), alcohol (3 ml), and ether. The dyes IIIa, c, and d were crystallized from methanol.

Nonsymmetrical Carbocyanines IVa-d. A mixture of 0.5 mmole of the salt IIa-d with 49 mmoles of 1-ethyl-4-(2-anilinovinyl)lepidinium iodide 0.4 ml of alcohol, and 0.6 ml of acetic anhydride was boiled for 5 min, then 0.5 ml of triethylamine was added dropwise to the boiling solution. Boiling was continued for another 2 min. The solutions were cooled; in the case of the dyes IVb and c crystals precipitated, were filtered off, and were crystallized from alcohol. In the case of the dyes IVa and d, sodium iodide was added, the solution was poured out into 30 ml of water, and the dyes were extracted with methylene chloride, precipitated with ether, and washed with water (2 ml). The substance was reprecipitated from methanol and methylene chloride with ethyl acetate.

Styryl Dyes Va-d. These were produced by boiling 3 mmoles of the salt IIa-d in 3 ml of acetic anhydride with 4 mmoles of p-dimethylaminobenzaldehyde. They were crystallized from methanol.

The characteristics of the dyes are cited in Table 2.

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SPIN—SPIN COUPLING CONSTANTS OF $^{13}C-^{1}H$ AND $^{1}H-^{1}H$ IN 4-SUBSTITUTED PYRIDINES

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The spin—spin coupling constants (SSCC) of $^{13}C-^{1}H$ and $^{1}H-^{1}H$ in 4-substituted pyridines, C_5H_4NX [X=CH_3, CN, $COCH_3$, $COOCH_3$, $N(CH_3)_2$, NO_2, OCH_3, Cl, Br], were investigated. To determine the constants, the proton-coupled NMR spectra of ^{13}C and ^{13}C-satellites in the PMR spectra of the compounds, recorded for monomolecular solutions of 4-substituted pyridines in DMSO-D_6, were analyzed. The interrelationship of the SSCC of $^{13}C-^{1}H$ and $^{1}H-^{1}H$ in 4-substituted pyridines with the analogous constants in monosubstittued benzenes were obtained. The correlations of the constants with the F- and R-parameters of the substituents are discussed.

According to the theoretical investigations conducted earlier [1, 2], the SSCC of $^{13}C-^{1}H$ and $^{1}H-^{1}H$ are an effective source of information on the structure and electronic effects in organic compounds. Of special interest is the use of these parameters for investigations of the effects of substitution on the NMR spectra of aromatic and heteroaromatic compounds [3]. Precise values of the SSCC of $^{13}C-^{1}H$ and $^{1}H-^{1}H$ have been obtained for a number of monosubstituted benzenes [3, 4] and 2-substituted and 3-substituted pyridines [5], and the similarity of the influence of substituents on the spin—spin interaction of the nuclei in these compounds was established.

In this work we continued an investigation of the parameters of the proton-coupled NMR spectra of ^{13}C and the high-resolution PMR spectra for 4-substituted pyridines. The conditions of the measurements and the selection of the substituents were analogous to those used in [5].

Table 1 presents the values of the chemical shifts of the protons and the SSCC of $^{1}H-^{1}H$. In view of the complexity of the analysis of the PMR spectra obtained for the main ^{12}C-isotopomers of the compounds, we additionally used the signals of the ^{13}C-satellites of the protons. As an example, Fig. 1 presents the experimental and calculated PMR spectra of 4-cyanopyridine. The use of such a procedure for the analysis of the PMR spectra permitted a substantial increase in the accuracy of the measurement of the SSCC of $^{1}H-^{1}H$ in tetrasubstituted pyridines. A comparison of the constants that we obtained with those known previously [6-8] showed that the most reliable results are cited in [8]; however, in this work not all the SSCC of $^{1}H-^{1}H$ were determined. In the course of the investigations it was also found that the SSCC $J_{H_2H_6}$ changes sign in the transition from compounds containing substituents that can be arbitrarily characterized [5] as electrically neutral and π-acceptors according to their effects on the system studied (the ring of the heterocycle) to compounds with substituents possessing π-donor properties and halogens.

The SSCC of $^{1}H-^{1}H$ in 4-substituted pyridines were compared with the analogous constants in monosubstituted benzenes [4, 9, 10]. A great similarity of the effects of substitution on the SSCC of $^{1}H-^{1}H$ was found in these compounds.

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