Chemistry of Heterocyclic Compounds, Vol. 29, No. 10, 1993

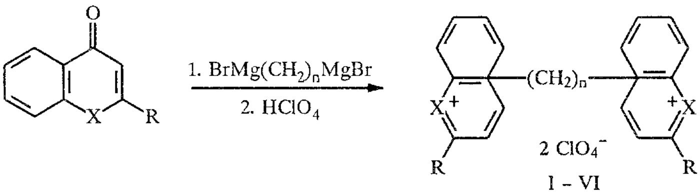
PYRYLOCYANINES.
31.* BENZOPYRYLOCARBOCYANINES WITH BRIDGED GROUPINGS IN THE CHROMOPHORE

M. A. Kudinova, E. I. Maiboroda, Yu. L. Slominskii,
and A. I. Tolmachev

4,4'-Tetramethylene- and 4,4'-pentamethylenebisflavylium salts and their sulfur- and selenium-containing analogs were synthesized. Trimethinecyanine dyes with ethylene and trimethylene bridged groupings in the chromophore were obtained from these salts. The factors that affect the color of these dyes were analyzed thoroughly.

Hydrocarbon bridged groupings in the chromophore of polymethine dyes may not only affect their spectral-luminescence properties but may also sharply increase their thermal and photochemical stabilities. In series of derivatives of nitrogen-containing heterocycles cyclization of the chromophore by bridged groupings has been described for dyes with various lengths of the polymethine chain that contain from 3 to 11 methylidyne groups [2, 3]. On the other hand, in the pyrylo- and benzopyrylocyanine series only polycarbocyanines with a polymethine chain consisting of seven or more methylidyne groups have thus far been described [4-6], while tri- and pentamethinecyanines have remained unknown.

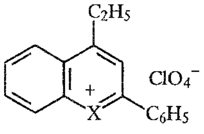
The task of the present research was to work out the synthesis of benzopyrylo-4-carbocyanines and their heteroanalogs, the trimethylidyne chromophore of which participates in the closure of the ethylene or trimethylene bridged grouping. With this end in mind, polymethylenebis(benzopyrylium) and benzothio- and benzoselenopyrylium salts I-VI were synthesized by the reaction of 2-tert-butylchromone and flavone and its thio and seleno analogs with the Grignard reagents obtained from 1,4-dibromobutane and 1,5-dibromopentane:



I - VI

I R = $C(CH_3)_3$; II—IV R = C_6H_5; I, II, IV, VI n = 4, III, V n = 5; I—III X = O; IV, V X = S; VI X = Se

In addition to the bis salts presented above, 4-ethylflavylium perchlorate VII and its sulfur-containing analogs VIII were obtained as model compounds by the same method [7].



VII, VIII

VII X = O; VIII X = S

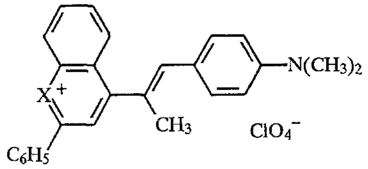
---

[*] For Communication 30 see [1] .

Institute of Organic Chemistry, Academy of Sciences of Ukraine, Kiev 252660. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 10, pp. 1319-1323, October, 1993. Original article submitted October 4, 1993.

In the case of bisflavylium salt II it was shown that, in obtaining it, the utilization of the corresponding dilithium derivative instead of the Grignard reagent provides no advantages. The structures of the salts obtained were confirmed by the results of electronic and PMR spectroscopy. In the electronic spectra of all of the 2-phenyl-substituted dications one observes absorption bands at 390-410 nm, the molecular absorption coefficients of which, as expected, are higher than for the corresponding monocations, as, for example, by a factor of almost two for salts VII and VIII. In the PMR spectra of the dicationic salts, in addition to signals of aromatic protons, one observes signals of protons of methylene groups of polymethylene chains.

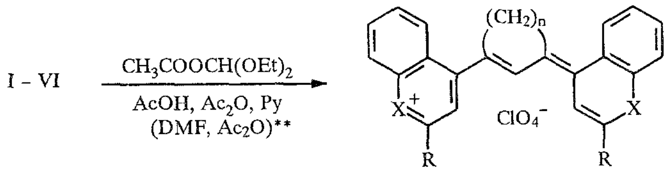
Replacement of the methyl groups in the 4-methylflavylium and 4-methylthioflavylium salts by alkyl groups decreases their activity with respect to electrophilic agents. In contrast to the 4-methyl derivatives, which readily form diverse polymethine dyes [8, 9], only styryl dyes IX and X could be synthesized by the reaction of these salts with p-dimethylaminobenzaldehyde. Symmetrical carbocyanines could not be obtained from these salts either by the action of triethyl orthoformate or diethoxymethyl acetate on them.



IX, X

IX X = O, λ_{max} 698 nm (690), lgε 4,81 (5,06)*;
X X = S, λ_{max} 738 nm (733), lgε 4,67 (5,04)

In addition, not one of the dicationic salts I-VI reacts with triethyl orthoformate. However, in the case of the action on salts I-IV of diethoxymethyl acetate, which has higher electrophilicity, we were able to obtain carbocyanines IX-XIV, which contain di- and trimethylene groupings in the chromophore.



XI - XVI

XI R = C(CH$_3$)$_3$; XII—XVI R = C$_6$H$_5$; XI, XII, XIV, XVI n = 2; XIII, XV n = 3; XI—XIII X = O;
XIV, XV X = S; XVI X = Se

We found that the same dyes are formed (and even more easily) by the action of dimethylformamide (DMF) on the indicated salts, while thioflavylocarbocyanine XIII, which contains a trimethylene grouping, could be obtained only by using this reagent. On the basis of the spectral data (the development of an absorption band with a maximum at 890 nm) one may conclude that selenoflavylium salt VI also reacts with dimethylformamide; however, the corresponding dye XVI could not be isolated in an analytically pure state. The fact of the formation of dyes with cyclic groupings in the chromophore follows unambiguously from the data from the PMR spectra, which, because of the low solubility of the dyes in ordinary solvents, could be obtained only for some of them in solution in deuteronitrobenzene, in which the signals of the aromatic protons of the compounds are not always traced. The most nearly complete spectrum was obtained for 2,2′-di-tert-butyl-substituted benzopyrylocarbocyanine XI: δ 1.39 [18H, s, C(CH$_3$)$_3$], 3.06 (4H, s, CH$_2$), 6.95 (2H, s, ring β-H), 7.45 (2H, t, 6-H), 7.45 (2H, t, 6-H), 7.63 (2H, t, 7-H), 8.05 (2H, d, 8-H), and 8.60 ppm (1H, s, chromophore CH). In the PMR spectrum of flavylocyanine XIII with a trimethylene bridge one observes a signal of CH$_2$ groups adjacent to the chromophore, which is situated at stronger field at 2.86 ppm (4H, doublet of triplets) and a signal of the middle methylene link of the bridge at 2.45 ppm (2H, m). Signals of the indicated groups are found in the same regions in the spectrum of thioflavylotrimethinecyanine

---

*For solutions in CH$_2$Cl$_2$; data for analogs with an unsubstituted chromophore are presented in parentheses.

**Only DMF for salts V and VI.

XIV. The location of the signal of the CH_2 groups of the ethylene bridge as compared with the signal of the corresponding CH_2 groups of the trimethylene bridge at weaker field may serve as an indication of its stronger electron-donor effect on the chromophore of the dye.

Data from the electronic spectra of the synthesized dyes are compared with the corresponding characteristics of analogous trimethinecyanines with an unclosed chromophore in Table 2 [10, 11].

It is apparent from the data presented here that carbocyanines with cyclic groupings are more deeply colored than their analogs with an unsubstituted chromophore; ethylene groupings prove to be more effective than trimethylene groupings. The intensities of the absorption bands of the dyes that contain rings, on the other hand, are lower than the intensities of their analogs with an unclosed chromophore. It follows from a comparison of the $\log\varepsilon$ values for flavylocyanines XII and XIII that the trimethylene bridge gives rise to a more pronounced decrease in the intensity than an ethylene bridge. The deepening of the color and the decrease in the absorption intensity under the influence of the bridged grouping can be explained by steric hindrance, which is undoubtedly present in the entire series of these dyes. However, superimposed on the steric effect of the groupings is their electronic effect, which, like the steric effect, leads to deepening of their color. The great bathochromic shift under the influence of an ethylene bridge, which results in a smaller degree of steric hindrance, is also explained precisely by this effect, which is due, in the case of a five-membered ring, by the closure by a single bond of the methyl groups that participate in the overall conjugation system.

EXPERIMENTAL

The absorption spectra of I-XVI were recorded with a Specord M-40 spectrophotometer. The Spectra of I-VIII were obtained from solutions in acetonitrile containing 20% perchloric acid, while the spectra of IX-XVI were obtained from solutions in methylene chloride stabilized with 1% absolute ethanol.

The purity of the preparations was monitored by TLC on Silufol UV-254 plates with acetonitrile as the eluent. The PMR spectra of solutions in CF_3COOD (I-VI) were recorded with a Bruker WP-200 spectrometer at operating frequencies of 200 and 132 MHz, while the PMR spectra of solutions in d_5-nitrobenzene (XI-XIV) were recorded with a Jemini-200 spectrometer at an operating frequency of 200 MHz; all recordings were made at 25°C with hexamethyldisiloxane (HMDS) as the internal standard.

The results of elementary analysis for C, H, Cl, S, and Se were in agreement with the calculated values.

4,4′-Tetramethylenebisflavylium Diperchlorate (II). A. A solution of a Grignard reagent obtained from 0.5 g (0.02 g-atom) of magnesium metal and 2.16 g (10 mmole) of 1,4-dibromobutane in 10 ml of absolute ether was added dropwise with stirring to a solution of 2.2 g (10 mmole) of flavone in 70 ml of anhydrous ether, after which the reaction mixture was heated for 2 h at 40°C. The solvent was then removed in vacuo, and 2 ml of 57% perchloric acid and 15 ml of 20% perchloric acid were added successively. The resulting precipitate was removed by filtration and washed with acetic acid and ether to give salt II. UV spectrum, λ_{max} ($\log\varepsilon$): 248 (4.58), 388 nm (4.92). PMR spectrum: 1.9 (4H, s, β-CH_2), 3.3 (4H, s, α-CH_2), 7.29-8.13 (18H, m, Ar—H), 8.22 ppm (2H, s, β-H).

B. Butyl-1,4-dilithium, obtained from 0.37 g (0.053 g-atom) of lithium and 2.2 g (10 mmole) of 1,4-dibromobutane in 5 ml of absolute ether at −10°C, was added dropwise with stirring in an argon atmosphere to a solution of 4.4 g (20 mmole) of flavone in 140 ml of absolute ether, after which the reaction mixture was maintained at the same temperature for 1 h and then for 2 h at 23°C. The solvent was removed by distillation, and 2 ml of 57% perchloric acid and 15 ml of 20% perchloric acid were added successively with cooling to the residue. The resulting precipitate was removed by filtration and washed successively with ether, water, and ether to give salt II (see Table 1).

4,4′-Tetramethylenebis(2,2′-tert-butylbenzopyrylium) (I), -thioflavylium (IV), and -selenoflavylium (VI) Diperchlorates and 4,4′-Pentamethylenebisflavylium (III) and -thioflavylium (V) Diperchlorates. These compounds were obtained in the same way as II by method A, but in the case of salt I monoglyme was used as the solvent, while tetrahydrofuran was used as the solvent in the case of salts IV and VI. Compound I: UV spectrum, λ_{max} ($\log\varepsilon$): 243 (4.81), 327 nm (4.53). PMR spectrum: 1.26 [18H, s, $C(CH_3)_3$], 1.8 (4H, s, β-CH_2), 3.3 (4H, s, α-CH_2), 7.6-7.95 (10H, m, Ar—H), 8.15 ppm (2H, d, β-H). Compound III: UV spectrum, λ_{max} ($\log\varepsilon$): 248 (4.68), 387 nm (4.99). PMR spectrum: 1.55 (2H, m, γ-CH_2), 1.72 (4H, m, β-CH_2), 3.19 (4H, t, α-CH_2), 7.25-8.20 ppm (20H, m, Ar—H). Compound IV: UV spectrum, λ_{max} ($\log\varepsilon$): 264 (4.70), 391 nm (4.61). PMR spectrum: 1.98 (4H, s, β-CH_2), 3.354 (4H, s, α-CH_2), 7.2-8.18 (18H,m, Ar—H), 8.48 ppm (2H, s, β-H). Compound V: UV spectrum, λ_{max} ($\log\varepsilon$): 265 (4.77), 390 nm (4.3). PMR spectrum: 1.72 (6H, m, β,γ-

TABLE 1. Characteristics of the Synthesized I-VII and X-XV*

Compound	Empirical formula	mp, °C	Yield % (meth.)	Compound	Empirical formula	mp, °C	Yield % (meth.)
I	$C_{30}H_{36}Cl_2O_{10}$	268...270	18	IX	$C_{26}H_{24}ClNO_5$	165...166	37
II	$C_{34}H_{28}Cl_2O_{10}$	216...218	95 (A) 35 (B)	X	$C26H_{24}ClNO_4$	172...173	36
III	$C_{35}H_{30}Cl_2O_{10}$	234...235	87	XI	$C31H_{33}ClO_6$	243...244	71
IV	$C_{34}H_{28}Cl_2O_8S_2$	230...231	91	XII	$C_{35}H_{25}ClO_6$	224...225	75
V	$C_{35}H_{30}Cl_2O_8S_2$	201...203	55	XIII	$C36H_{27}ClO_6$	226...227	31
VI	$C_{34}H_{28}Cl_2O_8Se_2$	175 (с разл.)	70	XIV	$C35H_{25}ClO_4S_2$	279...280	96
VII	$C_{17}H_{15}ClO_5$	183...184	35	XV	$C36H_{27}ClO_4S_2$	169...170	77

---

*The compounds were crystallized: I-VI from acetic acid—acetonitrile (2:1), VII-X from glacial acetic acid, and XI-XV from acetic acid.

TABLE 2. Characteristics of the Long-Wave Absorption Bands of Solutions of Dyes XI-XVI in Methylene Chloride*

Compound	λ_{max}, nm	lgε	Compound	λ'_{max}, nm	lgε
XI	731 (665)	5,17 (5,46)	XIV	862 (800)	5,07 (-)
XII	790 (715)	5,14 (5,31)	XV	839 (800)	4,46 (-)
XIII	767 (715)	4,72 (5,31)	XVI	890 (845)	— (-)

---

*The corresponding characteristics of the analogous trimethylcyanines with an unclosed chromophore are given in parentheses.

CH_2), 3.33 (4H, t, α-CH_2), 7.24-8.50 ppm (20H, m, Ar—H). Compound VI: UV spectrum, λ_{max} (log ε): 272 (4.48), 407 nm (4.44). PMR spectrum: 1.96 (4H, s, β-CH_2), 3.33 (4H, s, α-CH_2), 7.20-8.80 (18H, m, Ar—H), 2H, s, β-H).

4-Ethylflavylium perchlorate VII was obtained in the same way as II from flavone and ethyl bromide. Benzene was used as the solvent for flavone. UV spectrum, λ_{max} (log ε): 248 (4.39), 388 nm (4.37).

4-[1-Methyl-2-(4-dimethylaminophenyl)ethenyl]flavylium Perchlorate (IX). A mixture of 334 mg (1 mmole) of VII, 149 mg (1 mmole) of p-dimethylaminobenzaldehyde, and 3 ml of acetic anhydride was heated for 15 min at 135°C. The dye was removed by filtration and washed with acetic acid and ether.

4-[1-Methyl-2-(4-dimethylaminophenyl)ethenyl]thioflavylium perchlorate (X) was obtained in the same way as IX from salt VIII.

3-[(2-tert-Butyl-4-chromenylidene)-1,3-dimethylene-1-propen-1-yl]-2-tert-butylchromylium Perchlorate (XI). A mixture of 0.12 g (0.22 mmole) of salt I, 70 mg (0.46 mmole) of diethoxymethyl acetate, 0.12 g (0.15 mmole) of pyridine, and 1 ml of a mixture of acetic acid with acetic anhydride was heated for 30 min at 130°C. The dye was removed by filtration and washed with acetic acid and ether.

Carbocyanines XII, XIII, and XIV were obtained in the same way as XI from salts II, III, and IV, respectively, but the mixtures were heated for 1.5 h.

3-[(Thio-4-flavenylidene)-1,3-trimethylene-1-propen-1-yl]thioflavylium Perchlorate (XV). A mixture of 0.11 g (0.15 mmole) of salt V, 23 mg (0.3 mmole) of dimethylformamide, and 0.5 ml of acetic anhydride was refluxed for 2 min. The dye was precipitated with 20% perchloric acid, removed by filtration, and washed with ether, acetic acid, and ether.

REFERENCES

1. N. A. Derevyanko, A. A. Ishchenko, and A. I. Tolmachev, Khim. Geterotsikl. Soedin., No. 3, 345 (1992).

2. Yu. L. Slominskii, G. G. Dyadyusha, I. K. Ushenko, I. D. Radchenko, and A. I. Tolmachev, Ukr. Khim. Zh., **40**, 1163 (1974).
3. A. I. Tolmachev, Yu. L. Slominskii, and M. A. Kudinova, Usp. Nauchn. Fotografii, **22**, 12 (1984).
4. A. A. Ishchenko, M. A. Kudinova, Yu. L. Slominskii, and A. I. Tolmachev, Zh. Org. Khim., **22**, 170 (1986).
5. Yu. L. Slominskii, A. L. Smirnova, M. A. Kudinova, N. I. Efimenko, and A. I. Tolmachev, Ukr. Khim. Zh., **44**, 838 (1978).
6. M. A. Kudinova, Yu. L. Slominskii, and A. I. Tolmachev, Khim. Geterotsikl. Soedin., No. 1, 117 (1981).
7. Sh. Watanabe, H. Nakazumi, S. Kado, and T. Kitao, J. Chem. Res. Synop., No. 2, 50 (1990).
8. R. Wizinger and H. Tobel, Helv. Chim. Acta, **40**, 1305 (1957).
9. A. I. Tolmachev and M. A. Kudinova, Khim. Geterotsikl. Soedin., No. 5, 804 (1969).
10. A. I. Tolmachev, N. A. Derevyanko, and A. A. Ishchenko, Khim. Geterotsikl. Soedin., No. 9, 1173 (1982).
11. A. I. Tolmachev and M. A. Kudinova, Khim. Geterotsikl. Soedin., No. 7, 924 (1971).