REACTIONS OF 2- AND 4-METHYLPYRYLIUM SALTS WITH ETHYL ORTHOFORMATE

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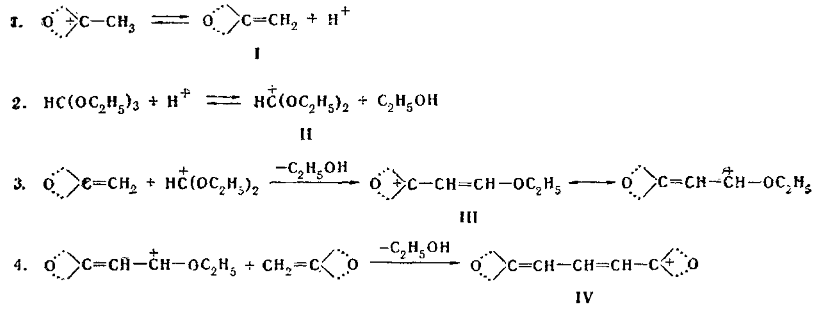
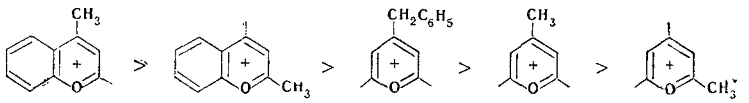
Under mild conditions 2- and 4-methylpyrylium salts react with ethyl orthoformate to give their β-ethoxyvinyl derivatives. Symmetrical and unsymmetrical cyanine dyes were synthesized by heating the latter with 2- and 4-methylpyrylium salts or N-methylquinaldinium perchlorate. The pyrylocyanines react with perchloric acid to give bispyrylium salts, and they are converted to the corresponding pyridine bases by the action of ammonium acetate.

We recently began a systematic study of the reaction of pyrylium salts containing active methyl groups with ortho esters [1].

In the present study in the reactions of 2- and 4-methylpyrylium and benzopyrylium salts with ethyl orthoformate we selected conditions that make it possible to obtain cyanine dyes or to stop the reaction at the step involving the formation of 2- and 4-β-ethoxyvinylpyrylium salts. The transformations that occur in this case can be represented by the following scheme:



The reaction with 4-methylbenzopyrylium salts proceeds at 30-35°C. 2-Methylbenzopyrylium salts form 2-β-ethoxyvinyl derivatives at higher temperatures (80-90°). More severe conditions (100-110°) and longer reaction times are required for the reaction of ethyl orthoformate with monocyclic [1] 2- and 4-methylpyrylium salts. 4-Benzylpyrylium salts occupy an intermediate position with respect to the activity of the methyl group in reactions with ethyl orthoformate:



This order of reactivities is also confirmed by the reactions of these methylpyrylium salts with their β-ethoxyvinyl derivatives.

The individuality of the compounds obtained and the completeness of the reaction were monitored from the disappearance of the signal of the protons of the methyl group of the starting pyrylium salt and also by

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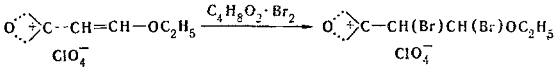
chromatography. Signals of the protons of the vinyl group and of the methyl and methylene groups of the ethyl group are present in the PMR spectra of the β-ethoxyvinylpyrylium salts.

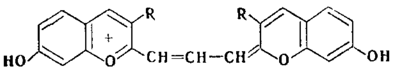
An absorption band at 1620-1635 cm^{-1}, which is characteristic for the stretching vibrations of the pyrylium cation, and a band at 1250–1240 cm^{-1}, which is related to the stretching vibrations of an ether group, were isolated in the IR spectra of the β-ethoxyvinylpyrylium salts.

A new absorption at 500-800 nm as compared with the starting methylpyrylium salts appears in the UV spectra of the synthesized compounds.

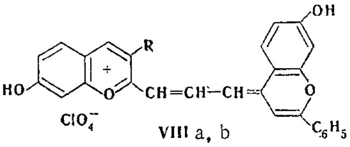
The presence of a vinyl group is also confirmed by bromination, which is easily realized by the addition of an equimolecular amount of bromine to a warm solution of the β-ethoxyvinylpyrylium salt in dioxane. The yields of the dibromo derivatives were 70-80%.



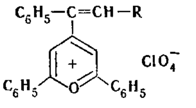
Cyanine dyes are formed by heating the 2- and 4-methylbenzopyrylium salts or 4-benzyl-2,6-diphenylpyrylium salt with their β-ethoxyvinyl derivatives; any pair of these components undergoes this reaction. The formulas of the synthesized pyrylocyanines are presented below.



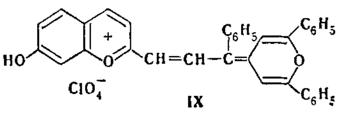
V a, b



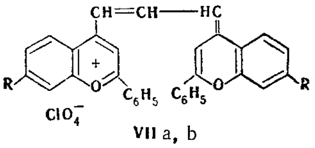
VIII a, b



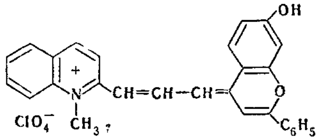
VI a, b



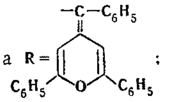
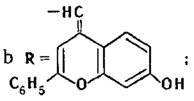
IX



VII a, b

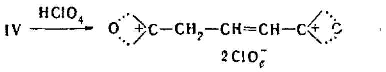


X

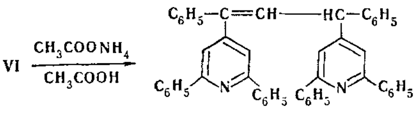
V-VIII a R=H; Vb, VIII b R=$COOC_2H_5$; VI a R=  ; VI b R=  ;
VII b R=OH

In the absence of bases, 2-methyl-4,6-diphenylpyrylium and 4-methyl-2,6-diphenylpyrylium perchlorates do not form cyanines even on refluxing in acetic anhydride. Cyanine dyes cannot be obtained by heating these salts with β-ethoxyvinylflavylium perchlorate or with their β-ethoxyvinyl derivatives or by condensation of the latter with 4-methylbenzopyrylium salts.

The pyrylocyanines react with perchloric acid to give bispyrylium salts. This sort of formation of bispyrylium salts was previously described [2, 3] for monomethylidynepyrylocyanine.



Trimethylidynecyanines from monocyclic pyrylium salts are capable of exchanging a heterocyclic oxygen for nitrogen. Thus when cyanine VI is refluxed with ammonium acetate in acetic acid it is converted to pyridinocyanine XI.



XI

TABLE 1. Pyrylocyanines

Compound	mp, °C	Empirical formula	Found, %			Calc., %			IR spectrum, cm⁻¹	UV spectrum, λ_{max}, nm	$\varepsilon \cdot 10^{-3}$	Yield, %
			C	H	Cl	C	H	Cl				
Va	282	$C_{21}H_{15}ClO_8$	58,6	3,8	8,0	58,5	3,4	8,2	3500, 1640, 1620, 1590, 1100	745	40,00	87.5
Vb	215	$C_{27}H_{23}ClO_{12}$	56,0	4,1	6,3	56,3	4,0	6,2	3500, 1725, 1700, 1620, 1590, 1100	700	53,84	100
VIa	295[5]	$C_{49}H_{35}ClO_6$	—	—	—	—	—	—	1640, 1610, 1590, 1095	750	56,00	60
VIb	300 Dec.	$C_{41}H_{29}ClO_7$	73,7	4,5	5,4	73,5	4,3	5,3	3550, 1640, 1625, 1600, 1100	630	14,55	60
VIIa	284[6]	$C_{33}H_{23}ClO_6$	—	—	—	—	—	—	1650, 1620, 1600, 1100	745	42,22	100
VIIb	278	$C_{33}H_{23}ClO_8$	67,4	3,7	6,2	67,9	3,9	6,1	3550, 1645, 1625, 1590, 1100	750	53,84	73
VIIIa	293	$C_{27}H_{19}ClO_8$	64,1	3,5	6,8	63,9	3,7	7,0	3500, 1640, 1615, 1590, 1100	645	10,28	72
VIIIb	285	$C_{30}H_{23}ClO_{10}$	62,4	4,0	6,3	62,2	4,0	6,1	3500, 1725, 1625, 1590, 1100	650	12,31	86
IX	300 Dec.	$C_{35}H_{25}ClO_7$	71,7	4,5	5,3	70,8	4,2	5,9	3500, 1650, 1620, 1590, 1100	645	15,24	52
X	242	$C_{28}H_{22}NClO_6$*	66,4	4,0	7,0	66,7	4,3	7,0	3500, 1645	600	7,49	96

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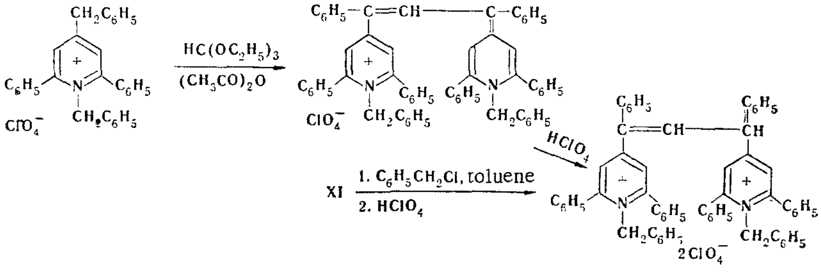
* Found: N 3.0%. Calculated: N 2.8%.

The structure of XI was confirmed by chemical methods. It was shown that the condensation of 4-benzyl-2, 6-diphenyl-N-benzylpyridinium perchlorate with ethyl orthoformate and subsequent treatment with 70% perchloric acid gives a compound identical to diperchlorate XII obtained from dipyridine XI and benzyl chloride with subsequent treatment with 70% perchloric acid. The transformations presented above indicate that both oxygen atoms in the pyrylocyanine undergo replacement by nitrogen.



XII

A bathochromic shift of 40-70 nm as compared with the β-ethoxyvinylpyrylium salts is observed in the UV spectra of the synthesized cyanines; an increase in the bathochromic effect is observed on passing from monocyclic to condensed pyrylium salts.

EXPERIMENTAL

The IR spectra of mineral-oil suspensions of the compounds were recorded with a UR-20 spectrometer. The UV spectra of acetic acid solutions were recorded with a Specord UV-vis spectrophotometer. The PMR spectra of trifluoroacetic acid solutions were recorded with an RYa-2305 spectrometer with tetramethylsilane as the internal standard. Chromatography was carried out on Silufol in nitromethane–chloroform–acetic acid (1 : 1 : 1).

Starting Methylpyrylium Salts. A Grignard reagent obtained from 3.7 ml of methyl iodide and 1.5 g of magnesium in 45 ml of absolute ether was added to a suspension of 0.016 mole of γ-unsubstituted pyrylium perchlorate in 60 ml of dry ether, and the resulting solution was stirred at room temperature for 20 min. It was then cooled with ice and decomposed with ammonium chloride solution. The ether layer was separated, washed with 1 N sodium carbonate solution and water (three times), and dried with anhydrous sodium sulfate. Acetic anhydride (10 ml) and 1.6 ml of 70% perchloric acid were added to the dried ether solution. The resulting salt was removed by filtration and recrystallized from acetic acid. This method was used to obtain 2,6-diphenyl-4-methylpyrylium perchlorate (mp 270° [4]) in 60% yield and 4-methylflavylium perchlorate (mp 200° 6]) in 40% yield.

2,6-Diphenyl-4-β-ethoxyvinylpyrylium Perchlorate. A 0.3-g (1 mmole) sample of 2,6-diphenyl-4-methylpyrylium perchlorate was dissolved in glacial acetic acid, and 0.4 ml (2 mmole) of ethyl orthoformate was added to the hot solution. The solution was cooled to crystallize out 0.32 g (80%) of a product with mp 194° (from acetic acid). IR spectrum: 1630, 1600, 1245, and 1100 cm^{-1}. UV spectrum, λ_{max}, nm ($\varepsilon\cdot10^{-3}$): 650 (27.03). PMR spectrum, δ, ppm: s[*] of aromatic protons 7.75, 7.5, 7.25; d of vinyl protons 5.88 and 5.75; q 4.0 ($\mathbf{CH_2}CH_3$); t 1.12 ($CH_2\mathbf{CH_3}$). R_f 0.73. Found: C 62.3; H 4.9; Cl 8.5%. $C_{21}H_{19}ClO_6$. Calculated: C 62.5; H 4.7; Cl 8.8%. 2,6-Diphenyl-4-α-phenyl-β-ethoxyvinylpyrylium perchlorate with mp 200° and R_f 0.75 was similarly obtained in 85% yield. Found: C 67.5; H 5.0; Cl 7.4%. $C_{27}H_{24}ClO_6$. Calculated: C 67.5; H 5.0; Cl 7.4%. IR spectrum: 1635, 1590, 1250, and 1100 cm^{-1}. UV spectrum, λ_{max}, nm ($\varepsilon\cdot10^{-3}$): 710 (29.68).

4-β-Ethoxyvinylflavylium Perchlorate. A) A 0.4-ml (2 mmole) sample of ethyl orthoformate was added to a warm solution of 0.3 g (1 mmole) of 4-methylflavylium perchlorate in nitromethane (30-35°). After 1-1.5 h, the mixture was diluted with ether, and the precipitate was removed by filtration to give 0.32 g (90%) of a product with mp 180-182° and R_f 0.70. IR spectrum: 1620, 1600, 1245, and 1110 cm^{-1}. UV spectrum, λ_{max}, nm ($\varepsilon\cdot10^{-3}$): 680 (25.79). PMR spectrum, δ, ppm: s of aromatic protons 7.62, 7.12, 6.88; d of vinyl protons 6.32, 6.12; q 4.0 ($\mathbf{CH_2}CH_3$); t 1.0 ($CH_2\mathbf{CH_3}$). Found: C 60.5; H 4.4; Cl 9.6%. $C_{19}H_{17}ClO_6$. Calculated: C 60.5; H 4.5; Cl 9.4%. 4-β-Ethoxyvinyl-7-hydroxyflavylium perchlorate with mp 204° was similarly obtained in 90% yield. IR spectrum: 3550, 1620, 1600, 1250, and 1100 cm^{-1}. UV spectrum, λ_{max}, nm ($\varepsilon\cdot10^{-3}$): 700 (36.84). Found: C 57.5; H 4.4; Cl 8.9%. $C_{19}H_{17}ClO_7$. Calculated: C 58.0; H 4.3; Cl 9.0%.

B) A 1.6-ml (0.01 mole) sample of ethyl orthoformate was added to a solution of 0.3 g (1 mmole) of 4-methylflavyliumperchlorate in acetic acid (100-105°). After 1-1.5 h, the mixture was diluted with ether, and the precipitated 4-β-ethoxyflavylium perchlorate was removed by filtration to give 0.31 g (89%) of product. The samples obtained by the two methods were identical, as demonstrated by a comparison of the melting points of mixtures of the samples and the IR spectra in the fingerprint region. A similar procedure was used to obtain 2-β-ethoxyvinyl-7-hydroxybenzopyrylium perchlorate with mp 175° in 66% yield. IR spectrum: 3500, 1630, 1590, 1245, and 1090 cm^{-1}. UV spectrum, λ_{max}, nm ($\varepsilon\cdot10^{-3}$): 650 (23.42). Found: C 49.4; H 4.1; Cl 11.3%. $C_{13}H_{13}ClO_7$. Calculated: C 49.2; H 4.1; Cl 11.2%.

2,4-Diphenyl-6-(α, β-dibromo-β-ethoxyethyl)pyrylium Perchlorate. A 0.05-ml sample of bromine was added with stirring to a solution of 0.4 g (1 mmole) of 2,4-diphenyl-6-β-ethoxyvinylpyrylium perchlorate in dioxane. After 12 h, the dibromo derivative was removed by filtration to give 0.41 g (71%) of a product with mp 269-270° (from acetic acid). IR spectrum: 1620, 1590, 1520, and 580 cm^{-1}. Found: C 45.0; H 3,8; Cl, Br 34.4%. $C_{21}H_{19}Br_2ClO_6$. Calculated: C 44.8; H 3.4; Cl, Br 34.7%. A similar procedure was used to obtain the following compounds. 2,6-Diphenyl-4-(α,β-dibromo-β-ethoxyethyl)pyryliumperchlorate with mp 226° was obtained in 75% yield. Found: C 44.6; H 3.3; Cl, Br 35.2%. $C_{21}H_{19}Br_2ClO_6$. Calculated: C 44.8; H 3.3; Cl, Br 34.8. 7-Hydroxy-4-(α,β-dibromo-β-ethoxyethyl)flavylium perchlorate with mp 272° was obtained in 74.5 yield. Found: C 41.6; H 3.0; Cl, Br 35.7%. $C_{19}H_{17}Br_2ClO_7$. Calculated: C 41.2; H 3.1; Cl, Br 35.4%.

Bisflavenetrimethylidyne Perchlorate (VIIa). A) A 0.2-ml (1 mmole) sample of ethyl orthoformate was added to 0.3 g (1 mmole) of 4-methylflavylium perchlorate in acetic acid–nitromethane (90-95°). After 2-3 h, the solid was removed by filtration to give 0.33 g (60%) of a product with mp 284-286° (from acetic acid) [6].

B) A 0.3-g (1 mmole) sample of 4-methylflavylium perchlorate was dissolved in a mixture of 2 ml of acetic acid and 1 ml of acetic anhydride, and 0.38 g (1 mmole) of 4-β-ethoxyvinylflavylium perchlorate was added to the hot solution. The mixture was heated to completely dissolve the solids. It was then cooled, and the resulting green plates were removed by filtration to give 0.55 g (100%) of product. The other cyanine dyes were similarly obtained (see Table 1).

1,3-Bis(2-phenyl-4-benzopyrylium)propene Diperchlorate. A 0.05-ml (0.5 mmole) sample of 70% perchloric acid was added to a solution of 0.3 g (0.5 mmole) of VIIa in acetic acid. A yellow substance crystallized out when the mixture was cooled. Workup gave 0.65 g (100%) of a product with mp 300° (dec.). IR spectrum: 1650, 1625, 1600, and 1100 cm^{-1}. Found: C 60.6; H 3.4; Cl 10.5%. $C_{33}H_{24}Cl_2O_{10}$. Calculated: C 60.8; H 3.7; Cl 10.9%. A bispyrylium salt with mp 300° (dec.) was similarly obtained from Vb. IR spectrum: 3500, 1725, 1645, 1620, 1590, and 1100 cm^{-1}. Found: C 48.4; H 3.2; Cl 10.8%. $C_{27}H_{24}Cl_2O_{16}$. Calculated: C 48.0; H 3.5; Cl 10.5%.

1,3-Diphenyl-1,3-bis(2,6-diphenyl-4-pyridyl)propene (XI). A 0.76-g (1 mmole) sample of VIa was re-

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[*] Here and subsequently, s is singlet, d is doublet, t is triplet, and q is quartet.

fluxed in acetic acid with excess ammonium acetate for 2.5-3 h, after which the mixture was poured into ice water. The colorless substance that formed after a few hours was removed by filtration to give 0.49 g (75%) of a product with mp 90-92°. IR spectrum: 1610, 1590 cm^{-1}. Found: C 89.8; H 5.0; N 4.3%. $C_{49}H_{36}N_2$. Calculated: C 90.2; H 5.5; N 4.3%.

1,3-Diphenyl-1,3-(1-benzyl-2,6-diphenyl-4-pyridinium)propene Diperchlorate (XII). A) A 0.65-g (1 mmole) sample of XI was refluxed in toluene with 0.3 ml (2 mmole) of benzyl chloride for 2-3 h. The mixture was cooled, and the precipitate was removed by filtration and converted to the diperchlorate by the action of 0.3 ml of 70% perchloric acid in acetic acid. The yield of product with mp 300° (dec.) was 0.6 g (60%). Found: C 73.3; H 5.0; Cl 7.1; N 2.5%. $C_{63}H_{50}N_2Cl_2O_8$. Calculated: C 73.2; H 4.8; Cl 6.9; N 2.7%.

B) A 0.51-g (1 mmole) sample of 2,6-diphenyl-4-benzyl-N-benzylpyridinium perchlorate was refluxed with 0.1 ml (0.5 mmole) of ethyl orthoformate in acetic anhydride for 8-10 h. The mixture was then cooled, and the solid was removed by filtration and converted to the diperchlorate by the action of 70% perchloric acid in acetic acid. The yield of product with mp 300° (dec.) was 0.8 g (80%). The substances obtained by methods A and B were identical (according to the IR spectra at 600-1800 cm^{-1}).

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