1,2,3-TRIALKOXYCARBONYL-4H-CYCLOPENTA[b]QUINOXALINES

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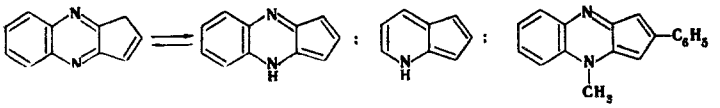
UDC 547.863.07

1,2,3-Trialkoxycarbonyl-4H-cyclopenta[b]quinoxalines were synthesized by condensation of o-phenylenediamine with trialkoxycarbonyl-2-hydroxycyclopentadien-1-ones. The compounds obtained were characterized as π-electron analogs of azulene on the basis of their spectra and quantum-mechanical calculations.

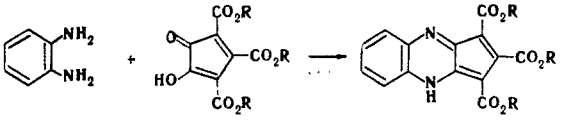
Cyclopentaquinoxalines obtained by condensation of o-phenylenediamine with cyclopentenediones [1] may exist in two tautomeric forms (A and B).



A B I II

The 4H-tautomers (B), like the corresponding tautomers of pyridines (I) [2], are heteroaromatic π-electron analogs of azulene. The 2-R-cyclopentaquinoxalines (R = H, Ph, CH_3, OH, and Cl) described in the literature [1, 3, 4] have the structure of the 1H-tautomer (A) and are colorless [1, 3] or slightly colored [4] compounds. The introduction of an alkyl group into the 4 position of the cylopentaquinoxaline gives a deeply colored heteroaromatic compound (II) [5].

We have found [6] that condensation of o-phenylenediamine with trialkoxycarbonyl-2-hydroxycyclopentadien-1-ones gives quinoxalines that exist entirely in the form of the 4H-tautomer (Table 1).



III a-c

III a R = CH_3; b R = C_2H_5; c R = $CH(CH_3)_2$

The absorption band in the IR spectrum at 3200 cm^{-1}, which is characteristic for an intramolecular NH hydrogen bond, constitutes evidence for the presence of an NH group in these compounds (Table 1). The position of this band is independent of the concentration of the CCl_4 solutions and the temperature. In addition, the PMR spectrum of a solution of IIIc in CCl_4 contains a broad singlet at 11.7 ppm, which is characteristic for the NH group (Table 2). We did not find signals that could be assigned to the protons of the cyclopentene ring (1H-tautomer) in the spectra of any of these compounds. The most weighty argument indicating the absence of appreciable amounts of the 1H-tautomer is the complete conicidence of the electronic spectra of IIIa-c (Fig. 1) and of the methyl derivative of IIIc (VIc, Table 3) and the similarity between their absorption spectra and the spectrum of II, for which there is no doubt that the methyl group is in the 4 position [5]. The formation of 4H-tautomers in our case is apparently due to the electron-acceptor effect of three alkoxycarbonyl groups.

All-Union Scientific-Research and Construction-Design Institute of Petrochemistry, Kiev. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 5, pp. 699-704, May, 1975. Original article submitted November 21, 1973; revision submitted October 1, 1974.

TABLE 1. 1,2,3-Trialkoxycarbonyl-4H-cyclopenta[b]quinoxalines (IIa-c, VIc)

Compound	mp, °C (dec.)	Empirical formula	Found, %			Calculated, %			ν_{NH}*, cm^{-1}	Yield, %
			C	H	N	C	H	N		
IIIa	265	$C_{17}H_{14}N_2O_6$	59,5	4,2	8,2	59,7	4,1	8,2	3220	85
IIIb	217	$C_{20}H_{20}N_2O_6$	62,5	5,2	7,2	62,5	5,2	7,3	3260	80
IIIc	168—170	$C_{23}H_{26}N_2O_6$†	64,9	6,2	6,6	64,8	6,2	6,6	3170	87
VIc	186	$C_{24}H_{28}N_2O_6$	65,2	6,3	6,4	65,4	6,4	6,7	—	76

* Potassium bromide pellets (3285 cm^{-1} in CCl_4 for IIIc).
† Found cryoscopically in benzene: Mol. wt. 414. Calculated: Mol. wt. 427.

TABLE 2. PMR Spectra of Trialkoxycarbonylcyclopentaquinoxalines

Compound	Solvent	Group	δ, ppm	No. of protons, signal multiplicity*
IIIa	Pyridine	CH_3	3,64 4,14	6, s 3, s
IVa	CF_3CO_2H	CH_3	3,70 3,86	6, s 3, s
IIIb	Pyridine	CH_3	1,00 1,25	6, t 3, t
		CH_2	3,88 4,22	4, q 2, q
IVb	CF_3CO_2H	CH_3	1,09 1,21	6, t 3, t
		CH_2	4,08 4,21	4, q 2, q
IIIc†	CCl_4	CH_3	1,27 1,40	12, d 6, d
		NH	11,7	1, s
VIc†	CCl_4	CH_3	1,41 1,28	12, d 6, d
		NCH_3	4,46	3, s

* Abbreviations: s is singlet, d is doublet, t is triplet, and q is quartet.
† The proton attached to the tertiary carbon atom of the isopropyl group gives a complex multiplet at ~5.3 ppm.

TABLE 3. Electronic Spectra of 4H-Cyclopenta[b]quinoxalines (II, III, and VI) and Their Cations (IV, VII) and Anions (V) in Alcohol

Compound	λ_{max}, nm	lg ε
IIIa	505, 365, 350, 283, 277	3,39; 4,30; 4,17; 4,80; 4,80
IIIb	506, 365, 350, 285, 280	3,46; 4,37; 4,25; 4,89; 4,89
IIIc	508, 365, 350, 285, 277	3,40; 4,31; 4,19; 4,80; 4,80
VIc	510, 370, 354, 287	3,48; 4,29; 4,18; 4,83
IVa	604, 400, 315*, 278	3,05; 4,53; 3,49; 4,76
IVb	605, 403, 315*, 280	3,11; 4,51; 3,92; 4,82
IVc	615, 412, 315, 308, 273	3,23; 4,48; 4,22; 4,22; 4,75
VIIc†	620, 413, 313, 260	3,11; 4,48; 4,74; 4,29
Va	452, 353, 345, 309, 278	3,59; 4,09; 4,03; 4,53; 4,98
Vb	452, 353, 345, 309, 278	3,64; 4,13; 4,07; 4,58; 4,97
Vc	452, 356, 347, 309, 282	3,68; 4,19; 4,16; 4,60; 4,93
II[5]	599, 412, 392, 283	3,00; 4,43; 4,51; 4,62

* Shoulder.
† Of an alcohol solution of VIc in the presence of 50 vol. % H_2SO_4.

Like pyridines, trialkoxycarbonyl-4H-cyclopenta[b]quinoxalines are relatively strong acids*: pK_a^{25} 5.65 for IIIa in 80% aqueous CH_3OH. They dissolve readily in dilute aqueous solutions of alkalis to give yellow-orange solutions (Table 3, Va-c; Fig. 1), whereas they dissolve in mineral acids and CF_3CO_2H to give

* For pyridines, pK_a ~5.7 [2].

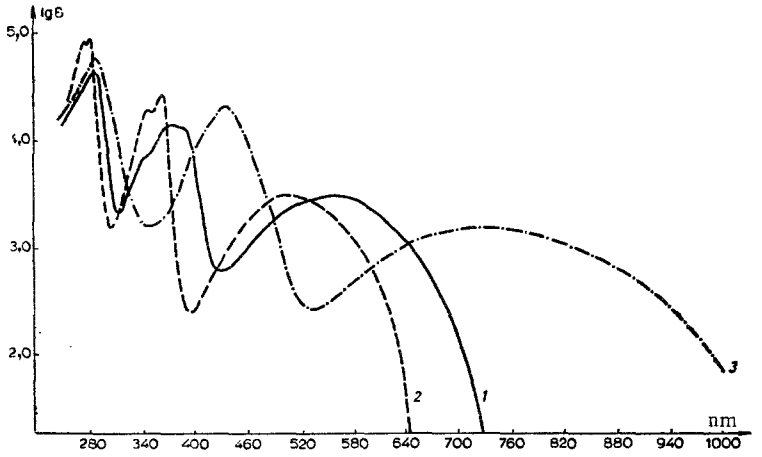


Fig. 1. Electronic spectra of 1,2,3-triethoxycarbonyl-4H-cyclopenta[b]quinoxaline (IIIb) in alcohol: 1) neutral solution; 2) in a 0.2 M solution in $(C_2H_5)_3N$; 3) in 50 vol. % H_2SO_4.

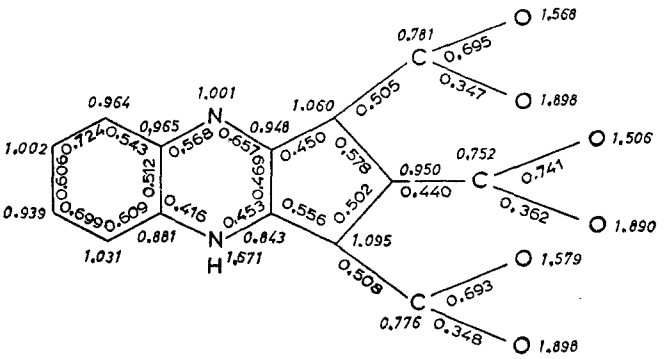
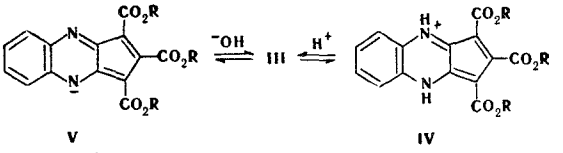


Fig. 2. Molecular diagram of 1,2,3-trialkoxycarbonyl-4H-cyclopenta[b]quinoxalines.

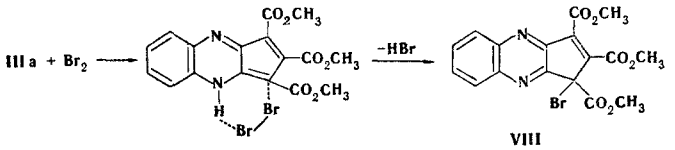
blue solutions (Table 3, IVa-c; Fig. 1). The ease of these transformations is apparently associated with the formation of stable symmetrical aromatic anions (V) and cations (IV).

Alkaline salts V are readily isolated from alcohol solutions of III when alkoxides are added. On reaction with CH_3I they readily form N-methyl derivatives (Table 1, VIc), which also give blue solutions in acids (Table 3, VIIc).



V IV

Compound IIIa reacts readily with bromine to give, as in the case of benzopyridine [7], a colorless labile compound (VIII). Hydrogen is evidently replaced by bromine with rearrangement of the π-electron system of the molecule as a result of transfer of the reaction center from nitrogen to carbon.

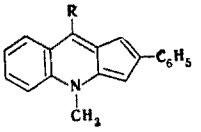


VIII

It is apparent from the PMR spectra of IIIa-c that the protons of the alkoxy carbonyl groups in the 1 and 3 positions are equivalent, whereas the signals of the protons of the alkoxycarbonyl group in the 2 position are shifted to weaker field (Table 2). The observed equivalence of the protons of the alkoxy carbonyl

groups in these positions is apparently provided by rapid intermolecular exchange of hydrogen between the nitrogen atoms. Evidence for the increased electron density in the 1 and 3 positions is provided by our quantum-mechanical calculations (Fig. 2) and also by the direction of electrophilic attack by bromine. However, one must take into account the fact that the three alkoxy carbonyl groups of the cyclopentane ring can hardly be located in a single plane. From energy considerations, deviation from the plane of the alkoxy carbonyl group in the 2 position is most likely, and this possibly also is responsible for the difference in the signals of the protons in the 2 position. This assumption also provides a possibility for the explanation of the PMR spectrum of the N-methyl derivative (VIc). In this case, two groups (in the 2 and 3 positions) deviate from the plane and the signal at 1.41 ppm corresponds to them, whereas the signal at 1.28 ppm corresponds to the group in the 1 position (in the spectrum of IIIc, the signal at 1.40 ppm corresponds to the alkoxy carbonyl group in the 2 position, which deviates from the plane, whereas the signal at 1.27 ppm corresponds to the groups in the 1 and 3 positions, which lie in a single plane).

The electronic spectra of the investigated compounds indicate similarity between their electronic structure and the structure of azulene. As in the case of azulene, they consist of series of bands with gradually increasing intensity on the short-wavelength side [8]. This sort of character of the spectra is typical for compounds with a cyclic system of electrons. The long-wave band of azulene is very sensitive to the effect of polar substituents in conformity with Plattner's rule and its generalization [9]. This is also observed in a number of cyclopentaquinoxalines. In conformity with the hypsochromic effect of electron-acceptor substituents in the 1 and 3 positions of azulene, the carbonyl groups in III and VIc lead to a sharp violet shift of the long-wave band as compared with well-known II (Table 3). On the other hand, the same substituents or replacement of the carbon atom by a more electronegative atom in the 4 and 8 positions of azulene (this corresponds to the nitrogen atoms in our compounds) should cause a bathochromic shift. Shifts of this sort are actually observed on passing from cyclopentaquinoline (IX) to its 9-methoxycarbonyl derivative (X) [10] and subsequently to quinoxaline II. In our case this regularity is manifested as a remarkable change in the color on passing from anions V to cations IV, during which the long-wave absorption band traverses a large portion of the visible region of the spectrum. The small bathochromic shift of the bands when the hydrogen attached to the nitrogen atom is replaced by a methyl group (transition from IIIc to VIc) both in the visible region and in the far-UV region, where the absorption is apparently associated with excitation of the electrons of the carbonyl groups, may constitute evidence for disruption of the coplanarity of the adjacent alkoxycarbonyl groups.



IX R=H. λ_{max} 532 nm
X R=CO_2CH_3, λ_{max} 574 nm

EXPERIMENTAL METHOD

The electronic spectra of alcohol solutions in the presence of ~0.05 mole/liter CH_3CO_2H* for III, ~0.2 mole/liter $(C_2H_5)_3N$ for V, and ~50 vol. % H_2SO_4 for IV and VIIc were recorded with a Unicam PS 8000 spectrophotometer. Under these conditions, the investigated solutions follow the Lambert–Beer law. The IR spectra were recorded with a UR-20 spectrometer. The PMR spectra were recorded with a Tesla BS 477 spectrometer (60 MHz) with hexamethyldisiloxane as the internal standard. The molecular diagram of III was calculated by the Hückel MO LCAO method with Streitwieser's parameters [11]. The ionization constant was determined potentiometrically in 80% methanol [12] with an LPU-01 potentiometer.

1,2,3-Trimethoxycarbonyl-4H-cyclopenta[b]quinoxaline (IIIa). A solution of 1.04 g (9.6 mmole) of o-phenylenediamine in 5 ml of CH_3CO_2H was added at 100° to a solution of 2 g (7.4 mmole) of trimethoxycarbonyl-2-hydroxycyclopentadien-1-one in 40 ml of CH_3CO_2H, and the mixture was stirred on a water bath for 30 min. The bulk of the solvent was then removed by distillation, the residual solution was cooled, and the resulting red crystals were removed by filtration. The product was crystallized from CH_3OH.

Compounds IIIb, c were similarly obtained; IIIb was crystallized from benzene, and IIIc was crystallized from benzene–hexane (1 : 5).

1,2,3-Triisopropoxycarbonyl-4-methyl-4H-cyclopenta[b]quinoxaline (VIc). A solution of 1.32 g (3 mmole) of IIIc in 30 ml of CH_3OH and a solution of 0.069 g of sodium (3 mg-atom) in 5 ml of CH_3OH were

*The addition of CH_3CO_2H is necessary for suppression of the ionization of III.

mixed, and the resulting mixture was heated for 10 min. It was then cooled, and the resulting yellow crystals of the sodium salt of IIIc were removed by filtration. A 0.35-ml (7 mmole) sample of CH_3I was added to a solution of 1.8 g (4 mmole) of this salt in 40 ml of DMF, and the mixture was heated on a water bath for 30 min. It was then cooled, and VIc was precipitated by the addition of water. The product was crystallized from benzene.

The preparations obtained are finely crystalline intensely red compounds (the characteristic spectrum of IIIb is presented in Fig. 1). Compounds IIIa, b are slightly soluble in pyridine, DMF, CH_3CN, CH_3CO_2H, and CH_3OH; IIIc and VIc are quite soluble in ordinary organic solvents (benzene, ether, THF, CCl_4, and $CHCl_3$).

1,2,3-Trimethoxycarbonyl-1-bromo-1H-cyclopenta[b]quinoxaline (VIII). A 0.2 M solution of Br_2 in CH_3CO_2H was added to a solution of 0.205 g (0.6 mmole) of IIIa in 25 ml of CH_3CO_2H until the color of IIIa vanished, after which the solution was diluted with 15 ml of water, and the resulting white precipitate of VIII was removed by filtration to give 0.218 g (87%) of a product with mp 133-135° (dec.). Found: Br 18.9%. $C_{17}H_{13}BrN_2O_6$. Calculated: Br 19.4%.

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