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Investigation of the Spectral Properties of the Crowned Retinals and Bacteriorhodopsin Analogs

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The spectral properties of new crowned retinal analogs and their bacteriorhodopsin complexes are described.

Keywords: benzocrown ethers and its dithiaderivatives; crowned bacteriorhodopsin and retinal analogs; ionophore; spectral data

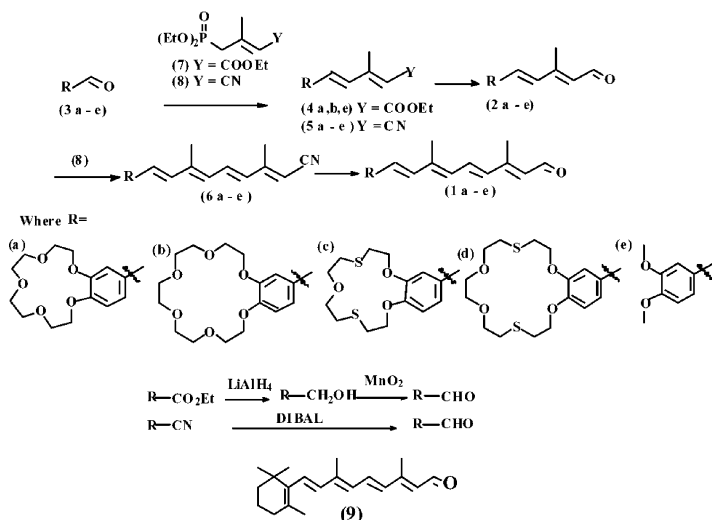
INTRODUCTION

Nowadays bacteriorhodopsin (BR) is a simple object, as compared with other known photosynthetic systems, that performs the solar energy transduction function. This natural biophotochrome was discovered in 1971 in *Halobacterium salinarum* and functions as a light-driven proton pump. Its polypeptide part (bacterioopsin) consists of a sole peptide chain. The chromophoric group of BR is a protonated retinal Schiff base (SB) with ϵ -aminogroup Lys-216. Recently, we proposed a number effective approaches for the synthesis of new crowned polyenes (**1**, **2**, **4–6 a–d**) and reference compounds (**1**, **2**, **4–6 e**), related to the retinal, in order to study their spectral properties and ion-binding capability and spectral behaviour of their complexes with bacterioopsin. Here, we described the spectral properties of the new retinal analogs and their artificial bacteriorhodopsin (ABR) complexes.

EXPERIMENTAL

Polyene Synthesis

In the previous papers we designed and described effective synthetic routes to unsaturated crowned compounds with variable length of the conjugation chain (one or two C=C bonds), crown-ether ring size and nature of terminal polar group [1–4]. Below, we present a new example of successful application of this synthetic strategy for the preparation of retinal analogs. As ionophoric moieties, we selected benzo-15-crown-5 (**a**) and benzo-18-crown-6 (**b**) fragments for alkali, alkali-earth, and rare-earth metal ions and their dithiaderivatives (**c**, **d**) for transition and heavy metal ions. Compounds (**1**, **2**, **4–6 a–e**) were synthesized by the Horner-Emmons olefination of the corresponding 4'-formylbenzocrown ethers (**3a–d**) using the C₅-phosphonate reagents (**7**, **8**), containing the ester or cyano terminal group (see Scheme 1). Also, we synthesized the corresponding reference compound (**1 e**), in which the crown-ether moiety was replaced by a related structure of 3,4-dimethoxyphenyl residue. This fragment has similar electron-donating properties but it lacks cation-binding ability. The



SCHEME 1

transformation of the ester group in the intermediate esters into the hydroxymethyl function by LiAlH_4 reduction followed by MnO_2 oxidation leads to the key aldehydes. For conversion of the nitrile group into the aldehyde function we used a one-step procedure of DIBAL reduction. The configuration of the new $\text{C}=\text{C}$ bond and the isomer ratio in the products were determined using ^1H -NMR spectroscopy by comparing the integral intensities of the proton signals for the polyene chain (doublets with J 16.0 Hz and J 12.0 Hz for *E*- and *Z*-isomers, respectively). It was found, that the Horner olefination follows preferably *E*-selectivity for the newly formed bond with moderate or high product yields in all the series of compounds (**a-e**). The structure of all compounds was confirmed unambiguously by IR; UV; ^1H NMR-spectroscopy and mass-spectrometry.

Finally, five series of compounds (**1,2 a-e**) containing monobenzo-15-crown-5- and monobenzo-18-crown-6-ether; their dithiaderivatives and compounds containing 3,4-dimethoxyphenyl fragment with different length of the conjugation chain were prepared.

RESULTS AND DISCUSSION

Interaction of Retinal Analogs (**1 a-e**) with Bacterioopsin

The synthesized retinal analogs (**1 a-e**) and their short-cut derivatives (**2 a-e**) were further tested in recombination with bacterioopsin (BO)

TABLE 1 Spectral Properties of Retinal Analogs (**1 a–e**) and their ABR Complexes

ABR chromophore code	λ_{\max} of aldehyde, nm, MeCN ($\epsilon \cdot 10^{-4}$, $M^{-1} \text{ cm}^{-1}$)	λ_{\max} of pigment ^{DA} with BO, nm	Photocycle effectiveness, %
9	381 (4.8)	558	100
1a	400 (5.2)	495	23
1b	400 (5.1)	495	22
1c	396 (5.0)	497	n.d.*
1d	396 (5.5)	497	n.d.*
1e	402 (4.0)	500	35

*not studied yet

from apomembranes *H. salinarum* (strain ET1001). It was found that the formation of pigments takes place already within 1–2 hours. The spectral parameters of these pigments (**ABR-1 a–e**) are presented in the Table 1. It should be noted that λ_{\max} of ABR is located within the wavelength range typical of pigments, in which trimethylcyclohexene ring of the retinal is replaced by other aromatic rings (460–530 nm) [2,5].

We have studied the photochemical properties of the crowned ABR (**ABR-1 a, b**) and reference ABR (**ABR-1 e**) prepared from crowned polyenal (**1 a, b**) and 3,4-dimethoxyphenylretinal (**1 e**), respectively. The exposure of ABR samples to laser light flashes caused reversible bleaching of the main absorption band of the pigments (absorption changes induced by laser flash ($\lambda = 532 \text{ nm}$, $t_{1/2} = 15 \text{ ns}$) in a suspension of membrane samples at 21°C). The photocycle of the pigments includes an **M**-like intermediate.

The quantum efficiency of the crowned ABR (**ABR-1a, b**) photocycle was about 22–23% that found for the control BR. This estimate was obtained from analysis of the photoinduced response amplitude in the main absorption band as normalized to the absorption value in this band: $\Delta D^{\text{ABR}}/D^{\text{ABR}}$ and $\Delta D^{570}/D^{570}$ (control BR). The measurements were done at equal protein concentration or equal absorption level at the actinic light wavelength. According to the relaxation kinetics of the M-like intermediate, the photocycle rate of the crowned ABR was significantly lower than that in the control BR. Also, we have demonstrated that for short-cut polyenals (**2 a–e**), ABR formation with the $\lambda_{\max} \sim 450\text{--}460 \text{ nm}$ is possible.

We investigated the spectral properties and the ion-binding capability of the crowned and reference compounds. The electronic spectra of all compounds under study exhibit two groups of bands located in the 200–240 and 270–500 nm spectral regions. Comparison of the spectral characteristics of the crowned polyenes with identical terminal groups but different sizes and nature of the crown-ether fragment has demonstrated almost complete coincidence of the spectral characteristics of these compounds and the corresponding 3,4-dimethoxyphenyl analogs containing no crown ether fragments (Table 1–3).

This means that the long-wavelength absorption of these compounds is due to the same system of conjugated bonds. The position of the long-wavelength absorption bands depends on the length of the conjugated chain and the nature of the terminal group. An increase in the chain length and the electron-withdrawing capability of the terminal groups results in bathochromic shifts of the absorption bands (see Tables 2, 3). Unlike the 3,4-dimethoxyphenyl analogs (**1**, **2**, **4-6 e**), in the case of crowned compounds, the introduction of metal salts into their solutions in acetonitrile induces hypsochromic shifts of the absorption bands – λ_{\max} (see Tables 2, 3). The observed spectral changes are due to complex formation between the metal ions and the crown-ether fragments. The hypsochromic shift depends on the nature of the metal ion. The magnitude of the $\Delta\lambda_{\max}$ for the 15-crown-5 derivatives decreases in the sequence $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Ba}^{2+} > \text{La}^{3+} > \text{Na}^{+} > \text{Li}^{+} > \text{K}^{+}$, while for 18-crown-6, this sequence is different, namely,

TABLE 2 UV–Vis Spectral Data for *E*-Isomers of Compounds (**1**, **2**, **5**, **6 a–b**, **1e**) and their Complexes with Various Metal Cations

[illegible]

TABLE 3 UV-Vis Spectral Data for *E*-Isomers of Compounds (**1**, **2**, **5**, **6 c-d**) and their Complexes with Various Metal Cations

No.	λ_{\max} of free ligand, nm [ε 10^{-4} , $M^{-1} \text{ cm}^{-1}$]	λ_{\max} , nm ($\Delta\lambda_{\max} = \lambda_L - \lambda_{ML}$), in MeCN, $c_M/c_L = 1000$			
		Ag^+	Hg^{2+}	Pb^{2+}	La^{3+}
5c	341[3.2]	336(3)	329(10)	325(14)	340(1)
2c	354[2.7]	349(5)	341(13)	338(16)	353(1)
6c	379[4.5]	375(4)	372(7)	370(9)	379(0)
1c	396[5.0]	389(7)	388(8)	384(12)	396(0)
5d	339[2.3]	336(5)	331(10)	330(11)	341(0)
2d	359[2.9]	352(7)	346(13)	342(17)	357(2)
6d	379[4.2]	375(4)	373(6)	371(8)	379(1)
1d	396[5.5]	393(3)	388(8)	386(10)	396(0)

$La^{3+} > Ca^{2+} > Ba^{2+} > K^+ > Na^+ > Mg^{2+} > Li^+$. This shift is due to the decrease in the electron-donating ability of the oxygen atoms in the macroheterocycle. Unlike oxygen-containing crowns series (**a**, **b**), ionophores of the dithia-crowned series (**c**, **d**) don't bind the alkali, alkaline-earth, or rare-earth metal ions, but interact effectively with heavy metal ions (Ag^+ , Hg^{2+} , Pb^{2+}) (see Table 3).

Thus, spectral data show that metal complex formation is observed only for the crowned compounds. We hope that they could find an application as ionophoric dye units for the development of optical sensors, ion-selective electrodes and photocontrolled supramolecular systems.

REFERENCES

- [1] Khodonov, A. A., Lukin, A. Yu., Shevyakov, S. V. et al. (2000). *Mol. Cryst. Liq. Cryst.*, 345, 15.
- [2] Mironova, E. V., Lukin, A. Yu., Shevyakov, S.V. et al. (2001). *Biochemistry (Moscow)*, 63, 1323.
- [3] Lukin, A. Yu., Laptev, A. V., Shevyakov, S. V. et al. (2004). *J. Inclusion Phenomena*, 49, 153.
- [4] Strokach, P. Yu., Valova, T. M., Barachevsky, V. A. et al. (2003). *Izv. AN. Ser. Khim.*, 2514. [*Russ. Chem. Bull.*, 52, 2656 (2003) (Engl. Transl.)].
- [5] Drachev, L. A., Zorina, V. V., Khitrina, L. V., Mitsner, B. I., Khodonov, A. A., Chekulaeva, L. N. (1987). *Biochemistry (Moscow)*, 52, 1559.