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Bifunctional fluorescent and colorimetric ‘naked eye’ aroylhydrazone chemosensors for Hg^{2+} and F^- ions detection

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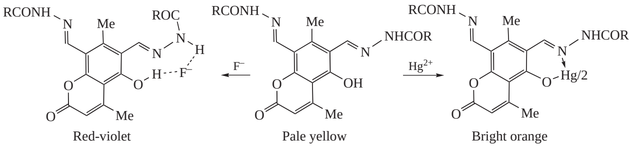
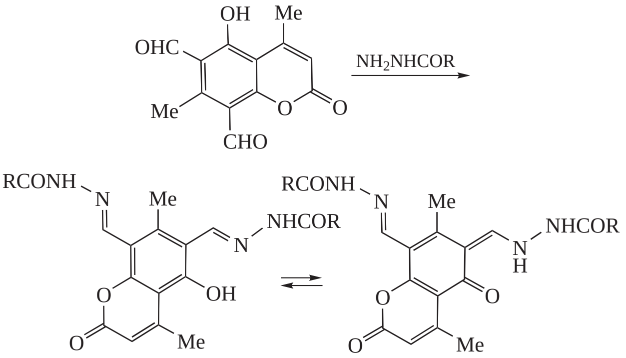
Bis-aroylhydrazones of 5-hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde display the properties of bifunctional fluorescent and colorimetric ‘naked-eye’ chemosensors for mercury(II) cations and fluoride anions detection.



Colorimetric, fluorogenic and electrochemical chemosensor systems are widely used in organic, biological, medical chemistry and environmental sciences for monitoring cations and anions.[1–6] Of special efficiency are fluorogenic sensors which use fluorescence for detection of various analytes, allow one to perform measurements *in situ* and *in vivo* and are distinguished by highest sensitivity and selectivity.[7–9] Recently a new scientific area in chemosensorics arose which is associated with the design of multi- and bifunctional sensors capable of independent detection of two or more kinds of ions-‘guests’ due to the specific spectral responses *via* the same or different channels.[10–14] Herein, we report the synthesis and study of spectral, fluorescent and sensing properties of new representatives of this group of chemosensors, bis-aroylhydrazones of 5-hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde, being functionalized coumarins.[†] The choice of coumarin as the signal group is due to the bright fluorescence of its derivatives ensuring many successful applications for the design of new functional materials, sensor elements and devices.[15,16] *o*-Hydroxy hydrazone fragment in the target molecules helps to identify metal cations,[17] whereas hydrazone NH groups can coordinate fluoride anions *via* formation of the N–H···F^- bonds.[18,19]

Aroylhydrazones **1a–c** were synthesized by the condensation of 5-hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde with the hydrazides of aromatic and heterocyclic acids (Scheme 1).[‡]



A **1a–c** **B**

a R = 4-$MeOC_6H_4$
b R = 4-PhC_6H_4
c R = 2-furyl

Scheme 1

IR spectra of **1a–c** contain characteristic bands of coumarin and hydrazone carbonyl and C=N groups at 1716–1728, 1655–1672 and 1611–1630 cm^{-1}, respectively. ^1H NMR spectra of each hydrazone in DMSO-d_6 exhibit two three-proton singlet signals at 2.65–2.69 and 2.75–2.88 ppm, which correspond to the methyl groups in the 4- and 7-positions, and one-proton singlet signals at 6.24–6.28 ppm corresponding to the H^3 protons of coumarin moiety. The protons of both methoxy groups of **1a** appear as a singlet at 3.84 ppm. Two one-proton singlet signals of CH and NH groups are found at 8.83–8.91 and 9.03–9.12 ppm, and at

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[†] The ^1H NMR spectra were obtained on a Varian Unity 300 spectrometer (300 MHz) in DMSO-d_6, the signals were referred to the signal of residual protons of DMSO (δ 2.49 ppm), δ values were measured with precision 0.01 ppm. The IR spectra were recorded on a Varian Excalibur 3100 FT-IR instrument using the attenuated total internal reflection (ATR) technique (ZnSe crystal). The electronic absorption spectra were recorded on a Varian Cary 100 spectrophotometer. Electronic emission spectra were recorded on a Varian Cary Eclipse spectrofluorimeter. Acetonitrile and DMSO of the spectroscopic grade, *d*-metal perchlorates and tetrabutylammonium salts (Aldrich) were used to prepare solutions. Melting points were determined on a PTP (M) instrument and were not corrected.

[‡] *Aroylhydrazones* **1a–c** *(general procedure)*. A mixture of 5-hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde[23] (1 mmol, 0.25 g) and 2 mmol of hydrazide of corresponding aryl(hetaryl)carboxylic acid in propan-2-ol was refluxed for 1.5 h. The precipitate was filtered, rinsed with propan-2-ol and recrystallized from DMF.

*5-Hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde bis-*N*-(4-methoxybenzoyl)hydrazone* **1a**. Yield 0.29 g (54%), mp 210–212 °C. IR (ν/cm^{-1}): 3449, 2971, 2932, 1728 (C=O), 1630 (C=N), 1591 (C=C_{Ar}), 1508. ^1H NMR (300 MHz, DMSO-d_6) δ: 2.66 (s, 3H, Me), 2.75 (s, 3H, Me), 3.84 (s, 6H, 2OMe), 6.24 (s, 1H, H^3), 7.03–7.10 (m, 4H, H_{Ar}), 7.92–7.94 (d, 4H, H_{Ar}, *J* 6.6 Hz), 8.83 (s, 1H, CH), 9.03 (s, 1H, CH), 11.93 (s, 1H, NH), 12.23 (s, 1H, NH), 14.69 (s, 1H, OH). Found (%): C, 64.46; H, 4.65; N, 10.11. Calc. for $C_{29}H_{26}N_4O_7$ (%): C, 64.20; H, 4.83; N, 10.33.

Table 1 Electronic spectra of compounds **1a**–**c**.

Compound	Absorption, $\lambda_{\max}$/nm ($\varepsilon_{\max}$/dm^3 mol^{-1} cm^{-1}) MeCN	DMSO	Fluorescence,[a] $\lambda_{\max}$/nm [*I* (arbitrary units)]
1a	305 (22160), 368 (sh, 4920)	313 (19160), 431 (4840)	488 (482)
1b	306 (24970), 368 (sh, 5670)	307 (18090), 370 (sh, 5680), 458 (4180)	542 (343)
1c	306 (26440), 366 (sh, 4980)	309 (22900), 368 (sh, 6130), 440 (3070)	515 (461)

[a] MeCN, 1.3×10^{-5} mol dm^{-3}.

11.93–12.13 and 12.23–12.46 ppm, respectively. Signals of the coumarin hydroxy groups appear at 14.54–14.69 ppm as one-proton singlets. These spectral data indicate that aroylhydrazones **1a**–**c** exist predominantly in the form of hydroxy hydrazone tautomer **A** (Scheme 1). The electronic absorption spectra of **1a**–**c** in acetonitrile (and less polar solvents as well) contain bands with the maxima in the range of 305–306 and 366–368 nm with the molar extinction coefficients 22160–26440 and 4920-5670 dm^3 mol^{-1} cm^{-1}, respectively (Table 1), corresponding to hydroxy imine derivatives of coumarin compounds. Only in DMSO it is possible to observe a low-intensity absorption bands of keto hydrazine tautomers **B** in the spectral region of 431–458 nm, which are characteristic of keto form[20] [Figure 1(*a*), Table 1].

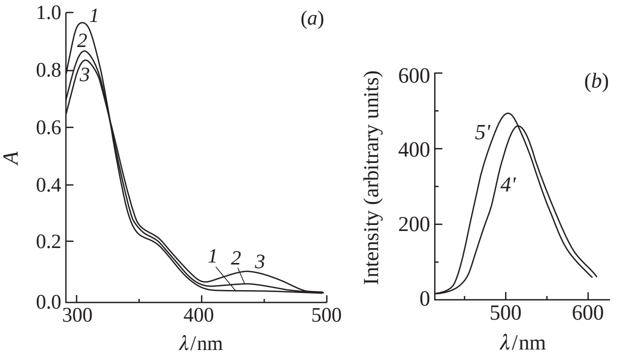

Figure 1 Electronic spectra of **1c**: (*a*) absorption in (*1*) acetonitrile, (*2*) acetonitrile–DMSO (1:1) and (*3*) DMSO (3.65×10^{-5} mol dm^{-3}); (*b*) fluorescence of the solution (*2*) observed upon excitation with the light at λ_{exc} of (*4′*) 370 and (*5′*) 420 nm.

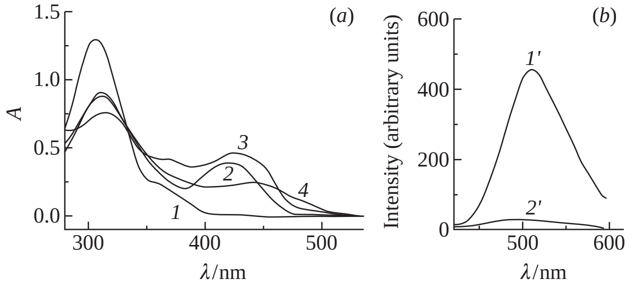

Figure 2 Electronic spectra of **1c** in acetonitrile: (*a*) absorption (*1*) before and after addition of (*2*) Zn^{2+}, (*3*) Ni^{2+} and (*4*) Hg^{2+} (5×10^{-5} mol dm^{-3}), (*b*) fluorescence (*1′*) before and (*2′*) after addition of Hg^{2+} (1.3×10^{-5} mol dm^{-3}).

Compounds **1a**–**c** display fluorescence in the region of 488–542 nm with large Stokes shifts (Table 1). This emission is associated, apparently, with the ESIPT-effect (Excited-State Intramolecular Proton Transfer) caused by the rapid intramolecular O→N proton transfers in the singlet excited states.[21,22] This assumption is confirmed, in particular, by the fact that the fluorescence excitations in the absorption maxima as hydroxy (**A**) and keto (**B**) isomers result in almost identical emission peaks [Figure 1(*b*)].

The addition of *d*-metal perchlorates to the solutions of **1a**–**c** in acetonitrile leads to appearance of a new absorption maximum in the visible spectral region at 420–440 nm [Figure 2(*a*)]. The highest bathochromic shift takes place in the presence of Hg^{2+} ions and, moreover, addition of Hg^{2+} perchlorate allows one to observe a distinct ‘naked-eye’ effect (the change of colour from pale-yellow to bright-orange). Simultaneously the initial fluorescence of the solution is almost completely quenched [Figure 2(*b*)]. The detection limit of mercury(II) cation sensing for aroylhydrazone **1a** is 2.7 μmol dm^{-3}. For hydroxy imine structures the observed CHEQ-effect (Chelation-Enhanced Fluorescence Quenching) is commonly supposed to be associated with complete or partial substitution of the OH protons by metal cations resulting in significant deactivation of ESIPT-process.[17,21,22]

Addition to the solutions of **1a**–**c** in acetonitrile of fluoride, cyanide and acetate anions, as their tetrabutylammonium salts, leads to the appearance of a new absorption maximum in the visible spectral region (Table 2, Figure 3). The most distinctive colorimetric ‘naked-eye’ effect is manifested when the solutions are exposed to F$^-$ anions.

Similar changes are observed in the spectra of complexes of **1b** and **1c** in the presence of F$^-$ in their solutions. Noteworthy is

Table 2 Electronic absorption spectra of complexes of **1a**–**c** with anions in acetonitrile.

Compound	$\lambda_{\max}$/nm ($\varepsilon_{\max}$/dm^3 mol^{-1} cm^{-1}) AcO$^-$	CN$^-$	F$^-$
1a	480 (7150)	480 (7300)	481 (16070)
1b	485 (9100)	485 (9640)	490 (10240)
1c	478 (9180)	478 (8620)	482 (9780)

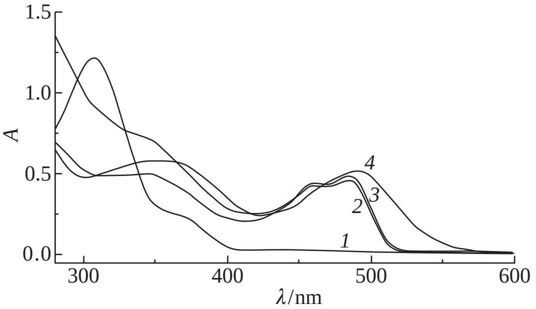

Figure 3 Electronic spectra of **1b** in acetonitrile (*1*) before and after addition of (*2*) AcO$^-$, (*3*) CN$^-$ and (*4*) F$^-$ (5×10^{-5} mol dm^{-3}).

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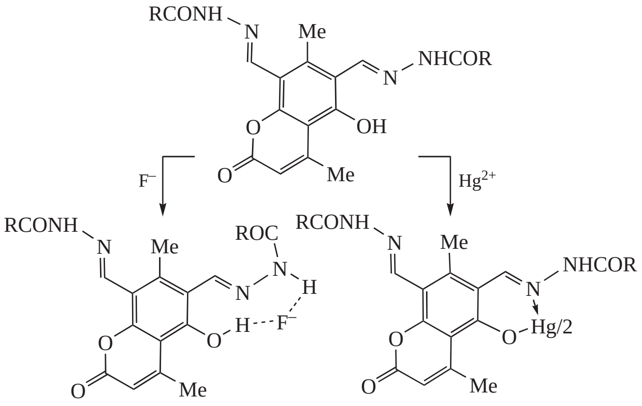
*5-Hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde bis-*N*-(4-phenylbenzoyl)hydrazone* **1b**. Yield 0.32 g (44%), mp 218–220 °C. IR (ν/cm^{-1}): 3613, 3259, 3047, 2930, 1716 (C=O), 1672 (C=O), 1611 (C=N), 1567 (C=C$_{\text{Ar}}$), 1542. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 2.69 (s, 3H, Me), 2.81 (s, 3H, Me), 6.28 (s, 1H, H^3), 7.42–7.43 (d, 2H, H$_{\text{Ar}}$, *J* 2.7 Hz), 7.45–7.46 (d, 2H, H$_{\text{Ar}}$, *J* 1.8 Hz), 7.48–7.54 (td, 4H, H$_{\text{Ar}}$, *J* 2.7, 1.8, 1.8, 7.8 and 8.1 Hz), 7.54–7.78 (d, 4H, H$_{\text{Ar}}$, *J* 7.2 Hz), 7.82–7.85 (d, 2H, H$_{\text{Ar}}$, *J* 8.1 Hz), 7.87–8.89 (d, 2H, H$_{\text{Ar}}$, *J* 8.1 Hz), 8.05–8.08 (d, 4H, H$_{\text{Ar}}$, *J* 8.4 Hz), 8.91 (s, 1H, CH), 9.12 (s, 1H, CH), 12.13 (s, 1H, NH), 12.46 (br.s, 1H, NH). Found (%): C, 73.28; H, 5.20; N, 8.30. Calc. for $C_{39}H_{30}N_4O_5$ (%): C, 73.80; H, 4.76; N, 8.83.

*5-Hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde bis-*N*-(furan-2-carbonyl)hydrazone* **1c**. Yield 0.20 g (44%), mp 195–197 °C. IR (ν/cm^{-1}): 3251, 3138, 3051, 2929, 1728 (C=O), 1655 (C=O), 1613 (C=N), 1592, 1561 (C=C$_{\text{Ar}}$), 1536. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 2.65 (s, 3H, Me), 2.88 (s, 3H, Me), 6.24 (s, 1H, H^3), 6.69–6.74 (m, 2H, H$_{\text{furyl}}$), 7.32–7.33 (d, 2H, H$_{\text{furyl}}$, *J* 3.0 Hz), 7.94 (s, 1H, H$_{\text{furyl}}$), 8.00 (s, 1H, H$_{\text{furyl}}$), 8.83 (s, 1H, CH), 9.06 (s, 1H, CH), 12.05 (s, 1H, NH), 12.40 (s, 1H, NH), 14.54 (s, 1H, OH). Found (%): C, 59.36; H, 3.62; N, 12.03. Calc. for $C_{23}H_{18}N_4O_7$ (%): C, 59.74; H, 3.92; N, 12.12.

that the complex of bis-*N*-(4-methoxybenzoyl)hydrazone **1a** with F^- is characterized by the highest molar extinction coefficient (Table 2) and the 'naked-eye' effect in this case differs from that observed for other compounds of this series (the colour of solution changes from pale-yellow to red-violet). Furthermore, the formation of complex of **1a** with fluoride anions is accompanied by the decrease in the relative intensity of the initial fluorescence I_0/I by ~22 times, whereas for analogous complexes of **1b** and **1c** this parameter changes to a lesser extent. According to the data of spectrophotometric titration and the isomolar series method, compound **1a** forms with fluoride anions a complex with 1:1 composition and its detection limit is 1.5 μmol dm^{-3} (see Figures S1 and S2, Online Supplementary Materials).



Scheme 2 A tentative scheme of the mechanisms of sensing Hg^{2+} and F^- ions by the bifunctional chemosensors **1a**–**c**.

In summary, the synthesized aroylhydrazones can serve as the bifunctional optical chemosensors exhibiting sensor activity for mercury cations and also fluoride, cyanide and acetate anions (Scheme 2). Bis-*N*-(4-methoxybenzoyl)hydrazine of 5-hydroxy-4,7-dimethyl-2-oxo-2*H*-chromene-6,8-dicarbaldehyde **1a** represents a bifunctional chemosensor system for the selective detection of Hg^{2+} and F^- based on the combination of colorimetric 'naked-eye' effect and quenching of fluorescent properties. For this compound the above-described visual changes are clearly reflected both in the analysis of mercury(II) cations in the mixture of Zn^{2+} and Ni^{2+}, and detection of the fluoride anion in the presence of AcO^- and CN^- ions.

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Online Supplementary Materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.mencom.2016.09.012.

References

1 *Chemosensors: Principles, Strategies, and Applications*, eds. B. Wang and E. V. Anslyn, Wiley, Hoboken, NJ, 2011.
2 V. A. Bren, *Russ. Chem. Rev.*, 2001, **70**, 1017 (*Usp. Khim.*, 2001, **70**, 1152).
3 N. Kaur and S. Kumar, *Tetrahedron*, 2011, **67**, 9233.
4 J. Wu, W. Liu, J. Ge, H. Zhang and P. Wang, *Chem. Soc. Rev*., 2011, **40**, 3483.
5 M. Formica, V. Fusi, L. Giorgi and M. Micheloni, *Coord. Chem. Rev*., 2012, **256**, 170.
6 Z. Liu, W. He and Z. Guo, *Chem. Soc. Rev*., 2013, **42**, 1568.
7 J. R. Lakowicz, *Principles of Fluorescence Spectroscopy*, 3rd edn., Springer, New York, 2006.
8 B. Valeur and M. N. Berberan-Santos, *Molecular Fluorescence: Principles and Applications*, 2nd edn., Wiley-VCH, Weinheim, 2012.
9 H. Kobayashi, M. Ogawa, R. Alford, P. L. Choyke and Y. Urano, *Chem. Rev*., 2010, **110**, 2620.
10 L. Yu, S. Wang, K. Huang, Z. Liu, F. Gao and W. Zeng, *Tetrahedron*, 2015, **71**, 4679.
11 V. Bhalla, R. Kumar, M. Kumar and A. Dhir, *Tetrahedron*, 2007, **63**, 11153.
12 A. S. Burlov, A. V. Tsukanov, G. S. Borodkin, Yu. V. Revinskii, A. D. Dubonosov, V. A. Bren, A. D. Garnovskii, A. Yu. Tsivadze and V. I. Minkin, *Russ. J. Gen. Chem*., 2006, **76**, 992 (*Zh. Obshch. Khim*., 2006, **76**, 1037).
13 I. E. Tolpygin, V. P. Rybalkin, E. N. Shepelenko, L. L. Popova, Yu. V. Revinskii, A. V. Tsukanov, O. I. Dmitrieva, A. D. Dubonosov, V. A. Bren' and V. I. Minkin, *Russ. J. Org. Chem*., 2008, **44**, 557 (*Zh. Org. Khim*., 2008, **44**, 562).
14 K. Rezaeian and H. Khanmohammadi, *Supramol. Chem*., 2016, **28**, 256.
15 V. F. Traven, A. V. Manaev, A. Yu. Bochkov, T. A. Chibisova and I. V. Ivanov, *Russ. Chem. Bull., Int. Ed*., 2012, **61**, 1342 (*Izv. Akad. Nauk, Ser. Khim*., 2012, 1327).
16 Y. Song, Z. Chen and H. Li, *Curr. Org. Chem.*, 2012, **16**, 2690.
17 A. D. Dubonosov, V. A. Bren and V. I. Minkin, in *Tautomerism: Concepts and Applications in Science and Technology*, ed. L. Antonov, Wiley-VCH, Weinheim, 2016, ch. 10, p. 229.
18 Y. Zhou, J. F. Zhang and J. Yoon, *Chem. Rev.*, 2014, **114**, 5511.
19 A. D. Dubonosov, V. A. Bren, V. I. Minkin, E. N. Shepelenko, K. S. Tikhomirova, A. G. Starikov and Yu. V. Revinskii, *Tetrahedron*, 2015, **71**, 8817.
20 V. I. Minkin, A. D. Dubonosov, V. A. Bren', O. G. Nikolaeva, A. V. Tsukanov, O. N. Burov and A. Yu. Fedyanina, *Russ. J. Org. Chem*., 2013, **49**, 374 (*Zh. Org. Khim*., 2013, **49**, 387).
21 J. E. Kwon and S. Y. Park, *Adv. Mater*., 2011, **23**, 3615.
22 J. Zhao, S. Ji, Y. Chen, H. Guo and P. Yang, *Phys. Chem. Chem. Phys*., 2012, **14**, 8803.
23 R. M. Naik and V. M. Thakor, *J. Org. Chem.*, 1957, **22**, 1626.

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