Synthesis and spectral luminescence properties of 2-aryl-5-methyl-1,3,4-oxadiazoles and zinc(II) 2-(2-hydroxyphenyl)-5-methyl-1,3,4-oxadiazole complex

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2-Aryl-5-methyl-1,3,4-oxadiazoles were synthesized by reflux of equimolar amounts of acyl hydrazides with triethyl orthoacetate in *o*-xylene. The obtained oxadiazoles, except for 2-(2-hydroxyphenyl)-5-methyl-1,3,4-oxadiazole, luminesce with a high quantum yield in polar and nonpolar solvents ($\lambda^{\text{fl}}_{\text{max}}$ = 300—339 nm, φ = 0.11—0.63). 2-(2-Hydroxyphenyl)-5-methyl-1,3,4-oxadiazole emits intensely only in highly polar aprotic DMSO ($\lambda^{\text{fl}}_{\text{max}}$ = 346 nm, φ = 0.15), whereas its chelate complex with Zn^{II} luminesces in all solvents with a high quantum yield in a longer-wavelength range of the visible spectrum ($\lambda^{\text{fl}}_{\text{max}}$ = 413—419 nm, φ = 0.36—0.55).

Key words: 2-aryl-5-methyl-1,3,4-oxadiazoles, metal complexes, luminescence, organic and metallocomplex luminophores.

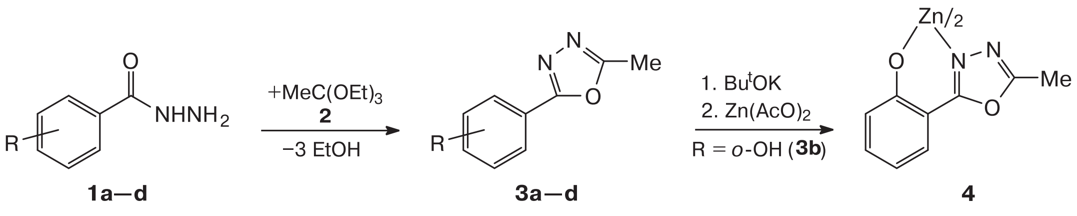
1,3,4-Oxadiazoles and related chelate metal complexes are widely used for the preparation of the organic[1,2] and metallocomplex luminophores[3—5] intensely emitting in the short-wavelength range of the visible spectrum and are applied as highly selective fluorescent chemosensors to "heavy" metal cations.[6]

In order to extend the scope of compounds of this class and to study their spectral luminescence properties, we refluxed equimolar amounts of acyl hydrazides (**1a—d**) with triethyl orthoacetate (**2**) in *o*-xylene to obtain 2-aryl-5-methyl-1,3,4-oxadiazoles (**3a—d**). The chelate complex of zinc(II), L_2Zn (**4**), was synthesized by reflux of 2-(2-hydroxyphenyl)-5-methyl-1,3,4-oxadiazole (**3b**) with 0.5 equivalent of zinc acetate dihydrate in methanol using an equivalent amount of Bu^{t}OK as a base (Scheme 1).

The compositions and structures of newly synthesized oxadiazoles **3a,c,d** and the chelate complex of Zn^{II} with ligand **3b** were determined using elemental analysis, IR spectroscopy, and ^{1}H and ^{13}C NMR spectroscopy. In addition, the spectral luminescence properties of these compounds were studied.

In the absorption spectra of oxadiazoles **3a—d**, the long-wavelength maximum caused by the electronic transitions $S_0 \rightarrow S_1$ of the $\pi\rightarrow\pi^*$-type in the mutually conjugated 1,3,4-oxadiazole and aryl fragments lies in a range of 272—316 nm, indicating that the compounds exist in solutions as benzoid-type structures of the type of **3**. The presence of the electron-donor substituents in the aryl core results in the shift of these bands to the long-wavelength range by 8—44 nm, whereas the polarity of the solvent exerts almost no effect on their position. The formation of lived phototautomer was detected earlier[7] by fluorescence analysis for 2-(2-hydroxyphenyl)-5-methyl-1,3,4-oxadiazole (**3b**). The phototautomer was formed due

Scheme 1



R = H (**a**), *o*-OH (**b**), *o*-OMe (**c**), *p*-OMe (**d**)

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to the intramolecular transfer of the proton in the excited state from the phenolic oxygen to the nearest nitrogen atom of the oxadiazole cycle (ESIPT process). This is indicated by the fluorescence spectra of oxadiazole **3b** in isooctane and acetonitrile in which the long-wavelength radiation ($\lambda^{\text{fl}}_{\text{max}}$ = 475—490 nm, φ = 0.001—0.004) from the phototautomer formed *via* the ESIPT mechanism is observed along with the short-wavelength band ($\lambda^{\text{fl}}_{\text{max}}$ = 332—339 nm, φ = 0.005—0.007) from benzoid form **3**.[7—9] However, the emission spectrum of oxadiazole **3b** in DMSO contains only one short-wavelength intense band ($\lambda^{\text{fl}}_{\text{max}}$ = 346 nm, φ = 0.15)[7] assigned to benzoid structure **3** with allowance for the fluorescence excitation spectra. This is explained by the formation of the strong intermolecular hydrogen bond between the phenolic hydroxyl of oxadiazole **3b** and highly polar aprotic DMSO that inhibits the ESIPT process. Oxadiazoles **3a,c,d**, in which the ESIPT process is impossible because they have no mobile proton of *ortho*-phenolic hydroxyl, emit intensely in the short-wavelength range of the visible spectrum ($\lambda^{\text{fl}}_{\text{max}}$ = 300—339 nm, φ = 0.11—0.63), and their emission spectra exhibit the bathochromic shift of the luminescence maximum with an increase in the polarity of the solvent (by 2—15 nm) and upon the introduction of electron-donor substituents into the aryl ring (by 15—34 nm).

The IR spectrum of metal complex **4** exhibits no absorption from the phenolic hydroxyl, which is observed in the spectrum of ligand **3b** at 3187 cm^{-1}. In addition, the band at 1610 cm^{-1} of vibrations of the C=N bond involved in complex formation undergoes a downfield shift by 18 cm^{-1} compared to the corresponding band in the initial ligand (1628 cm^{-1}). The ^{1}H and ^{13}C NMR spectra of metal complex **4** contain the full set of signals from the hydrogen and carbon atoms appeared in their characteristic ranges. The ^{1}H NMR spectra of complex **4** contains no signal at δ 10.22 of the phenolic hydroxyl, which is present in the spectrum of ligand **3b**. Complex formation also results in the upfield shift of the signals in the ^{1}H and ^{13}C NMR spectra of metal complex **4** compared to the corresponding signal of its ligand **3b**.

The long-wavelength absorption band maximum of zinc complex **4** is shifted to the long-wavelength range (λ_{max} = 348—359 nm) compared to the spectra of oxadiazoles **3a—d** because of the charge-transfer band between the ligand and metal, and the maximum of its single luminescence band ($\lambda^{\text{fl}}_{\text{max}}$ = 413—419 nm) lies between the emission signals of the benzoid structure of compound **3b** and its phototautomer. The rigid structure of metal complex **4** prevents the nonradiative deactivation of its excited state, and the complex intensely luminesces (φ = 0.36—0.55) in the UV spectral range in both polar and nonpolar solvents. Therefore, this complex is an efficient metallocomplex luminophore, and oxadiazole ligand **3b** can be used as a chemosensor to the zinc cation.

Thus, it is shown that 2-aryl-5-methyl-1,3,4-oxadiazoles **3a,c,d** intensely luminesce ($\lambda^{\text{fl}}_{\text{max}}$ = 300—339 nm, φ = 0.11—0.63), which allows their assignment to widely demanded organic luminophores of UV radiation. The metallocomplex luminophore L_2Zn, which intensely emits in the UV spectral range ($\lambda^{\text{fl}}_{\text{max}}$ = 413—419 nm, φ = 0.36—0.55), was synthesized from ligand **3b** with the *ortho*-phenol substituent in position 2 of the oxadiazole cycle. This opens prospects for using oxadiazole **3b** as a chemosensor to the zinc cation.

Experimental

IR spectra were recorded on a Varian Excalibur 3100 FT-IR spectrometer. ^{1}H (250.13, 600 MHz) and ^{13}C (62.90, 151 MHz) NMR spectra were detected on Bruker DPX-250 and Bruker Avance-600 instruments. Absorption and fluorescence spectra were measured on a Cary Scan 100 spectrophotometer and on a Cary Eclipse spectrofluorimeter, respectively. Fluorescence quantum yields were determined relative to an acetonitrile solution of anthracene.[9]

5-Methyl-2-phenyl-1,3,4-oxadiazole (3a). Triethyl orthoacetate **2** (1.8 mL, 0.01 mol) in anhydrous *o*-xylene (10 mL) was added by small portions with stirring to a solution of benzhydrazide **1a** (1.36 g, 0.01 mol) in anhydrous *o*-xylene (50 mL) at ~20 °C. The reaction mixture was refluxed for 6 h monitoring the formation of the reaction product by TLC. The solvent was removed *in vacuo*, and the product was isolated by column chromatography on silica (0.063—0.200 mm, ethyl acetate—petroleum ether (1 : 10) as eluent) collecting the fraction with R_f = 0.80. The yield was 1.46 g (83%), colorless crystals, m.p. 66—67 °C. Found (%): C, 67.53; H, 5.05; N, 17.44. $C_9H_8N_2O$. Calculated (%): C, 67.49; H, 5.03; N, 17.49. IR (KBr), ν/cm^{-1}: 663, 693, 707, 710; 757 δ(C—H); 798, 812; 851 δ(C_{Ar}—H); 929, 960; 1075, 1179, 1250, 1300, 1351, 1422; 1451 ν(N—N); 1500; 1552, 1579 (C=C); 1629, 1641 (C=N); 3337, 3442 ν(C—H). UV, λ_{max}/nm [$\varepsilon \cdot 10^{-4}$/L mol^{-1} cm^{-1}, λ_{exc} = 260 nm]: isooctane, 203 [1.80], 244 sh [1.52], 249 [1.65], 254 [1.60], 260 sh [1.32], 272 sh [0.46], $\lambda^{\text{fl}}_{\text{max}}$ (φ): 300 (0.11); acetonitrile, 244 sh [1.84], 249 [1.95], 255 sh [1.84], 259 [1.56], 273 sh [0.56], $\lambda^{\text{fl}}_{\text{max}}$ (φ): 301 (0.19). ^{1}H NMR (250.13 MHz, $CDCl_3$), δ: 2.65 (s, 3 H, Me); 7.48—7.56 (m, 3 H, H_{Ar}); 8.06 (d, 2 H, H_{Ar}, J = 7.0 Hz). ^{13}C NMR (62.90 MHz, $CDCl_3$), δ_C: 10.97 (CH_3), 123.88 (C_{Ar} quat.), 126.51 (2 C_{Ar}), 128.91 (2 C_{Ar}), 131.41 (C_{Ar}), 163.54 (C_{Ht}), 164.67 (C_{Ht}).

2-(5-Methyl-1,3,4-oxadiazol-2-yl)phenol (3b) was synthesized by the reaction of salicylic acid hydrazide **1b** with triethyl orthoacetate **2** similarly to oxadiazole **3a**. The yield was 1.40 g (81%), colorless crystals, m.p. 74—75 °C (*cf.* Ref. 7: m.p. 74—75 °C). The IR, UV, and ^{1}H and ^{13}C NMR spectra of compound **3b** are consistent with the corresponding published spectra of this substance.[7]

5-Methyl-2-(2-methoxyphenyl)-1,3,4-oxadiazole (3c) was synthesized by the reaction of *o*-anisic acid hydrazide **1c** with triethyl orthoacetate **2** similarly to oxadiazole **3a**. The yield was 1.41 g (79%), colorless crystals, m.p. 118—120 °C. Found (%): C, 63.12; H, 5.27; N, 14.78. $C_{10}H_{10}N_2O_2$. Calculated (%): C, 63.15; H, 5.30; N, 14.73. IR (KBr), ν/cm^{-1}: 709; 753 δ(C—H); 774 δ(C_{Ar}—H); 980, 1016, 1066, 1140, 1166, 1264, 1285; 1432, 1498 ν(N—N); 1557, 1597 (C=C); 1630, 1646 (C=N); 3335, 3447 ν(C—H). UV, λ_{max}/nm [$\varepsilon \cdot 10^{-4}$/L mol^{-1} cm^{-1}, λ_{exc} = 290 nm]: isooctane, 211 [2.18], 248 [1.19], 255 sh [1.60], 263 sh [0.68], 295 [0.55], 307 sh [0.38], λ^{fl}_{max} (φ): 324 (0.45); acetonitrile, 247 [1.24], 253 sh [1.17], 264 sh [0.62], 296 [0.58], 309 sh [0.37], λ^{fl}_{max} (φ): 334 (0.47); DMSO, 298 [0.65], 313 sh [0.38], λ^{fl}_{max} (φ): 339 (0.43). ^{1}H NMR (250.13 MHz, CDCl$_3$), δ: 2.48 (s, 3 H, Me); 3.85 (s, 3 H, OMe); 6.93—6.98 (m, 2 H, H$_{Ar}$); 7.38 (dd, 1 H, H$_{Ar}$, J_1 = 7.5 Hz, J_2 = 7.6 Hz); 7.78 (dd, 1 H, H$_{Ar}$, J_1 = 2.5 Hz, J_2 = 7.7 Hz). ^{13}C NMR (62.90 MHz, CDCl$_3$), δ_C: 11.03 (CH$_3$), 55.92 (OCH$_3$), 111.89 (C$_{Ar}$), 113.09 (C$_{Ar}$ quat.), 120.64 (C$_{Ar}$), 130.27 (C$_{Ar}$), 132.84 (C$_{Ar}$), 157.68 (C$_{Ar}$ quat.), 163.26 (C$_{Ht}$), 163.51 (C$_{Ht}$).

5-Methyl-2-(4-methoxyphenyl)-1,3,4-oxadiazole (3d) was synthesized by the reaction of *p*-anisic acid hydrazide **1d** with triethyl orthoacetate **2** similarly to oxadiazole **3a**. The yield was 1.36 g (76%), colorless crystals, m.p. 92—93 °C. Found (%): C, 63.21; H, 5.25; N, 14.76. $C_{10}H_{10}N_2O_2$. Calculated (%): C, 63.15; H, 5.30; N, 14.73. IR (KBr), ν/cm^{-1}: 708; 761 δ(C—H); 779 δ(C$_{Ar}$—H); 988, 1069, 1140, 1164, 1285, 1307; 1437, 1463 ν(N—N); 1513, 1557, 1597 (C=C); 1630, 1646 (C=N); 3335, 3447 ν(C—H). UV, λ_{max}/nm [$\varepsilon \cdot 10^{-4}$/L mol^{-1} cm^{-1}, λ_{exc} = 270 nm]: isooctane, 259 [0.61], 271 sh [0.52], 285 sh [0.23], λ^{fl}_{max} (φ): 312 (0.29); dioxane, 272 sh [0.52], 286 sh [0.26], λ^{fl}_{max} (φ): 317 (0.40); acetonitrile, 260 [0.64], 272 sh [0.50], 283 sh [0.29], λ^{fl}_{max} (φ): 317 (0.63). ^{1}H NMR (250.13 MHz, CDCl$_3$), δ: 2.68 (s, 3 H, Me); 3.88 (s, 3 H, OMe); 7.64 (d, 2 H, H$_{Ar}$, J = 8.0 Hz); 7.96 (d, 2 H, H$_{Ar}$, J = 8.0 Hz). ^{13}C NMR (62.90 MHz, CDCl$_3$), δ_C: 11.37 (CH$_3$), 48.80 (OCH$_3$), 127.21 (2 C$_{Ar}$), 129.64 (C$_{Ar}$ quat.), 130.05 (2 C$_{Ar}$), 163.96 (C$_{Ht}$), 164.09(C$_{Ht}$).

Bis[2-(2-hydroxyphenyl)-5-methyl-1,3,4-oxadiazolyl]zinc(II) (4). A solution of Bu^{t}OK (0.22 g, 0.002 mol) in methanol (5 mL) was added at ~20 °C with stirring to a solution of 1,3,4-oxadiazole **3b** (0.35 g, 0.002 mol) in methanol (15 mL). The mixture was refluxed for 1 h and cooled down to ~20 °C, and zinc acetate dihydrate (0.22 g, 0.001 mol) in methanol (5 mL) was added. The reaction mixture was refluxed for 4 h, and precipitated complex **4** was filtered off, washed with methanol (2×10 mL), and recrystallized from acetonitrile (300 mL). The yield was 0.32 g (77%), colorless crystals, m.p. 324—325 °C. Found (%): C, 52.06; H, 3.37; N, 13.52. $C_{18}H_{14}N_4O_4Zn$. Calculated (%): C, 52.01; H, 3.39; N, 13.48. IR (Nujol), ν/cm^{-1}: 648, 664; 765, 776 δ(C—H); 851 δ(C$_{Ar}$—H); 1135, 1156, 1224, 1239, 1258, 1276, 1348, 1400, 1436; 1472 ν(N—N); 1531, 1557,1596 (C=C); 1610 (C=N). UV, λ_{max}/nm [$\varepsilon \cdot 10^{-4}$/L mol^{-1} cm^{-1}, λ_{exc} = 350 nm]: dioxane, 305 [1.19], 312 [1.16], 350 [0.40], λ^{fl}_{max} (φ): 416 (0.36); acetonitrile, 236 [1.69], 246 [1.74], 252 [2.01], 257 sh [1.72], 263 [1.58], 304 [0.77], 311 [0.76], 348 [0.36], λ^{fl}_{max} (φ): 413 (0.40); DMSO, 303 [1.69], 313 sh [1.42], 359 [0.29], λ^{fl}_{max} (φ): 419 (0.55). ^{1}H NMR (600 MHz, DMSO-d$_6$, 90 °C), δ: 2.49 (s, 3 H, Me); 6.40 (dd, 1 H, H$_{Ar}$, J_1 = 7.8 Hz, J_2 = 7.9 Hz); 6.64 (d, 1 H, H$_{Ar}$, J = 7.9 Hz); 7.12 (dd, 1 H, H$_{Ar}$, J_1 = 7.9 Hz, J_2 = 8.0 Hz); 7.51 (dd, 1 H, H$_{Ar}$, J_1 = 1.8 Hz, J_2 = 8.0 Hz). ^{13}C NMR (151 MHz, DMSO-d$_6$), δ_C: 9.81 (CH$_3$), 108.21 (C$_{Ar}$ quat.), 111.55 (C$_{Ar}$), 121.77 (C$_{Ar}$), 127.39 (C$_{Ar}$), 132.32 (C$_{Ar}$), 160.44 (C$_{Ar}$ quat.), 165.32 (C$_{Ht}$), 167.60 (C$_{Ht}$).

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References

1. I. E. Mikhailov, L. D. Popov, N. I. Vikrishchuk, A. D. Beldovskaya, Yu. V. Revinskii, G. A. Dushenko, V. I. Minkin, *Russ. J. Gen. Chem.*, 2015, **85**, 203.
2. Yu. M. Artyushkina, I. E. Mikhailov, O. N. Burov, G. A. Dushenko, O. I. Mikhailova, Yu. V. Revinskii, V. I. Minkin, *Russ. J. Gen. Chem.*, 2016, **86**, 2702.
3. R. Deng, L. Li, M. Song, Sh. Zhao, L. Zhou, Sh. Yao, *CrystEngComm.*, 2016, **18**, 4382.
4. I. E. Mikhailov, L. D. Popov, V. V. Tkachev, S. M. Aldoshin, G. A. Dushenko, Yu. V. Revinskii, V. I. Minkin, *J. Mol. Struct.,* 2018, **1157**, 374.
5. I. E. Mikhailov, G. A. Dushenko, M. E. Gurskii, N. I. Vikrischuk, L. D. Popov, Yu. V. Revinskii, K. A. Lyssenko, V. I. Minkin, *Polyhedron,* 2019, **166**, 73.
6. L. Lin, D. Wang, S.-H. Chen, D.-J. Wang, G.-D. Yin, *Spectrochim. Acta. Part A*, 2017, **174**, 272.
7. I. E. Mikhailov, Yu. M. Artyushkina, G. A. Dushenko, O. I. Mikhailova, Yu. V. Revinskii, O. N. Burov, V. I. Minkin, *Russ. J. Org. Chem.*, 2016, **52**, 1700.
8. I. E. Mikhailov, Yu. M. Artyushkina, O. N. Burov, G. A. Dushenko, Yu. V. Revinskii, V. I. Minkin, *Russ. J. Gen. Chem.*, 2016, **86**, 406.
9. A. O. Doroshenko, E. A. Posokhov, A. A. Verezubova, L. M. Ptyagina, *J. Phys. Org. Chem.,* 2000, **13**, 253.

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