

Luminescent properties of europium carboxylates



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ABSTRACT

Mixed-ligand europium carboxylates with nitrogen- and phosphorus-containing neutral ligands having polymer or island structure were studied by the luminescent and X-ray photoelectron spectroscopy methods. In similar groups of the compounds, the value of Stark splitting of the 7F_1 – level decreased with decrease of the electron density transfer from europium ion to ligand (covalence of metal-ligand bond increases) and the relative intensity of electro-dipole ${}^5D_0 - {}^7F_4$ transition rised.

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1. Introduction

Such properties of the lanthanide compounds at tendency to complexing and sublimation, ability to intensive absorption and luminescence depend directly on the lanthanide electron structure and the nature of the chemical bond in the mixed-ligand complexes. It is known that substitutes, even distant from reaction centers of ligand molecules, change distribution of the electron density in these molecules and therefore influence on the physico-chemical and analytical properties of the compounds: strength of Ln-ligand bond, its character, and optic characteristics of the compounds. The change of the atom change may be a measure of the change of electron distribution [1–5].

For an accurate estimation of influence of the nature of the environmental on the spectral – luminescence properties of the

rare-earth complexes one should have knowledge on peculiarities of their electron structure. Wide use of the lanthanide compounds [6,7] is a cause of increased interest to study of their electron structure nature of chemical bond.

The literature analysis testifies to insufficient investigation of correlation of the Ln^{3+} luminescent parameters with the characteristics of its electron structure determined by the photo- and X-ray electron spectroscopy methods [1–3,8–10]. The mixed-ligand europium(III) compound with β -diketones were studied by the luminescent and X-ray spectroscopy methods [11,12] while the rare-earth compounds with carboxylic acids were not practically investigated [13,14].

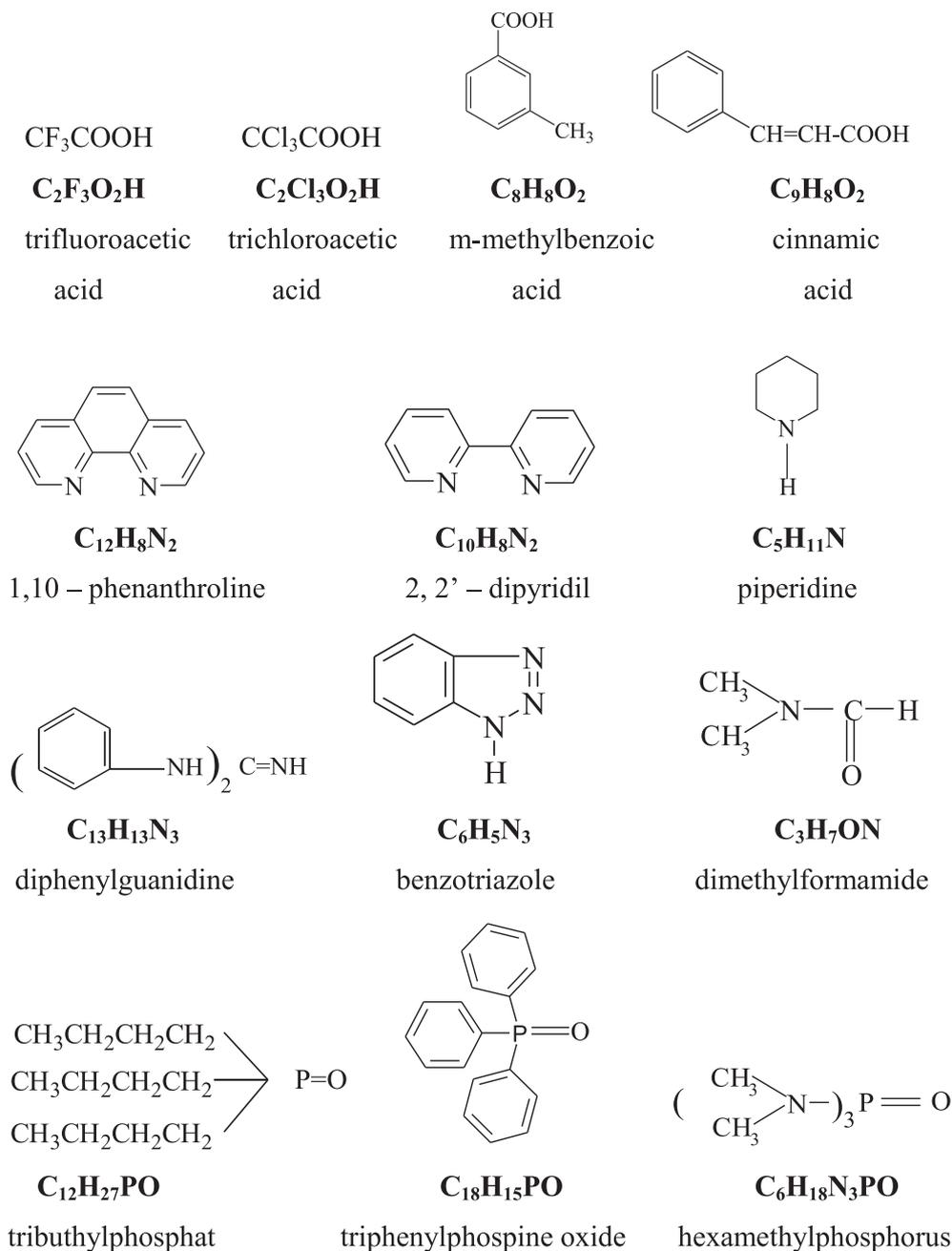
2. Experimental

2.1. Materials

For synthesis of the compounds the following reagents were used:

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2.2. Synthesis

Europium complexes were obtained by interaction of europium trifluoroacetate and trichloroacetate hydrates and neutral ligand (in the 1: 2 M ratio). Mixed-ligand compounds with meta-methylbenzoic and cinnamic acids were prepared by interaction of a europium salt, sodium salt of the acid, and a neutral ligand (in the molar ratio 1: 3: 2). The method was described in detail in Refs. [15–17].

2.3. Chemical elemental analysis

The elemental contents of complexes were measured with

EURO EA 3000.

2.4. Luminescence measurements

The luminescence spectra were registered on a SDL-1 diffraction spectrometer at 300 K and 77 K. The resolution of the diffraction spectrometer ~1 nm. In order to estimate intensity of luminescence we carried out integration of the areas of the luminescence bands which positions were determined to an approximation of $\pm 2\text{--}3\text{ cm}^{-1}$.

The luminescence excitation spectra were recorded on the installation assembled on the basis of a SDL-1 spectrometer and a MPD-23 monochromator; a Tunggram 2500 W xenon lamp served

Table 1
Elemental analyses mixed-ligand europium compounds with trichloroacetic acids.

Compounds	Found (%)					Calculated (%)				
	C	H	N	H ₂ O	Eu	C	H	N	H ₂ O	Eu
Eu(C ₂ Cl ₃ O ₂) ₃ ·3H ₂ O	10.41	1.11	—	7.60	21.61	10.38	0.87	—	7.79	21.92
Eu(C ₂ Cl ₃ O ₂) ₃ ·2C ₁₀ H ₈ N ₂ ·H ₂ O	32.50	1.91	5.90	1.80	15.60	32.18	1.86	5.78	1.87	15.68
Eu(C ₂ Cl ₃ O ₂) ₃ ·2C ₁₂ H ₈ N ₂ ·H ₂ O	35.21	1.90	5.90	1.73	14.63	35.38	1.77	5.50	1.77	14.93

as an excitation source. Measurements were carried out at 300 and 77 K.

2.5. X-ray electron measurements

The X-ray photoelectron spectra of carbon, oxygen, and nitrogen and europium were recorded on a ES-2401 spectrometer (Russia) at the room temperature using nonmonochromatic AlK_α-radiation. Due to suggestion of the binding energies (*E_b*) of the electrons of functional groups atoms to be constant [18], the scale of the bond energies in the series of europium compounds with trifluoroacetate was calibrated against *E_b* of the F1s electrons of the –CF₃ groups (687.9 eV). Meta-methylbenzoic and cinnamic spectra were calibrated against *E_b* of the C1s electrons of the of meta-methylbenzoic and cinnamic acids benzene rings (284.9 eV) [18]. The determination of the bond energies equaled 0.1 eV.

3. Results and discussion

The data on the chemical elemental analysis for the europium(III) complex carboxylates are presented in Refs. [15–17]. The results for the mixed –ligand europium(III) trichloroacetates are given in Table 1. The composition and structure of the europium(III) complex compounds are described on the basis of the X-ray [19–22] and IR spectroscopy [15–17] data.

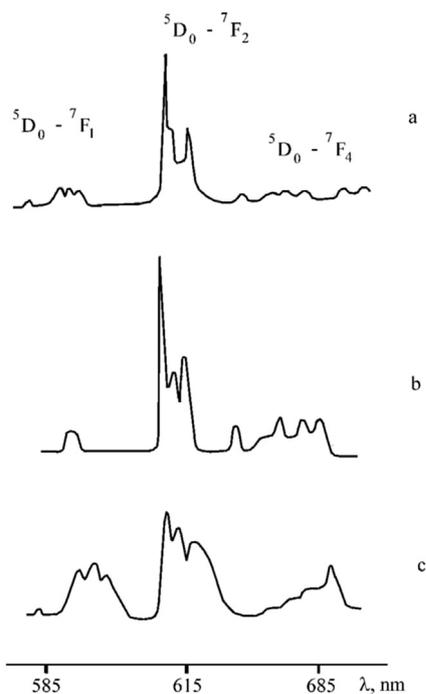


Fig. 1. Luminescence spectra of europium(III) compounds at 77 K: a – [Eu(C₈H₇O₂)₃·C₁₀H₈N₂]₂, b – Eu(C₉H₇O₂)₃·2C₁₂H₈N₂·H₂O, c – Eu(C₂F₃O₂)₃·2C₃H₇ON·H₂O.

The mixed-ligand europium compounds with trifluoroacetic, trichloroacetic, m-methylbenzoic and cinnamic acids display red luminescence at both room temperature and 77 K. Their luminescence spectra (77 K) are given in Fig. 1. As it may be seen, all the compounds may be divided into two groups. In the spectra of the first group compounds, the bands corresponding to the ⁵D₀ – ⁷F₂ electro-dipole transition are the most intensive that is typical for most of the luminescent Eu compounds [23,24]. Compounds [Eu(C₈H₇O₂)₃·xD·nH₂O]_m and Eu(C₉H₇O₂)₃·xD·nH₂O has such spectra (Fig. 1a, b). It should be noted that the band distribution of the ⁵D₀ – ⁷F_j transition (j = 1, 2) in the spectra of monomer and dimeric compounds differ slightly. It may be connected with the fact that the crystal field in the homologous series studied in this work changes insignificantly. The low – temperature spectra of these compounds have linear character. In this case maximum possible number of components of the ⁵D₀ – ⁷F_j (j = 0–4) transitions of Stark structure is observed. The value of Stark splitting magneto–dipole transition ⁵D₀ – ⁷F₁ (ΔF₁) equals 150–200 cm^{–1}.

In the spectra of the second group compounds, the bands of the ⁵D₀ – ⁷F₁ magneto–dipole transition (580–590 nm) are rather intensive. Thus, for most of carboxylates containing substituents with strong negative effect (–CCl₃, –CF₃), intensity of the ⁵D₀ – ⁷F₁ magneto–dipole transition is comparable or two time less than that of the ⁵D₀ – ⁷F₂ electro-dipole transition (Fig. 1c). In the luminescence spectra of Eu(C₂F₃O₂)₃·xD·nH₂O (where D – C₁₂H₈N₂, C₁₀H₈N₂), relative intensity of the bands of the ⁵D₀ – ⁷F₁ magneto–dipole transition is higher than for other compounds of the first group, but lower than for the complexes of the second one. Increase of intensity of the ⁵D₀ – ⁷F_j transition in the luminescence spectra of the compounds Eu(TFA)₃D, where D – dipy or phen, is explained by coordination of the most donor molecules dipy and

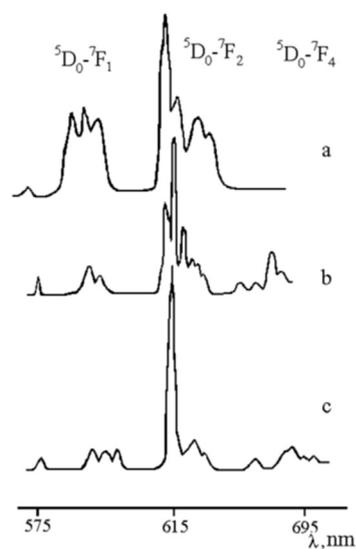


Fig. 2. Luminescence spectra of europium(III) compounds at 300 K: a – [Eu(C₂F₃O₂)₃·3·H₂O]₂, b – Eu(C₂F₃O₂)₃·2C₁₂H₈N₂·H₂O, c – [Eu(C₂F₃O₂)₃·C₁₀H₈N₂·3H₂O]·C₁₀H₈N₂.

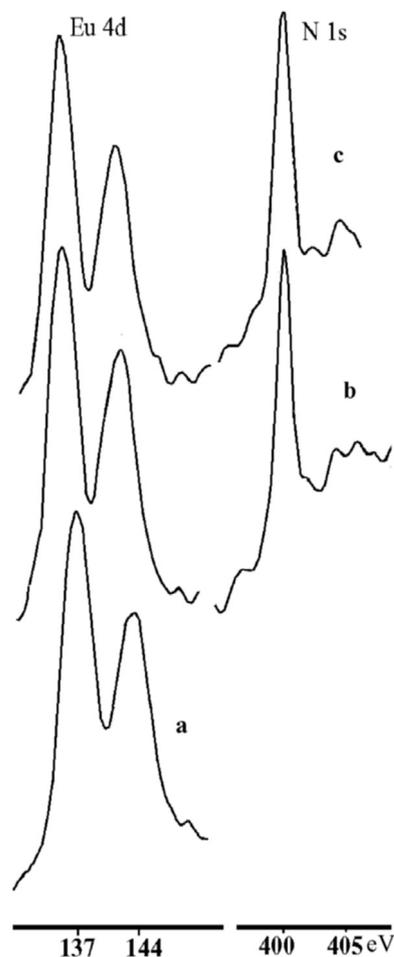


Fig. 3. EXP spectra of europium(III) compounds: a – $[\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 3\text{H}_2\text{O}]_2$, b – $[\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot \text{C}_{10}\text{H}_8\text{N}_2 \cdot 3\text{H}_2\text{O}] \cdot \text{C}_{10}\text{H}_8\text{N}_2$, c – $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$.

phen to Eu(III) and growth of the electron density at the Eu(III) atom (Fig. 2). The luminescence spectra of the complexes are structured, the band number equals 3 for the $^5\text{D}_0 - ^7\text{F}_1$ and 4–6.

$^5\text{D}_0 - ^7\text{F}_2$ transitions, respectively. ΔF_1 value for this group complexes is 105–150 cm^{-1} .

The values of the $^5\text{D}_0 - ^7\text{F}_1$ magneto–dipole transition splitting (ΔF_1), the shift of the $^5\text{D}_0 - ^7\text{F}_0$ transition band Δv (with respect $^5\text{D}_0 - ^7\text{F}_0$ transition to Eu(III) – aqua compounds) for the mixed-ligand europium carboxylates obtained as well as the value of the bond energies measured by the XPS are presented in Table. It is known that the Stark splitting values for $^7\text{F}_{1,2}$ Eu^{3+} levels are sensitive to substitution of acido- or donor ligand. These values are conditioned by polarization of 4f-shell connected with change of the features of the electric field in which Eu^{3+} ions is [25]. Intensification of electric interaction of a rare-earth ion with ligand anions and symmetry lowering also results in increase of the value of levels splitting [26].

It is seen from the table that the value of Stark splitting ΔF_1 and displacement of the band of the $^5\text{D}_0 - ^7\text{F}_0$ electro-dipole transition Δv for mixed-ligand europium trifluoro-, trichloroacetates monotonely decrease in the following succession: $\text{C}_{13}\text{H}_{13}\text{N}_3 > \text{C}_3\text{H}_7\text{ON} > \text{C}_{18}\text{H}_{15}\text{PO} > \text{C}_6\text{H}_{18}\text{N}_3\text{PO} > \text{C}_6\text{H}_5\text{N}_3 > \text{C}_{10}\text{H}_8\text{N}_2 > \text{C}_{12}\text{H}_8\text{N}_2$ that is conditioned by strengthening of Eu^{3+} interaction with nitrogen- and phosphorus – containing neutral ligands in the for mixed-ligand europium compounds. Moreover, minimal ΔF_1 values in the coordination compounds having island structure are observed for $[\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot \text{C}_{10}\text{H}_8\text{N}_2 \cdot 3\text{H}_2\text{O}]\text{C}_{10}\text{H}_8\text{N}_2$, $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$ and $\text{Eu}(\text{C}_2\text{Cl}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$. The XPS data show that these compounds have the least charge on the europium atom (E_b of $\text{Eu}4d_{5/2}$ equal 136.3 and 136.1 eV) (Fig. 3). The highest ΔF_1 value in the series of the mixed-ligand compounds is typical for $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_3\text{H}_7\text{ON} \cdot \text{H}_2\text{O}$ (E_b of $\text{Eu}4d_{5/2}$ equal 137.0 eV). In the compound $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_3\text{H}_7\text{ON} \cdot \text{H}_2\text{O}$ the bond energy N1s binding energy equals 400.5 eV that shows to coordination of dimethylformamide through oxygen atom [27].

Europium trifluoroacetate trihydrate has another structure as compared to the europium mixed-ligand compounds obtained.

Table 2

Luminescent features and core electrons binding energies (eV) in mixed-ligand europium carboxylates.

Compounds	η_1	η_2	ΔF_1	ν_0, cm^{-1}	$\Delta v, \text{cm}^{-1}$	$\text{Eu}4d_{5/2}$	N1s	P2p
$[\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 3\text{H}_2\text{O}]_2$	0.45	0.10	40	17248	16	137.5		
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_27\text{PO} \cdot \text{H}_2\text{O}$	0.24	0.12	164	17250	14			
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot \text{C}_{13}\text{H}_{13}\text{N}_3 \cdot 2\text{H}_2\text{O}$	0.24	0.15	161	17251	13			
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_3\text{H}_7\text{ON} \cdot \text{H}_2\text{O}$	0.35	0.17	158	17253	11	137.0	400.5	
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{18}\text{H}_{15}\text{PO} \cdot 3\text{H}_2\text{O}$	0.25	0.19	154	17255	9	136.7		133.2
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_6\text{H}_{18}\text{N}_3\text{PO} \cdot \text{H}_2\text{O}$	0.25	0.20	149	17256	8			
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_6\text{H}_5\text{N}_3 \cdot \text{H}_2\text{O}$	0.24	0.22	142	17258	6			
$[\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot \text{C}_{10}\text{H}_8\text{N}_2 \cdot 3\text{H}_2\text{O}] \text{C}_{10}\text{H}_8\text{N}_2$	0.27	0.28	90	17262	2	136.3	399.5	
$\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$	0.24	0.28	72	17263	1	136.3	399.5	
$\text{Eu}(\text{C}_2\text{Cl}_3\text{O}_2)_3 \cdot 3\text{H}_2\text{O}$	0.47	–	86	17228	36	137.7	–	
$\text{Eu}(\text{C}_2\text{Cl}_3\text{O}_2)_3 \cdot 2\text{C}_{10}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$	0.59	0.41	168	17232	32	136.5	399.3	
$\text{Eu}(\text{C}_2\text{Cl}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$	0.61	0.43	155	17260	4	136.1	398.9	
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot 2\text{H}_2\text{O}]_n$	0.20	–	200	17228	36	137.3	–	
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{18}\text{H}_{15}\text{PO}]_2 \cdot 2\text{H}_2\text{O}$	0.14	0.05	161	17230	34	136.8	–	133.2
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_6\text{H}_{18}\text{N}_3\text{PO}]_2 \cdot 2\text{H}_2\text{O}$	0.15	0.11	159	17232	32			
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_5\text{H}_{11}\text{N}]_2$	0.20	0.16	157	17235	29			
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_3\text{H}_7\text{ON}]_2 \cdot 2\text{H}_2\text{O}$	0.14	0.15	155	17241	23			
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3]_2 \cdot 2\text{C}_{13}\text{H}_{13}\text{N}_3$	0.13	0.16	154	17246	18			
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_6\text{H}_5\text{N}_3]_2 \cdot 2\text{H}_2\text{O}$	0.13	0.16	151	17248	16			
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{10}\text{H}_8\text{N}_2]_2$	0.17	0.20	149	17250	14	136.5	399.5	
$[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{12}\text{H}_8\text{N}_2]_2$	0.16	0.18	146	17253	11	136.4	399.5	
$[\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3]_n$	0.10	0.11	21	17237	27	137.3	–	
$\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot \text{C}_{13}\text{H}_{13}\text{N}_3 \cdot 2\text{H}_2\text{O}$	0.20	0.16	120	17246	18	136.8	400.5	
$\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot \text{C}_{18}\text{H}_{15}\text{PO} \cdot \text{H}_2\text{O}$	0.17	0.12	108	17252	12	136.7	–	133.3
$\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot 2\text{C}_{10}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$	0.18	0.24	86	17256	8	136.6	399.5	
$\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot 2\text{C}_6\text{H}_5\text{N}_3$	0.15	0.16	80	17257	7			
$\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$	0.16	0.20	73	17259	5	136.4	399.5	

According to [15], it is dimmer therefore its luminescent features are given (Table 2) but are not compared with the data for the mixed-ligand compounds.

In the luminescence spectra of m-methylbenzoates, $\Delta\nu$ and ΔF_1 values decrease in the series from $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot 2\text{H}_2\text{O}]_n$, $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{18}\text{H}_{15}\text{PO}]_2 \cdot 2\text{H}_2\text{O}$, $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_6\text{H}_{18}\text{N}_3\text{PO}]_2 \cdot 2\text{H}_2\text{O}$, $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_6\text{H}_5\text{N}_3]_2 \cdot 2\text{H}_2\text{O}$, $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{10}\text{H}_8\text{N}_2]_2$ to $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{12}\text{H}_8\text{N}_2]_2$ (Table 2). The XPS data show that this series is characterized by increase of the electron density on Eu^{3+} (decrease of E_b for $\text{Eu}4d_{5/2}$) that, in turn, indicates to strengthening of Eu bond with neutral ligand. The highest ΔF_1 value is typical for europium m-methylbenzoate trihydrate which has also the highest E_b value of $\text{Eu}4d_{5/2}$ (137.3 eV).

In the similar series of the mixed-ligand Eu cinnamates, successive decrease of Stark splitting ΔF_1 takes place with strengthening of electron–donor activity of the neutral molecule (Table 2); moreover, minimum ΔF_1 values are observed in adducts with nitrogen-containing neutral molecules ($\text{C}_{10}\text{H}_8\text{N}_2$, $\text{C}_{12}\text{H}_8\text{N}_2$) for both europium trifluoroacetates and m-methylbenzoates. It should be noted that going from europium hydrates to compounds with neutral ligands having larger donor strength (increase of covalence of metal–ligand bond), bathochromic shift of the ${}^5\text{D}_0 - {}^7\text{F}_0$ transition band ($\Delta\nu$) is observed.

The XPS investigation show that going from anhydrous europium cinnamate to mixed-ligand compounds, E_b for $\text{Eu}4d_{5/2}$ electrons decreases that indicates to donation of electron density from neutral ligands to europium ion (Table 2). In $\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot \text{C}_{13}\text{H}_{13}\text{N}_3 \cdot 2\text{H}_2\text{O}$ the bond energy N1s binding energy equals 400.5 eV showing to insignificant donation from nitrogen atom. It may be explained by the structure of the neutral ligand. Diphenylguanidine composition includes voluminous phenyl substitutes.

Besides analysis of the values of Stark splitting ΔF_1 and shift of the ${}^5\text{D}_0 - {}^7\text{F}_0$ transition band, calculation of ration of the integral intensities of the bands of the ${}^5\text{D}_0 - {}^7\text{F}_j$ transition ($j = 1, 4$) to the ${}^5\text{D}_0 - {}^7\text{F}_2$ electro-dipole transition was carried out.

$$\left(\eta_1 = \frac{{}^5\text{D}_0 - {}^7\text{F}_1}{{}^5\text{D}_0 - {}^7\text{F}_2}, \eta_2 = \frac{{}^5\text{D}_0 - {}^7\text{F}_4}{{}^5\text{D}_0 - {}^7\text{F}_2} \right).$$

As it is shown in Table 2, going from the $[\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3]_n$ to compounds with electron donor neutral ligands, η_1 value increases for europium cinnamates. In the series of trifluoroacetates and m-methylbenzoic it changes slightly. The value η_2 for the series of the coordination compounds studied changes more considerably. Thus, going from $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_27\text{PO} \cdot \text{H}_2\text{O}$ to $\text{Eu}(\text{C}_2\text{F}_3\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2 \cdot \text{H}_2\text{O}$, η_2 increases 2.4 times, but in the series of europium m-methylbenzoic and cinnamates, going from $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{18}\text{H}_{15}\text{PO}]_2 \cdot 2\text{H}_2\text{O}$ to $[\text{Eu}(\text{C}_8\text{H}_7\text{O}_2)_3 \cdot \text{C}_{12}\text{H}_8\text{N}_2]_2$ and from $\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot \text{C}_{13}\text{H}_{13}\text{N}_3 \cdot 2\text{H}_2\text{O}$ to $[\text{Eu}(\text{C}_9\text{H}_7\text{O}_2)_3 \cdot 2\text{C}_{12}\text{H}_8\text{N}_2]_2$ this value rises 3.6 and 1.3 times respectively (Table). According to the XPS data, the complex compounds with high intensity of the ${}^5\text{D}_0 - {}^7\text{F}_4$ transition is characterized by the least value of the bond energy $\text{Eu}4d_{5/2}$ binding energy that indicates to increase of electron density on the europium atom.

4. Conclusion

Hence, the XPS and luminescence spectroscopy data show that

the ratio of intensities of the luminescent bands, splitting of the ${}^5\text{D}_0 - {}^7\text{F}_1$ magnetodipole transition ΔF_1 , and charge state of the central europium atom correlate between each other: in similar series of the mixed-ligand europium carboxylates the value of Stark splitting ΔF_1 decreases with increase of electron density on the europium atom (increase of covalence of metal–ligand bond) and intensity of the ${}^5\text{D}_0 - {}^7\text{F}_4$ electro-dipole transition (η_2) rise.

Conflict of interest

The authors declare that they have no conflict of interest.

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