

Synthesis and characterization of europium (III), terbium (III) complexes and their mixture for making white light emission powder

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Received: 11 October 2022 / Accepted: 11 June 2023

Abstract. The enhanced luminescence of lanthanide complexes coordinated to antenna ligands has potential applications for developing devices like screens and lamps. Herein, three β -diketone antenna ligands were incorporated into Eu(III) and Tb(III) metals to synthesize five complexes. Their luminescence properties in solid state and the energy levels of the electronic states for the ligands and the metals were recorded and probed by UV-vis and fluorescence spectroscopies. Under UV light, a white-light emission powder was observed by mixing red-emission europium and green-emission terbium complexes, with blue-emission laundry powder. The powder composition was tuned by using spectroscopic analysis and CIE 1931 color diagram.

Keywords: Lanthanides complexes / antenna effect / energy-level diagram / white light emitting device

1 Introduction

In recent years, there has been a great deal of interest in the luminescent properties of lanthanides (Ln) complexes and their use as white-light-emitting (WLE) materials [1–3]. The notable attractions for WLE materials ascribed to their potential applications in solid-state lighting, full-color screens and low-cost back-lighting [4–6]. Currently, WLE objects, such as lamps and screens, are fabricated by combining a series of different organic fluorophores. The use of only one type of material, such as Ln complexes, would simplify their fabrication and increase the stability of the objects [7].

Ln(III) cations, such as Tb(III) and Eu(III), show a significant role in various aspects of life, including industrial, technological, and biomedical applications [7–9]. They display exclusive photophysical properties ascribed to their special electronic configuration along with spin-orbit coupling. Ln³⁺ ions are unique in terms of their optical properties such as long excited state lifetimes, the sharpness and the intensity of their luminescence [10]. Ln(III) luminescence is caused by a sequence of radiative emissive excited states and energetic sublevels, resulting in various ($f^* - f$) transitions. However, the direct excitation of Ln(III) is highly ineffective ($\varepsilon < 1 \text{ M}^{-1} \text{ cm}^{-1}$) due to the selection rules that forbid the $4f-4f^*$ electronic transitions. To overcome this, “antenna” ligands are used

to absorb energy in the UV region of the spectrum. For effective energy transfer, the antenna must have a high absorption coefficient and efficient intersystem crossing [11]. The Ln-complexes with β -diketone ligands show high and sharply spiked luminescence caused by the β -diketone structure. These ligands have been reported to have a strong absorption within the UV range and can efficiently transmit the energy to the Ln³⁺ ions [12]. Their structure separates –CH and –OH bonds from the coordination site, preventing a quenching effect from their vibrations. In addition, the absorption range of β -diketones can be tuned if necessary, by simple ligand modifications [13]. Such complexes have attracted attention for promising applications. The three used β -diketone ligands (tmh, tdh and tta) of europium(III) and terbium(III) complexes proved to be an effective antenna in which hard oxygen donors form thermodynamically stable complexes with Ln(III), and acted as an effective antenna for sensitization of Eu(III) or Tb(III) luminescence. The distinct optical characteristics of lanthanide coordination complexes, especially, their primary color range emissions (red, green and blue) that can extend in the whole visible spectrum, they become suitable for designing white light emitting materials. Eu(III) and Tb(III) complexes emit red and green intense light, respectively. Consequently, mixed europium and terbium complexes with additional blue emission powders lead to producing white light emission. In this work, three β -diketonate ligands and 2,2'-bipyridine were incorporated into two Ln (III)

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Fig. 1. Europium(III) and terbium(III) complexes under 365 nm UV light from left to right: Tb(tdh)₃bpy, Tb(tmh)₃bpy, Eu(tta)₃bpy, Eu(tmh)₃bpy and Eu(tdh)₃bpy.

cations, Eu(III) and Tb(III), to synthesize five different Luminescent Eu(III) and Tb(III) complexes. The forbidden nature of the 4f lanthanide metal transitions were circumvented by an antenna effect of three β -diketonate ligands. Under UV irradiation, the light was absorbed by these ligands and transferred into the lanthanide metal inducing a 4f-4f* (ligand field) transition. The excited electrons were relaxed from 4f* to ground states leading to visible light emission. Luminescence properties were studied using spectroscopic analysis and information was used for the construction of energy-level diagrams. Finally, a white emission powder was synthesized using Tb(tdh)₃bpy, Eu(tdh)₃bpy and a blue emission laundry powder.

2 Experimental section

All chemicals and solvents were purchased from commercial suppliers and used without further purification. The β -diketonate ligands: 2,2,6,6-tetramethyl-3,5-heptanedione (tmh), 1,1,1-trifluoro-5,5-dimethyl-2,4-hexanedione (tdh) and thenoyltrifluoroacetone (tta), as well as europium(III) chloride hexahydrate were commercially available from Sigma Aldrich, terbium(III) chloride hexahydrate from Acros Organics and 2,2'-bipyridine (bpy) from Prolabo. Sodium hydroxide and absolute ethanol were provided by the laboratory. Excitation and emission spectra were recorded using a UV/Vis spectrophotometer and a SAFAS Xenius Fluorometer. The excitation and emission slit widths were 2 nm and the PMT voltage was fixed at 400 V. The luminescence study of the six metal complexes was done by placing the powder of the complexes on a glass slide and tapping it with a coverslide and photoexciting the complex at the wavelength that corresponds to the π - π^* transition of the β -diketonate. The luminescent characteristics of Eu(III) and Tb(III) complexes in solid state were measured at room temperature by using $\lambda_{exc} = 365$ nm. Identical experimental conditions were used for all complexes.

2.1 Synthesis of Eu(tmh)₃bpy complex

A solution of 7.5 ml of absolute ethanol and 2.1 mmol (0.39 g) of tmh was prepared. To this tmh solution, 2.1 mmol (21 ml) of 0.10 M sodium hydroxide were added. A solution of 7.5 ml of absolute ethanol and 0.70 mmol (0.11 g) of bpy was prepared separately and stirred until dissolution. The bpy solution was poured into the tmh solution. The previous ligand solution was stirred for 30 min. A solution of 5 ml of distilled water and 0.70 mmol

(0.26 g) of europium(III) chloride hexahydrate was prepared and gently swirled until dissolution. After 30 min, the europium salt solution was dropped in the stirring ligand solution by using a disposable Pasteur pipette. After the addition of the solution the mixture was stirred for 5 additional minutes. The solution was vacuum filtered, and the precipitate was washed three times with 10 ml of cold water. The product was transferred to a watch glass. A white-colored product of 1.11 g was obtained before drying. The theoretical expected yield was 0.59 g [14]. Experimental yields before drying were higher due to the presence of remaining water and solvents. This was also expected for all the remaining synthesis. The synthesis of Eu(III) and Tb(III) complexes is illustrated in Scheme 1.

2.2 Synthesis of Tb(tmh)₃bpy complex

The preceding protocol was replicated with the exception of substituting the lanthanide salt solution, europium(III) chloride hexahydrate, with 0.7 mmol (0.26 g) of terbium(III) chloride hexahydrate. A white-colored product of 1.10 g was obtained before drying. The theoretical expected yield was 0.60 g [14].

2.3 Synthesis of Eu(tta)₃bpy and Eu(tdh)₃bpy complexes

The synthesis for the Eu(tta)₃bpy and Eu(tdh)₃bpy complexes was carried out in the same manner as described previously in the synthesis of Eu(tmh)₃bpy complex. Changes were done in the first solution prepared, where the β -diketonate, tmh, was replaced by 2.1 mmol (0.47 g) of tta and 2.1 mmol (0.41 g) of tdh, respectively, in order to prepare the Eu(tta)₃bpy and Eu(tdh)₃bpy complexes. White-colored products of 0.65 g and 2.07 g were obtained, respectively, for Eu(tta)₃bpy and Eu(tdh)₃bpy before drying. The theoretical expected yield were 0.68 g and 0.62 g, respectively [14].

2.4 Synthesis of Tb(tdh)₃bpy complex

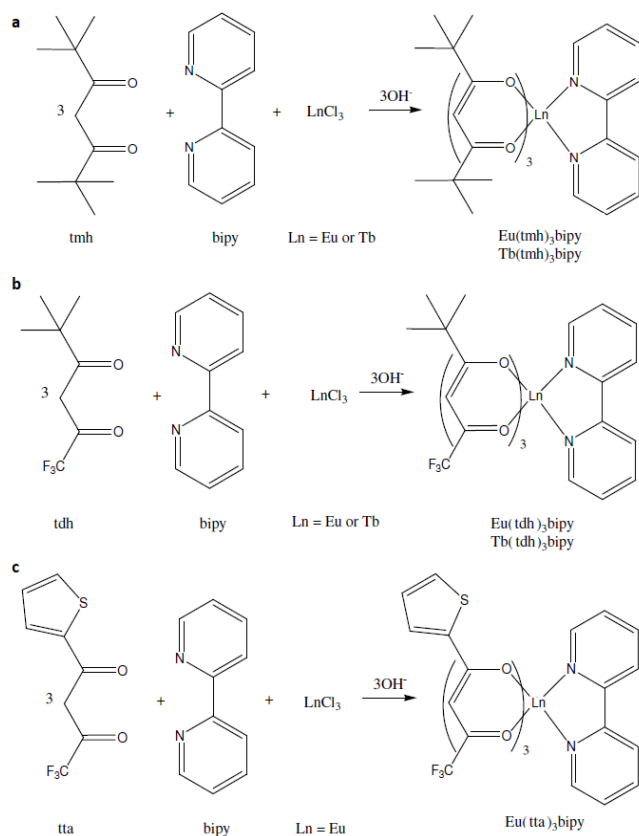
The synthesis of Tb(tmh)₃bpy complex was followed as described before. Changes were done in the first solution prepared, where the β -diketonate tmh, was replaced by 2.1 mmol (0.41 g) of tdh, in order to prepare Tb(tdh)₃bpy complex instead. Prior to drying, a white product of 1.81 g was obtained, while the theoretical expected yield was 0.63 g [14].

2.5 Synthesis of white emission powder

By using a mortar and pestle, 600 mg of Tb(tdh)₃bpy, 150 mg of Eu(tdh)₃bpy and 100 mg of detergent powder "Dash" (Lessive en poudre) were grinded together to create a powder of 850 mg.

3 Results and discussion

After air drying, the europium complexes appeared as a pale-yellow powder, whereas the terbium complexes are isolated as a green powder under UV lamp (Fig. 1). The



Scheme 1. Synthesis of europium(III) and terbium(III) complexes: (a) $\text{Eu}(\text{tmh})_3\text{bpy}$ and $\text{Tb}(\text{tmh})_3\text{bpy}$, (b) $\text{Eu}(\text{tdh})_3\text{bpy}$ and $\text{Tb}(\text{tdh})_3\text{bpy}$ and (c) $\text{Eu}(\text{tta})_3\text{bpy}$.

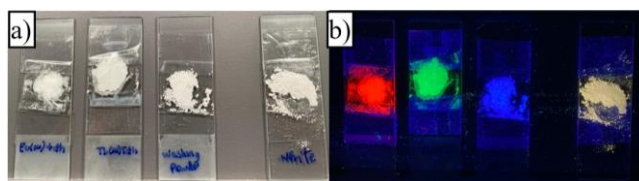


Fig. 2. From left to right: (a) $\text{Eu}(\text{tdh})_3\text{bpy}$, $\text{Tb}(\text{tdh})_3\text{bpy}$, laundry powder and white emission powder; (b) irradiation under 365 nm UV light.

energy transfer mainly occurs from β -diketonate ligand as the absorption of 2,2'-bipyridyl ligand occurs at higher energy and the ratio between the two ligands in the complex is 3:1. Table 1 summarizes the emission wavelengths and intensities for all the complexes. Emission wavelengths are assigned to the transitions between electronic states of centered lanthanide ions. $\text{Tb}(\text{tta})_3\text{bpy}\cdot x\text{H}_2\text{O}$ is omitted since it showed no luminescence.

The excitation spectra of all complexes exhibit a broad band located in the UV that correspond to the S_0 - S_1 (π - π^*) transition of β -diketonate. All complexes were excited at 365 nm corresponding to the π - π^* transition of the β -diketonate. The two lanthanides (III) cations, Tb(III) and Eu(III), have a ground state with electronic configuration of $[\text{Xe}]4f^8$ and $[\text{Xe}]4f^6$ respectively, with six unpaired

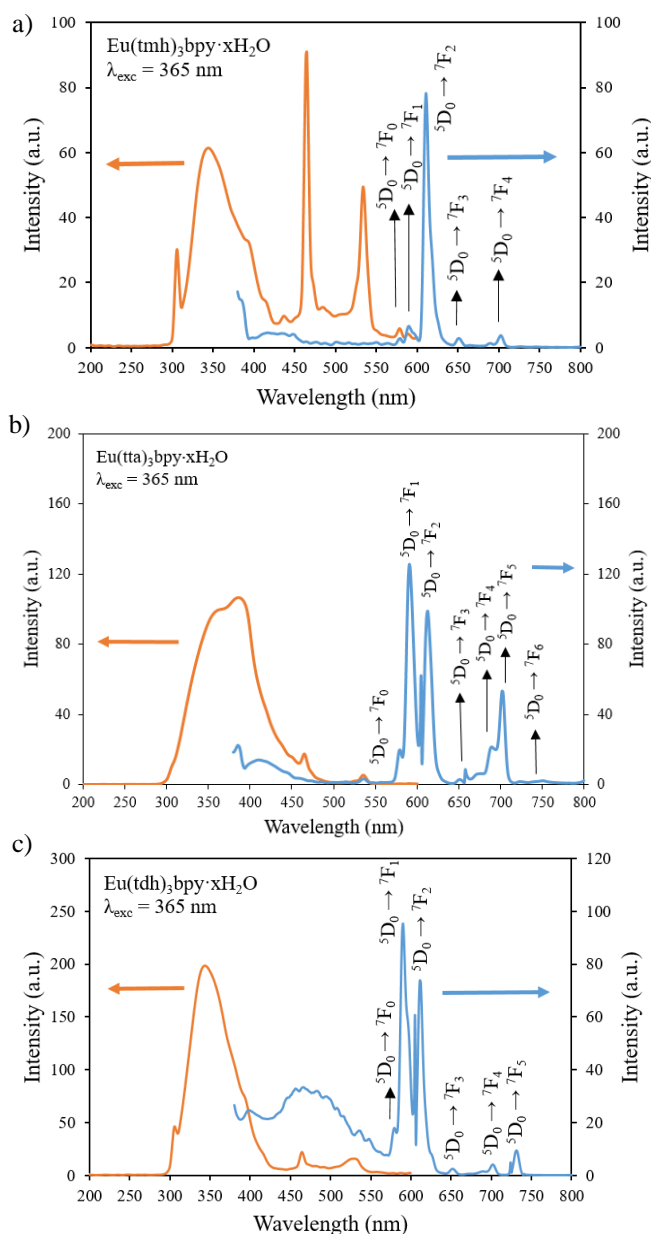


Fig. 3. Emission and excitation spectrum of (a) $\text{Eu}(\text{tmh})_3\text{bpy}\cdot x\text{H}_2\text{O}$, (b) $\text{Eu}(\text{tta})_3\text{bpy}\cdot x\text{H}_2\text{O}$, (c) $\text{Eu}(\text{tdh})_3\text{bpy}\cdot x\text{H}_2\text{O}$ in solid. The excitation and emission slit widths were 2 nm and the PMT voltage was 400 V. Excitation spectrum in orange, emission spectrum in blue.

electrons for both cations. Due to spin-orbit coupling, the degeneracy of the ground state is lifted, leading to multiple electronic states with different energy levels. Seven possible energy levels exist, that correspond to $J = 0, 1, 2, 3, 4, 5, 6$ and with configuration of $7F_J$. The energy level positions and configuration of two centered ions were taken from articles of [15,16]. Commonly observed emission wavelengths of Eu(III) and Tb(III) complexes were reported in the review of [9]. Based on these literatures, emission wavelengths of our synthesized complexes can be assigned to their transitions in Table 1.

Table 1. Emission intensities for europium and terbium luminescent complexes in solid. All complexes were excited at $\lambda_{exc} = 365$ nm. The slit widths were 2 nm and the PMT voltage was 400 V.

Complex	Excitation band/nm (Intensity/ a.u.)	Wavelength/nm (Intensity/a.u.)	Assigned transition
Eu(tmh) ₃ bpy·xH ₂ O	350 (60)	578 (2.3)	⁵ D ₀ → ⁷ F ₀
		589 (6.3)	⁵ D ₀ → ⁷ F ₁
		611 (78.2)	⁵ D ₀ → ⁷ F ₂
		648 (2.2)	⁵ D ₀ → ⁷ F ₃
		700 (2.9)	⁵ D ₀ → ⁷ F ₄
Tb(tmh) ₃ bpy·xH ₂ O	367 (133.2)	492 (90)	⁵ D ₄ → ⁷ F ₆
		545 (255.2)	⁵ D ₄ → ⁷ F ₅
		587 (20.7)	⁵ D ₄ → ⁷ F ₄
		623 (10.8)	⁵ D ₄ → ⁷ F ₂
		650 (1.9)	⁵ D ₄ → ⁷ F ₂
Eu(tta) ₃ bpy·xH ₂ O	365 (99.7)	579 (19.7)	⁵ D ₀ → ⁷ F ₀
		591 (125.5)	⁵ D ₀ → ⁷ F ₁
		613 (98.8)	⁵ D ₀ → ⁷ F ₂
		658 (8.5)	⁵ D ₀ → ⁷ F ₃
		691 (21.1)	⁵ D ₀ → ⁷ F ₄
		702 (53.2)	⁵ D ₀ → ⁷ F ₅
Eu(tdh) ₃ bpy·xH ₂ O	350 (190.3)	579 (18)	⁵ D ₀ → ⁷ F ₀
		590 (95.4)	⁵ D ₀ → ⁷ F ₁
		611 (73.8)	⁵ D ₀ → ⁷ F ₂
		652 (2.5)	⁵ D ₀ → ⁷ F ₃
		704 (3.4)	⁵ D ₀ → ⁷ F ₄
Tb(tdh) ₃ bpy·xH ₂ O	346 (272.5)	491 (46.4)	⁵ D ₄ → ⁷ F ₆
		546 (98.3)	⁵ D ₄ → ⁷ F ₅
		586 (11.5)	⁵ D ₄ → ⁷ F ₄
		621 (6)	⁵ D ₄ → ⁷ F ₂
		653 (1.1)	⁵ D ₄ → ⁷ F ₂

Six distinguishable bands in the emission spectra of Eu(tta)₃bpy complexes can be observed, while for Eu(tdh)₃bpy and Tb(tdh)₃bpy there are five bands present. Only five bands for Eu(tmh)₃bpy and Tb(tmh)₃bpy complexes shown in Figures 3 and 4. The presence of certain quenching processes in the complexes could be attributed to the remaining water molecules that were not completely dried out.

The luminescence intensity of Tb(III) complex appears stronger than Eu(III) when binding to the same ligand. It was observed in the case of Tb(tmh)₃bpy·xH₂O complex which showed higher luminescence than that of Eu(tmh)₃bpy·xH₂O. The explanation can be attributed to the law of energy gap, the smaller the difference in energy between two electronic states, the higher the non-radiative rate constant and the more efficient the conversion becomes. Based on the obtained data, Figures 5 and 6 are plotted. In a previous report by [17], it was noted that the T1 energy levels of ligands tmh and tta were around 24,000 cm⁻¹ and 20,000 cm⁻¹, respectively. The T1 energy level of tdh ligand were referred to article of [14]. Values for energy levels of lanthanide centered ions were estimated based on literatures [15,16]. Because the energy level of the emitting level ⁵D₄ of Tb(III) is higher than the level ⁵D₀ of

Eu(III), the gap with triplet state of tta is smaller for Tb(tmh)₃bpy·xH₂ (Figs. 5 and 6). This favors the energy transfer process for Tb(III) complex, compared with Eu(III) complex [14], hence higher luminescence. The similar phenomenon was observed for Eu(tdh)₃bpy·xH₂O and Tb(tdh)₃bpy·xH₂O complexes (Tab. 1). This phenomenon was also expected for the two complexes Tb(tta)₃bpy·xH₂O and Eu(tta)₃bpy·xH₂O, however, fluorescence was not observed in case of the former complex of Tb(III) (see Sect. 4).

From the energy diagrams (Figs. 5 and 6), it is observed that the structure of ligands influences the luminescence spectra of the complexes. The β -diketones that contain heavier C-F bonds like tta and tdh avoid the fluorescence deactivation by vibrational quenching in presence of C-H bonds [14]. This leads to longer lifetime and stronger luminescence of the complexes, compared to tmh ligand which does not have any fluorine atoms. Specifically for Eu(III) complexes, Eu(tta)₃bpy·xH₂O was the product that illustrated the most luminescence, followed by Eu(tdh)₃bpy·xH₂O and Eu(tmh)₃bpy·xH₂O was the least bright product (Tab. 1). It is because tmh bears the highest number of C-H bonds in its structure while other two ligands tta and tdh contain more fluorine atoms.

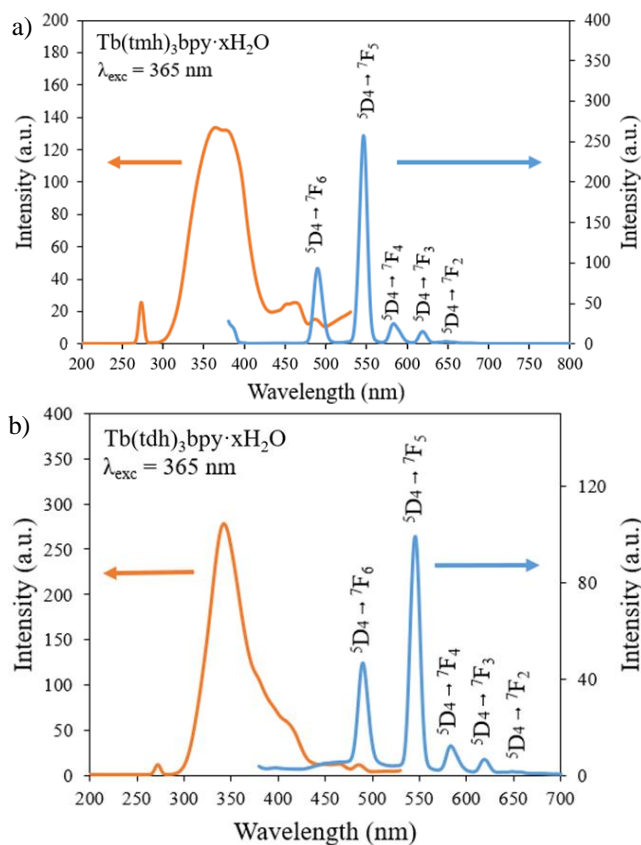


Fig. 4. Emission and excitation spectrum of (a) $\text{Tb}(\text{tmh})_3\text{bpy}\cdot x\text{H}_2\text{O}$ and (b) $\text{Tb}(\text{tdh})_3\text{bpy}\cdot x\text{H}_2\text{O}$ in solid (bottom). The excitation and emission slit widths were 2 nm and the PMT voltage was 250 V. Excitation spectrum in orange, emission spectrum in blue.

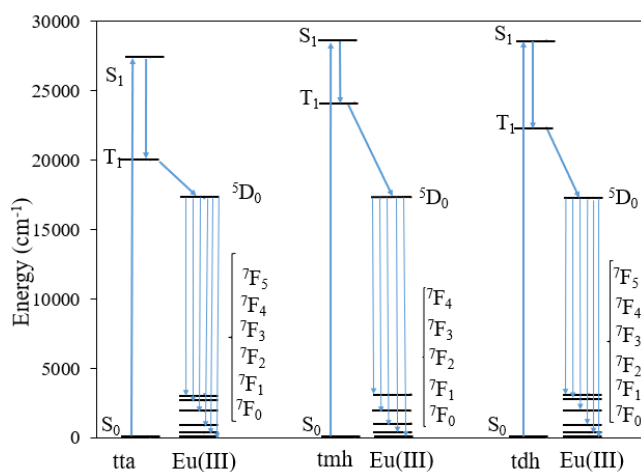


Fig. 5. Energy level diagram for the europium complexes. Excitation by UV radiation and emission energy transfers are indicated by arrows.

The luminescence of the synthesized white powder under UV light can be observed in Figure 2, as well as the emission spectrum in Figure 7. CIE 1931 color space was used in order to determine the chromatic coordinate for the synthesized white powder (Fig. 8). The values

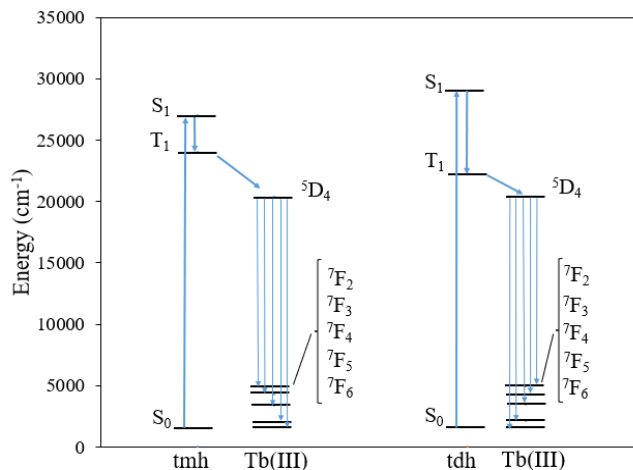


Fig. 6. Energy level diagram for the terbium complexes excited by UV radiation. Emission energy transfers are indicated by arrows.

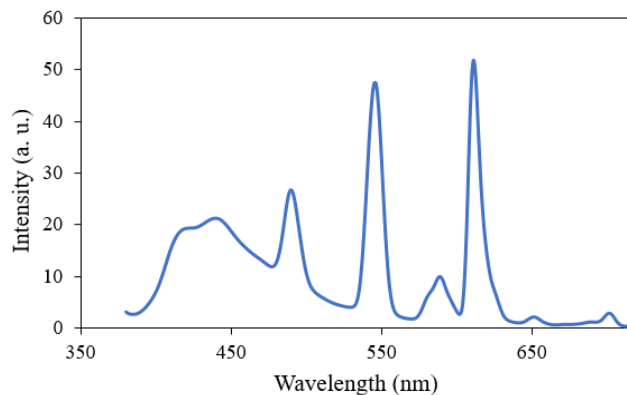


Fig. 7. Emission spectrum of the synthesized white powder at $\lambda_{exc} = 365$ nm.

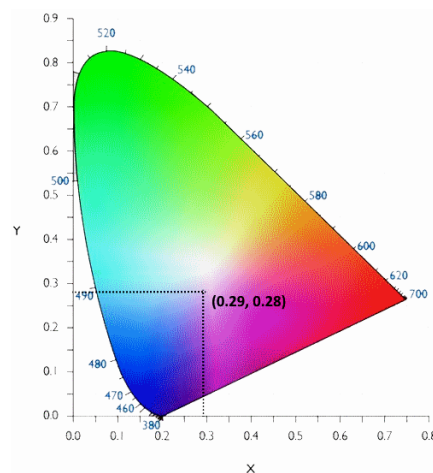


Fig. 8. Chromatic coordinates for the synthesized white powder.

obtained for x and y were 0.29 and 0.28 respectively, locating the powder in the blue-white area of the diagram. Additional combinations of green, red and blue emission powders need to be done in order to create a powder located in the (0.33, 0.33) coordinates corresponding to color white.

4 Dead-end

Besides the five synthesized complexes, an additional terbium(III) complex was prepared ($\text{Tb}(\text{tta})_3\text{bpy}\cdot x\text{H}_2\text{O}$). This complex was synthesized by following the same synthesis procedure of $\text{Tb}(\text{tdh})_3\text{bpy}$ complex. The only change was done in the first prepared solution, where the tdh was replaced by 2.1 mmol (0.47 g) of tta . White product, 0.87 g, obtained before drying for $\text{Tb}(\text{tta})_3\text{bpy}$. Theoretical yield = 0.68 g for $\text{Tb}(\text{tta})_3\text{bpy}$ [14]. Spectrum of $\text{Tb}(\text{tta})_3\text{bpy}\cdot x\text{H}_2\text{O}$ complex did not show any excitation nor emission bands. The reason for non-luminescent $\text{Tb}(\text{tta})_3\text{bpy}\cdot x\text{H}_2\text{O}$ may be attributed to the triplet state level of tta , which is lower in energy than the $^5\text{D}_4$ level of $\text{Tb}(\text{III})$, meaning no electronic transition occurred [17]. Another reason might be due to the presence of water remaining in the crude products. The terbium(III) chloride hexahydrate used for this synthesis was moisturized greatly, which deactivates the metal emission through $-\text{OH}$ vibrations [14].

Several attempts of mixing the synthesized products $\text{Tb}(\text{tdh})_3\text{bpy}$, $\text{Eu}(\text{tdh})_3\text{bpy}$ and the laundry powder were conducted to produce the white emission powder. Firstly, 100 mg of each mentioned ingredients were mixed together. After observing the incorrect chromatic coordinate on CIE 1931 color space, 500 mg of $\text{Tb}(\text{tdh})_3\text{bpy}$ was put in the mixture. The final attempt was done by adding 50 mg of $\text{Eu}(\text{tdh})_3\text{bpy}$, providing the mixture with the best proximity of $x = 0.29$, $y = 0.28$. It was indeed difficult to reach chromatic coordinate $x = 0.33$, $y = 0.33$ and obtain the perfect white emission powder.

5 Conclusions

The synthesis and fluorescence properties of $\text{Eu}(\text{III})$ and $\text{Tb}(\text{III})$ complexes with three different ligands were reported. The role played by the ligand in the energy-transfer process is well understood by use of different β -diketonates with varied absorption maxima. All the five europium(III) and terbium(III) complexes were luminescent in nature due to induced intra-configurational $f-f^*$ transitions involving indirect excitation via the antenna ligands. Attempts to synthesize white emission powder were made, positioning the resulting mixture close to the white region in the color space diagram. Additional combinations need to be carried out to create a white emission powder.

The authors would like to acknowledge scholarships from the Université Paris-Saclay International Master's Scholarship Programme. A special acknowledgment is extended to Dr. Jonathan Piard for his valuable guidance. Authors would also like to thank

École Normale Supérieure Paris-Saclay for the research facilities used in this work.

References

1. S. Reineke, F. Lindner, G. Schwartz, N. Seidler, K. Walzer, B. Lüssem, K. Leo, White organic light-emitting diodes with fluorescent tube efficiency, *Nature* **459**, 234–238 (2009)
2. S. Seetha Lekshmi, A.R. Ramya, M.L.P. Reddy, S. Varughese, Lanthanide complex-derived white-light emitting solids: a survey on design strategies, *J. Photochem. Photobiol. C* **33**, 109–131 (2017)
3. A.R. Ramya, S. Varughese, M.L.P. Reddy, Tunable white-light emission from a mixed lanthanide (Eu^{3+} , Gd^{3+} , Tb^{3+}) coordination polymers derived from 4-(dipyridin-2-yl) amino, *Dalton Trans.* **43**, 10940–10946 (2014)
4. B.W. D'Andrade, S.R. Forrest, White organic light-emitting devices for solid-state lighting, *Adv. Mater.* **16**, 1585–1595 (2004)
5. Y. Kubo, R. Nishiyabu, White-light emissive materials based on dynamic polymerization in supramolecular chemistry, *Polymer* **128**, 257–275 (2017)
6. S. Mukherjee, P. Thilagar, Organic white-light emitting materials, *Dyes Pigments* **110**, 2–27 (2014)
7. O. Kotova, S. Comby, C. Lincheneau, T. Gunnlaugsson, White-light emission from discrete heterometallic lanthanide-directed self-assembled complexes in solution, *Chem. Sci.* **8**, 3419–3426 (2017)
8. J.-C.G. Bünzli, C. Piguet, Taking advantage of luminescent lanthanide ions, *Chem. Soc. Rev.* **34**, 1048 (2005)
9. M.C. Heffern, L.M. Matosziuk, T.J. Meade, Lanthanide probes for bioresponsive imaging, *Chem. Rev.* **114**, 4496–4539 (2014)
10. Z. Abbas, S. Dasari, M.J. Beltrán-Leiva, P. Cantero-López, D. Páez-Hernández, R. Arratia-Pérez, R.J. Butcher, A.K. Patra, Luminescent europium(III) and terbium(III) complexes of β -diketonate and substituted terpyridine ligands: synthesis, crystal structures and elucidation of energy transfer pathways, *New J. Chem.* **43**, 15139–15152 (2019)
11. D.B.A. Raj, S. Biju, M.L.P. Reddy, One-, two-, and three-dimensional arrays of Eu^{3+} -4,4,5,5,5-pentafluoro-1-(naphthalen-2-yl)pentane-1,3-dione complexes: synthesis, crystal structure and photophysical properties, *Inorg. Chem.* **47**, 8091–8100 (2008)
12. D. Singh, K. Singh, S. Bhagwan, R.K. Saini, R. Srivastava, I. Singh, Preparation and photoluminescence enhancement in terbium(III) ternary complexes with β -diketone and monodentate auxiliary ligands, *Cogent. Chem.* **2**, 1134993 (2016)
13. L. Arrué, J. Santoyo-Flores, N. Pizarro, X. Zarate, D. Páez-Hernández, E. Schott, The role played by structural and energy parameters of β -diketones derivatives as antenna ligands in $\text{Eu}(\text{III})$ complexes, *Chem. Phys. Lett.* **773**, 138600 (2021)
14. S. Swavey, Synthesis and characterization of europium(III) and terbium(III) complexes: an advanced undergraduate inorganic chemistry experiment, *J. Chem. Educ.* **87**, 727–729 (2010)
15. J.-C.G. Bünzli, Benefiting from the unique properties of lanthanide ions, *Acc. Chem. Res.* **39**, 53–61 (2006)

16. W.T. Carnall, G.L. Goodman, K. Rajnak, R.S. Rana, A systematic analysis of the spectra of the lanthanides doped into single crystal LaF₃, J. Chem. Phys. **90**, 3443–3457 (1989)
17. Y. Hasegawa, K. Yuichi, Thermo-sensitive luminescence of lanthanide complexes, clusters, coordination polymers and metal–organic frameworks with organic photosensitizers, J. Mater. Chem. C **7**, 7494–7511 (2019)

Cite this article as: Dung Duong Viet, Masa Johar, Haziq Naseer Khan, Yutzil Segura-Ramírez. Synthesis and characterization of europium (III), terbium (III) complexes and their mixture for making white light emission powder, Emergent Scientist **7**, 3 (2023)