# Spectral Study of Some Lanthanides Complexes with Quaternary Pyridinium Ligands

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Some lanthanides complexes with two N-heterocyclic ligands derived from 4,4'-bipyridinium and 1,2-bis-(4-pyridinium) ethane (noted BP and BPE) were studied in presence of triethylamine and methanol in view of their application as cytotoxic agents. Absorption spectra have been recorded by UV-Vis spectroscopy during the complexation process in solution. The ligands demonstrate preferential arrangements in lanthanide's electronic structure which is identified much clearly in ultraviolet range. La(III)-BP solution indicates absorption at  $\lambda_{max} = 206$  nm while La(III)-BPE at  $\lambda_{max} = 0000$  nm. The solution from the Nd(III)-BPE complex synthesis shows the highest absorbance at  $\lambda_{max} = 220$  nm, compared with Nd(III)-BP at  $\lambda_{max} = 212$ nm. The bathochromic shifts of the spectral bands can be assigned to the physical interaction of Ln(III) ions with ligands. No major changes were observed in the absorption, hypsochromic and hyperchromic effects when varying the ligand. The complexes spectral properties were performed by dissolving them in methanol in three phases until a complete dissolution of the precipitates was achieved.

Keywords: pyridinium ligands, lanthanide complexes, UV-Vis, conductivity

The lanthanide complexes have received a progressive attention in the last decades, mainly because of their biomedical applications [1, 2]. Lanthanide (III) ions can form complexes with a wide variety of ligands and the new compounds synthesis is influenced by the ionic radii of the metallic ions. Being electropositive, reactive metals and hard Lewis acids due to their high charge density lanthanides ions prefer to bind to oxygen, nitrogen and sulfur [3]. The exquisite lanthanide properties are based on their electrons from the 4f orbital. Due to their shielding in the  $5s^2 5p^6$  subshells the electronic transition 4f-4f is ligand independent and is Laporte forbidden [4]. Their luminescence is in millisecond range in comparison with the organic dyes which is in the nanosecond range [5]. Typically, lanthanides form trivalent ions with an electronic structure consisting of a Xenon core and 4f valence electrons [Xe]4f<sup>n</sup>, except cerium, terbium, praseodymium with oxidation number +4 and samarium, europium and terbium with oxidation number +2. The 4f electrons are responsible for the easy separation from the rest of the elements but difficult in the series because their energy level is close to the 5d layer. An important aspect of their electronic configuration is the decrease of the ionic radii in the lanthanide series which is referred as the lanthanide contraction. This phenomenon is the result of a high nuclear charge [6]. It was noticed that lanthanides can be mediators in a wide range of degenerative disease based on their antioxidant properties and their role as ROS (reactive oxygen species) scavenger. It is also interesting that they lose this property when they bond to the cellular membrane and they can't create free radicals [1]. New experimental methods regarding lanthanides ions role in the biochemical process have been developed. Based on the physical and spectral properties, lanthanides have numerous applications, such as fluorescent probes in biological assays [7, 8].

The physiological effects of lanthanides ions observed at the cellular level are mainly explained by the similarity

of their ionic radii to the calcium ionic radii [1, 2]. In rat organs, cerium and praseodymium ions have shown hepatotoxic effects such as jaundice, steatosis and increased aminotransferases. The toxic effects of gadolinium include mineral deposits in capillary, liver and spleen necrosis, gastric mucosa demineralization and thrombocytopenia. Cerium is responsible for magnesium deficit, which may be a cause of cardiac fibrosis that could lead to cardiomyopathy. Other lanthanides ions have a protective liver effect [9]. However, the toxic effect of lanthanides ions may be a combination of hepatotoxic action of the active metabolite generated by the microsomal metabolism and the effects of lanthanum ions, which is the selective blocking of the cells by the calcium channels. A study of the thyroid cells has determined that lanthanide ions are calcium antagonists [1]. Ions that have short ionic radii are the most potent inhibitors and the blocking potential varies inversely as the ionic radii. Lanthanides ions inhibit the  $Ca^{2+}$  from the sarcoplasmic reticulum of the skeletal muscle fibers [10-12].

Lanthanide complexes exhibit special magnetic, optical and catalytic properties [13-18]. To create a new generation of metal complexes and understand their biological behavior we must evaluate the complexes and their ligands for their physicochemical and optical properties.

Studies were initiated for obtaining lanthanides complexes using quaternary pyridinium salts in methanol as solvent. We chose quaternary pyridinium salts derived from 4,4'-bipyridinium and 1,2-bis-(4-pyridinium) ethane because their structure recommends them as important organic ligands and so far, no data has been published concerning their complexation with lanthanum ions like La(III) and Nd(III). Several key factors which influence the stability of lanthanide (III) complexes with organic ligands were highlighted through successive extraction in methanol.

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## **Experimental part**

The studies of some lanthanide complexes with Nheterocyclic ligands (Ln:L ration 1:1) was initiated using dilute solutions of La(III) and Nd(III) ions (12 mM), bipyridinium salts (0.1 mM) and triethylamine (Et,N). The lanthanide oxides were provided by Chempur. All other reagents were provided by Merck and used as were received without any purification and distilled before synthesis. The ligands are N-heterocyclic salts derived from the N,N'bis(p-bromofenacil)-4,4'- bipyridinium referred as BP and N,N'bis (p-bromofenacil)-1,2-bis (4-pyridyl) ethane referred as BPE, having ethylene in a symmetric position of the structure. The ligands were synthesized and structurally characterized, according to references [19-21].



Dibromide of N,N' bis-(p-bromophenacyl)-4,4'-bipyridinium (BP)



Dibromide of N,N' bis-(p-bromophenacyl) -1,2-bis(4-pyridil)-ethane (BPE)

#### Structures of the quaternary pyridinium ligands

The synthesis of lanthanide complexes was carried out in methanol as amphiprotic solvent, but also in an aqueous medium using ultrapure twice distilled water. Synthesizes were performed at room temperature, stirred when reagents were added and kept for seven days. Ln(III) sulfate solutions (60 mM) were obtained from lanthanides oxides treated with  $H_2SO_4$  (97%) until it was totally dissolved. The sulfates dissociated solutions of Ln(III) are yellow-green (*p*H=0.5) and those of Nd(III) are pale purple (*p*H 1). Dilute sulfate Ln(III) solutions (1.2 mM), stable over time (*p*H=1) with molar conductivity of 125 mS·cm<sup>2</sup>·M<sup>-1</sup> for La(III) and 108 mS·cm<sup>2</sup>·M<sup>-1</sup> for Nd(III) were obtained.

Physical and chemical properties of all reagents combinations for the synthesis of four lanthanide complexes were analyzed by pH and conductivity measurements (Multiparameter Consort C862). Spectral properties were evaluated during the complexation process. The samples were analyzed by UV-Vis spectra using quartz cells and methanol as a reference solvent (Spectrophotometer T90 +).

### **Results and discussions**

## Physicochemical properties

Four lanthanide complexes with N-heterocyclic ligands were synthesized and analyzed. For the beginning the ligands were studied. The aqueous solution of the quaternary pyridinium salts (0.1 mM) changes color depending on the *p*H. In case of BP from yellow at acidic pH to purple at alkaline *p*H was observed. BPE shows a yellow-orange color in alkaline range due to structure deprotonation [21, 22]. Ligands in alcoholic medium were stable over time and indicate a lower acid *p*H of 4.5 for BP and 5 for BPE [20, 23].

In methanol, lanthanum ions - La(III), Nd(III) were also stable over time and shown a *p*H from 10.5 to 11.2 with a varying conductivity between 2.7 mS/cm for La(III) to 1.8 mS/cm for Nd(III). Ln(III) sulfate solutions with Nheterocyclic ligands (Ln:L ration 1:1) and triethylamine (Et<sub>3</sub>N) were kept at room temperature without stirring and after seven days the reaction products in aqueous medium and methanol were compared. The precipitates formed in methanol were in higher amount and their color was more intense than in aqueous medium. Some of the precipitates obtained in methanol were separated and studied by dissolution through successive extractions in methanol. To the initial precipitate 10 mL of methanol were added and after 48 h new precipitated deposits were observed. Hereby successive separations and extractions were performed. The alcoholic fraction of the extraction was used to perform further physical-chemical and spectral analysis. To the remaining residue another 10 mL of methanol were added and stirred until complete dissolution. The alcoholic extract was transferred in closed vials to avoid the solvent evaporation. The *p*H, conductivity measurements and UV-Vis spectra were evaluated to observe spectral changes in the complexation process of the La(III) and Nd(III) ions with the organic ligands BP and BPE respectively. For the successive methanol extractions *p*H and conductivity variations were noticed (fig. 1).



After each extraction with 10 mL methanol the *p*H value lowers for all solutions. The most alkaline value was recorded for the extracts containing La-BP system (as high as pH 11) and it was noticed that the pH varies with one unit until the third extraction in methanol. The extracts containing Nd(III) and BP showed a pH of 10.8 and a variation of 0.75 pH units at successive extractions. Finally, for Nd(III) and BPE a pH of 10.9 units was measured and a variation of 0.84 pH units was observed at successive extractions. The conductivity values indicate some differences as well. Thus, in the alcoholic extracts of Nd(III) ions with BPE ligand (1.60 mS/cm, respectively 27 mS·cm<sup>2</sup>·M<sup>-1</sup>) a slightly dissociation is observed in comparison with the La(III) ions (1.40 mS/cm 24  $mS \cdot cm^2 \cdot M^{-1}$  respectively). However BP induces lower dissociation than BPE with a variation of 0.20 mS /cm for both lanthanum ions over time.

### Spectral characterization

The solvatochromic changes in the presence of both ligands were studied. The structural spectral variations in the spectrum domain were recorded by UV-Vis absorption spectra. Although they have comparable properties, lanthanum ions have different behavior because their ionic radii are different and differently populated with electrons in the 4f layer, so their compounds present adsorption at different wavelengths, with variations for the allowed transitions [1, 16].

transitions [1, 16]. The UV-Vis spectra of the methanolic solution of the initial complexation of lanthanum ions with N-heterocyclic ligands are shown in figure 2. The La(III) ions with BP ( $\epsilon$ =10164 mol<sup>-1</sup> cm<sup>-1</sup>) indicate a  $\lambda_{max}$  of 206 nm and it shifts to Carol Davila University of Medicine and Pharmacy,  $\lambda_{max}$  212 nm for Nd(III) with the same ligand ( $\epsilon$  = 20076 mol<sup>-1</sup>cm<sup>-1</sup>), due to a bathochromic effect. The La(III) ions with BPE ( $\epsilon$ =14984 mol<sup>-1</sup>cm<sup>-1</sup>), indicate a  $\lambda_{max}$  of 208 nm and it shifts to  $\lambda_{max}$  220 nm for Nd(III) ions ( $\epsilon$ =30644 mol<sup>-1</sup>cm<sup>-1</sup>) with the same ligand.





Shifting to higher  $\lambda$  is explained by the possible decrease of the allowed transition  $\pi \rightarrow \pi^*$  in the BPE structure, which is more favorable than BP. In the same time the absorbance value is twice higher for the compound formed between Nd(III) ions and BPE, compared with the same ligand and La(III) ions. These results demonstrate preferential arrangements of the ligands in the electronic structure of new compounds, more favorable for BPE.

To elucidate which of the chemical component has a significant contribution in the absorption spectra, for each combination of reagents, UV-Vis spectra were performed initially and after adding each of them. Therefore, the spectra were done initially and after seven days of keeping the samples at ambient temperature.

## The influence of dibromide of N,N' bis-(p-bromophenacyl)-4,4'-bipyridinium (BP)

There were initiated studies in methanol as solvent for ligands, Ln(III) ions in sulfate solution and the combinations between them. The BP ligand in methanol showed a  $\lambda_{\text{max}}$ of 214 nm which after seven days shifted to 218 nm (bathochromic effect) and the absorbance's intensity increases through hyperchromic effect, compared with aq. solution when BP shown a  $\lambda_{max}$  of 250 nm [22]. Et<sub>3</sub>N in methanol indicates a  $\lambda$  shift from 206 nm to 210 nm in time, due to a bathochromic effect. The BP-Et<sub>3</sub>N combination has the same effect, shifting from 212 nm to 219 nm, but the absorbance decreases, due to a hypochromic effect. In all samples a shifting of 4 - 7 nm to larger  $\lambda$  is observed over time.

Figure 3 shows the spectrophotometric analysis of the systems containing La(III) ions with BP (fig. 3a) and Nd(III) with the same ligand (fig. 3b) after seven days. Comparing the adsorption spectra from the first day (fig. 2) and after seven days we conclude that, over time, the absorbance increases, and  $\lambda$  for each combination moves towards higher values to visible region. In case of the solution of

La(III)-Et<sub>a</sub>N, the initial  $\lambda$  of 220 nm shifts to 212 nm, reflecting a slightly hypochromic effect (fig. 3a). If the absorbance intensity increases over time for Et,N methanolic solution, for the La(III)-Et<sub>3</sub>N solutions absorbance reaches stability due to a mild hyperchromic effect in the presence of the lanthanum ions. For the solution containing only La(III)-BP the absorbance intensity increases with about 1 u.a. due to an intense hyperchromic effect. The methanol solutions which contains both ligands, La(III)-BP-Et<sub>3</sub>N indicate the  $\lambda_{max}$  of 208nm and the absorbance intensity remains constant over time which shows a very good stability of the system formed.

The UV-Vis spectra of the system containing Nd(III) ions with BP were performed. Initially, the methanolic solutions indicate a higher intensity absorbance value. In the system which contains both ligands, Nd(III)-BP-Et<sub>3</sub>N, the intensity value increases significantly but  $\lambda$  shifts from 210 nm to 209nm only (not shown). Shifting towards lower  $\lambda$  is explained by the possible increased energy in  $n \rightarrow \pi^*$ transition due to the hypochromic effect. Significant changes are observed for the Nd(III)-Et<sub>a</sub>N system too.

Although the methanol solution of the Nd(III)-BP-Et,N system shows initially maximum absorbance (fig. 2) after seven days (fig. 3b) the absorbance is minimum, and over time, the absorbance value shifts to higher  $\lambda$ (bathochromic effect). In this way, we consider that the Nd(III) ions became more stable over time in the complexes structural arrangement with BP.

## The influence of dibromide of N,N'bis-(p-bromophenacyl)-1.2-bis(4-pyridil)-ethane (BPE)

The BPE solution record some differences in alcoholic medium like a lower absorbance in time, although the electronic absorbance is higher compared to BP. If initially, the UV-Vis spectra indicate a shift in both directions due to deprotonation-protonation equilibrium, after some time the absorbance spectra indicates a higher  $\lambda$  (bathochromic

b



Fig. 3. Absorption spectra for the reagents combinations in Ln(III) complexation process with ligand BP after seven days



effect) due to the mobile ethylene group from the ligand's structure. BPE in methanol also indicates similar absorbance values in the UV-Vis spectra after seven days. In the case of BPE-Et, N combination in methanol, initially  $\lambda_{max}$  is 208 nm, over time reaching 215 nm (bathochromic effect). The system absorbance was maintained at the same value, indicating stability in the allowed transitions of the new structures.

Similar behavior is observed for the La(III)-BPE-Et<sub>3</sub>N system and for La(III)-Et<sub>4</sub>N in methanol after seven days (fig. 4a). For La(III)-BPE-Et<sub>3</sub>N in methanol the shifting towards  $\lambda$ =214 nm (from 215 nm initially) can be explained by the reduced number of allowed transition  $\pi \rightarrow \pi^*$  in BPE structure which induces a decrease in the intensity of the absorbance (hypochromic effect).

For alcoholic solutions, the complex Nd(III)-BPE-Et<sub>3</sub>N presents initially maximum absorbance and a much lower value after seven days (fig. 4b). However, for the compound Nd(III)-BPE-Et<sub>3</sub>N in methanol,  $\lambda$  shifts from 213 nm to 218 nm, due to an intense bathochromic effect, and the absorbance increases over time due to a hyperchromic effect. Moving to higher  $\lambda$  is explained by increased energy for the allowed transition  $n \rightarrow \pi^*$ , and the shifting towards lower  $\lambda$  is explained by lower energy transition for  $\pi \rightarrow \pi^*$ . In the UV-Vis spectra, Nd(III)-BPE-Et<sub>3</sub>N complexes

In the UV-Vis spectra, Nd(III)-BPE-Et<sub>3</sub>N complexes indicate similar absorbance values, initially and after seven

Fig. 4. Absorption spectra for the reagents combinations in Ln complexation process with ligand BPE, after seven days

days. The maximum electronic absorbance is recorded for the solution formed of Nd(III) ions with BPE.

In conclusion, the absorbances of the solutions that contain BPE as a ligand show a lower absorbance value initially than after seven days due to its structure, acting as a mobile ligand with an ethylenic group in a symmetrical position. BPE needs time for allowed transitions on the energy levels of the new Ln compounds electronic structures, more for La(III) ions than for Nd(III) ions.

## *UV-Vis spectra for successive extractions of Ln(III) complexes in methanol*

The spectral properties evaluation of the lanthanum compounds with organic ligands was analyzed by successive dissolution in methanol. Initially, the UV-Vis spectra of the precipitates were performed after one day. There have been carried out three successive extractions by adding each time 10 mL of methanol to the precipitate formed in the sample.

The La(III)-BP system presents  $\lambda$  shifting in the 210 - 204 nm range and a decreasing in absorbance by hypochromic and hypsochromic effect. For Nd(III) and same ligand, BP the ë shifting is between 220 - 207 nm explained by a hipsocromic and bathochromic effect. For La(III) with BPE,  $\lambda$  shifts between 216 nm and 206 nm and for Nd(III) and BPE  $\lambda$  shifts between 220 - 212 nm due





to a hipsochromic effect (fig. 5). Moving to higher  $\lambda$ , when the volume of methanol increases is explained by the reduction of allowed  $\pi \rightarrow \pi^*$  transitions energy when it interacts with the solvent. The migration towards lower  $\lambda$ is explained by the increase of the  $n \rightarrow \pi^*$  transition energy.

Figure 6 shows the spectrophotometric assay for lanthanum compounds with N-heterocyclic ligands after the complete dissolution of the precipitate (fig. ure 6a) and with modified absorbance parameters (fig. 6b). All alcoholic solutions at the end of the dissolution process indicate a minimum absorbance at  $\lambda$  between 270 nm and 276 nm in the following order:

La(III)-BPE < La(III)-BP < Nd(III)-BP< Nd(III)-BPE

Shifting towards lower  $\lambda$  is explained by an increase in  $n \rightarrow \pi^*$  transition, BPE being suitable for these transitions with Nd(III) ions. In the presence of the BP, as rigid ligand the absorbance of the alcoholic solutions is lower compared with the presence of the mobile ligand BPE. The highest absorbance, measured for the Nd(III)-BPE solution is about three times higher than the intensity of the La(III)-BP solution.

### Conclusions

The synthesis of some complexes of La(III) and Nd(III) ions with quaternary pyridinium ligands and their spectral analysis was carried out. The ethylene group from the N,N'bis (p-bromophenacyl)-1,2-bis(4-pyridyl)-ethane dibromide (BPE) induces changes in the spectroelectrochemical performance in comparison with the ligand N,N'bis(p-bromophenacyl)-4,4'-bipyridinium dibromide (BP) and the effect is their preferential arrangement in Ln complexes. An influence of the ionic radii of La(III) or Nd(III) ions is also observed in lanthanides complexes structure.

The alcoholic medium affects the stability of the solution through ionic dissociation of the ligands and lanthanides complexes. The ligands conductivity is different indicating differences of the protonated/ deprotonated form of the free ligands and in Ln(III) complexes also.

UV-Vis absorption spectra of the lanthanide complexes confirm the synthesis of the new structures. The absorbance of the solutions with La(III) ions registers a lower value compared with Nd(III) ions, which is more favorable for complexation because of its ionic radii. Furthermore, BPE induces a higher absorbance than BP. The spectra indicate various wavelength shifting and a bathochromic effect which is associated with Ln(III) complexes interactions in the solvent. The assessment of the spectral character of Ln(III) complexes was carried out in stages by successive dilutions in methanol and the results shown a hypsochromic and hypochromic effect in



comparison with the free ligands. These results show the key role of the ligand's nature on lanthanide complexes.

### References

Nd-BPE

Nd-BP

La-BPE

La-BP

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