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Determination of Lanthanum in Human Blood Serum Using the Zero and First Derivative Spectrophotometry in Micellar Media

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A simple and sensitive method for the determination of lanthanum by zero and first derivative spectrophotometry is described. Lanthanum reacts with xylenol orange in ammonia-ammonium chloride buffer (pH = 8) and cetylpyridiminium chloride. Beer's law is obeyed $1.44–2.0 \times 10^2$ ng mL^{-1} of lanthanum. The corresponding value of Sandell's sensitivity is 6.90×10^{-4} μg cm^{-2}. The relative standard deviation evaluated from 10 independent determinations of lanthanum is 1.09. The detection limit based on $3S_b$ is 4.32×10^{-3} μg mL^{-1} of lanthanum. The above method was used for determination of lanthanum in synthetic and human blood serum samples.

Key Words: Lanthanum, Derivative spectrophotometry, Xylenol orange, Human blood, Serum.

INTRODUCTION

In our modern society, rare-earth elements (REEs) are widely used in ceramics, semiconductors, magnets, magnetic resonance imaging (MRI), contrast reagents, fertilizers and so forth[1–3]. The presence of trace quantities of rare-earth elements in high purity metals, semiconductors and glasses has an important influence on the electrical, magnetic, mechanical, nuclear and optical properties. The light lanthanide ions are materially larger than those of the heavy lanthanides[4].

Some dental ceramic materials contain lanthanum oxide to improve their resistance to corrosion and chemical attack. These materials may contain as much as 40% lanthanum oxide in glass phase[5]. Since lanthanum is present in such large quantities, it may be expected that it will find its way into the body from devices made from these materials and naturally the question of toxicity becomes a concern[6]. Also lanthanum salts have been found to be cytotoxic and exhibit anticoagulant and hepatotoxic effects[7, 8]. Therefore, it is of considerable interest to find a suitable method of analysis for estimating the extent of lanthanum released from these materials into the body. More sensitive procedures such as inductively copuled plasma spectrometry (ICPS)[9–12], inductively coupled plasma-

mass spectrometry (ICP-MS)[13–16] and indirect air-acetylene atomic absorption spectrophotometry[6, 17] methods for determining of lanthanum were reported. Determination of lanthanum in human blood serum by inductively coupled plasma mass spectrometry after preconcentration were also reported[18, 19]. All these techniques are very sensitive, but they are difficult and expensive.

Spectrophotometric methods are very simple and inexpensive but have low selectivity and sensitivity. By using of complexing agents and derivative spectrophotometry, sensitivity and selectivity could be increased. Derivative spectrophotometry is a powerful tool for overcoming interferences due to spectral overlap[20, 21]. Therefore, it has been widely employed in biochemical, forensic, clinical and pharmaceutical analysis[22, 23]. The derivative spectra method based on the 4*f*-electron hypersensitive transitions of REEs is not only simple and selective, but also improves the sensitivity[24–27]. In this work, the absorption spectra of the 4*f*-electron transition of the lanthanum complex with xylenol orange in cationic micellar media containing cetylpyridinium chloride, making use of zero and first derivative spectrophotometry methods, are reported and the application of this rapid and sensitive method for determination of lanthanum in synthetic and human blood serum is described.

EXPERIMENTAL

A spectrophotomer (UV-3101 PC, Shimadzu, Japan) with 10 mm fused silica cells was used for recording normal and derivative spectra. The first derivative spectra was recorded with $\Delta\lambda = 2$ nm and a band width 3.0 nm. A corning digital pH-meter (ion analyzer 255) was used for pH measurements. All chemicals used were of analytical reagent grade. La^{3+} solution was prepared by dissolving the corresponding oxide (99.99%, Merck) in 0.1 molar nitric acid. A 1.0×10^{-3} M solution of xylenol orange (XO, Merck) was prepared freshly by dissolving appropriate amounts of XO (16.8 mg) in 25 mL water. A 2% solution of cetylpyridinium chloride (CPC) (Merck) was used in experiments.

Preparation of human blood serum samples: Human blood samples were collected from four different sites with 30 mL polypropylene syringes equipped with a silicon-coated stainless steel needle. These samples were transferred to silicon-coated glass tubes and centrifuged at 3000 rpm for 25 min. The supernatants were collected as the blood serum samples.

Transferred a known volume of lanthanum solution to a 25 mL standard flask followed by addition of 0.70 mL of 1.0×10^{-3} M xylenol orange, 3.0 mL of pH = 8 ammonia-ammonium chloride and 1 mL of 2% (w/w) cetylpyridinium chloride. Diluted to mark with distilled water and its zero and first derivative spectrum recorded against a blank as reference, using 10 mm cells. In order to investigate the effect of pH on the complexation reaction, two sets of solutions, with and without the metal ion, in different pH, were prepared. In order to study the dependence of the absorbance of the system on the type and concentration of buffer, concentration of ligand or metal and type and concentration of surfactant, solution of the ligand and its La^{3+} complex were prepared at optimum pH. All parameters were kept constant except for the concentration of the component under investigation.

Determination of lanthanum in human blood serum: A known amount of lanthanum standard solution was spiked in serum samples and digested as follows[18]: Blood serum (8 mL) was placed in a teflon beaker (100 mL) and after adding 2 mL of concentrated HNO_3 the serum sample was heated almost to dryness on a hot-plate at 110°C. Then 2 mL of concentrated HNO_3 were again added to the residue and the solution was heated at 150°C for 2 h. After adding a further 2 mL of concentrated HNO_3 and 1 mL of 60% $HClO_4$, the solution was heated at 150°C for 4 h until white fumes appeared. This procedure was repeated twice. Finally, 0.76 mL of concentrated HNO_3 and *ca.* 1 mL of pure water were added to dissolve the residue with heating at 110°C for 1 h; the solution was transferred to a 25 mL standard flask and after addition of reagents and diluting to 25 mL with water, it was subjected to analysis.

RESULTS AND DISCUSSION

Optimization of reaction conditions

Lanthanum complexes with xylenol orange in various pH were prepared and the formed complexes show a maximum absorbance at every pH, but in all pH the peaks of ligand and complex are strongly overlapped. The maximum absorbance is observed in pH = 8; this pH is selected for analysis. Various buffers such as universal buffer (boric acid-phosphoric acid-acetic acid and sodium hydroxide), boric acid-sodium hydroxide, potassium dihydrogen phosphate-sodium hydroxide, hexamine-hydrochloric acid and ammonia-ammonium chloride buffers could be used; to produce the optimum pH of 8.0, both ammonia-ammonium chloride and boric acid-sodium hydroxide buffers were useful. The effect of cationic [cetylpyridinium chloride (CPC), cetyltrimethyl ammonium bromide (CTAB), N-cetyl, N,N,N-trimethyl ammonium chloride, benzyl dimethy tetradecyl ammonium chloride], anionic [sodium dodecyl sulphate (SDS)], sodium lauryl sulphate (SLS) and non-ionic [Triton X-100, Brij 35, polyvinyl alcohol, gum Arabic] surfactants on absorption of complex in the above two buffers was also studied. In boric acid-sodium hydroxide buffer and SDS system, after addition of surfactant, a precipitate was formed and it was observed that CPC and CTAB ammonia buffer showed greater change in absorbance of complex compared with the other surfactants. The ammonia buffer with CPC surfactant system was better than other systems and so this system was used for subsequent studies. As can be seen from Fig. 1, the presence of CPC not only increases the absorbance of complex[28] but also decreases the spectral overlapping of complex and ligand. The optimum working concentration of surfactant was determined by plotting the absorbance of the complex at 615.5 nm *vs.* concentration of CPC and was found to be above 0.20% (Fig. 2). A further increase in concentration of the surfactant has no significant change on the absorbance of the complex but increases the viscosity of the solution. Therefore, the CPC concentration was kept at 0.20% for subsequent studies.

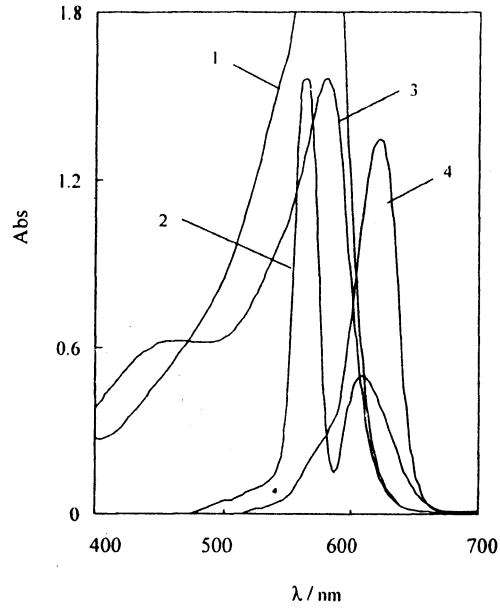

Fig. 1. Absorption of lanthanum complexes [XO] = 1.0×10^{-4} M, 5 mL of ammonia buffer (pH=8.0); [La] (μg mL^{-1}): 1,3: 0.000, 2: 0.500, 4: 0.200; [CPC] (%) (w/w) 1,2: 0.0;3,4: 0.2.

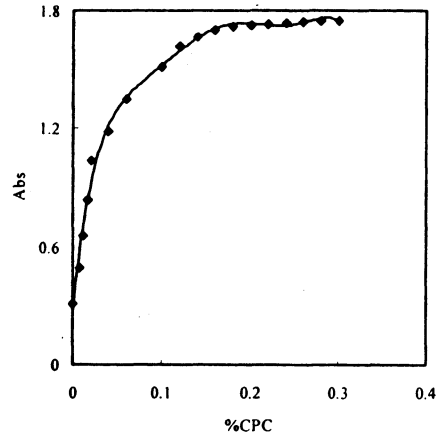

Fig. 2. Effect of CPC on the absorption of the lanthanum complex: [La] = 0.200 μg mL^{-1}; [XO] = 1.0×10^{-4} M, 5 mL of ammonia buffer (pH = 8.0).

To study the effect of xylenol orange concentration on the absorption, a series of solutions containing La^{3+} at constant concentration, but with different amount of ligand, was prepared and the absorption spectra of these solutions were then recorded. The absorbance of the complex (corrected for the absorbance due to the presence of the ligand) increases with increase in xylenol orange concentration up to 50-fold excess. During the present study, the XO concentration was maintained within this range wherever possible.

Job's method of continuous variation was used to determine the stoichiometry of the complexes in the presence of CPC. Metal-to-ligand ratio was found to be

1 : 5 (metal-to-ligand). Similar stoichiometry has been reported for Nd in similar conditions[29].

The change in the absorbance of the ligand and its La^{3+} complex was plotted against time at room temperature (22°C) and pH = 8.0 at 468 and 615.5 nm, respectively. The complex formation took 1 min and the absorbance was stable for at least 8 h.

Optimization of instrumental parameters

In the derivative mode, the position of isodifferential depends upon the instrumental and experimental conditions. Instrumental parameters such as scan speed, slit width, $\Delta\lambda$ and response time which affect the shape of derivative spectra were optimized with respect to reduction of the noise level to give a well-resolved peak and a constant position of isodifferential or zero-crossing points for linear calibration graphs. The best results were obtained at a slit width of 3.0 nm, a scan speed of 90 nm min^{-1} (medium speed) and a $\Delta\lambda = 2$ nm for first derivative mode. The response time is automatically selected by the spectrophotometer in accordance with the optical energy and scan speed.

Zero and first-order spectra of solutions containing increasing amounts of metal ion at a fixed and excess concentration of xylenol orange were plotted.

The absorbance at λ_{max} of the complex, 615.5 nm, increases with increasing concentration of La^{3+} ion. The change in absorbance at 615.5 nm shows a linear relationship with metal ion concentration (Table-1).

TABLE-1.
LINEAR REGRESSION ANALYSIS OF La^{3+} ION CONCENTRATION IN μg mL^{-1} ON ABSORBANCE IN NORMAL MODE AND AMPLITUDE (H, PEAK HEIGHT; T, TROUGH DEPTH; PP, PEAK TO PEAK) IN DERIVATIVE MODES FOR La^{3+}-XO-CPC.

Regression equation	Regression coefficient, r
Absorption at 615.5 nm:	
$A = 9.932C_{La} - 1.949 \times 10^{-3}$	0.999799*
First–derivative mode:	
$T_{623.8} = 0.458C_{La} - 2.539 \times 10^{-4}$	0.999700*
$H_{602.0} = 0.438C_{La} - 2.551 \times 10^{-3}$	0.997910
$PP_{623.8-602.0} = 0.912C_{La} + 1.114 \times 10^{-3}$	0.999854*

*Recommended for determination.

First-order derivative spectra of these solutions exhibit the crossover point corresponding to the wavelength of maximum absorption of the complex, *i.e.*, 615.5 nm. The first order derivative spectrum shows maximum amplitudes at 602.0 nm and minima at 623.8 nm. Amplitudes of the derivative plots of the

complex are proportional to metal ion concentration. Table-1 shows the correlation coefficients for these methods. The values of regression coefficient obtained by linear regression of these amplitudes on the metal ion concentration are indicative of distinct advantages in making the determination in derivative mode. Consequently, a simple procedure for La^{3+} ion determination is proposed.

The molar absorption coefficient (ε), absorption coefficient (a) and Sandell's sensitivity (s) of the method were found to be 7.15×10^4 L mol^{-1} cm^{-1}, 0.52 mL g^{-1} cm^{-1} and 5.2×10^{-4} μg cm^{-2}, respectively. The other analytical parameters are summarized in Table-2. The sensitivity of the method is expressed as the analytical sensitivity, $S_A = S_s/m$, where S_s is the standard deviation of the analytical signal at a particular concentration and m is the slope of calibration graph. The detection limit, C_L (n = 10, k = 3) and determination limit (limit of quantitation), CQ (n = 10, k = 10) are reporteted in Table 2; the latter was used to establish the lower limit of the dynamic range. From the RSD values (Table-2), it may be inferred that the determination of La^{3+} ion in the derivative mode is more precise than in the normal mode.

TABLE-2.
CHARACTERISTICS OF THE METHODS FOR La^{3+} DETERMINATION

Method	Analytical sensitivity $S_A = S_S/m$ (ng mL^{-1})	Detection limit C_L (K = 3) (ng mL^{-1})	Limit of quantification C_Q (k = 10) (ng mL^{-1})	Linear dynamic range (ng mL^{-1})	RSD % (n = 10)
Zero order, 615.5 nm	0.70	1.2	3.8	$3.8–1.8 \times 10^2$	1.16
First order, $T_{623.8\ nm}$	0.69	4.3	14.4	$14.4–2.0 \times 10^2$	1.09
$PP_{623.8–602.0\ nm}$	3.30	8.2	27.4	$27.4–2.0 \times 10^2$	4.27
$H_{602.0\ nm}$	1.50	7.2	24.1	$24.1–2.0 \times 10^2$	2.20

Effect of diverse ions: The effects of the presence of different diverse ions on the photometric determination of La^{3+} ions was examined in normal and derivative modes. This was achieved by calculating the change in the absorbance (ΔA) of a set of solutions containing varying amounts of the diverse ion, but fixed amounts of the ligand, analyte (0.060 μg mL^{-1}) and xylenol orange. The amounts of the various diverse ions studied (Table-3). As can be seen in Table-3 the Mn^{2+}, Cu^{2+}, Zn^{2+} and EDTA strongly interfere. By addition of citrate (200 mg mL^{-1}) as masking agent and using derivative mode, the limit of interference of ions increases. The tolerance limit of special cations in determination of La^{3+} with xylenol orange in presence of CPC is enhanced if the determination is carried out in the derivative mode.

The proposed method for determination of La^{3+} was successfully applied for direct determination of lanthanum in synthetic and human blood serum samples. The results obtained are presented in Tables-4 and 5.

TABLE-3.
TOLERATED LIMIT OF DIVERSE IONS IN THE DETERMINATION OF La^{3+} (0.060 μg mL^{-1})

Diverse ions		Concentration added (μg mL^{-1})	Error (%)	Diverse ions	Concentration added (μg mL^{-1})	Error (%)
Cations	Mg^{2+}	20	−3.8	Sr^{2+}	200	−2.8
	Ca^{2+}	20	+3.8	Zn^{2+}	0.2	−3.3
	Cu^{2+}	0.20	+3.2	Zn^{2+}	2.0	−2.0[c]
	Cu^{2+}	0.40	+2.8[c]	Co^{2+}	1.5	+2.2
	Mn^{2+}	0.03	+4.0[a]	Fe^{3+}	2.0	−1.6
	Mn^{2+}	0.35	+3.2[b]	Pb^{2+}	0.5	−1.2
	Mn^{2+}	2.00	+2.5[c]	Pb^{2+}	4.0	−2.5[c]
Anions	F^-	1860	−1.0	EDTA	0.1	1.2[a]
	BO_2^-	1300	−1.8	Br^-	1750	−1.3
	PO_4^{3-}	290	−3.7	NO_3^-	3000	−3.5
	$C_2O_4^{2-}$	170	+3.9	SO_3^-	1750	+0.9
	NO_2^-	3800	−3.2	CN^-	200	+3.7
	SCN^-	—	—[d]	CN^-	400	+3.5[c]
Citrate		300	−2.9	Barbiturate	15	−3.2
Ascorbate		150	−3.3	Barbiturate	30	−3.5[c]
Acetate		5500	−1.7	Formate	3900	−2.5
Ascorbate		250	−1.9[c]	Tartarate	570	+2.5

[a]Interfere strongly [b]In the presence fo citrate (200 μg mL^{-1})
[c]In derivative modes [d]Precipitate

TABLE-4
DETERMINATION OF La^{3+} IN SYNTHETIC SOLUTIONS

	Added(μg mL^{-1})	Found* ± SD (μg mL^{-1})	
		Zero order (λ = 615.5 nm)	First order ($T_{623.8\ nm}$)
1	0.050	0.046 ± 0.003	0.048 ± 0.002
2	0.100	0.102 ± 0.004	0.099 ± 0.002
3	0.150	0.147 ± 0.005	0.151 ± 0.003

*Mean of five determinations.

TABLE-5
DETERMINATION OF La^{3+} IN HUMAN BLOOD SERUM SAMPLES BY FIRST DERIVATIVE ($T_{623.8\ nm}$)

	Added (μgmL^{-1})				Found* ± SD (μg mL^{-1})			
Sample 1	0.020	0.050	0.080	0.100	0.021 ± 0.002	0.048 ± 0.002	0.081 ± 0.002	0.102 ± 0.002
Sample 2	0.015	0.075	0.090	0.120	0.015 ± 0.002	0.076 ± 0.002	0.091 ± 0.002	0.119 ± 0.003
Sample 3	0.018	0.060	0.100	0.140	0.018 ± 0.002	0.061 ± 0.002	0.098 ± 0.002	0.142 ± 0.003
Sample 4	0.024	0.040	0.130	0.180	0.023 ± 0.003	0.042 ± 0.002	0.131 ± 0.003	0.183 ± 0.004

*Mean of five determinations.

Conclusion

We reported a relatively simple, sensitive and inxpensive zero- and first derivative spectrophotometric methods for determination of lanthanum with xylenol orange in cationic micellar media. Although many cations interfere in this determination but compared with other analytical techniques, such as ICPMS[18], the proposed method is not only sensitive, with detection limit of 4.32 ng mL^{-1}, but is also less expensive and less complicated in terms of assay procedure and equipment used. The method is useful for determination of lanthanum and also total rare earth elements in biological materials and fluids.

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