An Implication of Spectral Interference of Lanthanum on Different Analytes for Their Determination in Lanthanum Matrix by CCD Detector-based ICP-AES

Arijit Sengupta^{a*}, Nishesh Kumar Gupta^b, and Yougant Airan^c

^a Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai, India

^b Chemistry Dept., National Institute of Technology, Rourkela, Odisha, India

^c Chemistry Department, Hindu College, University of Delhi, Delhi, India

INTRODUCTION

Inductively coupled plasma atomic emission spectrometry (ICP-AES) is one of the most widely used analytical techniques for trace metal characterization due to its simplicity and simultaneous multi-element determination capability coupled with adequate sensitivity, analytical range, and good precision of the determinations (1-6). ICP-AES has demerit as well with regard to spectral interference from emission-rich matrix elements, especially rare earth elements, on the determination of analytes at trace levels (7-12). In addition, interferences in ICP-AES are of chemical origin and during nebulization and atomization. To minimize spectral interference, the emission-rich matrix element is preferentially separated from the trace analytes either physically using the d.c. arc carrier distillation techniques or chemically by selective extraction of the emission-rich matrix element from the analytes using a suitable ligand system (13-18). These techniques are time-consuming for sample preparation including dissolution of the solid samples, feed conditioning, separation, etc. The most challenging task is the selective separation of one rare earth element from others, especially for the determination of trace rare earth elements in other rare earth matrices.

Lanthanides are found in a number of minerals, but their separation into individual metals requires complex techniques and the whole

ABSTRACT

Lanthanum is found in relatively large quantities in the Earth's crust (32 ppm). Thus, there is a greater chance of La to be present in living systems, geological samples, and minerals. The presence of La even at trace amounts can interfere in the determination of other analytes in the samples. The present work is a systematic study of spectral interference caused by La on different analytes (Ag, Al, Ba, B, Bi, Ca, Cd, Co, Nd, Er, Pr, Lu, Ce, Dy, Eu, Sm, Cr, Cu, Fe, Ga, Gd, Mg, Mn, Na, Ni, Sr, Zn, and Pb) in order to establish the interference-free analytical lines for the analytes under investigation in a La matrix and using a highly sensitive capacitive coupled device (CCD) detector-based ICP-AES. A reliable method for trace level determination of these analytes without chemical separation is developed. The analytical performance (detection limit, sensitivity, etc.) and the correction factor were evaluated. The proposed method was validated by analyzing synthetic samples prepared for all of the analytes under study.

process is cumbersome. Lanthanum ($[Xe] 5d^1 6s^2$) finds various industrial applications (19-23) and is used to make Mischmetal, a pyrophoric alloy. As lanthanum oxide is used in vacuum tubes, optical glasses, and telescope lenses. Compounds of lanthanum serve as catalysts in petroleum cracking and cerium-doped lanthanum halides are used as inorganic scintillators. For industrial application, high purity La is the foremost require-

ment which leads to developing a sound methodology for the trace level determination of analytes in a La matrix.

The direct determination of analytes at trace levels in an emission-rich matrix without any separation requires a systematic study on the spectral interference of the emission-rich element on the analytes. Keeping this objective in view, the present study on the spectral interference of La on different analytes (Ag, Al, Ba, B, Bi, Ca, Cd, Co, Nd, Er, Pr, Lu, Ce, Dy, Eu, Sm, Cr, Cu, Fe, Ga, Gd, Mg, Mn, Na, Ni, Sr, Zn, and Pb) has been conducted which involves identification of acceptable interference-free analytical lines, the tolerance level of La on the different analytical lines of these elements, and evaluation of the correction factors for these lines. Also the analytical performance of these lines in a La matrix involving detection limit, precision, sensitivity, and linear dynamic range were studied systematically. Considering these mentioned factors, a method was developed for the direct determination of these analytes at trace level in a La matrix without any separation. The results obtained with the proposed method were validated by using synthetic samples.

EXPERIMENTAL

Instrumentation and Operating Conditions

The analysis was carried out using a Spectro-Arcos inductively coupled plasma atomic emission spectrometer (ICP-AES) (Spectro-Arcos, Germany), with argon plasma as the excitation source and

*Corresponding author.
E-mail: arijita@barc.gov.in

a capacitive coupled device (CCD) as the detector system. The instrumental specifications and optimized operating conditions are summarized in Table I.

Standard Solutions and Reagents

The standard solutions for all of the elements were prepared using CertiPUR® ICP standard reference material solution of individual elements (E-Merck, Darmstadt, Germany). Suprapur® HNO₃ (E-Merck, Darmstadt, Germany) and quartz double-distilled water were used for all experimental purposes. Multi-point standardizations were carried out using 0.5 M HNO₃ as the lower standard and 0.05–1000 mg/L of the corresponding elemental standard as the higher standard for each line after proper peak search, auto attenuation, etc. For the analysis of each sample, 10 replicate measurements were performed, while for the determination of detection limits and sensitivity, 25 replicate measurements were taken into consideration.

Methods

A series of La solutions (commercially available standard reference material elemental solution from E-Merck, Darmstadt, Germany) of varying concentrations from 0.05 to 1000 mg/L were prepared. Evaluation of the correction factor, contribution due to La in every different channel of each analyte, tolerance level, along with the analytical performance (detection limit, sensitivity, linear dynamic range, and precision for each analyte) were studied. By exploiting the idea of dependence of correction factor on concentration of the interfering element (La), it is much easier to directly determine the interference in the presence of other analytes by ICP-AES. Further, the analytical performance for each identified line of La was evaluated.

The developed methodology for the direct determination of trace amounts of the analytes was validated using synthetic samples without chemical separation.

RESULTS AND DISCUSSION

Determination of La by ICP-AES

The correction factor which quantifies the contribution of La depends on the concentration of La. For evaluating the contribution of La to different analytes, precise estimation of the amount in the sample is needed. In this study, an ICP-AES-based method was developed for the simultaneous determination of La along with different analytes under investigation, including some rare earth elements. Three different lines of La, i.e.,

333.749 nm, 379.478 nm, and 408.672 nm were chosen on the basis of the analytical performance. The calibration curves for these three lines were established and are illustrated in Figure 1.

The sensitivity of these analytical lines followed the trend: 408.672 nm > 379.478 nm > 333.749 nm, while for the detection limits the reverse trend was observed: 333.749 nm > 379.478 nm > 408.672 nm. For the sensitivity of the analytical lines, the slope of the calibration curves was taken into account, whereas the detection limits were calculated as the concentration equivalent to the intensity of the blank ($< x >$) + 5 times the relative standard deviation for the blank (5σ). Synthetic samples containing La in the concentration

TABLE I
Specifications and Instrumental Operating Conditions of ICP-AES

Instrumental Specifications	
Model No.	Arcos FH12 ICP-AES
Optical design	Paschen-Runge mounting, Circular design
Focal length	750 mm
Grating	Holographic
Groove density	1800 grooves/mm (1), 3600 grooves/mm (2)
Wavelength range	130-800 nm
Entrance slit width	15 microns
Resolution (FWHM)	0.01 nm from 130-450 nm 0.02 nm from 450-800 nm
Thermal regulation	Controlled to 30 ± 1 °C
Frequency	27.12 MHz
Pump	Dual channel peristaltic pump
Detector	Linear arrays of CCD (3648 pixels/array)
Nebulizer	Concentric nebulizer with cyclonic spray chamber
ICP torch	Demountable, radial viewing
Operating Condition	
Coolant flow	16 L/min
Auxiliary flow	0.7 L/min
Total time of measurement	30 s
Pump speed	25 Rpm
RF power output	1.0 kW
Input power	230 V AC

range of 0.05–1000 mg/L were analyzed using these analytical lines. The results obtained are tabulated in Table II revealing that the three lines of La can be used for the determination of La up to 1000 mg/L with an acceptable (%)RSD (relative standard deviation). Beyond this concentration, no experiment was conducted because of choking in the nebulizer system. Based on the above study, it is clear that the La 408.672-nm line is the best line for its ICP-AES determination.

Spectral Interference of La on Other Analytes

Lanthanum, like other members of the lanthanide series, has emission line-rich spectra due to its multi-electronic nature and hence, may interfere in the analysis of other analytes most of which do not have emission-rich spectra and, therefore, have fewer lines for the analysis. On the basis of spectral interference and analytical performance (detection limit, sensitivity, linear dynamic range, and precision), the best line for each analyte was chosen. In the present study, all analytes under investigation with respect to the spectral interference of La are grouped separately.

Spectral Interference on Ag, B, Ba, Bi, Ca, Er, Lu, Fe, Ga, Mn, Sr, and Pb

The spectral interference of La on Ag, B, Ba, Bi, Ca, Er, Lu, Fe, Ga, Mn, Sr, and Pb was studied thoroughly using the different analytical lines of these analytes. For all of these analytical lines, the analytical performance was also evaluated in the presence of a La matrix (1000 mg/L). As depicted in Table III, the lines of Ag 328.068 nm, B 208.959 nm, Ba 455.404 nm, Bi 306.772 nm, Ca 315.887 nm, Er 337.271 nm, Lu 307.760 nm, Fe 373.486 nm, Ga 417.206 nm, Mn 294.921 nm, Sr 460.733 nm, and Pb 405.778 nm were free of any spectral interference from La (1000 mg/L). Fortunately, all of these analytical lines showed better analytical performance, including sensitivity, detection limits, etc. (see Table IV). In view of this, all of the analytical lines mentioned above can be chosen for the trace level determination of these analytes in the presence of a La matrix. Among these analytes, the lines of Al 176.641 nm, Bi 143.683 nm, Er 326.478 nm, Dy 364.540 nm, and Na 330.298 nm (see Table III) showed significant spectral interference and were not used for the determination of these analytes in the presence of a La matrix.

Spectral Interference on Al, Pr, Cr, and Ni

For these analytes, two of the analytical lines were interference-free. The results of the spectral interference of La on Al, Pr, Cr, and Ni are listed in Table V, while the analytical performance of the least interfered analytical lines of these elements are listed in Table VI.

Aluminum (Al)

For Al, six different analytical lines were chosen for this study (167.078 nm, 396.152 nm, 394.401 nm, 176.641 nm, 308.215 nm, and 309.271 nm). Al 308.215 nm and Al 309.271 nm showed least interference for La matrix. By taking the analytical performance (detection limits, sensitivity, etc.) into consideration, Al 308.215 nm is believed to be the best line for further investigation. The Al 176.641 nm line interfered to maximum and should not be taken into consideration for trace level study.

Praseodymium (Pr)

For Pr, four different analytical lines were chosen for the spectral interference study (411.846 nm, 417.939 nm, 422.535 nm, and 414.311 nm). Two of the four lines of Pr 417.939 nm and Pr 422.535 nm were free of any spectral interference of La. Pr 417.939 nm with a detection limit of 0.038 mg/L and a sensitivity of 3600 counts/mg/L appeared to be the best choice for

Fig.1. Calibration curves for different analytical lines of La.

TABLE II
Determination of La by ICP-AES

Analytical Line (nm)	333.749	379.478	408.672
Sensitivity (counts mg L ⁻¹)	4120	4551	4709
Detection limit (mg L ⁻¹)	0.036	0.033	0.01
Linear dynamic range (mg L ⁻¹)	0.036-1600	0.033-1400	0.01-2000
RSD (%)	2	1.6	1.1

TABLE III:
Spectral Interference of La on
Ag, B, Ba, Bi, Ca, Er, Lu, Fe, Ga, Mn, Sr, and Pb

Elements	Analytical Lines (nm)	Contribution (mg/L)	Elements	Analytical Lines (nm)	Contribution (mg/L)
Ag	338.289	0.18	Lu	261.542	0.03
	328.068	*		291.139	0.09
	224.641	6.66		307.760	*
	243.779	1.77		219.554	0.23
B	249.773	0.41	Fe	259.941	0.25
	249.677	0.20		238.204	0.42
	182.641	0.38		239.562	0.24
	208.959	*		244.451	2.09
Ba	136.246	21.56		261.187	0.37
	455.404	*		262.567	2.71
	233.527	0.84		262.829	1.32
	230.424	0.43		275.573	0.64
Bi	223.061	9.89		241.331	1.19
	190.241	7.69		373.486	*
	306.772	*	Ga	141.444	80.00
	222.825	7.71		417.206	*
	153.317	50.00		294.364	0.31
	143.683	363.00		287.424	6.77
Ca	206.170	3.86	Mn	257.611	0.04
	396.847	0.36		259.373	0.04
	393.366	0.39		260.569	0.04
	317.933	0.37		294.921	*
	315.887	*		403.076	2.81
	183.801	11.33	Sr	407.771	0.43
	422.673	0.17		421.552	0.02
	337.271	*		460.733	*
Er	349.910	140.00	Pb	220.353	0.89
	326.478	560.00		168.215	50.00
	323.058	30.00		167.153	60.00
				172.680	50.00
				405.778	*
				283.305	0.31
				261.418	2.57

the trace level determination of Pr in La matrix.

Chromium (Cr)

The contribution of La for the four lines of Cr followed the trend: 283.563 nm ~284.325 nm < 205.618 nm < 267.716 nm < 284.984 nm. Cr 283.563 nm and Cr 284.325 nm, with zero spectral interference at 1000 mg/L of La, were further investigated for analytical performance. It was found that Cr 283.563 nm is the obvious selection for further analytical study.

Nickel (Ni)

In the case of Ni, of the seven lines (231.604 nm, 221.648 nm, 232.003 nm, 227.021 nm, 174.828 nm, 300.249 nm, and 341.476 nm) only Ni 300.249 nm and Ni 341.476 nm showed zero contribution value due to La. Ni 341.476 nm exceeded Ni 300.249 nm in analytical performance with a detection limit of 0.013 mg/L and sensitivity of 4200 counts/mg/L and is thus considered suitable for the trace level determination of Ni in a La matrix.

Spectral Interference on Nd, Ce, Dy, Eu, Sm, and Gd

Due to the line-rich emission spectra of rare earth elements (REEs), additional analytical lines are available, but complication increases due to higher chances of interference. Moreover, elements of this group have similar chemistry and because of this trace level determination of REEs in a rare earth matrix becomes difficult. The spectral interference results for these REEs are listed in Table VII and the analytical performance of the least interfered analytical lines is listed in Table VIII.

Neodymium (Nd)

Among the four analytical lines of Nd (401.225 nm, 430.358 nm, 406.109 nm, and 417.731 nm), spectral interference from La up to 1000 mg/L was observed only for Nd 417.731 nm. For detection lim-

TABLE IV
Least Interfered Lines Ag, B, Ba, Bi, Ca, Er, Lu, Fe, Ga, Mn, Sr, and Pb
and Their Analytical Performances In the Presence of La Matrix

Elements	Analytical Lines (nm)	Tolerance Level (mg/L)	Correction Factor	Detection Limits (mg/L)	Sensitivity (counts/mg/L)
Ag	328.068	1000	-	0.010	1.37E+04
B	208.959	1000	-	0.010	4.31E+03
Ba	455.404	1000	-	0.030	2.48E+03
Bi	306.772	1000	-	0.340	1.52E+03
Ca	315.887	1000	-	0.100	1.11E+03
Lu	307.76	1000	-	0.095	2.86E+03
Fe	373.486	1000	-	0.052	2.17E+03
Ga	417.206	1000	-	0.033	7.69E+03
Mn	294.921	1000	-	0.040	1.83E+03
Sr	460.733	1000	-	0.033	2.31E+03
Pb	405.778	1000	-	0.127	7.77E+02

TABLE V
Spectral Interference of La on Al, Pr, Cr, and Ni

Elements	Analytical Lines (nm)	Contribution (mg/L)	Elements	Analytical Lines (nm)	Contribution (mg/L)
Al	167.078	73.00	Pr	411.846	0.61
	396.152	0.09		417.939	*
	394.401	6.36		422.535	*
	176.641	1400.00	Ni	414.311	0.30
	308.215	*		231.604	0.45
Cr	309.271	*		221.648	0.32
	267.716	0.30		232.003	0.73
	205.618	0.07		227.021	1.06
	283.563	*		174.828	60.00
	284.325	*		300.249	*
	284.984	0.33		341.476	*

its, the trend followed the order: 401.225 nm < 430.358 nm < 406.109 nm, while for sensitivity it followed 430.358 nm < 406.109 nm < 401.225 nm. In accordance with the analytical performance, the Nd 401.225 nm line is considered to be the best line for Nd determination in a La matrix.

Cerium (Ce)

For Ce, the five analytical lines (418.660 nm, 448.691 nm, 413.765 nm, 413.380 nm, and 393.373 nm) were interference-free from La. The detection limits for the analytical lines of Ce followed the order: 413.765 nm < 413.382 nm < 418.660 nm < 393.373 nm < 448.691 nm. The trend followed on the basis of sensitivity was: 448.691 nm < 418.660 nm < 393.373 nm < 413.380 ~ 413.765 nm. Considering the analytical performance, Ce 413.765 nm can be chosen for further study.

Dysprosium (Dy)

Of the five analytical lines for Dy chosen for the present purpose (353.170 nm, 394.468 nm, 340.780 nm, 353.602 nm, and 364.540 nm), the three analytical lines of Dy 353.170 nm, Dy 340.780 nm, and Dy 353.602 nm showed least interference from La, while the Dy 364.540 nm line was most interfered from La. With regard to analytical performance, the Dy 353.170 nm and Dy 340.780 nm lines have the same detection limit value, but Dy 353.170 nm has maximum sensitivity and should be considered for further investigation.

Europium (Eu)

Of the four analytical lines of Eu (420.505 nm, 381.967 nm, 393.048 nm, and 390.710 nm), only Eu 381.967 nm was slightly interfered by La. The trend for the detection limit value for interference-free analytical lines of Eu is as follows: 420.505 nm < 393.048 nm < 390.710 nm. Sensitivity followed the order: 393.048 nm < 390.710

TABLE VI
Least Interfered Lines Of Al, Pr, Cr, and Ni and Their Analytical Performances In Presence Of La Matrix

Elements	Analytical Lines (nm)	Tolerance Level (mg/L)	Correction Factor	Detection Limits (mg/L)	Sensitivity (counts/mg/L)
Al	308.215	1000	-	0.040	1.82E+03
Al	309.271	1000	-	1.890	3.13E+03
Pr	417.939	1000	-	0.038	3.60E+03
Pr	422.535	1000	-	0.034	2.98E+03
Cr	283.563	1000	-	0.010	3.60E+03
Cr	284.325	1000	-	0.080	1.56E+03
Ni	300.249	1000	-	0.111	6.42E+02
Ni	341.476	1000	-	0.013	4.20E+03

TABLE VII
Spectral Interference of La on Nd, Ce, Dy, Eu, Sm and Gd

Elements	Analytical Lines (nm)	Contribution (mg/L)	Elements	Analytical Lines (nm)	Contribution (mg/L)
Nd	401.225	*	Eu	420.505	*
	430.358	*		381.967	0.03
	406.109	*		393.048	*
	417.731	3.50		390.710	*
Ce	418.660	*	Sm	359.260	*
	448.691	*		442.434	*
	413.765	*		428.079	*
	413.380	*		360.428	*
Dy	393.373	*	Gd	342.247	*
	353.170	*		335.047	*
	394.468	1.01		336.223	*
	340.780	*		335.862	*
	353.602	*			
	364.540	410.00			

nm < 420.505 nm. Accordingly, Eu 420.505 nm is the best line for further analytical study of Eu in a La matrix.

Samarium (Sm)

For Sm, the four analytical lines (359.260 nm, 442.434 nm, 428.079 nm, and 360.428 nm) were free of any spectral interference by La up to 1000 mg/L. Of the four, although Sm 428.079 nm and Sm 360.428 nm showed least detection limit values, the sensitivity for Sm 428.079 nm was higher and is considered the best line for trace level estimation of Sm in a La matrix.

Gadolinium (Gd)

The four analytical lines of Gd (342.247 nm, 335.047 nm, 336.223 nm, and 335.862 nm) remain unaffected in the presence of a La matrix and showed no contribution, leaving the analytical performance as the only criterion for selecting the best line. Gd 335.047 nm with least detection limit and maximum sensitivity is the best line for trace level determination of Gd in a La matrix.

Spectral Interference on Cd, Co, Cu, Mg, Na, and Zn

The analytical lines of Cd, Co, Cu, Mg, Na, and Zn were interfered by the La matrix at 1000 mg/L. The best line for trace level determination of all of these analytes in a La matrix was based on analytical performances. Table IX shows analytical performance of Cd, Co, Cu, Mg, Na, and Zn in the presence of La at 1000 mg/L. The analytical performance of the least interfered lines for all of these analytes are listed in Table X.

Cadmium (Cd)

The spectral interference of La on the four analytical lines of Cd followed the trend: 226.502 nm < 214.438 nm < 228.802 nm < 361.051 nm. The analytical performance (detection limit and sensitivity) for the Cd 226.502 nm was

TABLE VIII
Least Interfered Lines of Nd, Ce, Dy, Eu, Sm and Gd
and Their Analytical Performance in Presence of La Matrix

Elements	Analytical Lines (nm)	Tolerance Level (mg/L)	Correction Factor	Detection Limits (mg/L)	Sensitivity (counts/mg/L)
Nd	401.225	1000	-	0.004	2.96E+03
Nd	430.358	1000	-	0.034	1.98E+03
Nd	406.109	1000	-	0.057	2.95E+03
Ce	418.66	1000	-	0.090	1.90E+03
Ce	448.691	1000	-	0.850	5.88E+01
Ce	413.765	1000	-	0.060	2.31E+03
Ce	413.38	1000	-	0.080	2.31E+03
Ce	393.373	1000	-	0.210	2.22E+03
Dy	353.17	1000	-	0.020	1.41E+04
Dy	340.78	1000	-	0.020	4.30E+03
Dy	353.602	1000	-	0.050	4.04E+03
Eu	420.505	1000	-	0.006	1.74E+04
Eu	393.048	1000	-	0.010	2.13E+03
Eu	390.71	1000	-	0.050	3.19E+03
Sm	359.26	1000	-	0.040	3.34E+03
Sm	442.434	1000	-	0.050	1.13E+03
Sm	428.079	1000	-	0.010	6.24E+03
Sm	360.428	1000	-	0.010	2.46E+02
Gd	342.247	1000	-	0.014	5.07E+03
Gd	335.047	1000	-	0.007	6.47E+03
Gd	336.223	1000	-	0.027	4.42E+03
Gd	335.862	1000	-	0.015	3.73E+03

TABLE IX
Spectral Interference of La on Cd, Co, Cu, Mg, Na, and Zn

Elements	Analytical Lines (nm)	Contribution (mg/L)	Elements	Analytical Lines (nm)	Contribution (mg/L)
Cd	214.438	0.06	Co	228.616	0.40
	226.502	0.02		238.892	0.43
	228.802	0.15		230.786	1.58
	361.051	4.04		237.862	0.27
Cu	324.754	0.04	Na	589.592	0.09
	327.396	0.03		588.995	0.08
	224.700	0.19		330.237	24.00
	219.226	0.89	Mg	330.298	2250.00
Zn	219.958	0.44		279.553	0.07
	213.856	0.07		280.270	0.08
	206.200	1.28		285.213	0.06
	202.613	0.25		279.079	0.64
	334.502	25.00		202.647	0.64

found to be superior over the other lines and hence, was chosen as the best line for the determination of Cd in the presence of La.

Copper (Cu)

For Cu, five analytical lines (324.754 nm, 327.396 nm, 224.700 nm, 219.226 nm, and 219.958 nm) were taken into consideration. The Cu 324.754 nm and Cu 327.396 nm lines showed least interference. The Cu 327.396 nm line with a detection limit of 0.003 mg/L and sensitivity of 3.40E+04 counts/mg/L is considered the best line for trace level Cu determination with a tolerance level of 750 mg/L.

Zinc (Zn)

The spectral interference study of La on the Zn 213.856 nm, Zn 206.200 nm, Zn 202.613 nm, and Zn 334.502 nm lines revealed that the Zn 213.856 nm line was least interfered by La with a tolerance level of 500 mg/L. The same line also showed the detection limit of 0.023 mg/L in a La matrix. Based on these factors, the Zn 213.856 nm line should be the best choice for further investigation.

Cobalt (Co)

The spectral interference of a La matrix on the Co determination followed the trend: 237.862 nm < 228.616 nm < 238.892 nm < 230.786 nm. The Co 237.862 nm line with a detection limit of 0.05 mg/L and sensitivity of 826 counts/mg/L is the best choice for the trace level determination of Co in a La matrix in 100 mg/L tolerance level.

Sodium (Na)

In case of Na, the 330.298 nm line had severe spectral interference from La and should not be considered for study. Of the four analytical lines of Na (589.592 nm, 588.995 nm, 330.237 nm, and 330.298 nm), the 588.995 nm line with a 400 mg/L La tolerance level was chosen for further investiga-

TABLE X
Least Interfered Lines of Cd, Co, Cu, Mg, Na, and Zn and Their Analytical Performance in Presence of La Matrix

Elements	Analytical Lines (nm)	Tolerance Level (mg/L)	Correction Factor	Detection Limits (mg/L)	Sensitivity (counts/mg/L)
Cd	226.502	800	2 E-6	0.003	1.15E+04
Co	228.616	100	4 E-4	0.050	8.26E+02
Cu	327.396	750	3 E-6	0.003	3.40E+04
Mg	285.213	500	6.00E-05	0.005	1.55E+04
Na	588.995	400	8.00E-05	0.016	5.34E+04
Zn	213.856	500	7.00E-05	0.023	4.57E+03

TABLE XI
Validation of Method Using Synthetic Samples Containing Ag, Al, Ba, B, Bi, Ca, Nd, Er, Pr, Lu, Ce, Dy, Eu, Sm, Cr, Fe, Ga, Gd, Mn, Ni, Sr, and Pb in Lanthanum Matrix

Elements	Amount Added (mg/L)	Amount Estimated (mg/L)	Elements	Amount Added (mg/L)	Amount Estimated (mg/L)
Ag	0.05	0.048 ±0.003	Eu	0.05	0.050 ±0.004
Al	0.05	0.047 ±0.004	Sm	0.05	0.049 ±0.003
B	0.05	0.050 ±0.006	Cr	0.05	0.050 ±0.001
Ba	0.05	0.048 ±0.002	Er	0.05	0.052 ±0.002
Bi	0.05	0.051 ±0.003	Fe	0.05	0.048 ±0.003
Ca	0.05	0.052 ±0.002	Ga	0.05	0.049 ±0.004
Nd	0.05	0.049 ±0.003	Gd	0.05	0.051 ±0.005
Pr	0.05	0.051 ±0.003	Mn	0.05	0.049 ±0.003
Lu	0.05	0.049 ±0.001	Ni	0.05	0.048 ±0.001
Ce	0.05	0.048 ±0.006	Sr	0.05	0.050 ±0.002
Dy	0.05	0.049 ±0.002	Pb	0.05	0.052 ±0.003

TABLE XII
Validation of Method Using Synthetic Samples Containing Cd, Co, Cu, Mg, Na, and Zn in Lanthanum Matrix

Element	Amount Added (mg/L)	Amount Estimated (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)
Cd	0.1	0.13	0.11
Co	0.1	0.51	0.11
Cu	0.1	0.12	0.09
Mg	0.1	0.15	0.09
Na	0.1	0.18	0.1
Zn	0.1	0.16	0.09

tion. The detection limit of the Na 588.995 nm line was 0.016 mg/L with a sensitivity of 5.34E+04 counts/mg/L.

Magnesium (Mg)

The five analytical lines of Mg showed some interference in a La matrix. The trend followed 285.213 nm < 279.553 nm < 280.270 nm < 279.079 nm ~ 202.647 nm. For the trace level determination of Mg in a La matrix, the Mg 285.213 nm line (detection limit of 0.005 mg/L, sensitivity of 1.55E+04) is the best option with a 500 mg/L tolerance level of La.

Validation of Method Using Synthetic Samples Containing Analytes in a La Matrix

The main aim of the present study was to develop a simple methodology for the direct determination of the analytes in the presence of a La matrix without any need for chemical separation. Based on the above studies, the most suitable analytical lines of the analytes were identified. A set of synthetic samples was prepared using commercially available standard reference materials of the individual element solutions followed by feeding of the samples into the plasma directly without chemical separation and the results were analyzed. The following synthetic samples were prepared to validate the proposed method:

(a). 0.05 mg/L of Ag, Al, Ba, B, Bi, Ca, Nd, Er, Pr, Lu, Ce, Dy, Eu, Sm, Cr, Fe, Ga, Gd, Mn, Ni, Sr, and Pb in 1000 mg/L of La.

(b). 0.1 mg/L of Cd, Co, Cu, Mg, Na and Zn in 1000 mg/L of La.

The amount added to the synthetic samples and that estimated by application of the ICP-AES-based proposed method was in close agreement after incorporating the correction factor for some of the analytical lines of the analytes. Tables XI and XII show the results

obtained for all of the analytes under investigation. Thus, the developed method was validated for the direct determination of the analytes at trace level in the presence of a La matrix without using any chemical separation.

CONCLUSION

The detailed and systematic studies on the spectral interference by La on different analytes and the analytical performance of the different analytical lines of these analytes revealed that the following lines: Ag 328.068 nm, Al 308.215 nm, B 208.959 nm, Ba 455.404 nm, Bi 306.772 nm, Ca 315.887 nm, Nd 401.225 nm, Er 337.271 nm, Pr 417.939 nm, Lu 307.760 nm, Ce 413.765 nm, Dy 353.170 nm, Eu 420.505 nm, Sm 428.079 nm, Cr 283.563 nm, Fe 373.486 nm, Ga 471.206 nm, Gd 335.047 nm, Mn 294.921 nm, Ni 341.476 nm, Sr 460.733 nm, and Pb 405.778 nm were not interfered by the La matrix and also showed the best analytical performance. These lines can be chosen for the determination of these analytes in the presence of a La matrix without chemical separation. Integrated with the correction factor, Cd 226.502 nm, Co 228.616 nm, Cu 327.396 nm, Mg 285.213 nm, Na 588.995 nm, and Zn 213.856 nm are the analytical lines that can serve the purpose of trace level determination for Cd, Co, Cu, Mg, Na, and Zn, respectively, in a La matrix.

A simple, rapid ICP-AES-based method was developed for the determination of these analytes in a La matrix without chemical separation. The method was validated using synthetic samples prepared from reference materials.

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