An Implication of Spectral Interference of Praseodymium on Trace Metal Assay by Capacitively Coupled Device-based ICP-AES

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INTRODUCTION

The atomic emission spectroscopic technique is a simultaneously multi-elemental with acceptable merits of analytical performance and is routinely used in the trace level determination of different analytes (1-5). Spectral interference from emission-rich matrix elements on the determination of analytes at trace level is one of the major problems faced by researchers (6-10). To suppress the spectral interference, the emission-rich matrix element is preferentially separated from the trace analytes either physically using the d.c. arc carrier distillation technique utilizing the differences in the volatilization characteristics (11-14), or chemically by selective extraction of the emission-rich matrix element from analytes using a suitable ligand system followed by analysis of the raffinate (15-21). Even though the d.c. arc technique is advantageous due to its simplicity, requiring less sample handling and less time, it suffers from poor precision due to arc wandering (22-23). In addition, ICP-AES requires a selective extractant for almost quantitative separation of the major matrix without loss of the constituents even at trace levels. This involves more handling of the samples and a sufficiently large time for sample preparation including dissolution of the solid samples, feed conditioning, separation, etc. Moreover, it is very challenging for preferential separation of one rare earth element (REE) from other rare earths, especially when the aim is

ABSTRACT

An attempt was made to understand the spectral interference of Pr on 27 analytes (Ag, Ba, Bi, Cd, Cr, Cu, Dy, Li, Mg, Mn, Na, Nd, Sr, Zn, Ca, B, Co, Fe, Ga, La, Ni, Ti, Ce, Pb, Al, Gd, and In) using a capacitively coupled device (CCD)-based detector system with ICP-AES. The present study includes identification of suitable interference-free analytical lines of these analytes, evaluation of correction factor of each analytical line, determination of tolerance levels of Pr on these analytical lines along with the analytical performance of these lines (i.e., detection limits, sensitivity, linear dynamic range, precession, etc.) in the presence of a Pr matrix. Based on the spectral interference as well as the analytical performance study, a new approach for the direct ICP-AES determination of these analytes at trace levels without chemical separation was adopted. This method was found to be simple, precise, sensitive, and less time-consuming. The developed methodology was validated using synthetic samples prepared from commercially available standard reference material solutions of individual elements with satisfactory results. The method was also compared with the other existing techniques.

to determine the trace rare earth elements in other rare earth matrices. Thus, it appears to be attractive to determine trace constituents including rare earth elements in one of the rare earths, i.e., a Pr matrix, by ICP-AES without requiring physical/chemical separation.

To serve the above purpose, a systematic study of the spectral interference of Pr on the analytes is required. Several attempts were made to understand the spectral interference of the rare earth element on other rare earths by ICP-AES using a photomultiplier tube-based detection system (24-28). Due to the advancements of the capacitively coupled device (CCD)-based detection system in ICP-AES, the choice of alternative analytical lines of the elements, increases, which is of great significance in a situation when the best analytically performed line of an analyte is significantly interfered by the emission-rich matrix element.

In this work, a systematic study was carried out to understand the spectral interference of Pr on different analytes, including some of the rare earth elements. An ICP-AES-based method for the determination of these analytes in a Pr matrix is presented without requiring any separation. The method was validated using synthetic samples prepared from commercially available standard reference materials of the individual elemental solution. Moreover, the methodology was also compared with other analytical techniques.

EXPERIMENTAL

Instrumental and Operating Conditions

The analysis was carried out using a Model Arcos FHS12 ICP-AES (Spectro-Arcos, Germany) with a high-performing capacitively coupled device (CCD) as the detector and inductively coupled plasma as the excitation source. The instru-

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mental operating conditions and specifications are listed in Table I. The detector system, consisting of linear arrays of the CCD detector (3648 pixels/array), thermally stabilized together with the optical system, provides the ability to choose alternate analytical lines.

Standard Solutions and Reagents

Standard solutions for the elements were prepared from Certipur® ICP standard solutions, which are also the standard reference material solution of the individual elements (E-Merck, Darmstadt, Germany) by proper dilution. Suprapur® HNO₃ (E-Merck, Darmstadt, Germany) and quartz doubly distilled water (Milli-Q® system, Millipore Corporation, USA) were used throughout the study. ICP-AES exhibits a high degree of linear dynamic range, so in order to obtain more precise calibration curves, multi-point standardization was carried out using 0.5 M HNO₃ as a lower standard and 0.05–1000 mg/L of the corresponding elemental standard as the higher standard for each line after proper peak search.

Methods

A series of Pr solutions (commercially available standard reference material elemental solution from E-Merck, Darmstadt, Germany) of varying concentrations (between 0.05 mg/L to 1000 mg/L) were prepared and fed into the argon plasma. The spectral interference of Pr was monitored by observing the contribution in the different channels of the specified analytes. For each analyte, the least interfered analytical lines were identified and the correction factor was evaluated. The tolerance levels of Pr on these lines were also evaluated. The analytical performance of the detection limits, sensitivity, and linear dynamic range were studied for all of the analytical lines.

TABLE I
Specifications and Operating Conditions of ICP-AES

Instrumental Specification for FHS12 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	0.6 L/min
Total measurement time	28 s
Pump speed	30 Rpm
RF power output	1.2 kW
Input power	230 V AC

Since the correction factor arising due to the spectral interference is a function of the concentration of the interfering element (Pr), an ICP-AES-based method was also developed for the simultaneous determination of Pr along with the analytes. The analytical performance, including detection limits, sensitivity, linear dynamic range, etc., was evaluated for the identified analytical lines of Pr.

Synthetic samples were used to validate the methodology of direct trace level determination of these analytes in a Pr matrix without using any chemical separation. The method was also compared with some existing analytical techniques used for trace level determination of these analytes. For common analytes (except for Ag), the d.c. arc

carrier distillation technique was used, while for rare earth elements ion chromatography was used for comparison purposes. Ag being added to the samples in the form of AgCl in the d.c. arc carrier distillation technique, an independent atomic absorption spectroscopy technique was used to compare the results obtained with the newly developed method.

RESULTS AND DISCUSSION

Simultaneous Determination of the Interfering Element: Pr

For quantification of the spectral interference, a correction factor needs to be evaluated for the analytical line under investigation. It was observed that the contribution from Pr on different analytes depends on the Pr concentration

level in the sample. Therefore, it is required to determine the Pr concentration precisely to evaluate the correct contribution from Pr. In this study, an ICP-AES-based method was developed for the simultaneous determination of Pr along with the analytes. Since Pr is a rare earth with line-rich emission spectra, all lines cannot be considered as the analytical line. For the present investigation, four different lines (411.846 nm, 414.311 nm, 417.939 nm, and 422.535 nm) were chosen. The detection limit of Pr using these lines was found to follow the trend: 414.311 nm < 411.846 nm ~ 422.535 nm < 417.939 nm, while the sensitivity followed the order: 414.311 nm > 417.939 nm > 411.846 nm > 422.535 nm. In case of Pr, the most sensitive line of 414.311 nm was found to have the lowest detection limit. The slope of the calibration curves was considered as the sensitivity of the analytical lines, whereas the detection limits were calculated as the concentration equivalent to the intensity of blank ($< x > + 5$ times of the relative standard deviation values for blank (5σ)). For the analysis of each sample, 10 replicate measurements were carried out, while for the

determination of the detection limits and sensitivity, 25 replicate measurements were taken into account.

Synthetic samples containing Pr in the concentration range of 0.05 mg/L – 1000 mg/L were analyzed using these analytical lines. The analytical results shown in Table II revealed that all four lines can be used for the determination of Pr up to 1000 mg/L, beyond which the experiment was not carried out because of the choking problem in the nebulizer system.

Spectral Interference of Pr on the Analytes

Due to the advancement in the detector system from a photomultiplier tube (PMT) to a capacitively coupled device (CCD), not only the overall analytical performance is improved, but the CCD-based system also gives an opportunity to choose additional analytical lines of the analytes. This factor is very important in studying spectral interference. In the case when the least interfered analytical line showed the best analytical performance, the situation is simpler. If the best performed analytical line shows significant spectral interference, alternative analytical lines should be

looked into. In view of these factors, spectral interference as well as the analytical performance should be taken into consideration when choosing the best line for an analyte in an emission-rich matrix for its determination at trace levels. In the present study, all analytes under investigation with regard to the spectral interference of Pr are grouped separately.

Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn

The spectral interference of Pr on Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn was studied thoroughly using the different analytical lines of these analytes. For all of these lines, the analytical performance was also studied in the presence of a Pr matrix (1000 mg/L). As can be seen from Table III, the lines for Bi 306.772 nm, Cu 327.396 nm, Li 670.780 nm, Cd 214.438 nm and Zn 213.856 nm were found to be free of any spectral interference from Pr (1000 mg/L). Fortunately, all of these analytical lines showed very good analytical performance, including sensitivity, detection limits, etc. (see Table IV). Therefore, the above-mentioned lines can be chosen for the determination of these analytes at trace level in the presence of a Pr matrix. Interestingly, for Mg, Mn, Na, and Sr, two of their analytical lines were free of spectral interference from Pr (Mg 279.553 nm and 280.270; Mn 257.611 nm and 259.373 nm; Na 589.592 nm and 588.995 nm; Sr 407.771 nm and 421.552 nm). These pairs of lines also showed the best analytical performance and hence, were chosen for further investigation. Among these analytes, it was also observed that the Na 330.298 nm and 330.237 nm lines and the Zn 334.502 nm line were significantly interfered by the Pr line. Therefore, these lines are not recommended for the determination of these analytes in the presence of a Pr matrix.

Table II
Determination of Pr by ICP-AES

Pr (mg/L)	411.846 nm (mg/L)	414.311 nm (mg/L)	417.939 nm (mg/L)	422.535 nm (mg/L)
1	0.94 ± 0.03	0.96 ± 0.04	0.97 ± 0.05	0.96 ± 0.04
5	5.0 ± 0.3	4.8 ± 0.4	5.1 ± 0.4	5.0 ± 0.2
10	10.3 ± 0.8	9.4 ± 0.6	9.8 ± 0.6	9.7 ± 0.5
20	19.1 ± 0.8	19.4 ± 0.8	20.8 ± 0.6	20.7 ± 0.6
50	51.8 ± 1.8	49.5 ± 1.2	48.7 ± 1.2	50.8 ± 1.0
100	99.1 ± 2.0	102.3 ± 1.9	100.3 ± 2.0	98.6 ± 1.8
500	498 ± 3	503 ± 4	496 ± 5	504 ± 4
1000	1009 ± 10	997 ± 8	995 ± 7	1002 ± 6
D.L. (mg/L)	0.030	0.019	0.038	0.034
Sensitivity (counts/mg/L)	3257	4095	3605	2983
Linear Dynamic Range (mg/L)	0.03-1000	0.019-1000	0.04-1000	0.0002-1000

TABLE III
Spectral Interference of Pr on Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn

Ele- ments	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)	Ele- ments	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)
Bi	223.061	3.335	3.3×10^{-3}	50	Mn	257.611	*	-	1000
	190.241	8.126	8.1×10^{-3}	100		259.373	*	-	1000
	306.772	*	-	1000		260.569	0.102	1.0×10^{-4}	500
	223.061	8.794	8.8×10^{-3}	200		294.921	0.277	2.7×10^{-4}	200
	206.17	4.551	4.6×10^{-3}	100		403.076	1.825	1.8×10^{-3}	50
Cu	324.754	0.263	2.6×10^{-4}	200	Na	589.592	*	-	1000
	327.396	*	-	1000		588.995	*	-	1000
	224.7	0.735	7.3×10^{-4}	50		330.237	#	Rejected	10
	219.226	1.465	1.5×10^{-3}	50		330.298	#	Rejected	50
	219.958	0.768	7.7×10^{-4}	50	Cd	214.438	0.142	1.4×10^{-4}	500
Li	670.780	*	-	1000		226.502	*	-	1000
	460.289	11.46	1.1×10^{-2}	10		228.802	0.757	7.6×10^{-4}	50
	323.261	6.14	6.1×10^{-3}	10		361.051	10.11	1.0×10^{-2}	10
	274.118	11.83	1.1×10^{-2}	50	Sr	407.771	*	-	1000
Mg	279.553	*	-	1000		421.552	*	-	1000
	280.27	*	-	1000		460.733	1.107	1.1×10^{-3}	50
	285.213	0.134	1.3×10^{-4}	500	Zn	213.856	*	-	1000
	279.079	1.403	1.4×10^{-3}	200		206.2	1.516	1.5×10^{-3}	100
	202.647	2.932	2.9×10^{-3}	10		202.613	0.252	2.5×10^{-4}	200
						334.502	#	Rejected	5

#Significant Interference. *No Interference.

Table IV
Analytical Performance of Bi, Cu, Li, Mg, Mn, Na, Cd, Sr and Zn in the Presence of Pr

Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)	Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)
Bi	190.241	1.29	39	1.29- 800	3.2	Mn	257.611	0.002	12854	0.002-1000	2.1
	206.17	0.44	76	0.44-950	2.8		259.373	0.004	10246	0.004-1000	1.6
	222.825	1.45	48	1.45-950	2.6		260.569	0.01	5858	0.01-950	2.5
	223.061	0.30	346	0.30-1000	2.3		294.921	0.04	1832	0.04-900	3.2
	306.772	0.34	1521	0.34-1000	1.9		403.076	0.002	9246	0.002-1000	1.5
Cu	219.226	0.12	377	0.12-950	3.9	Na	330.237	0.81	84.25	0.81-750	4.1
	219.958	0.039	762	0.039-1000	2.7		330.298	1.69	52	1.69-600	3.7
	224.700	0.037	1859	0.037-850	3.1		588.995	0.01	53418	0.01-1000	1.9
	324.754	0.003	52029	0.003-1000	1.2		589.592	0.01	32488	0.01-1000	1.5
	327.396	0.003	34031	0.003-1000	0.95	Cd	214.438	0.006	5244	0.006-1000	2.1
Li	274.118	0.81	41	0.81-800	4.7		226.502	0.005	11493	0.005-1000	2.3
	323.261	0.05	199	0.05-1000	1.5		228.802	0.02	1884	0.02-950	3.6
	460.289	0.18	201	0.18-950	3.7		361.051	0.17	318	0.17-500	4.9
	670.780	0.001	200525	0.001-1000	0.86	Sr	407.771	0.0002	346709	0.0002-1000	0.98
Mg	202.647	0.03	495	0.03-750	4.6		421.552	0.0006	262155	0.0006-1000	1.1
	279.079	0.23	390	0.23-800	4.4		460.733	0.03	2307	0.03-980	2.5
	279.553	0.0005	65352	0.0005-1000	1.1	Zn	202.613	0.008	2058	0.008-1000	1.1
	280.270	0.0009	48536	0.0009-1000	1.2		206.200	0.21	157	0.21-850	4.6
	285.213	0.005	15455	0.005-1000	1.1		213.856	0.001	18060	0.001-1000	1.5
							334.502	0.12	453	0.12-900	2.8

B, Ba, Ca, Co, Cr, La, Fe, Pb, Tl, Lu, and Dy

The results of spectral interference of Pr on B, Ba, Ca, Co, Cr, La, Fe, Pb, Tl, Lu, and Dy are listed in Table V, while the analytical performance of the different analytical lines of these elements is listed in Table VI.

Boron (B)

For B, four different analytical lines (249.773 nm, 249.677 nm, 182.641 nm, and 208.959 nm) were chosen for the spectral interference study. The tolerance level of these lines was found to be 100 mg/L, 200 mg/L, 200 mg/L, and 500 mg/L of Pr, respectively, whereas the lowest contribution from Pr was seen for the Pr 208.959 nm line.

The detection limit for these analytical lines followed the trend of 249.773 nm ~ 208.959 nm < 182.641 nm < 249.677 nm, while the sensitivity followed the order of 208.959 nm > 249.773 nm > 249.677 nm > 182.641 nm. In view of the above study, the B 208.959 nm line was found to be the best for the determination of B in a Pr matrix.

Barium (Ba)

Of the three analytical lines for Ba chosen for the present purpose (455.404 nm, 233.527 nm and 230.424 nm), the Ba 455.404 nm line showed relatively low interference from Pr with the tolerance level for 500 mg/L of Pr, while the Ba 233.527 nm line showed maximum interference from Pr with tol-

erance level at 10 mg/L. With regard to analytical performance, even though Ba 230.424 nm showed the lowest detection limit, the sensitivity of this line was poorer in comparison to the Ba 455.404 nm line. Therefore, the 455.404 nm line of Ba shows to be the best choice in the present situation.

Calcium (Ca)

The contribution from 1000 mg/L of Pr on the different analytical lines of Ca was found to follow the trend of 393.366 nm < 396.847 nm < 422.673 nm < 317.933 nm < 315.887 nm < 183.801 nm. Though the Ca 315.887-nm line was found to tolerate 200 mg/L of Pr, the contribution beyond 200 mg/L of Pr was quite large. The detection limit of these analytical lines of Pr

TABLE V
Spectral Interference of Pr on B, Ba, Ca, Co, Cr, La, Fe, Pb, Tl, Lu, and Dy

Elements	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)	Elements	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)
B	249.773	0.656	6.5×10^{-4}	100	Fe	259.941	0.323	3.2×10^{-4}	200
	249.677	0.352	3.5×10^{-4}	200		238.204	0.65	6.5×10^{-4}	200
	182.641	0.337	3.3×10^{-4}	200		239.562	0.23	2.3×10^{-4}	200
	208.959	0.099	9.9×10^{-5}	500		244.451	6.124	6.1×10^{-3}	10
Ba	455.404	0.183	1.8×10^{-4}	500	Pb	261.187	0.852	8.5×10^{-4}	50
	233.527	1.588	1.5×10^{-3}	10		262.567	2.944	2.9×10^{-3}	200
	230.424	0.772	7.7×10^{-4}	50		262.829	1.887	1.8×10^{-3}	200
Ca	396.847	0.351	3.5×10^{-4}	10		275.573	1.146	1.1×10^{-3}	200
	393.366	0.242	2.4×10^{-4}	10	Tl	241.331	2.733	2.7×10^{-3}	200
	317.933	1.352	1.3×10^{-3}	10		373.486	9.342	9.3×10^{-3}	5
	315.887	1.922	1.9×10^{-3}	200		220.353	1.643	1.6×10^{-3}	50
Co	183.801	12.86	1.2×10^{-2}	10		405.778	17.48	1.7×10^{-2}	50
	422.673	0.842	8.4×10^{-4}	10	Lu	283.305	0.623	6.2×10^{-4}	200
	228.616	1.242	1.2×10^{-3}	50		261.418	4.156	4.1×10^{-3}	10
	238.892	0.54	5.4×10^{-4}	100		190.864	0.422	4.2×10^{-4}	200
Cr	230.786	1.203	1.2×10^{-3}	50		276.787	#	Rejected	-
	237.862	0.676	6.7×10^{-4}	50	Dy	261.542	0.08	8.0×10^{-5}	500
	267.716	0.593	5.9×10^{-4}	100		291.139	0.455	4.5×10^{-4}	200
	205.618	0.07	7.0×10^{-5}	500		307.76	1.168	1.1×10^{-3}	100
La	283.563	0.099	9.9×10^{-5}	500		219.554	0.457	4.5×10^{-4}	100
	284.325	0.49	4.9×10^{-4}	200		353.170	0.398	3.9×10^{-4}	200
	284.984	0.622	6.2×10^{-4}	50		394.468	7.288	7.2×10^{-3}	10
	408.672	9.503	9.5×10^{-3}	5		340.780	0.546	5.4×10^{-4}	200
	333.749	0.493	4.9×10^{-4}	100		353.602	1.804	1.8×10^{-3}	50
	379.468	10.05	1.0×10^{-2}	100		364.54	8.014	8.0×10^{-3}	10

*No Interference. #Significant Interference.

followed the same order as the contribution from Pr, while exactly the reverse trend was observed for sensitivity. Based on these studies, the Ca 393.366 nm line was the best for its trace level determination.

Cobalt (Co)

For Co, four different analytical lines were chosen for this study (228.616 nm, 238.892 nm, 230.786 nm, and 237.862 nm). The Co 238.892 nm line showed least interference with a Pr tolerance level at 100 mg/L, while for the rest of the lines the tolerance level for Pr was 50 mg/L. The analytical performance of the Co 238.892 nm line was found to be the best with a detection limit of 0.032 mg/L and a sensi-

tivity of 2001 counts/mg/L. Thus, it can be chosen for further investigation.

Chromium (Cr)

For Cr, the 267.716 nm, 205.618 nm, 283.563 nm, 284.325 nm, and 284.984 nm lines were chosen to investigate the spectral interference of Pr. It was found that the Cr 205.618 nm line was slightly interfered by 1000 mg/L of Pr, while for the other lines the tolerance level followed the trend of 283.563 nm > 284.325 nm > 267.716 nm > 284.984 nm. The sensitivity of the Cr 205.618 nm line was the highest with the lowest detection limit (sensitivity 4588 counts/mg/L,

detection limit 0.005 mg/L). Hence, it is believed to be the best line for the present situation.

Lanthanum (La)

For La, the analytical performance of the 408.672 nm and 379.468 nm lines was moderately better than the 333.749 nm La line. The former two lines were significantly interfered by Pr and the La 333.749 nm line appeared to be the best line of choice.

Iron (Fe)

Fe is one of the transition elements having emission-rich spectra. Out of 10 analytical lines of Fe chosen in the present study, the 259.941 nm, 238.204 nm, 239.562

TABLE VI
Analytical Performance of B, Ba, Ca, Co, Cr, La, Fe, Pb, Tl, Lu and Dy Analytes in Presence of Pr

Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)	Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)
B	182.641	0.024	757	0.024 - 1000	1.2	Fe	238.204	0.093	800	0.093 - 800	2.5
	208.959	0.013	4309	0.013 - 1000	1.1		239.562	0.032	2063	0.032 - 950	2.3
	249.677	0.025	1013	0.025 - 975	1.0		241.331	0.27	229	0.27 - 550	1.6
	249.773	0.013	1587	0.013 - 1000	1.1		244.451	0.53	157	0.53 - 550	1.7
Ba	230.424	0.012	793	0.012 - 980	2.1		259.941	0.017	1689	0.017 - 990	2.1
	233.527	0.091	388	0.091 - 790	2.2		261.187	0.025	943	0.025 - 950	2.0
	455.404	0.028	2479	0.028 - 975	1.1		262.567	0.29	136	0.29 - 750	4.8
Ca	183.801	0.53	30	0.53 - 600	3.1		262.829	0.37	194	0.37 - 650	4.3
	315.887	0.10	1114	0.10 - 890	4.2		275.573	0.13	293	0.13 - 800	4.0
	317.933	0.039	3613	0.039 - 780	2.2		373.486	0.051	2173	0.051 - 950	1.9
	393.366	0.001	521209	0.001 - 1000	0.98	Pb	220.353	0.12	274	0.12 - 950	2.8
Co	396.847	0.002	400267	0.002 - 1000	0.90		261.418	0.28	99	0.28 - 800	1.6
	422.673	0.004	25333	0.004 - 1000	1.2		283.305	0.068	719	0.068 - 1000	1.5
	228.616	0.049	826	0.049 - 800	2.2	Tl	405.778	0.13	777	0.13 - 900	1.9
	230.786	0.13	658	0.13 - 500	4.8		190.864	0.027	848	0.027 - 980	1.9
Cr	237.862	0.043	1457	0.043 - 970	1.2		276.787	0.83	27	0.83 - 800	4.3
	238.892	0.032	2001	0.032 - 990	2.2	Lu	219.554	0.045	911	0.045 - 800	2.1
	205.618	0.005	4588	0.005 - 1000	1.1		261.542	0.003	7454	0.003 - 1000	0.8
	267.716	0.069	659	0.069 - 950	1.7		291.139	0.021	2427	0.021 - 1000	0.9
La	283.563	0.010	3603	0.010 - 950	2.2	Dy	307.76	0.095	2856	0.095 - 950	1.1
	284.325	0.079	1559	0.079 - 950	3.1		340.78	0.022	4299	0.022 - 990	1.7
	284.984	0.018	512	0.018 - 700	4.1		353.170	0.020	14075	0.020 - 1000	1.3
	333.749	0.017	3927	0.017 - 990	2.2		353.602	0.053	4040	0.053 - 990	1.6
	379.478	0.013	5142	0.013 - 1000	3.1		364.540	0.032	4864	0.032 - 1000	1.6
	408.672	0.012	5525	0.012 - 1000	1.5		394.468	0.042	3884	0.042 - 1000	1.9

nm, 262.567 nm, 262.829 nm, 275.573 nm, and 241.331 nm lines were found to tolerate 200 mg/L of Pr, while for the remaining lines (244.451 nm, 261.187 nm, 373.486 nm) the tolerance level was found to be poorer. The sensitivity and the detection limits of the Fe 259.941 nm and 239.562 nm lines were found to be better and mutually comparable (sensitivity: 1689 counts/mg/L and 2063 counts/mg/L, detection limit: 0.017 mg/L and 0.032 mg/L). The same was observed in case of the Pr contribution to these Fe lines. Therefore, these two lines appeared to be the best choice for the determination of Fe at trace level in a Pr matrix.

Lead (Pb)

The spectral interference study of Pr on the Pb 220.353 nm, 261.418 nm, 283.305 nm, and 405.778 nm lines revealed that the 283.305 nm line was least interfered by Pr with a tolerance of 200 mg/L. The same line also showed the lowest detection limit (0.068 mg/L) in a Pr matrix. Based on both factors, the Pb 283.305 nm line

should be the best choice for further investigation.

Lutetium (Lu)

Similarly, of the four Lu analytical lines of 219.554 nm, 261.542 nm, 291.139 nm, and 307.760 nm, the least interference was observed for Lu 261.542 nm, with the best analytical performance (detection limit: 0.003 mg/L, sensitivity: 7454 counts/mg/L). Therefore, the Lu 261.542 nm line can be chosen for the determination of trace level Lu in a Pr matrix.

Tellurium (Tl)

In case of Tl, the 276.787 nm line had severe spectral interference from Pr. Thus, the Tl 190.864 nm line with a 200 mg/L Pr tolerance level was chosen for further investigation. The detection limit of the Tl 190.864 nm line was 0.027 mg/L with a sensitivity of ~850 counts/mg/L.

Dysprosium (Dy)

For Dy, the five analytical lines chosen are 340.780 nm, 353.170 nm, 353.602 nm, 364.540 nm, and 394.468 nm. The contribution from

Pr on these lines followed the trend of 353.170 nm < 340.780 nm < 353.602 nm < 364.540 nm < 394.468 nm. The least interfered line of 353.170 nm was found to have the best analytical performance (detection limit: 0.020 mg/L, sensitivity: 4075 counts/mg/L).

Ag, Al, Ga, In, Ni, Gd and Ce

The spectral interference of Pr on Ag, Al, Ga, In, Ni, Gd, and Ce (Table VII) revealed that the Ag 224.641 nm, Al 394.401 nm, Ga 417.206 nm, In 451.131 nm, and Ce 448.691 nm and 393.373 nm analytical lines were significantly interfered by Pr. Therefore, these lines could not be recommended for the determination these analytes in a Pr matrix. The minimum interfered lines for Ag, Al, Ga, In, Ni, Gd, and Ce were found to be 338.289 nm, 309.271 nm, 294.364 nm, 230.606 nm, 221.648 nm, 335.862 nm and 418.660 nm, respectively. Studies on the analytical performance of different analytical lines of the above-mentioned analytes (Table VIII) revealed that the Ag 328.068 nm, Al 396.152 nm,

TABLE VII
Spectral Interferences of Pr on Ag, Al, Ga, In, Ni, Gd and Ce

Elements	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)	Elements	Analytical Lines (nm)	Contribution From 1000 mg/L of Pr	Correction Factor	Tolerance Level (mg/L)
Ag	338.289	0.73	7.3×10^{-4}	100	Ni	231.604	0.77	7.7×10^{-4}	50
	328.068	1.05	1.0×10^{-3}	50		221.648	0.48	4.8×10^{-4}	200
	224.641	#	Rejected	-		232.003	3.15	3.1×10^{-3}	10
	243.779	1.77	1.7×10^{-3}	200		227.021	1.24	1.2×10^{-3}	100
Al	396.152	7.30	7.3×10^{-3}	10	Gd	300.249	2.42	2.4×10^{-3}	50
	394.401	#	Rejected	-		341.476	0.52	5.2×10^{-4}	200
	308.215	1.94	1.9×10^{-3}	10		342.247	1.17	1.2×10^{-3}	50
	309.271	*		1000		335.047	1.58	1.6×10^{-3}	50
Ga	417.206	#	Rejected	-	Ce	336.223	2.93	2.9×10^{-3}	10
	294.364	1.13	1.1×10^{-3}	10		335.862	1.10	1.1×10^{-3}	10
	287.424	2.68	2.7×10^{-3}	200		418.660	2.74	2.7×10^{-3}	5
	230.606	1.24	1.2×10^{-3}	50		448.691	#	Rejected	-
In	325.609	1.90	1.9×10^{-3}	10		413.765	5.31	5.3×10^{-3}	10
	451.131	#	Rejected	-		413.38	16.8	1.7×10^{-2}	5
	303.936	1.32	1.3×10^{-3}	200		393.373	#	Rejected	-

*No Interference.

#Significant Interference.

Ga 417.206 nm, In 325.609 nm, Ni 341.476 nm, Gd 335.047 nm, and Ce 417.380 nm lines showed the best performance in the presence of a Pr matrix. Unfortunately, in this group of analytes the best performed lines are not the least interfered lines from Pr. Therefore, optimization is required to choose the best line of these analytes in the presence of a Pr matrix. The spectral interference as well as the analytical performance of the lines has to be taken into account. For Ag, the 338.289 nm line showed the least contribution from Pr with 100 mg/L of tolerance and good analytical performance, i.e., 0.018 mg/L detection limit, 7156 counts/mg/L sensitivity. Hence, this line was found to be suitable. Tables VII and VIII revealed that the Al 308.215 nm, Ga 294.368 nm, In 230.606 nm, Ni 341.476 nm, Gd 342.247 nm, and Ce 418.660 nm lines were found to be the most suitable lines for these analytes for their determination in a Pr matrix.

Direct Determination of the Analytes in a Pr Matrix

The main aim of this study was to develop a methodology for the direct determination of the analytes in the presence of a Pr matrix without any 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 elemental solutions. Then the samples were fed into the plasma directly without chemical separation and the results were analyzed. The following six synthetic samples were prepared to study the metal concentrations:

1. Synthetic sample 1 (S 1): 0.1 mg/L of Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn in 1000 mg/L of Pr
2. Synthetic sample 2 (S 2): 1 mg/L of Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn in 1000 mg/L of Pr
3. Synthetic sample 3 (S 3): 0.3 mg/L of B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu, and Dy in 1000 mg/L of Pr

4. Synthetic sample 4 (S 4): 3 mg/L of B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu, and Dy in 1000 mg/L of Pr

5. Synthetic sample 5 (S 5): 1 mg/L of Ag, Al, Ga, In, Ni, Gd, and Ce in 1000 mg/L of Pr

6. Synthetic sample 6 (S 6): 10 mg/L of Ag, Al, Ga, In, Ni, Gd, and Ce in 1000 mg/L of Pr

The results revealed that Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn can be determined even at 0.1 mg/L concentration in the presence of a Pr matrix (1000 mg/L), while B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu, and Dy can be determined at the 0.3 mg/L level without any chemical separation with an RSD < 5%. It also showed that for Ag, Al, Ga, In, Ni, Gd, and Ce, 1 mg/L can be determined in the presence of 1000 mg/L of Pr as the best performed analytical lines were found to have significant spectral interference. The analyses results of the synthetic samples are listed in Tables IX to XI.

TABLE VIII
Analytical Performance of Ag, Al, Ga, In, Ni, Gd, and Ce in the Presence of Pr

Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)	Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	RSD (%)
Ag	224.641	1.55	38	1.55 - 700	5.0	Ni	221.648	0.13	848	0.13 - 780	3.1
	243.779	0.22	346	0.22 - 950	4.0		227.021	0.046	154	0.046 - 950	2.9
	328.068	0.012	13737	0.012 - 1000	0.5		231.604	0.014	853	0.014 - 1000	2.6
	338.289	0.018	7156	0.018 - 1000	1.1		232.003	0.068	703	0.068 - 980	1.5
	308.215	0.036	1821	0.036 - 950	3.0		300.249	0.11	642	0.11 - 880	4.2
Al	309.271	1.89	3130	1.89 - 800	2.5	Gd	341.476	0.012	4201	0.012 - 1000	0.97
	394.401	0.016	3109	0.016 - 995	1.6		335.047	0.007	6474	0.007 - 1000	1.5
	396.152	0.013	10037	0.031 - 1000	1.8		335.862	0.015	3729	0.015 - 1000	1.3
Ga	287.424	0.26	182	0.26 - 750	3.6		336.223	0.027	4423	0.027 - 990	2.2
	294.364	0.032	864	0.032 - 700	4.3		342.247	0.013	5073	0.013 - 750	2.2
In	417.206	0.033	7693	0.033 - 970	2.2	Ce	393.373	0.21	2216	0.21 - 800	2.3
	230.606	0.069	577	0.069 - 650	4.9		413.380	0.055	2313	0.055 - 950	3.9
	303.936	0.10	535	0.10 - 700	4.7		413.765	0.083	2312	0.083 - 975	1.2
	325.609	0.074	1489	0.074 - 990	2.3		418.660	0.093	1899	0.093 - 1000	2.6
	451.131	8.4	31	8.4 - 500	4.4		448.691	0.85	59	0.85 - 700	1.9

Comparison of Present Method With Other Analytical Method

An attempt was also made to compare the analytical results of the synthetic samples of the present methodology with that of other analytical methods (see Table XII). The synthetic samples contained 0.5 mg/L of Bi, Cu, Li,

Mg, Mn, Na, Cd, Sr, Zn, B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu, and Dy; 1.5 mg/L concentration of Ag, Al, Ga, In, Ni, Gd, and Ce in 1000 mg/L of Pr matrix. The synthetic sample was directly fed to the plasma for analysis without chemical separation. The results were corrected for spectral interference of Pr using the

correction factors evaluated previously. The analytical results thus obtained were compared with the existing analytical techniques. For Ag the atomic absorption spectroscopic technique was used for comparison purposes (29). For Ba, Bi, Cd, Cr, Cu, Li, Mg, Mn, Na, Sr, Zn, Ca, B Co, Fe, Ga, Ni, Tl, and Pb the d.c. arc carrier distillation technique (30) was used. For the rare earth elements (Dy, Ce, Lu, Nd, La, and Pr), ion chromatography was employed (31). The results obtained by the present method were found to compare well with the existing methods.

CONCLUSION

A systematic study was carried out to understand the spectral interference of Pr on 27 analytes (Ag, Ba, Bi, Cd, Cr, Cu, Dy, Li, Mg, Mn, Na, Nd, Sr, Zn, Ca, B, Co, Fe, Ga, La, Ni, Tl, Ce, Pb, Al, Gd, and In), and its implication on the analysis of these analytes at trace level in the presence of a Pr matrix. Based on the spectral interference and the analytical performance,

TABLE IX
Analysis of Bi, Cu, Li, Mg, Mn, Na, Cd, Sr and Zn in Pr Matrix
Using Synthetic Samples Prepared From Commercially Available
Standard Reference Materials of Individual Solutions

Ele- ments	Analytical Lines (nm)	S1		S2	
		Actual Conc. (mg/L)	Amount After Incorporating Correction Factor (mg/L)	Actual Conc. (mg/L)	Amount After Incorporating Correction Factor (mg/L)
Bi	306.772	0.10	0.12 ± 0.03	1.0	1.02 ± 0.04
Cu	327.396	0.10	0.97 ± 0.01	1.0	0.99 ± 0.05
Li	670.78	0.10	0.99 ± 0.03	1.0	0.97 ± 0.05
Mg	279.553	0.10	0.10 ± 0.02	1.0	1.06 ± 0.04
	280.27	0.10	0.98 ± 0.03	1.0	1.03 ± 0.03
Mn	259.373	0.10	0.97 ± 0.03	1.0	0.97 ± 0.03
Na	588.995	0.10	0.11 ± 0.02	1.0	1.00 ± 0.04
Cd	226.502	0.10	0.10 ± 0.02	1.0	1.10 ± 0.07
Sr	421.552	0.10	0.11 ± 0.03	1.0	0.96 ± 0.05
	407.771	0.10	0.97 ± 0.03	1.0	1.03 ± 0.05
Zn	213.856	0.10	0.99 ± 0.03	1.0	1.10 ± 0.06

TABLE X
Analyses of B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu and Dy in Pr Matrix Using Synthetic Samples
Prepared From Commercially Available Standard Reference Materials of Individual Solutions

Ele- ments	Analytical Lines (nm)	S3			S4		
		Actual Conc. (mg/L)	Amount Before Incorporating Correction Factor (mg/L)	Amount After (mg/L)	Actual Conc. (mg/L)	Amount Before Incorporating Correction Factor (mg/L)	Amount After (mg/L)
B	208.959	0.3	0.40 ± 0.02	0.31 ± 0.02	3.0	3.16 ± 0.22	3.07 ± 0.06
Ba	455.404	0.3	0.50 ± 0.03	0.32 ± 0.01	3.0	3.25 ± 0.15	3.06 ± 0.07
Ca	393.366	0.3	0.55 ± 0.04	0.31 ± 0.02	3.0	3.25 ± 0.12	3.01 ± 0.07
Co	238.892	0.3	0.85 ± 0.03	0.31 ± 0.01	3.0	3.55 ± 0.15	3.01 ± 0.07
Cr	205.618	0.3	0.41 ± 0.02	0.33 ± 0.01	3.0	3.11 ± 0.16	3.04 ± 0.08
Fe	239.562	0.3	0.75 ± 0.06	0.26 ± 0.03	3.0	3.45 ± 0.19	2.96 ± 0.08
	259.941	0.3	0.62 ± 0.03	0.28 ± 0.01	3.0	3.34 ± 0.14	3.02 ± 0.07
Pb	283.305	0.3	0.53 ± 0.01	0.30 ± 0.01	3.0	3.23 ± 0.13	3.00 ± 0.07
Tl	190.864	0.3	0.90 ± 0.04	0.28 ± 0.02	3.0	3.50 ± 0.18	2.88 ± 0.09
La	333.749	0.3	0.41 ± 0.03	0.32 ± 0.02	3.0	3.10 ± 0.15	3.02 ± 0.07
Lu	261.542	0.3	0.73 ± 0.05	0.31 ± 0.03	3.0	3.40 ± 0.10	2.98 ± 0.05
Dy	353.17	0.3	0.72 ± 0.04	0.33 ± 0.02	3.0	3.41 ± 0.08	3.02 ± 0.04

TABLE XI
Analysis of Ag, Al, Ga, In, Ni, Gd and Ce in Pr Matrix Using Synthetic Samples
Prepared From Commercially Available Standard Reference Materials of Individual Solutions

Ele- ments	Analytical Lines (nm)	S5			S6		
		Actual Conc. (mg/L)	Amount Before Incorporating Correction Factor (mg/L)	After (mg/L)	Actual Conc. (mg/L)	Amount Before Incorporating Correction Factor (mg/L)	After (mg/L)
Ag	338.289	1.0	1.86 ± 0.06	1.13 ± 0.04	10.0	10.6 ± 0.4	9.87 ± 0.08
Al	308.215	1.0	3.00 ± 0.08	1.06 ± 0.04	10.0	12.2 ± 0.3	10.26 ± 0.14
Ga	294.364	1.0	2.03 ± 0.05	0.90 ± 0.02	10.0	11.0 ± 0.4	9.87 ± 0.21
In	230.606	1.0	2.14 ± 0.07	0.90 ± 0.03	10.0	11.3 ± 0.2	10.06 ± 0.11
Ni	341.476	1.0	1.51 ± 0.08	0.99 ± 0.04	10.0	10.1 ± 0.2	9.58 ± 0.09
Gd	342.247	1.0	2.22 ± 0.07	1.05 ± 0.04	10.0	11.0 ± 0.3	9.83 ± 0.11
Ce	418.660	1.0	3.81 ± 0.07	1.07 ± 0.04	10.0	12.5 ± 0.4	9.76 ± 0.12

the analytical lines of Ag 338.289 nm, Al 308.215 nm, Ga 294.361 nm, In 230.606 nm, Ni 341.476 nm, Gd 342.247 nm, Ce 418.660 nm, B 208.959 nm, Ba 455.404 nm, Ca 393.366 nm, Co 238.892 nm, Cr 205.618 nm, Pb 283.305 nm, Tl 190.864 nm, La 333.749 nm, Lu 261.542 nm, Dy 353.170 nm, Bi 306.772 nm, Cu 327.396 nm, Li 670.780 nm, Mn 259.373 nm, Na 588.995 nm, Cd 226.502 nm, and Zn 213.856 nm were found to be suitable for the determination of these analytes in a Pr matrix. For the analytes Fe, Mg, and Sr, two analytical lines for each (239.562 nm and 259.941 nm; 279.553 nm and 280.270 nm; 421.552 nm and 407.771 nm, respectively) were found to be suitable. A methodology for the direct determination of the analytes in a Pr matrix without any chemical separation was developed, and it revealed that Bi, Cu, Li, Mg, Mn, Na, Cd, Sr, and Zn can be determined at 0.1 mg/L and B, Ba, Ca, Co, Cr, Fe, Pb, Tl, La, Lu, and Dy can be determined at the 0.3 mg/L concentration level, while Ag, Al, Ga, In, Ni, Gd, and Ce can be determined at 1 mg/L concentration. The methodology was validated using synthetic samples, prepared from commercially available standard reference material solution of individual ele-

ments, and was also compared with existing analytical techniques. The analytical results were found to be encouraging.

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REFERENCES

1. I. Jarvis and K. E. Jarvis, *Chem. Geology* 95, 1 (1992).
2. P. W. J. M. Boumans, *Spectrochim. Acta* 358, 57 (1979).
3. S. L. Maxwell, M. A. Bernarda, M. R. Nelson, and L. D. Youmans, *Talanta* 76, 432 (2008).
4. Z. U. Bae, S. H. Lee, and S. H. Lee, *Talanta* 44, 37 (1997).
5. J. L. Todolić, L. Gras, V. Hernandis, and J. Mora, *J. Anal. At. Spectrom.* 17, 142 (2002).
6. V.C. Adya, A. Sengupta, and S.V. Godbole, *Atom Spectrosc.* 35(1), 25 (2014).
7. A. Sengupta, V.C. Adya, and S.V. Godbole, *J. Radioanal. Nucl.*

Chem., DOI 10.1007/s10967-013-2520-0 (2014).

8. A. Sengupta, B. Rajeswari, R.M. Kadam, and R. Acharya, *At. Spectrosc.* 32(5), 200 (2011).
9. A. Sengupta, and V.C. Adya, *At. Spectrosc.* 34(6), 207 (2013).
10. A. Sengupta, and V.C. Adya, *J. Radioanal. Nucl. Chem.* 299, 2023 (2014).
11. N.K. Porwal, A.A. Argekar, P.J. Purohit, A.G. Page, and M.D. Sastri, *Fresenius J. Anal. Chem.* 338, 255 (1990).
12. A.G. Page, K.H. Madraswala, S.V. Godbole, M.J. Kulkarni, V.S. Mallapurkar, and B.D. Joshi, *Fresenius Z. Anal. Chem.* 315, 38 (1983).
13. A.G. Page, S.V. Godbole, S. Deshkar, Y. Babu, and B.D. Joshi, *Fresenius J. Anal. Chem.* 287, 304 (1977).
14. A.G.I. Dalvi, C.S. Deodhar, T.K. Seshagiri, M.S. Khalap, and B.D. Joshi, *Talanta* 25, 665 (1978).
15. B. Rajeswari, B.A. Dhawale, T.R. Bangia, J.N. Mathur, and A.G. Page, *J. Radioanal. Nucl. Chem.* 254(3), 479 (2002).
16. A. Sengupta, M. J. Kulkarni, and S. V. Godbole, *J. Radioanal. Nucl. Chem.* 289(3), 961 (2011).
17. A.A. Argekar, M.J. Kulkarni, J.N. Mathur, and A.G. Page, *Talanta* 56(4), 591 (2002).

TABLE XII
Comparison of Present Methodology
With Existing Analytical Techniques

Elements	Analytical Lines (nm)	Estimated by Present Method (mg/L)	Comparison With Other Method (mg/L)
Ag	338.289	1.52 ± 0.02	1.46 ± 0.08#
Al	308.215	1.49 ± 0.03	1.51 ± 0.06**
Ga	294.364	1.46 ± 0.05	1.52 ± 0.08**
In	230.606	1.42 ± 0.08	1.49 ± 0.07**
Ni	341.476	1.40 ± 0.07	1.46 ± 0.06**
Gd	342.247	1.55 ± 0.09	1.40 ± 0.07*
Ce	418.660	1.54 ± 0.08	1.43 ± 0.09*
B	208.959	0.52 ± 0.02	0.48 ± 0.03**
Ba	455.404	0.48 ± 0.02	0.51 ± 0.03**
Ca	393.366	0.50 ± 0.04	0.52 ± 0.04**
Co	238.892	0.50 ± 0.04	0.49 ± 0.04**
Cr	205.618	0.47 ± 0.03	0.46 ± 0.04**
Fe	239.562	0.47 ± 0.02	0.52 ± 0.03**
	259.941	0.51 ± 0.02	0.54 ± 0.04**
Pb	283.305	0.52 ± 0.03	0.47 ± 0.03**
Tl	190.864	0.52 ± 0.03	0.47 ± 0.05**
La	333.749	0.48 ± 0.01	0.46 ± 0.06*
Lu	261.542	0.50 ± 0.03	0.51 ± 0.02*
Dy	353.170	0.53 ± 0.04	0.50 ± 0.05*
Bi	306.772	0.48 ± 0.03	0.53 ± 0.04**
Cu	327.396	0.49 ± 0.02	0.54 ± 0.06**
Li	670.780	0.52 ± 0.03	0.46 ± 0.04**
Mg	279.553	0.52 ± 0.03	0.47 ± 0.05**
	280.270	0.48 ± 0.01	0.46 ± 0.06**
Mn	259.373	0.50 ± 0.03	0.51 ± 0.02**
Na	588.995	0.53 ± 0.04	0.50 ± 0.05**
Cd	226.502	0.48 ± 0.03	0.53 ± 0.04**
Sr	421.552	0.49 ± 0.02	0.54 ± 0.06**
	407.771	0.52 ± 0.03	0.46 ± 0.04**
Zn	213.856	0.48 ± 0.01	0.46 ± 0.06**

Note: The Pr concentration in the synthetic sample is 1000 mg/L.

Analysis by Atomic Absorption Spectroscopy.

** Analysis by D.C. arc carrier distillation technique.

* Analysis by chromatographic technique.

18. C. Mahan, S. Bonchin, D. Figg, D. Gcrth, and C. Collier, J. Anal. At. Spectrom. 15 (8), 929 (2000).
19. S. Marin, S. Cornejo, C. Jara, and N. Duran, Fresenius J. Anal. Chem. 355, 680 (5-6) (1996).
20. E.A. Huff, At. Spectrosc. 42(1-2), 275 (1987).
21. E.A. Huff and D.L. Bowers, Appl. Spectrosc. 43(2), 223 (1989).
22. M.D. Sastry, M.K. Bhide, K. Savitri, Y. Babu, and B.D. Joshi, Fresenius Z. Anal. Chem. 308, 456 (1981).
23. B.F. Scribner, and H.R. Mullin, J. Res. Natl. Bur. Stds. 37, 379 (1946).
24. P.W.J.M. Boumans, Spectrochim. Acta 438(2), 173 (1988).
25. A. Mazzucotelli, F. de Paz, E. Magi, and R. Frache, Anal. Sci. 8, 189 (1992).
26. E. Kostadinova, L. Aleksieva, S. Velichkov, and N. Daskalova, Spectrochim. Acta Part B 55, 689 (2000).
27. K-S. Choi, C-H Lee, J-G Kim, W-H Kim, and J-G Kang, Talanta 71, 662 (2007).
28. S. Gu, H. Ying, Z. Zhang, Z. Zhuang, P. Yang, X. Wang, B. Huang, and L. Bing, Spectrochim. Acta B 52, 1567 (1997).
29. T. Blazheva, and A. Delijska - Krushchevska, Fresenius J. Anal. Chem. 338, 294 (1990).
30. N. Pathak, V.C. Adya, S.K. Thulasidas, A. Sengupta, T.K. Seshagiri, and S.V. Godbole, At. Spectrosc. 35(1), 17 (2014).
31. M.C. Bruzzoniti, E. Mentasti, C. Sarzanini, M. Braglia, G. Cocito, and J. Kraus, Anal. Chim. Acta 332, 49 (1996).