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Scientific paper

A Dynamic Electrode for the Estimation of Praseodymium(III) using 1,5-Bis-(o-aminophenol)-3-thiapentane as an Ionophore

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Abstract

This study is related with the development of Pr^{3+} selective membrane sensor using 1,5-Bis-(o-aminophenol)-3-thiapentane as a neutral carrier. The sensor with membrane composition of 33% PVC, 54%, *o*-NPOE, 8% NaTPB and 5% ionophore, exhibits a Nernstian response for Pr^{3+} ion, with a wide concentration range of 3.0×10^{-9}–1.0×10^{-2} mol/L, low detection limit (1.0×10^{-9} mol/L) and slope of 23.50.3mV decade^{-1} of activity with in pH range of 2.0–8.8 and fast response time of 7s. The sensor was also found to work satisfactorily in partially non-aqueous media up to 25% (v/v) content of methanol, ethanol or acetone and could be used for a period of 8 months without any change in response characteristics. The proposed membrane electrode was successfully applied as an indicator electrode for the titration of Pr^{3+} ion (1.0×10^{-3} M) with a standard EDTA solution (1.0×10^{-3} M).

Keywords: Praseodymium, Ionophore, 1,5-Bis-(o-aminophenol-3-thiapentane, sensor

1. Introduction

Praseodymium is a soft malleable, silvery-yellow metal in the lanthanide group. Praseodymium was separated from didymium in 1885 by Carl Auer von Welsbach along with another rare earth element neodymium. Naturally praseodymium occurs as ^{141}Pr isotope in Earth's crust (9.5 ppm). Praseodymium is usually found only in two different kinds of ores monazite and bastnäsite.[1] Praseodymium is one of the rare chemicals that can be found in houses in equipment such as colour televisions, fluorescent lamps, energy-saving lamps and used to give color to glass, ceramics, enamels, and other materials.[2] Misch metal, used in making cigarette lighters, contains about 5% praseodymium metal. Like all rare metals praseodymium is of low to moderate toxicity. Soluble praseodymium salts are mildly toxic by ingestion, but insoluble salts are non toxic, they are skin and eye irritants.[3] Praseodymium is mostly dangerous in the working environment, due to the fact that damps and gasses can be inhaled with air. This can cause lung embolisms, especially during long-term exposure. Praseodymium can be a threat to the liver when it accumulates in the human body.[3–4]

Praseodymium is dumped in the environment in many different places, mainly by petrol producing industries. It can also enter the environment when household equipment is thrown away. Praseodymium will gradually accumulate in soils and water soils and this will eventually lead to increasing concentrations in humans, animals and soil particles.[5]

In compounds praseodymium generally occurs in +3 and +4 oxidation state. Praseodymium (IV) is a strong oxidant, instantly oxidizing water to elemental oxygen (O), or hydrochloric acid to elemental chlorine (Cl). Thus, in aqueous solution, only the +3 oxidation state is encountered. There are lot of techniques for the determination of Pr^{3+} ion such as absorption spectra of *4d*-electron transitions,[6] derivative spectroscopy,[7] atomic absorption spectroscopy,[8] etc. available in the literature. However these methods are time consuming, involving sample manipulation, relatively expensive and required large infrastructure. Potentiometric sensors based on ion-selective electrodes are especially suited for such determination because they offer advantages such as selectivity, sensitivity, good precision and low cost.[9–22] A literature survey revels that few ionophores such as 1,3-diphenylpropane-1,3-diylidenebis(azan-1-ylidene)diphenol and N,N'-bis(pyridoxylideneeiminato) ethylene,[23] Npsila-(pyridin-2-ylmethylene)benzohydrazide (PBH),[24] 1,6,7,12-Tetramine-2,5,8,11-tetraoxo-1(12),6(7)-di(biphenyl)-dodecane,[25] N'1,N'2-bis(2-oxo-1,2 diphenyl ethylidene) ethanedihydrazide (BEH),[26] *N*'-(pyridin-2-ylmethylene)benzohydrazide (PBA)[27] have been used as a membrane carrier for the analysis of Pr^{3+}.

The main problem in quantitative analysis of elements belong to lanthanide family is the selectivity. Many reagents have been reported for the spectrophotometric determination of lanthanides but they have not been specific and even the most selective requires extractive separation to remove interfering elements. Hence, finding a simple device like an electrode which is able to measure one of these elements selectively is of importance. The presence of soft base sulphur (S) in the proposed ionophore (1,5-Bis(o-aminophenol)-3-thiapentane) improve the selectivity towards Pr^{3+} over wide variety of cations as compared to previously reported electrodes, and increase the response characteristics of the electrode, which is the main aim of this study

2. Experimental

2. 1. Reagents and Equipments

All the analytical grade reagents were used as purchased. 1,5-dichloro-3-thiapentane and o-aminophenol were purchased from Sigma Aldrich (Wisconsin, USA). High molecular weight poly(vinyl chloride) (PVC), oleic acid (OA), dibutyl-butylphosphonate (DBBP), dioctylphthalate (DOP), dibutylphthalate (DBP), *o*-nitrophenyl octyl ether (*o*-NPOE), tris(2-ethylhexyl)phosphate (TEP), sodium tetraphenylborate (NaTPB) tetrahydrofuran (THF), and cyclohexanone were purchased from Fluka (Ronkonkoma, NYS). All metal nitrates were also brought from Sisco research Lab. (Mumbai, India) and the stock solution of metal nitrates was obtained by dissolving weighed amounts of corresponding salt in double distilled water. Double distilled water was used throughout the investigation. All potentiometric measurements were made at 25 ± 1 °C with a digital potentiometer ECIL, Hyderabad, India (Model pH 5662) using Pr^{3+} selective membrane sensor in conjunction with an ECIL, Hyderabad, India double junction Ag/AgCl reference electrode (Model 90-02) containing 10% (w/w) potassium nitrate solution in the outer compartment. pH measurements were made on a digital pH meter (model pH 5662, ECIL, Hyderabad, India;

2. 2. Synthesis of Ionophore

The ionophore (Fig.1) 1,5-Bis(o-aminophenol-3-thiapentane was synthesized by stirring 1,5-dichloro-3-thiapentane (1 mmol in 15mL acetone) and o-aminophenol (1 mmol in 15 mL acetone) in reflux for 24 hrs. Evaporation of the solution in vacuum gave crystalline ligand which were washed with 5 mL of cooled absolute ethanol and then recrystallized from acetone-/chloroform. The analytical and physical data of the ligand are given below.

Empirical formula: $C_{16}H_{20}N_2O_2S$, yield: 73%.

Analysis: ^{1}H-NMR ($CDCl_3$, pap): δ = 9.18 (s, 2H, OH), 8.53 (d, 2H, aromatic), 3.42 (s, 2H, amine), 7.67 (t, 4H, aromatic), 6.85 (d, 2H, aromatic), 2.86 (t, 4H, CH2 aliphatic), 2.66 (t, 4H, CH2 aliphatic).

^{13}**C** NMR (CD_3CN, pap): δ = (12 C aromatic); 161.12, 160.53, 135.52, 134.46, 123.25, 122.46, 119.72, 119.62, 118.38, 117.84, 110.23, 109.95; (4C aliphatic); 32.63, 31.68, 31.23, 30.72.

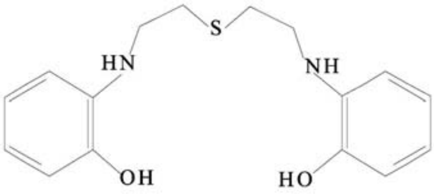

Fig. 1: 1, 5-Bis (o-aminophenol-3-thiapentane

2. 3. Preparation of Electrode

The membranes have been fabricated as suggested by Crags et al.[28]. The PVC-based membranes have been prepared by dissolving a mixture of 33% PVC, 54% plasticizer (DBBP, DBP, OA, DOP *o*-NPOE respectively), and 8% NaTPB, and 5% ionophore in 15 mL THF. The components were added in terms of weight percentage. After complete evaporation of THF a membrane sheet about 0.5 mm of thickness and 8 mm diameter was cut away and glued at one end of a glass tube with the help of araldite and M-seal to avoid leakage. The membrane electrode was finally conditioned by soaking in a 0.1 M Pr $(NO_3)_3$ solutions for 5 days. A saturated silver electrode was inserted in the tube for electrical contact and another saturated silver electrode was used as an external reference electrode.

The emf measurements were carried out with the cell assembly given below:

Internal reference Silver electrode	Internal reference solution (0.01 M Pr^{3+})	Pr^{3+}ion Selective Membrane	Test solution of Pr^{3+} ion	External reference Silver electrode

3. Results and Discussion

3. 1. Optimization of Membrane Composition and Effect of Plasticizer

Plasticizers are additives that increase the plasticity or fluidity of the material, to which they are added. The nature of plasticizer has been found to improve the sensitivity and stability of membrane sensor due to characteristics such as lipophilicity, high molecular weight, low pressure and high capacity to dissolve the substrate and other additives present in the polymeric membrane.[29] Hence several membranes of varying compositions and different plasticizers i.e. o-NPOE, DBP, DBBP, TEP, DOP and OA in PVC matrix were prepared.

The result presented in Table 1 and Fig. 1 indicates that o-NPOE plasticized the membrane, dissolve the ion association complexes and adjust both permittivity and ion exchanger sites mobility to give highest possible selectivity and sensitivity. The best result was obtained by membrane no. 1 (Table 1) using o-NPOE as plasticizer in the composition of *o*-NPOE: NaTPB: ionophore: PVC of 54: 8: 5: 33 (%, w/w).

The addition of lipophilic anionic additives in cation-selective electrodes in not only increases the behavior and selectivity but also increases the sensitivity of membrane electrode. The original motive for adding a sodium tetraphenyl borate (NaTPB) to the membrane of a Pr^{3+}-selective electrode is to reduce the anionic interference. Incorporating NaTPB in the membrane composition in the proportion of 8% (w/w) relative to the other component, showed best performance characteristics. This is due to the fact that NaTPB acts as charge compensation counter ion in the membrane sensor and thus facilitate the process of ion charge transduction.[30]

The membrane without plasticizer worked in the linear concentration range of $3.2 \times 10^{-8} - 1 \times 10^{-4}$ M with the Nernstian slope of 21.02 ± 0.30 mV/decade. The membrane No.1 exhibits significantly enhanced selectivity towards Pr^{3+} ion over the concentration range 3.0×10^{-9} to 1.0×10^{-2} M with a limit of detection 1.0×10^{-9} M and a Nernstian compliance (23.5. ± 0.3 mV $decade^{-1}$ of activity) (Fig. 2), within pH range 2.0–8.8.

3. 2. Determination of Formation Constant

Formation constant of the ion-ionophore complex within the membrane phase is very important parameter that dictates the practical selectivity of the sensor. In this work the complexation between metal cations and the ionophore were measured in terms of formation constant (K_f) using molar conductance ratio[31] (equation 1 and 2) in acetonitrile solution at 25 ± 1 °C.

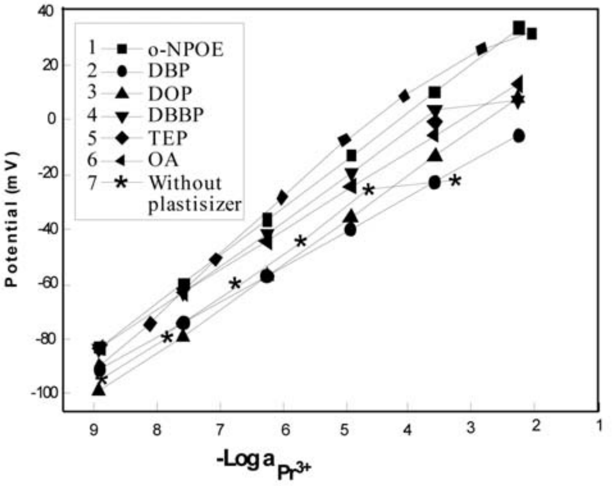

Fig. 2. Variation of potential of Pr (III) Selective membrane with different plasticizers

$$K_f = \frac{[ML^+]}{[M^+][L]} \times \frac{(\Lambda_M - \Lambda_{obs})}{(\Lambda_{obs} - \Lambda_{ML})[L]} \tag{1}$$

where

$$[L] = C_L - \frac{C_M(\Lambda_M - \Lambda_{obs})}{(\Lambda_M - \Lambda_{ML})} \tag{2}$$

Here, Λ_M is the molar conductance of the cation before addition of ligand, Λ_{ML} the molar conductance of the complex, Λ_{obs} the molar conductance of the solution during titration, C_L the analytical concentration of the ionophore added, and C_M the analytical concentration of the cation. The complex formation constants, K_f, and the molar conductance of complex, Λ_{obs}, were obtained by using a nonlinear least squares program KINFIT,[32] and the results are summarized in table 2. The value of $\log K_f$ is highest for Pr^{3+} thus the stability of complex of ionophore with

Table 1. Membrane optimization with different plasticizers

Membrane No.	Composition of membrane (%) o-NPOE	DBP	DOP	DBBP	TEP	OA	NaTPB	Ionophore	PVC	Working Concentration Range (M)	Slope (*mV decade^{-1} of activity*)	Response Time (sec)
1	54						8	5	33	3.0×10^{-9}–1.0×10^{-2}	23.50 ± 0.3	7
2		54					8	5	33	1.5×10^{-9}–1.0×10^{-2}	23.00 ± 0.3	10
3			54				8	5	33	2.6×10^{-9}–1.0×10^{-2}	23.00 ± 0.1	18
4				54			8	5	33	2.2×10^{-9}–1.0×10^{-2}	22.80 ± 0.3	16
5					54		8	5	33	1.4×10^{-9}–1.0×10^{-2}	22.50 ± 0.1	16
6						54	8	5	33	2.8×10^{-9}–1.0×10^{-2}	21.50 ± 0.3	11
7. Without plastisizer							8	5	33	3.2×10^{-8}–1.0×10^{-4}	21.02 ± 0.3	21

the tested cations follow the order of $Pr^{3+} > Yb^{3+} > Sm^{3+} > Lu^{3+} > Ce^{3+} > La^{3+} > Gd^{3+} > Nd^{3+} > Ho^{3+} > Hg^{2+} > Cu^{2+} > Co^{2+} > Eu^{3+} > Ni^{2+} > Th^{4+} > Zn^{2+} > Ag^{+} > Pb^{2+} > Mg^{2}$.

Table 2: Formation constant of metal ions-ligand (1,5-Bis(o-aminophenol-3-thiapentane)

Cation	Log K_f
Pr^{3+}	6.27 ± 0.12
Ce^{3+}	4.13 ± 0.30
Nd^{3+}	3.32 ± 0.11
Th^{4+}	2.18 ± 0.80
Eu^{3+}	2.35 ± 0.14
Cu^{2+}	2.56 ± 0.07
Zn^{2+}	1.84 ± 0.18
Mg^{2+}	1.65 ± 0.15
Co^{2+}	2.38 ± 0.12
Ni^{2+}	2.19 ± 0.09
Pb^{2+}	1.69 ± 0.11
Hg^{2+}	2.72 ± 0.13
Ag^{+}	1.73 ± 0.12
Yb^{3+}	4.73 ± 0.16
Sm^{3+}	4.20 ± 0.08
Lu^{3+}	4.16 ± 0.14
La^{3+}	3.83 ± 0.03
Gd^{3+}	3.67 ± 0.18
Ho^{3+}	3.21 ± 0.12

3. 3. pH and Non-aqueous Effect

The effect of pH on the response characteristics can be explained by coordination competition between ionophore and hydroxide ion. The influence of pH of the test solution of 1.0×10^{-2} M Pr^{3+} ion on the potentiometric response of the membrane electrode was examined in the range of 1–10. The proposed electrode work satisfactorily in the pH range of 2.0–8.8 (Fig. 3.)

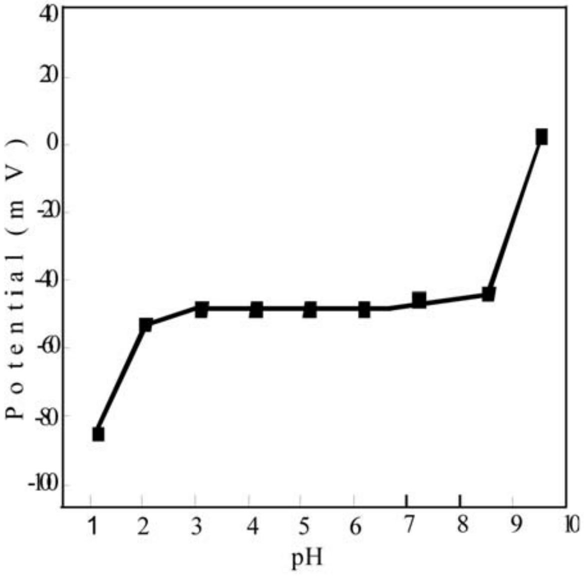

Fig. 3. Effect of pH on cell potential of membrane No. 1 for 1.0×10^{-2} M Pr^{3+} solution.

A potential change was observed at pH > 8.8, which may be due to the formation of hydroxyl complex of the cation. The proposed membrane sensor also works satisfactory in non-aqueous medium such as methanol, ethanol acetone up to 25% (v/v) solution (Table 3). But above 25% of non-aqueous content, electrode sensor showed potential drift with time.

3. 4. Static Response Time and Life Time

The average time required for the electrode to produce the static potential known as static response time. In this study, the response time was investigated by dipping method[33–36] and was measured at various concentrations (1.0×10^{-2}–1.0×10^{-5} M) of the test solution (Fig.4). The static response time of the electrode was found to be about 7 seconds in the whole concentrations. This is highly likely due to the fast complexation-decomplexation exchange kinetics of Pr^{3+} ion with the ionophore at the test solution-membrane interface. To evaluate the reversibility of the electrode, a similar procedure with increasing concentration (1.0×10^{-5}–1.0×10^{-2} M) was adapted and it was found that same curve was traced back.

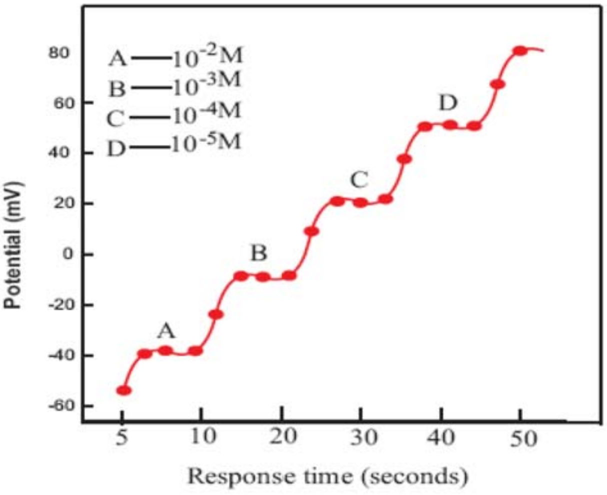

Fig. 4: Response time curve for Pr^{3+}-selective electrode.

The degradation of the sensitivity in polymeric membrane may be dependent upon the lipophilicity and chemical stability of the ionophore, which can result in the ionophore bleeding from the membrane. The membrane electrode could be used for a period of 8 months without any considerable divergence in potentials. However, it is important to emphasize that it should be stored in 1.0 M Pr^{3+} solution when not in use. After 8 months the slope and detection limit of membrane will decrease due to loss of plasticizer and/ or ion-carrier from the polymeric membrane.

3. 5. Potentiometric Selectivity

Selectivity is the most important characteristic of any electrode, which defines nature of the device and the extent to which it may be employed in the determination of a particular ion in presence of other metal ions[37]. In the present study, the selectivity of membrane sensor was detected by Fixed Interference Method (FIM) (IUPAC recommendation), and the results were presented in terms of potentiometric selectivity coefficients ($\log K^{POT}_{Pr^{3+},M^{n+}}$) which has been measured at 1×10^{-3} M concentration of metal ions using the modified the Nicolsky equation (Eq. 3).[38–39]

$$K^{POT}_{\mathrm{Pr}^{3+},M^{n+}} = \frac{a_{\mathrm{Pr}^{3+}}}{a_{M^{n+}}^{z_{\mathrm{Pr}^{3+}}/z_{M^{n+}}}} \qquad (3)$$

Where $a_{Pr}{}^{3+}$ is the activity of the primary ion and $^aM^{n+}$ is the activity of other metal ions $^zPr^{3+}$ and $^zM^{n+}$ are their respective charges. The selectivity coefficient pattern (Table 4) clearly indicates that the electrodes are efficiently selective to Pr^{3+} ions.

The value of selectivity coefficient equal to 1.0 indicates that the sensor responds equally to primary as well as other metal ions (interfering ions). However, values smaller then 1.0 indicate that membrane sensor is responding more to primary ion than to other metal ions and in such a cases the sensor is said to be selective to primary ion over other metal ions. Further, smaller is the selectivity coefficient, higher is the selectivity order.

Table 3: Effect of partially non-aqueous medium on the working of Pr^{3+} sensor (No.1)

Non-aqueous content (%v/v)	Slope (mV / decade) of activity	Working Conc. Range (M)	Response time (Sec)
0	23.5 ± 0.3	$3.0 \times 10^{-9} - 1.0 \times 10^{-2}$	07:00
Methanol			
10	23.50 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
20	23.50 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
25	23.10 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
30	18.20 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	10:00
40	17.50 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	13:00
Ethanol			
10	23.50 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
20	23.30 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
25	23.30 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
30	18.30 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	10:00
40	16.30 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	13:00
Acetone			
10	23.70 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
20	23.01 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
25	22.70 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	07:00
30	18.50 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	12:00
40	16.80 ± 0.3	$1.0 \times 10^{-8} – 1.0 \times 10^{-2}$	14:00

Table 4. Selectivity Coefficient values calculated by Fixed Interference Method

Metal Ions	Selectivity $\left[-\log K^{Pot}_{\mathrm{Pr}^{3+},M^{n+}}\right]$		Coefficient
	Fixed (FIM)	Interference	Method
Ce^{3+}	6.43		
Nd^{3+}	4.38		
Th^{4+}	4.23		
Eu^{3+}	3.82		
Cu^{2+}	2.86		
Zn^{2+}	2.83		
Mg^{2+}	2.76		
Co^{2+}	2.71		
Ni^{2+}	2.65		
Pb^{2+}	2.46		
Hg^{2+}	2.32		
Ag^{+}	1.92		
Yb^{3+}	4.6		
Sm^{3+}	3.8		
Lu^{3+}	2.9		
La^{3+}	4.8		
Gd^{3+}	4.3		
Ho^{3+}	5.2		

The value of selectivity coefficient presented in Table 4 shows that selectivity coefficient values for the present sensor are much smaller than 1.0 over a number of studied mono, di and trivalent cations. Hence, the sensor (no.1) is sufficiently selective over these ions and can therefore be used to estimate Pr^{3+} in the presence of these ions by direct potentiometry. A number of metal ion electrodes were prepared by using the proposed ionophore, but after extensive studies of selectivity coefficient and potential responses of proposed electrode towards various metal cations, it has cleared that the present ionophoric membrane electrode is extremely selective to Pr^{3+} cation (Fig. 5).

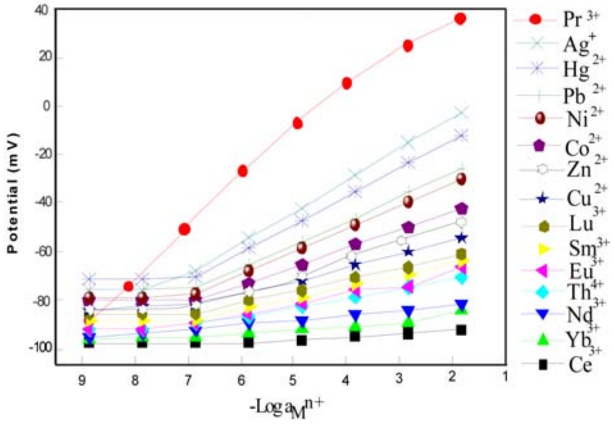

Fig. 5. Potentiometric calibration response of a PVC-based sensor using 1, 5-Bis(o aminophenol-3-thiapentane as an ionophore towards various metal ions.

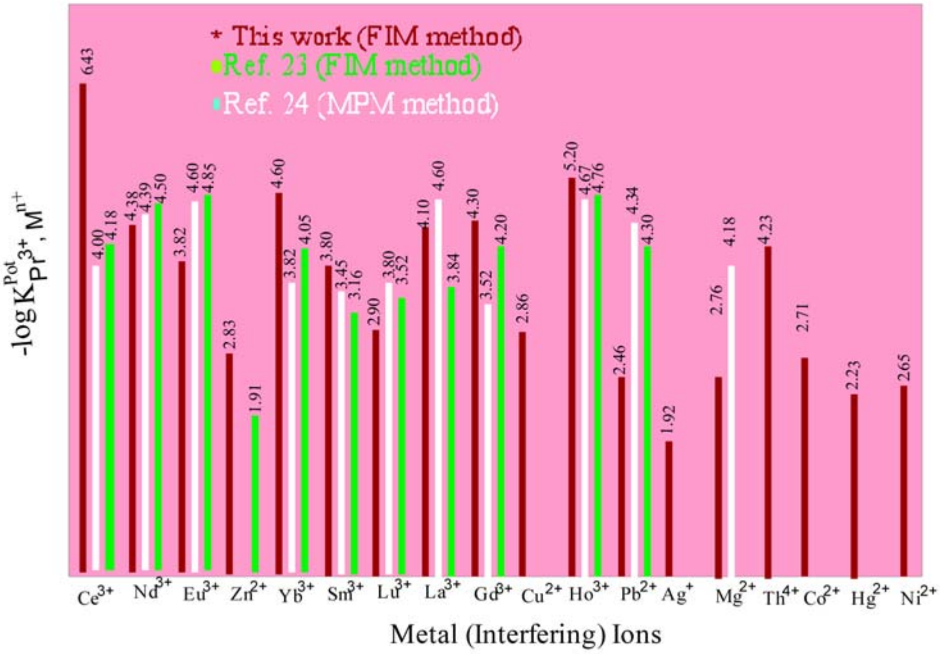

Fig. 6. Comparison of selectivity coefficient of proposed sensor with two different reported sensors

The comparison of selectivity coefficient of proposed sensor and the best two sensors available in the literature is shown in Fig. 6. This figure also indicates the high selectivity of proposed sensor toward Pr^{3+} ion over variety of metal ions.

The performance characteristics of the proposed electrode and those of some reported electrodes[23–27] were compared and it was found that the proposed electrode has wide concentration range, fast response time (7s) and long life time (8 months). The proposed membrane electrode was successfully applied as an indicator electrode for the titration of Pr^{3+} ion (1.0×10^{-3} M) with a standard EDTA solution (1.0×10^{-3} M). The resulting titration curve is shown in figure 7. It has a sharp inflection point, and the amount of Pr^{3+} ions in solution can be accurately determined.

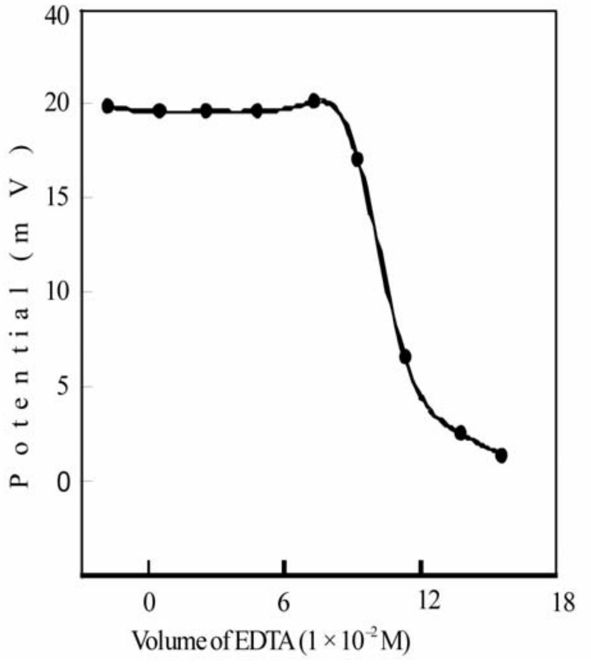

Fig. 7. Potentiometric titration curve of 10^{-3} M Pr^{3+} ion solution with 8 ml, 1×10^{-3} M EDTA solution

4. Analytical Applications

In addition, the electrode was successfully used for determination of Pr^{3+} in monazite, bastnasite and waste water of petrol-producing industries. The test solution of bastnasite and monazite was prepared by dissolving 0.40 g ores separately in 25 mL of 55% HNO_3 and the solutions were heated until the fumes were observed. 5 mL of water was added to each solution after it had been cooled to room temperature and the solutions were again heated until fumes were observed. The same treatment was repeated till the time to ensure the complete dissolution of the sample and the pH of the resulting solutions were adjusted about 3.0–7.8. Final solution was transferred into a 100 mL volumetric flask and diluted up to the mark with distilled water. Finally, 3 mL of this solution was further diluted to 500 mL in a volumetric flask with distilled water. The obtained values are quite comparable to those obtained with AAS and ICP, thereby illustrating the utility of the sensor for determining the Pr^{3+} in real samples (Table 5).

Table 5: Practical Application of proposed electrode

Sample	**Pr^{3+}-ISE (μg/L)**	**AAS (μg/L)**	**ICP (μg/L)**
Monazite	2.4	2.2	2.1
Bastnasite	12.5	12.4	12.5
Industrial waste water	11.4	11.2	11.3

5. Conclusion

The new chelate, 1,5-Bis(o-aminophenol-3-thiapentane was tested as an excellent ionophore for selective determination of Pr^{3+}. The sensor no. 1 having membrane with composition o-NPOE :PVC: Ionophore: NaTPB in ratio of 54%:33%:5%:8% (w/w), was found to perform best. Membrane electrode has good potentiometric figures of merit for the determination of Pr^{3+} ions, including high sensitivity, wide concentration range (3.0×10^{-9}–1.0×10^{-2} M), low detection limit (1.0×10^{-9} M), and fast response time (7s), with a slope of 23.5 ± 0.3 mV/decade of activity with in the pH range of 2.0–8.8. The proposed membrane electrode was successfully applied as an indicator electrode for the titration of Pr^{3+} ion (1.0×10^{-3} M) with a standard EDTA solution (1.0×10^{-3} M). The proposed membrane electrode was also used for determination of Pr^{3+} in monazite, bastnasite and waste water of petrol-producing industries. The values obtained by proposed membrane electrode are quite comparable to those obtained with AAS and ICP.

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Povzetek

Predstavljena študija opisuje razvoj za Pr^{3+} selektivnega membranskega senzorja z 1,5-bis-(*o*-aminofenol)-3-tiapentanom kot nevtralnim nosilcem. Senzor s sestavo membrane 33 % PVC, 54 % *o*-NPOE, 8 % NaTPB in 5 % ionofora daje Nernstov odziv za Pr^{3+} ion v širokem koncentracijskem območju $3{,}0 \times 10^{-9}$–$1{,}0 \times 10^{-2}$ mol/L, nizko mejo zaznave ($1{,}0 \times 10^{-9}$ mol/L) ter naklon 23,5 ± 0,3 mV na dekado aktivnosti znotraj pH območja 2,0–8,8 ter hiter odzivni čas 7 s. Ugotovili smo tudi, da senzor zadovoljivo deluje v deloma nevodnem mediju do 25 % (*v/v*) metanola, etanola ali acetona. Uporaben je 8 mesecev brez sprememb v karakteristikah odziva. Predlagano membransko elektrodo smo uspešno uporabili kot indikatorsko elektrodo za titracijo Pr^{3+} iona ($1{,}0 \times 10^{-3}$ M) s standardno raztopino EDTA ($1{,}0 \times 10^{-3}$ M).