Ion-Selective Electrode for the Determination of Iron(III) in Vitamin Formulations

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Construiu-se um eletrodo íon-seletivo de grafite-epoxi recoberto para Fe(III), baseado no par-iônico formado entre o ânion $[Fe(citrato)_2]^{3-}$ e o cátion tricaprililmetilamônio (Aliquat 336) incorporado em uma matriz de PVC (cloreto de polivinila). Uma membrana fina foi preparada pela incorporação deste par-iônico, ftalato de dibutila (DBPh) em PVC e aplicados diretamente em um tubo Perspex® contendo o condutor de grafite-epoxi. A solução de recobrimento foi preparada pela dissolução de 30% (m/m) de PVC em 10 mL de tetraidrofurano seguido da adição de 65% (m/m) de plastificante DBPh e 5% (m/m) do par-iônico. Investigou-se o efeito do pH, concentração de citrato e de alguns cátions sobre a resposta do eletrodo. O eletrodo apresentou uma resposta linear para E(mV) *vs.* $\log[Fe(citrato)_2]^{3-}$ no intervalo de concentração de ferro(III) de $1,0 \times 10^{-3}$ a $1,0 \times 10^{-1}$ mol/L em meio de citrato 1,0 mol/L, uma inclinação de $19,3 \pm 0,5$ mV/década e um tempo de vida de pelos menos 6 meses (mais de 800 determinações por cada membrana polimérica usada). O limite de detecção foi $7,5 \times 10^{-4}$ mol/L e o desvio padrão relativo foi menor de 3% para solução contendo $5,0 \times 10^{-3}$ mol/L de Fe(III) (n = 10). A aplicação deste eletrodo na determinação de ferro em amostras de vitamina é descrito. Os resultados obtidos com esse procedimento estão em concordância com aqueles obtidos usando espectrofotometria de absorção atômica (r = 0,9999).

A coated graphite-epoxy ion-selective electrode for iron(III), based on the ion-pair formed between $[Fe(citrate)_2]^{3-}$ and the tricaprylylmethylammonium cation (Aliquat 336) in a poly(vinylchloride) (PVC) matrix has been constructed. A thin membrane film of this ion-pair, dibutylphthalate (DBPh) in PVC was deposited directly onto a Perspex® tube, which contained a graphite-epoxy conductor substrate. The coating solution was prepared by dissolving 30% (w/w) of PVC in 10 mL of tetrahydrofuran following addition of 65% (w/w) DBPh and 5% (w/w) of the ionic pair. The effect of pH, citrate concentration and some cations on the electrode response has been investigated. The E(mV) *vs.* $\log[Fe(citrate)_2]^{3-}$ electrode response was linear for iron(III) concentration from 1.0×10^{-3} mol/L to 1.0×10^{-1} mol/L in 1.0 mol/L citrate medium, with a slope of 19.3 ± 0.5 mV/decade and a useful lifetime of at least six months (more than 800 determinations for each polymeric membrane used). The detection limit was 7.5×10^{-4} mol/L and the relative standard deviation was less than 3% for a solution containing 5.0×10^{-3} mol/L of iron(III) (n = 10). The application of this electrode for iron(III) determination in samples of vitamin formulations is described. The results obtained with this procedure are in close agreement with those obtained using AA spectrophotometry (r = 0.9999).

Keywords: *iron(III) ion-selective electrode, iron determination, vitamin formulations*

Introduction

Iron(II) is a constituent of hemoglobin which is essential for the normal transportation of oxygen to the tissues.

In the foods ingested during a day, approximately 10-15 mg of iron are present and studies indicate that normal subjects absorb ten per cent of iron in the food[1]. The absence of iron

in the organism causes anemia, the result of a decreased red blood cell content. This deficiency is treated with iron salts via oral or intramuscular[2] ministration. The excess of iron during treatment with iron salts may produce severe poisoning, causing symptoms of gastric irritation, vomit, pallor and circulatory collapse[3].

Liquid membrane ion-selective electrodes (ISE) in particular have much importance for the analysis of pharmaceutical products. The relatively low cost, high simplicity, selectivity and low analysis time are advantages of using ISE compared with tedious procedures suggested in the pharmacopeias[4,5].

Recently, we developed a coated graphite-epoxy iron(III) electrode[6]. A graphite-epoxy conductor was coated with the ionic pair $[Fe(oxalate)_3][Aliquat\ 336]_3$ incorporated in a PVC matrix. This electrode showed a linear response for the concentration of iron(III) from 2.9 x 10^{-6} mol/L to 1.0 x 10^{-2} mol/L and a slope of 18.7 ± 0.5 mV/dec, in a pH working range of 2-8 and in 0.3 mol/L oxalate medium. Application of this electrode for iron(III) determination in biotonic samples (Brazilian tonic formula) was described. The results obtained with this procedure were compared with those from atomic absorption spectrophotometry. The same active material was used in a tubular electrode in a flow injection system[7]. In this flow injection procedure, an increase of reproducibility, precision and analysis rate were obtained.

The present work describes the construction and application of a coated graphite-epoxy ion-selective electrode of iron(III) in citric medium. The iron(III) electrode was constructed by a prior complexation of iron(III) with citrate anion, followed by the formation of an ionic pair with tricaprylylmethylammonium cation (Aliquat 336), $[Fe(citrate)_2][Aliquat\ 336]_3$. After convenient separation, this ion-pair was incorporated in a PVC matrix onto a graphite-epoxy conductor substrate attached to the end of a Perspex[R] tube, using the same procedure previously described[6-9]. This electrode, which needs no internal reference solution or internal reference electrode, is easier and cheaper to make than the conventional PVC membranes[10,11]. The effect of pH, citrate concentration and some cations on the electrode response was investigated.

Experimental

Apparatus

All potentiometric measurements were carried out at 25 ± 0.2 °C in a thermostatted glass cell with the iron(III) ion-selective electrode and a R684 model Analion Ag/AgCl double junction reference electrode, both connected to a EA 940 model Orion pH/ion meter(USA) with ± 0.1 mV precision.

All pH measurements were made with the same pHmeter and a 10/402/3092 model Ingold glass membrane electrode(USA). Calibration curves were obtained by addition of an iron(III) standard solution in citrate medium at controlled pH, using a E274 model Metrohm microburette, to a citrate solution at the same pH and ionic strength. In the study of response time, electrode stability and lifetime, the signals were recorded on a two-channel strip-chart recorder (Cole Parmer, model 12020000-USA). A Varian model Gemini AA 12/1475 atomic absorption spectrophotometer was used for the determination of iron in the samples.

Reagents and solutions

All solutions were prepared using Millipore Milli-Q water. All chemicals were analytical reagent grade and were used without further purification.

The 0.1 mol/L iron(III) chloride stock solution was previously standardized[12], and used to prepare iron(III) reference solutions in 0.5; 1.0; 1.5 mol/L sodium citrate medium, in the pH range from 4 to 8.

Metallic cation solutions (Cd(II), Mn(II), Ni(II), Zn(II), Co(II), Cu(II), Mg(II), Ca(II), Sn(II), Hg(II), Cr(III) and Al(III)) in 5.0 10^{-3} mol/L citrate solution were prepared for potentiometric selectivity coefficient determinations.

A 0.1 mol/L tricaprylylmethylammonium cation chloroform solution was prepared by dissolving 4.0417 g of Aliquat 336 (Aldrich, 99%) in a 100 mL volumetric flask.

High-molecular weight poly(vinylchloride) (PVC, pure grade, available from Fluka), tetrahydrofuran (reagent grade, Aldrich), dibutylphthalate (Aldrich), carbon powder, epoxy resin, Perspex tube were used in the construction of the electrode.

Construction of the ion selective electrode

A sensor solution of $[Fe(citrate)_2][Aliquat\ 336]_3$, dibutylphthalate and PVC was used for preparing the membranes. Initially, 50 mL of 0.05 mol/L iron(III) in 1.0 mol/L citrate solution was shaken with 75 mL of 0.1 mol/L tricaprylylmethylammonium chloride in chloroform during 10 min. The ionic pair $[Fe(citrate)_2][Aliquat\ 336S]_3$ extracted in the organic solvent was dried with sodium sulfate and chloroform was evaporated in a rotary evaporator. The membrane solutions were prepared by dissolving 30% (w/w) of PVC in 10 ml of tetrahydrofuran (THF) following the addition of 65% (w/w) DBPh and of 5% (w/w) of the ionic pair.

The coated graphite-epoxy conductor electrodes were constructed as described elsewhere[9]. A thin membrane film was prepared embedding the ion-pair, dibutylphthalate (DBPh) and PVC (compositions shown above) onto an electrically conductive graphite-epoxy support located inside a Perspex® tube with help of a dropper; then it was dried for 3-4 h. Before use, the electrode was conditioned for 1-2 h by immersion in a 0.1 mol/L Fe(III) in 1.0 mol/L citrate solution, at the working pH (2-8), and finally rinsed with water and 1.0 mol/L oxalate solution.
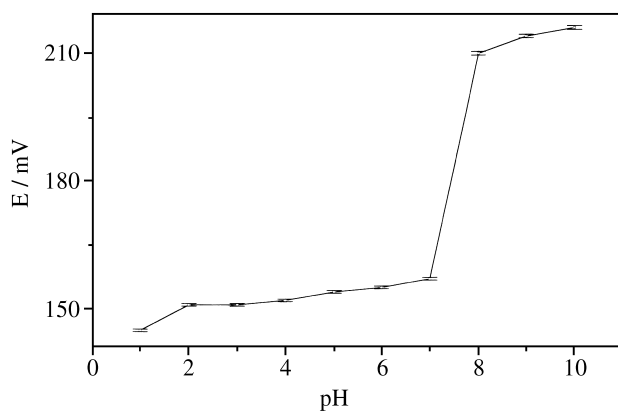
Sample preparation

For the potentiometric determination of iron(III) in two vitamin formulations (Brazilian tonic formulas), 150-300 µL of liquid samples were initially heated until dryness. Then, the samples were dissolved in 1 mL of *aqua-regia* and heated to dryness to oxidize Fe(II) to Fe(III). After that, the samples were dissolved in a 1.0 mol/L sodium citrate solution and transferred to a 50 mL volumetric flask and this volume was completed with the same solution. The percentage content of iron in this sample was determined by the standard addition method and by atomic absorption spectrophotometry[13] at a wavelength of 248.3 nm.

Results and Discussion

Effect of pH

The effect of pH on the response of the iron(III) electrode was determined in solutions with 1.0×10^{-2} mol/L Fe(III) in a 1.0 mol/L citrate solution. The pH of the solutions was altered by the addition of 2 mol/L HCl or 2 mol/L NaOH solutions.

The E *vs.* pH plot (Fig. 1) shows that there are no significant variations in the values of potential when the pH of the solution is varied between 2 and 7, which demonstrates that the iron(III) complex with citrate is sufficiently stable ($K_f = 6.3 \times 10^{37}$)[14]. For pH values less than 2 there is a decrease in potential of the electrode due to the protonation of the citrate anion. At pH higher than 7 the [Fe(cit-rate)$_2$]$^{3-}$ complexis hydrolysed, resulting in a abrupt increase of the electrode potential.

Effect of citrate concentration

Figure 2 shows the potential response of the electrode at pH 6 and citrate concentrations of 0.5; 1.0 and 1.5 mol/L as a function of log[Fe(III)]. Table 1 shows the linearity ranges, slopes (mV/dec.) and detection limits of this electrode in these media. The sensitivity of this electrode decreases with the decrease of citrate concentration (Fig. 2), due to the decreasing [Fe(citrate)$_2$]$^{3-}$ complex concentration, which can be demonstrated by the distribution of iron-citrate complexes as a function of citrate concentration (Fig. 3)[15].

Potentiometric selectivity coefficients

Potentiometric selectivity coefficients were determined by the separate solutions method following IUPAC's recommendation[16,17]. In this method the concentration of Fe(III) and interfering ion were fixed at 5.0×10^{-3} mol/L in a 1.0 mol/L citrate solution, at pH 6. The log $K^{pot}_{Fe, X}$ values (Fig. 4) were calculated using the cell potential of the iron(III) ion selective electrode *vs.* reference electrode, obtained each of two separate solutions, one containing the iron(III) ion and other containing the interfering ion. These results show a good selectivity of the ion selective electrode for all anionic complex solutions tested.

Figure 1. Effect of pH on the response of the iron(III) ion-selective electrode for iron(III) concentration of 1.0×10^{-2} mol/L in 1.0 mol/L citrate solution, at 25.0 °C.
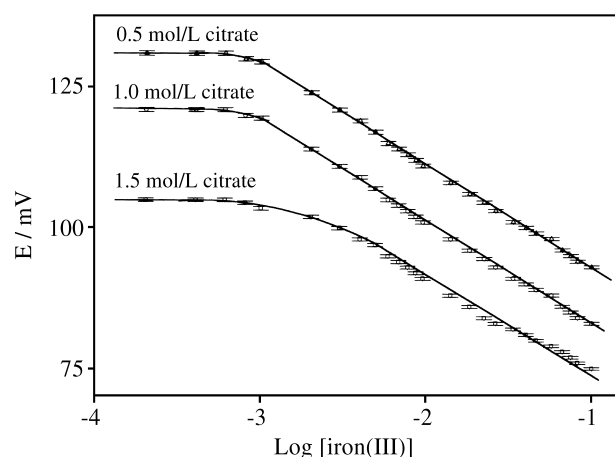

Figure 2. Effect of citrate concentration on the analytical curves of the iron(III) ion selective electrode: □□□ : 0.5 , OOO : 1.0 and ΔΔΔ: 1.5 mol/L, at pH 6.0 and 25 °C.

Table 1. Effect of citrate concentration on the response of the iron(III) ion-selective electrode, at pH 6.0.

[Citrate]	Linear range (mol/L)	slope (mV/dec)	Detection limit (mol/L)	r
0.5 mol/L	3.2×10^{-3} - 1.0×10^{-1}	-16.6 ± 1.0	1.7×10^{-3}	0.9969
1.0 mol/L	1.0×10^{-3} - 1.0×10^{-1}	-19.3 ± 0.5	7.5×10^{-4}	0.9995
1.5 mol/L	1.0×10^{-3} - 1.0×10^{-1}	-19.4 ± 0.7	8.2×10^{-4}	0.9993
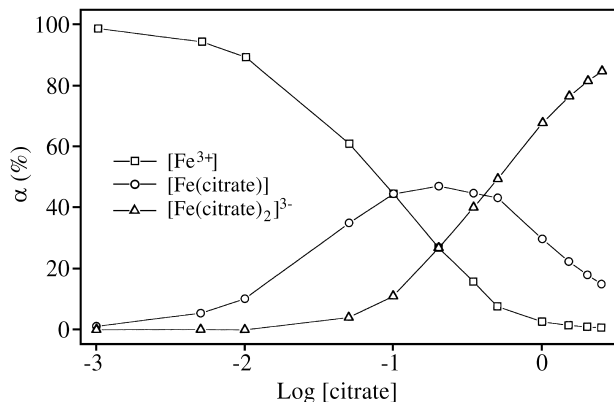
Figure 3. Distribution of iron-citrate complex as a function of citrate: ☐☐☐: α_0 ([Fe^{3+}]) OOO: α_1 ([Fe(citrate)] and $\Delta\Delta\Delta$: α_2 ([Fe(citrate)$_2$]$^{3-}$).
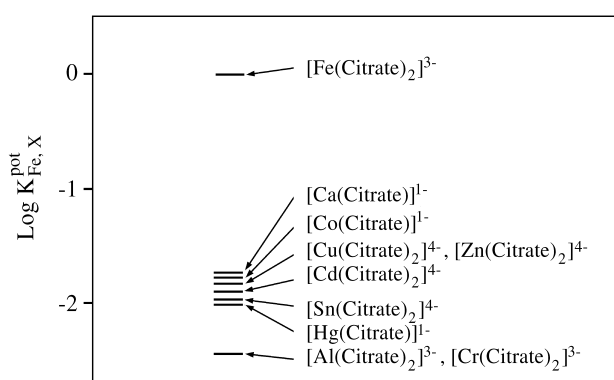

Figure 4. Potentiometric selectivity coefficients for iron(III) ion-selective electrode (log K $_{Fe,X}^{pot}$) in 1.0 mol/L citrate solution, determined by separate solutions method[16,17] at 5.0 x 10^{-3} mol/L concentration of interfering ions.

General response

Stable potentials were achieved within a few seconds (less than 5 s) and the relative standard deviation of 10 identical measurements was less than 3% for a solution containing 5.0 x 10^{-3} mol/L iron(III). No memory effect occurred for seven potential measurements in solutions containing 5.0 x 10^{-3} mol/L and 5.0 x 10^{-2} mol/L [Fe(citrate)$_2$]$^{3-}$, alternatively.

This electrode presented a useful lifetime of at least six months (more than 800 determinations/polymeric membrane) without significant loss in sensitivity.
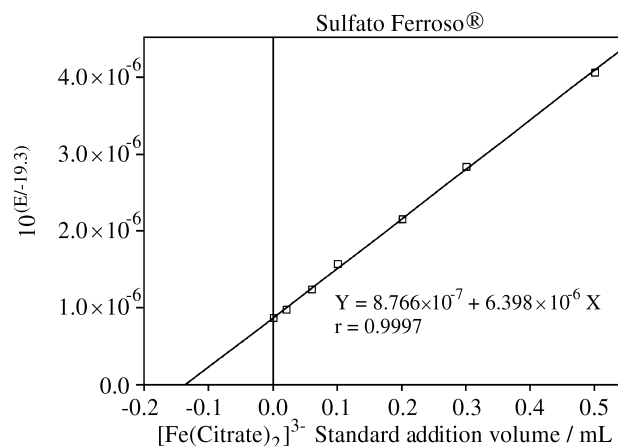
Figure 5. Determination of iron(III) in 10.0 mL of Sulfato ferroso® using the multiple-standard addition procedure.
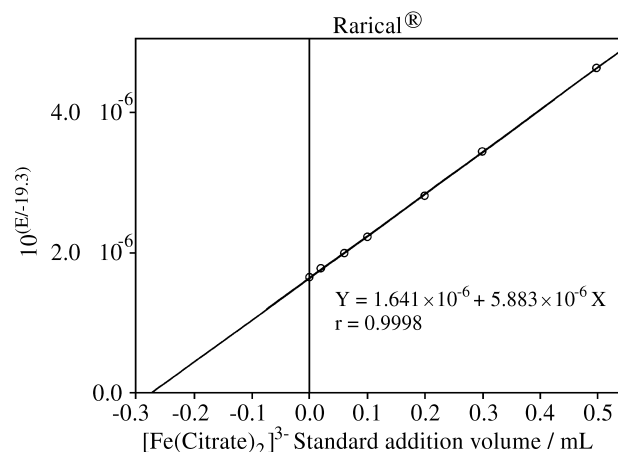
Figure 6. Determination of iron(III) in 10.0 mL of Rarical® using the multiple-standard addition procedure.

Analytical applications

Table 2 shows the results obtained for iron(III) determination in vitamin formulation samples using potentiometric (multiple-standard addition)[18] and atomic absorption spectrosphotometric methods. Figures 5 and 6 show typical plots obtained for multiple 1.0 x 10^{-1} mol/L [Fe(citrate)$_2$]$^{3-}$ standard additive procedure for sulfato ferroso® and rarical®, respectively. The results are in good agreement with those obtained by atomic absorption spec-

Table 2. Determination of iron(III) in vitamin formulations using iron(III) ion-selective electrode and atomic absorption spectrophotometric procedures.

Sample	mg of Fe/mL of samples			Relative Error (%)	
	Label value	Spectrophotometry	Potentiometry	E_1	E_2
Sulfato Ferroso®	18.3	19.0 ± 0.3	19.5 ± 1.0	6.5	2.6
Rarical®	25.0	24.7 ± 0.5	25.6 ± 1.1	2.4	3.6

n = 5, confidence level of 95%;

E_1 = potentiometry *vs.* label value;

E_2 = potentiometry *vs.* Spectrophometry.

trophotometry and are within an acceptable range of error. The samples analyzed by the standard-addition method presented recoveries close to 99% (r = 0.9999), indicating that this electrode can be used for determination of iron(III) in these samples.

Conclusions

The iron(III) ion-selective electrode which has been developed is easy to make, has a low cost, a long lifetime and good selectivity. This electrode was successfully used for iron(III) determination in vitamin formulations, and was demonstrated to be rapid and precise.

Acknowledgements

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