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USE OF TETRACYCLINE AS COMPLEXING AGENT IN ANALYTICAL CHEMISTRY(*)

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ABSTRACT

The behavior of tetracycline as complexing agent in solvent extraction studies is presented.

The extraction curves for the lanthanide elements, scandium, thorium, uranium and neptunium have been determined for the extraction system benzyl alcohol-tetracycline, as well as the acid and extractant dependences of extraction of the lanthanide elements.

Separation between uranium and neptunium has been performed by carrying out the extraction experiment at a proper pH value.

Use has been made of masking agents, namely, ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA), in order to obtain separations of uranium from scandium and lanthanides as well as of uranium and thorium, respectively.

The extraction experiments were carried out by using radioisotopes of each element, except for uranium in which case the determinations were made by using epithermal neutron activation analysis.

INTRODUCTION

The antibiotic tetracycline(TC) has been used as complexing agent for several elements[2,4,6]. Studies have been carried out in our laboratories concerning the behavior of TC as complexing agent for the lanthanide and actinide elements. Previous works dealt with the solvent extraction behavior of the complexes formed between the TC molecule and the lanthanide elements using benzyl alcohol-TC as extractant[7] and the determination of the stability constants of such complexes[8].

This paper presents the studies in connection with the variation of percentage of metal extracted into the organic phase as function of pH and of concentration of the extractant for all the 15 lanthanide elements, the use of TC-benzyl alcohol for the extraction of neptunium and the use of TC in conjunction with masking agents in order to obtain separation of uranium from lanthanides, scandium and thorium.

EXPERIMENTAL

1 – Preparation of Solutions

The radioisotopes of the lanthanide elements were obtained by irradiation of their respective oxides (Johnson Matthey) in a thermal neutron flux of about 5×10^{12} $n.cm^{-2}.sec^{-1}$ for 0.5 or 8 hours, according to the nuclear properties of each particular radioisotope. After irradiation, the oxides were dissolved in hot hydrochloric acid or perchloric acid depending on the supporting electrolite to be added to the aqueous phase, i.e., NaCl or $NaClO_4$. The solutions were then diluted to the desired

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concentrations that ranged from 10^{-4} to 10^{-5} M in metal ion. ^{147}Pm carrier-free isotope was obtained from New England Nuclear (Boston, Mass.) and suitable aliquots of the original stock solution were diluted with 0.1 N HCl solution. ^{239}Np was separated from irradiated U_3O_8. Irradiation of U_3O_8 was carried out using cadmium containers, in order to practically eliminate the thermal neutron fission of ^{235}U. The ^{239}Np carrier-free radioisotope was isolated from the uranium solutions by coprecipitation of neptunium in the +III oxidation state with lanthanum fluoride[5]. Radioactive purity of ^{239}Np radioisotope used in the solvent extraction experiments was checked by half-life determinations for which integral mode counting was carried out using a 5.0 x 4.4 cm well-type NaI(Tl) detector coupled to a single channel gamma-ray spectrometer. The half-life corresponded to 2.35 days, in agreement with the tabulated half-life of ^{239}Np. The gamma-ray spectrum obtained using a Ge-Li detector (27 cm^3 and with a resolution corresponding to 2.1 keV for the 1.33 keV photopeak of ^{60}Co) presented only the ^{239}Np photopeaks. The ^{234}Th tracer was obtained by passing an uranyl nitrate solution through a column of alumina and removing ^{234}Th with hot HCl[1].

Uranium and thorium solutions were prepared by dissolving U_3O_8 and ThO_2 with nitric acid solution.

Tetracycline hydrochloride(TC) was dissolved in benzyl alcohol (p.a. Carlo Erba) previously washed with distilled water. The concentration of TC in the alcohol was 10^{-2} M and the solution was used within six hours after its preparation.

2 – Mode of Operation

The extraction system was made up of 5.0 ml of 10^{-2} M benzyl alcohol-TC solution and 5.0 ml of the aqueous solutions of each of the radioactive lanthanide tracer (10^{-4} M to 10^{-5} M) or of the ^{239}Np carrier-free radioisotope, or of uranyl nitrate (7.0×10^{-5} M in U) or of thorium nitrate (5.0×10^{-4} M in Th).

For the study of acid and extractant dependences of the extraction of the lanthanides as well as for ^{239}Np studies the supporting electrolite was NaCl at a concentration equal to 1.0 M. In the cases where masking agents were present in the extraction system the aqueous phases were 0.1 M in $NaClO_4$.

The acid dependence of extraction of the lanthanides was studied between pH 1.50 and 3.50 and between 0.50 and 2.00 for thorium, uranium and scandium. The extractant dependence was studied for a TC concentration range varying from 1.25×10^{-3} M to 20.0×10^{-3} M. In this case the pH value at which each set of experiments for a specific lanthanide was carried out was held constant, Table I.

Table I

pH Values at Which Extractant Dependence Was Studied

Element	pH
La	3.00
Ce	3.00
Pr	3.05
Nd	2.80
Pm	2.80
Sm	2.50
Eu	2.45
Gd	2.50
Tb	2.40
Dy	2.30
Ho	2.40
Er	2.35
Tm	2.40
Yb	2.40
Lu	2.30

The masking agent, ethylenediaminetetraacetic acid (EDTA) or diethylenetriaminepentaacetic acid (DTPA), was added to the aqueous phases so that its final concentration was equal to 2.5×10^{-3} M.

The pH values of the aqueous phases were adjusted by adding dilute acid solutions (HCl or $HClO_4$) and dilute NaOH solution. Both phases were then equilibrated by shaking mechanically for 30 minutes at a temperature of 25.0 ± 0.5°C. The phases were then separated, centrifuged, the pH of the aqueous phases measured and one milliliter aliquots of both phases were withdraw for counting. Whenever there was only one radioelement present in the samples a well-type NaI(Tl) scintillation counter, coupled to a single channel analyser was used for integral mode gamma-ray counting. In the case of samples containing more than one radioelement a Ge-Li detector coupled to a 4096-channel analyser was used. A proportional gas flow counter was used to measure the activities of ^{147}Pm samples.

Concentration of uranium in both phases was determined by epithermal neutron activation analysis[3], by measuring the activity corresponding to the 74.6 keV photopeak of ^{239}U.

RESULTS AND DISCUSSION

I – Extraction Behavior of the Lanthanide Elements and Neptunium as Function of pH

Figure 1 presents the extraction curves (percent extraction (%E) x pH) for the 15 lanthanide elements besides those for thorium, uranium and scandium obtained when a 10^{-2} M benzyl alcohol-TC solution was used.

To be sure that the metals were extracted as the metal-TC complexes, experiments were carried out in which the respective tracer solutions were agitated with benzyl alcohol alone, i.e., in the absence of TC. This set of experiments was accomplished covering the pH range at which the extraction curves were obtained and all the values found for the percent extraction of metals were below 0.50%. Such values found were probably due to the slight miscibility between benzyl alcohol and water.

Figure 1 shows that it will be necessary to resort to a multi-stage extraction procedure if a separation between any pair of the lanthanide elements or between uranium and thorium is to be achieved.

Figure 2 shows the extraction curves for uranium and neptunium, considering the benzyl alcohol-TC system. It can be seen that in this case it is rather simple to obtain a good separation between uranium and neptunium by a mere choice of the pH value at which the extraction procedure is to be carried out.

To demonstrate the effectiveness of such separation procedure an extraction experiment was carried out in which the aqueous phase consisted of a solution obtained by dissolving uranium (U_3O_8) irradiated for 8 hours with thermal neutrons and let to cool for 18 hours in order to grow ^{239}Np. The organic phase was a 10^{-2} M benzyl alcohol-TC solution. The pH of the aqueous phase was adjusted to the value 1.90 and the extraction procedure was accomplished as previously described. The percentage of both metals found in the organic phase were 98.0% for U and 2.5% for Np.

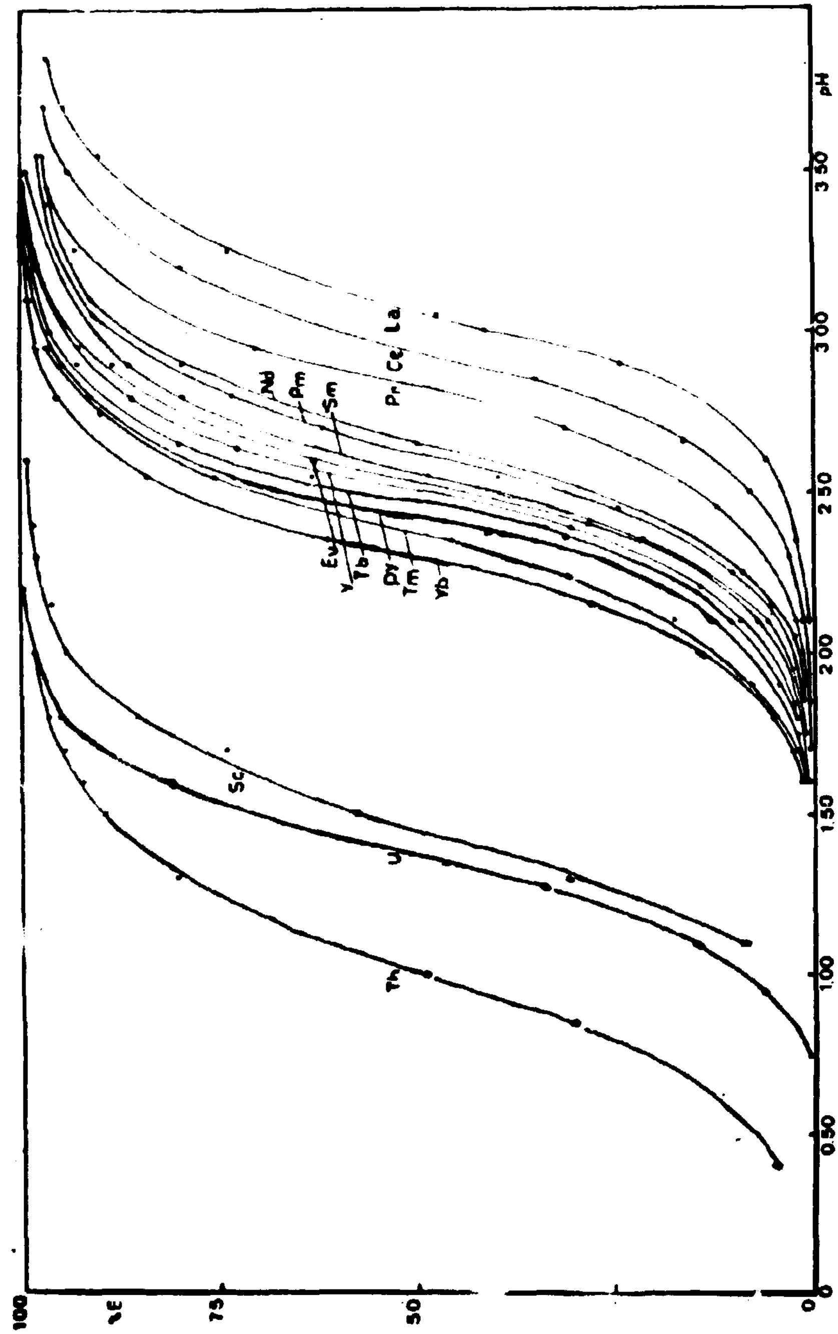

Figure 1 – Extraction Curves for Th, U, Sc and Lanthanide Elements. Concentration of:
NaCl: 1.0 M
TC: 10^{-2} M
All metal ions: 10^{-5} M

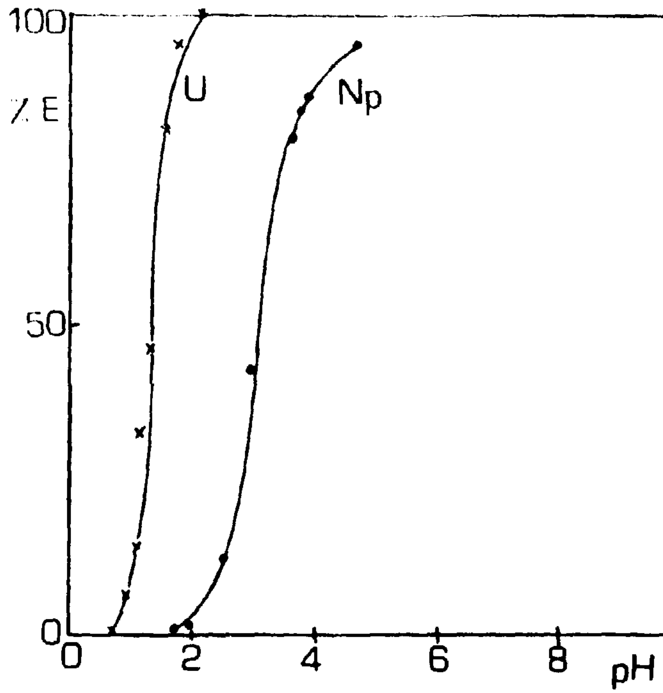

Figure 2 – Extraction Curves of U and Np. Concentration of
NaCl: 1.0 M
TC: 10^{-2} M
U: 5×10^{-5} M
^{239}Np: carrier-free

II – Acid Dependence and Multi-Stage Separation of the Lanthanides

Figure 3 presents the acid dependence of extraction of the lanthanides. The slopes of the lines obtained by plotting the logarithm of the distribution ratio (D) as function of pH, log D = a pH + b, found for each of those elements are shown in Table II.

The separation factor for any pair of lanthanides were calculated for solutions of pH equal to 2.50 giving the values, for the pairs Pr-Eu, Eu-Yb and Pr-Yb, 4.05↑ 5.38 and 21.77, respectively. Taking into account the values found, a 23-stage procedure for separation of praseodymium europium and ytterbium was carried out.

Figure 4 shows both the experimental and theoretical distribution curves. The ordinate values correspond to the fraction of element present in each tube (both phases) and the abscissa values correspond to the serial number of the tubes. The determination of such fractions has been made by counting the radioisotopes present in aliquots of both aqueous and organic phases, namely, ^{142}Pr, ^{152}Eu and ^{175}Yb. It can be seen in Figure 4 that a 23-stage process yields complete separation of the Pr-Yb pair. However, a higher number of stages is necessary in order to obtain the complete separation of the three components.

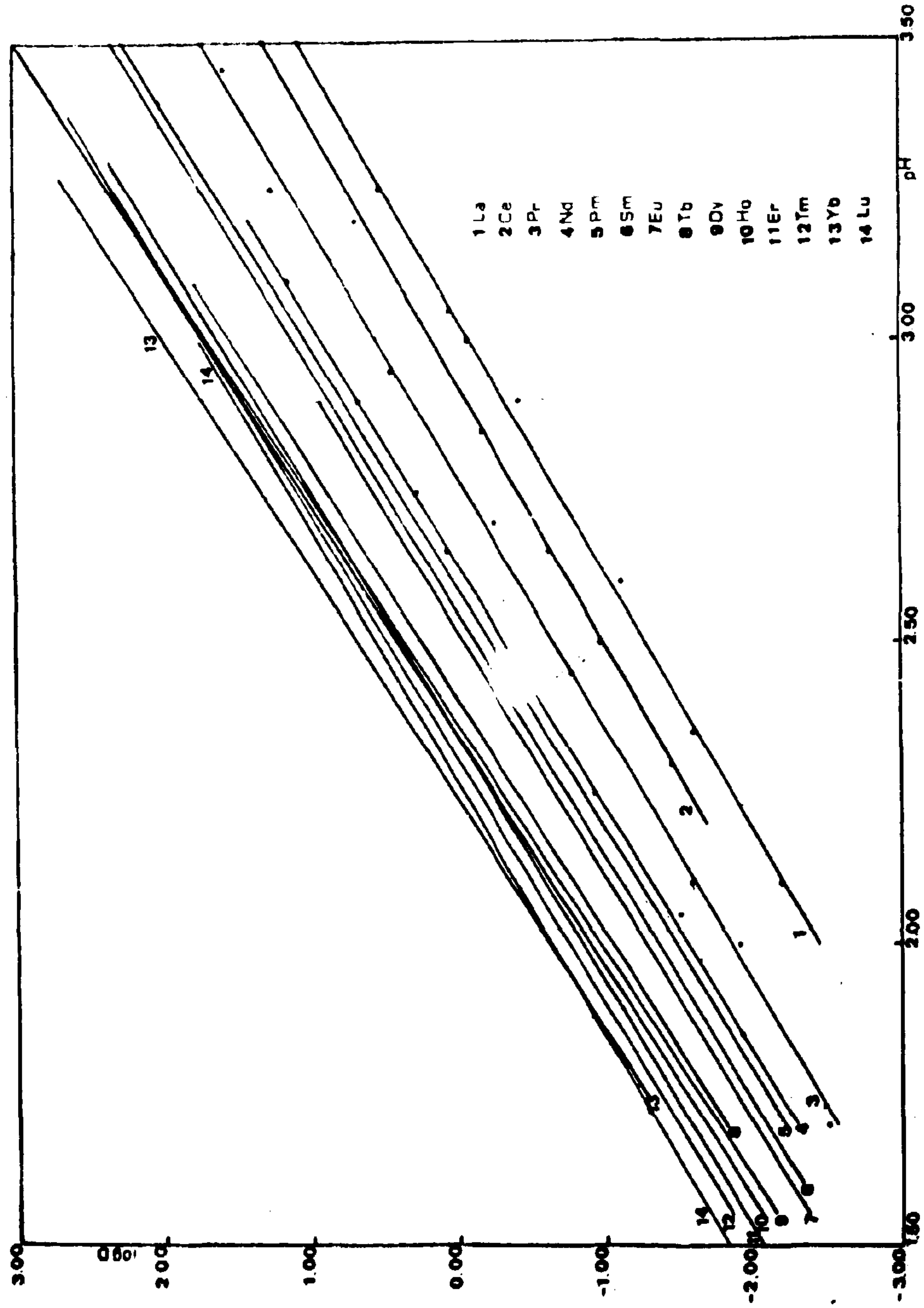

Figure 3 – pH Dependence of the Extraction of Lanthanide Ions into Benzyl Alcohol-Tetracycline
Concentration of:
NaCl: 1.0 M
TC: 10^{-2} M
Lanthanides: 10^{-5} M

Table II

Slopes of the Lines Log D = apH + b for the Lanthanide Elements

	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
a	2.36	2.31	2.39	2.47	2.50	2.46	2.46	2.48	2.57	2.66	2.59	2.46	2.45	2.61	2.37
σ_a	0.06	0.03	0.04	0.04	0.03	0.02	0.02	0.03	0.05	0.02	0.03	0.02	0.03	0.04	0.05
c.c.	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999

σ_a = Standard deviation of a.

c.c. = Correlation Coefficient.

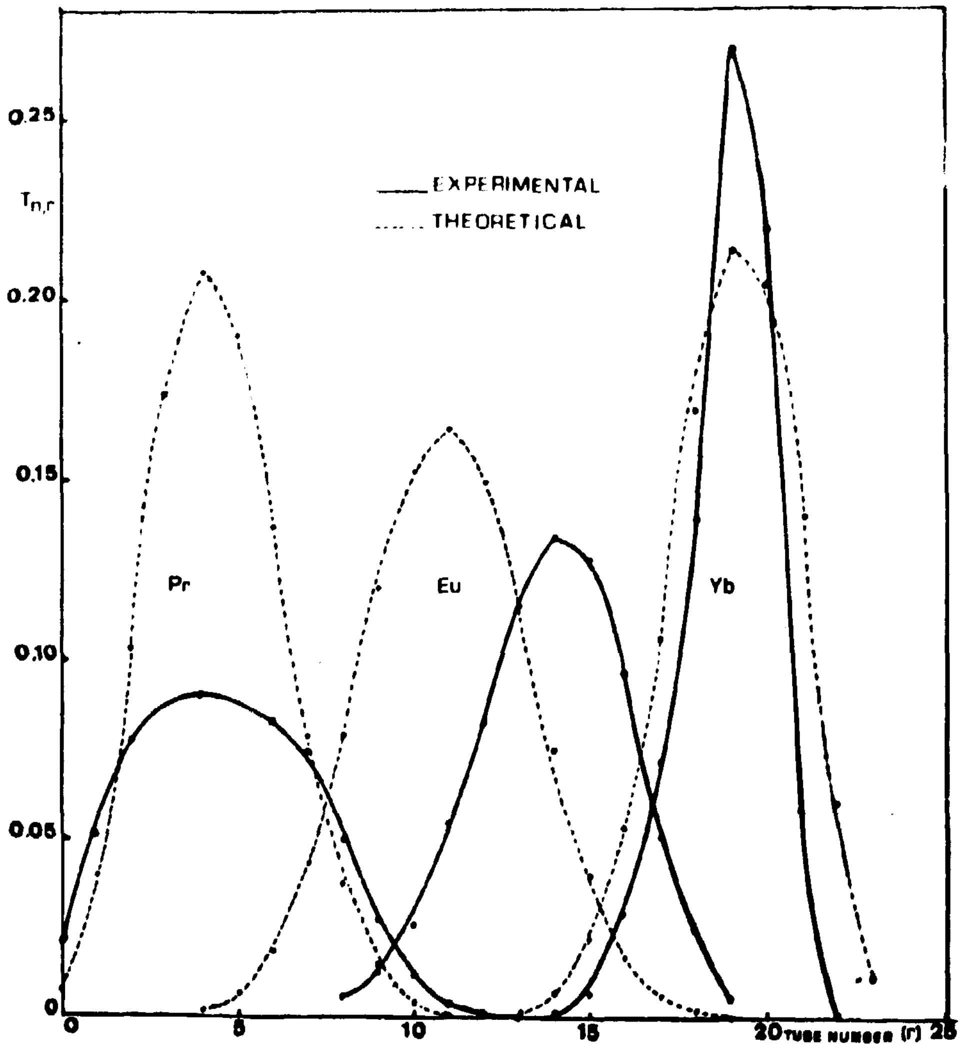

Figure 4 – Distribution Curves for Pr, Eu and Yb after a 23-Stage Extraction Procedure. pH of Aqueous solutions: 2.50

III – Extractant Dependence

The least square method was used to determine the slopes of the lines obtained by plotting the logarithm of distribution ratio (D) versus tetracycline concentration for each of the lanthanides. The values obtained are shown in Table III.

Since no hydrolysis of the lanthanide elements is likely to occur in the pH range in which the partition experiments were carried out and since it has been shown[7] that the ion Cl is not coextracted with the complex formed, the lower than 3 slopes' values found for log D as a function of pH or as a function of tetracycline concentration in the organic phases, would indicate a stepwise formation of the complexes.

IV – Separations Using Masking Agen

IV.1 – Separation of Uranium from Scandium and Lanthanu

Figure 5 shows the extraction curves for scandium, uranium, thulium, europium and lanthanum when the extraction system benzyl alcohol-TC (10^{-2} M) was used without masking agent. It can be seen in Figure 5 that separation of U from Sc, La, Eu and Tm would only be possible by use of a milti-stage extraction procedure

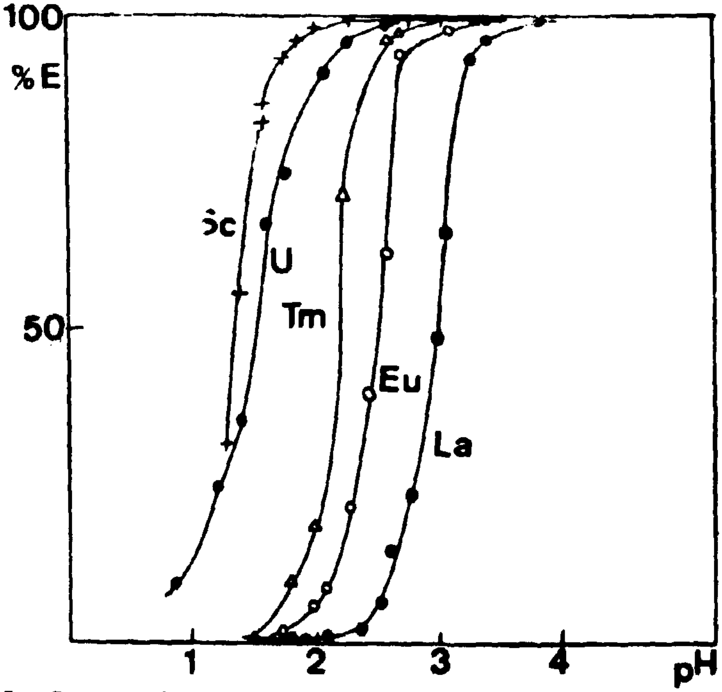

Figure 5 – Extraction Curves for U, Sc and Lanthanide Elements Using Only Benzyl Alcohol-TC Solution
Concentration of:
$NaClO_4$: 10^{-1} M
TC: 10^{-2} M
U: 7×10^{-5} M
Sc: 10^{-5} M
Lanthanides: 10^{-4} to 10^{-5} M

Table III

Slopes of the Lines Log D = a'pH + b' for the Lanthanide Elements

	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
a'	2.40	2.52	2.58	2.65	2.52	2.50	2.69	2.65	2.64	2.66	2.70	2.59	2.80	2.80	2.55
$\sigma_{a'}$	0.06	0.10	0.05	0.07	0.08	0.06	0.08	0.05	0.04	0.06	0.07	0.02	0.04	0.03	0.03
c.c.	0.997	0.994	0.999	0.997	0.996	0.997	0.996	0.999	0.999	0.998	0.998	0.999	0.999	0.999	0.999

$\sigma_{a'}$ = Standard deviation of a'.

c.c. = Correlation Coefficient.

However, masking of scandium-TC and of the lanthanides-TC reactions with EDTA with the formation of non-extractable Sc-EDTA and lanthanide-EDTA complexes, gives an excellent separation of uranium from both scandium and the lanthanides. In this case uranium is extracted into the organic phase as the uranyl TC complex while scandium and the lanthanide elements remain in the aqueous phase as non-extractable EDTA complexes. Figure 6 shows the extraction behavior of uranium, scandium and the lanthanides in the extraction system benzyl alcohol-TC plus the masking agent EDTA.

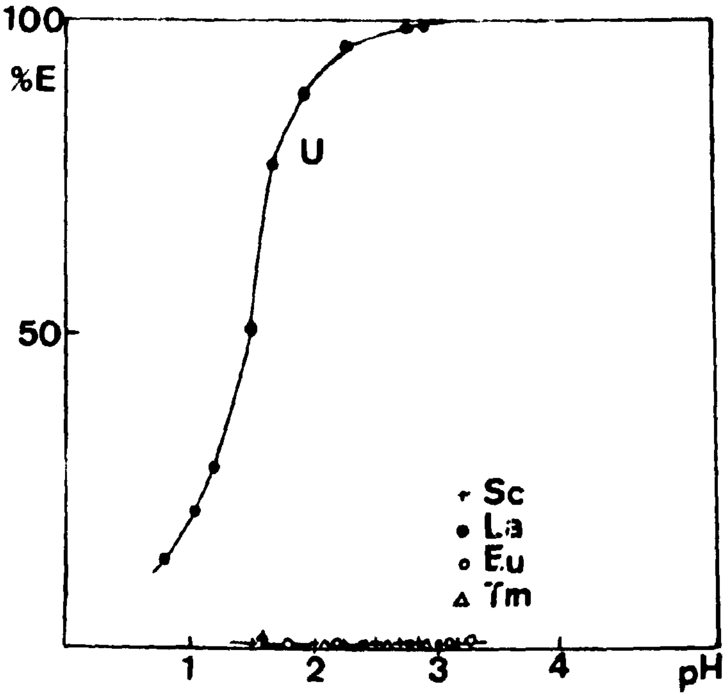

Figure 6 – Extraction Curves for U, Sc and Lanthanide Elements Using EDTA as Masking Agent.
Concentration of:
$NaClO_4$: 10^{-1} M
TC: 10^{-2} M
U: 8×10^{-5} M
Sc: 10^{-5} M
Lanthanides: 10^{-4} to 10^{-5} M
EDTA: $2,5 \times 10^{-3}$ M

The stability constants for the lanthanides-EDTA and Sc-EDTA complexes[9] are higher than the ones for the lanthanides-TC complexes[8]. Consequently, TC does not displace the lanthanides and scandium from their respective EDTA complexes, which remain in the aqueous phase while uranium is extracted into the organic phase.

IV.2 – Separation of Uranium and Thorium

Figure 7 shows the extraction curves for uranium and thorium. It can be seen in Figure 7 that separation between these two elements by pH change would be a rather inefficient method since the curves lie too close to each other.

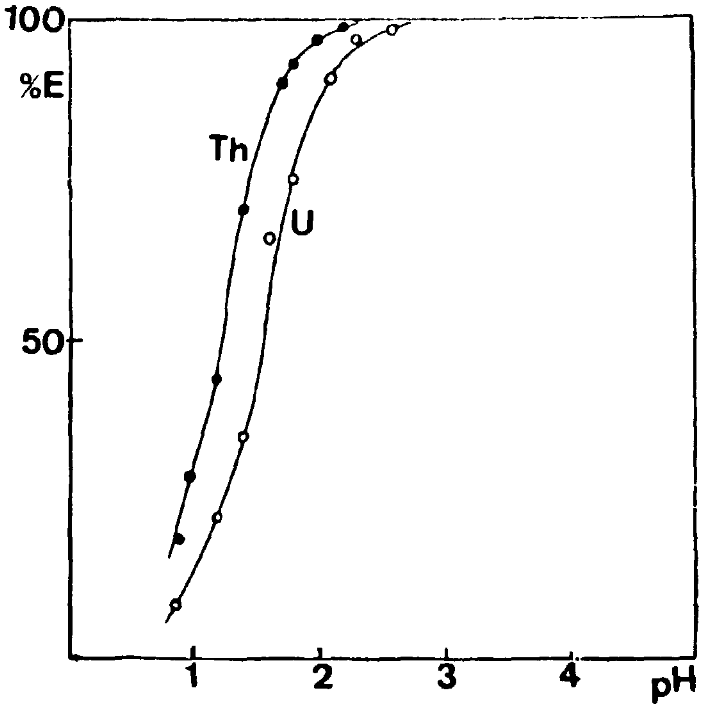

Figure 7 – Extraction Curves of Th and U Using Only Benzyl Alcohol-TC Solution. Concentration of:
$NaClO_4$: 10^{-1} M
TC: 10^{-2} M
U: 7×10^{-5} M
Th: 5×10^{-4} M

Figure 8 shows the extraction curves for uranium and thorium when EDTA was tried as the masking agent added to the benzyl alcohol-TC system. It can be seen in Figure 8 that masking of thorium-TC reaction with EDTA is not effective to prevent thorium extraction together with uranium.

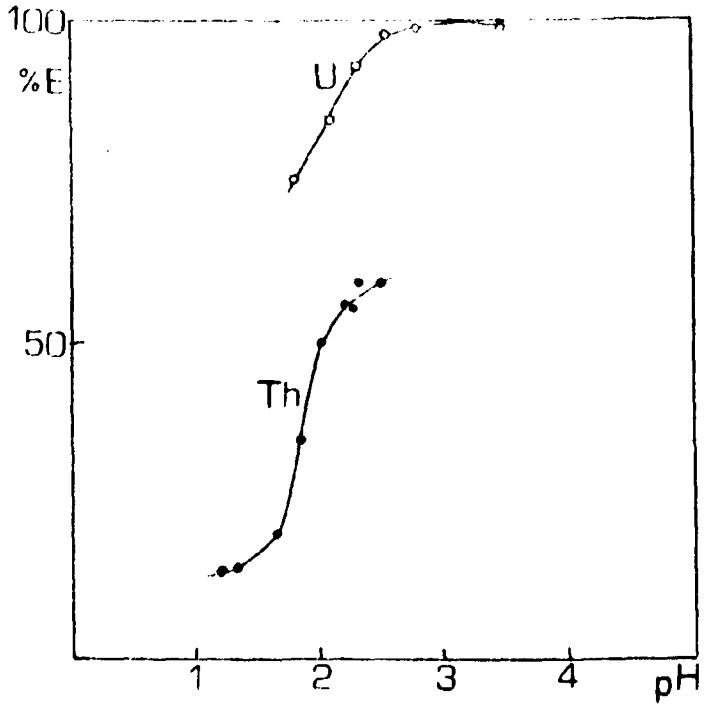

Figure 8 – Extraction Curves for U and Th Using EDTA as Masking Agent. Concentration of:
$NaClO_4$: 10^{-1} M
TC: 10^{-2} M
U: 6×10^{-5} M
Th: 5×10^{-4} M
EDTA: 2.5×10^{-3} M

However, masking of thorium-TC reaction with DTPA, forming the non-extractable Th-DTPA complex, gives an excellent separation of both metals, with thorium remaining in the aqueous phase. Figure 9 shows the extraction curves for uranium and thorium in a mixture of uranyl nitrate and thorium nitrate, when the masking agent DTPA is added to the benzyl alcohol-TC system. The pH range at which the amount of thorium extracted is practically nil lies between 2.0 and 2.6.

Although the stability constant of the complex Th-EDTA is high[9] ($\log \beta = 23.2$), thorium was partially extracted into the organic phase (benzyl alcohol-TC) under the experimental conditions described, indicating a displacement of thorium by TC from the complex Th-EDTA. Preliminary experiments has shown that the complexes Th-EDTA as well as Th-DTPA were not extracted into benzyl alcohol if tetracycline was not present in the organic phase. The same is true for the complexes uranyl-EDTA and uranyl-DTPA which are not extracted by pure benzyl alcohol.

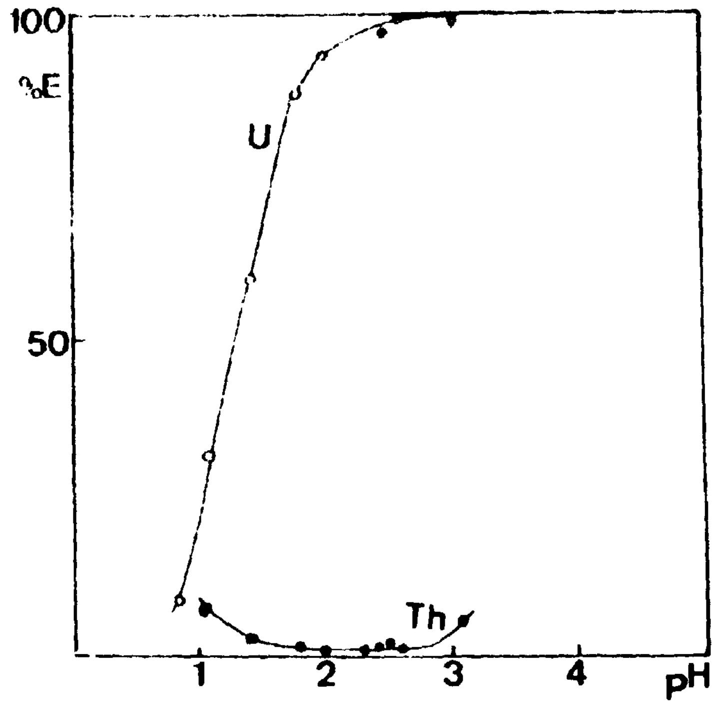

Figure 9 – Extraction Curves for U and Th Using DTPA as Masking Agent. Concentration of:
$NaClO_4$: 10^{-1} M
TC: 10^{-2} M
U: 7×10^{-5} M
Th: 5×10^{-4} M
DTPA: 2.5×10^{-3} M

The stability constant of Th-DTPA complex is rather high[9] ($\log \beta > 27$) and there is no displacement of Th by TC from Th-DTPA complex. Consequently the extraction of thorium into benzyl alcohol-TC does not take place when DTPA is present. The complex uranyl-TC is preferentially formed over uranyl-DTPA complex. The result is that uranium is extracted into the organic phase (benzyl alcohol-TC) as the complex uraniyl-TC and thorium remains in the aqueous phase as the complex Th-DTPA, which is too stable to be broken by tetracycline, allowing, in this way, a separation between thorium and uranium.

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RESUMO

São apresentadas as curvas de extração de lantanídios, escândio, tório, urânio e neptúnio considerando-se o sistema de extração formado por uma solução de tetraciclina em álcool benzílico. É também examinada a extração dos lantanídios em função do pH da fase aquosa e da concentração do agente extrator na fase orgânica.

É estudada a separação entre urânio e neptúnio pela escolha do valor adequado do pH da fase aquosa.

Os agentes mascarantes, ácido etilenodiaminotetraacético (EDTA) e dietilenotriaminopentaacético (DTPA) foram usados para obter separações entre urânio e lantanídios e entre urânio e tório, respectivamente.

Os experimentos foram realizados usando soluções dos radioisótopos dos elementos considerados, com exceção do urânio, do qual foi usada uma solução da mistura natural de isótopos, sendo que, neste caso, as determinações foram feitas pela técnica de ativação com nêutrons epitérmicos.

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