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URANIUM ISOTOPIC EFFECT STUDIES ON CATION  
AND ANION EXCHANGE RESINS

*by*

S. K. Sarpal and A. R. Gupta  
Chemistry Division

DHABHA ATOMIC RESEARCH CENTRE  
EOMBAY, INDIA

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### ABSTRACT

Uranium isotope effects in exchange reactions involving hexavalent and tetravalent uranium, on ion exchange resins, have been re-examined. The earlier work on uranium isotope effects in electron exchange reactions involving hexavalent and tetravalent uranium, has been critically reviewed. New experimental data on these systems in hydrochloric acid medium, has been obtained, using break-through technique on anion-exchange columns. The isotope effects in these break-through experiments have been re-interpreted in a way which is consistent with the anion exchange behaviour of the various uranium species in these systems.

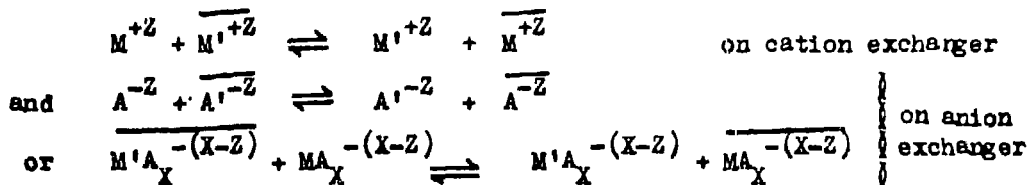
# URANIUM ISOTOPIC EFFECT STUDIES ON CATION AND ANION EXCHANGE RESINS

by

S.K. Sarpal and A.R. Gupta

## 1. INTRODUCTION

In the past twenty five years a number of studies on fractionation of isotopes by ion exchange resins have been reported. Such studies include pure ion exchange reactions as well as those involving chemical exchange. An ion exchange reaction involving isotopic exchange can be represented as



(where anionic complexes of metal ions are involved). The bars in the above equations indicate resin phase. The single stage separation factor ( $\alpha$ ) for an isotopic ion exchange reaction, represented by the above equations is usually small, e.g., in isotopic exchange of lithium<sup>(1)</sup>, sodium<sup>(2)</sup>, nitrogen<sup>(3)</sup> (as ammonium) and copper<sup>(4)</sup> ions on ion exchangers. Generally, an increase in the atomic mass of the ions, decreases  $\alpha$  and for a heavy element like uranium,  $\alpha$  for a pure ion exchange reaction should be very small. In agreement with this, negligibly small uranium isotope effect in (uranyl)<sub>resin</sub> / (uranyl)<sub>soln.</sub> exchange system has been observed by Kurihara et al<sup>(5)</sup> and Eutenberg & Drury<sup>(6)</sup>. On the other hand Spedding and coworkers<sup>(7)</sup> and Ciric<sup>(8)</sup> have reported significant values for this exchange. Kurihara and coworkers<sup>(9)</sup> have also observed that larger values of  $\alpha$  can be attained in simple ion exchange reaction if tetravalent uranium is used instead of hexavalent. However, largest isotope effects were

observed by Kakihana et al<sup>(9-13)</sup> and Shimokawa & coworkers<sup>(14-17)</sup> in ion exchange systems involving U(IV)/U(VI). Kakihana et al<sup>(5)</sup> have also given a theoretical analysis of such systems.

As the results of the system  $U(VI)_{\text{resin}} / U(VI)_{\text{soln.}}$  on cation exchanger vary, a systematic study of this system was undertaken. Two types of experiments, namely, the breakthrough and the band displacement experiments, were performed. The breakthrough experiments were carried out as functions of resin crosslinking and solution flow rate. The band displacement experiment has been performed on the lines of Ciric's work<sup>(8)</sup>. The results are reported in Section 2 of this report.

The experimental single stage separation factor values reported by Kakihana et al<sup>(9)</sup> for U(IV)/U(VI) exchange system on anion exchanger are not correct because: (i) the column capacity used for the computation of  $\alpha$  is the capacity at U(VI) breakthrough whereas the isotopic data is for the fractions at the U(IV) breakthrough; (ii) the measured isotope effect has been attributed to U(IV)/U(VI) exchange whereas at the U(IV) breakthrough (where the isotopic effect was observed) only 20% of the column is in U(IV) + U(VI) form and 80% is in pure U(IV) form. As such it was considered worthwhile to investigate this exchange system in greater detail. For this, uranium solutions of different compositions of U(IV) and U(VI) mixture were used. The composition range selected was where the highest values of isotope effects have been reported by Kakihana et al. The results are given in Section 3 of the report.

## 2. $U(VI)_{\text{resin}} / U(VI)_{\text{soln.}}$ EXCHANGE STUDIES ON CATION-EXCHANGER

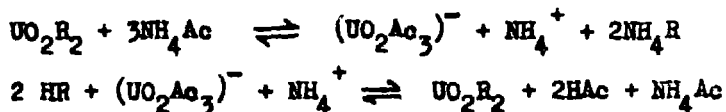
### 2.1 Breakthrough Experiments

These studies were carried out using 12 mm I.D. glass columns packed with  $H^+$  form of 100 - 200 mesh Dowex-50W resins of various cross-

linkings, using 0.5 N uranyl nitrate solution in 0.2 N HNO<sub>3</sub> at different flow rates. Chemical analysis of uranium fractions were carried out gravimetrically<sup>(18)</sup>. Sharp fronts were obtained in all the cases. Isotopic analysis was carried out mass spectrometrically. The relevant details of these experiments are given in Table I. The results show no detectable fractionation of uranium isotopes in any of the experiments.

## 2.2. Band displacement experiment

A band displacement experiment was carried out. For this 12 mm I.D. glass columns packed with H<sup>+</sup> form of Dowex-50WX8 (100 - 200 mesh) resin were used in cycle to displace an 8 cm uranyl band through 493 cm bed length with 0.25 N ammonium acetate (pH = 4.95) at a solution flow rate of 1.0 ml/min. The rate of band movement was ~ 5 cm/hr. The isotopic exchange involved is between UO<sub>2</sub><sup>2+</sup> in the resin and  $\left[ \overline{UO_2}(\text{acetate})_3 \right]^-$  in the solution phase. The rear and the front boundaries of the band remained sharp during the course of the experiment because of the following reactions at the rear and the front boundaries.



The first uranium fraction containing 4.24 mg of U was of 0.724 ± 0.003% U<sup>235</sup> and the last fraction of the band containing 2.34 mg U was of 0.721 ± 0.004% U<sup>235</sup>, the U<sup>235</sup> content of the feed uranium solution being 0.718 ± 0.002%. This confirms that the U(VI)<sub>resin</sub> / U(VI)<sub>soln.</sub> exchange does not lead to any measurable uranium isotope effects.

## 3. URANIUM ISOTOPE EFFECTS IN U(IV)/U(VI) EXCHANGE ON ION EXCHANGE COLUMNS

The uranium isotope effects in U(IV)/U(VI) exchange systems on cation as well as anion exchange columns have been reported by Kakihana and coworkers<sup>(5)</sup>. Breakthrough experiments, under a variety of conditions,

were carried out by them. As the best results were observed in anion exchange systems, these experiments on anion exchangers will be discussed in detail. For these experiments uranium solutions, containing U(IV) and U(VI) species in different proportions, in 8M HCl were used. In 8M HCl all the uranium is expected to be present in the form of anionic chloro-complexes<sup>(19)</sup>, predominantly as a species carrying two negative charges i.e. as  $(UO_2Cl_4)^{2-}$  or  $(UCl_6)^{2-}$  rather than  $(UO_2Cl_5)^-$  and  $(UCl_5)^-$ . In the rest of this report the symbols U(VI) or U(IV) would be used to represent such anionic species. A brief account of the theory of isotope effects in such experiments is given followed by a discussion of these experiments as ion exchange systems. The experimental results are also examined from the point of view of isotope effects.

### 3.1. Theoretical

The theoretical analysis of uranium isotope effects in U(IV)/U(VI) exchange systems on ion exchange columns was carried out by Kakihana et al<sup>(5)</sup>. According to this treatment, fundamental equation for the separation factor for  $^{235}U$  and  $^{238}U$  isotopes is given as

$$\ln S_S^5 = \ln(1 + \Delta t) - \ln(1 + \Delta c) + \ln(1 + \bar{\Delta}c) \quad \dots (1)$$

where  $S_S^5$  is the separation factor,  $\Delta t$  is an isotope effect caused by an isotope exchange of a certain chemical species between two phases; and  $\Delta c$  and  $\bar{\Delta}c$  are isotope effects caused by the chemical reactions in the first and second phase, respectively. Considering the specific case of U(IV) and U(VI) solutions in hydrochloric acid in equilibrium with anion exchange resins, the above equation led to the following expression for the isotope effect:

$$\ln S_S^5 = \ln S_{VI} - \ln \left[ 1 + x(K_e - 1) \right] + \ln \left[ 1 + \bar{x}(\bar{K}_e - 1) \right] \quad \dots (2)$$

where  $x$  and  $\bar{x}$  are the mole fractions of U(IV) species in the two phases



(bar now specifically represents the exchanger phase),  $S_{VI}$  (or  $S_{IV}$ ) is the separation factor with  $U(VI)$  (or  $U(IV)$ ) species only, and  $K_e$  and  $\bar{K}_e$  are the isotopic equilibrium coefficients for the electron exchange reaction in solution and exchanger phase, respectively, i.e.,



and

$$\bar{K}_e = K_e \left( \frac{S_{IV}}{S_{VI}} \right)$$

### 3.2., Anion exchange behaviour of U(IV) and U(VI) species on anion exchange columns

The selectivity behaviour of the strong base anion exchangers with reference to  $U(IV)$  or  $U(VI)$  under the experimental conditions used in the isotopes effect experiments, shows that  $U(VI)$  is the preferred anion<sup>(19)</sup>. At any specific composition of  $U(IV)$  and  $U(VI)$  in the feed solution used for the breakthrough experiment, the resin phase in equilibrium with the feed contains a much larger amount of  $U(VI)$ , e.g. with 20%  $U(VI)$  in feed, resin phase contains 75%  $U(VI)$ . At the start of the breakthrough experiment,  $U(VI)$  along with some  $U(IV)$  is absorbed by the exchanger i.e. feed solution is stripped off the  $U(VI)$  component, which is absorbed by the resin and displaces some  $U(IV)$  species. Eventually, only  $U(IV)$  species remain in the solution and form a  $U(IV)$  band in the front. Thus two separate bands are formed in the resin - rear band (first band) consists of  $U(VI)$  (as major component) and  $U(IV)$  (as minor component) and remains in chemical equilibrium with the feed solution; front band (second band) consists of only  $U(IV)$  species, which equilibrates with the  $U(IV)$  solution (which is formed from the feed solution because of preferential sorption of  $U(VI)$  species). Hence the effluent samples at the uranium breakthrough from the column, consist

of pure U(IV) species. As the experiment is continued further, first band continues to grow at the expense of the second band and eventually the whole column is converted to the composite  $\overline{U(VI) + U(IV)}$  band and the second band of pure U(IV) disappears. At this stage U(VI) breaks through the column.

3.3. Isotope effects in  $\overline{U(VI) + U(IV)}$  breakthrough experiments on anion exchange columns - a discussion of Japanese work

Kakihana et al <sup>(9)</sup> in their breakthrough experiments (described above), analysed the effluent samples at U(IV) breakthrough for their isotopic content. At that stage, upper part of the column has been converted to U(VI) + U(IV) (first band), in chemical equilibrium with the feed solution and the lower part of the column is in U(IV) form in equilibrium with the effluent. From the isotopic content of these samples, the single stage factor for the process was computed by material balance equation, using the available information regarding the uranium capacity of the column. This single stage factor was attributed to U(VI)/U(IV) exchange, i.e., this was taken as the value of  $S_{\beta}^5$ , defined in equation (2)

This interpretation and the value of the separation factor are in error. From an analysis of their data, it seems that the value of the uranium capacity of the column used by them, is the capacity at the U(VI) breakthrough (when the column is in equilibrium with the feed solution) and not the capacity at U(IV) breakthrough. The latter column capacity is usually smaller, as is shown by our data also (see later). As the isotopic analysis of the samples was carried out at U(IV) breakthrough, the uranium capacity at U(IV) breakthrough should have been used for the computation of  $\alpha$ . (Some of their  $\alpha$  values have been recalculated on this basis and are reported later.) However, their assignment of this  $\alpha$  value to the

$S_G^5$ , is more questionable.  $S_G^5$  is defined as the single stage factor for  $U(VI) - U(IV)$  exchange on anion exchangers. As has been pointed out above, at the  $U(IV)$  breakthrough (when the isotopic analysis was carried out) only a small part of the column is in the composite  $U(VI) + U(IV)$  form, which is at least in chemical equilibrium with the feed solution. (The question of isotopic equilibrium in that section of the column will be discussed later). The isotope effects arising in that section of the column should lead to  $S_G^5$ . On the other hand, at  $U(IV)$  breakthrough, when the major part of the column is in  $U(IV)$  form,  $U(IV)_{resin} / U(IV)_{soln}$  exchange should make a substantial contribution to the observed isotope effects, as the single stage factor for this exchange systems is quite appreciable. Therefore, the interpretation of observed isotope effects at  $U(IV)$  breakthrough in terms of  $S_G^5$ , as done by Kakihana et al, is wrong. Their further analysis of  $S_G^5$  values, at various  $U(IV)$ ,  $U(VI)$  feed compositions in terms of  $K_e$ , is obviously not valid.

From the above analysis, it is obvious that a clear understanding of  $U(IV) + U(VI)$  breakthrough experiments on anion exchangers, is needed before one can discuss the magnitude of the single stage separation factor,  $S_G^5$  and the isotopic equilibrium constant for the electron exchange reaction,  $K_e$ . Before discussing these questions, a brief account of our experimental work is first given.

#### 5.4. New experimental results

Kakihana and coworkers<sup>(9)</sup> had confined their experiments on  $U(IV)/U(VI)$  exchange on anion exchangers to uranium feed solutions containing up to 78%  $U(IV)$ . Accordingly, we have carried out detailed investigations on these exchange systems, containing more than 75%  $U(IV)$  in the feed

solution. The breakthrough experiments were carried out on anion exchange columns (12 mm I.D. and 120 cm resin bed height), containing  $\text{Cl}^-$  form of Dowex 1x8 (100-200 mesh). The feed solutions of varying U(IV) and U(VI) compositions, total uranium content being 0.1 M, in 8M HCl were used. Stock U(IV) and U(VI) solutions for this purpose were prepared as follows. Stock U(IV) solutions were prepared by dissolving uranium metal in HCl and were kept in a nitrogen atmosphere, in the dark<sup>(20)</sup>. U(VI) stock solutions were prepared by oxidizing U(IV) solution with  $\text{H}_2\text{O}_2$ . The anion exchange columns were first conditioned with 8M HCl and then the feed solution was passed at a flow rate of  $\sim 0.25$  ml/min. Two sharp bands were observed - the first being the yellow coloured mixed U(IV) - U(VI) band and the second one the green coloured U(IV) band. At the uranium  $\overline{\text{U(IV)}}$  breakthrough, the effluent samples were collected for chemical and isotopic analysis. The experiment was continued till the column was completely converted into the composite, U(IV) + U(VI), yellow coloured band and U(VI) appeared in the effluent uranium solution. Samples were collected for analysis at this point also. The uranium absorbed in the column was eluted by 0.1 M HCl. The eluted solution was analysed for total uranium content and its U(IV), U(VI) composition.

The chemical analysis of the uranium (IV) solutions was carried out volumetrically<sup>(21)</sup>, using standard dichromate solution. The total uranium and U(VI) contents were estimated by first reducing the U(VI) in a Jones reductor column and then titrating it as U(IV). Isotopic analysis of the uranium fractions was carried out mass spectrometrically.

The single stage factors were computed from the data by material balance, using the uranium column capacity at U(IV) breakthrough. The relevant data for the various experiments is summarized in Table III. The data of

Kakihana and coworkers on similar experiments was re-evaluated, using the column capacity at U(IV) breakthrough and is included in the same table.

The data in Table II show that there is good agreement between the present  $\alpha$  values and Japanese values for the pure U(IV) and ~78% U(IV) systems, in spite of the different resins used in the two studies. This agreement is not surprising as both the resins are strong base anion exchangers with nearly the same degree of crosslinking. From the combined data in Table II one can see that the observed separation factor has the maximum value ( 0.9980 ) at about 78% U(IV) in the feed solution. This value of  $\alpha_{obs}$  is larger than  $S_{VI}$  or  $S_{IV}$ . As explained previously, the  $\alpha_{obs}$  does not refer to U(VI)/U(IV) exchange alone because of the contribution of  $U(IV)_{resin} / U(IV)_{soln.}$  exchange to the observed isotope effects in these breakthrough experiments. Before discussing the contribution of  $S_{IV}^5$  to  $\alpha_{obs}$ , the variations in  $S_{IV}^5$  with resin or solution phase composition will be examined.

2.6. Uranium isotope effects in U(VI)/U(IV) exchange reactions in 8 M HCl on anion exchangers - theoretically expected values

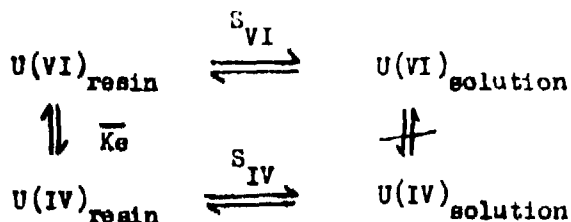
Recently a detailed study of the selectivity of a strong base anion exchanger, Dowex 1x8, towards the U(IV) and U(VI) species in 8 M HCl had been carried out in these laboratories<sup>(19)</sup>. The exchange isotherm for U(VI)/U(IV) exchange reaction on this resin was computed from the data on ternary exchange system U(VI) - U(IV) - Cl<sup>-</sup> and is given in Fig. 1. As this resin is very similar to Dowex 2x10,  $\alpha$ ,  $\bar{X}$  values from Fig. 1 have been combined with  $S_{IV}$ ,  $S_{VI}$  values in Table II to compute  $S_{IV}^5$  by equation 2 for various assumed values of  $K_1$ , for the whole range of  $\alpha$  values from 0 to 1. The results are plotted in Fig. 2. From a plot of the values of  $\alpha$ ,  $S_{IV}^5$  has a maximum value of 0.99 - 0.90. The actual separation factor, of course,

will depend upon the value of  $K_e$ . The actual value of  $S_8^5$  is not known, as  $\alpha_{obs}$  does not correspond to  $S_8^5$  (see above). Kakihana et al erroneously took it to be so. Hence, their value of  $K_e$ , obtained by comparing  $\alpha_{obs}$  with the computed values of  $S_8^5$  (equation 2), is not valid.

### 3.6. As interpretation of U(IV) + U(VI) breakthrough experiments

From the conclusions in the previous section, it is clear that the maximum contribution of  $S_8^5$  to  $\alpha_{obs}$  should be at a solution composition of 85 - 90% U(IV). The data in Table II are consistent with this expectation. The contribution of  $S_8^5$  to  $\alpha_{obs}$  can come via the composite U(VI) + U(IV) band (Band I). If in this band all the species in solution and resin phases are in isotopic equilibrium, one should expect the maximum isotope effects at U(VI) breakthrough. To verify this, the effluent samples at U(VI) breakthrough in experiment 3 (Table II) were analysed isotopically. There were indications of slight enrichment in a few samples but the effect was very small. Barring one sample which showed an isotopic composition of 0.725 atom percent  $^{235}\text{U}$ , all the other samples were in the range of 0.721 - 0.718 atom %  $^{235}\text{U}$  (natural composition being 0.718%). As the accuracy of mass-spectrometric analysis is  $\pm 0.003$  atom%, these numbers cannot be interpreted unambiguously as showing enrichment. These observations indicate that the species either in the resin or, and, solution phases are not in isotopic equilibrium. The results of the isotopic exchange kinetics in solution phase between U(IV) and U(VI) species in 8 M HCl have shown<sup>(12)</sup> that the  $t_{1/2}$  under these conditions is  $\sim 30$  hours. This means that in the time taken to complete these breakthrough experiments, U(IV) and U(VI) species do not exchange in solution phase. All the same in the feed solution U(IV) and U(VI) species must be in isotopic equilibrium, i.e.,  $^{235}\text{U}$  content of U(IV) species must be greater by a factor  $K_e$  compared to

$^{235}\text{U}$  in  $\text{U(VI)}$ . Also it is possible that  $\text{U(IV)} - \text{U(VI)}$  exchange in the resin phase is faster and contributes to the isotope effect via the following scheme:



As the feed solution goes down the column isotopic composition of  $\text{U(VI)}$  species in the resin and solution phases remain the same as  $S_{\text{VI}}$  is close to unity. Isotopic composition of  $\text{U(IV)}$  species in resin and solution changes through  $S_{\text{IV}}$  and perhaps  $\overline{K_e}$ . Effectively  $\text{U(IV)}$  species in the solution phase become increasingly richer in  $^{235}\text{U}$  as compared to its isotopic content in the feed. At the start of the experiment these enriched  $\text{U(IV)}$  species are adsorbed on the column as  $\text{U(IV)}$  band - in front of the composite  $\text{U(VI)} + \text{U(IV)}$  band. Subsequent volumes of the feed solution, after equilibration with the composite band, reach the  $\text{U(IV)}$  band. Part of the enriched  $\text{U(IV)}$  species are displaced by the  $\text{U(VI)}$  species. These displaced  $\text{U(IV)}$  species and the  $\text{U(IV)}$  in the solution phase, then reach the boundary (which travels down as the experiment progresses) of Band I and Band II, and effectively act as the feed for the  $\text{U(IV)}_{\text{resin}} / \text{U(IV)}_{\text{soln.}}$  exchange in Band II and go down the column as in a simple  $\text{U(IV)}$  breakthrough experiment. In other words, these  $\text{U(VI)} - \text{U(IV)}$  breakthrough experiments can be, in part, considered as  $\text{U(IV)}$  breakthrough experiments carried out with enriched feed solutions. The overall separation observed at  $\text{U(IV)}$  front, then depends upon the effective enrichment in  $\text{U(IV)}$  species at  $\text{U(VI)}$  front, which in turn is governed by the  $\text{U(VI)} - \text{U(IV)}$  composition of the feed solution and the effective contribution from the isotopic  $\text{U(VI)} - \text{U(IV)}$  exchange processes in resin phase (see above).

Therefore,  $\alpha_{\text{obs}}$  can not be interpreted in terms of  $S_{\text{U}}^5$ . Actually one can not get any information regarding the value of  $S_{\text{U}}^5$  from these experiments except that its value is much larger than  $S_{\text{IV}}$  or  $S_{\text{VI}}$  and contributes to the observed isotope effect at U(IV) front. The main hurdle in the determination of  $S_{\text{U}}^5$  or its more direct utilisation for enrichment purposes is still the slow rate of the U(IV) - U(VI) exchange processes in the solution phase. However, a recent study<sup>(22)</sup> on the kinetics of isotopic exchange in U(IV) - U(VI) in some other systems have reported very encouraging results. At present, we are looking into these systems from the point of view of isotope effects.

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Table I

RESULTS OF THE BREAKTHROUGH EXPERIMENTS WITH 0.5N URANYL NITRATE  
(IN 0.2 N  $\text{HClO}_3$ ) ON DOWEX-50W RESIN COLUMNS

Expt. No.	Resin (100-200 mesh)	Col. Cap. (meq. of $\text{H}^+$ )	Bed height (cm)	Soln. flow rate (ml/min)	Rate of band movement (cm/hr)	Fraction Number	Quantity of U in the fraction (mg)	$^{235}\text{U}$ content (%)
1	Dowex-50W $\times$ 4	96.2	47.2	0.97	13.20	First	26.8	$0.721 \pm 0.004$
2	Dowex-50W $\times$ 8	104.6	39.5	1.01	11.30	First	31.8	$0.720 \pm 0.003$
3	Dowex-50W $\times$ 12	132.8	40.2	1.01	9.45	First	65.1	$0.721 \pm 0.003$
4	Dowex-50W $\times$ 8	390.0	136.0	0.50	5.16	First	17.8	$0.721 \pm 0.003$
						Second	62.4	$0.719 \pm 0.004$
						Third	95.0	$0.720 \pm 0.004$
5	Dowex-50W $\times$ 8	334.0	115.0	1.03	10.70	First	38.9	$0.720 \pm 0.006$
						Second	196.5	$0.718 \pm 0.003$
6	Dowex-50W $\times$ 8	334.0	113.5	1.51	15.84	First	28.3	$0.719 \pm 0.002$
						Second	148.0	$0.721 \pm 0.005$

$^{235}\text{U}$  content of feed uranyl nitrate solution =  $0.718 \pm 0.002\%$

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Table II

URANIUM ISOTOPE EFFECTS IN U(IV)/U(VI) EXCHANGE SYSTEM IN BR 401  
ON STRONG BASE ANION EXCHANGER COLUMN

Expt. No.	U-soln. conc. (M)	Percentage of U(IV) in solution	Column capacity* for U at U(IV) breakthrough (m moles)	Percentage of U(IV) in the composite U(IV)-U(VI) band	$\alpha$
1	0.0975	100	72.45	-	0.9994
2	0.1004	93.4	76.30	49.8	0.9985
3	0.101	76.3	91.37	17.9	0.9981
4	0.0904	100	39.3	-	0.9993
5	0.1021	78	54.9	21.2	0.9980
6	0.105	63	61.1	9.0	0.9984
7	0.126	38	62.1	6.3	0.9909
8	0.100	0	-	-	1.0000

\*These capacities refer to the point upto which uranium isotopic analysis was carried out.

Note: Experiments 1-3 refer to this study on Dowex-1X8 (100-200 mesh) column of 12 mm I.D. and 120 cm bed height at solution flow rate of 14.8 ml/hr. Experiments 4-8 are by Kakihana et al<sup>(9)</sup> on Dowex-2X10 (100-200 mesh) column of 12 mm I.D. and 100 cm bed height at a flow rate of 16 ml/hr.

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10.6.75

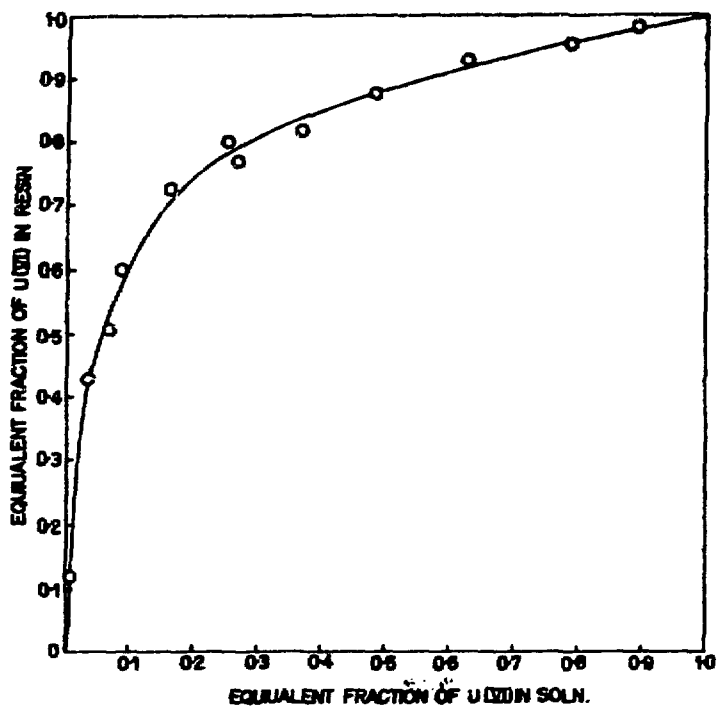


Fig. 1. SORPTION ISOTHERM FOR  $U(III)/U(IV)$  EXCHANGE ON DOWEX-1X8 (COMPUTED FROM THE TERNARY EXCHANGE  $U(III) + U(IV) + Cl$ )

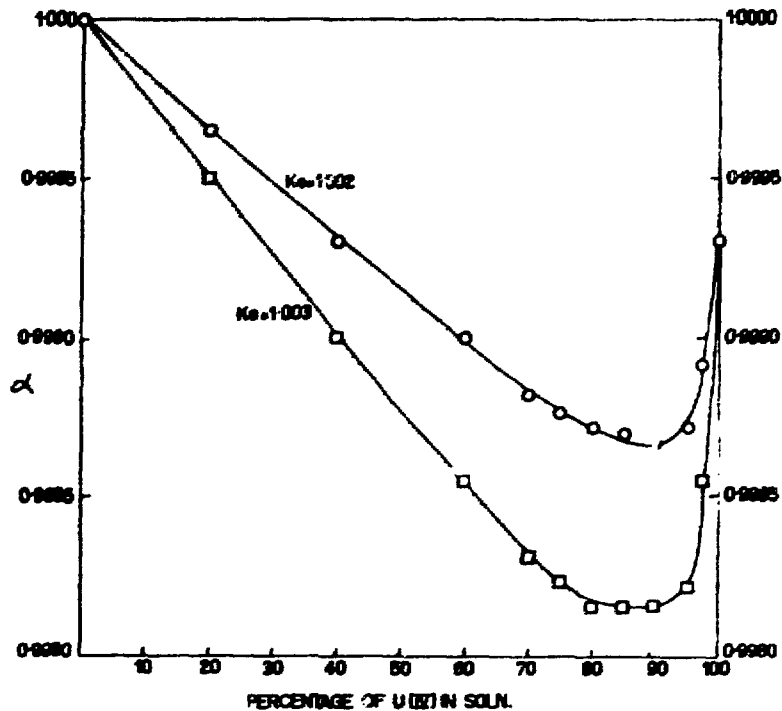


Fig. 2. VARIATION OF  $\alpha$  (FOR  $U(III)/U(IV)$  ISOTOPIC EXCHANGE IN 8M HCl ON DOWEX-1X8 RESIN) AS A FUNCTION OF PERCENTAGE OF  $U(III)$  IN SOLUTION PHASE. COMPUTED FROM EQUATION 2.