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DATA OF ION EXCHANGE

July 1977

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イオン交換データ集

日本原子力研究所ラジオアイソトープ・原子炉研修所
吾勝永子

（1977年6月28日受理）

イオン交換系における諸元素の挙動データを集め周期表の形の図で示した。図は30あり，イオン交換樹脂のほか無機イオン交換体，活性炭，シリカゲルの系のデータも含めた。

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Data of Ion Exchange

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Behavior of ion exchange of several elements are compiled as 30 figures in the sequence of periodic system. Exchangers are Dowex, Diaion and inorganic ion exchangers. Data of adsorption on charcoal and silica gel are also given.

Keywords: Ion exchange, Dowex 50, Dowex 1, Diaion, Zirconium phosphate, Adsorption, Charcoal, Silica gel, Data

Data of Ion Exchange

Ion exchange of metal complexes has been studied by many investigators from various point of view. Among these studies the part of theoretical was excellently compiled by Marcus and Kertes. They also gave some data of ion exchange together with those of solvent extraction in the style of Fig. 2, but the systems were not enough for general purpose. In this report more of the published data were compiled and illustrated in the figures that was more convenient to get situation at a glance. When data were originally given in tables, they were converted to the form of figures. The ion exchange systems taken were listed in Table 1. Some results on inorganic exchangers and adsorbents are also contained. In most cases the data were obtained by the radiochemical technique with radioactive tracers: the useful method to get data of many elements in a similar experimental conditions. Each figure was explained with reference, exchanger, aqueous phase, temperature, determination method of distribution ratio and analyses of elements. "Distribution ratio" was used here for the value defined as the amount of an element per gram exchanger/the amount of the element per milliliter of the aqueous phase, since the chemical species of an element in the resin phase should be different from that in the aqueous phase.

Data are represented in Figs. 1 - 30. Most of them are given in the sequence of the periodic system.

Table 1 List of Figures

No. of Fig.	Exchanger	Aq. phase
1	Dowex 1, x10	HCl
2	Dowex 1, x10	HCl
3	Dowex 1, x10	HNO_3
4	Dowex 1, x10	HNO_3
5	Dowex 1, x8	HNO_3
6	Dowex 1, x10	HF
7	Dowex 1, x10	HF
8	Dowex 1, x4	HF+HNO_3
9	Dowex 2, x8	H_2SO_4,H_3PO_4
10	Dowex 1, x8	HAc
11	Dowex 1, x8	HAc, HAc+HNO_3
12	Dowex 1, x8	thiocyanate
13	Dowex 50, x4	HCl
14	Dowex 50, x4	HCl
15	Dowex 50, x4	HBr
16	Dowex 50, x4	$HClO_4$
17	Dowex 50, x4	$HClO_4$
18	Diaion SKN-1	HCl
19	Diaion SAN-1	HCl
20	Diaion PA 316	HCl
20	Diaion PK 216	HCl
21	Diaion PA 306	NaCl
22	Diaion PA 306	Na_2CO_3
23	Diaion PA 306	Na_2SO_4
24	Ionite-C (Zr phosphate)	HNO_3,NH_4NO_3
25	Silica gel	HNO_3,NH_4NO_3
26	Charcoal	HNO_3,NH_4NO_3
27	Zr phosphate	pH 1, 3 and 5 by HNO_3 or NH_4OH
28	Zr molybdate	
29	Zr tungstate	
30	Hydrous Zr oxide	

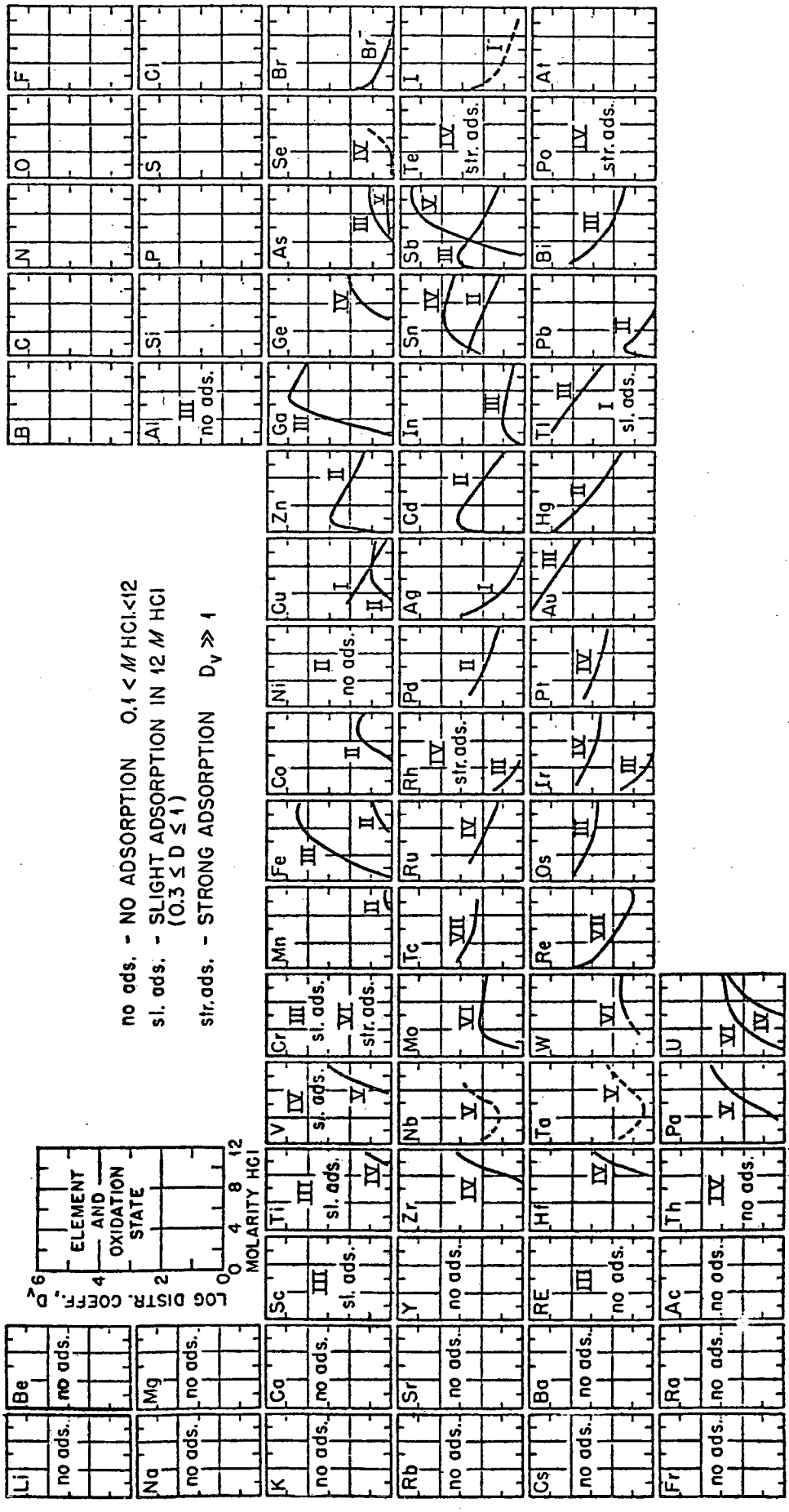

no ads. - NO ADSORPTION 0.1 < M HCl<12
sl. ads. - SLIGHT ADSORPTION IN 12 M HCl (0.3 ≤ D ≤ 1)
str. ads. - STRONG ADSORPTION $D_v \gg 1$
LOG DISTR. COEFF., D_v
ELEMENT AND OXIDATION STATE
MOLARITY HCl
0 4 8 12
0 2 4 6
Li Be B C N O F
Na Mg Al Si P S Cl
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I
Cs Ba RE Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At
Fr Ra Ac Th Pa U
no ads.
sl. ads.
str. ads.
Br^-
I^-

Fig. 1

Fig. 1 Dowex 1 - HCl system

Reference	Kraus K. A., Nelson F.:Proc. 1st Geneva Conf., 7, 113 (1956), P/837
Exchanger	Quarternary amine polystyrene divinyl benzene resin, ca. 200 mesh, 10% DVB
Aq. phase	0.1 - 12M HCl
Equilibration	Column effluent analysis, column scanning and batch equilibration
Temp.	---
Loading	About 1%
Analysis	Measurement of radioactivity for 55 elements
Distribution ratio	Dv:amount per liter of wet resin/amount per liter of soln.
Separation	(Zr,Nb) J. Am. Chem. Soc., 73, 4474 (1951) (U,Th) Bull. Chem. Soc. Japan, 29, 78 (1956)
Appendix	1, Kraus K. A., Nelson F., Clough F. B., Carlston R. C.:J. Am. Chem. Soc., 77, 1391 (1955); Mn(II) Kd=550 at 12M LiCl-0.1M HCl and Be(II) Kd=8 at 13M LiCl-0.1M HCl in Dowex 1 system 2, Bunny L. R., Ballou N. E., Pascaul J., Foti S.: Anal. Chem., 31, 324 (1959); Data of Mo(VI), Ru, Pa, Nb, Zr, U(VI), Sr, Y, Ce(III), Th and Am in Dowex 2, x8, 200-400 mesh system

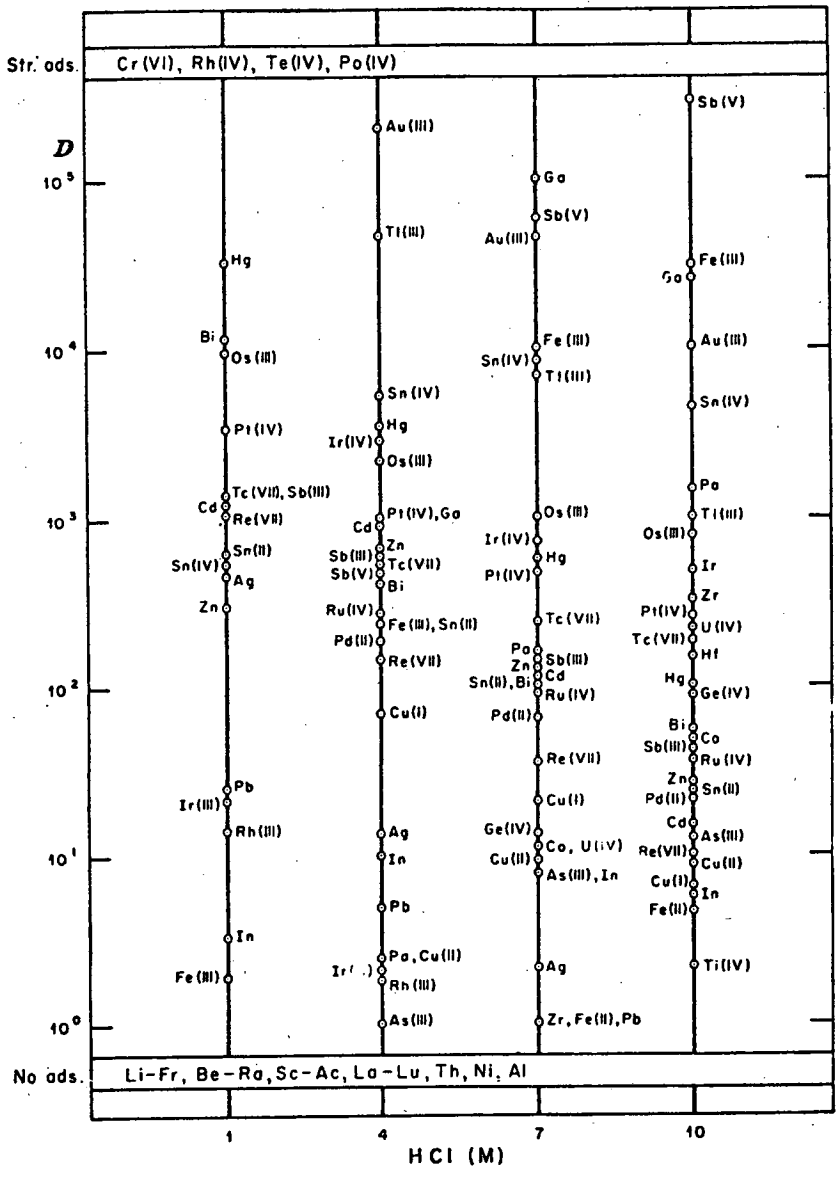


Fig. 2 Dowex 1 - HCl system

Reference Marcus K. A., Kertes A. S.:"Ion Exchange and Solvent Extraction of Metal Complexes", Wiley-Interscience, London, 940 (1969)

The other items are the same as Fig. 1.

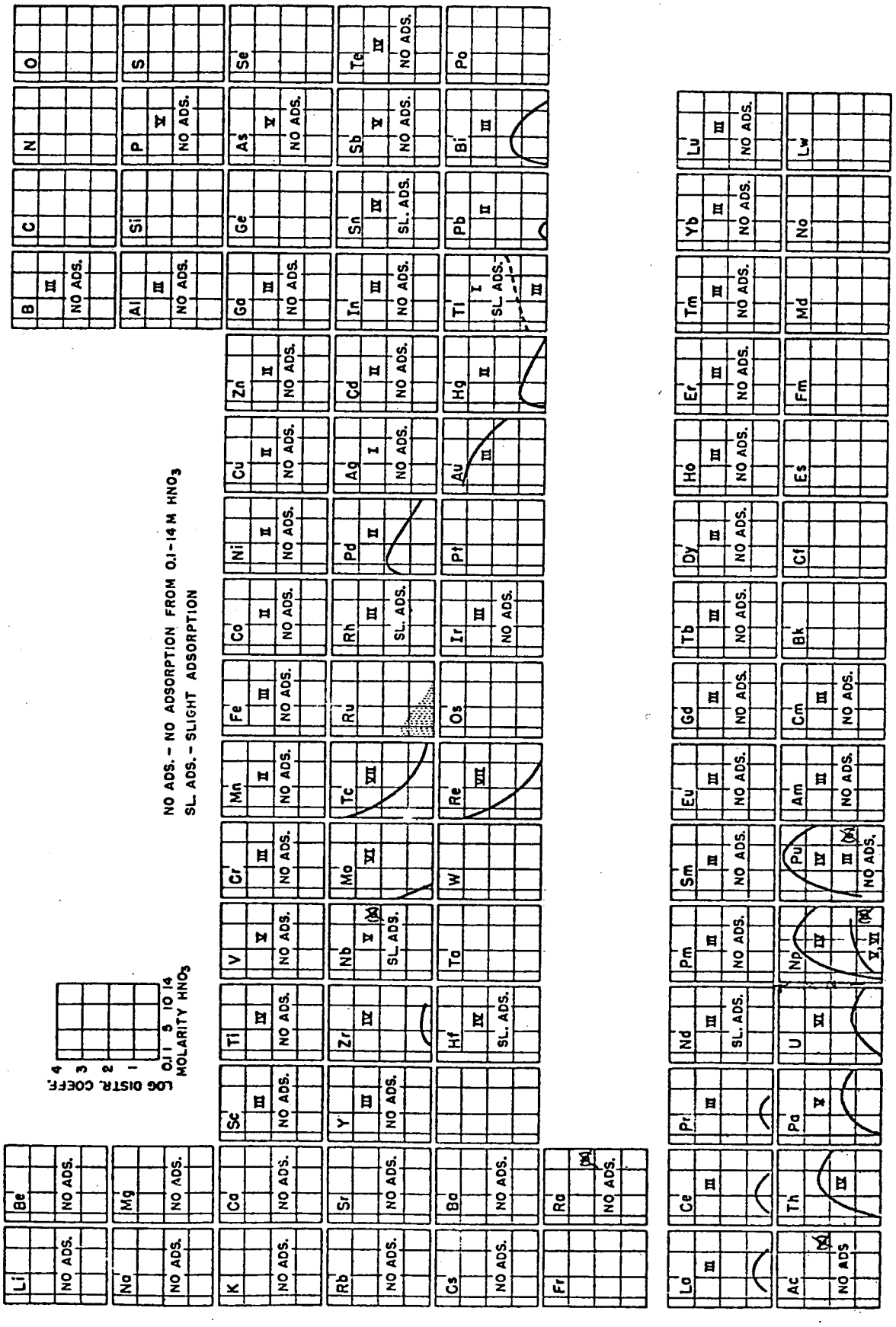

NO ADS. - NO ADSORPTION FROM 0.1-14 M HNO3
SL. ADS. - SLIGHT ADSORPTION
LOG DISTR. COEFF.
MOLARITY HNO3
0.1 1 5 10 14
4 3 2 1

Fig. 3

Fig. 3 Dowex 1 - HNO_3 system

Reference	Faris J. P., Buchanan R. F.: ANL-6811 (1964)
Exchanger	Dowex 1, x-10, 200-400 mesh, Cl form dried at 100°C, weighed and converted to nitrate form, 3 $meq.g^{-1}$
Aq. phase	0.1-14M HNO_3, exception(Np(IV) with 0.1M ferrous sulfamate)
Temp.	Room temp. (about 25°C)
Equilibration	Batch or column
Loading	Less than 1% capacity
Analysis	Emission spectrography or counting α, β, or γ radioactivity
Distribution ratio	concn. per gram dry resin/concn. per ml soln.
Appendix	Bunny L. R., Ballou N. E., Pascaul J., Foti S.: Anal. Chem., 31, 324 (1959) Data of Zr, Nb, Mo(VI), Ru, Pa, Th, U(VI), Sr, Y, Ce and Am in Dowex 2, x8, 200-400 mesh system are given.

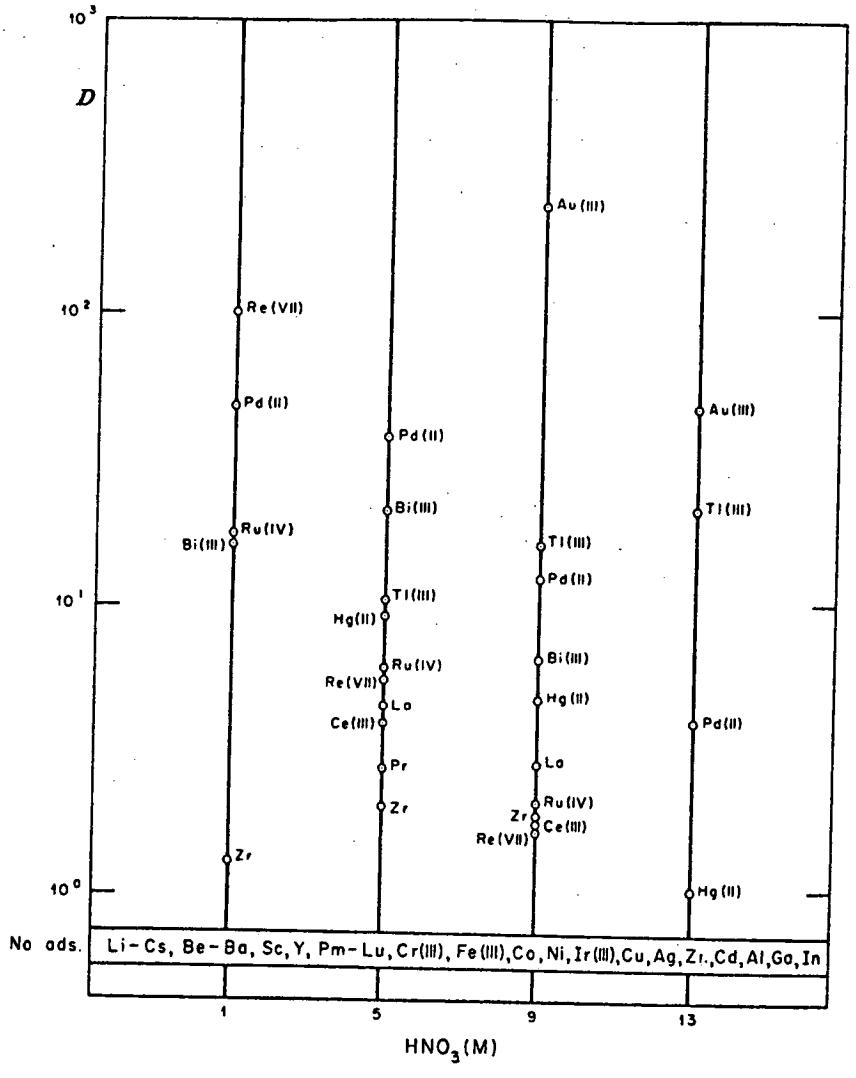


Fig. 4 Dowex 1 - HNO_3 system

Reference Marcus K. A., Kertes A. S.:"Ion Exchange and Solvent Extraction of Metal Complexes", Wiley-Interscience, London, 940 (1969)

The other items are the same as Fig. 3.

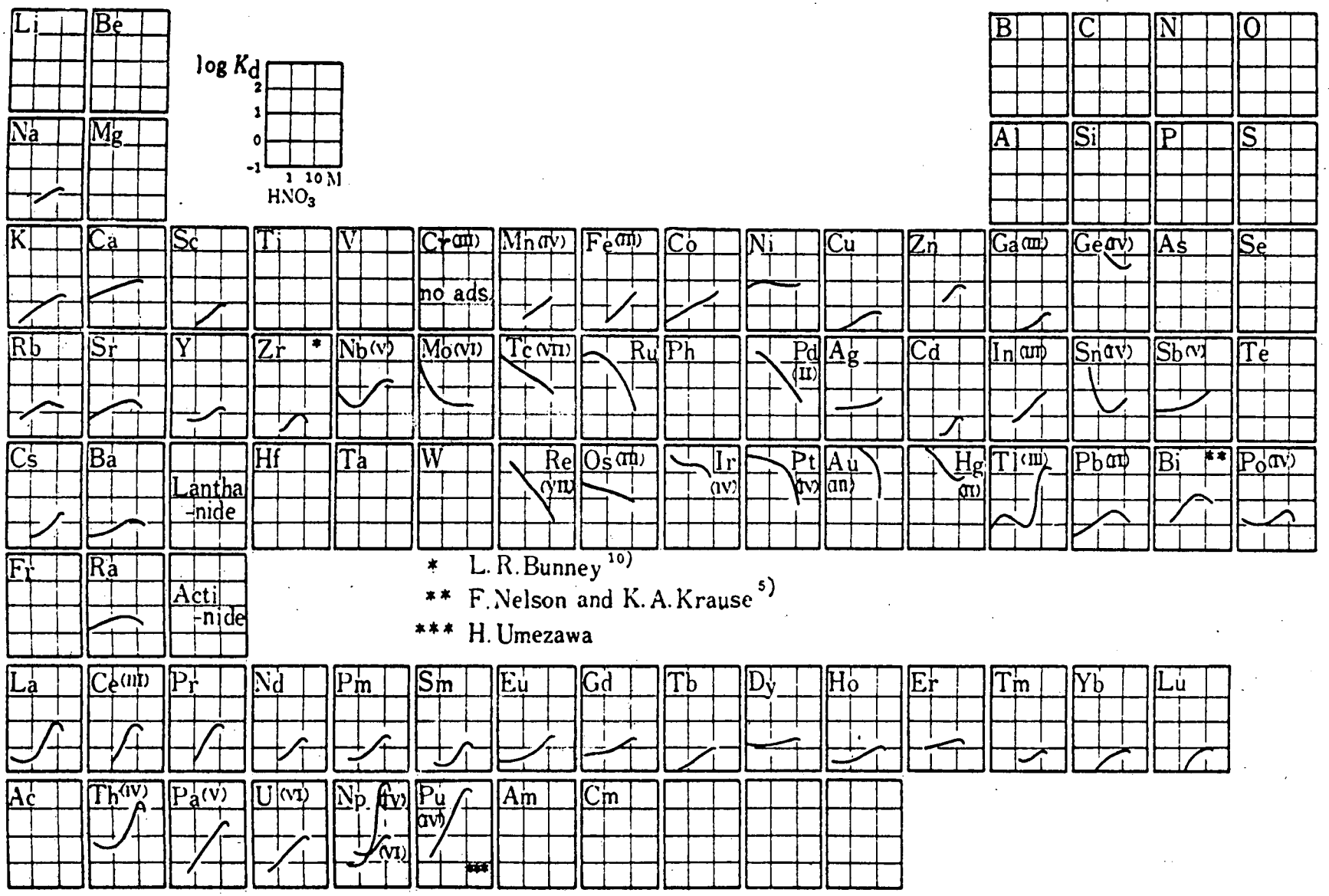

log K_d
2
1
0
-1
1 10 M
HNO_3
Li
Be
B
C
N
O
Na
Mg
Al
Si
P
S
K
Ca
Sc
Ti
V
Cr(III)
no ads.
Mn(IV)
Fe(III)
Co
Ni
Cu
Zn
Ga(III)
Ge(IV)
As
Se
Rb
Sr
Y
Zr *
Nb(V)
Mo(VI)
Tc(VII)
Ru
Rh
Pd(II)
Ag
Cd
In(III)
Sn(IV)
Sb(V)
Te
Cs
Ba
Lantha-nide
Hf
Ta
W
Re(VII)
Os(III)
Ir(IV)
Pt(IV)
Au(III)
Hg(II)
Tl(III)
Pb(II)
Bi **
Po(IV)
Fr
Ra
Acti-nide
* L. R. Bunney [10]
** F. Nelson and K. A. Krause [5]
*** H. Umezawa
La
Ce(III)
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Ac
Th(IV)
Pa(V)
U(VI)
Np(IV)
(VI)
Pu(IV)
***
Am
Cm

Fig. 5

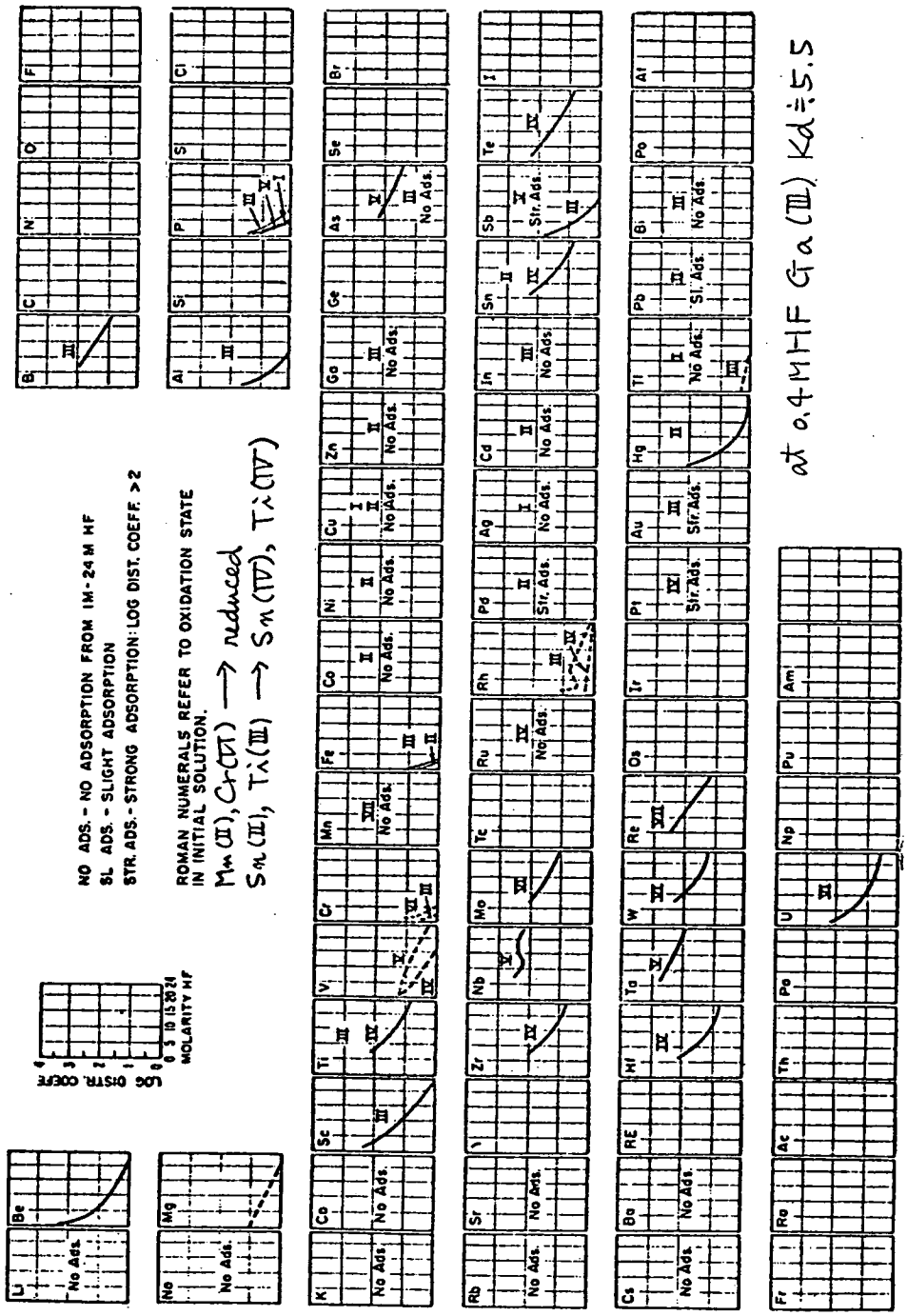

NO ADS. - NO ADSORPTION FROM 1M-24 M HF
SL ADS. - SLIGHT ADSORPTION
STR. ADS. - STRONG ADSORPTION: LOG DIST. COEFF. >2
ROMAN NUMERALS REFER TO OXIDATION STATE IN INITIAL SOLUTION.
Mn(II), Cr(VI) → reduced
Sn(II), Ti(III) → Sn(IV), Ti(IV)
LOG DISTR. COEFF.
MOLARITY HF
at 0.4MHF Ga(III) Kd≒5.5

Fig. 6

Fig. 5 Dowex 1 - HNO_3 system

Reference	Ichikawa F., Uruno S., Imai H.:Bull. Chem. Soc. Japan, 34, 952 (1961)
Exchanger	Dowex 1, x8, 100-200 mesh, nitrate form
Aq. phase	0.1-14.5M HNO_3
Equilibration	24 hrs shaking of resin and aq. soln.
Temp.	Room temp.
Loading	Tracer
Analysis	Radiometric
Distribution ratio	Kd; amount per g resin/amount per ml soln.
Separation	(Np, F.P., U) Ichikawa F.:Bull. Chem. Soc. Japan,31, 778 (1958)

Fig. 6 Dowex 1 - HF system

Reference	Faris J. P.:Anal. Chem., 32, 520 (1960)
Exchanger	Dowex 1, x10, 200 mesh, fluoride form, 3 $meq.g^{-1}$
Aq. phase	24, 20, 16, 12, 8, 4, 2, 1M HF
Equilibration	Column method
Temp.	Room temp.
Loading	10-40 μg for 2.8g resin in most cases, 500 and 0.1 μg in the cases of phosphate and beryllium
Analysis	Spectrography by copper spark method
Distribution ratio	Kd, (number of column volume at the peak of elution curve) x (volume of liq. phase in column/mass of resin)
Separation	(Nb, Ta)

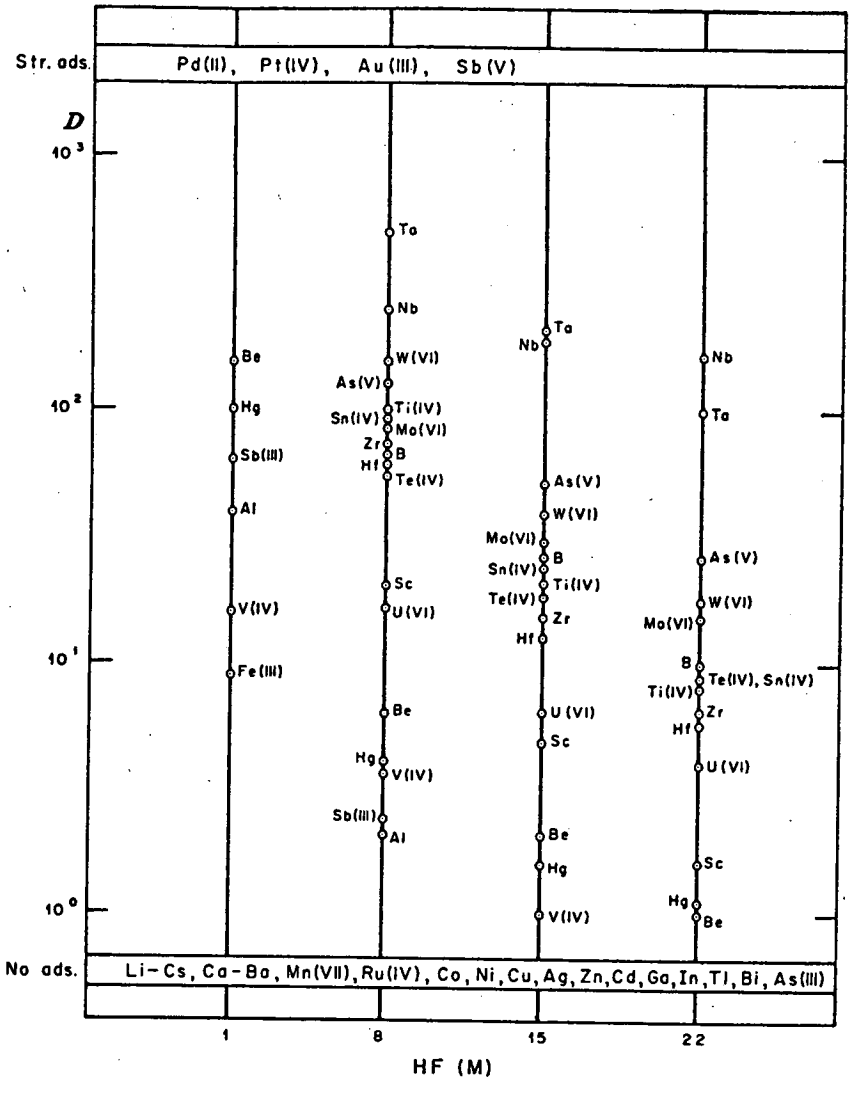


Fig. 7 Dowex 1 - HF system

Reference Marcus K. A., Kertes A. S.:"Ion Exchange and Solvent Extraction of Metal Complexes", Wiley-Interscience, London, 940 (1969)

The other items are the same as Fig. 6.

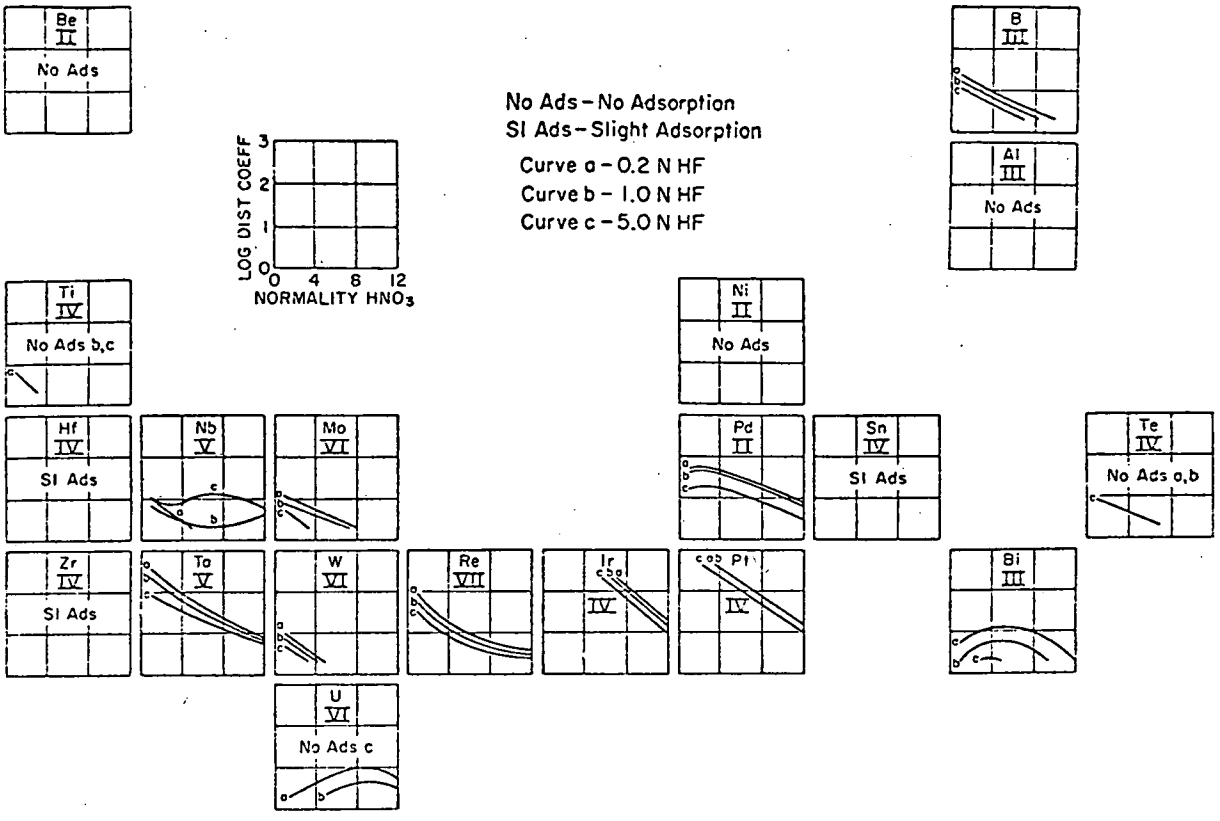


Fig. 8 Dowex 1 - HNO_3+HF system

Reference Huff E. A., Anal. Chem., 36, 1921 (1964)

Exchanger Dowex 1, x4, 100-200 mesh, nitrate form

Aq. phase 1, 3, 5, 8, 12M HNO_3 + 0.2, 1.0 or 5.0M HF

Equilibration Column method

Temp. ---

Loading 0.1 ml of 200-1000 $\mu g.ml^{-1}$ soln. was used

Analysis Copper spark method

Distribution ratio Kd = V/m

V:the volume in milliliters at which an element appears at its maximum concentration(corrected for the interstitial column volume)

m:the weight of the dry resin in grams

Separation Impurities in Tantalum

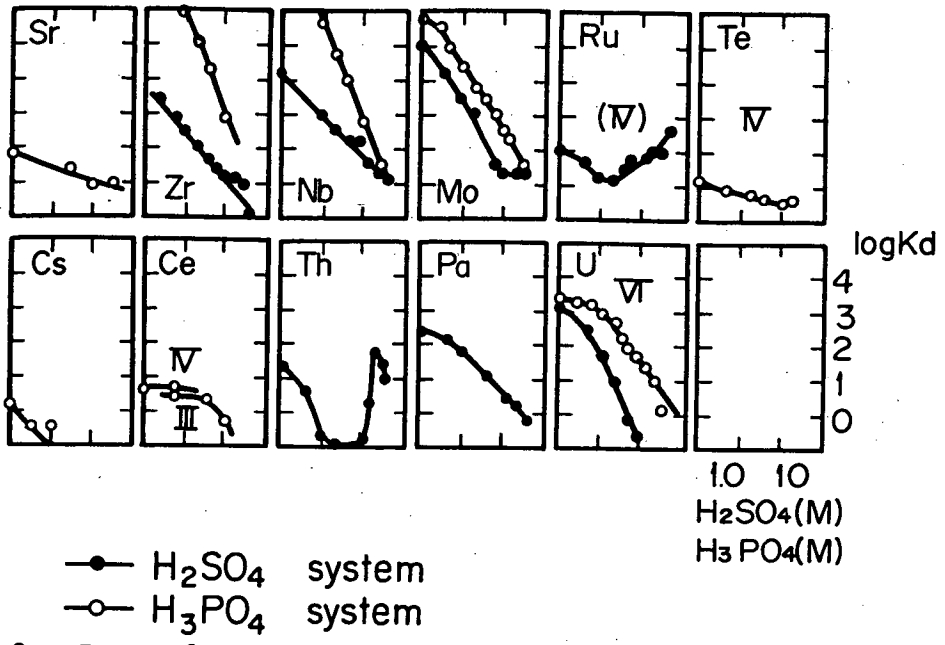


Fig. 9 Dowex 2 - H_2SO_4 and H_3PO_4 systems

Reference	Bunny L. R., Ballou N. E., Pascaul J., Foti S.:Anal. Chem., 31, 324 (1959)	Freiling E. C., Pascaul J., Delucchi A. A.:Anal. Chem., 31, 330 (1959)
Exchanger	Dowex 2, x8, 200-400 mesh, sulfate form	Dowex 2, x8, 200-400 mesh, phosphate form
Aq. phase	0.1 -36M H_2SO_4	0.1 - 30M H_3PO_4
Equilibration	Batch method	Batch method, 18 hrs. shaking
Temp.	---	Room temp.(25 $\pm$ 2°C)
Loading	Trace - 0.04M metal ion	Trace
Analysis	Mo:spectrophotometry Th, U:Colorimetry Am, Ce, Sr, Zr, Nb, Pa and Ru:measurement of radioactivity	Measurement of radioactivity
Distribution ratio	Kd, amount of metal ion per gram of dry resin/amount of metal ion per ml. of soln.	radioactivity per gram of resin/radioactivity per ml. of soln.

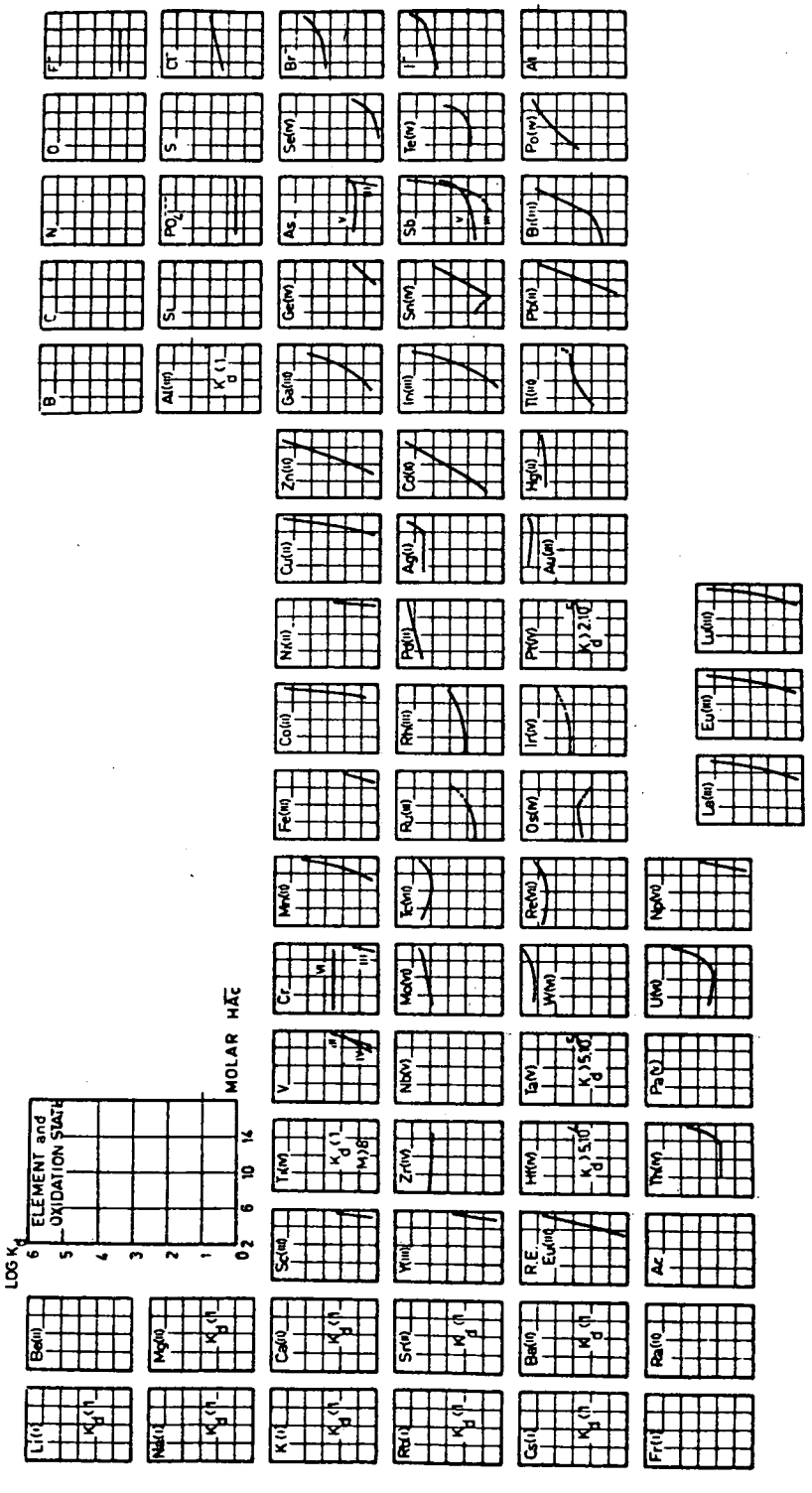

LOG K_d
ELEMENT and OXIDATION STATE
MOLAR HAE
6
5
4
3
2
1
0
2
6
10
14
Li(I)
Be(II)
B
C
N
O
F
Na(I)
Mg(II)
Al(III)
Si
PO4
S
Cl
K(I)
Ca(II)
Sc(III)
Ti(IV)
V
Cr
Mn(II)
Fe(III)
Co(II)
Ni(II)
Cu(II)
Zn(II)
Ga(III)
Ge(IV)
As
Se(IV)
Br
Rb(I)
Sr(II)
Y(III)
Zr(IV)
Nb(V)
Mo(VI)
Tc(VII)
Ru(III)
Rh(III)
Pd(II)
Ag(I)
Cd(II)
In(III)
Sn(IV)
Sb
Te(IV)
I
Cs(I)
Ba(II)
R.E.
Eu(III)
Hf(IV)
Ta(V)
W(VI)
Re(VII)
Os(IV)
Ir(IV)
Pt(IV)
Au(III)
Hg(II)
Tl(III)
Pb(II)
Bi(III)
Po(IV)
At
Fr(I)
Ra(II)
Ac
Th(IV)
Pa(V)
U(VI)
Np(V)
La(III)
Eu(III)
Lu(III)

Fig. 10

Fig. 10 Dowex 1 - acetic acid system

Reference	Van Den Winkel P., De Corte F., Hoste J.:Anal. Chim. Acta, 56, 241 (1971)
Exchanger	Dowex 1, x8, 100-200 mesh, acetate form
Aq. phase	2-17.4M acetic acid
Equilibration	Column elution or batch equilibration method
Temp.	25°C
Loading	Less than 1%
Analysis	Radiometric Ti, V, Nb:spectrophotometrically Ca:EGTA titration Li:atomic absorption F:electrode
Distribution ratio	Kd, amount of element per gram of dry resin/amount of element per milliliter of soln.
Separation	(Cu, Zn)(Mn, Cu, Zn)(Na, As(III), Cu)(U, Np)

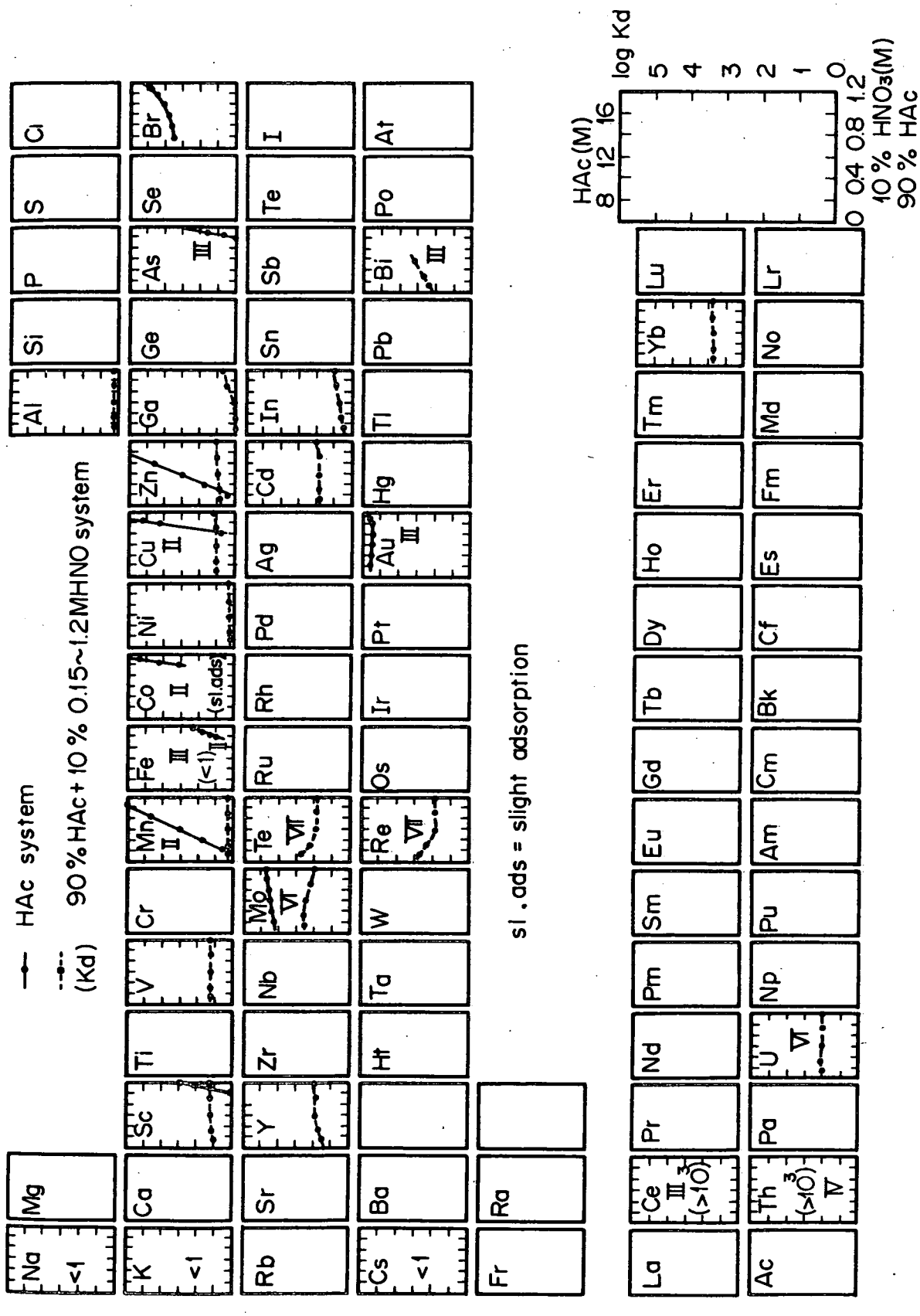

HAc system
(Kd) 90% HAc+10% 0.15~1.2MHNO system
sl.ads = slight adsorption
HAc(M) 8 12 16
log Kd 5 4 3 2 1 0
0 0.4 0.8 1.2
10% HNO3(M)
90% HAc

Fig. 11

Fig. 11 Dowex 1 - acetic acid and -acetic acid+nitric acid systems

Acetic acid system

Reference	Van Den Winkel P., De Corte F., Speecke A., Hoste J.:Anal. Chim. Acta, 42, 340 (1968)
Exchanger	Dowex 1, x8, 100-200 mesh
Aq. phase	6-17.5M acetic acid
Distribution ratio	Kd amount of element per gram of dry resin/amount of element per milliliter of soln.

Acetic acid+nitric acid system

Reference	Walter C. W., Korkisch J.:Mikrochim. Acta, 181(1971)
Exchanger	Dowex 1, x8, 100-200 mesh, nitrate form
Aq. phase	90vol% acetic acid+ 10vol% 0.15, 0.3, 0.6, 0.9, 1.2M nitric acid
Equilibration	Batch method(10 hours shaking)
Analysis	Radiometric, spectrophotometric, pptn. titration(Mo(VI)) and complexometric titration(U, V, Al, In, Ga)
Distribution ratio	μg element per gram resin/μg element per milliliter soln.

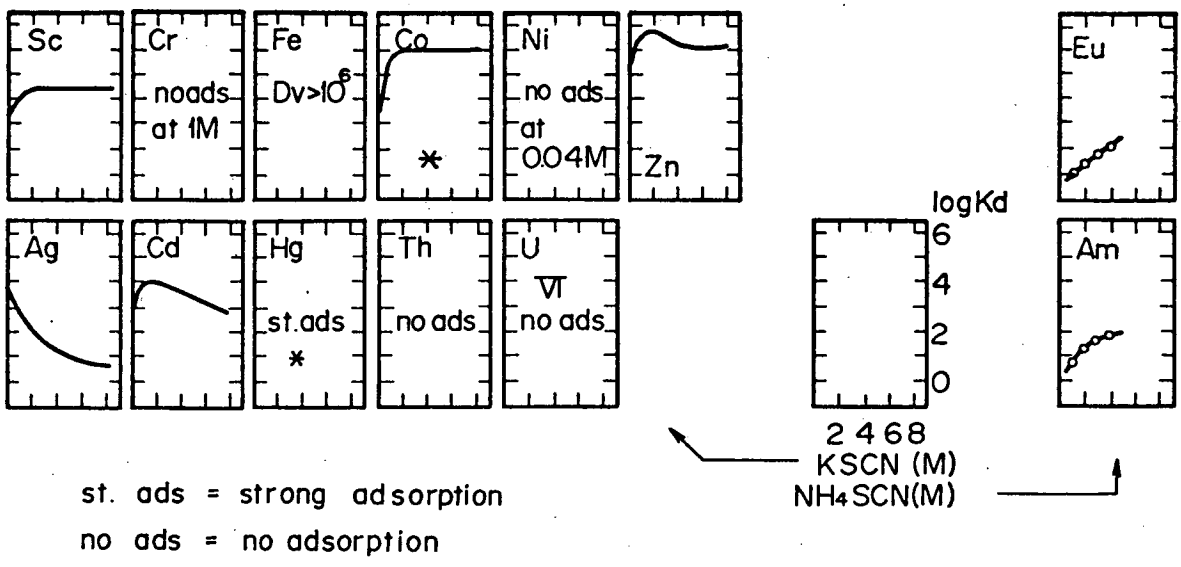


Fig. 12 Dowex 1 - thiocyanate system

References	Turner J. B., Philip R. H., Day Jr. R. A.:Anal. Chim. Acta,26, 94(1962)	Surls Jr. J. P., Choppin G. R.: J. Inorg. Nucl. Chem., 4, 62 (1957)
Exchanger	Dowex 1, x 8, 80-100 mesh, thiocyanate form, air-dried resin 5.6% moisture	Dowex 1 x 8, 200-400 mesh, chloride form, 1.2 eq.$l^{-1}$of wet resin
Aq. phase	KSCN soln.	NH_4SCN soln.(pH 3.5)
Equilibration	Column and batch method, shaking overnight	Batch method
Temp.	Room temp.(25-30°C)	Room temp.
Loading	Less than 1% capacity	Tracer
Analysis	Spot tests and measurement of radioactivity	Measurement of radioactivity
Distribution ratio	Dv	Kd, concn. of an ion in the resin phase/ that in the aq. phase

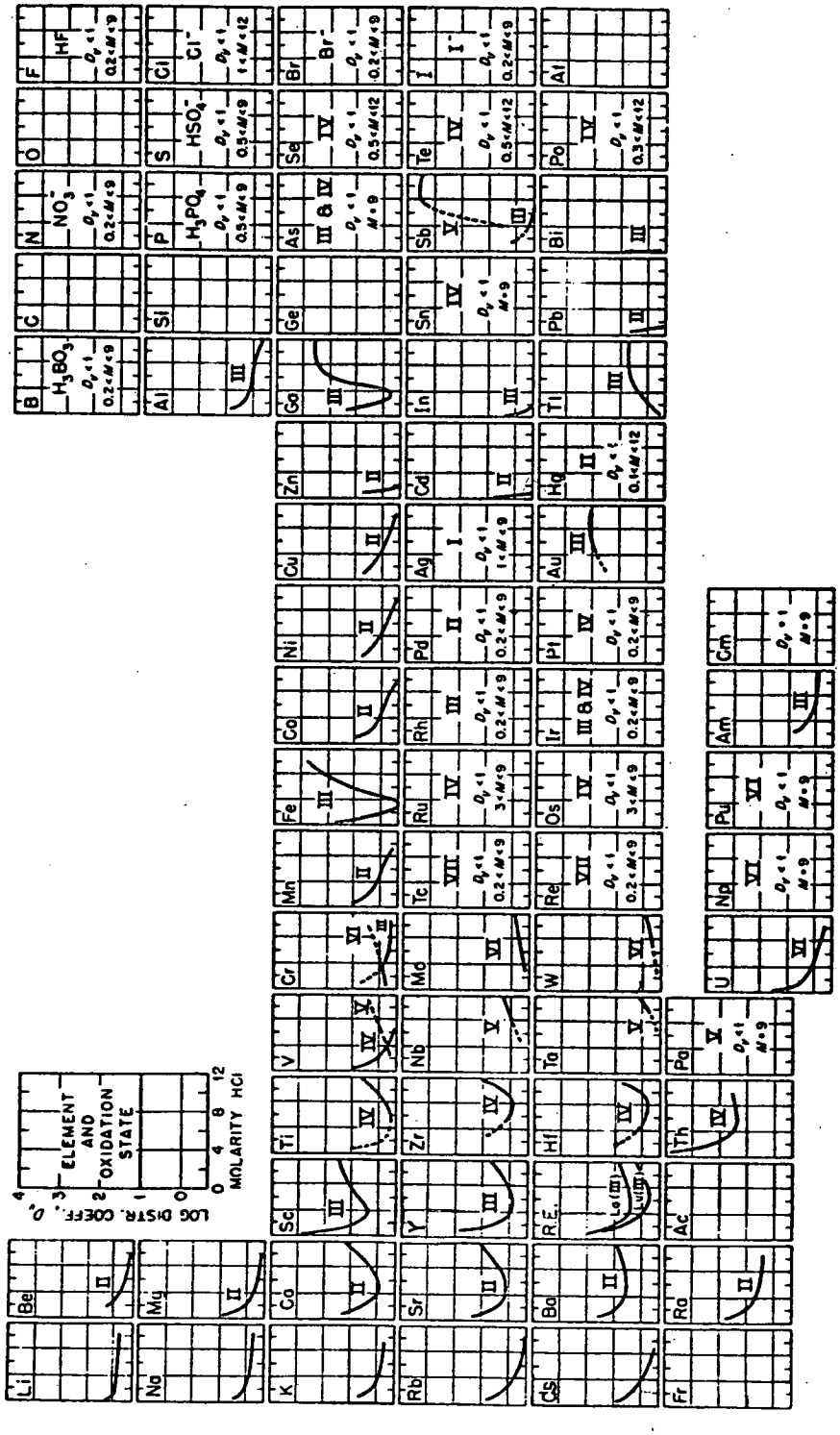

LOG DISTR. COEFF. D_v
ELEMENT AND OXIDATION STATE
MOLARITY HCl
Li
Be
Na
Mg
K
Ca
Rb
Sr
Cs
Ba
Fr
Ra
Sc
Y
R.E.
Ac
Ti
Zr
Hf
Th
V
Nb
Ta
Pa
Cr
Mo
W
U
Mn
Tc
Re
Np
Fe
Ru
Os
Pu
Co
Rh
Ir
Am
Ni
Pd
Pt
Cm
Cu
Ag
Au
Zn
Cd
Hg
B
Al
C
Si
Ge
Sn
Pb
N
P
As
Sb
Bi
O
S
Se
Te
Po
F
Cl
Br
I
At
H_3BO_3
NO_3^-
H_3PO_4
HSO_4^-
HF
Cl^-
Br^-
I^-

Fig. 13

Fig. 13 Dowex 50 - HCl system

Reference	Nelson F., Murase T., Kraus K. A.:J. Chromatog., 13, 503 (1964)
Exchanger	Dowex 50, x 4, 200-270 mesh for batch and 270-325 mesh (water wet) for column experiment, 5.12 eq.kg^{-1}(dry H form)
Aq. phase	HCl
Equilibration	10-72 hours shaking for batch equilibration or column method
Loading	Less than 1% capacity
Temp.	25°C
Distribution ratio	Dv, amount per liter of exchanger/amount per liter of soln.; D, amount per kg dry resin/amount per liter of soln.; $D=Dv/\rho$ ρ:bed density in the medium of interest
Analysis	Al:spot testing with alizalin or EDTA titration Li,B:Flame testing HNO_3:brown fumes with conc.HCl HF:LaF_3 pptn. HCl:AgCl pptn. H_2SO_4:$BaSO_4$ pptn. the others: α, β, or γ radioactivity measurement

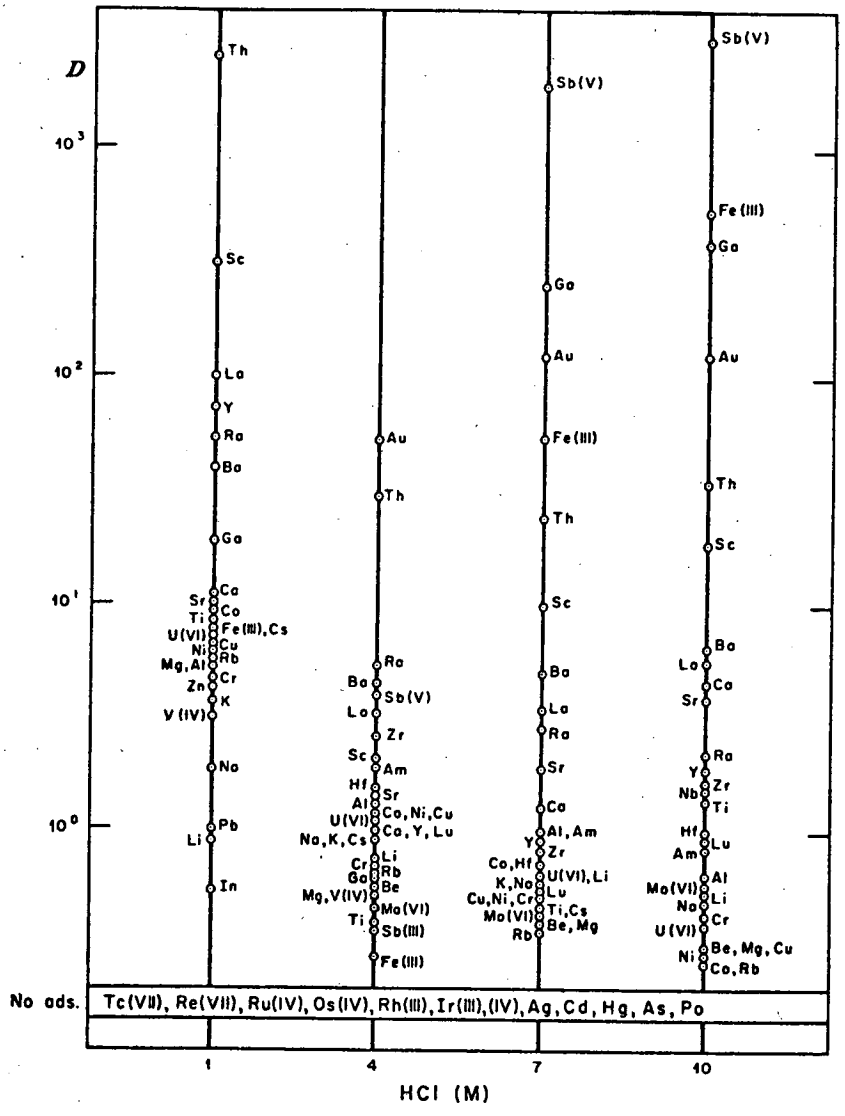


Fig. 14 Dowex 50 - HCl system

Reference Marcus K. A., Kertes A. S.:"Ion Exchange and Solvent Extraction of Metal Complexes", Wiley-Interscience, London, 940 (1969)

The other items are the same as Fig. 13

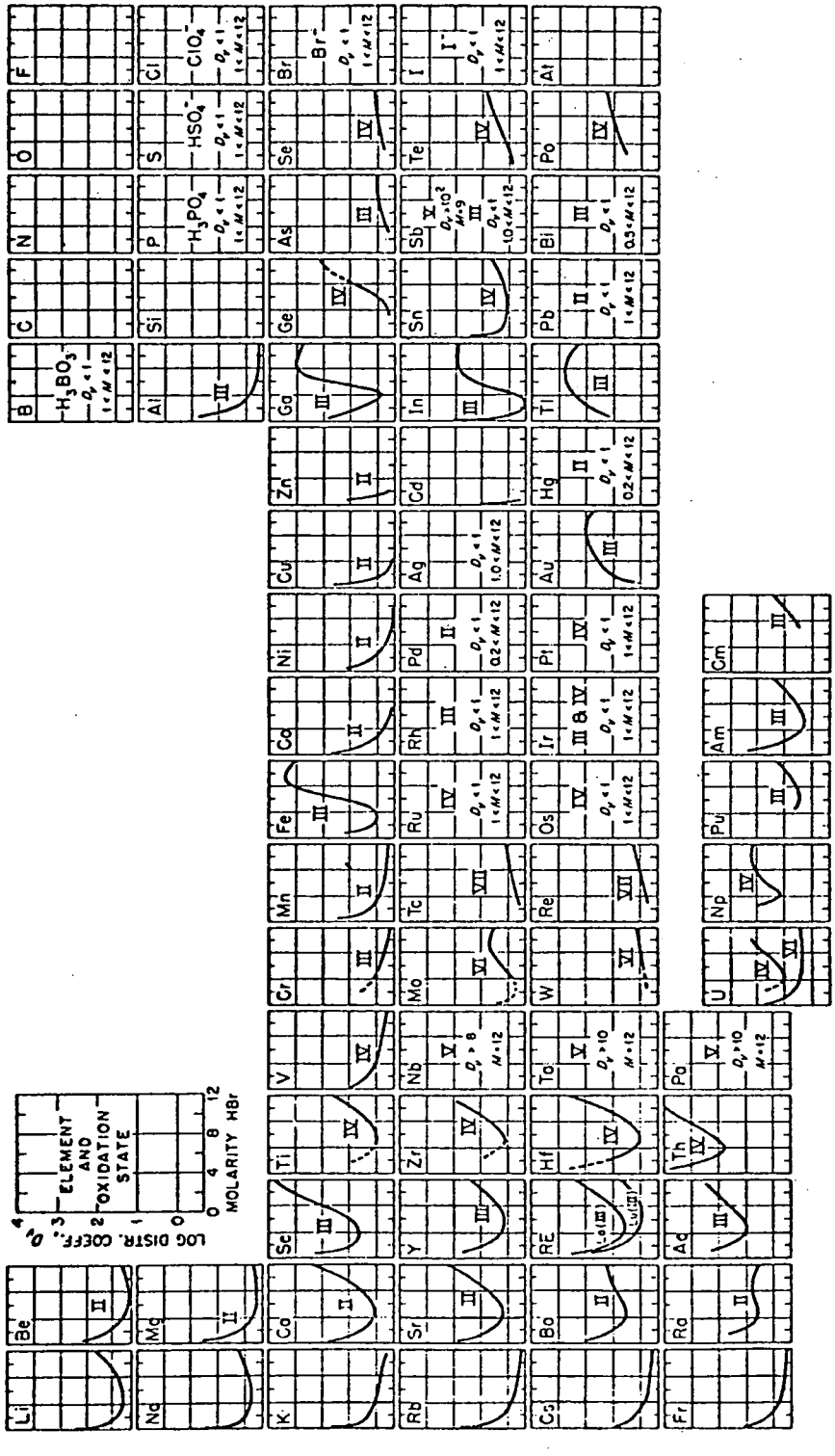

ELEMENT AND OXIDATION STATE
LOG DISTR. COEFF. D_v
MOLARITY HBr
0
4
8
12
1
2
3
4
Li
Be
Na
Mg
K
Ca
Rb
Sr
Cs
Ba
Fr
Ra
Sc
Y
RE
Ac
Ti
Zr
Hf
Th
V
Nb
Ta
Pa
Cr
Mo
W
U
Mn
Tc
Re
Np
Fe
Ru
Os
Pu
Co
Rh
Ir
Am
Ni
Pd
Pt
Cm
Cu
Ag
Au
Zn
Cd
Hg
B
H_3BO_3
Al
C
Si
Ge
Sn
Pb
N
P
As
Sb
Bi
H_3PO_4
O
S
Se
Te
Po
HSO_4^-
F
Cl
Br
I
At
ClO_4^-
Br^-
I^-

Fig. 15

Fig. 15 Dowex 50 - HBr system

Reference	Nelson F., Michelson D. C. :J. Chromatog., 25, 414 (1966)
Exchanger	Dowex 50,x 4, 270-325 mesh(in water), 5.12 eq.$kg^{-1}$of dry resin
Aq. phase	1, 3, 6, 9, 12M HBr
Equilibration	Column or batch method
Loading	Less than 1% capacity
Temp.	25°C
Analysis	The same as that given in Fig.16
Distribution	Dv, amount per liter of wet exchanger/amount per liter of soln.
Separation	(Na, Li) (Mg, Ca)(Be, Mg, Ra, Ba, Sr, Ca)(W, Mo)(Ag, Au)(Se, Te)

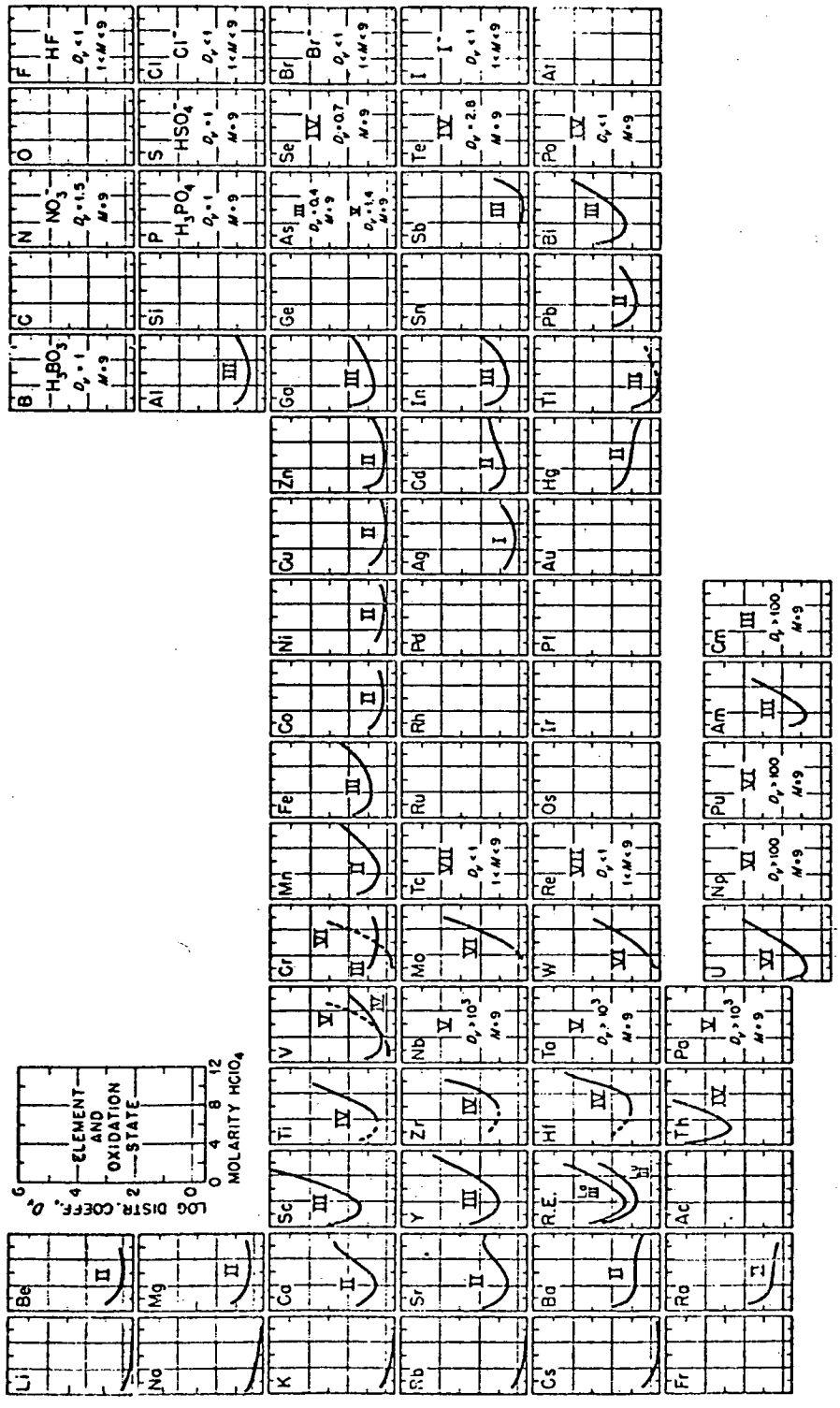

LOG DISTR. COEFF. D_v
ELEMENT AND OXIDATION STATE
MOLARITY $HClO_4$
0
4
8
12
2
4
6
Li
Be
Na
Mg
K
Ca
Rb
Sr
Cs
Ba
Fr
Ra
Sc
Y
R.E.
Ac
Ti
Zr
Hf
Th
V
Nb
Ta
Pa
Cr
Mo
W
U
Mn
Tc
Re
Np
Fe
Ru
Os
Pu
Co
Rh
Ir
Am
Ni
Pd
Pt
Cm
Cu
Ag
Au
Zn
Cd
Hg
B
H_3BO_3
Al
Ga
In
Tl
C
Si
Ge
Sn
Pb
N
NO_3^-
P
H_3PO_4
As
Sb
Bi
O
S
HSO_4^-
Se
Te
Po
F
HF
Cl
Cl^-
Br
Br^-
I
I^-
At

Fig. 16

Fig. 16 Dowex 50 - $HClO_4$

Reference	Nelson F., Murase T., Kraus K. A.:J. Chromatog., 13, 503 (1964)
Exchanger	Dowex 50, x 4, 200-270 mesh(in water) for batch and 270-325 mesh for column equilibration
Aq. phase	$HClO_4$
Equilibration	10-72 hrs. shaking for batch equilibration
Temp.	25°C
Loading	Less than 1% capacity, except for Ag(I), Hg(II), Bi(III) Tl(III)
Analysis	Al:spot testing with alizalin or EDTA titration Li, B:flame testing in column method HNO_3:brown fumes with conc.HCl HF:LaF_3 pptn. HCl:AgCl pptn. H_2SO_4:$BaSO_4$ pptn. The others: α, β or γ radioactivity measurement
Distribution ratio	Dv, amount per liter of wet exchanger/amount per liter of soln.; D, amount per kg dry resin/amount per liter of soln. $D=Dv/\rho$ ρ:bed density in the medium of interest
Separation	(Be, Ba, Sr)(Ni, Cr, V)(Co, Mn)
Appendix	Sullivan J. C., Cohen D., Hindman J. C.:J. Am. Chem. Soc., 77, 6203 (1955) Kd of Np(IV), Np(V), Np(VI) are 12, 14 and 74.6 in Dowex 50, X 12, 200-400 mesh system at 25°C

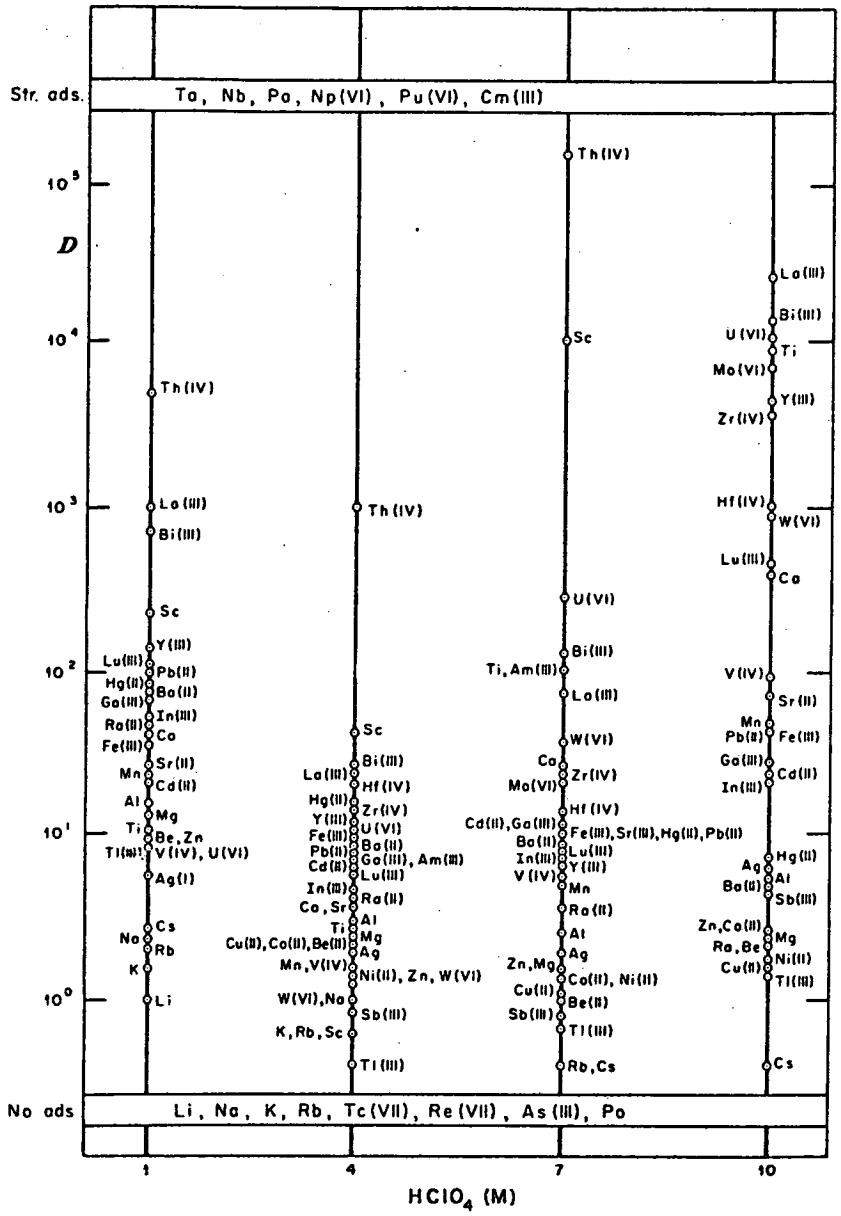


Fig. 17 Dowex 50 - $HClO_4$ system

Reference Marcus K. A., Kertes A. S.:"Ion Exchange and Solvent Extraction of Metal Complexes", Wiley-Interscience, London, 940 (1969)

The other items are the same as Fig. 16.

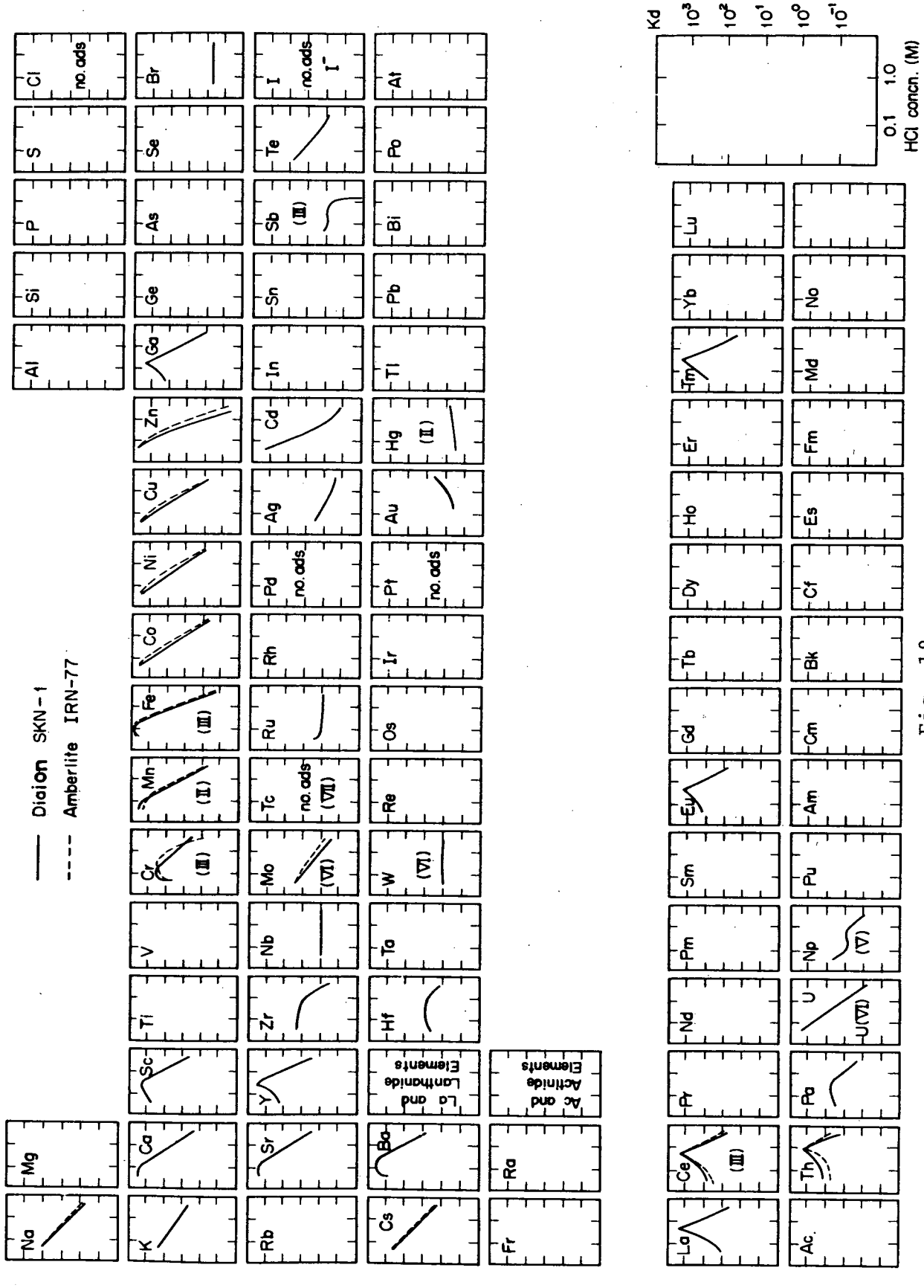

Diaion SKN-1
Amberlite IRN-77
Kd
HCl concn. (M)
0.1
1.0
no.ads
La and Lanthanide Elements
Ac and Actinide Elements

Fig. 18

Fig. 18 Diaion SKN-1 - HCl system

Reference Yokotsuka, S., Akatsu E., Ueno K.:J. Nucl. Sci. Technol., 8, 622 (1971)

Exchanger Diaion SKN-1 3.56 meq.g^{-1}, water content 29.5%, 20-50 mesh, DVB content 8%, H form; Amberlite IRN-77, 3.50 meq.g^{-1} water content 32.7%, 20-50 mesh, DVB content 8%, H form

Aq. phase 0, 1.0, 3.0,6.0, 9.0, 12M HCl

Equilibration Batch method(10 minutes shaking) and column elution method

Temp. Room temp.

Loading Tracer

Analysis Measurement of radioactivity

Distribution ratio Kd, counts per gram air-dried resin/counts per milliliter soln.

Table 2 Distribution ratios between water and cation exchange resinss

Element	Kd ($ml \cdot g^{-1}$)		Element	Kd ($ml \cdot g^{-1}$)	
	Diaion SKN-1	Amberlite IRN-77		Diaion SKN-1	Amberlite IRN-77
Na	3.8×10^{3}	3.0×10^{3}	Pd	6.8×10^{1}	
Cl	no ads.		Ag(I)	7.1×10^{1}	
K	6.7×10^{3}		Cd	3.5×10^{1}	
Ca	5.8×10^{2}		Sb(Ⅲ)	no ads.	
Sc	2.3×10^{2}		Te	4.3×10^{2}	
Cr	6.1	1.1×10^{1}	I	no ads.	
Mn(Ⅱ)	1.4×10^{2}	5.0×10^{1}	Cs	2.3×10^{2}	1.8×10^{3}
Fe(Ⅲ)	4.7×10^{1}	6.9×10^{1}	Ba	9.4×10^{1}	
Co(Ⅱ)	1.0×10^{2}	4.9×10^{1}	La	4.6×10^{1}	
Ni	8.7×10^{2}	2.9×10^{2}	Ce(Ⅲ)	1.4×10^{1}	1.3×10^{1}
Cu	1.9×10^{2}	6.5×10^{1}	Eu	8.5×10^{1}	
Zn	1.2×10^{2}	4.1×10^{1}	Tm	4.0×10^{1}	
Ga	4.8×10^{1}		Hf	1.3	
Br	9.3×10^{-1}		W(Ⅵ)	1.2	
Sr	3.0×10^{1}		Pt	no ads.	
Y	3.9×10^{1}		Au	5.1	
Zr	2.5×10^{1}		Hg	3.2	
Nb	1.5×10^{-1}		Th	1.4×10^{2}	3.6×10^{1}
Mo(Ⅵ)	6.5		Pa	1.3×10^{1}	
Tc(Ⅶ)	no ads.		U(Ⅵ)	10^{1}	
Ru	4.0		Np(Ⅴ)	1.4×10^{2}	

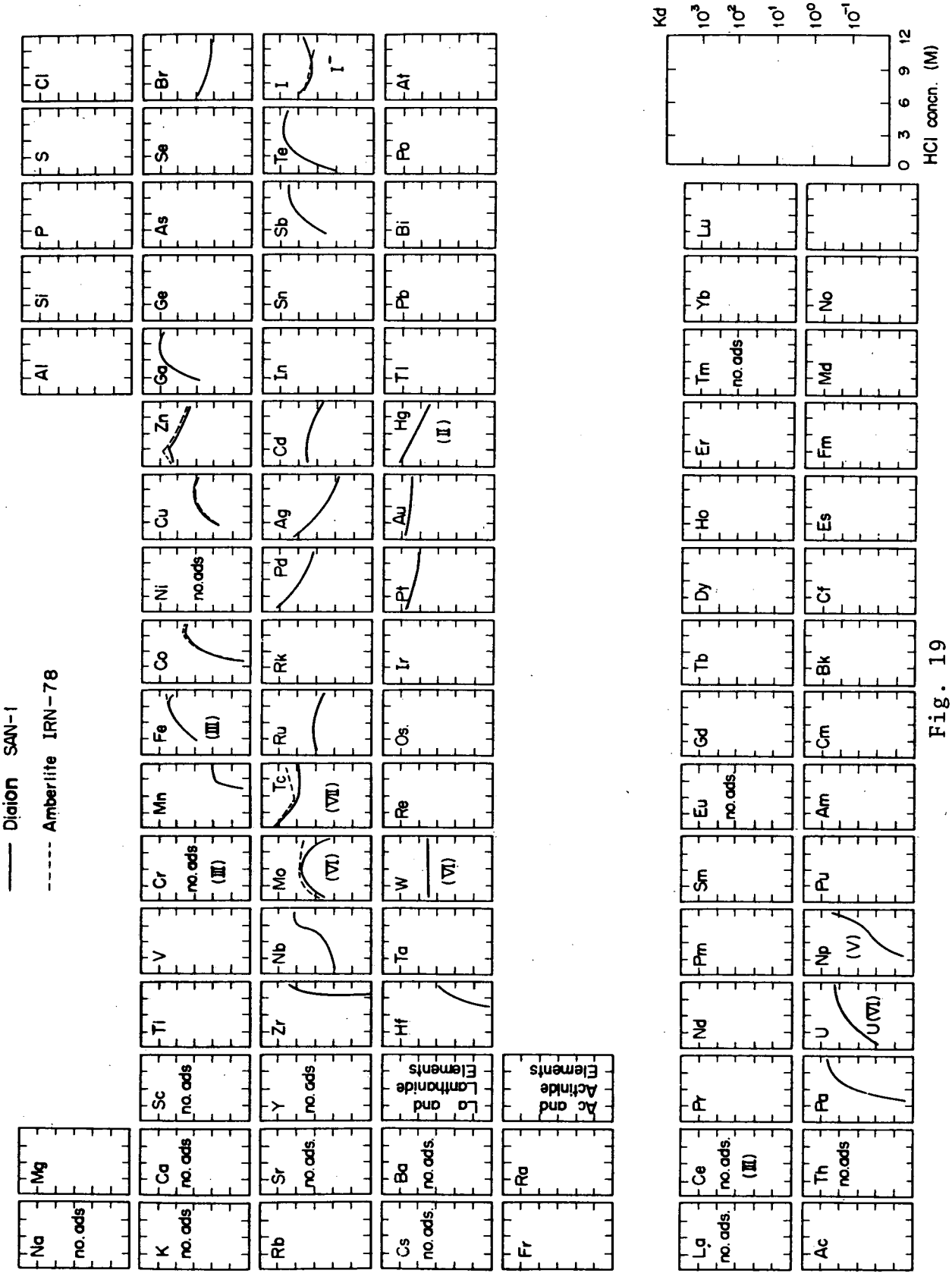

Diaion SAN-1
Amberlite IRN-78
Kd
HCl concn. (M)
0 3 6 9 12
Na no.ads
Mg
Al
Si
P
S
Cl
K no.ads
Ca no.ads
Sc no.ads
Ti
V
Cr no.ads (III)
Mn
Fe (III)
Co
Ni no.ads
Cu
Zn
Ga
Ge
As
Se
Br
Rb
Sr no.ads
Y no.ads
Zr
Nb
Mo (VI)
Tc (VII)
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I I⁻
Cs no.ads
Ba no.ads
La and Lanthanide Elements
Hf
Ta
W (VI)
Re
Os
Ir
Pt
Au
Hg (II)
Tl
Pb
Bi
Po
At
Fr
Ra
Ac and Actinide Elements
La no.ads
Ce no.ads (III)
Pr
Nd
Pm
Sm
Eu no.ads
Gd
Tb
Dy
Ho
Er
Tm no.ads
Yb
Lu
Ac
Th no.ads
Pa
U U(VI)
Np (V)
Pu
Am
Cm
Bk
Cf
Es
Fm
Md
No

Fig. 19

Fig. 19 Diaion SAN-1 - HCl system

Reference Yokotsuka S., Akatsu E., Ueno K.:J. Nucl. Sci. Technol., 8, 622 (1971)

Exchanger Diaion SAN-1, 2.61 meq.g^{-1}, water content 30.2%, 20-50 mesh, DVB content 8%, Cl form; Amberlite IRN-78, 2.77 meq.g^{-1}, water content 26.7%, 20-50 mesh, DVB content 8%, Cl form

Aq. phase 0, 1.0, 3.0, 6.0, 9.0, 12M HCl

Equilibration Batch method(10 minutes shaking) and column elution method

Temp. Room temp.

Loading Tracer

Analysis Measurement of radioactivity

Distribution ratio Kd, counts per gram air-dried resin/counts per milliliter soln.

Fig. 20 Diaion PK 216, PA 316 - HCl system

Reference Akatsu E., Aratono Y., Bahk C. Y.:J. Nucl. Sci. Technol., 10, 453 (1973)

Exchangers

Properties	Cation exchange resin		Anion exchange resin	
	Diaion PK-216	Amberlite IR-200	Diaion PA-316	Amberlite IRA-900
Particle size (mm)	0.40~0.55	0.42~0.84	0.35~0.55	—
DVB (%)	8	~25	8	~10
Weight exchange capacity (meq.g^{-1})	4.63	4.56	3.91	3.80
Volume exchange capacity (meq.ml^{-1})	1.91	1.83	1.46	1.03
Type	Sulfonic acid type		Tetramethylammonium type	
Form	H		Cl	

Aq. phase 0, 0.1, 0.2, 0.5, 1.0M HCl

Equilibration Batch method, 30 minutes shaking

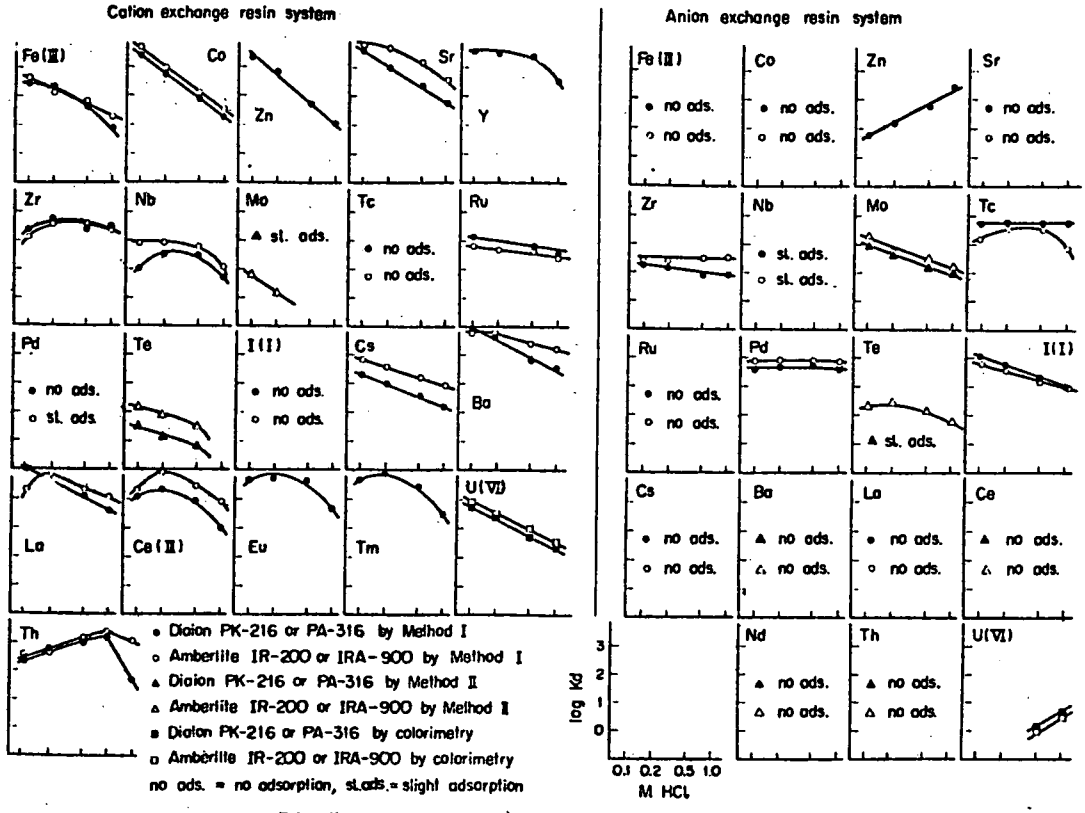
Temp. Room temp.

Loading Trace

Analysis Measurement of radioactivity

Distribution ratio Kd

$$Kd(ml\cdot g^{-1}) = \frac{\text{Volume of aqueous phase (m}l)}{\text{Weight of air-dried resin (g)}} \cdot \frac{\text{Counting rate of initial soln. (cpm}\cdot ml^{-1}) - \text{That of final soln. (cpm}\cdot ml^{-1})}{\text{Counting rate of final soln. (cpm}\cdot ml^{-1})}$$



Distribution ratio of elements between ion exchange resins of porous type and dilute hydrochloric acid solution

Fig. 20

Table 3 Distribution ratios between water and ion exchange resins

Tracer	Diaion PK-216	Amb. IR-200	Diaion PA-316	Amb. IRA-900
^{55,59}Fe(III)	7 ×10²	5 ×10²	No ads.	No ads.
^{60}Co	6.1×10²	5.3×10²	No ads.	No ads.
^{85}Sr	7.7×10²	1.2×10³	No ads.	No ads.
^{95}Zr	4 ×10	3 ×10	2 ×10	2 ×10
^{95}Nb	7 ×10	6 ×10	4	2 ×10
^{99}Mo†	7	5	9.0×10²	1.2×10²
^{99m}Tc	No ads.	No ads.	2.8×10²	1.5×10²
^{106}Ru	7 ×10	8 ×10	No ads.	No ads.
^{109}Pd	4 ×10	1.5×10²	2 ×10²	6 ×10
^{131}I	No ads.	No ads.	1 ×10³	2 ×10³
^{137}Cs	1.4×10³	5.5×10³	No ads.	No ads.
^{139}Ba	7 ×10²	3 ×10³	No ads.	No ads.
^{140}La	1 ×10²	3 ×10	No ads.	No ads.
^{144}Ce(III)	3 ×10	4 ×10	No ads.	No ads.
^{147}Nd†	9 ×10	3 ×10	No ads.	No ads.
^{234}Th	5 ×10	5 ×10	No ads.	No ads.
nat. U(VI)	1.8×10³	1.6×10³	No ads.	No ads.

† Method II
Amb.: Amberlite, No ads.: no adsorption

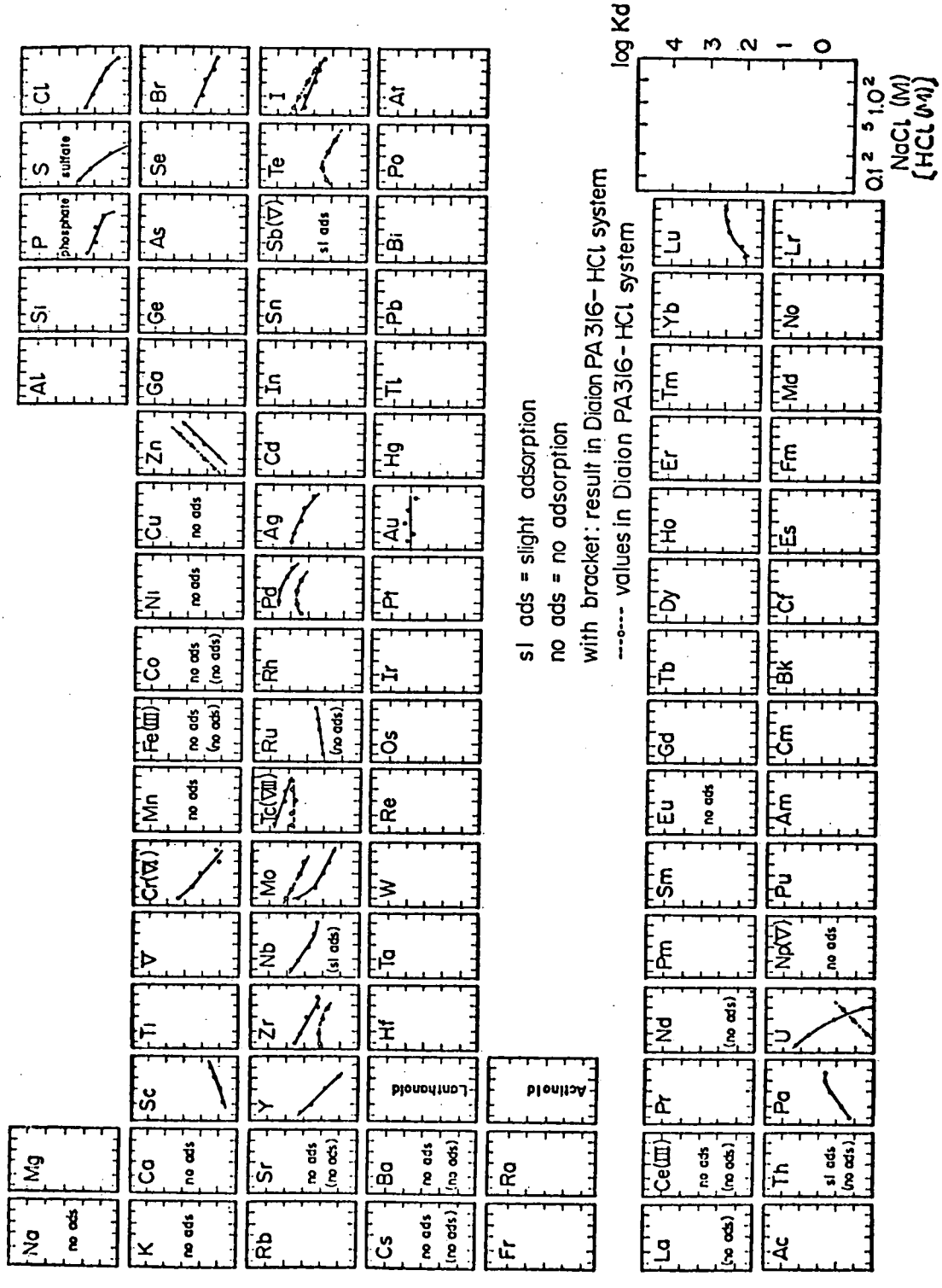

sl ads = slight adsorption
no ads = no adsorption
with bracket: result in Diaion PA316-HCl system
---o--- values in Diaion PA316-HCl system
log Kd
4
3
2
1
0
0.1
2
5
1.0
2
NaCl (M)
(HCl (M))

Fig. 21

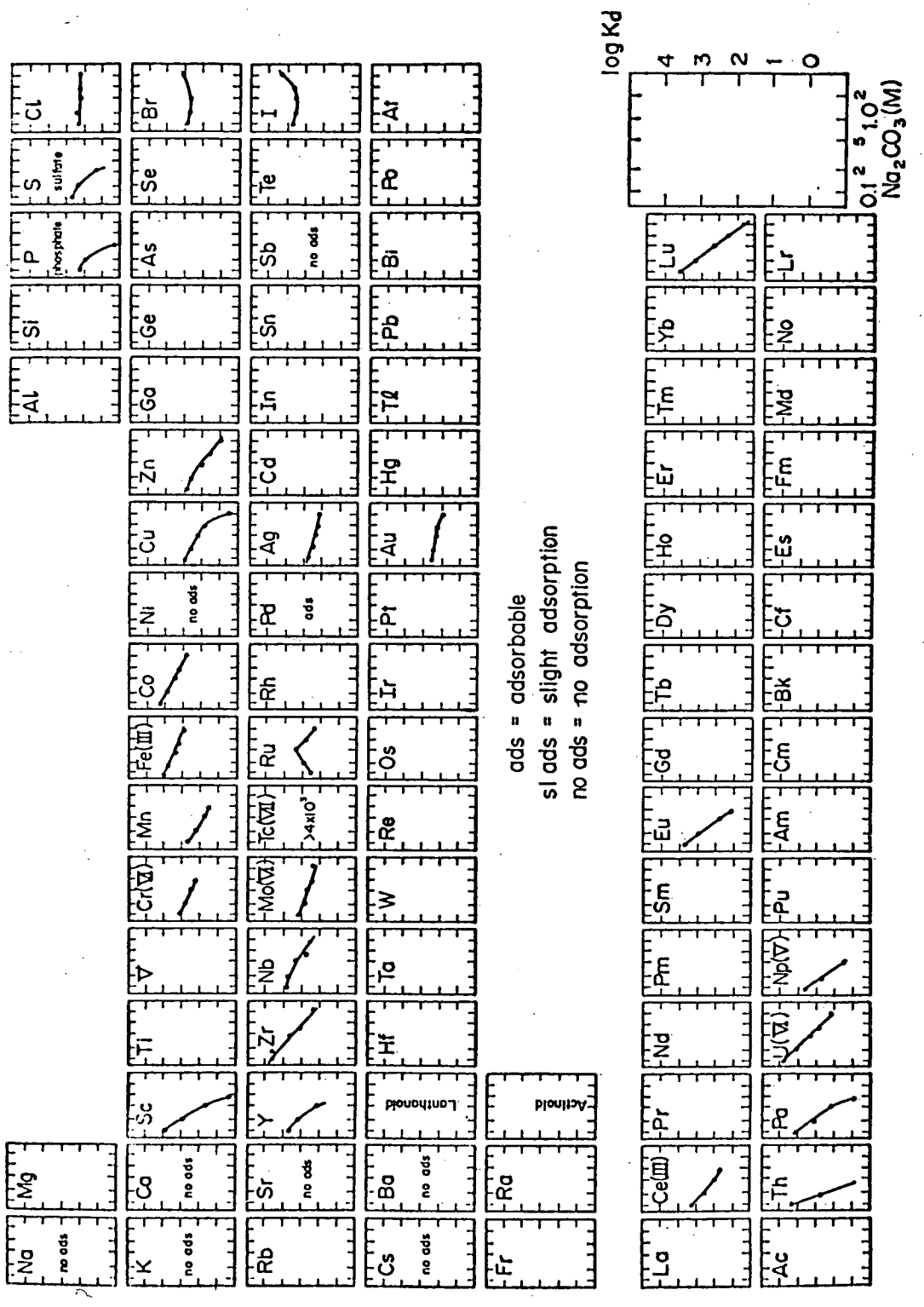

ads = adsorbable
sl ads = slight adsorption
no ads = no adsorption
log Kd
4
3
2
1
0
0.1 2 5 1.0 2
Na2CO3(M)
Lanthanoid
Actinoid

Fig. 22

Fig. 21 Diaion PA 306 - NaCl system

Reference	Akatsu E., Watanabe H.: Anal. Chim. Acta, to be published
Exchanger	Diaion PA 306, DVB content 3%, 1190-297 microns, chloride form
Aq. phase	0.1, 0.2, 0.5, 1.0, 2.0M NaCl
Equilibration	Batch method, 30 minutes shaking
Temp.	Room temp. (20-30°C)
Loading	Tracer
Analysis	Measurment of radioactivity
Distribution ratio	Kd, amount of an element per gram dry resin/amount of the element per milliliter soln.

Fig. 22 Diaion PA 306 - Na_2CO_3 system

Reference	Akatsu E., Watanabe H.:Anal. Chim. Acta, to be published
Exchanger	Diaion PA 306, DVB content 3%, 1190-297 microns, carbonate form
Aq. phase	0.1, 0.2, 0.5, 0.8, 2.0M Na_2CO_3
Equilibration	Batch method, 30 minutes shaking
Temp.	Room temp. (20-30°C)
Loading	Tracer
Analysis	Measurement of radioactivity
Distribution ratio	Kd, amount of an element per gram dry resin/amount of the element per milliliter soln.

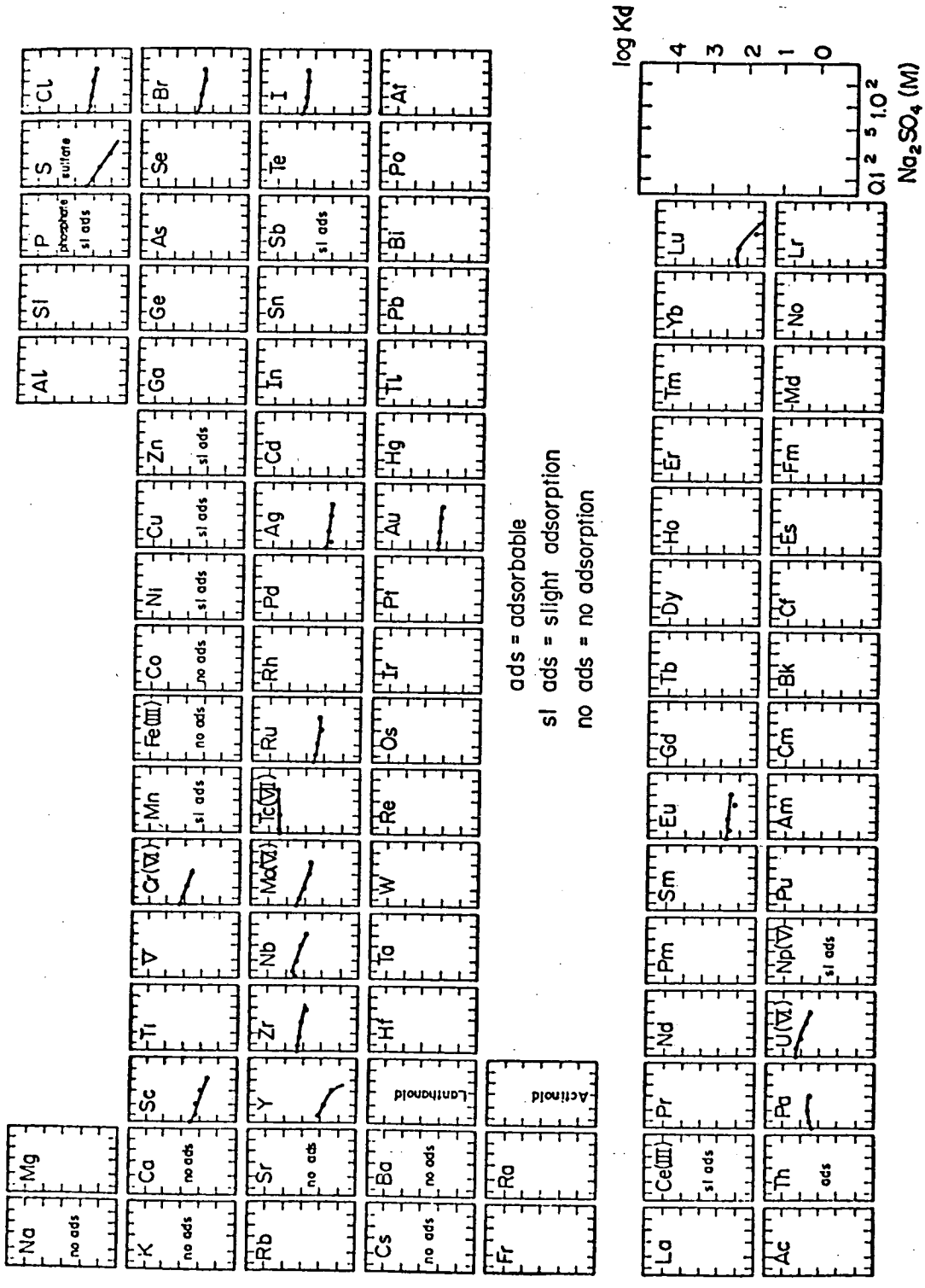

ads = adsorbable
sl ads = slight adsorption
no ads = no adsorption
log Kd
4
3
2
1
0
0.1 2 5 1.0 2
Na_2SO_4 (M)
Actinoid
Lanthanoid
Ce(III) sl ads
Th ads
U(VI) sl ads
Np(V) sl ads
Cr(VI)
Mo(VI)
Tc(VII)
Fe(III) no ads
Co no ads
Mn sl ads
Ni sl ads
Cu sl ads
Zn sl ads
Sb sl ads
P phosphate sl ads
S sulfate
Mg no ads
Ca no ads
K no ads
Sr no ads
Ba no ads
Cs no ads
Sc
Ti
V
Zr
Nb
Y
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rh
Ru
Pd
Ag
Cd
In
Sn
Te
I
Ge
Ga
As
Se
Br
Al
Si
Cl
Rb
Fr
Ra
Ac
La
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Pa
Pu
Am
Cm
Bk
Cf
Es
Fm
Md
No
Lr

Fig. 23

Fig. 23 Diaion PA 306 - Na_2SO_4

Reference	Akatsu E., Watanabe H.:Anal. Chim. Acta, to be published
Exchanger	Diaion PA 306, DVB content 3%,1190-297 microns, sulfate form
Aq. phase	0.05, 0.1, 0.2,0.5,1.0M Na_2SO_4
Equilibration	Batch method, 30 minutes shaking
Temp.	Room temp.(20-30°C)
Loading	Tracer
Analysis	Measurement of radioactivity
Distribution ratio	Kd, amount of an element per gram of dry resin/amount of the element per milliliter of soln.

Fig. 24 Ionite-C - HNO_3, NH_4NO_3 system

Reference	Akatsu E., Ono R., Tsukuechi K., Uchiyama H.:J Nucl. Sci. Technol., 2, 141 (1965)
Exchanger	Ionite-C(zirconium phosphate by Shin-nihon-kinzoku) 30-80 mesh
Aq. phase	0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10M HNO_3 or NH_4NO_3
Equilibration	Batch method(one hour shaking)
Temp.	Room temp.
Loading	Tracer
Analysis	Measurement of radioactivity
Distribution ratio	Kd, counts per gram adsorbent/counts per milliliter soln.

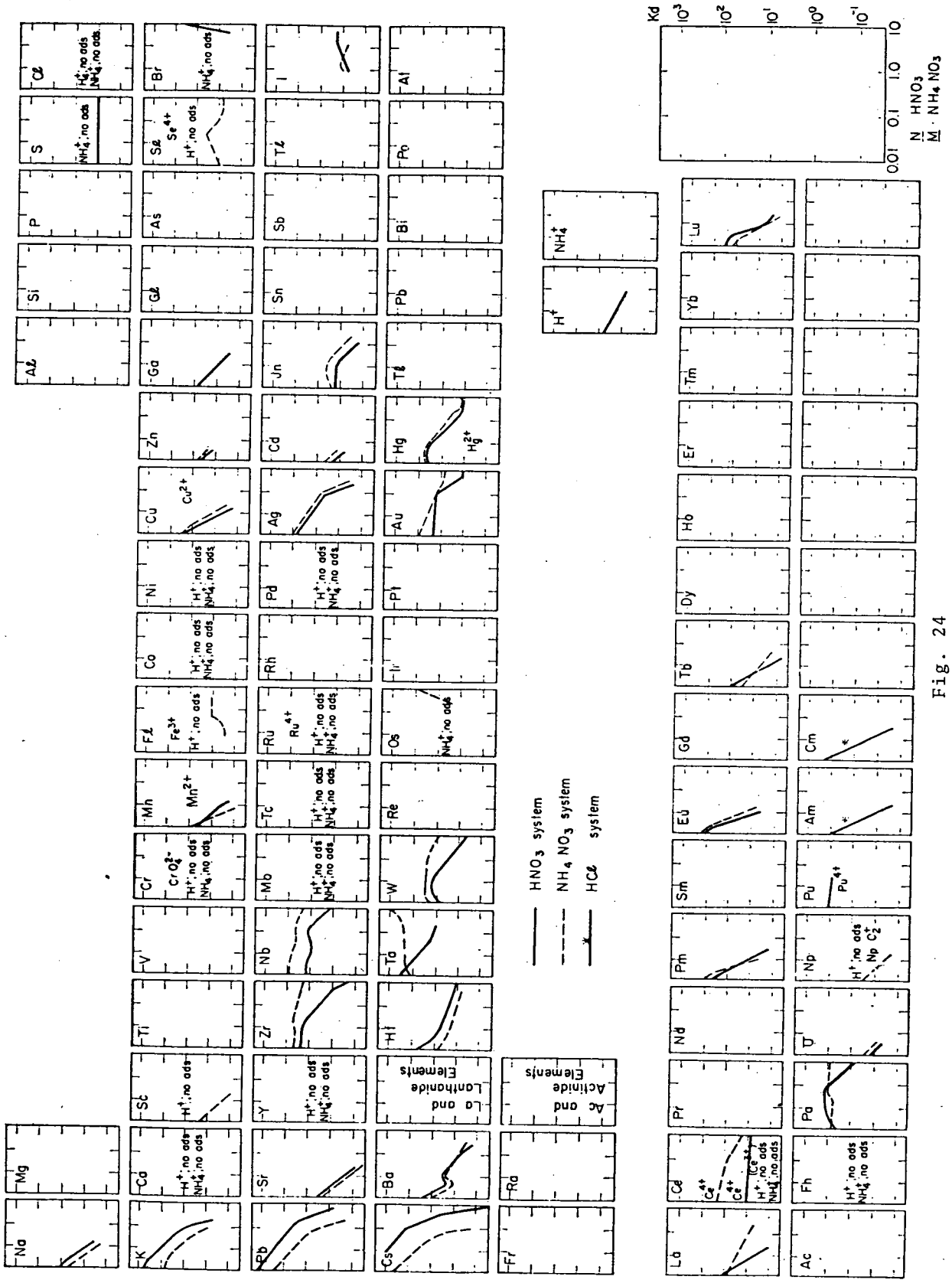

Kd
10^3
10^2
10^1
10^0
10^{-1}
0.01
0.1
1.0
10
N HNO3
M NH4NO3
HNO3 system
NH4NO3 system
HCl system
La and Lanthanide Elements
Ac and Actinide Elements

Fig. 24

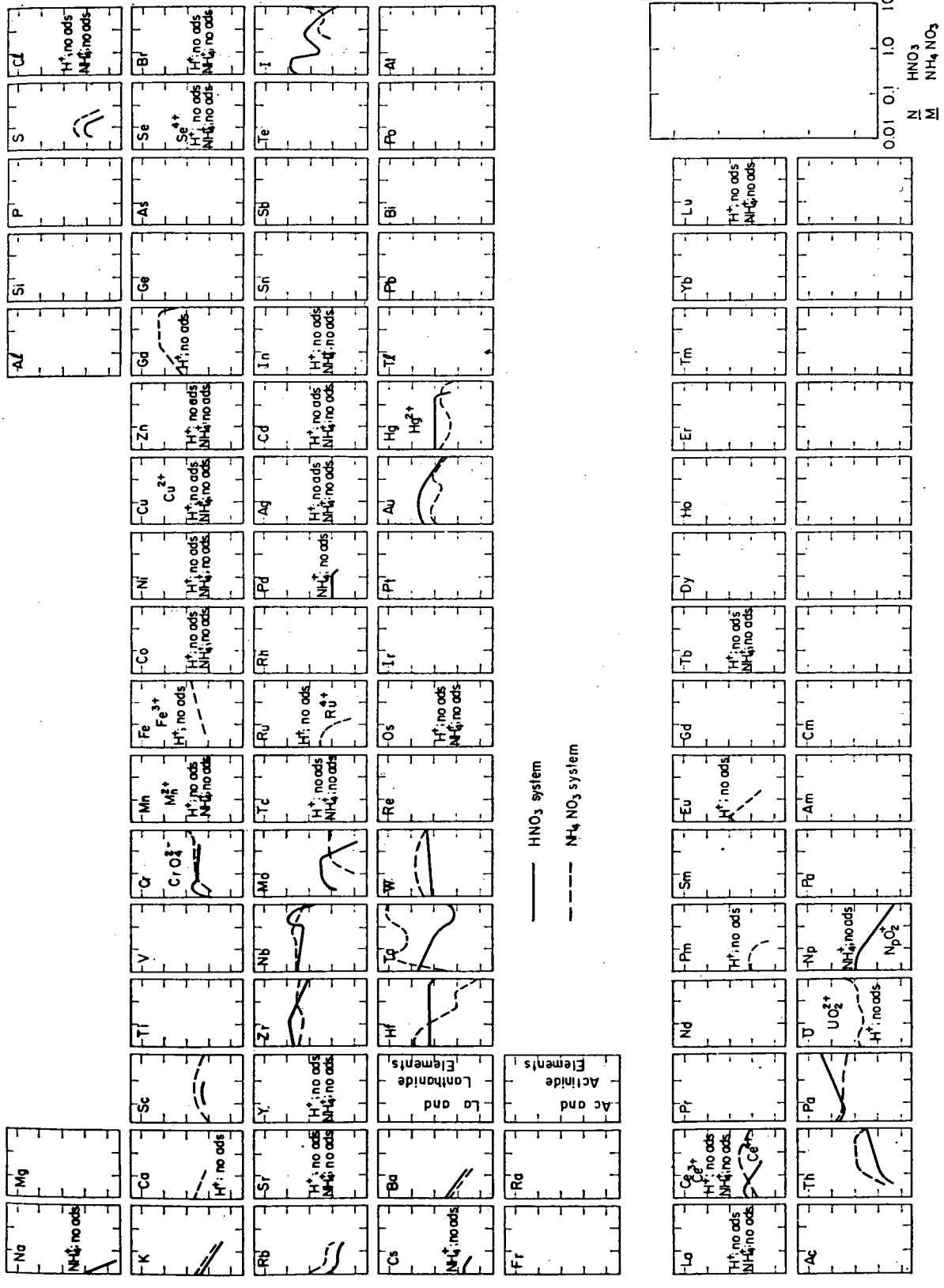

HNO3 system
NH4NO3 system
Lanthanide Elements
Actinide Elements
Kd
HNO3
NH4NO3
N
M

Fig. 25

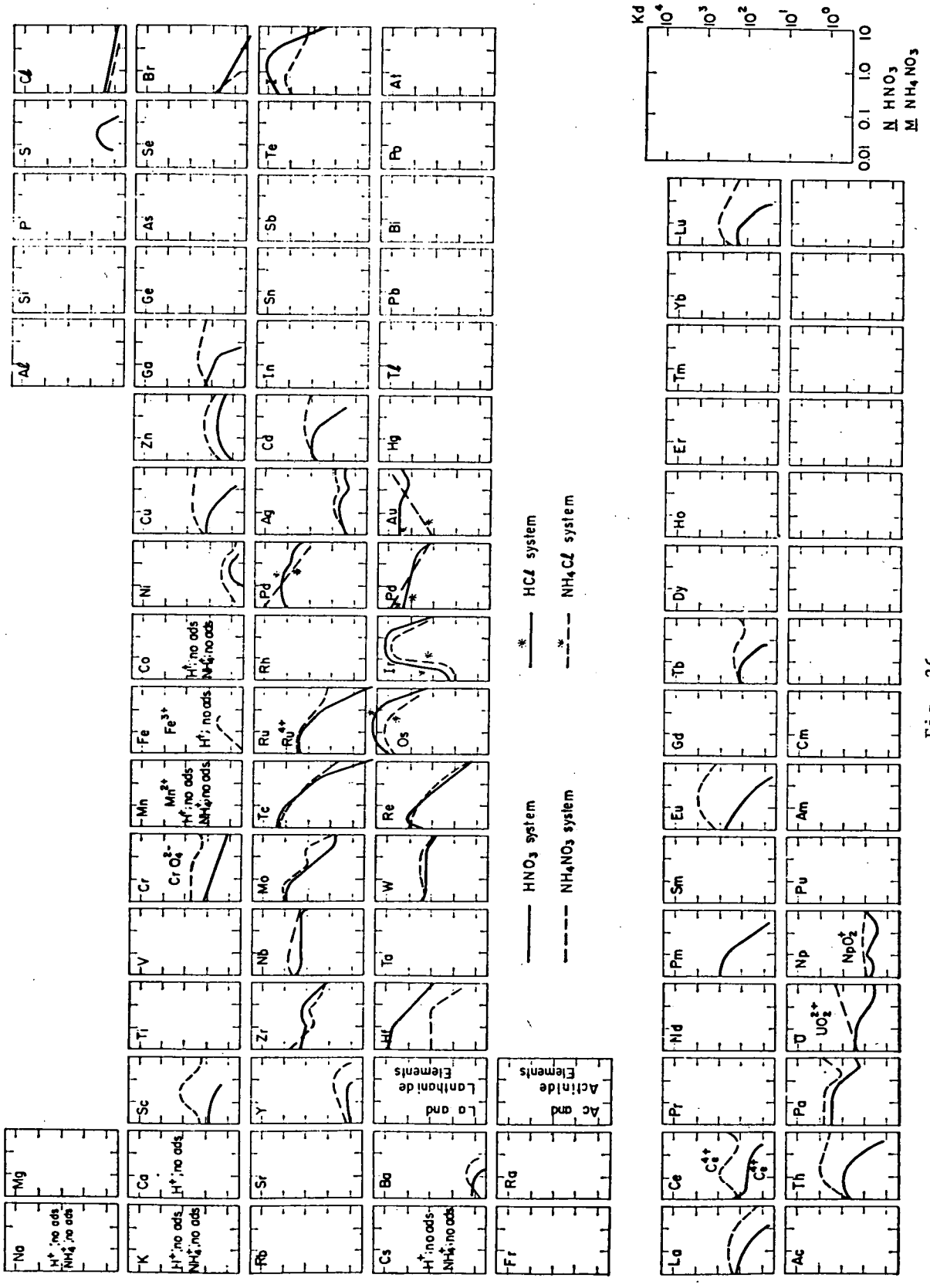

Kd
10^4
10^3
10^2
10^1
10^0
0.01 0.1 1.0 10
N HNO_3
M NH_4NO_3
HNO_3 system
NH_4NO_3 system
HCl system
NH_4Cl system
Actinide Elements
La and Lanthanide Elements
H^+; no ads
NH_4^+; no ads
$Cr\,O_4^{2-}$
Mn^{2+}
Fe^{3+}
Ru^{4+}
Pd^{+}
Ce^{4+}
Th^{4+}
UO_2^{2+}
NpO_2^{+}

Fig. 26

Fig. 25 Silica gel - HNO_3 system

Reference	Akatsu E., Ono R., Tsukuechi K., Uchiyama H.:J. Nucl. Sci. Technol., 2, 141 (1965)
Adsorbent	Silica gel(white) 30-80 mesh(Kanto-Kagaku)
Aq. phase	0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10M HNO_3 or NH_4NO_3
Equilibration	Batch method(one hour shaking)
Temp.	Room temp.
Loading	Tracer
Analysis	Measurement of radioactivity
Distribution ratio	Kd, counts per gram adsorbent/counts per milliliter soln.

Fig. 26 Charcoal - HNO_3, NH_4NO_3 system

Reference	Akatsu E., Ono R., Tsukuechi K., Uchiyama H.:J. Nucl. Sci. Technol., 2, 141 (1965)
Adsorbent	Active charcoal, 50 - 100mesh(Dainihon Kasseitan)
Aq. phase	0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10M HNO_3 or NH_4NO_3
Equilibration	Batch method(40 minutes shaking)
Temp.	Room temp.
Loading	Tracer
Analysis	Measurement of radioactivity
Distribution ratio	Kd, counts per gram adsorbent/counts per milliliter soln.

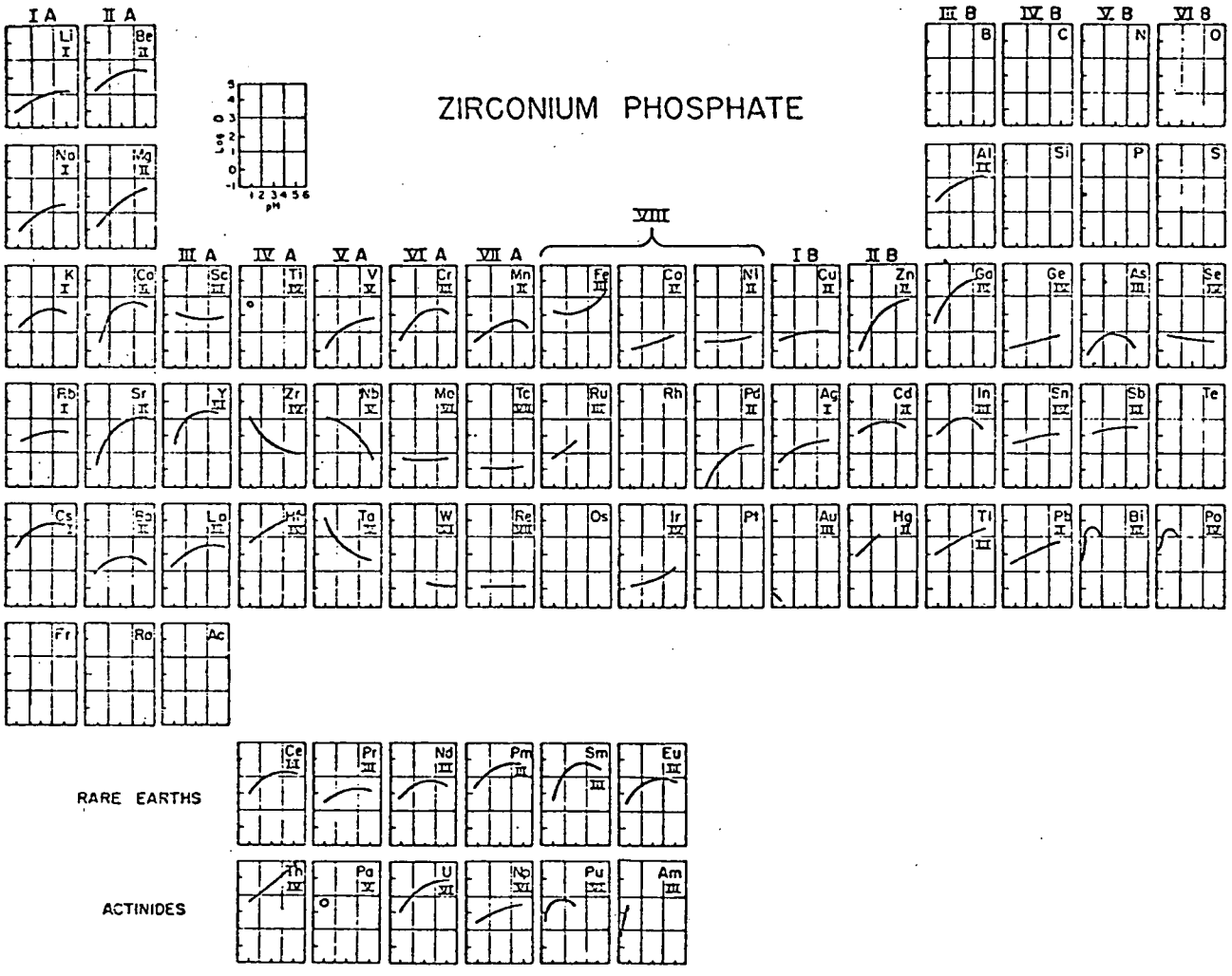


Fig. 27 Zirconium phosphate system

Reference	Maeck W. J., Kussy M. E., Rein J. E.: Anal. Chem., 35, 2086 (1963)
Exchanger	Zirconium phosphate(Bio-Rad Laboratories) 100-200 mesh, 1.05 meq of Cs. g^{-1} at pH 4.
Aq. phase	0.005M metal ion and its tracer, pH 1, 3 and 5 adjusted by HNO_3 or NH_4OH
Equilibration	Batch method(one hour on a 33 r.p.m. wheel)
Temp.	Room temp.
Loading	0.50g exchanger + 10 ml of 0.005M soln. of a metal ion and its radioactive tracer
Analysis	Radiometric
Distribution ratio	D, amount of a metal ion adsorbed per gram of exchanger/amount of the metal ion per milliliter of contacting soln.

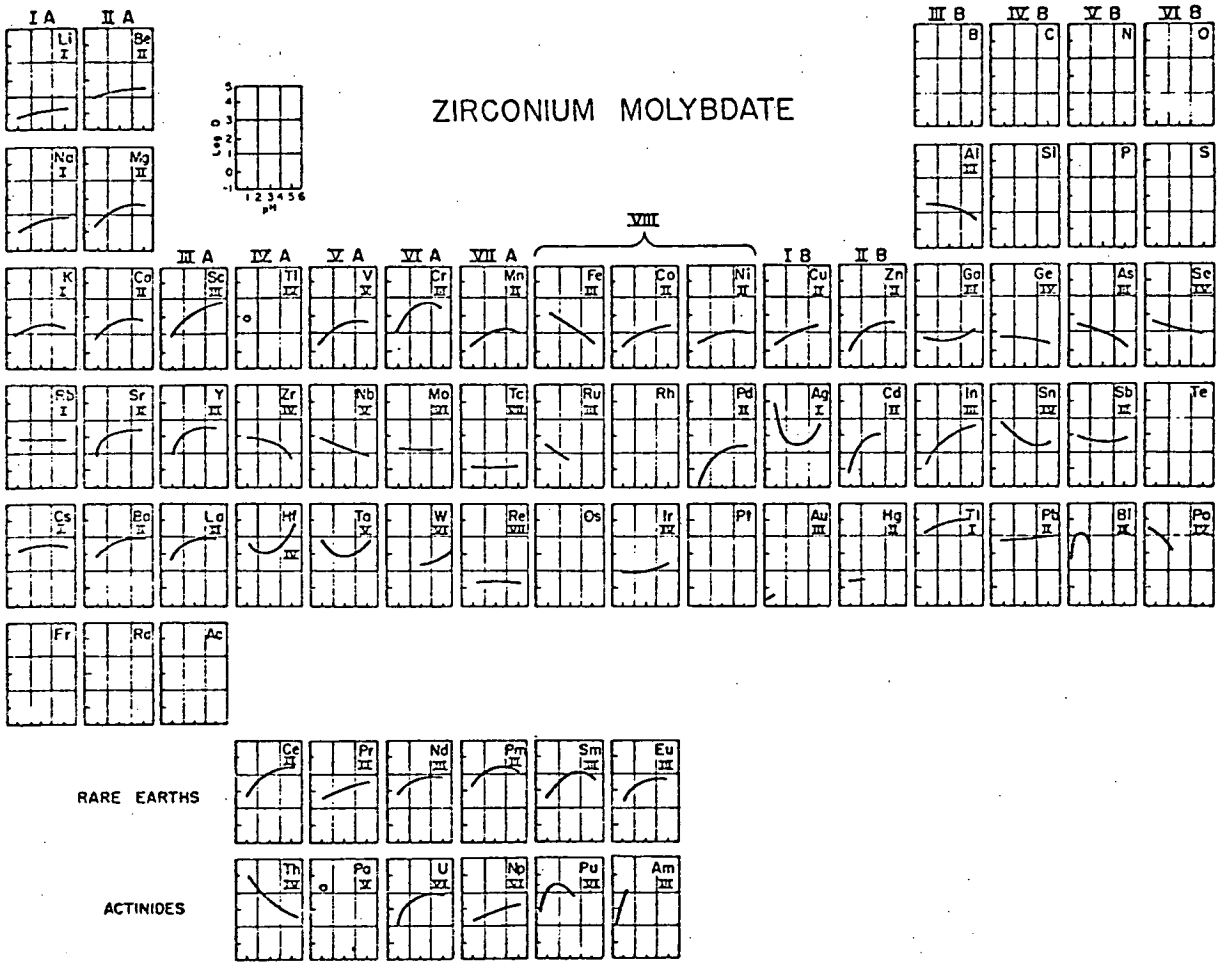


Fig. 28 Zirconium molybdate system

Reference	Maeck W. J., Kussy M.E., Rein J. E.: Anal. Chem., 35, 2086 (1963)
Exchanger	Zirconium molybdate (Bio-Rad Laboratories) 100-200 mesh, 1.12 meq. of $Cs.g^{-1}$ at pH 4.
Aq. phase	0.005M metal ion soln. and its tracer. pH was adjusted with HNO_3 or NH_4OH to pH 1, 3 or 5.
Equilibration	One hour on a 33 r.p.m. wheel, batch method
Temp.	Room temp.
Loading	0.50g exchanger + 10 ml of 0.005M soln. of a metal ion and its tracer
Analysis	Radiometric
Distribution ratio	D, amount of a metal ion adsorbed per gram of exchanger/ amount of the metal ion per milliliter of contacting soln.

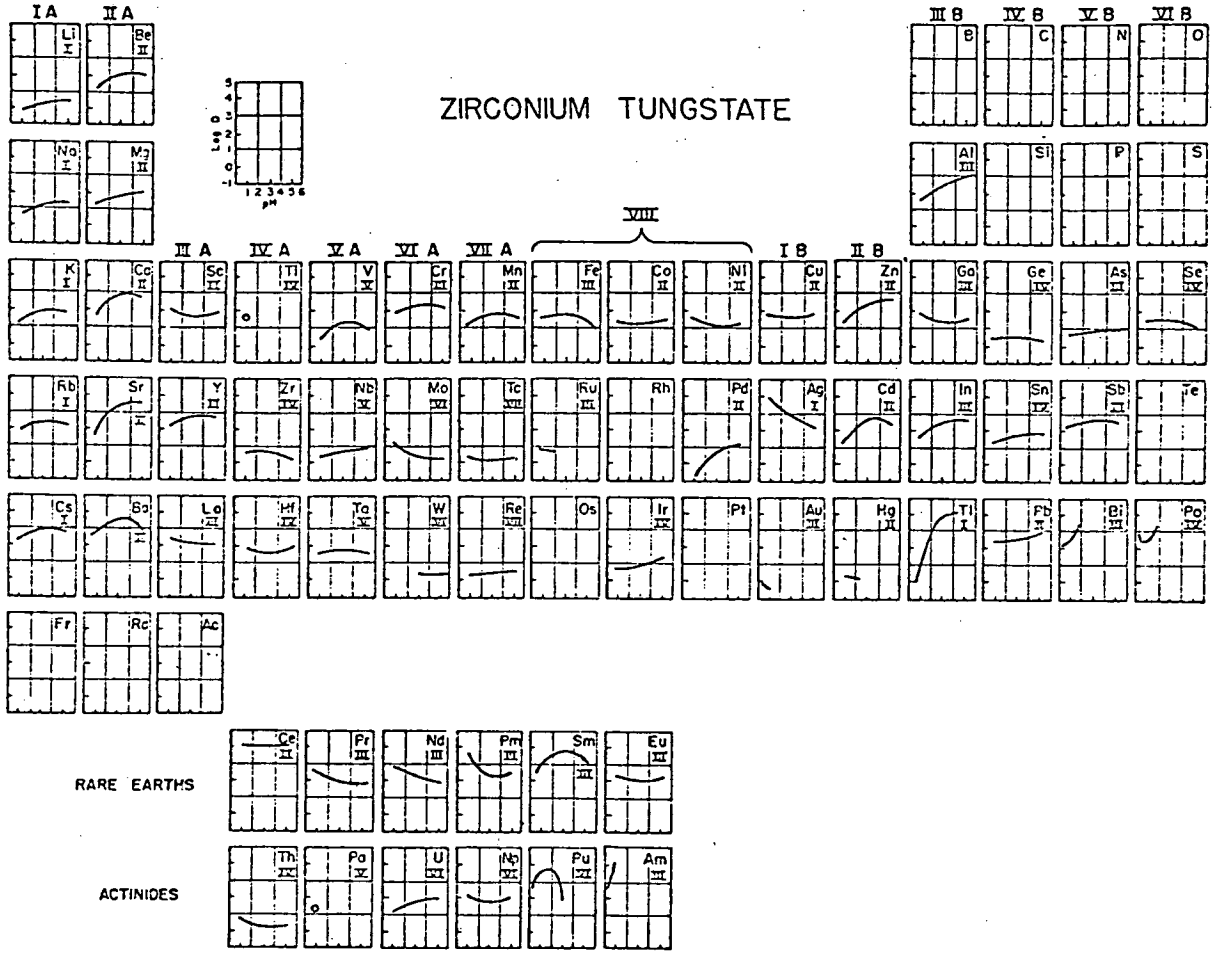


Fig. 29 Zirconium tungstate system

Reference Maeck W. J., Kussy M. E., Rein J. E.: Anal. Chem., 35, 2086 (1963)

Exchanger Zirconium tungstate (Bio-Rad Laboratories) 100-200 mesh, 0.77 meq. of Cs.g^{-1} at pH4

Aq. phase 0.05M metal ion soln. and its radioactive tracer at pH 1, 3 and 5 adjusted by HNO_3 or NH_4OH

Equilibration Batch method, one hour on a 33 r.p.m. wheel

Temp. Room temp.

Loading 0.50g exchanger + 10 ml of 0.005M soln. of a metal ion and its radioactive tracer

Analysis Radiometric

Distribution ratio D, amount of a metal ion adsorbed per gram of exchanger/ amount of the metal ion per milliliter of contacting soln.

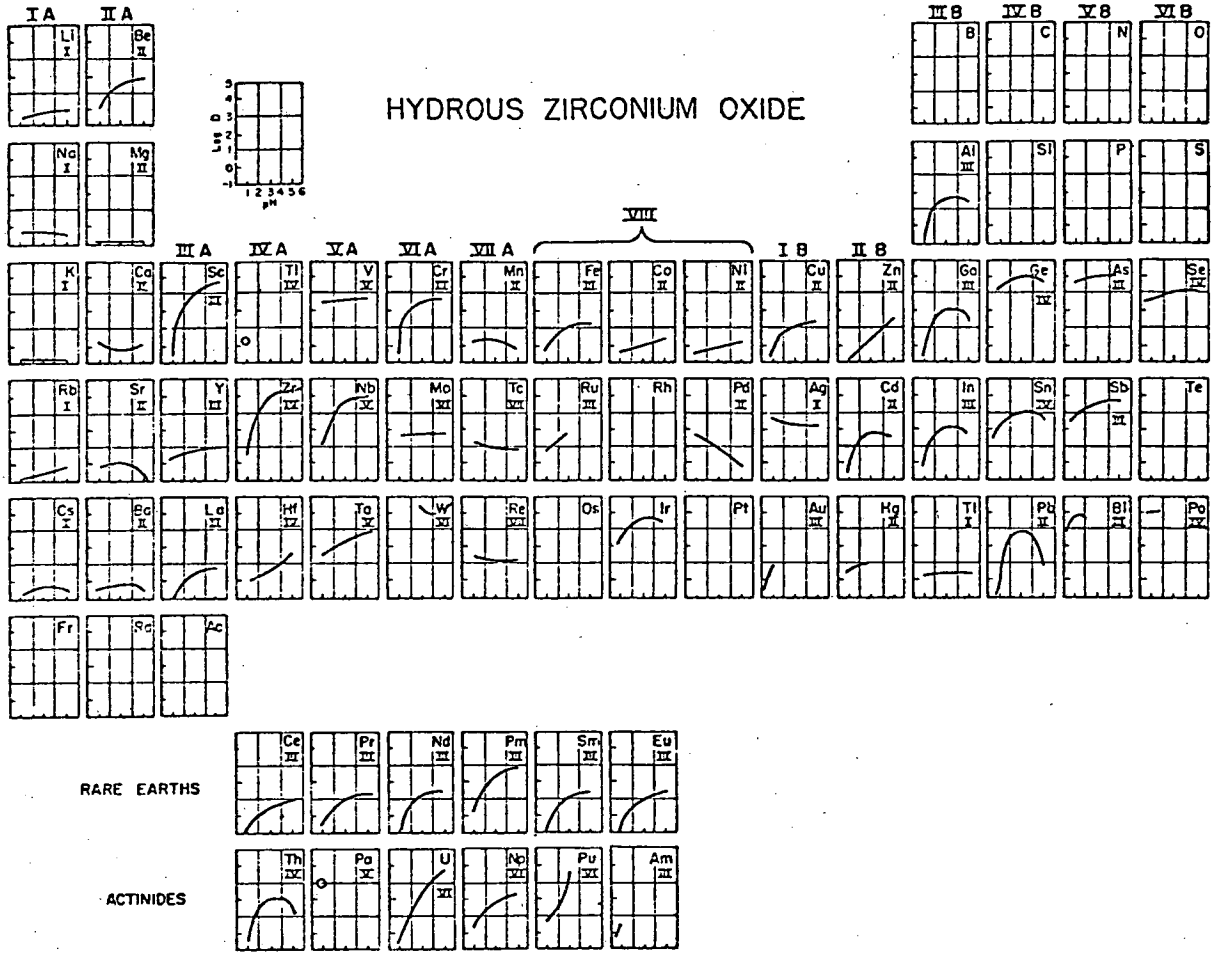


Fig. 30 Hydrous zirconium oxide system

Reference Maeck W. J., Kussy M. E., Rein J. E.: Anal. Chem., 35, 2086 (1963)

Exchanger Hydrous zirconium oxide(Bio-Rad Laboratories) 100-200 mesh, (1.05 meq of $Cr_2O_7^{2-}$ .g^{-1} at pH 1

Aq. phase 0.05M metal ion soln. and its radioactive tracer at pH 1, 3 and 5 adjusted by HNO_3 or NH_4OH

Equilibration Batch method, one hour ona 33 r.p.m. wheel

Temp. Room temp.

Loading 0.50 g exchanger + 10 ml of 0.005M soln. of a metal ion and its radioactive tracer

Analysis Radiometric

Distribution ratio D, amount of a metal ion adsorbed per gram of exchanger/amount of the metal ion per milliliter of contacting soln.