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CATION EXCHANGE IN ACETONE-WATER-HYDROCHLORIC ACID*

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Abstract

Distribution coefficients have been measured for the partition of metal ions between cation exchange resin and acetone-water-hydrochloric acid solutions. The differences in distribution coefficients of metal ions are greater in acetone-water media than in aqueous media of the same hydrochloric acid concentration. Using distribution coefficient data, conditions for column separations of mixtures can be selected. Column separations of metal ion mixtures can be effected by eluting with acetone-water-hydrochloric acid solutions of different compositions. Successful separations of a number of mixtures are reported.

INTRODUCTION

The separation of metal ions as halogen complexes by elution from a cation exchange column with an aqueous hydrohalic acid solution is now an established analytical technique. Fritz, Garralda, and Karraker (10) separated many metal ions using 0.1M or 1M hydrofluoric acid as the

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eluting agent. Yoshimo and Kojima (25) and Strelow (20) separated cadmium(II) from zinc(II) and other metal ions by elution with 0.5M hydrochloric acid. Fritz and Garralda (9) separated mercury(II), bismuth(III), cadmium(II), and lead(II) from each other and from other metal ions using 0.1 to 0.6M hydrobromic acid as the eluting agent. The extensive distribution coefficients of metal cations at various concentrations of hydrochloric acid measured by Strelow (21) and by Mann and Swanson (17) are a useful guide to possible cation exchange separations in aqueous solution.

It has been shown that metal ions are taken up more strongly and at lower hydrochloric acid concentrations by an anion exchange column if an appreciable amount of a water-miscible organic solvent is added to the aqueous hydrochloric acid (12, 24). This behavior indicated the possibility of using a nonaqueous solvent to promote metal-halide complex formation for the selective elution of metal ions from a cation exchange column. Preliminary work by Pietrzyk (18) indicated that acetone is the most effective of the solvents tested.

Kakinana and Sekiguchi have studied the variation of sodium(I) selectivity with acetone concentration in acetone-water-hydrochloric acid using cation exchange resin (14). Bafna has measured the selectivity of lithium(I), sodium(I), potassium(I), and ammonium chlorides in acetone-

water-hydrochloric acid media (1). Davies and Owen separated lithium(I), sodium(I), and potassium(I) using 80% acetone-water-0.7M hydrochloric acid as eluting agent. These authors also postulated that the adsorption of metal ions on cation exchange resin in partially non-aqueous systems may be due to a solvent partition phenomenon (5). Buznea, et al. (3) and Ionescu, et al. (13) have effected the separation of copper(II) and zinc (II) on phenol formaldehyde-type cation exchange resin using acetone-water-hydrochloric acid solutions as eluting agents. Kember, et al., have studied the behavior of several metals on Zeo Karb 225, cation exchange resin using acetone-water-hydrochloric acid eluants, but were only able to separate copper(II) and nickel(II) successfully (15). Van Erkelens has studied the ion exchange separation of complex mixtures of metal cations and anions in radiochemical amounts using acetone-water-hydrochloric acid solutions as eluting agents. He observed that certain separations, such as cobalt(II)-manganese(II) and iron(III)-copper(II)-zinc(II) could not be effected, and that the addition of potassium iodide is necessary to effect the separation of copper(II)-cobalt(II) mixtures (23). In the present work, these mixtures are separated quite easily, and many other separations either have been accomplished or are suggested by the distribution coefficient data.

EXPERIMENTAL

Reagents, Solutions, and Apparatus

Cation Exchange Resin

Dowex 50W X8 "analyzed reagent" resin, 100-200 mesh, is used in the measurement of distribution coefficients and column separations.

Before use, the resin must be purified. Place the resin in a large column and backwash with distilled water to remove the very fine particles. Then wash the resin with 10% ammonium citrate, 3M hydrochloric acid, and finally distilled water until a negative chloride test is obtained with silver nitrate. Remove the excess water by suction filtration. Wash the resin with absolute alcohol, then with acetone, and allow it to dry. The air dried resin has a water content of 15 to 20% by weight.

EDTA (disodium dihydrogen (ethylenedinitrilo) tetraacetate dihydrate)

Prepare 0.05M and 0.005M solutions from "analyzed reagent" grade salt. Standardize by titration of zinc(II) from primary standard zinc metal. NAS indicator is recommended (8).

Metal Salts

Prepare 0.05M solutions of metal perchlorates by dissolving primary standard metal in perchloric acid. If the metal is not available as a primary standard, dissolve reagent grade metal perchlorates or nitrates. Nitric acid is added to bismuth solutions to prevent hydrolysis.

Acetone-Water-Hydrochloric Acid Solutions

The solutions are prepared so that the amount of organic solvent and water are expressed as per cent by volume and the hydrochloric acid concentration as molarity. For example, one liter of 0.5M hydrochloric acid in 70% acetone is prepared as follows: Mix together 700 ml. of acetone, 41.5 ml. of concentrated hydrochloric acid and 258.5 ml. of distilled water.

Volume changes due to mixing are disregarded.

Ion Exchange Columns

Conventional 12 mm. i. d. ion exchange columns are fitted with Teflon needle valve stoppers in order to provide a more reproducible flow rate. A 60° glass funnel is fitted to the top of the column with a rubber stopper. The entire volume of the eluting agent is placed in the funnel at the beginning of the elution.

Analytical Procedures-EDTA Titrations

<u>Metal</u>	<u>Titration Method</u>	<u>pH</u>	<u>Buffer</u>	<u>Indicator</u>	<u>Ref.</u>
Bi ⁺⁺⁺	Direct	2.5	Sodium Acetate	Xylenol Orange	(16)
Ca ⁺⁺	Direct	10	NH ₄ OH-NH ₄ Cl	Erio Black T	(2)
Cd ⁺⁺	Direct*	5.5	Pyridine	NAS	(8)
Co ⁺⁺	Direct	5.5	Pyridine	NA	(11)
Cu ⁺⁺	Direct	5.5	Pyridine	NAS	(8)
Fe ⁺⁺⁺	Spectro- photometrically	2.5	Sodium Acetate	Sulfosalicylic Acid	(22)
Ga ⁺⁺⁺	Back (Cu ⁺⁺)	5.5	Pyridine	NAS	(8)

<u>Metal</u>	<u>Titration Method</u>	<u>pH</u>	<u>Buffer</u>	<u>Indicator</u>	<u>Ref.</u>
In ⁺⁺⁺	Back (Cu ⁺⁺)	5.5	Pyridine	NAS	(8)
Mg ⁺⁺	Direct	10	NH ₄ OH-NH ₄ Cl	Erio Black T	(2)
Mn ⁺⁺	Direct	10	NH ₄ OH-NH ₄ Cl	Erio Black T	(6)
Ni ⁺⁺	Direct*	5.5	Pyridine	NAS	(8)
VO ⁺⁺	Direct	5.5	Pyridine	NAS	(8)
Zn ⁺⁺	Direct	5.5	Pyridine	NAS	(8)

Note: UO₂⁺⁺ is titrated with ceric sulfate after reduction in a lead reductor, using 1, 10-phenanthroline as indicator (19).

* A known amount of Cu⁺⁺ is added near the equivalence point and the titration continued to give a sharp color change.

Measurement of Distribution Coefficients

Weigh accurately approximately one gram of air-dried cation exchange resin into a 125 ml. glass-stoppered Erlenmeyer flask. Pipet into the flask 4 ml. of 0.05M metal salt solution and 50 ml. of the appropriate acetone-water-hydrochloric acid mixture. Stopper the flask and shake 24 hours. Pipet an aliquot from the supernatant liquid, evaporate the acid and organic solvent to near dryness, and determine the metal ion content by an appropriate analytical method as listed in Table I. Determine accurately the water content of the resin by oven drying a sample of known weight, and calculate the

distribution coefficients on a dry weight basis. Calculate the distribution coefficient with the following relation:

$$D = \frac{\frac{\text{millimoles of metal ion on resin}}{\text{gram of dry resin}}}{\frac{\text{millimoles of metal ion in solution}}{\text{total volume of solution}}}$$

Separation of Mixtures

Prepare the ion exchange column by making a slurry of the resin and the first eluting agent. Pour the slurry into a 1.2 cm. i. d. column and let settle to a height of 12.5 cm. Pass 10 ml. of the first eluting agent through the column at maximum flow rate in order to equilibrate the resin with the eluting agent.

Prepare a sample by pipetting into a 10 ml. beaker known amounts of standard metal salt solutions. Carefully evaporate the sample mixture to a volume of one to two milliliters and dilute with 10 ml. of 50% acetone. Concentrated nitric acid may be added during the evaporation to prevent salt hydrolysis.

Transfer the sample to the column, rinsing the beaker several times with one milliliter portions of the first eluting agent. After the sample has been rinsed onto the column, attach a 60° funnel to the top of the column with a rubber stopper. Fill the funnel with the amount of eluting agent required to elute the first ion and adjust the flow rate to 0.3-0.5 ml. per minute. Evaporate the excess acid and organic solvent from the effluent

fractions collected. Determine the amount of metal salt present by an appropriate titrimetric procedure.

Distribution Coefficients

Measurement of the batch distribution coefficient (D) offers a systematic method of choosing elution conditions, eliminating the necessity of trial and error selection. Although the distribution coefficient is measured on a batch basis, it may be used to predict the elution behavior of metals on an ion exchange column. In order to separate two metals, the elution conditions are chosen such that one of the metals has a very high distribution coefficient and will thus be strongly retained by the column. The distribution coefficient of the other metal should be very low (near one or less) in order that the metal ion may be eluted with a small volume of eluting agent.

The effect of the acetone upon the distribution coefficient may be seen in Figures 1 and 2 and Tables I and II. The distribution coefficients of all metal ions studied increase with increasing proportions of acetone at low percentages of acetone. At higher percentages of acetone however, the distribution coefficient of many metal ions drops sharply. The large decrease in distribution coefficient at high acetone percentages is attributed to the formation of chloro complexes which are held less strongly by the resin. Nickel(II) and vanadium(IV) do not exhibit a decrease in distribution coefficient in 0.5M hydrochloric acid, indicating that complexation is not

important at this acid concentration. The distribution coefficients of nickel(II) and manganese(II) decrease at high acetone concentration in 1.0M hydrochloric acid, illustrating the importance of acid concentration with regard to complexation.

The effect of the eluent anion upon the distribution coefficient of copper(II) may be seen in Figure 3. The curve of 0.5M hydrochloric acid media shows a decrease in distribution coefficient at about 65% acetone. This decrease is attributed to complexation. Yellow copper-chloro complexes are observed at acetone concentrations greater than 85%. The curve for the 0.5M HClO_4 -acetone-medium shows no decrease in distribution coefficient with increasing percentages of acetone. Thus, complexation by perchlorate ion is not important even at high acetone concentrations. The continual rise of distribution coefficient at high acetone concentrations may be due to a solvent partition phenomenon as suggested by Davies and Owen (5).

A comparison of the values of the distribution coefficients in aqueous 0.5M hydrochloric acid reported by Strelow (21) and those reported here in varying per cent acetone-0.5M hydrochloric acid shows that the acetone has the effect of enhancing the differences in distribution coefficients of many metal ions. This enhancement of differences in distribution coefficients is used as the basis of separation of mixtures.

Separation of Mixtures

In the present work, batch distribution coefficients were used as a guide to the selection of conditions for column separations (4). The volume required to elute a metal ion from a column agrees favorably with the volume predicted by distribution coefficient data for all metal ions studied except cobalt(II). Cobalt(II) has a distribution coefficient of 106 in 90% acetone-0.5M hydrochloric acid, yet it is eluted completely by 50 ml. of this eluting agent. Calculation of the required volume of eluting agent from the distribution coefficient would give a much higher volume. The actual volume of eluting agent required is often slightly larger than that indicated by the distribution coefficients, owing to tailing, which is more apt to occur in partially non-aqueous media. The volume of eluting agent required to elute a metal ion from a column was always determined by collecting fractions of effluent from a column and analyzing the fractions. An elution curve of a six-component mixture is shown in Figure 4. The extent of tailing and total volume of eluting agent required for each metal ion are obtained from this type of curve.

To separate two metal ions on a cation exchange column, a solvent composition and hydrochloric acid concentration are chosen such that one metal will be rapidly eluted from the column (D should be low, preferably one or less) while the other metal ion has a high D and is tightly held by the column. When several metal ions are to be separated from each other,

successive elution conditions are chosen so that only one metal ion is eluted by each eluting agent. In the present work, the concentration of acetone in the acetone-water mixture and the concentration of hydrochloric acid are the variables which determine the composition of the eluting agent.

From the distribution coefficient data and actual separations that have been effected, the elution scheme is as follows:

Bi⁺⁺⁺ is eluted with 60% Acetone-0.1M HCl
 Cd⁺ is eluted with 70% Acetone-0.2M HCl
 In⁺⁺⁺ is eluted with 40% Acetone-0.5M HCl
 Zn⁺⁺ is eluted with 70% Acetone-0.5M HCl
 Fe⁺⁺⁺ is eluted with 80% Acetone-0.5M HCl
 Cu⁺⁺ is eluted with 85% Acetone-0.5M HCl
 UO₂⁺⁺ is eluted with 85% Acetone-0.5M HCl
 Co⁺⁺ is eluted with 90% Acetone-0.5M HCl
 Ga⁺⁺⁺ is eluted with 90% Acetone-0.5M HCl
 Mn⁺⁺ is eluted with 92% Acetone-1.0M HCl
 Al⁺⁺⁺, Ca⁺⁺, Mg⁺⁺, Ni⁺⁺ are eluted as a group with aqueous 3M hydrochloric acid. VO⁺⁺ is eluted with 0.3% H₂O₂-0.1M HClO₄.

A number of separations using this elution scheme are presented in Table III. Even an eleven-component mixture was separated and analyzed

quantatively. In addition to the separations reported in Table III, the following mixtures were successfully separated and the individual metal ions titrated quantitatively: $Zn^{++}-Cu^{++}$, $Cu^{++}-Co^{++}$, $Zn^{++}-Cu^{++}-Co^{++}$, $Fe^{+++}-Cu^{++}-Ni^{++}$, $Co^{++}-Ni^{++}$, $Bi^{+++}-Cd^{++}$, $Bi^{+++}-Ni^{++}$, $Bi^{+++}-Zn^{++}$, $Cd^{++}-Zn^{++}-Mn^{++}$, $Co^{++}-Mn^{++}$, $In^{+++}-Fe^{+++}$, $Ga^{+++}-VO^{++}$, $Fe^{+++}-Co^{++}-Ni^{++}$, and $Bi^{+++}-Cd^{++}-VO^{++}$.

The average recovery for all separations (96 individual analyses) was slightly low (99.8%). The standard deviation for all data was $\pm 0.3\%$.

The elution method for VO^{++} is from studies by Fritz and Abbink (7). Copper(II) is eluted with 85% acetone-0.5M hydrochloric acid to permit separation from cobalt(II). If cobalt(II) is not present in the mixture, copper may be eluted more rapidly with 90% acetone-0.5M hydrochloric acid. Copper(II) and cobalt(II) cannot be separated by eluting copper(II) with 90% acetone-0.5M hydrochloric acid. Cobalt(II) elutes with the copper(II), which is contrary to the distribution coefficient data. Vanadium(IV) must be eluted before manganese(II) because vanadium is also eluted by 92% acetone-1.0M hydrochloric acid. The column is washed with at least 15 ml. of water to remove excess acid before the peroxide eluent is added to elute vanadium(IV). This is done to minimize gas bubble formation in the column. The bubbles do not seriously affect the subsequent elution of metal ions through the column. Transformation from a partially non-aqueous elution

medium to an aqueous medium and then back to a partially non-aqueous medium does not hinder the performance of the column.

Several separations are not possible using this scheme. Indium(III) and cadmium(II) can only be separated as a group. Aluminum(III), calcium(II), magnesium(II), nickel(II), and cobalt(II) and gallium(III) can be separated only as groups.

Tailing is a problem in the elution of cobalt(II) and uranium(VI). Cobalt is eluted with 90% acetone-0.5M hydrochloric acid or 90% acetone-1M hydrochloric acid. The elution of uranium(VI) with 90% acetone-1M hydrochloric acid is incomplete. A total volume of 50 ml. is required to elute cobalt with either eluting agent. Cadmium(II) and manganese(II) also tail, but not seriously. Tailing can be reduced by decreasing the flow rate; however, a convenient balance between flow rate and the time required to elute a metal ion must be found. A flow rate of 0.3-0.5 ml. per minute gives the most satisfactory results. Tailing can also be reduced by using a finer mesh resin, but this alternative has not been tried.

In the mixtures analyzed above, the sample constituents are present in approximately equi-molar amounts. The total amount of metal ions loaded onto the resin should not exceed 1.5 milliequivalents for a column 12.5 cm. x 1.2 cm. This maximum load represents a cation/resin ratio of 0.065. Heavier loading of the resin will increase tailing. A high ratio of

one or more sample constituents to another does not cause any difficulty as long as the column is not overloaded (see Table III).

Table I. Table of Distribution Coefficients 0.5M Hydrochloric Acid

Ion	% Acetone													
	0	10	20	30	40	50	60	70	80	90	92	94	96	
Bi ⁺⁺⁺	9.4	0	0	0	0	0	0	0	0	0				
Ca ⁺⁺										90	102	91	106	
Cd ⁺⁺	8.02	7.29	4.60	3.32	1.3	0	0	0	0	0				
Co ⁺⁺					263	349	478	591	558	106				
Cu ⁺⁺	88	88	96	92	150	185	193	136	44.0	3.50				
Fe ⁺⁺⁺					400	299	134	15.4	0	0				
Ga ⁺⁺⁺					1790	4360	1870	48.8	6.67	0				
In ⁺⁺⁺					1.66	0.45	0.08	0	0	0				
Mg ⁺⁺										83	82	81.7	96	
Mn ⁺⁺	105	119	110	119	273	330	461	551	174	290	174	108	37.7	
Ni ⁺⁺					210	251	407	708	730	708				
UO ₂ ⁺⁺					173	197	180	197	61	3.30				
Zn ⁺⁺	85.2	94.5	96	98	35.7	11.1	0.92	0	0	0				
VO ⁺⁺					162	131	165	167	163	151				

Table II. Table of Distribution Coefficients

Ion	% Acetone						
	40	50	60	70	80	90	92
	<u>1M HCl</u>						
Ca ⁺⁺						73	131
Co ⁺⁺	47.4	64.0	83.0	92.0	49.0	0	
Mg ⁺⁺						51.0	52.2
Mn ⁺⁺	49	63	87.6	112	75.7	12.6	4.13
Ni ⁺⁺	60	66.2	119	135	151	94.7	
	<u>0.3M HCl</u>						
Bi ⁺⁺⁺	0	0	0	0	0	0	
Cd ⁺⁺	16.11	5.02	1.03	0	0	0	
In ⁺⁺⁺	15.4	12.0	7.82	1.85	0	0	
	<u>0.2M HCl</u>						
Bi ⁺⁺⁺	0	0	0	0	0	0	
Cd ⁺⁺	71	30.7	7.35	0	0	0	
	<u>0.1M HCl</u>						
Bi ⁺⁺⁺	213	37.5	0	0	0	0	
Cd ⁺⁺	476	305	132	26	0	0	

Table III. Separation and Analysis of Synthetic Metal Ion Mixtures on Dowex 50W X8, 100 to 200 Mesh, Hydrogen Form Resin

Metals appear in the order of elution with the amount of wash solution included with the first eluted metal.

Eluting Agent		Milli Moles Taken	Milli Moles Found	% Recovery
$\text{Cd}^{++} - \text{Zn}^{++}$ (12.5 x 1.2 cm.) ^a				
Cd^{++}	25 ml. 40% A ^b - 0.5M HCl	0.2289	0.2279	99.6
Zn^{++}	25 ml. 70% A - 0.5M HCl	0.2023	0.2013	99.5
$\text{Mn}^{++} - \text{Ni}^{++}$ (12.5 x 1.2 cm.)				
Mn^{++}	45 ml. 92% A - 1M HCl	0.2023	0.2023	100.0
Ni^{++}	35 ml. Aqueous 3M HCl	0.2124	0.2118	99.8
$\text{Zn}^{++} - \text{Fe}^{+++} - \text{Cu}^{++} - \text{Mn}^{++} - \text{Ni}^{++}$ (12.5 x 1.2 cm.)				
Zn^{++}	20 ml. 60% A - 0.5M HCl	0.05036	0.05086	101.0
Fe^{+++}	20 ml. 70% A - 0.5M HCl			
	15 ml. 80% A - 0.5M HCl	0.2019	0.2009	99.5
Cu^{++}	32 ml. 80% A - 0.5M HCl	0.09115	0.09064	99.5
Mn^{++}	40 ml. 92% A - 1M HCl	0.1012	0.1012	100.0
Ni^{++}	30 ml. Aqueous 3M HCl	0.1093	0.1093	100.0
$\text{Fe}^{+++} - \text{Al}^{+++}$ (12.5 x 1.2 cm.)				
Fe^{+++}	35 ml. 80% A - 0.5M HCl	0.1883	0.1873	99.5
Al^{+++}	125 ml. Aqueous 3M HCl	0.1911	0.1907	99.8
$\text{Co}^{++} - \text{Ni}^{++}$ (12.5 x 1.2 cm.)				
Co^{++}	45 ml. 90% A - 0.5M HCl	0.01974	0.01969	99.8
Ni^{++}	50 ml. Aqueous 3M HCl	0.2080	0.2070	99.8

^a Metal Mixture (Column Dimensions).

^b A = Acetone.

Table III (cont.)

	Eluting Agent	Milli Moles Taken	Milli Moles Found	% Recovery
Co⁺⁺ - Ni⁺⁺ (12.5 x 1.2 cm.)				
Co ⁺⁺	45 ml. 90% A-0.5M HCl	0.2095	0.2090	99.8
Ni ⁺⁺	50 ml. Aqueous 3M HCl	0.2043	0.2042	99.9
Bi⁺⁺⁺ - Cd⁺⁺ - Zn⁺⁺ (12.5 x 1.2 cm.)				
Bi ⁺⁺⁺	25 ml. 60% A-0.1M HCl	0.1788	0.1788	100.0
Cd ⁺⁺	25 ml. 70% A-0.2M HCl	0.2030	0.2024	99.7
Zn ⁺⁺	30 ml. 70% A-0.5M HCl	0.2035	0.2035	100.0
Fe⁺⁺⁺ - Al⁺⁺⁺ (12.5 x 1.2 cm.)				
Fe ⁺⁺⁺	45 ml. 60% A-0.5M HCl	0.1878	0.1863	99.4
Al ⁺⁺⁺	200 ml. Aqueous 3M HCl	0.1958	0.1958	100.0
Fe⁺⁺⁺ - Al⁺⁺⁺ (12.5 x 1.2 cm.)				
Fe ⁺⁺⁺	45 ml. 60% A-0.5M HCl	0.01732	0.01727	99.7
Al ⁺⁺⁺	200 ml. Aqueous 3M HCl	0.1958	0.1953	99.8
Bi⁺⁺⁺ - Cd⁺⁺ - Zn⁺⁺ (12.5 x 1.2 cm.)				
Bi ⁺⁺⁺	25 ml. 60% A-0.1M HCl	0.1787	0.1787	100.0
Cd ⁺⁺	25 ml. 70% A-0.2M HCl	0.2030	0.2024	99.7
Zn ⁺⁺	30 ml. 70% A-0.5M HCl	0.2035	0.2035	100.0
In⁺⁺⁺ - Zn⁺⁺ - Mn⁺⁺ (12.5 x 1.2 cm.)				
In ⁺⁺⁺	35 ml. 40% A-0.5M HCl	0.2216	0.2201	99.3
Zn ⁺⁺	25 ml. 70% A-0.5M HCl	0.2024	0.2024	100.0
Mn ⁺⁺	50 ml. 92% A-1M HCl	0.2009	0.2009	100.0
In⁺⁺⁺ - Fe⁺⁺⁺ - Mn⁺⁺ - Ni⁺⁺ (12.5 x 1.2 cm.)				
In ⁺⁺⁺	25 ml. 40% A-0.5M HCl	0.05540	0.05540	100.0
Fe ⁺⁺⁺	28 ml. 80% A-0.5M HCl	0.1828	0.1828	100.0
Mn ⁺⁺	50 ml. 92% A-1M HCl	0.2009	0.2009	100.0
Ni ⁺⁺	30 ml. Aqueous 3M HCl	0.2090	0.2090	100.0

Table III (cont.)

Eluting Agent		Milli Moles Taken	Milli Moles Found	% Recovery
Zn^{++} - Fe^{+++} - Co^{++} - Mn^{++} (12.5 x 1.2 cm.)				
Zn^{++}	25 ml. 60% A-0.5M HCl	0.2035	0.2035	100.0
Fe^{+++}	25 ml. 80% A-0.5M HCl	0.1883	0.1878	99.7
Co^{++}	50 ml. 90% A-0.5M HCl	0.2085	0.2085	100.0
Mn^{++}	50 ml. 92% A-1M HCl	0.2009	0.2009	100.0
Co^{++} - VO^{++} - Mn^{++} (12.5 x 1.2 cm.)				
Co^{++}	50 ml. 90% A-0.5M HCl	0.2074	0.2074	100.0
VO^{++}	50 ml. 0.3% H_2O_2 -0.01M 15 ml. H_2O $HClO_4^*$	0.1226	0.1221	99.6
Mn^{++}	50 ml. 92% A-0.5M HCl	0.1995	0.1995	100.0
Cd^{++} - Zn^{++} - Cu^{++} - Co^{++} (12.5 x 1.2 cm.)				
Cd^{++}	25 ml. 40% A-0.5M HCl	0.2290	0.2280	99.6
Zn^{++}	25 ml. 70% A-0.5M HCl	0.2028	0.2023	99.8
Cu^{++}	25 ml. 90% A-0.5M HCl	0.2335	0.2339	100.2
Co^{++}	40 ml. 90% A-1M HCl	0.1958	0.1948	99.5
In^{+++} - Al^{+++} (12.5 x 1.2 cm.)				
In^{+++}	25 ml. 40% A-0.5M HCl	0.1938	0.1934	99.8
Al^{+++}	150 ml. Aqueous 3M HCl	0.1798	0.1793	99.7
In^{+++} - Mn^{++} (12.5 x 1.2 cm.)				
In^{+++}	25 ml. 40% A-0.5M HCl	0.1938	0.1934	99.8
Mn^{++}	50 ml. 92% A-0.5M HCl	0.2004	0.2000	99.7
In^{+++} - Fe^{+++} - Co^{++} - Ni^{++} (12.5 x 1.2 cm.)				
In^{+++}	30 ml. 40% A-0.5M HCl	0.1938	0.1933	99.7
Fe^{+++}	40 ml. 80% A-0.5M HCl	0.1891	0.1888	99.8
Co^{++}	50 ml. 90% A-0.5M HCl	0.2078	0.2068	99.5
Ni^{++}	60 ml. Aqueous 3M HCl	0.2044	0.2039	99.8

* Eluent passed through column at maximum flow rate.

Table III (cont.)

Eluting Agent	Milli Moles Taken	Milli Moles Found	% Recovery	
Bi ⁺⁺⁺ -Cd ⁺⁺ -Zn ⁺⁺ - (16.0 x 1.2 cm.) Fe ⁺⁺⁺ -Cu ⁺⁺ -Co ⁺⁺ - VO ⁺⁺ -Mn ⁺⁺ -Al ⁺⁺⁺ - Ni ⁺⁺ -Y ⁺⁺⁺				
Bi ⁺⁺⁺	35 ml. 60% A-0. 1M HCl	0.09971	0.09920	99.5
Cd ⁺⁺	30 ml. 40% A-0. 5M HCl	0.09527	0.09477	99.5
Zn ⁺⁺	35 ml. 60% A-0. 5M HCl	0.09971	0.09971	100.0
Fe ⁺⁺⁺	30 ml. 70% A-0. 5M HCl	0.09191	0.09141	99.5
	30 ml. 80% A-0. 5M HCl			
Cu ⁺⁺	55 ml. 80% A-0. 5M HCl	0.09230	0.09206	99.7
Co ⁺⁺	65 ml. 90% A-0. 5M HCl	0.1042	0.1039	99.7
VO ⁺⁺	35 ml. 0.3% H ₂ O ₂ -0.01M HClO ₄	0.04543	0.04393	95.6
Mn ⁺⁺	70 ml. 92% A-0. 1M HCl	0.1002	0.09995	99.8
Al ⁺⁺⁺	200 ml. 0.1M HF	0.07792	0.07792	100.0
Ni ⁺⁺	200 ml. 1.5M HNO ₃	0.1032	0.1032	100.0
Y ⁺⁺⁺	200 ml. 2.0M HNO ₃	0.09527	0.09501	99.7

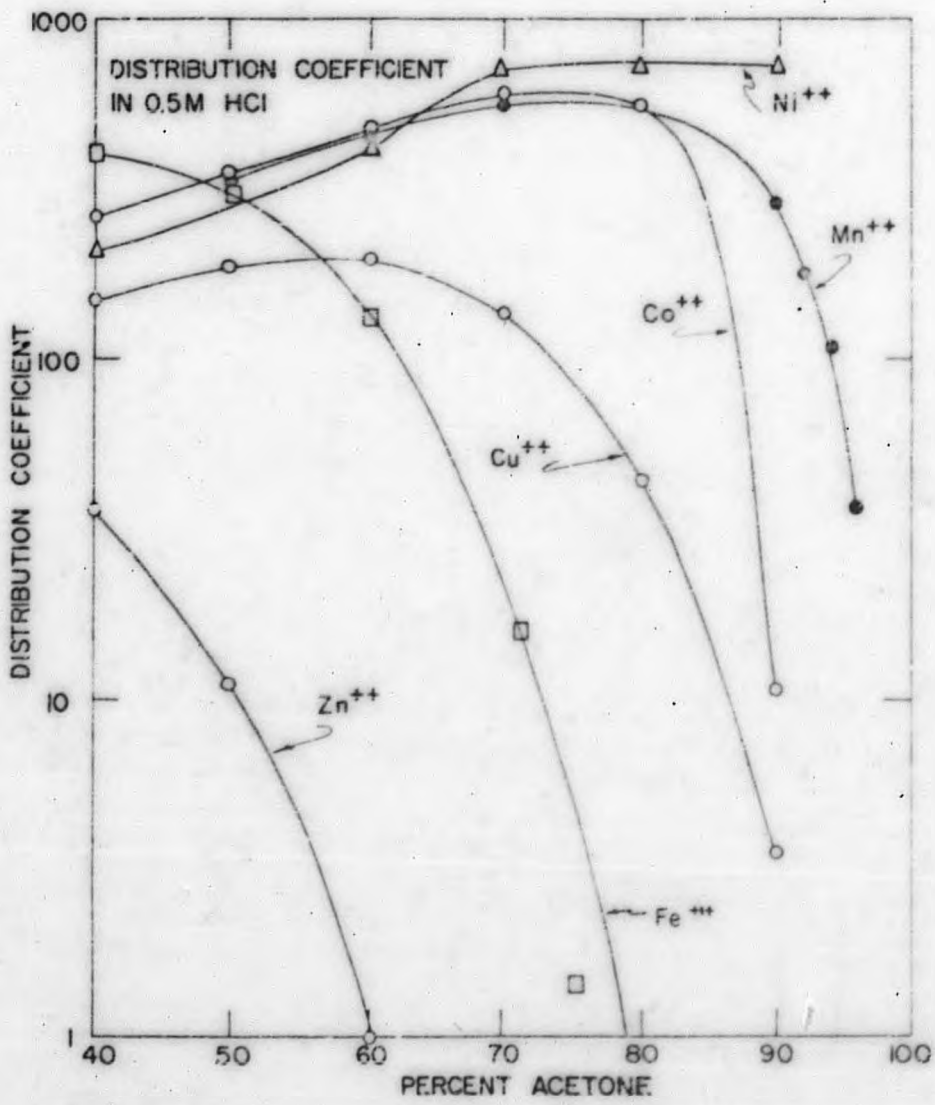


Figure 1. Distribution coefficients as a function of acetone concentration in 0.5M HCl.

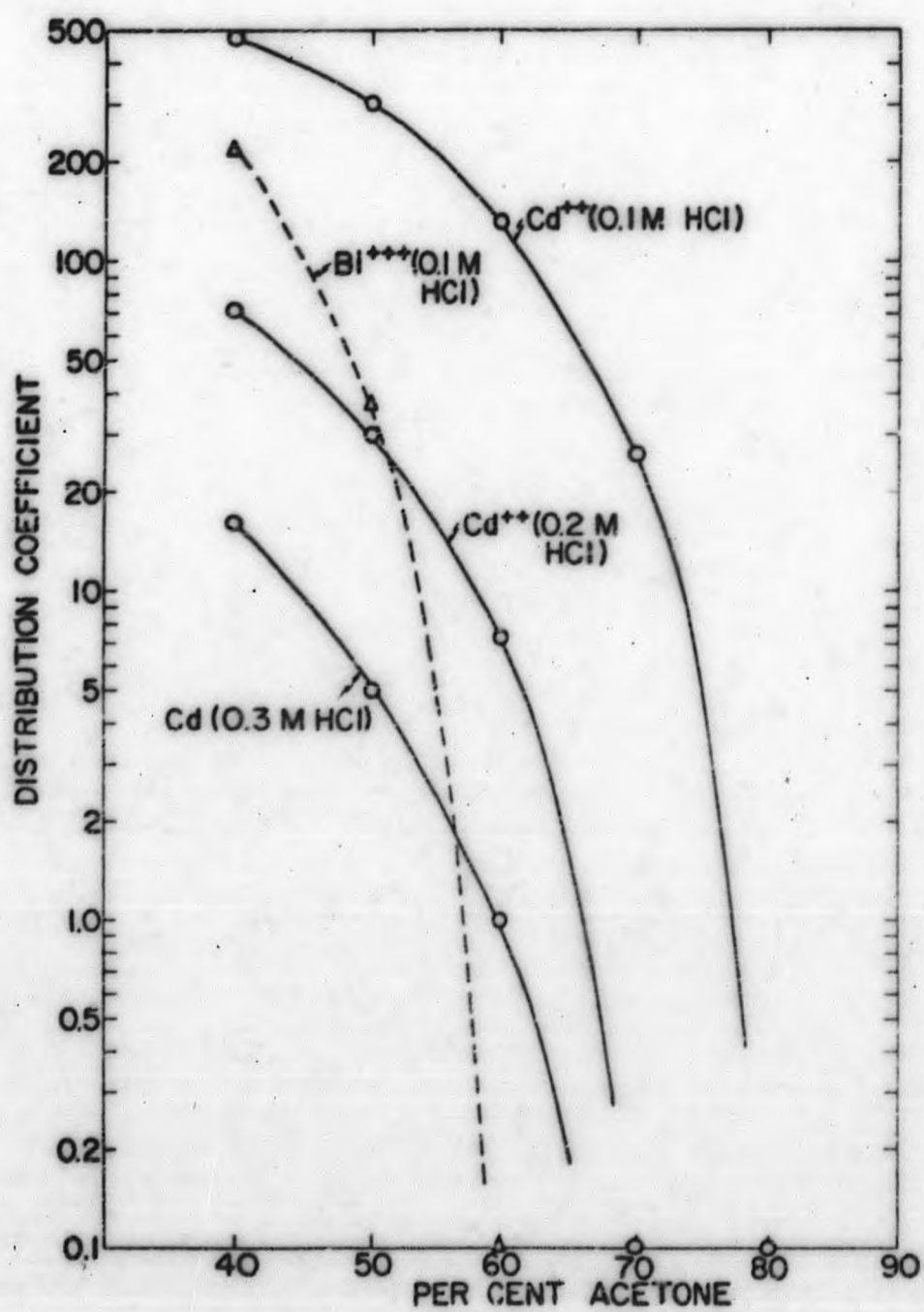


Figure 2. Distribution coefficients of bismuth(III) and cadmium(II).

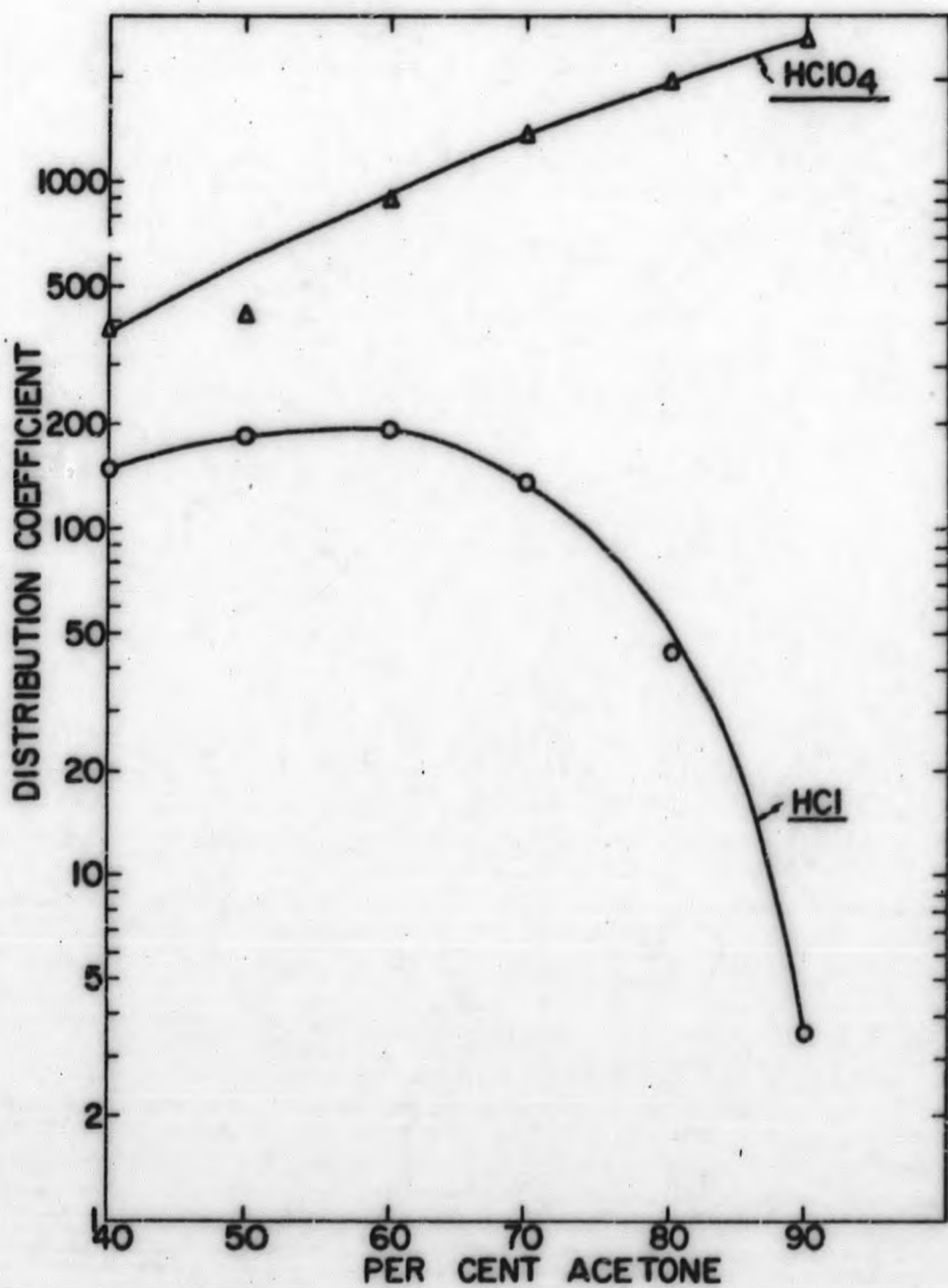


Figure 3. Distribution coefficients of copper(II) in 0.5M perchloric and in 0.5M hydrochloric acid.

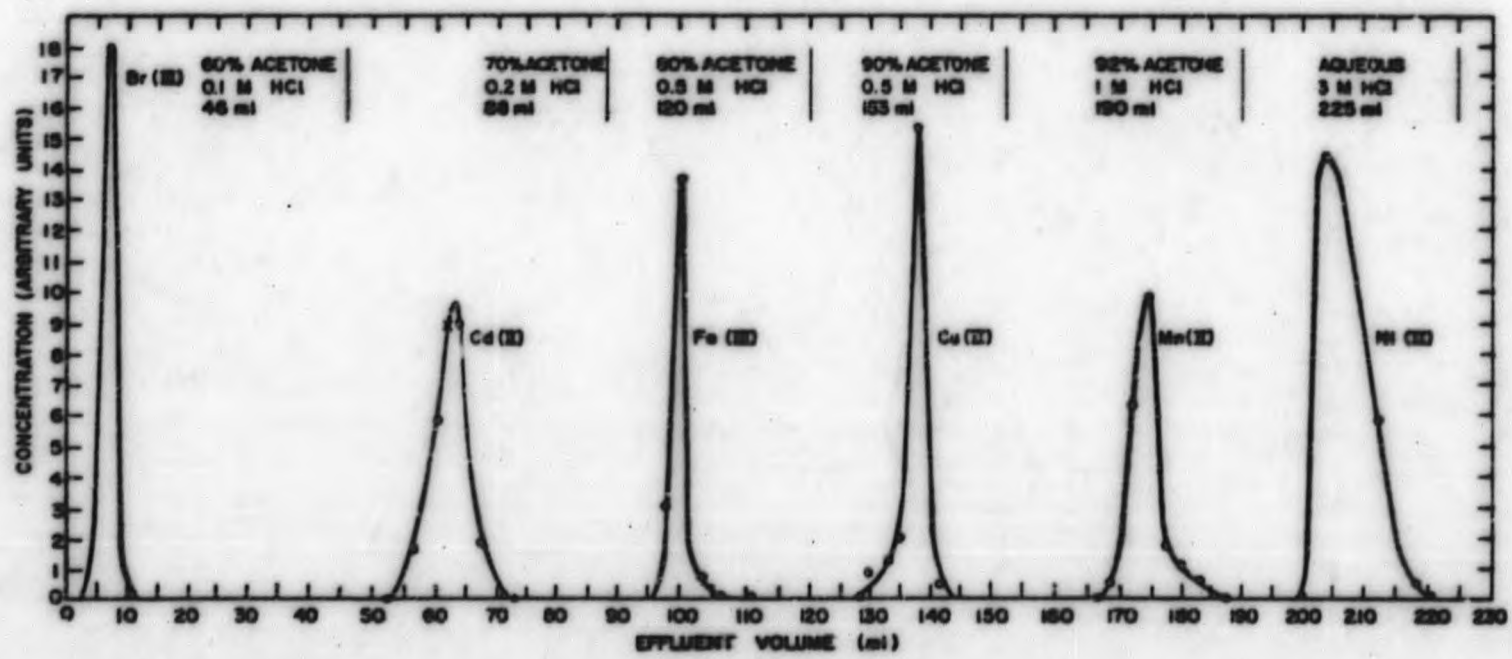


Figure 4. Elution curve for a six-component mixture.

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FIGURE CAPTIONS

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- Figure 3. Distribution coefficients of copper(II) in 0.5M perchloric and in 0.5M hydrochloric acid.
- Figure 4. Elution curve for a six-component mixture.

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