

Table of Contents

<i>Preface</i>	vii
I. INTRODUCTION	1
1. Historical Introduction	1
A. Inorganic Cation Exchangers	1
B. Organic Ion Exchangers	3
2. Scope of the Ion Exchange Method	4
A. Determination of Total Salt Concentration	6
B. Separation of Interfering Ions of Opposite Charge	6
C. Separation of Ions from Non-Electrolytes	8
D. Isolation of Trace Constituents	8
E. Separations Based upon Ionic Size	8
F. Separations Based upon Differences in Basic or Acid Strength	8
G. Separations Based upon Conversion of Non-Electrolytes to Ions by Complex Formation	9
3. Scope of Ion Exchange Chromatography	10
Bibliography	11

GENERAL PART

II. FUNDAMENTAL PROPERTIES OF ION EXCHANGE RESINS	12
1. Structure	12
2. Cation Exchange Resins of Sulfonic Acid Type	18
A. Ion Exchange Properties	18
B. Adsorption of Acids by Cation Exchange Resins	21
3. Cation Exchange Resins of Carboxylic Acid Type	22
4. Other Types of Cation Exchange Resins	23
5. Anion Exchange Resins of Weakly Basic Type	23
6. Anion Exchange Resins of Strongly Basic Type	25
Bibliography	26
III. ION EXCHANGE EQUILIBRIA	28
1. General Considerations	28
2. Cation Exchangers of Sulfonic Acid Type	29
A. Exchange of Cations of Equal Valence	29
a. The Donnan Theory	29
b. The Mass Action Law	31
c. Empirical Equations	33
d. Ion Exchange Affinity	33
B. Exchange of Cations of Different Valence	35
C. Equilibrium at Tracer Concentration	37
3. Cation Exchangers of Weakly Acid Type	38
4. Anion Exchangers of Strongly Basic Type	39
5. Anion Exchangers of Weakly Basic Type	40
Bibliography	41

IV. ION EXCHANGE KINETICS	43
Bibliography	44
V. ION EXCHANGE IN COLUMN OPERATION	45
1. General Considerations and Terminology	45
2. The Sorption Step	46
3. The Theory for Break-Through Curves	51
A. The Theory Based on Continuous Variables	51
B. The Plate Theory	54
4. Break-Through Curves from Cation Exchange Columns	54
A. Influence of the Particle Size	54
B. Influence of the Shape of the Column	56
C. Influence of the Flow Rate	57
D. Influence of the Temperature	58
E. Influence of the Acidity of the Solution	58
F. Influence of the Composition of the Solution	60
5. The Elution (Regeneration) Step	60
6. Elution (Regeneration) Curves from Cation Exchange Columns	65
A. Influence of the Particle Size	65
B. Influence of the Concentration of the Acid	66
C. Influence of the Flow Rate	67
7. Break-Through Curves from Anion Exchange Columns	68
8. Elution (Regeneration) Curves from Anion Exchange Columns	68
Bibliography	70

PRACTICAL PART

VI. TECHNIQUE OF ION EXCHANGE SEPARATIONS FOR ANALYTICAL PURPOSES	72
1. General Considerations	72
2. Column Operation and Batch Operation	72
3. Separations by Means of Cation Exchangers	73
A. The Choice of Resin	73
a. Sulfonic Acid Type	73
b. Carboxylic Acid Type	77
B. Grinding and Purification	77
C. Apparatus in Column Operation	79
a. The Shape of the Resin Bed	83
D. The Sorption Step	83
a. Regulation of the Filtration Rate	83
b. Concentration of Solution to be Analyzed	85
c. Acidity of Solution to be Analyzed	87
d. Temperature	89
E. The Washing Step	89
F. The Elution (Regeneration) Step	91

4. Separations by Means of Anion Exchangers	93
A. The Choice of Resin	93
B. Grinding and Purification	95
C. The Sorption Step	95
D. The Washing Step	95
E. The Elution (Regeneration) Step	96
a. Strongly Basic Resins	97
b. Weakly Basic Resins	97
5. Deionization	97
A. Two-Step Deionization	98
B. Reverse Deionization	99
C. Mixed-Resin Deionization	99
Bibliography	100
VII. TECHNIQUE OF ION EXCHANGE CHROMATOGRAPHY	102
1. General Considerations	102
2. Factors Affecting Separation	103
A. Factors Affecting the Equilibrium Separation	103
B. Factors Affecting Column Efficiency	105
C. Coupled Columns	108
3. Arrangements for Ion Exchange Chromatography	109
A. Conductometric Technique	110
B. Radioisotopes in Ion Exchange Chromatography	114
C. Simplified Procedure for Ions with Great Differences in Exchange Potentials	115
Bibliography	115

APPLICATIONS

VIII. DETERMINATION OF TOTAL SALT CONCENTRATION	117
1. Application of Cation Exchangers	117
A. General Considerations	117
B. Chlorides, Bromides, Iodides, Nitrates, Perchlorates, and Chlorates	121
C. Determination of Nitrate in Explosives	122
D. Sulfates	122
E. Phosphates	124
F. Bromates, Iodates, and Periodates	125
G. Thiocyanates	126
H. Borates	126
I. Calcium in Sulfite Cooking Acid	126
J. Acetates	127
K. Determination of Esters	128
L. Oxalates	129
M. Salts of Other Organic Acids	130
N. Total Salt Content of Vegetable Tanning Liquors	131

O. Application in Water Analysis	131
P. Total Salt Concentration in Blood Serum	132
2. Application of Anion Exchangers	133
Bibliography	134
IX. REMOVAL OF INTERFERING IONS IN INORGANIC ANALYSIS	136
1. Application of Cation Exchangers	136
A. Determination of Alkali Metals in the Presence of Different Anions	136
a. Potassium in the Presence of Sulfate	137
b. Sodium and Potassium in the Presence of Phosphate	137
c. Sodium and Potassium in the Presence of Complex Cyanides	139
d. Sodium and Potassium in the Presence of Chromate, Molybdate, Vanadate, Tungstate, Phosphomolybdate, Phosphotungstate, and Silicotungstate	141
B. Determination of Sulfate in the Presence of Various Cations	142
a. Determination of Sulfur in Pyrites	144
b. Determination of Sulfur in Nickel and Copper	145
c. Volumetric Determination of Sulfate	145
C. Determination of Chloride in the Presence of Various Metal Ions	145
D. Application to Phosphate Analysis	146
a. Calcium, Magnesium, Iron, and Aluminum in Phosphate Rock	147
b. Phosphorus in Phosphate Rock	147
c. Colorimetric Determination of Phosphate after Removal of Iron	148
E. Colorimetric Determination of Silica after Removal of Iron	149
F. Separation of Fluoride from Iron, Aluminum, and Beryllium	150
G. Determination of Uranium in Silicate Rocks and Slags	150
H. Determination of Selenium	151
I. Iodometric Determination of Arsenic	151
J. Determination of Arsenic and Phosphorus in Nickel and Copper	152
K. Separation of Arsenic from Antimony and Tin	152
L. Separation of Bismuth from Antimony	152
M. Separation of Molybdenum from Lead, Copper, Iron, and Vanadium	153
N. Removal of Contaminants in Tracers	153
O. Separation of Amphoteric Metals from Non-Amphoteric	153
2. Application of Anion Exchangers	154
A. Determination of Sodium and Potassium in the Presence of Sulfate and Phosphate	155
B. Separation of Alkali Metals from Various Cations	156
C. Determination of Chromium in the Presence of Nickel	157
D. Determination of Bismuth in the Presence of Copper	158
E. Determination of Aluminum in the Presence of Iron	158
F. Separation of Arsenic from Antimony	159
Bibliography	159
X. INORGANIC COLLOIDS AND HIGH POLYMER ELECTROLYTES	161
1. Application of Cation Exchangers	161

A. Inorganic Sols	161
B. Determination of Releasable Cations in Soils	162
2. Application of Anion Exchangers	163
A. Inorganic Sols	163
B. Separation of Low-Molecular-Weight Phosphates from High Polymer Metaphosphate	163
Bibliography	164
XI. ISOLATION OF TRACE CONSTITUENTS	165
1. General Considerations	165
2. Analysis of Natural Waters	166
3. Determination of the Composition of Atmospheric Precipitation	167
4. Analysis of Milk, Beer, and Apple Juice	167
5. Determination of Traces of Copper, Cadmium, Nickel, Cobalt, Zinc, and Manganese	168
Bibliography	168
XII. INORGANIC QUALITATIVE ANALYSIS	169
1. Separation of Interfering Ions	169
2. Precipitation of Group 2 Ions as Sulfides	170
Bibliography	171
XIII. CHROMATOGRAPHIC SEPARATIONS IN INORGANIC CHEMISTRY	172
1. Application of Cation Exchangers	172
A. Group Separations	172
B. Alkali Metals	173
C. Rare Earths	173
D. Transuranic Elements	174
E. Miscellaneous Applications	174
F. Isolation of Radioelements from Urine	175
G. Separation of Uranium and Thorium	176
H. Separation of Titanium and Iron	176
I. Separation of Bismuth from Copper and Lead	177
J. Determination of Calcium and Magnesium in Iron Ore	177
2. Application of Anion Exchangers	178
Bibliography	179
XIV. ISOLATION OF LOW-MOLECULAR-WEIGHT ORGANIC ACIDS	182
1. Separation from Various Contaminants	182
2. Separation from Aldehydes and Ketones	183
3. Chromatographic Separation of Organic Acids	184
Bibliography	185
XV. HIGH-MOLECULAR-WEIGHT ORGANIC ELECTROLYTES	186
1. Determination of the Degree of Substitution of Cellulose Xanthate	186
2. Purification of Direct Cotton Dyes	187
3. Soluble Pectin and Pectic Acid	187
Bibliography	189

XVI. ALDEHYDES AND KETONES	190
1. General Considerations	190
2. The Sorption Step	190
3. The Washing Step	192
4. The Elution Step	192
5. Determination of Alcohol in the Presence of Aldehydes and Ketones	193
6. Separation of Aldehydes from Ketones	194
7. Separation of Carbonyl Compounds from Acetal	195
Bibliography	195
XVII. SUGARS AND POLYHYDRIC ALCOHOLS	196
1. Sugars	196
A. Determination of Reducing Sugars in Plant Extracts	196
B. Miscellaneous Applications	197
C. Separation of Monosaccharides	198
2. Sugar Derivatives	198
3. Glycerol Removal from Aqueous Solutions by Anion Exchange	200
4. Determination of Inositol in Animal Tissues	200
Bibliography	200
XVIII. SULFITE WASTE LIQUOR	202
1. Application of Cation Exchangers	202
2. Application of Anion Exchangers of Weakly Basic Type	203
3. Application of Anion Exchangers of Strongly Basic Type	204
4. Determination of Thiosulfate and Polythionate	204
Bibliography	205
XIX. ALKALOIDS	206
1. Synthetic Zeolites	206
A. Determination of Morphine in Urine	206
2. Cation Exchange Resins	206
3. Anion Exchange Resins	207
Bibliography	208
XX. AMINO ACIDS	210
1. General Considerations	210
2. Synthetic Zeolites	211
3. Ion Exchange Resins	212
A. Cation Exchangers of Sulfonic Acid Type	212
B. Cation Exchangers of Carboxylic Acid Type	213
C. Anion Exchangers of Weakly Basic Type	214
D. Anion Exchangers of Strongly Basic Type	215
4. Group Separation Schemes	215
5. Chromatographic Separation of Amino Acids by Means of Cation Exchangers	216
6. Chromatographic Separation of Dicarboxylic Amino Acids by Means of Anion Exchangers of Weakly Basic Type	221

7. Chromatographic Separation of Amino Acids by Means of Anion Exchangers of Strongly Basic Type	221
Bibliography	222
XXI. NUCLEOTIDES, NUCLEOSIDES, AND PURINE AND PYRIMIDINE BASES.....	225
1. General Considerations	225
2. Nucleotides	225
3. Nucleosides	227
4. Purine and Pyrimidine Bases	227
Bibliography	228
XXII. VITAMINS	229
1. Synthetic Zeolites	229
A. Vitamin B ₁ (thiamine)	229
B. Vitamin B ₂ (riboflavin)	230
C. Vitamin K ₁	230
2. Cation Exchange Resins	230
A. Vitamin B ₁ (thiamine)	230
B. Vitamin B ₂ (riboflavin)	231
3. Anion Exchange Resins	231
A. Vitamin C (ascorbic acid)	231
B. Vitamin B ₆ (pyridoxine)	232
C. Other B-Vitamins	232
Bibliography	232
XXIII. ANTIBIOTICS.....	234
1. Penicillin	234
2. Streptomycin and Streptothricin	234
3. Other Antibiotics	235
Bibliography	235
XXIV. OTHER BIOCHEMICAL AND BIOLOGICAL APPLICATIONS.....	237
1. Amines	237
2. Peptides	237
3. Proteins	238
4. Enzymes	238
5. Viruses	240
6. Blood	240
7. Urine	241
8. Gastric Acidity	241
Bibliography	242
XXV. INVESTIGATIONS OF COMPLEX SALT SOLUTIONS	244
1. General Considerations	244
2. The Cation Exchange Equilibria in a Cation Exchanger	244
A. Anionic and Uncharged Complexes	244
B. Cationic Complexes	248
3. The Equilibrium Distribution of Anionic Ligands between a Cation Exchanger and a Solution Containing Complex Ions Having Positive Charge	250

4. The Column Method	252
5. Batchwise Operation under Non-Equilibrium Conditions	255
Bibliography	257
XXVI. PURIFICATION AND RECOVERY OF ANALYTICAL REAGENTS	259
1. Deionization of Water	259
2. Purification of Alcohol	260
3. Gelatin for Nephelometric Determination of Sulfate	260
4. Preparation of Carbonate-Free Sodium Hydroxide	260
5. Recovery of Analytical Reagents	261
Bibliography	261
APPENDIX	262
1. Characteristics of Some Commercially Available Ion Exchangers	262
2. Standard Screens	264
AUTHOR INDEX	265
SUBJECT INDEX	275