

ADSORPTION CHROMATOGRAPHY OF LOW-MELTING QUATERNARY AMMONIUM SALTS

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While conducting chemical reactions¹ between organic nonelectrolytes and molten quaternary ammonium salts, Q^+X^- , we found it convenient to separate the nonelectrolyte and salt fractions of the product by chromatography. The low-melting salts under investigation, having alkyl groups in the range pentyl-heptyl, were soluble in organic solvents and the reaction mixtures could be applied to silicic acid columns in benzene or chloroform solution. After elution of the organic nonelectrolyte, we found that continued elution with chloroform or chloroform containing ethanol would remove the salt, *e.g.*, tetra-*n*-pentylammonium picrate or bromide, as well². Since it appears not to be widely known that at least some organic salts are susceptible to standard adsorption chromatography, we have made use of the collection of pure low melting salts assembled for study of physical properties of the melts³ to investigate first the influence of structure on the chromatographic properties, and second, possible analytical and preparative applications. Chromatography of non-hydrolysing organic salts has been principally done on paper⁴⁻⁶. Thin-layer chromatography of salts has apparently only been carried out with developers containing water and usually containing electrolytes⁷⁻⁹. No systematic studies of cation and anion structure dependence are available in thin layer systems.

EXPERIMENTAL

Thin-layer chromatography

The salts used were the highly purified samples employed in the previous work³. Chromatography was carried out on 4 in. × 8 in. × 250 μ layers of silica gel G, supplied as pre-coated plates by Custom Service Chemicals, Wilmington, Del. Tailing of the quaternary ammonium salt spots on these plates when used as received was very pronounced, presumably due to ion exchange. However, treatment with a solution of 2.32 g of 85 % phosphoric acid in 250 ml of acetone, followed by thorough washing with acetone gave plates on which useful chromatograms could be obtained^{**}. Plates were dried at 125-135° for one hour just before use and were developed in saturated chambers. Acetone solutions (10 mg/ml) of the salts were spotted (3 μ l portions) onto the still warm plates. Spots were visualized with iodine vapor and recorded by placing the plate face down on the bed of a Xerox 914 office copier.

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** Q^+X^- chromatographed on plates washed with trifluoroacetic acid gave multiple spots.

*Column chromatographic preparation of tetra-*n*-pentylammonium thiocyanate*

A mixture of 2.0 g of potassium thiocyanate and 4.0 g of silicic acid (Mallinckrodt) was ground to a homogeneous powder in a mortar; 10 ml of methanol was added and the resulting pink paste was ground in a current of air until dry. After drying for 15 min at 45° and 15 mm, this material was slurried with chloroform and used to extend a column (20 mm diam.) prepared from 9.0 g of silicic acid in chloroform. The composite column was washed with 150 ml of chloroform-ethanol (3:1) which removed a brick-red band, presumably parathiocyanogen. A solution of 1.000 g (2.77 mmole) of tetra-*n*-pentylammonium nitrate in 8 ml of chloroform was applied to the column. Elution with 200 ml of chloroform and 300 ml of chloroform-ethanol (24:1) removed 1.027 g (2.88 mmole, 104 %) of tetra-*n*-pentylammonium thiocyanate, m.p. 43–48°. This was dissolved in 25.0 ml of 50 % aqueous methanol and the solution was used to titrate 0.495 mequiv. of silver nitrate (Volhard); 4.465 ml were required, corresponding to a yield of 2.77 mmole of tetra-*n*-pentylammonium thiocyanate. The yield is thus quantitative, and the product purity 96 %, the remainder principally ethanol which is very difficult to remove from the crystal mass by pumping.

RESULTS AND DISCUSSION

Results of thin-layer chromatograms for twenty-one salts representing six different quaternary ammonium cations and seven anions in three solvent systems are summarized in Table I. The R_F values are principally averages of two or more determinations; their precision from plate to plate was $\pm 8\%$ in solvent 1, and $\pm 2\%$ in solvents 2 and 3 as determined for tetra-*n*-pentylammonium perchlorate which was spotted on every plate as control. The precision of relative R_F values on a given plate is about twice the above. It proved necessary to acid-wash the plates to reduce tailing (see Experimental). The best attainable spot shape in solvents 1 and 2 still involved

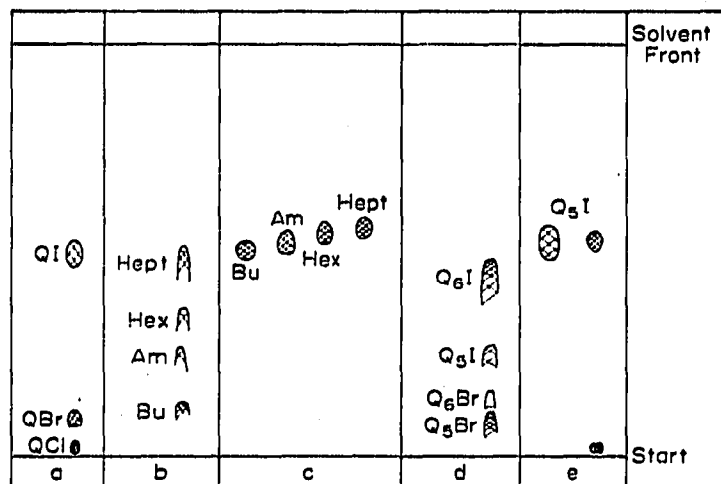


Fig. 1. Chromatograms of quaternary ammonium salts on thin layers of silica gel G. Solvents: (a), (c), (e) acetone-*N*-methylacetamide (200:1); (b), (d) chloroform-ethanol (96:4). (a) Separation of tetra-*n*-pentylammonium chloride, bromide and iodide. (b) Separation of tetra-*n*-butyl-, tetra-*n*-pentyl-, tetra-*n*-hexyl-, and tetra-*n*-heptylammonium iodides. (c) Movement of the salts of chromatogram (b) when run side by side in another solvent. (d) Spots from a mixture of tetra-*n*-pentylammonium iodide and tetra-*n*-hexylammonium bromide. (e) Two metathetical reactions. Left: $Q_5Cl + KI \rightarrow Q_5I + KCl$. Right: $Q_6Cl + Q_1I \rightarrow Q_6I + Q_1Cl$.

TABLE I

 R_F VALUES FOR QUATERNARY AMMONIUM SALTS ON SILICA GEL G CHROMATOPLATES

Anion ^a	Cation ^b					
	Q ₄₄₄₄	Q ₅₅₅₅	Q ₆₆₆₆	Q ₆₆₆₇	Q ₆₆₇₇	Q ₇₇₇₇
Solvent 1: CHCl ₃ -C ₂ H ₅ OH (24:1)						
Cl ⁻		0.032				
Br ⁻		0.096	0.15	0.16		0.20
I ⁻	0.12	0.27	0.40	0.43	0.45	0.50
NO ₃ ⁻		0.066	0.10	0.11		
SCN ⁻		0.11				
Pic ⁻		0.10 ^c				
ClO ₄ ⁻		0.38	0.52	0.53	0.55	0.62
Solvent 2: CHCl ₃ -C ₂ H ₅ OH (9:1)						
Cl ⁻		0.16				
Br ⁻		0.34	0.42	0.44		0.49
I ⁻	0.38	0.57	0.65	0.66	0.68	0.70
NO ₃ ⁻		0.25	0.32	0.34		
SCN ⁻		0.39				
Pic ⁻		0.58				
ClO ₄ ⁻		0.62	0.67	0.68	0.70	0.70
Solvent 3: Acetone-N-methylacetamide (200:1)						
Cl ⁻		0.034				
Br ⁻		0.12	0.15	0.15		0.17
I ⁻	0.46	0.54	0.55	0.56	0.56	0.57
NO ₃ ⁻		d				
SCN ⁻		0.51				
Pic ⁻		e				
ClO ₄ ⁻		0.79	0.82	0.85	0.86	0.88

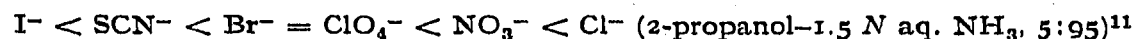
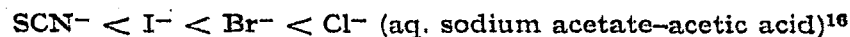
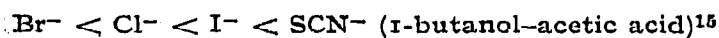
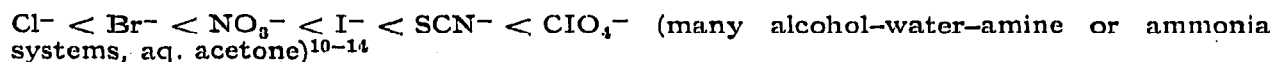
^a Pic = picrate.^b Q₄₄₄₄ = tetra-*n*-butylammonium; Q₆₆₆₇ = tri-*n*-hexyl-*n*-heptylammonium, etc.^c Also gives spot due to picric acid at $R_F \sim 0.43$.^d No spot.^e Gives picric acid spot only.

some tailing, especially when mixtures were chromatographed, however, the chromatograms are useful for some purposes. Solvent 3 gives excellent spot shapes but, while it differentiates the anions very well, it levels the R_F values for salts with different cations. Fig. 1 illustrates these effects.

The order of increasing R_F values for the inorganic anions is



Picrate ion appears below SCN⁻ in solvent 1 and above I⁻ in solvent 2. This order may be compared with those observed in paper chromatography



and on ion exchange impregnated papers (the most common order in several systems).

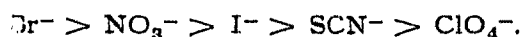


The order of anion elution in the present system differs from each of the others, suggesting possible analytical applications. The differentiation of the halide ions (Table I, Fig. 1a) appears to be sharper in the present system (solvent 3) than in any of the others. SEILER AND KAFFENBERGER⁷ also observed good separation of halide ions on thin silica gel G layers using a *n*-butanol-acetone-aqueous NH_3 developer.

The present order of anion R_F values is closely related to the order of preferential solvation of anions by water in aqueous dioxane¹⁹



and the order of miscibility of the molten quaternary ammonium salts, Q^+X^- , with polar associated liquids³



It is thus probably the inverse order of hydrogen bond strengths between adsorbant and anion²⁰.

Chromatography of reciprocal salt systems $\text{Q}_1^+\text{X}_1^- - \text{Q}_2^+\text{X}_2^-$ produces spots corresponding to the R_F values of all four possible salts, with the bulk of the material being concentrated in the spots of greatest and smallest R_F (Fig. 1d). Production of four spots is known in paper chromatography of amine salts²¹.

Finally the possibility of chromatographing a reciprocal salt system with one organic and one inorganic cation as a means of performing a metathetical reaction for synthetic purposes was evaluated. The desired product salt must of course have a greater R_F value than the starting salt. The left-hand chromatogram of Fig. 1e illustrates the conversion of Q^+Cl^- ($R_F = 0.034$) to Q^+I^- ($R_F = 0.54$) by means of potassium iodide. Potassium iodide and the quaternary chloride were spotted at the same point at the origin. This result was extended to column chromatographic preparation of tetra-*n*-pentylammonium thiocyanate (see Experimental) which we had previously obtained from the perchlorate by use of ion exchange resins as no simpler method is available. The reaction $\text{KSCN} + \text{QNO}_3 = \text{KNO}_3 + \text{QSCN}$ was conducted chromatographically somewhat more efficiently than with the resin, and the process should be capable of easy scale-up. It is possible that some of the efficiency may arise from a favorable $\text{KSCN}-\text{KNO}_3$ solid state equilibrium position in addition to the $\text{QSCN}-\text{QNO}_3$ R_F differential.

SUMMARY

Quaternary ammonium salts, $\text{R}_4\text{N}^+\text{X}^-$ ($\text{R} = n\text{-butyl to } n\text{-heptyl}$), were chromatographed on thin layers of silica gel G using solvents containing neither water nor electrolyte. R_F values were determined for 21 salts in three solvents, and the dependence of R_F on anion and cation structure was obtained. A number of efficient anion separations are possible in this system. Chromatography of reciprocal

salt systems was studied. Conversion of the quaternary ammonium salt of a slower anion, $Q^+X_1^-$, to that of a faster anion, $Q^+X_2^-$ can be accomplished by chromatography of a mixture of $Q^+X_1^-$ and an inorganic salt of X_2^- . A useful column preparation of tetra-*n*-pentylammonium thiocyanate from KCNS was worked out on this basis.

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