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Improved Gas Chromatographic Separations of Enantiomeric Secondary Amine Derivatives

J. A. Corbin and L. B. Rogers
Department of Chemistry
Purdue University
Lafayette, Indiana 47907

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ABSTRACT

A systematic study has been made of the variables in the gas chromatographic separation of enantiomeric secondary amine derivatives using as the stationary phase the ureide of L-valine isopropyl ester. Although α, the ratio of the corrected retention times, was not very temperature - sensitive for the liquid phase, it increased markedly when the stationary phase solidified. α values were also significantly larger for the pentafluoropropionyl derivative than for the corresponding trifluoroacetyl derivative. The solid could be used satisfactorily over a wide range of sample sizes and flow rates, but the α values on the solid phase were sensitive to degree of column loading, polar contaminants, and column materials.

The ureide of L-valine isopropyl ester has been shown by Feibush and Gil-Av (1) to be a useful stationary phase for the gas chromatographic resolution of enantiomers of a variety of secondary amine derivatives. The postulated separation mechanism was based on the formation of diastereoisomeric association complexes between the solute and solvent that had different stabilities. Feibush and Gil-Av (1) worked exclusively with trifluoroacetyl (N-TFA) derivatives of amines and at only one temperature, which was slightly above the melting point of the ureide.

We have successfully repeated many of Feibush and Gil-Av's (1) results with the liquid phase. In addition, the solid ureide has been shown to be a good adsorbent for the separations. Relative changes in the separation factor, α, above and below the melting point of the stationary phase have been studied for several sorbates. Factors affecting the separation on the solid ureide, such as temperature, percentage loading of the column, polar contaminants, sample size, column-wall material, and flow rate, have been studied. Also, the relative advantages of pentafluoropropionyl (N-PFP) and heptafluorobutyryl (N-HFB) amine derivatives have been evaluated.

EXPERIMENTAL

Reagents. The ureide of L-valine isopropyl ester (Miles Laboratories Elkhart, Indiana) was used as the stationary phase throughout this study and shall be referred to simply as the ureide. The 2-aminohexane, 3-aminohexane, 3-methylcyclohexylamine, pentafluoropropionic anhydride and heptafluorobutyric anhydride reagents were purchased from K and K Laboratories, Plainview, N.Y. The 2-aminoheptane, 2-amino-3,3-dimethylbutane, and trifluoroacetic anhydride were obtained from Aldrich Chemical Co., Milwaukee, Wisconsin and the α-methylbenzylamine from Eastman Organic Chemicals, Rochester, N.Y. The 99% normal pentane was from the Phillips Petroleum Co., and the dichloromethane was from Matheson, Coleman and Bell, Norwood, Ohio. All chemicals were used without further purification.

The solutions used to coat the open tubular columns were prepared by the weight/volume formula given by Ettre (2) using dry ether as a solvent. All gases were dried with 5A molecular sieve traps at ambient temperature.

The fluorinated amine derivatives were prepared by reacting one equivalent of the amine with two equivalents of the anhydride in stirred dichloromethane at 0° C for one hour. The dichloromethane was removed under vacuum and the residue treated with ice water. The derivative was then separated by filtration or by a separatory funnel, depending on whether it was a solid or liquid, and the product recrystallized from ethanol by precipitation with ice water. All derivatives were then carefully dried. Solid samples were air dried by placing them between two pieces of filter paper for 24 hours and then storing them in a desicator over Drierite. Liquid samples were dried by the addition of 5A molecular sieve pellets. As a check, the identity and purity of N-TFA - 2-aminoheptane were verified by microanalysis. The heptyl derivative, prepared by the above method, was found to be at least 95% pure.

Melting points, taken with a Fisher -Johns apparatus, of amine derivatives were: N-TFA-2-aminohexane-28°C, N-TFA-2-aminoheptane-29°C, N-TFA-3-aminohexane-32-35°C, N-TFA-2-amino-3,3-dimethylbutane-69-70°C, N-TFA-3-methylcyclohexylamine-59-60°C, and N-TFA-α-methylbenzylamine-65-66°C. N-PFP-2-aminohexane and N-HFB-2-aminohexane were liquids at room temperature.

Compounds exhibited boiling points in the range of 150°C to 200°C, and they remained completely stable during storage for several months.

Apparatus. The Aerograph 660 gas chromatograph was equipped with a Hamilton inlet splitter, and it was modified to minimize the dead volume in the system. The chromatograph was operated at a detector temperature of 180°C, an injection-port temperature of 200°C and a flow rate of 1-ml/min of nitrogen, unless otherwise stated. An Esterline-Angus Speed Servo recorder was used to record the data. A planimeter was used for determinations of peak areas.

Stainless steel, Pyrex and soft glass capillary columns were used. Glass columns were prepared from sections of tubing using a glass drawing machine obtained from Hupe Apparatebau, Karlsruhe, Germany. Prior to drawing, each section of glass tubing was cleaned with successive 15-ml portions of pentane, dichloromethane, and acetone. The sections were then thoroughly dried before use. The stainless steel capillary column was cleaned in the same manner. The open tubular columns were 40-m by 0.25-mm unless otherwise stated. Silanized columns were prepared by treatment of the drawn capillary tubing with 50 μls of hexamethyldisilazane at 100°C prior to coating.

The columns were coated by the plug method, using a microelectrolytic cell described by Kaiser (3). The plugs were forced to move downward through the columns at a rate of approximately 2 cm/sec. Then, using a flow rate of 0.25 ml/min of nitrogen, the columns were dried at room temperature for two hours and then conditioned for approximately two hours with gradual heating to the working temperature.

Capacity ratios, k, were calculated from the formula

$$k = \frac{t_r - t_m}{t_m} \qquad (1)$$

where t_r was the retention time of the sample component, and t_m was the retention time of methane, which was assumed to be non-retained. Separation factors, α, were calculated from the definition:

$$\alpha = \frac{k_2}{k_1} \qquad (2)$$

The k and α values were reproducible to ±0.005. Resolution, R, was calculated from:

$$R = \frac{t_{R_2} - t_{R_1}}{1/2\,(w_{b_1} + w_{b_2})} \qquad (3)$$

where t_{R_2} and t_{R_1} were the adjusted retention times of the sample components and w_{b_1} and w_{b_2} were the BASE peak widths in units of time. $\Delta(\Delta G^\circ)$ values, the differential free energies of interaction, were calculated from the relationship

$$\Delta(\Delta G^\circ) = -RT \ln \alpha \qquad (4)$$

where R was the gas constant and T was the Kelvin temperature. $\Delta(\Delta H^\circ)$ values, the differential enthalpies of interaction , were calculated from the difference in ΔH° values obtained from the slopes of $\ln k$ vs $1/T$ plots. $\Delta(\Delta S^\circ)$ values, the differential entropies of interaction, were calculated from the relationship

$$\Delta(\Delta G^\circ) = \Delta(\Delta H^\circ) - T\Delta(\Delta S^\circ) \qquad (5)$$

RESULTS

Preliminary Studies. Several experiments were run in order to make certain that a separation of enantiomers was indeed being achieved. First, the areas of the two peaks produced by racemic mixtures of optically active amine derivatives were identical on both the liquid and solid ureide phases. Second, the α values observed on the liquid phase agreed well with those reported by Feibush and Gil-Av (1). Furthermore, the N-TFA derivatives of an optically enriched sample of α-methylbenzylamine, which contained approximately 75% D-isomer, as measured with a polarimeter, produced areas of 3:1 on both the solidified and melted ureide phases. In contrast, a racemic N-TFA-α-methylbenzylamine sample produced areas of 1:1 on both the liquid and solid phases. Finally, N-TFA-1-aminohexane produced only one peak on the solid ureide phase while N-TFA-2-aminohexane produced two peaks. Therefore, there was no doubt that an enantiomer separation was being observed on the solid ureide phase.

Solid vs. Liquid Partitioning Phase. A survey of several amine derivatives on both the solid and liquid ureide phases is shown in Table I. A column coated from a 15% w/v solution was chosen for this study because of the large difference in k values between the solid and melted phases. For convenience, 100°C was chosen for the study of the behavior on the solid phase although somewhat lower temperatures would have been just as satisfactory. To allow comparison with the work of Feibush and Gil-Av (1), 120°C was chosen for the study of the liquid phase.

In all cases, the α values were much larger on the solid than on the melted ureide phase. Also, in all cases, the <u>k</u> values were much smaller on the solid phase than on the liquid ureide phase. Therefore, a baseline separation of these amine derivatives could be achieved in approximately one eighth of the time at a given flow rate by using the solid phase. Thus, in this system, adsorption chromatography showed a tremendous superiority over partition chromatography.

It is well recognized that a small increase in α produces a relatively large increase in the ease of separation, especially for values of approximately 1.1. Tables I and II show that, on the solid phase, pentafluoropropionyl and heptafluorobutyryl derivatives of 2-aminohexane gave a large enhancement of α over the corresponding trifluoroacetyl derivative with only a small change in <u>k.</u> The same trend was observed for other amines besides 2-aminohexane. N-HFB derivatives gave slightly larger α values, but the second peak was very broad relative to the N-PFP and N-TFA derivatives, thus making accurate peak measurement difficult. Therefore, N-PFP derivatives were found to be the best choice for use with the solid phase.

On the liquid ureide phase, within experimental error, the N-PFP, N-HFB, and N-TFA derivatives showed identical α values. However, the N-PFP derivatives eluted much faster than the corresponding N-TFA derivatives, thus allowing shorter analysis times.

Figure 1 shows a comparison of typical separations on the solid and liquid phases. Both peaks on the liquid phase were sharp and essentially identical. However, the second peak on the solid was much broader than the first. In all cases, the peaks were nearly Gaussian in shape with only a small degree of tailing. Figure 1 also shows that, while the k values were much less on the solid, the R values on both the solid and liquid phases were quite similar.

Table II compares the relative enhancements of α for various pairs of amine derivatives on the solid and liquid ureide phases. The addition of a CH_2 group on a straight-chain amine made little difference in α on either the solid or liquid phases. Moving the position of the amine group from the 2-position to the 3-position on n-hexane produced a significant decrease in α on both the liquid and solid phases but a larger differential change on the solid. The trend was expected since the degree of assymetry had now been reduced. On going to the dimethylbutane derivative, the trend toward lower α values continued and, on this occasion, significantly affected the α on the solid. Similarly, a straight-chain side-group produced a significantly greater α on the solid than did a saturated cyclic group. However, in this case, the effect was also observed with the liquid phase. The reason for the decrease in α with an increase in assymetry was puzzling because the opposite has been observed in other systems (4). Perhaps the steric hindrance had become so great in these cases that the hydrogen bonds necessary for selective interaction were now comparatively weak. It was interesting to find that the benzylamine derivative produced the largest α yet measured on both the solid and liquid ureide phases. Its relative change in α was much greater than for the corresponding saturated ring compound. Apparently, the orientation of the aromatic ring was such that it produced a very large differential steric interaction. Also, due to its planar configuration it was probably better able to "lie down" on and interact with the solid surface. The pi-electron system undoubtedly provided an additional source of bonding interaction.

Effect of Column Loading. Table III shows that there was a significant column-loading effect on the α values of the enantiomers of N-TFA-2-aminoheptane using the solid ureide. The same trend was observed for all other amine derivatives. However, using the liquid phase, α stayed constant with loading, within experimetnal error. The k values continued to increase for the solid as well as for the liquid phase as the loading increased, indicating that the available surface area of solid was increasing and that the surface was probably rough.

Effect of Temperature. Table IV shows the α and R values of the enantiomers of N-TFA and N-PFP-2-aminohexane. The k values varied inversely with temperature for the liquid phase, but α remained nearly constant. On the liquid phase, the change in α with a 20°C change in temperature was approximately 0.01 unit. However, α was very sensitive to temperature on the solid ureide phase. In addition, the α values were not only larger for the N-PFP derivative, but they increased faster as the temperature was lowered. Thus $\Delta(\Delta G^\circ)$ was sensitive to temperature, and the degree of sensitivity differed between compounds.

The ureide phase showed a significant supercooling effect. After having been melted, the phase required a low temperature, i.e., 70°C in order to return quickly and completely to the frozen state. For example, if the temperature was lowered quickly from 120°C to 100°C, the values of α were low and variable for over an hour, suggesting that part of the stationary phase was still liquid.

Table IV shows that the values for resolution, $\underline{R}$, were not only very similar on the liquid and solid phases but also decreased similarly on each phase as the temperature increased. However, there was one unusual feature that should be noted. Although one would generally expect $\underline{R}$ to increase with $\underline{k}$ or α, the larger α values for the PFP derivative did not result in a significantly larger $\underline{R}$. This came about because the second peak was relatively broader for the PFP derivative. Likewise, resolution for HFB derivatives actually got worse relative to a TFA derivative inspite of a larger α, again, because the second peak was correspondingly broader. Thus, on one column, for which the $\underline{R}$ values were available for all three 2-aminohexane derivatives, the solid ureide gave 1.24, 1.28, and 1.06 for the TFA, PFP and HFB derivatives respectively, and for the liquid ureide, 1.23, 1.14, and 1.18. The last three values agree within the limits of error for determining resolution. Hence, the PFP derivative would offer a slight advantage when working with the liquid ureide because both peaks would be eluted sooner while the resolution would be maintained.

<u>Effect of Sample Size</u>. Table V indicates that α values for the solid showed a significant decrease only at very large sample sizes which were roughly one hundred times normal. As expected, however, the resolution decreased steadily with increasing sample size, the decrease

being larger for the more lightly coated columns. Hence, the solid shows promise for small-scale preparative work if coated heavily on a support for use in a conventional packed column.

Effect of polar Contaminants. Samples containing 10 mg of solute in 1 ml of solvent were used in this study. Table VI and Figure 2 show that the α and k values for the solid phase were strongly influenced by polar contaminants. Small quantities of water and, especially, ethanol produced large and long-lasting changes in the observed k and α values. Apparently, these compounds adsorbed strongly onto the solid surface, and the enantiomers interacted in a non-selective manner with the water or ethanol to produce larger k values and smaller α values. The α values become smaller because, although the time difference between the two peaks remained essentially constant, both peaks were retained longer. One, therefore, observed the result of a combination of two chromatographic interactions, one of which was selective and the other, non-selective.

Even dichloromethane showed a similar effect but to a much lesser degree. It was shown, using a solid sampling syringe, that n-pentane in quantities of less than 0.01 μl per injection(after the splitter) did not influence the "true" enantiomeric separation to a significant degree. The fact that the two curves on the 40% column did not extrapolate to the same point suggested that even very small amounts of dichloromethane may have led to a very significant decrease in α.

These results emphasize the need to free all gases entering the column from polar contaminants so as to insure maximum α values and reproducibilities. Also, if a polar solvent were used, the results would not be reproducible unless one used exactly the same quantity of solvent in each injection and the same time between closely spaced injections.

Effect of Column Material. Table VII shows that Pyrex glass columns produced essentially no decrease in α or R with time during use or storage. In fact, Pyrex columns, which had been stored for several weeks, showed the same α and R values as when they had first been prepared. Pyrex columns also remained stable with use at 150°C and could be returned to 120°C with little change in observed resolution.

In contrast, soft glass columns did not show good stability. Early attempts to reporduce Feibush and Gil-Av's (1) work using soft glass columns resulted in a rapid loss of efficiency and a slow decrease in α. In addition, as evidenced by smaller initial k values, these columns retained a smaller quantity of ureide during the coating process than did Pyrex coated in an identical manner. Apparently, the liquid ureide phase did not wet the walls well, and it tended to flow into droplets that resulted in the loss of efficiency (5). Furthermore, because of the single peaks that resulted after use were relatively narrow, the loss in k and α on the soft glass columns was most-likely due to slow racemization and/or decomposition of the ureide phase.

A stainless steel column, coated in an identical manner, showed a gradual reduction in efficiency with time. However, the rate of loss was less than that shown by a soft glass column. The value of α remained constant within experimental error over a span of eight hours. The largest difference shown by the stainless steel column was its very low retention of ureide phase compared to either of the glass columns. The stainless steel column showed approximately one fourth the k values of a Pyrex glass column coated in an identical manner.

Effect of Flow Rate. Figure 3 shows that the liquid phase was much more efficient than the solid phase. Nevertheless, the large increase in α that was observed for the solid more than compensated for the lower efficiency.

DISCUSSION

Several important differences in partitioning behavior between the solid and liquid ureide phases have already been discussed. Another difference, which we have encountered almost universally, is the relatively broad peak for the more strongly retained enantiomer. Ordinarily, one would not expect compounds as similar as enantiomers to show such marked differences in behavior even though the greater free energy of adsorption for the second compound would be expected to accentuate differences in energies of surface sites.

Proof that the behavior shown in Figure 1 is typical of enantiomers (rather than an impurity) could have been obtained in two ways. First, one could have separated enough of one of the enantiomeric amines to measure its optical rotation. However, such a procedure would be very tedious. As an alternative one could start with a pure (or enriched) enantiomer and show that it corresponded with a particular peak in a racemic mixture. The latter approach was easier to do because pure enantiomers of amino acids are available.

In the present study the N-TFA derivative of the isopropyl ester of alanine was used. Three preparations involving D-alanine, L-alanine, and a racemic mixture (which had been shown by mass spectroscopy and NMR to be free of other compounds) were chromatographed at 100°C where the ureide was a solid. The derivative of each pure enantiomer gave a single peak which corresponded exactly in retention time and peak shape with the corresponding peaks for the preparation involving the racemic mixture. Furthermore, for two peaks of equal area, the more strongly retained L-isomer gave a peak 1.9 times wider than did the D-isomer. In addition, other behavior was closely similar to that shown by the amines. First, the α on the liquid was 1.07 whereas the α on the solid was much larger and was a function of loading: 1.21 for 20% and 1.35 for 40%. Second, the retention times on the liquid in a given column were 15 times longer than on the solid while the resolution was nearly the same. Such separation behavior indicates the superiority of the solid ureide not only for amine derivatives but also for amino-acid derivatives.

The precise reason for the enhancement of α on the solid phase was unclear. Karger et al(6) have shown, in a diastereoisomer system, that, as the molecule of solute was made more rigid through structural modifications, the α values increased. Similarly, the loss of extent of movement on going from a liquid to a solid stationary phase may have resulted in more nearly fixed (and, in these cases, more favorable) geometry for interaction.

A thermodynamic study was attempted in order to elucidate the nature of the two separation processes. Certain large differences were evident using both N-TFA and N-PFP-2-aminohexane. The results appear in Table VIII. It was evident that the larger α values on the solid phase were due primarily to the much greater differences in the differential enthalpies even though the differences in the entropies were playing an important role in determining the final α values.

The reason the N-PFP derivatives gave larger α values than the N-TFA derivatives on the solid, but not on the liquid phase, was also uncertain. The additional fluorine atoms in N-PFP presented the possibility of additional fluorine-hydrogen bonds. Gil-Av et al (7) have shown that the formation of fluorine-hydrogen bonds was not essential to the separation since chlorine derivatives also gave enantiomer separations. However, the chlorine derivatives did show smaller α values, indicating that the fluorine bonds might have improved the separation. Hence, the additional fluorines may have aided in pinning the adsorbates down. The smaller enhancement with N-HFB derivatives may have been the result of a less favorable geometry or simply the distance of the additional fluorines from the assymmetric carbon.

It was unlikely that the glass wall was playing a direct part in influencing α, but it may have had an indirect effect. For example, an uncoated glass column, even after silanization, showed such a strong activity toward the amine derivatives that small samples would not come off the column in detectable peaks. Larger samples trickled off as single, very broad peaks with long, variable ~~retintion~~ RETENTION times. All of the peaks observed in the study of percentage loading were sharp and possessed relatively short retention times. Possibly, the glass wall was orientating the first few layers of ureide molecules in such a way that they were not available for selective interaction with the enantiomers. However, these adsorbed layers still contributed to _k_.

In summary, the fastest separations of the enantiomers of derivatives of secondary amines and ~~of~~ amino acids were achieved on heavily-loaded, Pyrex columns at a temperature just below the melting point of the ureide. Low flow rates, very volatile non-polar solvents, and small samples gave the best results. Exposure to polar solvents or polar contaminants in the gas stream should be minimized.

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Table I. Average k and α Values as a Function of Column Temperature for a Series of Enantiomeric Amine Derivatives on a 15% Ureide Column

Compound	100, °C (SOLID)			120, °C (LIQUID)		
	k_1[a]	k_2[a]	α	k_1[a]	k_2[a]	α
N-TFA-2-aminohexane	0.90	1.18	1.31	12.23	12.82	1.05
N-PFP-2-aminohexane	0.96	1.47	1.53	9.85	10.29	1.05
N-HFB-2-aminohexane	1.31	2.14	1.64	11.43	12.02	1.05
N-TFA-3-aminohexane	1.13	1.22	1.08	11.68	11.91	1.02
N-TFA-2-aminoheptane	1.74	2.35	1.35	20.48	21.47	1.05
N-TFA-2-amino-3,3-dimethylbutane	0.40	0.44	1.08	4.66	4.87	1.05
N-TFA-3-methylcyclohexylamine	3.17	4.01	1.27	33.36	34.25	1.03
N-TFA-α-methylbenzylamine	6.12	11.72	1.92	73.44	82.98	1.13

[a] k_1 and k_2 are the respective capacity ratios of the enantiomers

Table II Effect of Solidification on the Ratio of α Values for Enantiomers in a Series of Amine Derivatives

Compounds	Solid Ureide, 100 °C	Liquid Ureide, 120 °C
N-TFA-2-aminoheptane N-TFA-2-aminohexane	1.03	1.00
N-TFA-2-aminohexane N-TFA-3-aminohexane	1.21	1.03
N-TFA-2-aminohexane N-TFA-2-amino-3,3-dimethylbutane	1.21	1.00
N-TFA-2-aminoheptane N-TFA-3-methylcyclohexylamine	1.06	1.02
N-TFA-α-methylbenzylamine N-TFA-3-methylcyclohexylamine	1.51	1.10
N-PFP-2-aminohexane N-TFA-2-aminohexane	1.17	1.00
N-HFB-2-aminohexane N-TFA-2-aminohexane	1.25	1.00
N-HFB-2-aminohexane N-PFP-2-aminohexane	1.07	1.00

Table III. Effect of Percentage Loading[a] on k and α of the Enantiomers of N-TFA-2-aminoheptane at 100 °C

Percentage Loading [a]	$\underline{k}_1$	$\underline{k}_2$	α
1.25	0.55	0.58	1.05
5.0	0.80	0.87	1.15
10.0	1.28	1.57	1.23
20.0	1.40	2.30	1.64
40.0	1.80	3.55	1.97

[a] Weight/volume concentrations of the coating solution.

Table IV. α and R as a Function of Temperature on a 20% Ureide Column

t, °C	N-TFA-2-aminohexane		N-PFP-2-aminohexane	
	α	R	α	R
90	1.57	1.15	2.15	1.25
95	1.51	1.12	2.07	1.21
100	1.42	1.10	1.86	1.15
115	1.05	1.25	1.05	1.20
120	1.05	1.20	1.04	1.15
125	1.04	1.15	1.04	1.12

Table VI Effect on α and *R* of the Amount of the Enantiomers of N-TFA-2-aminoheptane Injected[a]

Amount[b], ng	40% Column		10% Column			
	Solid, 100 °C		Solid, 100 °C		Liquid, 120 °C	
	α	*R*	α	*R*	α	*R*
20	1.99	1.59	1.23	0.92	1.05	1.72
100	1.97	1.45	1.22	0.85	1.05	1.50
1000	1.92	1.02	*c*	0.2	1.05	1.02
2000	1.75	0.85	*c*	*c*	1.05	0.95

[a] A constant amount (0.5 μl) of n-pentane per injection.

[b] Amount of racemic amine derivative that actually entered the column.

[c] Due to overlap of peaks, a reliable value could not be obtained.

Table VI. Effect of Water and Ethanol on the Separation of N-TFA-2-aminoheptane Enantiomers as a Function of Time Using a 15% Ureide Column at 100 °C.

Water					Ethanol				
Quantity, (μl)	Time [a], min.	k_1[c]	k_2[c]	α	Quantity, (μl)	Time [a], min.	k_1[c]	k_2[c]	α
none	-	1.52	1.86	1.22	none	-	1.38	1.71	1.24
0.5	b	3.01	3.40	1.13	1.0	b	6.20	6.61	1.07
20.0	b	4.51	4.93	1.09		60	5.08	5.51	1.08
	20	3.24	3.60	1.11		1440	3.27	3.73	1.14
	240	2.56	2.94	1.15					
	480	1.71	2.08	1.21					
50.0	b	7.01	7.40	1.05					

[a] Time elapsed after injection of the "poisoning agent" on the column.

[b] Measurements made immediately after injection of the "poisoning agent".

[c] k_1 and k_2 are the respective capacity ratios of the enantiomers.

Table VII. A Comparison of k, α and R on Pyrex, Soft Glass and Stainless Steel Capillary Columns at 120 °C Using a 20% Coating Solution

Time in Use, hrs	Pyrex Column				Soft Glass Column				Stainless Steel Column			
	k_1	k_2	α	R	k_1	k_2	α	R	k_1	k_2	α	R
a	20.67	21.70	1.05	0.85	16.22	17.04	1.05	0.80	4.96	5.20	1.05	0.35
2	20.57	21.62	1.05	0.83	16.07	16.78	1.04	0.60	5.05		b	0.30
15	19.90	20.88	1.05	0.82	9.44		1.03	b	4.92		b	b

a Measurements taken immediately after column installed

b Value could not be accurately determined.

Table VIII. Thermodynamic Study pf the Separations on the Solid and Liquid Ureide Phases

Column	N-TFA-2-aminohexane			N-PFP-2-aminohexane		
Condition	$\Delta(\Delta\underline{G}^{o})$, cal	$\Delta(\Delta\underline{H}^{o})$, cal	$\Delta(\Delta\underline{S}^{o})$, eu	$\Delta(\Delta\underline{G}^{o})$, cal	$\Delta(\Delta\underline{H}^{o})$, cal	$\Delta(\Delta\underline{S}^{o})$, eu
Solid, 95 °C	-313	-2000 ± 250	-4.6	-542	-2200 ± 250	-4.5
Liquid, 120 °C	-34	-125 ± 20	-0.2	-32	-250 ± 20	-0.6

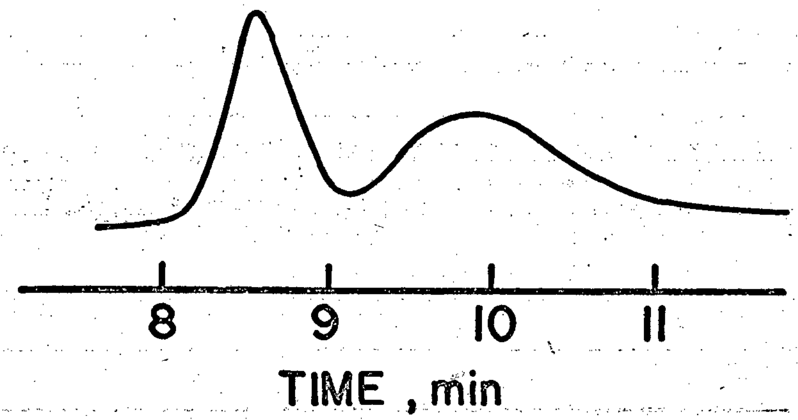
FIGURE CAPTIONS

Figure 1. Typical peak shapes of the enantiomers of N-TFA-2-aminoheptane on the solid and liquid ureide phases using a 20% column

Figure 2. Effect of sample size on the apparent α of N-TFA-2-aminooctane on 40% and 5% solid ureide columns

Figure 3. Van Deemter plots of the efficiences of the solid and liquid ureide phases using a 40% column

A. SOLID UREIDE SYSTEM



B. LIQUID UREIDE SYSTEM

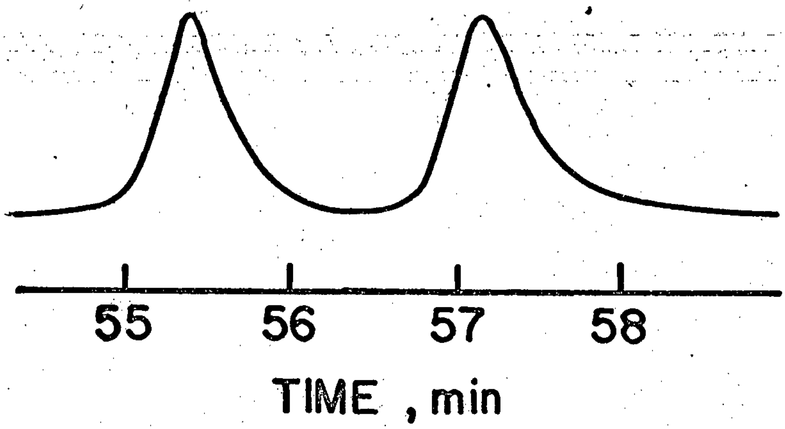


figure 1   Corbin + Rogers

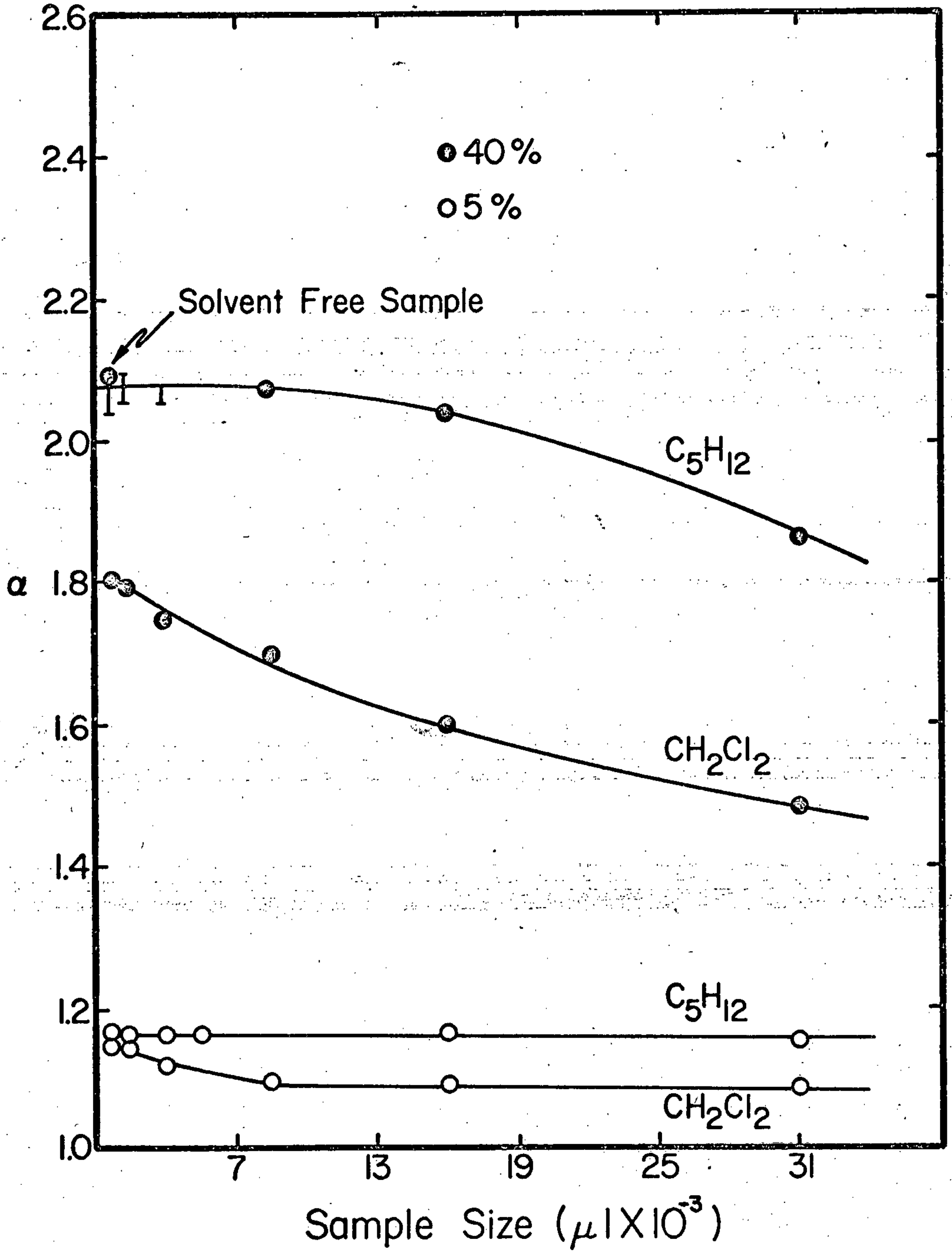


figure 2 Corbin + Rogers

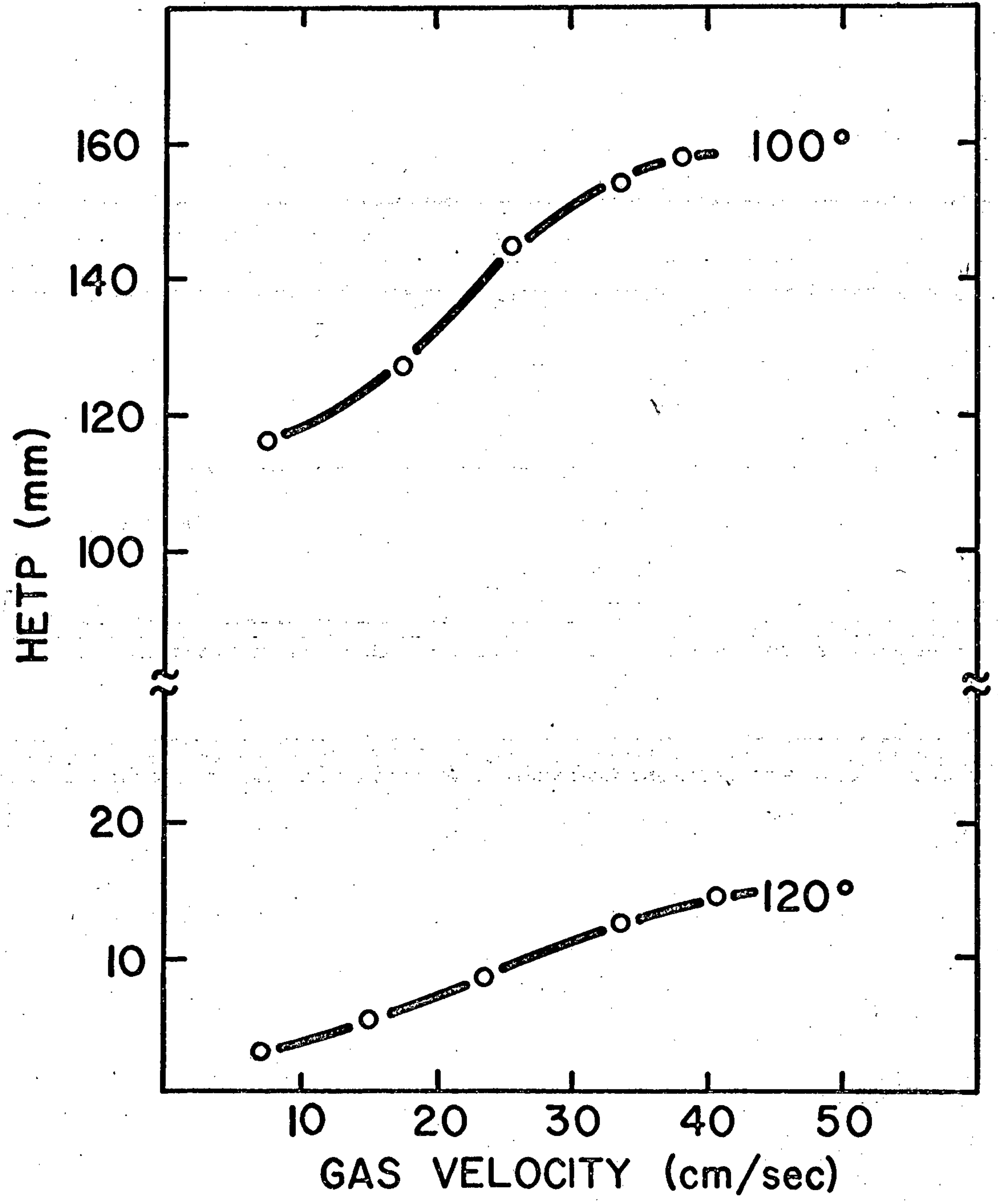


figure 3 Corbin + Rogers