ELSEVIER

Journal of Chromatography A, 695 (1995) 185–193

JOURNAL OF CHROMATOGRAPHY A

Comparison of 1-(1-naphthyl)ethylcarbamate derivatives of a carbohydrate bonded chiral stationary phase☆

Apryll M. Stalcup*, Karen L. Williams

Department of Chemistry, 2545 The Mall, University of Hawaii-Manoa, Honolulu, HI 96822, USA

First received 13 June 1994; revised manuscript received 23 November 1994; accepted 23 November 1994

Abstract

New chiral stationary bonded phases (CSPs) based on derivatized malto-oligosaccharides are reported. Chiral separations are reported for 3,5-dinitrobenzoyl-derivatized amines and amino acids as well as some 3,5-dinitrophenylcarbamoylated alcohols. These new CSPs incorporate a 1-(1-naphthyl)ethylcarbamate (NEC) moiety which introduces additional stereogenicity and provides a useful probe for investigating chiral recognition. The elution order, when known, was dependent upon the configuration of the NEC substituent; that is, the *S* enantiomers were retained longest on the *S* column and the *R* enantiomers were retained longest on the *R* column. Elution order from the *RS* column, when known, was the same as that observed for the *S* column. In most cases, retention correlated with bonded ligand concentration on the silica substrate. In general, the best enantioselectivities and resolution were obtained on the *S* column.

1. Introduction

Many different types of chiral stationary phases (CSPs) including cyclodextrin [1,2], Pirkle [3,4], protein [5–9], and chiral crown ether phases [10,11] are currently available. Although each of these CSPs is very successful at separating large numbers of enantiomers which, in many cases, are unresolvable using any other CSP, there remains a large number of unresolvable enantiomeric compounds. In addition, incomplete understanding of the chiral recognition mechanisms of many of these CSPs limits the realization of the full potential of existing CSPs and hampers development of new CSPs.

Cellulosic and amylosic phases, in which the hydroxyl functionalities are usually extensively derivatized [12], have also been used successfully for enantioseparations [13,14]. The enantioresolution of these CSPs is reported to be very dependent upon the substituents appended onto the native carbohydrate [15]. These phases are comprised of mixtures of derivatized carbohydrate polymers which are coated onto large pore silica. Even though these phases exhibit admirable enantioselectivities, they have some serious disadvantages. The large polymer size requires the use of fragile, large pore silica. In addition, the secondary structure of the polymer, which seems to be important in chiral recognition, may be altered irreversibly by storing the columns in polar solvents and thus restricts the types of

* Corresponding author.

☆ Presented in part at the *18th International Symposium on Column Liquid Chromatography, Minneapolis, MN, May 8–13, 1994.*

0021-9673/95/$09.50
SSDI 0021-9673(94)01164-8

mobile phases that can be used. The complex polymeric nature of these chiral selectors and the importance of the secondary structure also hamper the development of adequate models for the chiral recognition mechanism on these phases [16].

Carbohydrate-based phases employing small sugar moieties have been investigated for their utility for biological samples containing proteins [17–19]. Although these types of phases have demonstrated some utility for the chromatographic analysis of proteins, little is known about their potential for enantiomeric separations. Given the well documented enantioselectivities of the cellulosic, amylosic and cyclodextrin phases, it is reasonable to expect considerable enantioselectivity from other carbohydrate-derived bonded phases as well. Indeed, Aburatani et al. [20], reported on the enantioselectivity of exhaustively carbamoylated oligosaccharides of varying lengths coated onto a silica substrate. In addition, the use of small sugar moieties as chiral bonded ligands may offer several advantages over cyclodextrin, cellulosic and amylosic moieties including enhanced stability and high bonded ligand density [21]. Further, the carbohydrates may be attached through a variety of linkages and there are a wide variety of carbohydrates commercially available. In addition, the use of small, well-defined carbohydrate moieties may provide some valuable insight into the chiral recognition mechanisms of the derivatized amylosic and cellulosic phases.

The purpose of this work was to investigate the potential of bonded carbohydrate-based high-performance liquid chromatographic (HPLC) stationary phases for chiral separations. A bonded phase derived from a maltooligosaccharide mixture was used as the focus of initial investigations because maltooligosaccharides are comprised of D-glucose, bonded through the same α-1,4 linkages as in cyclodextrin. It was thought that this structural similarity with cyclodextrins might provide some guidance with regard to chiral solute selection as well as chromatographic conditions for chiral separations. It was also anticipated that the native sugar CSPs might not exhibit tremendous enantioselectivity despite the potentially high surface concentration of bonded ligand. In contrast to the native cyclodextrin phases as well as the derivatized cellulosic and amylosic phases, inclusion complexation may not play a major role in the enantioselectivity of these sugar-derived CSPs because of the greater flexibility of the maltooligosaccharides relative to cyclodextrin, cellulosic or amylosic chiral selectors. In addition, in the reversed-phase mode, the more abundant solvent molecules might compete more effectively with the solute for the secondary hydroxyls than is possible on the cyclodextrin phases because there is no well-defined hydrophobic cavity for the solute to occupy on the native sugar phases. Therefore, work focussed on derivatized carbohydrate phases under normal-phase conditions.

Stalcup et al. [22], previously reported naphthylethyl carbamoylated cyclodextrin phases which exhibited enantioselectivity in the normal-phase mode. In the normal-phase mode, these phases seemed to have selectivities comparable to that obtained on a Pirkle-type naphthylvaline column and were very successful at resolving a wide variety of 3,5-dinitrophenylderivatives of alcohols, amines, amino alcohols, amino acids, and carboxylic acids. In many cases, the configuration of the β-cyclodextrin substituent dominated the observed enantioselectivity, but in some cases, the enantioselectivity of the cyclodextrin also made a contribution. In addition, it was found that sometimes this contribution was nonequivalent for the two substituent configurations. Because comparison of the enantioselectivities obtained on the *R*-, *S*- and racemically derivatized cyclodextrin CSPs provided valuable insight into the separation mechanism, the derivatives chosen for this study were 1-(1-naphthyl)ethylcarbamates. Maltooligosaccharide bonded phases were prepared and further derivatized with pure *R*-, pure *S*- or *RS*-naphthylethyl isocyanate. It should be noted that the *R*-, *S*- and *RS*-designations refer only to the configuration of the substituent and not the underlying maltooligosaccharide. To enhance

solute–CSP interactions, solutes were derivatized with either 3,5-dinitrobenzoyl chloride or azide.

2. Experimental

2.1. Chemicals

The various solutes and the 3,5-dinitrobenzoyl chloride derivatizing reagent were obtained from Aldrich (Milwaukee, WI, USA). Absolute ethanol was obtained from Quantum (Tuscola, IL, USA). All other solvents were all obtained from Fischer Scientific (St.Louis, MO, USA). The maltooligosaccharides were obtained from Pfanstiehl Laboratories (Waukegan, IL, USA).

For the amines and amino acid esters, about 10 mg was reacted with an excess amount of 3,5-dinitrobenzoyl chloride in acetone or tetrahydrofuran. The mixture was heated to 60°C for 20 min. The acetone was then evaporated off and the product was dissolved in either methanol or ethanol. The alcohols were derivatized according to the procedure of Pirkle et al. [23].

2.2. Chromatographic bonded phase

The native carbohydrate-bonded sorbent (5 μm, spherical, Kromasil) was prepared according to Stalcup and Williams [24]. Briefly, the bonded phase consists of a mixture of maltooligosaccharides (3 to 10 glucose residues; average of 4), covalently attached to the silica through a spacer. The composition of the oligosaccharide mixture, as provided by the vendor, is detailed in Table 1.

The two-step process involves initial attachment of the spacer with subsequent addition of the carbohydrate moiety. Further derivatization, using a large excess of reagent, was accomplished according to Stalcup et al. [22]. Carbon analysis was performed by Galbraith Laboratories (Knoxville, TN, USA). The bonding results are presented in Table 2. The surface concentration of the bonded carbohydrate was calculated based on an average molecular mass, which was derived from the composition data provided by the vendor. The bonded sorbents were slurry packed into a 250 × 4.6 mm stainless-steel column.

Table 1
Composition of maltooligosaccharide mixture

Oligomer	No. C	MW	%Comp.	(%)·(MW)
Glucose	6	180	0.0	0.00
Maltose	12	342	1.5	5.13
Maltotriose	18	504	27.9	140.62
Maltotetraose	24	666	15.6	103.90
Maltopentaose	30	828	38.3	317.12
Maltohexaose	36	990	14.0	138.60
Maltoheptaose	42	1152	1.2	13.82
Maltooctaose	48	1314	0.5	6.57

2.3. Equipment

The HPLC system used for these experiments consisted of a Shimadzu LC-600 and SPD-6A UV detector interfaced to a Chromatopac CR-501 data station. The flow-rate was typically 1.0 or 2.0 ml/min. Supporting evidence for chiral separation was supplied by repeating the separation at different wavelengths. The mobile phase was chloroform–methanol–*n*-heptane (50:3:47, v/v/v). Chromatographic experiments were conducted at 18°C.

3. Results and discussion

3.1. Bonding results

According to the carbon analysis data presented in Table 2, the carbohydrate bonding procedure yielded a sorbent with a loading of approximately 14% C of which ca. 5% is due to the linkage. Considering that approximately half of the molecular mass of carbohydrates is oxygen, this loading would correspond to loading of about 20% C for a conventional C_{18} bonded phase. According to Stalcup and Williams [25], typical total %C for cyclodextrin bonded phases are ca. 4–5%. Thus, the use of small, flexible

Table 2
List of bonded sorbents

Columns	$\%C^{a}_{spac}$	$\%C^{b}_{sugar}$	$\%C^{c}_{tot}$	[spacer][d]	[sugars][d]	[der][d]
R	4.95	14.30	19.92	2.76	1.12	0.94
S	4.98	14.46	24.21	2.78	1.14	2.10
RS	4.98	14.46	30.52	2.78	1.14	3.80

[a] %C due to spacer.
[b] %C due to spacer plus carbohydrates.
[c] %C due to spacer plus carbohydrates plus naphthylethylcarbamate substituent.
[d] Surface concentration in $\mu mol/m^2$; [der] = carbamate.

carbohydrate moieties does allow for higher bonded ligand density than achievable with the more bulky and rigid cyclodextrins.

As mentioned previously, the surface concentration of the bonded carbohydrates was calculated based on an average molecular mass (approximately a tetrasaccharide), derived from the homologue distribution data provided by the vendor. Although the maltooligosaccharide material was a heterogeneous mixture of homologues, it is quite possible that the bonded phase is fairly homogeneous due to exclusion of the larger homologues from the pores as well as greater diffusion of the lower molecular mass homologues into the pores [26]. Current work on CSPs derived from pure homologues may provide some insight regarding this issue and will be the subject of another report.

Derivatization of the bonded sorbent further increased the amount of %C. The *R* phase had the lowest degree of substitution while the *RS* phase had the highest degree of substitution. Assuming that the bonded ligand is a tetrasaccharide, the *R* phase had approximately 1 substituent/ligand, the *S* had about 2 substituents/ligand and the *RS* had about 3 substituents/ligand. Because the same amount of derivatizing reagent was used in each case, the low loading of the *R*-CSP prompted preparation of a second batch. The results were virtually identical. Although more work needs to be done, it is possible that the bonded ligands have *R*- and *S*-selective sites and this may account for the high degree of substitution on the *RS*-CSP. Each glucose residue contributes 3 hydroxyls. Thus, as can be seen from Table 2, the calculated degree of substitution for each phase indicates the presence of residual hydroxyls. In contrast, as mentioned previously, the cellulosic and amylosic phases are exhaustively derivatized [12].

3.2. Chromatographic Results

The chromatographic results obtained for the various compounds used in this study on this new bonded phase are reported in Tables 3–5. A typical chromatogram is shown in Fig. 1. In general (10 out of 14 compounds), the longest retention for the first eluting enantiomer was obtained on the racemic column. However, the highest selectivities were usually obtained on the *S* column (12 out of 14). In addition, the *S* column also usually exhibited the largest resolution (12 out of 14).

Carbamoylation of the sugar bonded phase with the naphthylethyl-isocyanates used in this study incorporates π-base groups on the bonded ligand which provide a site for π-acid/π-basic interactions and presents opportunities for hydrogen bonding and dipole stacking with the carbamate linkage which are not present on the native sugar phase. As indicated by the larger retention of almost all of the analytes on the *RS*-NEC [1-(1-naphthyl)ethylcarbamate] column relative to the other two columns, solute retention may be largely attributed to these $\pi-\pi$ interactions. Comparison of the retention on the *R* column for the first eluting enantiomers of α-methylbenzylamine ($k' = 3.44$) vs. 1-(4-nitro-

Table 3
Chromatographic data for 3,5-dinitrobenzoyl-derivatized amines on the NEC Maltooligosaccharide chiral stationary phases[a]

Compound	CSP	$k'(1)^b$	$k'(2)$	α	R_s
1-Cyclohexylethylamine	*R*	1.84	–	1.00	0.00
	S	2.00	–	1.00	0.00
	RS	1.98	–	1.00	0.00
α-Methylbenzylamine	*R*	3.44^S	6.53	1.90	1.88
	S	3.45^R	7.34	2.13	2.05
	RS	4.16^R	8.98	2.16	1.42
1-(4-Nitrophenyl)-ethylamine	*R*	8.92^S	10.50	1.18	0.52
	S	10.36^R	12.63	1.22	0.50
	RS	13.16	–	1.00	0.00
1,2,3,4-Tetrahydro-1-naphthylethylamine	*R*	1.58	2.64	1.67	1.09
	S	1.73	3.06	1.77	1.40
	RS	2.25	3.92	1.74	0.93
1-(1-Naphthyl)ethylamine	*R*	2.39^S	6.98	2.92	3.14
	S	3.15^R	10.79	3.42	2.75
	RS	3.80^R	12.87	3.39	2.11

[a] Mobile phase: $CHCl_3$–MeOH–C_7H_{16} (50:3:47).
[b] Configuration indicated as a superscript, when known.

Table 4
Chromatographic data for 3,5-dinitrobenzoyl-derivatized amino acid esters on the NEC Maltooligosaccharide chiral stationary phases[a]

Compound	CSP	$k'(1)^b$	$k'(2)$	α	R_s
Alanine ethyl ester	*R*	2.11^L	3.04	1.44	1.01
	S	1.86^D	3.05	1.64	1.26
	RS	2.53^D	4.07	1.61	0.90
Norleucine methyl ester	*R*	1.42	2.03	1.43	0.67
	S	1.35	2.40	1.78	1.40
	RS	1.50	2.55	1.70	0.71
Valine methyl ester	*R*	1.39^L	2.29	1.65	1.14
	S	1.15^D	2.21	1.92	1.67
	RS	1.53^D	2.84	1.86	0.98
Aspartic acid dimethyl ester	*R*	2.82^L	3.59	1.27	0.48
	S	2.43^D	3.25	1.34	0.67
	RS	2.93^D	3.61	1.23	0.27
Phenylalanine methyl ester	*R*	2.35^L	2.64	1.12	0.26
	S	2.14^D	3.03	1.42	0.78
	RS	2.44^D	3.29	1.35	0.26
p-Chlorophenylalanine ethyl ester	*R*	2.13	2.74	1.29	0.39
	S	2.00	3.31	1.66	1.12
	RS	2.04	3.20	1.57	0.57
Tyrosine methyl ester	*R*	22.30	34.05	1.53	0.90
	S	15.04	29.48	1.96	1.30
	RS	22.42	42.91	1.91	0.90

[a] Mobile phase: $CHCl_3$–MeOH–C_7H_{16} (50:3:47).
[b] Configuration indicated as a superscript, when known.

Table 5
Chromatographic data for 3,5-dinitrophenyl-derivatized alcohols on the NEC maltooligosaccharide chiral stationary phases[a]

Compound	CSP	$k'(1)$[b]	$k'(2)$	α	R_s
2-Butanol	*R*	1.90	–	1.00	0.00
	S	1.68	–	1.00	0.00
	RS	1.96	–	1.00	0.00
2-Hexanol	*R*	1.32	–	1.00	0.00
	S	1.22	–	1.00	0.00
	RS	1.36	–	1.00	0.00
2-Octanol	*R*	1.17	–	1.00	0.00
	S	0.95	–	1.00	0.00
	RS	1.00	–	1.00	0.00
sec-Phenethyl alcohol	*R*	2.85^S	3.44	1.21	0.54
	S	2.29^R	3.11	1.36	0.76
	RS	2.53^R	3.24	1.28	0.42
1,2,3,4-Tetrahydro-1-naphthol	*R*	2.16^S	2.74	1.27	0.63
	S	1.89^R	2.21	1.17	0.32
	RS	2.18	–	1.00	0.00
Cyclopropyl benzyl alcohol	*R*	3.10	–	1.00	0.00
	S	2.30	2.88	1.25	0.49
	RS	3.00	–	1.00	0.00

[a] Mobile phase: $CHCl_3$–MeOH–C_7H_{16} (50:3:47).
[b] Configuration indicated as a superscript, when known.

phenyl)amine ($k' = 8.92$) or 1,2,3,4-tetrahydro-1-naphthylamine ($k' = 1.58$) vs. 1-(1-naphthyl)ethylamine ($k' = 2.39$) would also tend to support this interpretation (Table 3).

3.3. Amines

As can be seen from Table 3, for all of the amines studied, the longest retention of the first eluting enantiomer was obtained on the *RS* column and the shortest retention was obtained on the *R* column. As can be seen from Table 2, this correlates with the amount of stationary phase loading. It is also important to note, however, that the correlation between retention and carbamate loading is more apparent for the second eluting enantiomer and that the overall dispersion of capacity factors on the three phases is greater for the later eluting enantiomers than the first eluting enantiomers. This seems reasonable given that the second eluting enantiomer interacts more strongly with the stationary phase than the first eluting enantiomer.

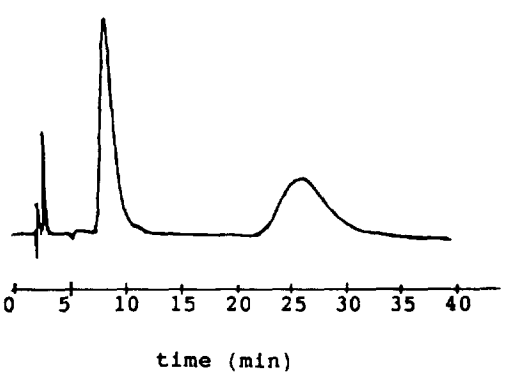

Fig. 1. Enantiomeric resolution of N-(3,5-dinitrobenzoyl)-1-(1-naphthyl)ethylamine on the *S*-NEC CSP. Mobile phase: $CHCl_3$–MeOH–heptane (50:3:47); 1 ml/min.

The importance of π-acid/π-basic interactions to retention may be indicated by the longer retention and stronger dependence of carbamate loading exhibited by 1-(4-nitrophenyl)ethylamine relative to the other amines studied.

When the elution order was known, the enantiomer which had the same configuration as the bonded ligand substituent was retained the longest while the *RS* column produced the same elution order as the *S* column. Superficially, this would seem to indicate that the substituent dominated the chiral interaction and that the

carbohydrate played little or no role in the overall chiral recognition. However, for α-methylbenzylamine, the highest selectivity was obtained on the *RS* column (α = 2.16 vs. 2.13 on *S* column; 1.90 on *R* column). In addition, the selectivities obtained for 1,2,3,4-tetrahydro-1-naphthylamine and 1-(1-naphthyl)ethylamine on the *RS* column (1.74 and 3.39) were only slightly less than those obtained on the *S* column (1.77 and 3.42). These results might suggest that the chiral recognition on the *RS* column may arise from chiral discrimination during the reaction with the isocyanate derivatizing agent. However, the lack of enantioselectivity for 1-(4-nitrophenyl)ethylamine on the *RS* column does not support this because comparable separations (1.18 vs. 1.22), with reversal of elution order, are obtained on the *R* and *S* columns. Thus, analogous to the derivatized cyclodextrin [22] and the derivatized cellulosic and amylosic CSPs [27], the underlying carbohydrate also seems to be contributing to the overall chiral recognition.

3.4. Amino acid esters

In the case of the aliphatic amino acid esters, the longest retention for the first eluting enantiomer was observed on the *RS* column (Table 4) as was seen for the amines. In contrast to the amines, however, the shortest retention was observed on the *S* column and not the *R*. As in the case of the amines, carbamate surface concentration seems to correlate better with retention for the second eluting enantiomer rather than the first. The highest selectivities for the aliphatic amino acid esters were obtained on the *S* column. In addition, the best resolution was obtained on the *S* column. Taken alone, the results obtained on the *RS* CSPs might suggest chiral discrimination in derivatization of the carbohydrate moieties. However, in the context of the results obtained for the amines, an alternative suggests itself. That is, as in the case of other derivatized carbohydrate-based phases [22,27], both the carbohydrate and the substituent contribute to chiral recognition but that the two configurations may contribute nonequivalently. For instance, although the *R* column had the lowest degree of substitution and this lesser substitution may be responsible for the generally smaller selectivities observed for this phase relative to the *S* and *RS* phases, this does not account for the intermediate retention observed on the *R* phase, relative to the *RS* (less than) or *S* (more than) columns. Recently, Kaida and Okamoto [27] reported that there was no evidence of chiral discrimination when racemic isocyanates were used to derivatize cellulose and amylose.

In the case of the aromatic amino acids, phenylalanine and tyrosine both had the longest retention on the *RS* column while *p*-chlorophenylalanine had the longest retention on the *R* column. The retention of the second eluting peak correlated with carbamate surface concentration only for phenylalanine. All three analytes exhibited the best separation and resolution on the *S* column. Although *p*-chlorophenylalanine had slightly reduced retention relative to phenylalanine, this may be due to the fact that the methyl ester of phenylalanine was used while the ethyl ester of*p*-chlorophenylalanine was used in this study. Stalcup et al. [22], reported reduced retention but enhanced enantioselectivity for tryptophan esters as the ester alkyl chain length increased. The same behavior may hold for these phases as well.

It is interesting to note the tremendous difference in retention for tyrosine methyl ester relative to the other two aromatic amino acid esters. Tyrosine has two functionalities available for derivatization. The incorporation of a second π-acidic functionality on the solute through derivatization, leading to enhanced associations with the bonded ligand substituents might account for this enhanced retention. However, NMR analysis of the tyrosine derivatization product confirmed the presence of the free hydroxyl. Hence, the enhanced retention of tyrosine may highlight the role of hydrogen bonding interactions to the overall retention mechanism.

3.5. Alcohols

Trends relating column loading or degree of substitution with retention or selectivity are even less readily apparent in the case of the alcohols

(Table 5) than in the case of the amines (Table 3) or amino acid esters (Table 4). For instance, *sec*-phenethyl alcohol and cyclopropyl benzyl alcohol both had the shortest retention but highest selectivities on the *S* column. In contrast, 1,2,3,4-tetrahydro-1-naphthol had the highest retention on the *RS* column but the highest selectivity on the *R* column. The lack of enantioselectivity for cyclopropyl benzyl alcohol or 1,2,3,4-tetrahydro-1-naphthol on the *RS* column may again dispute chiral discrimination during derivatization of the bonded ligand. The lack of chiral recognition on the *R* column for cyclopropyl benzyl alcohol was somewhat surprising considering that this CSP exhibited the longest retention for this compound. As in the case of the amines, the elution order, when known, was dictated by the configuration of the bonded phase carbamate substituent. It is interesting to note that the same elution orders were obtained for *sec*-phenethyl alcohol as for α-methylbenzylamine on all three columns. The role in elution order of the direction of the dipole moment of an amide adjacent to the chiral center has been the subject of some controversy [28,29]. In the present study, the carbamate linkage and the underlying carbohydrate further complicate the interactions. The overall reduced selectivities obtained for *sec*-phenethyl alcohol vs. α-methylbenzylamine and 1,2,3,4-tetrahydro-1-naphthol vs. 1,2,3,4-tetrahydro-1-naphthylamine may be reflective of the additional atom between the stereogenic center and the π-acidic 3,5-dinitrophenyl moiety. The importance of aromaticity in the solute in addition to the 3,5-dinitrobenzoyl moiety may be inferred from the lack of resolution obtained for the aliphatic alcohols and their generally low retention relative to the aromatic alcohols.

4. Conclusions

As can be seen from the results, maltooligosaccharide-based bonded phases have potential for chiral separations. Although this initial chromatographic study using the naphthylethyl carbamoylated maltooligosaccharide phases focussed on their normal-phase behavior using chloroform–heptane, the chiral recognition behavior of these phases under a variety of mobile phase conditions including the reversed-phase mode [30] is currently being investigated and will be reported elsewhere. In addition, the effect of carbohydrate chain length and the chiral recognition of other derivatized carbohydrate phases is being investigated.

Acknowledgements

The authors gratefully acknowledge the generous support of the National Institutes of Health, the National Science Foundation and the American Chemical Society Petroleum Research Fund.

References

[1] T.J. Ward and D.W. Armstrong, in M. Zief and L.J. Crane (Editors), *Chromatographic Chiral Separations*, Marcel Dekker, New York, NY, 1988, p. 131.
[2] D.W. Armstrong and W. DeMond, *J. Chromatogr. Sci.*, 22 (1984) 411.
[3] W.H. Pirkle, J.M. Finn, B.C. Hamper, J.L. Schreiner and J.R. Pribish, *Am. Chem. Soc. Symp. Ser.*, No. 185, 1982, Ch. 18.
[4] W.H. Pirkle and P.G. Murray, *J. Liq. Chromatogr.*, 13 (1990) 2123.
[5] J. Hermansson and M. Eriksson, *J. Liq. Chromatogr.*, 9 (1986) 621.
[6] G. Schill, I.W. Wainer and S.A. Barkin, *J. Liq. Chromatogr.*, 9 (1986) 641.
[7] S. Allenmark, *J. Liq. Chromatogr.*, 9 (1986) 425.
[8] M. Okamoto and H. Nakazawa, *J. Chromatogr.*, 508 (1990) 217.
[9] T. Miwa, H. Kuoda, S. Sakashita, N. Asakawa and Y. Miyake, *J. Chromatogr.*, 511 (1990) 89.
[10] T. Shinbo, T. Yamaguchi, K. Nishimura and M. Sugiura, *J. Chromatogr.*, 405 (1987) 145.
[11] M. Hilton and D.W. Armstrong, *J. Liq. Chromatogr.*, 14 (1991) 9.
[12] Y. Okamoto, T. Ohashi, Y. Kaida and E. Yashima, *Chirality*, 5 (1993) 616.
[13] H. Hopf, W. Grahn, D.G. Barrett, A. Gerdes, J. Hilmer, J. Hucker, Y. Okamoto and Y. Kaida., *Chem. Ber.*, 123 (1990) 841.
[14] Y. Okamoto, Y. Kaida, R. Aburatani and K. Hatada, *J. Chromatogr.*, 477 (1989) 367.
[15] Y. Okamoto, K. Hatano, R. Aburatani and K. Hatada, *Chem. Lett.* (1989) 715.

[16] T. Shibata, Y. Okamoto and K. Ishii, *J. Liq. Chromatogr.*, 9 (1986) 313.
[17] R.E. Huisden, T. Ooms, J.C. Kraak and H. Poppe, *Chromatographia*, 31 (1991) 263.
[18] R.E. Huisden, J.C. Kraak and H. Poppe, *J. Chromatogr.*, 508 (1990) 289.
[19] A.V. Kiselev, T.D. Khokhlova and Y.S. Nikitin, *Chromatographia*, 18 (1984) 69.
[20] R. Aburatani, Y. Okamoto and K. Hatada, *Bull. Chem. Soc. Jpn.*, 63 (1990) 3606.
[21] A.M. Stalcup, W. Wu and K.L. Williams, *Chirality*, submitted for publication.
[22] A.M. Stalcup, S.-C. Chang, and D.W. Armstrong, *J. Chromatogr.*, 540 (1991) 113.
[23] W.H. Pirkle, G. Mahler and M.H. Hyun, *J. Liq. Chromatogr.*, 9 (1986) 443.
[24] A.M. Stalcup and K.L. Williams, *Patent pending.*
[25] A.M. Stalcup and K.L. Williams, *J. Liq. Chromatogr.*, 15 (1992) 29.
[26] L.C. Sander and S.A. Wise, *J. Chromatogr.*, 316 (1984) 163.
[27] Y. Kaida and Y. Okamoto, *J. Chromatogr.*, 641(1993) 267.
[28] W.H. Pirkle and J.E. McCune, *J. Chromatogr.*, 469 (1989) 67.
[29] I.W. Wainer and M.C. Alembik, *J. Chromatogr.*, 367 (1986) 59.
[30] D.W. Armstrong, C.-D. Chang and S.H. Lee, *J. Chromatogr.*, 539 (1991) 83.