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Enantioseparation of amino acid derivatives on an immobilized network polymer derived from L-tartaric acid

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Abstract

Seven structurally related amino acid derivatives were successfully enantioseparated by HPLC with a commercially available column containing a chiral immobilized network polymer derived from L-tartaric acid. The experiments were carried out under normal-phase conditions. All the solutes could be baseline separated using *n*-hexane/2-propanol (95/5) as eluent at a flow rate of 1 ml/min at 25 °C, with reasonable retention time (<12 min). The effects of the polar alcohol modifier (type and content) in the mobile phase and the column temperature on the enantioseparation were studied. Apparent thermodynamic parameters were also calculated from the plots of $\ln \alpha$ or $\ln k'$ versus $1/T$. Some mechanistic aspects of chiral recognition were discussed with respect to the structures of the solutes. It was found that the enantioseparations are all enthalpy driven, and the *N*-acyl groups of the solutes have significant influence on the chiral recognition.

Keywords: Enantiomer separation; Derivatization, LC; Network polymer; Apparent thermodynamic parameters; Tartaric acid; Amino acids

1. Introduction

Separation of enantiomers is one of the most challenging tasks of modern chemistry, not only because of its application in many fields such as pharmaceuticals, natural products, agrochemicals and ferroelectric liquid crystals, but also because of its participation in theoretical research on noncovalent interactions [1,2]. Enantiomer separation by high performance liquid chromatography (HPLC) has progressed considerably in the past 20 years. It has become a useful method for determining enantiomeric purities or obtaining enantiomerically pure compounds. Chiral stationary phases (CSPs) are the key to enantioseparation by HPLC. Many CSPs for HPLC, such as proteins [3], polysaccharide derivatives [4,5], imprinted polymers [6] and brush-type CSPs [7,8] have already been prepared.

Understanding how chiral discrimination takes place is important for the chromatographer when designing more effective CSPs or when selecting better chromatographic condition. Atomic-level molecular modeling approaches and fitting procedures have been applied to discuss chiral recognition mechanisms [9]. Thermodynamic study is also useful to enable the chromatographer to understand the essence of chiral recognition. In other words, it may be useful to evaluate the effect of column temperature on chiral discrimination and then inspect the calculated thermodynamic parameters. Associated with the structures of the probed solutes, some meaningful mechanistic aspects of chiral recognition may be obtained.

Conventionally, we consider that the relationship of column temperature with thermodynamic parameters is as follows:

$$\ln k' = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} + \ln \Phi$$

$$-\Delta\Delta G^\circ = RT \ln \alpha = RT \ln \frac{k'_R}{k'_S}$$

$$\ln \alpha = -\left(\frac{\Delta\Delta H^\circ}{RT}\right) + \left(\frac{\Delta\Delta S^\circ}{R}\right)$$

where the subscript R refers arbitrarily to the second and S to the first eluted enantiomer, k' is the retention factor, α

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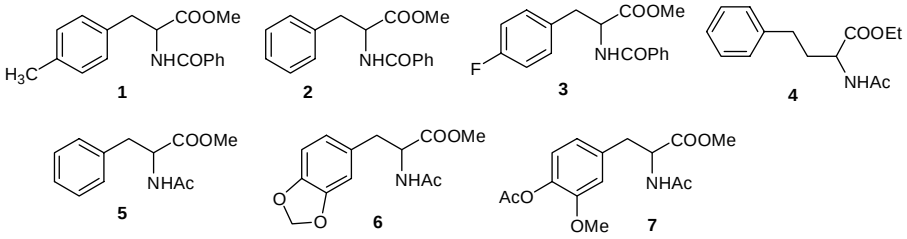

Fig. 1. Amino acid derivatives used in this study.

the separation factor, and Φ the phase ratio. ΔG°, ΔH° and ΔS° represent the differences in the free energy, enthalpy and entropy of one enantiomer in the stationary phase and mobile phase, respectively. $\Delta\Delta G^\circ$, $\Delta\Delta H^\circ$ and $\Delta\Delta S^\circ$ represent the differences of ΔG°, ΔH° and ΔS° for a given pair of enantiomers, respectively, and R is the gas constant. If the van't Hoff plots of $\ln k'$ or $\ln \alpha$ against $1/T$ are linear within a temperature range, the correlative thermodynamic parameters can be obtained from the slope or intercept of the straight lines. Indeed, some mechanistic aspects of chiral recognition were discussed by this means [10–17].

However some systematic researches, especially the work of Schurig's group [18–22] and Guiochon's group [6,23,24], have pointed out that the above methodology may offer doubtful results. The obtained thermodynamic parameters are apparent and not intrinsic. Separating nonchiral and chiral contributions to the retention is necessary in order to receive intrinsic data [25].

In this paper, we report the chromatographic enantioseparation of seven amino acid derivatives on one chiral stationary phase containing an immobilized network polymer derived from L-tartaric acid (Kromasil CHI-DMB). This commercially available CSP was introduced by Allenmark et al. and has been applied to enantioseparations of binaphthol, 2-arylpropionic acid, tocainide, bupivacaine, naproxen and ibuprofen, etc., with frequently excellent separation factors [26–28]. Our present study shows that this CSP is also effective for enantioseparation of amino acid derivatives, an important product of asymmetric catalytic hydrogenation [29]. Baseline resolution can be achieved for all amino acid derivatives studied using a simple binary mobile phase, *n*-hexane with polar alcohol modifier, in less than 12 min.

In order to discuss the mechanism of chiral recognition, the effects of the polar modifier (type and content) in the mobile phase and column temperature on the enantioseparation were studied and the thermodynamic parameters also calculated. It must be emphasized here that the attempts to separate the nonchiral and chiral contributions to the retention and enantioselectivity were not performed and the retention factors and separation factors were used directly to derive correlative thermodynamic data. This arbitrary decision is based on the following considerations. The most important consideration is that the separation factor remains constant when the surface bonding density of the L-tartaric acid derivative is changed. This hints that the interaction between the solute and the sorbent is in principal, chiral [27]. If the nonchiral interaction is noticeable, the apparent separation factor must be changeable with variation of the surface bonding density. This type of CSP possesses a mass of immobilized chiral selectors, unlike protein-based CSPs. High levels of chiral selector coverage and the type of matrix of this CSP (vinyl-silica) may suppress nonchiral interaction between the solute and the CSP. However, we still need to stress that the thermodynamic parameters obtained from this study are apparent, not intrinsic, and that apparent parameters were directly used to explain some aspects of the chiral recognition mechanism.

2. Experimental

2.1. Chemicals

n-Hexane, ethanol, 1-propanol, 2-propanol, *n*-butanol, *sec*-butanol, *tert*-butanol and 1-pentanol were all reagent grade. Anhydrous methanol was HPLC grade. The mixed binary mobile phases were filtrated through a 0.45 μm PTFE membrane and degassed by an ultrasonic bath before use. The amino acid derivatives (compounds **1**–**7**, Fig. 1) used in this study were kindly obtained from the Union Laboratory of Asymmetric Synthesis, Chengdu Institute of Organic Chemistry, Chinese Academy of Sciences. They were dissolved in anhydrous methanol to make concentrations of approximately 1 mg/ml.

2.2. Chromatography

Chromatographic studies were performed using a Waters (Milford, MA, USA) 600 pump equipped with a

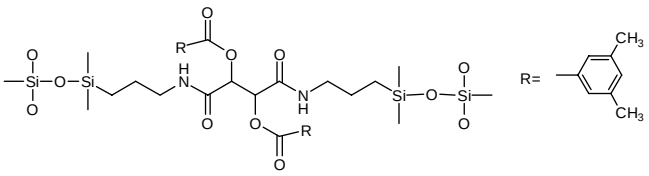

Fig. 2. Structure of the CSP.

Rheodyne 7725i injector (Cotati, CA, USA) and a Waters 2487 dual λ absorbance detector. Chromatographic data were acquired and processed with computer-based Millennium[32] software. A Kromasil CHI-DMB column (150 mm × 4.6 mm i.d.) packed with 10 μm *O*,*O*′-di(3,5-dimethylbenzoyl)-*N*,*N*′-diallyl-L-tartardiamide network polymer (AKZO-NOBEL, Bohus, Sweden) was used for analysis. The structure of the CSP is shown in Fig. 2.

The detection wavelength was set at 254 nm. The injection volume was 5 μl. The dead time was determined from the first perturbation of the base line. It was found to be unchanged for each individual chromatographic run at a flow rate of 1.0 ml/min and a value of $t_0 = 1.60$ min was used in further calculations. Mobile-phase compositions and other chromatographic conditions are given in Section 3. Retention factors, k', were calculated from $(t_R - t_0)/t_0$, where t_R is the retention time and t_0 the dead time. Selectivity (α) was calculated as the ratio of retention factors. Resolutions (Rs) were calculated according to the following relationship:

$$\mathrm{Rs} = \frac{2(t_R(\mathrm{b}) - t_R(\mathrm{a}))}{W_B(\mathrm{b}) + W_B(\mathrm{a})}$$

where t_R(b) and t_R(a) are the retention times of the second and the first eluted peaks (in min), respectively. W_B(b) and W_B(a) are the base widths of peaks b and a (in min), respectively.

3. Results and discussion

3.1. Effect of the concentration of the alcohol modifier

n-Hexane/2-propanol was used as the mobile phase initially. The effects of the concentration of 2-propanol on the retention and separation are shown in Table 1. The values of k' and Rs increased remarkably as the concentration of 2-propanol decreased. Selectivity (α) also increased on the whole, especially when the volume ratio of *n*-hexane

Table 1
The effect of the concentration of 2-propanol on the enantioseparation

Probe	2%				5%				10%			
	k'_1	k'_2	α	Rs	k'_1	k'_2	α	Rs	k'_1	k'_2	α	Rs
1	2.68	4.06	1.51	2.60	1.56	2.22	1.42	1.76	0.89	1.29	1.45	1.30
2	3.03	4.85	1.60	2.59	1.79	2.63	1.47	2.18	1.02	1.45	1.42	1.24
3	4.07	7.50	1.84	4.21	2.31	3.90	1.69	2.89	1.35	2.24	1.66	2.11
4	5.41	8.07	1.49	2.33	2.02	2.71	1.34	1.28	0.85	1.15	1.35	0.87
5	5.94	9.13	1.54	2.78	2.60	3.44	1.32	1.49	1.12	1.46	1.30	0.80
6	10.00	13.58	1.36	2.02	3.91	4.98	1.27	1.51	1.73	2.17	1.25	0.96
7	12.83	20.31	1.58	3.09	4.07	5.89	1.45	2.52	1.65	2.34	1.42	1.20

Conditions: flow rate: 1.0 ml/min; column temperature: 25 °C.

Table 2
The effect of the polar alcohol modifier on the enantioseparation

Probe	Ethanol			1-Propanol			2-Propanol			*n*-Butanol		
	k'_1	k'_2	α	k'_1	k'_2	α	k'_1	k'_2	α	k'_1	k'_2	α
1	1.86	2.47	1.33	1.37	1.84	1.34	1.56	2.22	1.42	1.29	1.74	1.35
2	2.15	2.89	1.34	1.57	2.13	1.36	1.79	2.63	1.47	1.46	2.01	1.38
3	2.16	3.06	1.42	2.03	3.17	1.56	2.31	3.90	1.69	2.04	3.24	1.59
4	2.28	2.80	1.23	1.54	1.92	1.25	2.02	2.71	1.34	1.42	1.88	1.32
5	2.74	3.31	1.21	2.04	2.49	1.22	2.60	3.44	1.32	1.80	2.28	1.27
6	4.32	5.20	1.20	3.03	3.72	1.23	3.91	4.98	1.27	3.01	3.78	1.26
7	4.20	5.54	1.32	2.93	3.96	1.35	4.07	5.89	1.45	2.96	4.12	1.39
	sec-Butanol			*tert*-Butanol			1-Pentanol					
	k'_1	k'_2	α	k'_1	k'_2	α	k'_1	k'_2	α			
1	1.41	2.14	1.52	1.67	2.73	1.63	1.25	1.74	1.39			
2	1.61	2.49	1.55	1.94	3.18	1.64	1.43	2.05	1.43			
3	2.26	4.11	1.82	2.74	5.10	1.86	1.98	3.06	1.55			
4	1.97	2.82	1.43	2.75	4.08	1.48	1.40	2.05	1.46			
5	2.36	3.16	1.34	3.51	4.95	1.41	1.64	2.14	1.30			
6	3.94	5.20	1.32	5.49	7.41	1.35	3.24	4.18	1.29			
7	4.56	6.82	1.50	6.69	10.25	1.53	3.30	4.85	1.47			

Conditions: mobile phase, *n*-hexane/alcohol: 95/5 (v/v); flow rate: 1.0 ml/min; column temperature: 25 °C.

Table 3
The effect of the column temperature on the enantioseparation

Probe	25 °C			30 °C			35 °C			40 °C		
	k'_1	k'_2	α	k'_1	k'_2	α	k'_1	k'_2	α	k'_1	k'_2	α
1	1.56	2.22	1.42	1.44	2.01	1.39	1.32	1.74	1.32	1.19	1.51	1.27
2	1.79	2.63	1.47	1.62	2.29	1.41	1.49	2.02	1.36	1.36	1.79	1.32
3	2.31	3.90	1.69	2.06	3.36	1.63	1.86	2.89	1.55	1.74	2.61	1.50
4	2.02	2.71	1.34	1.88	2.49	1.32	1.75	2.27	1.30	1.61	2.07	1.29
5	2.60	3.44	1.32	2.39	3.11	1.30	2.19	2.79	1.27	1.99	2.51	1.26
6	3.91	4.98	1.27	3.58	4.50	1.26	3.28	4.04	1.23	2.97	3.61	1.22
7	4.07	5.89	1.45	3.73	5.31	1.42	3.37	4.69	1.39	3.07	4.17	1.36

Conditions: mobile phase, *n*-hexane/2-propanol: 95/5 (v/v), flow rate: 1.0 ml/min.

to 2-propanol was 98:2. These facts imply that the selectand/selector associate, the enantioselective adsorption sites are affected by the alcohol modifier.

3.2. Effect of the polar alcohol modifier

Table 2 shows the influence of different polar alcohol modifiers on the enantioseparation. The retention factors and the separation factors were all higher when a more branched alcohol was used as the polar modifier. This fact may be due to two reasons. First, the interaction of the CSP with the linear alcohol is stronger than with the branched alcohol. Second, the linear alcohol is apt to undergo an OH–OH self-association to form cyclic tetramers [10] which then occupy the chiral cavities. For this type of CSP, hydrogen bonding interaction is believed to be the most important factor in the separation [27]. When a linear alcohol is used, the competitive hydrogen bonding interaction is stronger so the retention factors and the separation factors are all lower. Moreover, when the concentration of alcohol modifier decreases, the competitive hydrogen bonding interaction decreases as well, so the values of α and k' increase on the whole. Another phenomenon observed is that the values of α increase in general as the number of carbons in the linear alcohol increases, but the values of k'_1 (for the first eluted enantiomer) decrease. The values of k'_2 (for the second eluted enantiomer) decrease first and then increase again as the molecular weight of the linear alcohol increases.

Comparing the separation factors of **1**–**7**, we found that the solutes having electron-withdrawing substituents on the aromatic ring showed better chiral recognition ability than those having electron-donating substituents. This was especially true for compound **3**. Because the aromatic ring of the CSP having 3,5-dimethyl substituents exhibits π-base character, and compounds in which the aromatic ring has electron-withdrawing substituents (such as −F) exhibit π-acid character, we think that π–π interaction also affects the enantioselectivity. In addition, we found that compounds containing the –NHCOPh group exhibited better resolution on the whole than compounds containing the –NHAc group.

3.3. Temperature effect

In order to study the mechanism of chiral discrimination further, the variation with temperature was investigated. Table 3 shows the effect of column temperature on the enantioseparation. The values of k' and α decreased when the column temperature was increased. The plots of $\ln\alpha$ versus $1/T$ are shown in Fig. 3, and the plots of $\ln k'$ versus $1/T$ are shown in Fig. 4 and Fig. 5. For compounds **1**–**7**, these plots were all highly linear ($r^2 > 0.987$), suggesting that the conformation of the CSP was rigid over the temperature range of 25–40 °C [10]. The chiral discrimination mechanism remained unchanged, and corresponding thermodynamic parameters are temperature-independent [14].

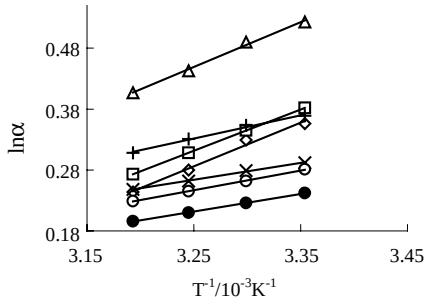

Fig. 3. The plots of $\ln\alpha$ vs. $1/T$ for enantioseparation of amino acid derivatives: (◇) **1**; (□) **2**; (△) **3**; (×) **4**; (○) **5**; (●) **6**; (+) **7**.

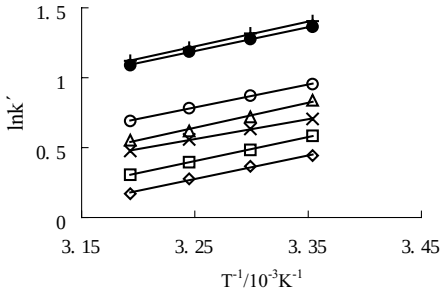

Fig. 4. The plots of $\ln k'$ vs. $1/T$ for the first eluted enantiomer of amino acid derivatives: (◇) **1**; (□) **2**; (△) **3**; (×) **4**; (○) **5**; (●) **6**; (+) **7**.

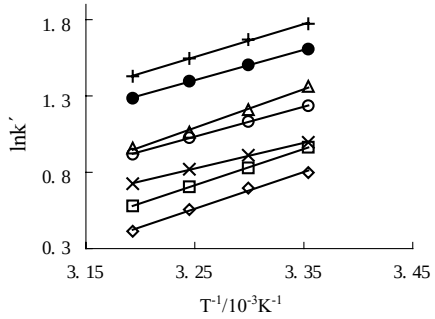

Fig. 5. The plots of $\ln k'$ vs. $1/T$ for the second eluted enantiomer of amino acid derivatives (◇) **1**; (□) **2**; (△) **3**; (×) **4**; (○) **5**; (●) **6**; (+) **7**.

The Gibbs–Helmholtz parameters, $\Delta\Delta H^\circ$ and $\Delta\Delta S^\circ$, can be calculated from the plots and are listed in Table 4. As mentioned above, they are apparent. The negative values indicate that the separations are all enthalpy driven, and the entropy term is unfavourable to chiral recognition. For compounds **1**–**3**, the absolute values of $\Delta\Delta H^\circ$ are distinctly larger than those of **4**–**7**, which shows that the interactions associated with enantioselectivity between compounds **1**–**3** and the CSP are higher. Inspections of the structures of these solutes reveal that the *N*-acyl groups are responsible for the different interactions of chiral discrimination.

The absolute values of $\Delta\Delta S^\circ$ of compounds **1**–**3** are also apparently greater than those of **4**–**7**, indicating that the loss of degrees of freedom experienced by the second eluted enantiomer of compounds **1**–**3** is more prominent than in compounds **4**–**7**.

For compounds **6** and **7**, the retention times were obviously larger than those of other solutes. One may think that the substituents on the aromatic ring have additional interactions with the CSP, so they are retained longer. In order to deeply understand the mechanism of chiral discrimination, thermodynamic data were also obtained from the plots of $\ln k'$ versus $1/T$ for each enantiomer of compounds **1**–**7**. The results are also listed in Table 4. For compound **4**, the values of $-\Delta H^\circ$ for the first and the second eluted enantiomer are both small, indicating that the skeleton of phenylbutyric amino acid has a weaker interaction with the CSP than phenylalanine. The values of $-\Delta H^\circ$ of the first eluted enantiomer for compounds **1**–**3** are similar to those for compounds **5**–**7**, implying that the *N*-acyl groups have a weak influence on the interaction of the first eluted enantiomer with the CSP. Interestingly however, we found that the values of $-\Delta H^\circ$ of the second eluted enantiomer for compounds **1**–**3** are clearly larger than those for compounds **5**–**7**. This implies that the *N*-acyl groups have a great influence on the interaction between the second eluted enantiomer and the CSP. The aromatic ring of the –NHCOPh group may participate in the interaction directly, or maybe, it changes the electron density of adjacent carbonyl group.

Though the retention times for compounds **6** and **7** were obviously larger than those of other solutes, the corresponding values of $-\Delta H^\circ$ did not follow this trend. This implies that the entropy factor also has an important impact on the retention. Actually, the formula for $\ln k'$ and $1/T$ clearly reveals this point. So if the change of the degrees of freedom in the solvation and desolvation of the solute and the CSP, and the formation of the selectand/selector complex is understood more distinctly, we can comprehend the mechanism of chiral recognition more exactly. The influence of the mobile phase deserves to be examined more meticulously.

The isoenantioselective temperatures (T_{iso}) for these solutes are also given in Table 4. T_{iso} is defined as the temperature at which the enthalpy and entropy terms are balanced and $\alpha = 1$. Above the isoenantioselective temperature, enantioseparation is entropy-controlled and a reversal of the elution order could be observed [17]. However supporting experiments are inconvenient to carry out because high temperature may damage the column.

Fig. 6 shows the typical chromatograms for enantioseparation of these seven amino acid derivatives. Baseline resolution could be achieved in all cases with reasonable

Table 4
The data for the thermodynamic parameters of compounds **1**–**7**

Probe	$\Delta\Delta H^\circ$ (kJ mol^{-1})	$\Delta\Delta S^\circ$ (J K^{-1} mol^{-1})	r^{2a}	$\Delta H^{\circ b}$ (kJ mol^{-1})	r^{2c}	$\Delta H^{\circ d}$ (kJ mol^{-1})	r^{2e}	$T_{iso}{}^{f}$ (K)
1	−5.96	−16.98	0.9890	−14.03	0.9930	−20.03	0.9930	350.8
2	−5.64	−15.73	1.0000	−14.28	0.9996	−19.85	0.9998	358.3
3	−6.11	−16.14	0.9954	−14.87	0.9876	−20.97	0.9946	378.9
4	−2.31	−5.30	0.9972	−11.75	0.9984	−14.01	0.9984	435.0
5	−2.68	−6.66	0.9993	−13.65	0.9985	−16.36	0.9993	402.7
6	−2.38	−5.99	0.9996	−14.14	0.9985	−16.54	0.9990	398.1
7	−3.17	−7.55	0.9917	−14.77	0.9986	−17.89	0.9979	420.0

[a] Linear correlation coefficient of Fig. 3.
[b] For the first eluted enantiomer.
[c] Linear correlation coefficient of Fig. 4.
[d] For the second eluted enantiomer.
[e] Linear correlation coefficient of Fig. 5.
[f] Calculated from $T_{iso} = \Delta\Delta H^\circ/\Delta\Delta S^\circ$.

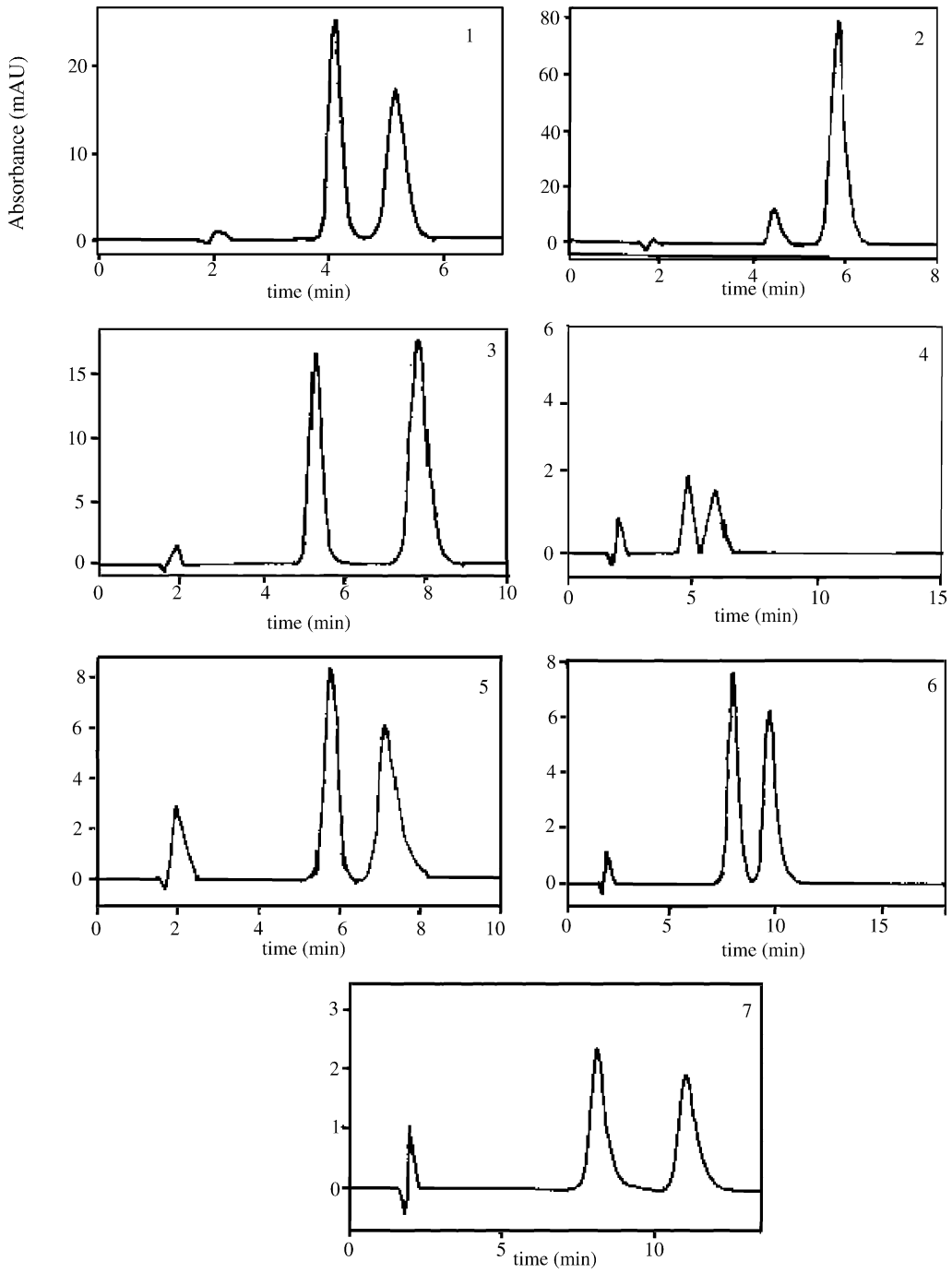

Fig. 6. Typical chromatograms for the enantioseparation of amino acid derivatives **1**–**7**. Conditions: mobile phase, *n*-hexane/2-propanol, 95/5 (v/v), flow rate, 1.0 ml/min, column temperature, 25 °C, detection wavelength, 254 nm.

retention times. The *R* configuration was assigned to the first eluted enantiomer of compounds **2** and **5**. For compound **3**, one enantiomer was in excess. The area deviation from the 1:1 ratio for the first and the second eluted enantiomer of compounds **2** and **3** was due to using the products of asymmetric catalytic synthesis. The chromatographic peaks were also confirmed by corresponding racemate previously.

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References

[1] N.M. Maier, P. Franco, W. Lindner, J. Chromatogr. A 906 (2001) 3.
[2] K. Müller-Dethlefs, P. Hobza, Chem. Rev. 100 (2000) 143.
[3] J. Haginaka, J. Chromatogr. A 906 (2001) 253.
[4] C. Perrin, V.A. Vu, N. Matthijs, M. Maftouh, D.L. Massart, Y.V. Heyden, J. Chromatogr. A 947 (2002) 69.
[5] C.B. Castells, P.W. Carr, J. Chromatogr. A 904 (2000) 17.
[6] P. Sajonz, M. Kele, G. Zhong, B. Sellergren, G. Guiochon, J. Chromatogr. A 810 (1998) 1.
[7] W.H. Pirkle, M.H. Hyun, J. Chromatogr. 322 (1985) 295.
[8] B.-A. Persson, S. Andersson, J. Chromatogr. A 906 (2001) 195.
[9] K.B. Lipkowitz, J. Chromatogr. A 694 (1995) 15.
[10] T. O'Brien, L. Crocker, R. Thompson, K. Thompson, P.H. Toma, D.A. Conlon, B. Feibush, C. Moeder, G. Bicher, N. Grinberg, Anal. Chem. 69 (1997) 1999.
[11] B. Galli, F. Gasparrini, D. Misiti, C. Villani, J. Chromatogr. A 666 (1994) 77.
[12] E. Küsters, V. Loux, E. Schmid, J. Chromatogr. A 666 (1994) 421.
[13] E. Küsters, C. Spöndlin, J. Chromatogr. A 737 (1996) 333.
[14] R. Cirilli, M.R.D. Giudice, R. Ferretti, F.L. Torre, J. Chromatogr. A 923 (2001) 27.
[15] R. Kuhn, F. Erni, T. Bereuter, J. Häusler, Anal. Chem. 64 (1992) 2815.
[16] W.H. Pirkle, R.S. Readnour, Anal. Chem. 63 (1991) 16.
[17] R. Cirilli, F. La Torre, J. Chromatogr. A 818 (1998) 53.
[18] M. Jung, D. Schmalzing, V. Schurig, J. Chromatogr. 552 (1991) 43.
[19] V. Schurig, M. Juza, J. Chromatogr. A 757 (1997) 119.
[20] I. Špánik, J. Krupčik, V. Schurig, J. Chromatogr. A 843 (1999) 123.
[21] V. Schurig, J. Chromatogr. A 906 (2001) 275.
[22] V. Schurig, R. Schmidt, J. Chromatogr. A 1000 (2003) 311.
[23] T. Fornstedt, P. Sajonz, G. Guiochon, J. Am. Chem. Soc. 119 (1997) 1254.
[24] T. Fornstedt, G. Götmar, M. Andersson, G. Guiochon, J. Am. Chem. Soc. 121 (1999) 1164.
[25] W.R. Oberleitner, N.M. Maier, W. Lindner, J. Chromatogr. A 960 (2002) 97.
[26] S. Allenmark, U. Skogsberg, L. Thunberg, Tetrahedron: Asymm. 11 (2000) 3527.
[27] S. Andersson, S. Allenmark, P. Möller, B. Persson, D. Sanchez, J. Chromatogr. A 741 (1996) 23.
[28] S.G. Allenmark, S. Andersson, P. Möller, D. Sanchez, Chirality 7 (1995) 248.
[29] Q.L. Zeng, H. Liu, X. Cui, A.M. Mi, Y.Z. Jiang, X.S. Li, M.C.K. Choi, A.S.C. Chan, Tetrahedron: Asymm. 13 (2002) 115.