Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Chromatography A, 985 (2003) 321–331
JOURNAL OF CHROMATOGRAPHY A
www.elsevier.com/locate/chroma

Chiral separation of γ-butyrolactone derivatives by gas chromatography on 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin

Maria da Conceição K.V. Ramos[a,*], Lis H.P. Teixeira[b], Francisco R. de Aquino Neto[a], Eliezer J. Barreiro[b], Carlos R. Rodrigues[b], Carlos A.M. Fraga[b]

[a]*Laboratório de Desenvolvimento Tecnológico (LADETEC), Centro de Tecnologia, Bloco A, Sala 607, Instituto de Química, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ 21949-900, Brazil*
[b]*LASSBIO, Faculdade de Farmácia, Universidade Federal do Rio de Janeiro, Ilha do Fundão, CCS, Rio de Janeiro, RJ, Brazil*

Abstract

The chiral GC separation of 2-alkyl-2-keto-γ-butyrolactone derivatives and their alcohol analogs using 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin (DIMETBCD) as chiral selector was discussed. The results, supported by the ketone preliminary molecular modelling calculations, suggest that the chiral recognition for DIMETBCD depends more on the geometry than on the polarity of the alkyl substituents on the butyrolactones. Hydrogen bonds and alkyl group steric effects should be an important function of the alcohol chiral recognition for DIMETBCD. Comparison of the retention times of the alcohol derivatives, in achiral and chiral stationary phases, suggests a specific structural effect for the cyclodextrin selector.

Keywords: Enantiomer separation; Molecular modelling; Cyclodextrins; Dimethylbutyldimethylsilylcyclodextrin; Butyrolactones; Alcohols; Lactones

1. Introduction

Substituted γ-butyrolactone derivatives (Fig. 1) are important synthons in the preparation of natural products and new bioactive compounds [1]. Improvements in the chiral analysis profile of these functionalized heterocyclic derivatives are important for their enantiomeric composition characterization [2].

Modified cyclodextrins (CDs) diluted in polysiloxanes are used as chiral stationary phases (CSPs), in enantioselective gas chromatographic (GC) separations of many chiral compounds with different geometries and functionalities [3–5].

The mechanism of chiral recognition necessarily includes a reversible diastereomeric association between each enantiomer and the chiral selector. For CD derivatives, host–guest interaction via inclusion complex formation is usually accepted as an explanation for the chiral resolution. Systematic studies of the enantioselectivity of α-, β- and γ-CD derivatives also provide evidence that the molecule could be included in the cavity, as a whole or in part, but more enantiomers seem to be resolved through external or multiple association than through an

*Corresponding author. Tel.: +55-21-2260-3967; fax: +55-21-2260-3967.
E-mail address: cklaus@iq.ufrj.br (M. da Conceição K.V. Ramos).

0021-9673/02/$ – see front matter
PII: S0021-9673(02)01824-1

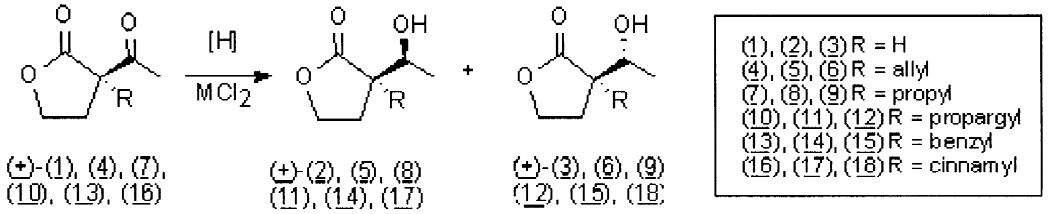


Fig. 1. Structures of γ-butyrolactones derivatives [1].

inclusion process [6–8]. However, despite several valuable contributions to the understanding of CD chiral mechanisms, most practical chiral analysis still depends on the experience obtained in a case-by-case basis.

The present study aims to investigate the enantiomeric GC separation of 2-acetyl-2-alkyl-γ-butyrolactones and the analogous alcohols (Fig. 1) employing 2,3-di-*O*-methyl-6-*O*-*tert.*-butyldimethylsilyl-β-cyclodextrin (DIMETBCD) diluted in polysiloxane, as the chiral stationary phase (CSP).

Our choice of DIMETBCD as a CSP to investigate these systems was based on literature information and on our own experience with this cyclodextrin derivative, which presents excellent versatility and special selectivity for the enantiomeric GC separation of alcohols without derivatization [9–11].

The substitution of the β-CD molecule in the 6-positions by bulky *tert.*-butyldimethylsilyl groups intended to narrow the secondary opening of the cavity and restrict access to the opening on the primary side of the cavity. These cavity modifications were expected to give rise to a better size selectivity and a tighter fixation of less polar or non-polar molecules within the cavity [12].

The literature shows that the enantioselectivity of a cyclodextrin can be affected by the nature of the polysiloxane [13]. The higher solubility of the DIMETBCD selector in the more lipophilic polysiloxane matrices (SE-30, SE-54) would allow a wider range of concentrations of this selector in polysiloxanes resulting in versatile separations and higher enantioselectivities. A better solubility in the polysiloxane matrices was expected due to the weaker self-association of the more lipophilic selector molecules. This would be a consequence of the bulky substitution and, possibly, of the better and more homogeneous solvation by the polysiloxane matrix [12,14].

2. Experimental

2.1. Equipment, materials and conditions

A Hewlett-Packard (Palo Alto, CA, USA) 5890 series II instrument equipped with a split–splitless injector (260 °C) and flame ionization detector (270 °C) was used for all separations. Hydrogen was used as carrier gas with a linear velocity of 50 cm/s. Gas hold up time was determined by injection of methane at the temperature of analysis. Chromatographic data were processed by a Chemstation Plus Family (from Agilent Technologies, Palo Alto, CA, USA).

GC separations were carried out by using laboratory-prepared Duran glass (Schott-Ruhrglass, Bayreuth, Germany) capillary columns of 20 m×0.3 mm, 0.3 μm, with a chiral stationary phase composed of 10% of DIMETBCD diluted in polysiloxanes: SE-54 (5% phenyl, 1% vinyl) and OV1701-OH (95% phenyl, 7% cyanopropyl) (Ohio Valley, Specialty Co., Marietta, USA). DIMETBCD was prepared in our laboratory as previously described [15].

All γ-butyrolactone derivatives (Fig. 1) investigated on this work were synthesized in our laboratory [1]. Volumes of 1.0 μl of samples were injected, as solutions in 1 mg/ml of dichloromethane, with a split ratio of 1/50.

Chiral separation factors (α^{ch}) and chiral resolutions (R_s^{ch}) were calculated by Eqs. (1) and (2), respectively, where subscripts 1 and 2 refer to a pair of enantiomers:

$$\alpha^{ch} = t'_{R2}/t'_{R1}; (t'_R = t_R - t_M) \quad (1)$$

$$R_s^{ch} = 1.18\,(\Delta t_R / w_{h1} + w_{h2}) \quad (2)$$

2.2. Computational methods

The conformational analyses of the compounds 2-acetyl-2-propyl-γ-butyrolactone (7), 2-acetyl-2-allyl-γ-butyrolactone (4), 2-acetyl-2-propargyl-γ-butyrolactone (10) were performed using the semiempirical AM1 method at the self-consistent field molecular orbital (SCF-MO) level [16] implemented on a Pentium III 900 MHz computer. After a re-optimization with the keywords GNORM = 0.2 and PRECISE, the minimal energy conformations structures were unequivocally characterized by Hessian matrix analysis. All dihedral angles were independently searched between 0° and 360° in 30° steps. The minimal energy conformations of each compound were submitted to full geometry optimization using 3-21G* basis set with SPARTAN 1.0.5 program (Wavefunction, Irvine, CA, USA, 2000).

3. Results and discussion

To obtain a preliminary evaluation of their enantiomeric separations, all the components of Fig. 1 were submitted to chiral HRGC on DIMETBCD/SE-54 under the temperature program conditions.

About 80% of the alcohols (2, 3, 5, 6, 8, 9, 11, 12, 17, 18) and 66% of the ketones (1, 4, 7 and 13) (Fig. 1) were separated into their enantiomers, confirming the excellent DIMETBCD chiral selectivity for alcohols. They were separated using oven temperature programs ranging from 100 to 130 °C, except for 17 and 18; these last two were retained longer and partially separated on a special temperature program ranging from 150 to 170 °C.

To obtain a better understanding of the chiral GC behavior of the substituted γ-butyrolactones, in the cyclodextrin stationary phase, we selected some ketones and alcohols among the γ-butyrolactone derivatives, to be analysed in comparable chromatographic conditions. They were 2-acetyl-γ-butyrolactone (1), 2-acetyl-2-allyl-γ-butyrolactone (4), 2-acetyl-2-propyl-γ-butyrolactone (7), 2-acetyl-2-propargyl-γ-butyrolactone (10) and their respective reduction products, alcohols (2 and 3), (5 and 6), (8 and 9) and (11 and 12).

The most important difference among the γ-butyrolactones derivatives undergoing investigation is their ketone versus alcohol functionality. Moreover, ketones have one stereocenter while alcohols have two and these should separate into two pairs of diastereomers, *anti* (2, 5, 8, 11, 14, 17) and *syn* (3, 6, 9, 12, 15, 18). The *anti* diastereomers are prone to intramolecular hydrogen bond that could influence the chiral recognition. Furthermore, the alkyl substituents differ on the kind of C–C bond on the end of chain, which could affect their conformational flexibility and consequently, would affect the butyrolactones ability to form chiral associations with the CD selector.

The bulky groups $-SiCH_3)_2C(CH_3)_3$ (TBDMS) bonded to position number 6 of the CD result in the lengthening and narrowing of the CD cavity. These groups can also restrict the access to the CD cavity on the primary side, while the methoxy substituents linked to the 2 and 3 positions, can block the secondary cavity.

Two conformers are suggested for DIMETBCD: one with the primary cavity blocked by the TBDMS group and the secondary cavity open; and another with the primary cavity partially blocked by TBDMS and the secondary cavity blocked by methoxy groups [12]. It is to be expected that the inclusion of the analytes in the larger secondary cavity, is achieved through their more apolar part [12].

Therefore, considering the low polarity of the investigated ketones and the absence of interactions of intermolecular hydrogen bonds with the chiral selector, the only possibility for their chiral recognition should be through their weak polar interactions, outside of the CD cavity, or through their geometrically dependent inclusion in the cavity. On the other hand, it is probable that the strong polar interaction, due to the intermolecular hydrogen bonds with the alcohols and the $-OCH_3$, on the 2 and 3 CD positions, or with –OTBDMS groups, on the 6 CD positions, is most important for their chiral separation.

The literature shows that the enantioselectivity of a cyclodextrin can be affected by the nature of the

polysiloxane [12–14]. In order to verify this assertion, chromatograms of all γ-butyrolactone derivatives were performed using DIMETBCD diluted in SE-54 (DIMETBCD/SE-54) and in OV1701-OH (DIMETBCD/OV1701-OH).

To guide these studies it was necessary to evaluate the chromatographic behavior of all γ-butyrolactone derivatives in similar conditions, which implies isotherm analysis. To help the selection of the most appropriate temperature, the γ-butyrolactone derivatives were divided in two groups, ketones and alcohols.

The ideal temperature was determined through the testing of several isotherms. The temperature that promoted fast enantiomeric separation for most of the analytes, without changing peak format was chosen. Thus, ketones (1, 4, 7, 10) were analyzed at 85 °C, and alcohols (2, 3, 5, 6, 8, 9, 11, and 12) at 115 °C.

3.1. Chiral chromatographic behavior of 2-keto-2-alkyl-γ-butyrolactones

All the selected ketones were analysed at 85 °C using DIMETBCD/OV1701-OH (Fig. 2A), and DIMETBCD/SE54 (Fig. 2B) as chiral stationary phases.

The results in Table 1 and Fig. 2A,B show that among the keto-butyrolactones, 2-propargyl-2-keto-γ-butyrolactone (10) and the non-substituted 2-keto-γ-butyrolactone (1) enantiomers did not separate. However, there is a hint that 1 due to the format of the peak suffers enolization under the analysis

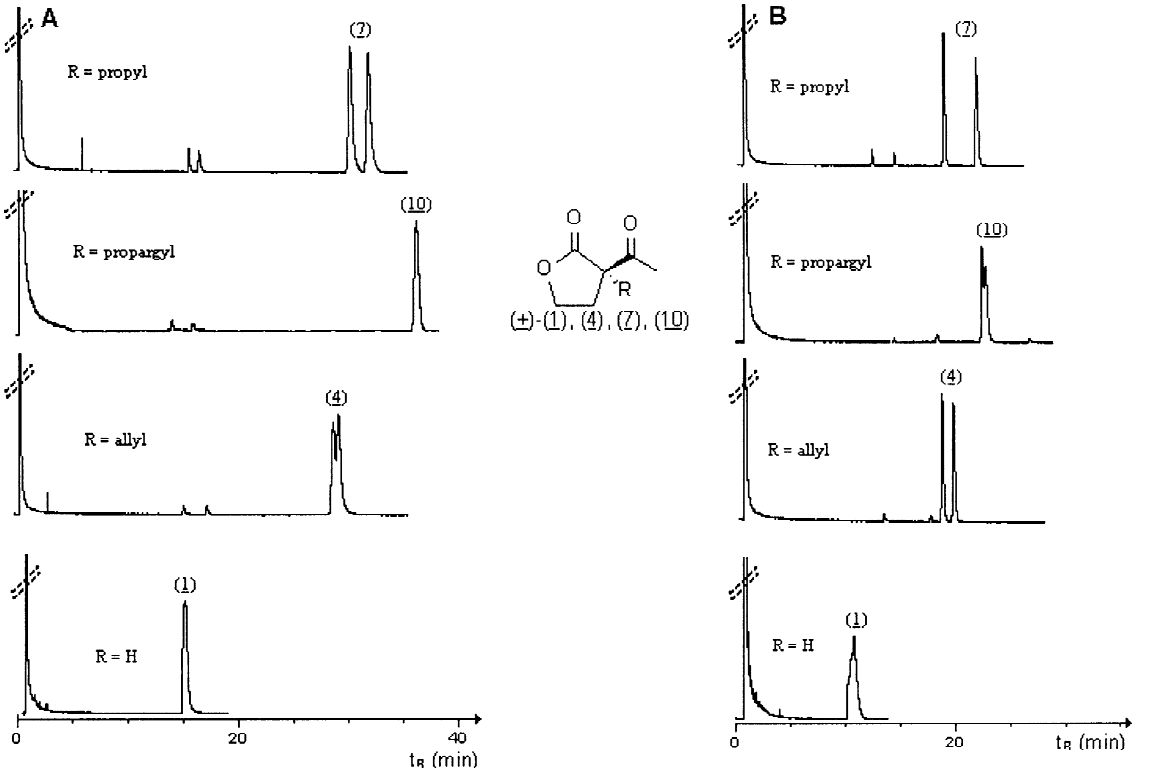
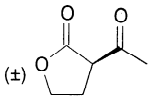
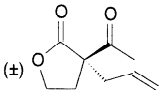
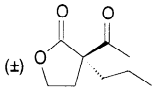
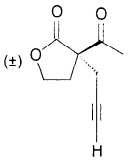


Fig. 2. Typical chromatograms of stereomers separation of 2-acetyl-2-alkyl-γ-butyrolactones on 10% 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin diluted in polysiloxanes, at 85 °C: (A) DIMETBCD/OV1701-OH and (B) DIMETBCD/SE-54, glass capillary column (20 m×0.3 mm, 0.3 μm).

Table 1
Retention time (t_R), enantioselectivity factor (α^{ch}) and chiral resolution (R_s^{ch}) of 2-acetyl-2-alkyl-γ-butyrolactones on 10% 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin diluted in polysiloxanes, at 85 °C

Structure	Compounds	DIMETBCD/OV1701-OH[a]			DIMETBCD/SE-54[a]		
		t_R (min)	α^{ch}[b]	R_s^{ch}	t_R (min)	α^{ch}	R_s^{ch}
(±) 	1	16.0	1.00	0	10.6 10.8	1.02	0.3
(±) 	4	26.8 27.3	1.02	0.7	17.3 18.2	1.05	2.9
(±) 	7	28.3 29.8	1.05	2.2	17.4 20.1	1.16	7.9
(±) 	10	34.3	1.00	0	20.6 20.9	1.01	0.7

[a] 20 m×0.3 mm, 0.3 μm.
[b] $\alpha^{ch}=t'_{R2}/t'_{R1}$, $t_M=40$ s.

conditions. The best selectivity and resolution happened for 2-propyl-2-keto-γ-butyrolactone (7), followed by 2-allyl-2-keto-γ-butyrolactone (4) on DIMETBCD/SE54.

Double and triple bonds present in the extremities of the alkyl substituted ketones (4) and (10) must contribute to the poorer enantiomeric separations. The rigidity and extension of the propargyl group certainly represent a severe hindrance to the chiral recognition. On the other hand, the best flexibility of the propyl group of (7) should contribute to the better fitting of its enantiomers to the CD selector.

The higher retention for all the ketones on DIMETBCD/OV1701-OH (Fig. 2A, Table 1) relative to DIMETBCD/SE-54 does not mean that the chiral separation factor and chiral resolution increased in the same way. Actually, the opposite effect happened: the chiral resolution for all the ketones on DIMETBCD/OV1701-OH was poorer.

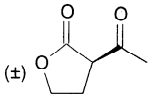
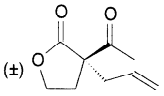
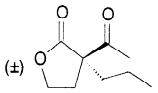
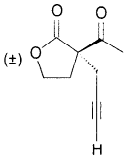
The retention time behavior in the achiral and chiral phases was evaluated by the analysis of the same analytes in both systems (Table 2). The arithmetic mean retention times between the enantiomers separated in the chiral phase did not show a clear trend when compared with the achiral retention times. This points to the fact that the mechanism of retention of each enantiomer in the chiral phase is not directly related to its association with the CD-selector. Otherwise the mean retention time would be greater than the achiral retention time

3.2. Chiral chromatographic behavior of 2-hydroxyacetyl-2-alkyl-γ-butyrolactones

All the alcohol derivatives were investigated in DIMETBCD/OV1701-OH (Fig. 3A) and DIMETBCD/SE-54 (Fig. 3B) stationary phases, at 115 °C.

The enantiomeric alcohols (except 2) were sepa-

Table 2
Retention time (t_R) of 2-acetyl-2-alkyl-γ-butyrolactone derivatives on achiral (OV1701-OH and SE-54) and chiral (DIMETBCD/OV1701-OH and DIMETBCD/SE-54) stationary phases, at 115 °C

Structure	Compounds	OV1701-OH, t_R (min)	DIMETBCD/OV1701-OH, t_R (min)[a]	SE-54, t_R (min)	DIMETBCD/SE-54, t_R (min)[a]
	1	–	16.0	7.7	10.7
	4	28.6	27.0	18.8	17.7
	7	31.4	29.0	21.5	18.8
	10	33.9	34.3	19.3	20.2

[a] Arithmetic mean between enantiomer retention times in chiral phases.

rated in DIMETBCD/SE-54 (Fig. 3B) with $\alpha_{ch} > 1.03$ and $R_s^{ch} > 1.3$ (Table 3). As for the ketones, the chiral resolution (R_s^{ch}) in decreasing order is propyl, allyl and propargyl derivatives.

In DIMETBCD/OV1701-OH the chiral resolution (R_s^{ch}) is of the same order as in DIMETBCD/SE-54, but somewhat poorer, as is described in Table 3 and shown in Fig. 3A.

The elution order for the alcohols was *anti*/*syn*, established by NMR spectroscopy and chiral GC [1]. The elution order could be attributed to the greater probability of the *anti* diastereomer to make intramolecular hydrogen bonding.

The separation of the enantiomers of allyl alcohols (5 and 6) was accomplished in DIMETBCD/OV1701-OH. The retention effect observed with the ketones was repeated here: in general the retention times were higher in that phase, but the chiral resolutions were lower than in DIMETBCD/SE-54.

The enantiomeric separation of propyl alcohols in DIMETBCD/OV1701-OH. (Fig. 3A) was doubtful, in spite of the elution of three peaks. However, by comparing this chromatogram with the other, in DIMETBCD/SE-54 (Fig. 3B), it was concluded that the first peak resulted from the co-elution of the lower retention, *anti* (8) and *syn* (9), diastereomers.

Interesting facts were observed in the chiral chromatographic analysis of the alcohols (Fig. 3A,B): i.e., larger differences of retention between the *syn* diastereomers (3, 6, 9, 12) relative to the *anti* diastereomers (2, 5, 8, 11) and abnormal chiral resolution values. These occurrences are most important in DIMETBCD/SE-54. In general, one of the *syn* diastereomers eluted closer to the *anti*. Furthermore, in the case of the propyl derivative, the lower retention *syn* diastereomer, eluted between the *anti* diastereomers.

To investigate these facts, comparison of *syn* diastereomers retention in achiral (SE-54 and OV1701-OH) and chiral phases were made (Table 4). Diastereomers average retention in the chiral phase, were obtained from the arithmetic mean between their retention times. The mean retention time of the diastereomers in the chiral phase was higher than the respective retentions in achiral phases. These larger retentions suggest a specific

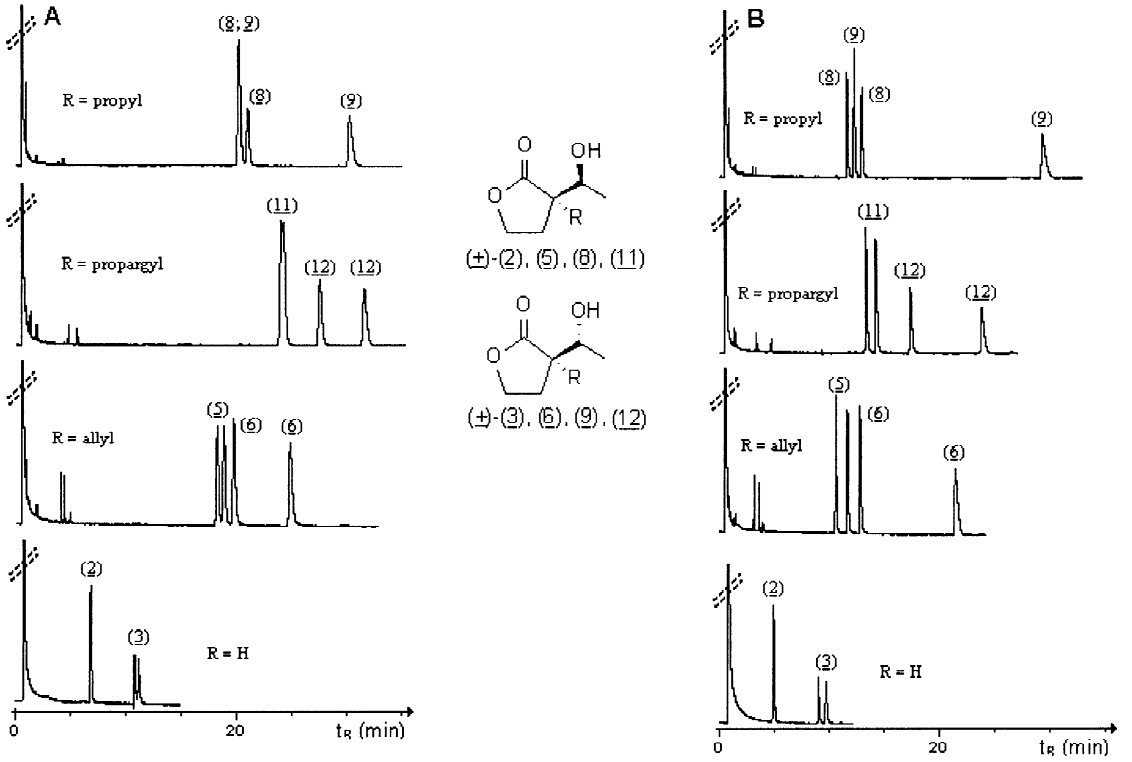


Fig. 3. Typical chromatograms of stereomers separation of 2-hydroxyacetyl-2-alkyl-γ-butyrolactones on 10% 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin, diluted in polysiloxanes, at 115 °C: (A) DIMETBCD/OV1701-OH, DIMETBCD/SE-54 and (B) glass capillary column (20 m×0.3 mm, 0.3 μm).

preference of one diastereomer for the CD selector. If it were only an attractive and a repulsive interaction, the average retention would be very similar to that in the achiral system, as is the case for the other diastereomeric pair (*anti* diastereomer).

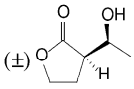
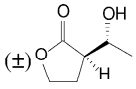
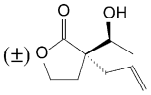
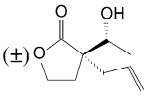
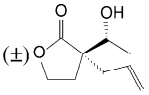
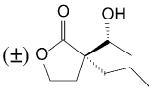
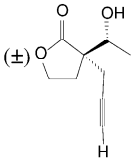
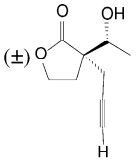
3.3. Molecular modelling studies

Preliminary molecular modelling calculations were performed in the ketone derivatives (4, 7 and 10) to investigate the effect of their conformational and physicochemical molecular parameters on differential GC behavior in DIMETBCD/SE-54 versus DIMETBCD/OV1701.

The full geometry optimization of compounds (4, 7 and 10), obtained by the 3-21G* basis set, was used in the measurement of the dipole moment and the molecular volume (Table 5). These data indicates that the retention times of propyl (7), allyl (4) and propargyl (10) derivatives are not directly correlated to their dipole moments in the more polar phase OV-1701. However, in the lipophilic stationary phase SE-54 the compound that presents the highest retention time is the propyl derivative (7), which has the smallest dipole moment (Table 5).

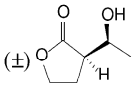
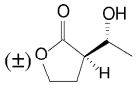
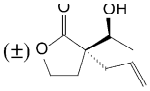
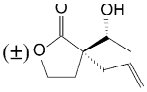
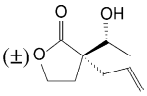
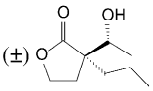
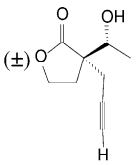
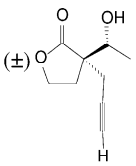
Differences in the resolution of these compounds are probably related to the fit into the CD-cavity, which could be dependent on the conformational flexibility of its alkyl side chain, which is reflected by the molecular volume of the analyte. In all analytical situations (Table 1), the largest propyl derivative (7) (Table 5) presented the best resolution (R_s), suggesting an ideal and complementary interaction between one of these enantiomers and the cavity of the chiral DIMETBCD selector.

Table 3
Retention time (t_R), enantioselectivity factor (α^{ch})[a] and chiral resolution (R_s^{ch})[a] of 2-hydroxyacetyl-2-alkyl-γ-butyrolactones on 10% 2,3-di-*O*-methyl-6-*O*-*tert*.-butyldimethylsilyl-β-cyclodextrin diluted in polysiloxanes, at 115 °C

Structure	Compounds	DIMETBCD/OV1701-OH[b]			DIMETBCD/SE-54[b]		
		t_R (min)	α^{chc}	R_s^{ch}	t_R (min)	α^{chc}	R_s^{ch}
	2	6.8	1	0	4.8 5.0	1.04	1.3
	3	10.8 11.1	1.03	2.9	9.0 9.7	1.08	3.3
	5	16.9 17.5	1.03	1.7	10.0 11.0	1.10	5.0
	6	18.3 23.0	1.26	9.6	12.0 20.0	1.70	24.1
	8	18.8[d] 19.5	1.04	1.9	11.0 12.2	1.11	5.7
	9	18.8[d] 28.0	1.51	20.5	11.6 27.3	2.44	39.7
	11	22.3 22.5	1.01	0.6	12.5 13.4	1.07	3.3
	12	25.5 29.2	1.15	8.7	16.2 22.2	1.38	15.4

[a] α and R_s for each enantiomeric pair.
[b] 20 m×0.3 mm, 0.3 μm.
[c] $\alpha^{ch}=t'_{R2}/t'_{R1}$, $t_M=40$ s.
[d] 18.8 min, retention time of the two co-eluted peaks, *anti* (8) and *syn* (9) propyl derivatives.

Table 4
Retention time (t_R) of 2-hydroxyacetyl-2-alkyl-γ-butyrolactone derivatives on achiral (OV1701-OH and SE-54) and chiral (DIMETBCD/OV1701-OH and DIMETBCD/SE-54) stationary phases, at 115 °C

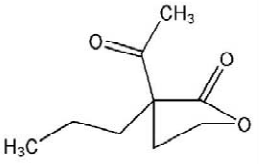
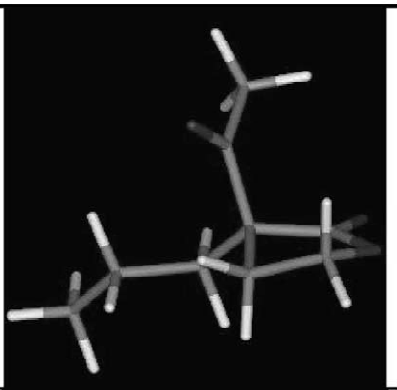
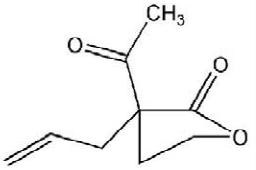
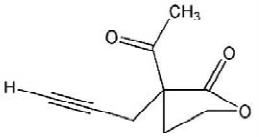
Structures	Compounds	OV1701-OH, t_R (min)	DIMETBCD/OV1701-OH, t_R (min)[a]	SE-54, t_R (min)	DIMETBCD/SE-54, t_R (min)[a]
	2	5.8	6.8	3.8	4.9
	3	7.5	11.0	4.3	9.3
	5	16.4[b]	17.2	10.2[b]	10.5
	6		20.7		16.0
	8	17.9	19.1	11.5	11.6
	9	18.5	23.4	11.9	19.4
	11	20.0	22.4	10.9	12.9
	12	21.3	27.4	11.1	19.2

[a] Arithmetic mean between diastereomer retention times in chiral phases.
[b] Diastereomers 5 and 6 did not separate on achiral phases SE-54 and OV1701-OH.

4. Conclusions

Ketone chiral recognition for DIMETBCD depends on the geometry and polarity of the alkyl substituents of the butyrolactones. It is possible that CD inclusion is more important than polarity interactions outside the CD cavity. On the other hand, hydrogen bonds, besides alkyl group steric effects

Table 5
Dipole moments (μ) and molecular volume ($Å^3$) of the minimum energy conformer of the ketone derivatives (7, 4 and 10)

Compounds	Minimum Energy Conformation[a]	μ (D)	Volume ($Å^3$)
 (7)		3.10	206.50
 (4)		3.57	200.43
 (10)		3.38	194.92

[a]Obtained from molecular modeling studies using 3-21G* basis set.

have an important function on the alcohol chiral recognition for DIMETBCD. The diastereomer elution order (*anti–syn*) is influenced by intramolecular hydrogen bonding. The enantiomers of propargyl alcohol derivative are separated on DIMETBCD/SE-54, so hydrogen bonding should make the difference if compared with the propargyl ketones behavior. Another important result was the higher retention of one *syn* diastereomer, which suggests a specific structural effect for CD recognition.

Acknowledgements

We thank FAPERJ, CNPq, CAPES and FUJB for financial support.

References

[1] L.P. Teixeira, M.C.B.V. Souza, M.C.K.V. Ramos, F.R. Aquino Neto, E.J. Barreiro, C.A.M. Fraga, Synth. Commun. 32 (2002) 505.
[2] M.C.K.V. Ramos, E.F. Silva, F.R. Aquino Neto, E.P. Peçanha, C.R. Rodrigues, E.J. Barreiro, C.A.M. Fraga, Anal. Chem. 72 (2000) 3056.
[3] W. Kein, A. Köhnes, W. Meltzow, H. Römer, J. High Resolut. Chromatogr. 14 (1991) 507.
[4] W.A. König, in: Enantioselective Gas Chromatography with Modified Cyclodextrins, Hüthig, Heidelberg, 1992.
[5] V. Schurig, J. Chromatogr. A 906 (2001) 275.
[6] D.W. Armstrong, W. Li, Y. Pitha, J. Anal. Chem. 62 (1990) 214.
[7] A. Berthod, W. Li, D.W. Armstrong, J. Anal. Chem. 64 (1992) 873.
[8] J. Krupcík, E. Benická, P. Májek, I. Skacáni, P. Sandra, J. Chromatogr. A 665 (1994) 175.
[9] B. Maas, A. Dietrich, A. Mosandl, J. High Resolut. Chromatogr. 17 (1994) 109.
[10] B. Maas, A. Dietrich, D. Bartschat, A. Mosandl, J. Chromatogr. Sci. 33 (1995) 223.
[11] C.A.M. Fraga, E.J. Barreiro, E.F. Silva, A.R. Santos, M.C.K.V. Ramos, F.R. Aquino Neto, Chirality 9 (1997) 321.
[12] F. Kobor, K. Angermund, G. Schomburg, J. High Resolut. Chromatogr. 16 (1993) 299.
[13] A. Dietrich, B. Maas, W. Meser, G. Bruche, V. Karl, A. Kaunzinger, A. Mosandl, J. High Resolut. Chromatogr. 15 (1992) 590.
[14] F. Kobor, G. Schomburg, J. High Resolut. Chromatogr. 16 (1993) 693.
[15] A.S. Pereira, E.F. Silva, F.R. Aquino Neto, J. Chromatogr. Sci. 36 (1998) 91.
[16] M.J.S. Dewar, J. Am. Chem. Soc. 107 (1995) 3902.