NEW LIGANDS FOR ENANTIOSELECTIVE RECOGNITION OF CHIRAL CARBOXYLATES BASED ON 1,1′-BINAPHTHALENE-2,2′-DIAMINE

Ivan STIBOR[a1,*], Roman HOLAKOVSKÝ[a2], Asiya R. MUSTAFINA[b] and Pavel LHOTÁK[a3]

[a] *Department of Organic Chemistry, Institute of Chemical Technology, Prague, Technická 5, 166 28 Prague 6, Czech Republic; e-mail: [1] stibori@vscht.cz, [2] roman.holakovsky@vscht.cz, [3] lhotakp@vscht.cz*

[b] *A. E. Arbuzov Institute of Organic and Physical Chemistry, Russian Academy of Sciences, 420088 Kazan, Russia; e-mail: asiya@iopc.knc.ru*

Received February 7, 2003
Accepted November 21, 2003

Simple bis(arylureido)binaphthalenes and (arylamido)binaphthalenes have been synthesized in both racemic as well as optically active forms. One of these compounds has been found to complex chiral anions with modest enantioselectivity.

Keywords: Biaryls; Binaphthalenes; Axial chirality; Chiral anion recognition; Complexation; Extractions; Amides.

Interest in the complexation of anionic species continues to attract the attention of the chemistry community as witnessed by numerous reviews published recently[1]. The importance of anions in biological systems is well recognized[2], and the same is true for the role of anions in chemical processes and environmental pollution. Given their importance, there has obviously been much effort expended in the design of anion-complexing ligands. The main strategies have traditionally focused on cationic, polyammonium, guanidinium, quaternary ammonium, porphyrin-based ligands, and a number of Lewis acids containing ligands. Neutral organic ligands that bind anions *via* favourable hydrogen bonding have also been studied[1,3] by several groups and also in our laboratory[4]. Our attention has been concentrated on simple aromatic and heteroaromatic amides as well as calixarene-based ligands[5]. We have developed theoretical methods for the prediction of bromide anion-binding ability of simple aromatic amides[6]. We have also found that these simple amides are able to act co-operatively. Triamides derived from tren (tris(2-aminoethyl)amine) and both pentafluorobenzoic and isonicotinic acids have been found to complex hydrogensulfate and dihydrogenphosphate with nice selectivity[5]. That

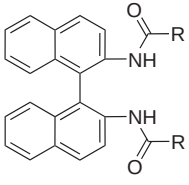
doi:10.1135/cccc20040365

is why we aimed to extend our studies to chiral, preferably aromatic scaffolds where several aromatic amides or ureas could bind anion cooperatively. Obviously, calix[*n*]arene and axially chiral 1,1′-binaphthalene molecular scaffolds were assumed to fulfil the purpose. While a number of calixarene-based ligands for anion binding has already been published and the calixarene literature is abundant[7,8], much less is known on application of axially chiral aromatic skeletons to anion recognition[9] despite the fact that 1,1′-binaphthalene-2,2′-diamine is commercially available in both enantiomerically pure forms. Consequently, we report here on easily accessible new chiral neutral ligands based on chiral 1,1′-binaphthalene-2,2′-diamine.

RESULTS AND DISCUSSION

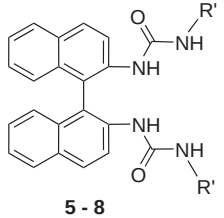
Synthesis

Syntheses of ligands were straightforward using acylation with acid chlorides or isocyanates under standard conditions. Surprisingly, the racemic 1,1′-binaphthalene-2,2′-diamine is not commercially available and has to be prepared according literature procedures. In our hands, the superior preparation was that based on Myiano's published procedure[10]. The main point is the product purity as the crude product is accompanied by starting 2-naphthylamine which has to be washed out by thorough extraction of crude product with hot water. Racemic ligands **1**–**3** have been prepared in good to excellent yields using a standard acylation procedure in the pres-



1 - 3

1, R = phenyl
2, R = 3,5-bis(trifluoromethyl)phenyl
3, R = 2,3,4,5,6-pentafluorophenyl

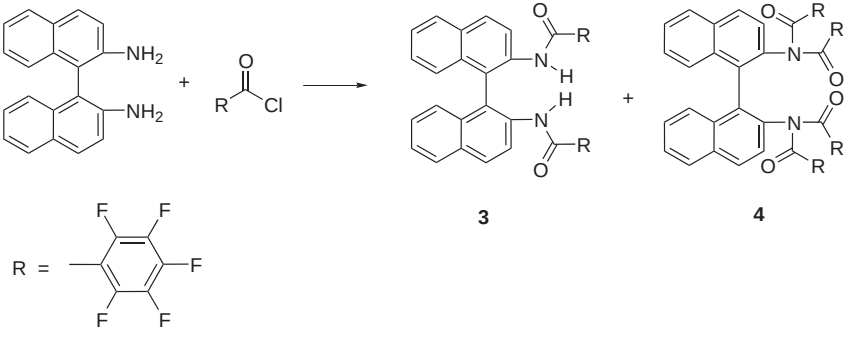


5 - 8

5, R´ = 3,5-bis(trifluoromethyl)phenyl
6, R´ = 4-methylphenyl
7, R´ = 4-nitrophenyl
8, R´ = dodecyl

ence of triethylamine with the only exception of the reaction with perfluorobenzoyl chloride. The "normal" amide **3** can only be obtained when acylation is performed at –78 °C. The same reaction at ambient tem-

perature has furnished tetraacyldiamine **4** (Scheme 1) that has been fully characterized including single-crystal X-ray analysis (Fig. 1).



SCHEME 1

Having these amides, we have performed the preliminary NMR titration experiments with bromide anion in $CDCl_3$. No change of ligand spectra (**1**–**3**) has been observed going from pure ligand to a ten-fold excess of corresponding Bu_4N^+ salt. On the other hand, it is known[3] that urea functions usually exhibit stronger complexation abilities towards anions if compared with the corresponding amides. Consequently, we have prepared a series of ureas **5**–**8** from both racemic and optically pure diamine and commercially available isocyanates.

We have found that racemic ligands are much less soluble than optically pure ones. Whereas DMSO was found to be the only solvent where concentration of racemic ligands 5×10^{-4} mol l^{-1} can be attained, the optically

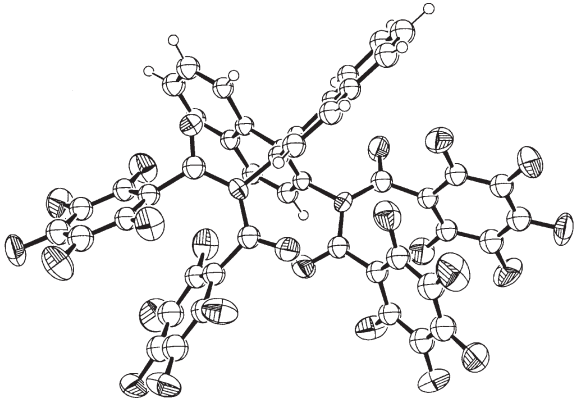


FIG. 1
ORTEP view[11] of crystal structure of **4** (thermal ellipsoids are drawn with 50% probability)

pure ligands are soluble in chloroform. As the stability of complexes formed with anion in DMSO are too low to be measured using NMR titration, only optically pure compounds have been used and the complexation studies were performed in $CDCl_3$. The ligand (*R*)-**5** was found to be superior to all the compounds prepared and was used throughout the study.

Complexation

It is a well-known fact[12] that substituted ureas spontaneously associate in non-competitive solvents. That is why a dilution experiment with (*R*)-**5** has been performed prior to stability constant measurement. The NMR spectrum of this ligand was found to remain unchanged (within ±1 Hz) at a concentration below 10^{-3} mol l^{-1} in $CDCl_3$. Consequently, all measurements have been made with concentration of the (*R*)-**5** ligand about 5×10^{-4} mol l^{-1} or lower where the influence of self-association of the free ligand can be neglected.

To test the complexation ability of the (*R*)-**5** ligand, a preliminary screening was carried out with several anions representing different geometry. Hence, the spherical bromide, planar nitrate and acetate, and the tetrahedral dihydrogenphosphate were used with tetrabutylammonium countercations. Using a conventional ^{1}H NMR titration experiment only the 1:1 stoichiometry (ligand:anion) was found. As shown in Fig. 2, the interaction

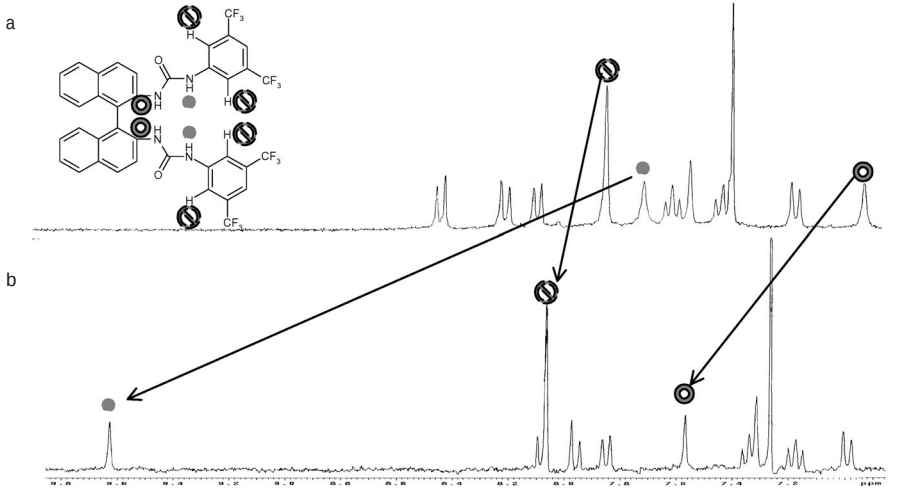


FIG. 2

NMR titration experiment: a free (*R*)-**5**, b (*R*)-**5** in the presence of 10 equivalents of tetrabutylammonium bromide in $CDCl_3$

of (*R*)-**5** ligand with Br^- leads to large complexation-induced chemical shifts (CIS) of both NH, and *ortho*-phenyl protons. The association constants obtained by a non-linear regression analysis are summarized in Table I.

To gain deeper insight into the binding phenomenon, the complex of (*R*)-**5** with tetrabutylammonium acetate was studied in CD_2Cl_2 solution using a 500 MHz NMR spectrometer. The assignment of all signals (free ligand *versus* ligand in the presence of 15 equivalents of Bu_4NAc) allowed us to determine the corresponding complexation induced chemical shifts (Table II).

As evidenced by large CIS values ($CIS_{[13]}$ = +1955 Hz, $CIS_{[11]}$ = +830 Hz), both NH groups in urea functions are engaged in the complexation of anion *via* the hydrogen bonding interactions. On the other hand, the remarkable difference in the NH shifts proves that the contribution of NH group in position 13 (CIS = 3.91 ppm) is much larger than that in position 11 (CIS = 1.66 ppm). Interestingly, the relatively high CIS value for *ortho*-hydrogens 15 ($CIS_{[15]}$ = 0.44 ppm) indicates that these hydrogens are presumably also engaged in the complexation exhibiting the C–H···anion interactions. At the same time, the signal of acetate is shifted upfield in the presence of (*R*)-**5**.

Encouraged by these results, we have decided to examine the ability of (*R*)-**5** to interact with chiral carboxylates[13]. Using conventional ^1H NMR titration experiment both L- and D-lactate have been found to form complexes with approximately the same stability constant 13400 ± 3500 l mol^{-1}. As the additional π–π interactions can be envisaged in aromatic carboxylates, we have focused our attention to the (*R*)- and (*S*)-mandelates. The NMR titration experiments proved the formation of the complexes with very high stability constants, in fact too stable to be reliably studied by NMR (the estimated stability constant in $CDCl_3$ > 10^5 l mol^{-1}). On the other hand, the CIS in DMSO-d_6 were negligible, showing thus the crucial role of hydrogen bonding in the complexation phenomenon. Unfortunately, our attempts to

TABLE I
Association constants (in l mol^{-1}) of complexes of (*R*)-**5** with anions of tetrabutylammonium salts in $CDCl_3$

Anion	Association constant
Bromide	3360 ± 450
Nitrate	2780 ± 380
Dihydrogenphosphate	1110 ± 180
Acetate	36 500 ± 8800

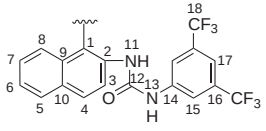
use UV/VIS spectroscopy in the complexation study of mandelates ($CHCl_3$) were also unsuccessful as no substantial changes in UV/VIS spectra were observed during the titration experiments.

The chiral recognition of mandelates with (*R*)-**5** was studied using simple extraction experiments where a chloroform solution of ligand (c = 0.01 mol l^{-1}, 1 ml) was stirred intensively (1100 rpm) with an aqueous solution of Bu_4N^+(*RS*)-mandelate (c = 0.01 mol l^{-1}, 1 ml) for 1 h. The mandelates remaining in the aqueous phase after extraction were monitored by HPLC on chiral column (Chiralcel OD-H, isopropanol:hexane:TFA = 1:4:trace). The integration of the corresponding peaks in chromatogram revealed that the (*R*)-mandelate is better extracted than (*S*)-mandelate (*S*:*R* = 4:6) while there were no enantioselectivity in the "background experiment" where no ligand was used in the organic layer. This experiment revealed, that the (*R*)-**5** ligand can be used in the recognition and complexation of chiral anions.

To specify the stoichiometry of complexes formed by the (*R*)-**5** ligand with anions, and with chiral carboxylates in particular, we have performed an extraction study ($D_2O/CDCl_3$) of anions using (*R*)-**5** ligand. The progress

TABLE II

^{1}H NMR chemical shifts (500 MHz) for (*R*)-**5** both free and complexed (15-fold excess of Bu_4NAc) in CD_2Cl_2 and CIS values



Position	Free ligand δ, Hz	Complexed ligand[a] δ, Hz	Δδ, Hz
3	4001	3994	–7
4	4057	4031	–26
5	3952	3958	+6
6	3725	3701	–24
7	3616	3611	–5
8	3504	3520	+16
11	3463	4293	+830
13	3746	5701	+1955
15	3798	4017	+219
17	3707	3669	–38

[a] 15 equivalents of Bu_4NAc added.

of extraction was monitored by ^{1}H NMR spectroscopy using the well resolved singlet of four *ortho*-hydrogens of 3,5-bis(trifluoromethyl)phenyl groups (around δ 7.73). Two procedures have been chosen to describe the complexation involved. Firstly, the downfield shifts of *ortho*-protons caused by the complexation of anions were plotted against C_g/C_h where C_g is the concentration of anion in aqueous phase and C_h is the concentration of (*R*)-**5** ligand in organic phase. The curves obtained were used to evaluate the extractability of anions by the ligand (*R*)-**5** (Fig. 3). While the benzoate clearly corresponds to the formation of 1:1 complex, the stoichiometry of

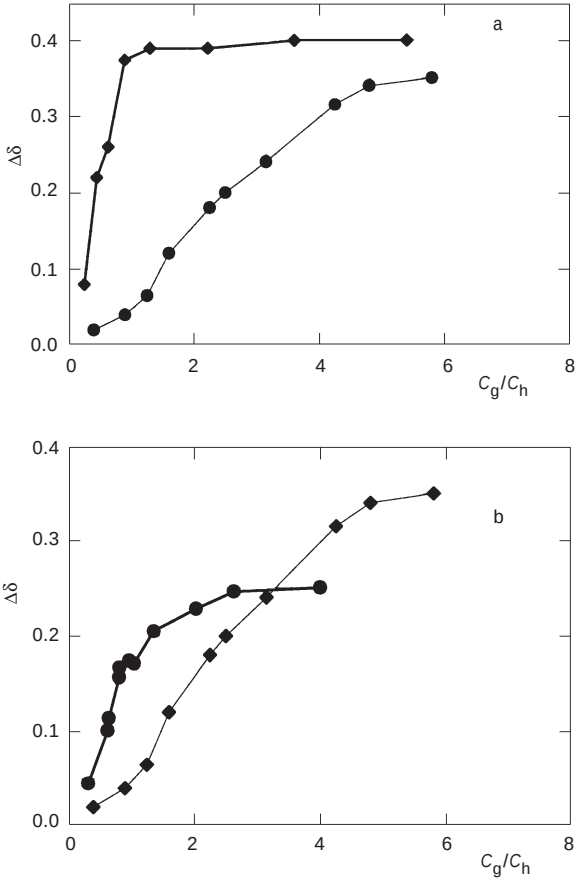


FIG. 3
Plot of the observed shift of *ortho*-proton, Δδ, against C_g/C_h (C_h, concentration of ligand in $CDCl_3$ phase; for other symbols, see Symbols). a Benzoate (◆), (*S*)-lactate (●); b acetate (◆), (*RS*)-mandelate (●)

other complexes shown in Fig. 3 is less obvious. Presumably, more than 1:1 stoichiometry is involved in the complexation.

Secondly, a log–log plot[14] (see Experimental) was constructed and results are summarized in Figs 4 and 5. Both K_{ex} and the complex stoichiometry under saturation conditions can be evaluated using this method.

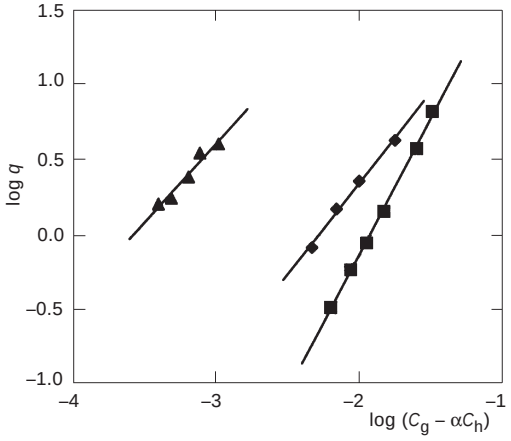


FIG. 4

Log–log analysis[14] of extraction data for achiral anions (C_h, concentration of ligand in $CDCl_3$ phase; for other symbols, see Symbols). Anions: bromide (◆), acetate (■), benzoate (▲)

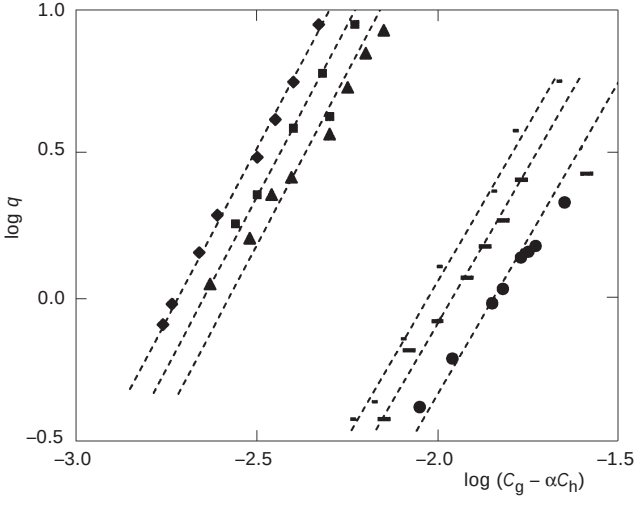


FIG. 5

Log–log plot[14] of extraction data for lactates and mandelates using (*R*)-**5**. For definition of symbols, see Symbols. Anions: (*RS*)-mandelate (◆), (*S*)-mandelate (■), (*R*)-mandelate (▲), (*R*)-lactate (-), (*RS*)-lactate (–), (*S*)-lactate (●)

The following important conclusions can be drawn from these data. Both bromide and benzoate have been found to form 1:1 complexes under all the conditions used. Acetate gave less clear results. The ligand:anion stoichiometry 1:2 seems to be more probable, but it is evident that saturation is achieved at a very high excess of anion and the complexation is likely to proceed in two steps. Unfortunately, an accurate evaluation of the first-step complexation data cannot be achieved due to simultaneous saturation of both 1:1 and 1:2 complexes. The $\Delta\delta$ of *ortho*-protons slightly increased going from bromide to acetate (0.315 to 0.334 ppm in water-saturated chloroform), which is in accordance with the data in Table I. The upfield $\Delta\delta$ for protons in positions 3, 4, and 6 of the binaphthalene skeleton are higher going from bromide to acetate. It can be interpreted as two-point binding of acetate to one urea unit in contrast to bromide where anion is cooperatively bound in the cleft formed by both units. More precise stability constants for acetate and benzoate in water-saturated chloroform could not be obtained due to overlap of *ortho*-protons with protons in positions 3, 4, and 6 in 300 MHz ^{1}H NMR spectra. Going from acetate to benzoate the upfield shift increases while binding of one benzoate anion resulted in a higher $\Delta\delta$ of proton 15 than the binding of two acetate anions. Taking into account the 1:1 stoichiometry and the increased efficiency of benzoate extraction it can be proposed that the efficient benzoate complexation occurs *via* four-point cleft-like binding of benzoate anion with all four N–H groups of both ureas of the ligand and aromatic stacking interaction of the benzoate with bis(trifluoromethyl)phenyl moieties. This is in line with the increased value of the $\Delta\delta$.

Extractions of lactates are similar to those of acetate. Complexation also appears to be stepwise with a 1:2 stoichiometry under saturated conditions (Fig. 3). The log–log plots for both lactates and benzoates are shown in Fig. 4. The presence of hydroxy group does not result in a more efficient complexation, but in predominant complexation of (*R*)-lactate with a rather high K^R/K^S ratio being nearly 4 (see Table III), which is in strong contradiction with the two-point binding *via* carboxylate oxygens. The analysis of spectra of both the complexes indicate that the binding of (*R*)-lactate results in higher up-field shifts of binaphthalene protons, while the $\Delta\delta$ of proton 15 is lower than that of (*S*)-lactate. It is therefore possible to propose, that (*R*)-lactate is predominantly bound *via* its carboxylate oxygen to 13-NH groups and lactate hydroxyl with 11-NH groups while (*S*)-lactate is likely to be bound inversely. It is important to stress that both binding sites of (*R*)-**5** behave in the same way.

Both the stability constants K_{ex} and CIS values of the racemic lactate have been found to lie between those for *R* and *S* isomers (Table III).

It is also apparent that both lactates and mandelates are complexed with a very similar stoichiometry, different from those of bromide and benzoate (1:1) and very close to that of acetate (stepwise 1:1 and 1:2). A comparison of extraction data for lactate and mandelate should also reveal the effect of aromatic host–guest interactions on the complex formation. From practical point of view, due to the presence of aromatic rings, the extraction can be monitored by combination of NMR (in chloroform solution) and UV spectra (aqueous phase). According to the NMR data, the extraction of mandelates results in both the downfield shift of proton 15 and the upfield shift of protons 3, 4, and 6. The analysis of Δδ data by log–log plot (Fig. 5) indicates that mandelates form complexes with much higher stability compared with lactate. But the Δδ values of proton 15 are lower for all mandelate measurements than those for acetate and lactate (Table III). Even more interestingly, the Δδ value is the highest for *S* isomer, decreasing in the following order *S* > *RS* > *R*, while the complexation constants decrease in the order *RS* > *S* > *R* (Table III). It is rather unexpected that going from lactate to mandelate, following profound changes have been found: (i) inversion of enantioselectivity; (ii) decrease in enantioselectivity (K_{ex}^{R}/K_{ex}^{S} is nearly 4 for lactate, while K_{ex}^{S}/K_{ex}^{R} is 1.3 for mandelate); (iii) stability of complexes

TABLE III
Extraction data for (*R*)-**5** anion from water to chloroform monitored by ^{1}H NMR spectra

Anion	Ligand:anion stoichiometry	log K_{ex}	CIS, ppm
Benzoate	1:1	3.60 ± 0.1[a]	0.402
Bromide	1:1	2.40 ± 0.05[a]	0.316
Acetate	1:2	4.10 ± 0.08[b]	0.334
(*R*)-Lactate	1:2	4.60 ± 0.07[b]	0.305
(*S*)-Lactate	1:2	3.96 ± 0.06[b]	0.346
(*RS*)-Lactate	1:2	4.36 ± 0.05[b]	0.315
(*S*)-Mandelate	1:2	6.5 ± 0.1[b]	0.273
(*R*)-Mandelate	1:2	6.4 ± 0.1[b]	0.236
(*RS*)-Mandelate	1:2	6.7 ± 0.1[b]	0.250

[a] Complexation constant K_{ex} (in l mol^{-1}) for 1:1 complexation process. [b] The overall complexation constant (in l^2 mol^{-2}) for 1:2 stoichiometry.

formed (1:2 stoichiometry) are increasing in the order *R* < *S* < *RS* for mandelates, while the order for lactate is *R* > *RS* > *S*.

In order to better understand what is going on with mandelates, we have followed their extraction with (*R*)-**5** under the conditions of 1:1 binding (*i.e.* molar excess of ligand (*R*)-**5** to mandelates) as a function of the ligand: anion ratio. The extraction of mandelates was studied by UV-VIS in the concentration region 0.0022–0.012 mol l^{-1}, while the concentration of (*R*)-**5** in organic phase (C_h) was kept unchanged at 0.009 mol l^{-1}. The dependences of extraction extent (evaluated as E = [Mand]/C_{Mand}, where [Mand] is equilibrium concentration of mandelate in aqueous phase, C_{Mand} is initial concentration) on the C_{Mand} were measured. The data obtained are summarized in Table IV.

TABLE IV
Extraction[a] of mandelates as a function of the (*R*)-**5**:mandelate ratio followed by UV/VIS spectrometry

Anion	C_{Mand}[b], mol l^{-1}	[Mand][c], mol l^{-1}	K_{ex}[d], l mol^{-1}
(*S*)-Mandelate	0.002064	0.00139	170
	0.003096	0.002094	183
	0.004128	0.002823	200
	0.00516	0.003602	209
	0.00619	0.00443	217
	0.00722	0.005313	210
(*R*)-Mandelate	0.00337	0.00245	143
	0.00510	0.0035	183
	0.00683	0.00513	173
	0.00816	0.00620	178
	0.00874	0.00690	168
(*RS*)-Mandelate	0.0027	0.0023	154
	0.00338	0.0019	186
	0.0047	0.00315	204
	0.00541	0.0033	436
	0.00679	0.00425	549

[a] Concentration of (*R*)-**5** (C_h) was 0.009 mol l^{-1} in all measurements, concentration of mandelate was varied within the concentration range 0.0022–0.012 mol l^{-1}. [b] C_{Mand}, initial concentration of mandelate in aqueous phase. [c] [Mand], equilibrium concentration of mandelate in aqueous phase. [d] K_{ex}, complexation constants computed for 1:1 stoichiometry; experimental errors are within ±10%, but data given above are reproducible better than ±5%.

We assume that the prevailing stoichiometry of complexes formed is 1:1 provided the concentration of the guest anion is below 0.01 mol l^{-1} (ligand: anion = 1:1 or less). It is evident (confer Table IV) that further increasing of the mandelate concentration (C_{Mand}) leads to an increase in extraction constants. This clearly indicates that the second step (1:2 binding) affects substantially the overall K_{ex} value. Nevertheless, a comparison of the extraction constants, computed from the highest ligand:anion ratios, indicates that the *RS*-enantioselectivity (the ratio of K_{ex}^S/K_{ex}^R) of the 1:1 extraction is very similar to those obtained from NMR data for the 1:2 extraction. The 1:1 extraction constant of (*RS*)-mandelate lies between the values for (*S*)- and (*R*)-mandelate, while the 1:2 extraction of (*RS*)-mandelate is noticeably more efficient than those of (*S*)- and (*R*)-mandelate (confer Table IV). Thus, (*R*)-**5** extracts (*RS*)-mandelate in two steps: the first step proceeds with the extraction constant being between those for *R* and *S* isomers, which in turn indicates that the extraction efficiency is determined by the competition of *R* and *S* isomers for complexation with (*R*)-**5**, the second step seems to be the most efficient for simultaneous binding of (*RS*)-mandelate. Interestingly, the comparison of 1:1 and 1:2 binding constants shows enhanced allosteric effect indicating that the complexation of the first mandelate suitably preorganises the molecule for the interations with the second anion.

The main problem is the difference between the binding modes of lactate and mandelate. Based on all the data obtained, namely the aromatic stacking interaction found for benzoates, and the Δδ value of proton 15 (lower for mandelates than those for lactates), we propose that 13-NH groups are in contact with hydroxy groups of mandelate, while 11-NH groups with carboxylate oxygens. According to this proposal the more efficient binding of *S* isomer should be explained by more efficient aromatic interactions, which in turn leads to the Δδ value for the complex with *S* isomer higher than that for the complex with *R* isomer. The main driving force for this kind of binding are the aromatic stacking interactions between electron-rich phenyls of mandelate and electron-deficient 3,5-bis(trifluoromethyl)-phenyls of the ligand.

We have also examined the transport of chiral anions (mandelate) across the liquid (chloroform) membrane by means of (*R*)-**5**. We have found that the ligand studied is not suitable for this application as its presence in the chloroform membrane slowed down the transport profoundly if compared with a blind experiment. This is probably due to high stability of (*R*)-**5**–mandelate complex.

In conclusion, we have prepared several chiral ligands based on commercially available 1,1′-binaphthalene-2,2′-diamine. Its urea derivatives have

been found to form complexes with anions. One of them, (*R*)-**5**, has been thoroughly studied and found to complex lactate with modest enantioselectivity. Inverse selectivity has been found for mandelate. An explanation based on NMR, UV, and extraction behavior of the complexes formed in solution has been suggested.

EXPERIMENTAL

Temperature data are not corrected, melting points were measured on a Kofler block, optical rotations were measured on a digital polarimeter Jasco DIP370. Specific rotations $[\alpha]_D^{20}$ are given in 10^{-1} deg cm^2 g^{-1} and concentrations are given in g/100 ml. UV spectra were measured on a Hewlett Packard 8452A diode array UV spectrometer. ^{1}H NMR and ^{13}C NMR spectra were measured on a Varian Gemini 300 HC with 300.075 MHz and on a Bruker 500 with 500.132 MHz for ^{1}H. Chemical shifts δ are given in ppm referenced to tetramethyl silane as internal standard. Coupling constants *J* are given in Hz. The solvent used is given with spectral data. Thin layer chromatography (TLC) was performed on commercial plates with Silica gel 60 F_{254} (Merck). Silica gel 60 (Merck) was used for (flash) column chromatography. HPLC analyses were performed using a HPLC pump LCP4010 (Pikron) equipped with a UV detector LCD 2082 (Ecom). The columns with chiral stationary phases were commercial Chiralpak OP+ (Daicel) and Chiralcel-ODH. Separation conditions are given for each case. Reactions are typically performed at ambient temperature. Evaporations *in vacuo* were performed under a pressure of 0.67 kPa at 50 °C. Chemicals were used as obtained from Aldrich, Fluka, Merck and Lancaster in analytical grade quality. Dichloromethane was distilled from calcium hydride; triethylamine was distilled from KOH pellets and stored over molecular sieves 4 Å.

X-Ray Measurement

X-Ray data for **4**: $C_{34}H_{14}F_{10}N_2O_2$, M = 672.481, orthorhombic system, space group $P2_122_1$, a = 12.024(1), b = 12.3331(7), c = 14.154(3) Å, V = 2098.9(5) Å^3, Z = 2, D_c = 1.0640 g cm^{-3}, μ(CuKα) = 8.576 cm^{-1}, a colorless crystal of dimensions of 0.1 × 0.3 × 0.3 mm. Data were measured at 293 K on an Enraf–Nonius CAD4 diffractometer with graphite-monochromatized CuKα radiation. The structure was solved by direct method[15] and refined (oxygen, fluorine and nitrogen atoms anisotropically and carbon atoms isotropically) by full-matrix least-squares on F values[16] to final R = 0.0709, R_w = 0.0738 and S = 1.0962 with 216 parameters using 2557 independent reflections (θ_{range} = 3.58–59.94°). Hydrogen atoms linked to carbon atoms were located from the expected geometry and were not refined. CCDC 201671 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; fax: +44 1223 336033; or deposit@ccdc.cam.ac.uk).

Stability Constants Measurements

^{1}H NMR spectroscopy: Typically, a stock solution of ligand in $CDCl_3$ and a stock solution of anion (as tetrabutylammonium salt in the same solvent) were mixed in an NMR tube (diluted with pure solvent) to obtain the final concentration of ligand 0.0005 mol l^{-1}. The

anion amounts used were: 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1.0; 1.1; 1.2; 1.3; 1.4; 1.5; 1.6; 1.7; 1.8; 1.9; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0 a 10.0 molar equivalents. $\Delta\delta$ data for all protons shifted were obtained and used as input for programme OPIUM [17] giving stability constants and CIS values for given stoichiometry of the complexes formed.

Extraction Method

Single extraction – HPLC assessment. A solution of ligand in chloroform (c = 0.01 mol l^{-1}, 1 ml) was stirred magnetically (1100 rpm) with an aqueous solution of tetrabutylammonium (*RS*)-mandelate (c = 0.01 mol l^{-1}, 1 ml) for 1 h. The aqueous phase was separated, the organic phase was evaporated *in vacuo*, redissolved in propan-2-ol (1 ml) and the solution thus obtained was subjected to HPLC analysis. The background effect was assessed in the same experiment but with no ligand.

Extraction – log–log procedure[14]. It is known that K_{ex} can be calculated based on extraction experiment as: $K_{ex} = \alpha(1 - \alpha)^{-1}(C_g - \alpha C_h)^{-1}$ for the 1:1 complex (ligand:anion) stoichiometry and in more general terms as: $K_{ex} = \alpha(1 - \alpha)^{-1}(C_g - \alpha C_h)^{-n}$ for the 1:n complex stoichiometry. All these simplified equations are based on assumption that the complex [(*R*)-**5**–anion] exists only in organic (chloroform) phase.

In logarithmic form we obtain:

$$\log K_{ex} = \log \alpha(1 - \alpha)^{-1} - n \log (C_g - \alpha C_h) ,$$

where α is an extent of complexation in the organic phase, defined as: $\alpha = (\Delta\delta)\ CIS^{-1}$; $q = \alpha(1 - \alpha)^{-1}$; finally $(C_g - \alpha C_h)$ is equilibrium concentration of uncomplexed anion in the aqueous phase.

By plotting experimentally accessible log q against log $(C_g - \alpha C_h)$ a straight line should be obtained. Its slope and intercept are n (stoichiometry of the complex) and log K_{ex}, respectively.

The extraction procedure – UV spectroscopy assessment (for mandelate only). Equilibrium concentration of Bu_4N mandelate was measured as follows. A ligand solution (0.009 mol l^{-1}, 2 ml) in chloroform was mixed with 5 ml of aqueous Bu_4N^+mandelate$^-$ of concentration in the range 0.002–0.012 mol l^{-1}. After stirring for 1 h and phase separation, the concentrations of mandelate were determined by UV spectroscopy both in aqueous and chloroform solutions from the measured absorbance and absorption coefficient according to the Lambert–Beer law at 260 nm.

The extraction procedure – ^1H NMR spectroscopy assessment (for mandelate only). The general extraction procedure was as follows: a chloroform ($CDCl_3$) solution of ligand (0.0089 mol l^{-1}, 1 ml) was stirred for 60 min with 1 ml of aqueous (D_2O) solution of tetrabutylammonium salts. Concentration of the salts varied from 0.003 to 0.03 mol l^{-1}. The extent of complexation was estimated from NMR spectroscopy data using $\alpha = \Delta\delta/CIS$.

Transport Eexperiments

These experiments were carried out in the transport cell with the design based on that in literature[18]. The liquid membrane was a chloroform solution of ligand (0.009 mol l^{-1}), the source phase was aqueous solution of Bu_4N mandelate (0.0045 mol l^{-1}), and the receiving phase was redistilled water. The volume of chloroform phase was 10 ml, the volume of both aqueous source and receiving phases was 2 ml. The equilibrium concentration of Bu_4N

mandelate was estimated spectrophotometrically from measured absorbances and absorption coefficient according to the Lambert–Berr law at 260 nm.

The aqueous receiving and source phases were also analysed by HPLC. In this case, a 1.8 ml aliquot of the aqueous phase was evaporated, then dissolved in 0.5 ml of propan-2-ol and directly analysed by HPLC (the HPLC conditions were similar to those used for Bu_4N mandelate).

1,1′-Binaphthalene-2,2′-diamine

2-Naphthol (40.0 g, 0.277 mol) and hydrazine monohydrate (7.2 ml, 0.14 mol) have been heated to 170–180 °C for 48 h. The solid obtained was melted on steam bath, transferred to a mixture of 300 ml of concentrated HCl and 300 ml of water, boiled for several minutes and the supernatant was decanted. This procedure was repeated three times with 300 ml of dilute HCl (1:1). Combined acid solutions were cooled to ambient temperature and carefully made alkaline (ice-water bath) by addition of NaOH pellets. The suspension thus obtained was heated to reflux for several minutes and the solid was separated by filtration. Water (500 ml) was added, boiled for several minutes and again filtered while hot. This procedure was repeated until no 2-aminonaphthalene was present in hot solution. The crude product was dissolved in 2 M HCl (400 ml), the hot solution was treated with charcoal, filtered and the product precipitated by addition of 10% aqueous NaOH to alkaline reaction. The solid was collected by filtration, washed with water and dried in air at 60 °C. Pure 1,1′-binaphthalene-2,2′-diamine (10.5 g, 27%) was obtained as white powder, m.p. 192–193 °C. ^{1}H NMR ($CDCl_3$): 3.69 (s, 4 H, NH_2); 7.08–7.27 (m, 6 H, ArH); 7.78–7.82 (m, 4 H, ArH).

(*R*)-2,2′-Dibenzamido-1,1′-binaphthalene ((*R*)-**1**)

Benzoyl chloride (107 mg, 0.088 ml, 0.756 mmol) in dry dichloromethane (12 ml) was added dropwise to solution of (*R*)-1,1′-binaphthalene-2,2′-diamine (100 mg, 0.35 mmol) and dry triethylamine (0.75 ml) in dichloromethane (4 ml) at ambient temperature overnight. The reaction was quenched with 20 ml of diluted HCl (10%), and the mixture was extracted washed with saturated aqueous $NaHCO_3$ (20 ml) and water (20 ml). Organic layer was dried with anhydrous $MgSO_4$, evaporated *in vacuo* leaving the crude product (281 mg). Column chromatography (silica gel, chloroform:methanol 98:2) furnished pure amide as yellowish powder. Yield 170 mg (98%), m.p. 195–196 °C, $[\alpha]_D^{20}$ +62.04 (*c* 0.751, chloroform). For $C_{34}H_{24}N_2O_2$ (492.6) calculated: 82.91% C, 4.91% H, 5.69% N; found: 82.87% C, 4.96% H, 5.67% N. ^{1}H NMR ($CDCl_3$): 6.85 (s, 2 H, NH); 6.86–8.77 (m, 22 H, ArH).

(*R*)-2,2′-Bis{[3,5-bis(trifluoromethyl)benzoyl]amino}-1,1′-binaphthalene ((*R*)-**2**)

The compound was prepared from (*R*)-1,1′-binaphthalene-2,2′-diamine (100 mg, 0.35 mmol) and 3,5-bis(trifluoromethyl)benzoyl chloride (213 mg, 0.77 mmol) using the same procedure as described for (*R*)-**1**. Yield 210 mg (78%), m.p. 203–204 °C, $[\alpha]_D^{20}$ +69.86 (*c* 0.814, chloroform). For $C_{38}H_{20}F_{12}N_2O_2$ (764.6) calculated: 59.70% C, 2.64% H, 29.82% F, 3.66% N; found: 59.67% C, 2.67% H, 29.78% F, 3.67% N. ^{1}H NMR ($CDCl_3$): 7.09 (s, 2 H, NH); 7.23–7.40 (m, 4 H, ArH); 7.33 (s, 2 H, ArH); 7.60 (t, 2 H, ArH, *J* = 8.2); 7.78 (s, 4 H, ArH); 8.00 (d, 2 H, ArH, *J* = 8.8); 8.08 (d, 2 H, ArH, *J* = 8.2); 8.28 (d, 2 H, ArH, *J* = 8.8).

(*R*)-2,2′-Bis[(pentafluorobenzoy)lamino]-1,1′-binaphthalene ((*R*)-**3**)

To (*R*)-1,1′-binaphthalene-2,2′-diamine (100 mg, 0.35 mmol) and dry triethylamine (0.75 ml) in dry dichloromethane (7.5 ml), a solution of pentafluorobenzoyl chloride (355 mg, 0.213 ml, 0.77 mmol) in dry dichloromethane (12 ml) was added dropwise at –78 °C. The reaction mixture was set aside for 12 h and isolated as above yielding the crude amide (203 mg) and, after chromatography (silica gel, chloroform), 97 mg (41%) of pure product, m.p. 162–163 °C, $[\alpha]_D^{20}$ +46.43 (*c* 1.00, chloroform). For $C_{34}H_{14}F_{10}N_2O_2$ (672.5) calculated: 60.73% C, 2.10% H, 28.25% F, 4.17% N; found: 60.71% C, 2.12% H, 28.15% F, 4.14% N. ^{1}H NMR ($CDCl_3$): 6.51 (d, 2 H, ArH, *J* = 8.8); 6.94 (t, 2 H, ArH, *J* = 7.1); 7.29 (s, 2 H, NH); 7.51 (t, 2 H, ArH, *J* = 8.2); 7.62 (d, 2 H, ArH, *J* = 8.8); 8.00 (d, 2 H, ArH, 8.2); 8.14 (d, 2 H, ArH, *J* = 8.8).

(*R*)-2,2′-Bis[bis(pentafluorobenzoyl)amino]-1,1′-binaphthalene ((*R*)-**4**)

The same procedure as for (*R*)-**3** performed at –20 °C has furnished 85 mg (42%), m.p. 144–145 °C, $[\alpha]_D^{20}$ 62.21 (*c* 0.655, chloroform). For $C_{48}H_{12}F_{20}N_2O_4$ (1060.6) calculated: 54.36% C, 1.14% H, 35.83% F, 2.64% N; found: 54.34% C, 1.16% H, 35.79% F, 2.63% N. ^{1}H NMR ($CDCl_3$): 6.52 (d, 2 H, ArH, *J* = 8.2); 6.94 (t, 2 H, ArH, *J* = 8.2); 7.52 (t, 2 H, ArH, *J* = 7.1); 7.63 (d, 2 H, ArH, *J* = 8.8); 8.01 (d, 2 H, ArH, *J* = 8.2); 8.15 (d, 2 H, ArH, *J* = 9.3).

2,2′-Bis(*N*-arylureido)-1,1′-binaphthalenes. General Procedure[19]

1,1′-Binaphthalene-2,2′-diamine (150 mg, 0.53 mmol) in dry dichloromethane (45 ml) was treated with aryl isocyanate (3.7 equivalents per NH_2 group) at ambient temperature for 12 h. The reaction was quenched with 10 ml methanol and stirred for another 12 h. The reaction mixture was evaporated *in vacuo* and purified by column chromatography on silica gel eluted with chloroform. The product is generally eluted as second UV-active compound.

2,2′-Bis{N-[3,5-bis(trifluoromethyl)phenyl]ureido}-1,1′-binaphthalene (**5**). Yield 370 mg (88%), m.p. > 360 °C. For $C_{38}H_{22}F_{12}N_4O_2$ (794.6) calculated: 57.44% C, 2.79% H, 28.69% F, 7.05% N; found: 57.41% C, 2.84% H, 28.67% F, 7.02% N. ^{1}H NMR (DMSO-d_6): 6.83 (d, 2 H, ArH, *J* = 8.2); 7.28 (t, 2 H, ArH, *J* = 7.7); 7.42 (s, 2 H, ArH); 7.45 (t, 2 H, ArH, *J* = 7.1); 7.48 (s, 2 H, NH); 7.81 (s, 4 H, ArH); 8.05 (d, 2 H, ArH, *J* = 7.7); 8.14 (d, 2 H, ArH, *J* = 7.7); 8.35 (d, 2 H, ArH, *J* = 8.8); 9.61 (s, 2 H, NH).

(R)-2,2′-Bis{N-[3,5-bis(trifluoromethyl)phenyl]ureido}-1,1′-binaphthalene ((*R*)-**5**). Yield 395 mg (98%), m.p. 128–130 °C, $[\alpha]_D^{20}$ 136.4 (*c* 1.00, methanol). For $C_{38}H_{22}F_{12}N_4O_2$ (794.6) calculated: 57.44% C, 2.79% H, 28.69% F, 7.05% N; found: 57.40% C, 2.82% H, 28.67% F, 7.03% N. ^{1}H NMR ($CDCl_3$): 6.72 (s, 2 H, NH); 7.02 (d, 2 H, ArH, *J* = 8.2); 7.28 (t, 2 H, ArH, *J* = 7.1); 7.42 (s, 2 H, ArH); 7.47 (t, 2 H, ArH, *J* = 6.6); 7.69 (s, 4 H, ArH); 7.95 (d, 2 H, ArH, *J* = 8.2); 8.07 (d, 2 H, ArH, *J* = 8.8); 8.27 (d, 2 H, ArH, *J* = 9.3); the other NH overlapped with chloroform.

2,2′-Bis(N-p-tolylureido)-1,1′-binaphthalene (**6**). Yield 170 mg (88%), m.p. 282–284 °C. For $C_{36}H_{30}N_4O$ (550.7) calculated: 78.52% C, 5.49% H, 10.17% N; found: 78.49% C, 5.52% H, 10.14% N. ^{1}H NMR (DMSO-d_6): 2.19 (s, 6 H, CH_3); 6.77 (d, 2 H, ArH, *J* = 8.2); 6.97–7.40 (m, 14 H, 12 ArH and 2 NH); 7.98 (d, 2 H, ArH, *J* = 8.2); 8.09 (d, 2 H, ArH, 8.8); 8.62 (d, 2 H, ArH, *J* = 8.8); 8.96 (s, 2 H, NH).

2,2′-Bis[N-(4-nitrophenyl)ureido]-1,1′-binaphthalene (**7**). Yield 125 mg (58%), m.p. > 360 °C. For $C_{34}H_{24}N_6O_6$ (612.6) calculated: 66.66% C, 3.95% H, 13.72% N; found: 66.62% C, 3.98% H,

13.70% N. ^{1}H NMR (DMSO-d_6): 6.81 (d, 2 H, ArH, J = 8.2); 7.26 (t, 2 H, ArH, J = 7.7); 7.43 (d, 4 H, ArH, J = 8.8); 7.66–8.22 (m, 12 H, 10 ArH and 2 NH); 8.38 (d, 2 H, ArH, J = 9.3); 9.58 (s, 2 H, NH).

2,2′-Bis(*N*-dodecylureido)-1,1′-binaphthalene (**8**)

2,2′-Diisocyanato-1,1′-binaphthalene[20]. 1,1′-Binaphthalene-2,2′-diamine (78 mg, 0.274 mmol) was dissolved in diphenyl ether (10 ml) at 50 °C, the resulting solution was treated with bis(trichloromethyl) carbonate (54.3 mg, 0.183 mmol) and the reaction mixture was stirred at 150 °C for 6 h. The cold solution was used without further purification in the subsequent reaction.

A solution of dodecylamine (80 mg, 0.43 mmol) in dichloromethane (5 ml) was added and the resulting mixture was stirred for 12 h. The reaction mixture was purified by column chromatography. Diphenyl ether was recovered by elution with chloroform:petroleum ether (1:1) followed by the product (chloroform). Yield 147 mg (76%), m.p. 174–176 °C. For $C_{46}H_{66}N_4O_2$ (707.1) calculated: 78.14% C, 9.41% H, 7.92% N; found: 78.11% C, 9.43% H, 7.89% N. ^{1}H NMR ($CDCl_3$): 0.88 (t, 6 H, CH_3, J = 6); 1.25 (m, 40 H, CH_2); 2.95 (t, 4 H, CH_2, J = 6); 6.35 (s, 2 H, NH); 7.00 (d, 2 H, ArH, J = 8.3); 7.23 (t, 2 H, ArH, J = 7.1); 7.29 (s, 2 H, NH); 7.40 (t, 2 H, ArH, J = 8.3); 7.89 (d, 2 H, ArH, J = 8.2); 7.98 (d, 2 H, ArH, J = 9.3); 8.27 (d, 2 H, ArH, J = 8.8).

SYMBOLS

C_g	concentration of guest, here concentration of anion in aqueous phase, mol l^{-1}
C_h	concentration of host, here concentration of ligand (*R*)-**5** in organic phase, mol l^{-1}
$C_g - \alpha C_h$	equilibrium concentration of uncomplexed anion in the aqueous phase
C_{Mand}	initial concentration of mandelate in extraction experiment, where dependence of extraction extent E = [Mand]/C_{Mand} on C_{Mand} was evaluated, mol l^{-1}
[Mand]	equilibrium concentration of mandelate in extraction experiment, where dependence of extraction extent E = [Mand]/C_{Mand} on C_{Mand} was evaluated, mol l^{-1}
CIS	complexation-induced shift for approximation CIS ≈ Δδ when large excess of anion is present ($C_g >> C_h$), ppm
K_{ex}	association constant of complex (1:1 or 1:2) obtained from extraction experiment, l mol^{-1}
K^R	association constant determined for anion of absolute configuration *R*, l mol^{-1}
K^S	association constant determined for anion of absolute configuration *S*, l mol^{-1}
q	defined as $q = \alpha(1 - \alpha)^{-1}$
α	extent of complexation in the organic phase, defined as $\alpha = (\Delta\delta)\ CIS^{-1}$
Δδ	shift of NMR signal caused by addition of anion, ppm

*This work was supported by the Ministry of Education, Youth and Sports (project COST D11/0008/98 and project MSM 2231 00001). We thank Dr J. Havlíček for measurement of 500 MHz NMR spectra of (R)-**5**.*

REFERENCES

1. a) Gale P. A.: *Coord. Chem. Rev.* **2003**, *240*, 191; b) Gale P. A.: *Coord. Chem. Rev.* **2001**, *213*, 79; c) Gale P. A.: *Coord. Chem. Rev.* **2000**, *199*, 181; d) Beer P. D., Hayes E. J.: *Coord. Chem. Rev.* **2003**, *240*, 167; e) Best M. D., Tobey S. L., Anslyn E. V.: *Coord. Chem. Rev.* **2003**, *240*, 3; f) Gale P. A., Beer P. D.: *Angew. Chem., Int. Ed.* **2001**, *40*, 487; g) Bianchi A., Bowman-James K., Garcia-Espana E. (Eds): *Supramolecular Chemistry of Anions*. Wiley-VCH, New York 1997; h) Hartley J. H., James T. D., Ward C. J.: *J. Chem. Soc., Perkin Trans. 1* **2000**, 3155; i) Schmidtchen F. P., Berger M.: *Chem. Rev.* **1997**, *97*, 1609.
2. Smith D. K.: *Org. Biomol. Chem.* **2003**, *1*, 3874.
3. a) Bondy C. R., Loeb S. J.: *Coord. Chem. Rev.* **2003**, *240*, 77; b) Choi K., Hamilton A. D.: *Coord. Chem. Rev.* **2003**, *240*, 101; c) Antonisse M. M. G., Reinhoudt D. N.: *Chem. Commun.* **1998**, *443*; d) Herges R., Dikmans A., Jana U., Koehler F., Jones P. G., Dix I., Fricke T., Koenig B.: *Eur. J. Org. Chem.* **2002**, 3004; e) Shogemori K., Nishizawa S., Yokobori T., Shioya T., Teramae N.: *New J. Chem.* **2002**, *26*, 1102; f) Werner F., Schneider H. J.: *Helv. Chim. Acta* **2000**, *83*, 465.
4. a) Budka J., Lhoták P., Michlová V., Stibor I.: *Tetrahedron Lett.* **2001**, *42*, 1583; b) Šťastný V., Lhoták P., Michlová V., Stibor I., Sykora J.: *Tetrahedron* **2002**, *58*, 7207; c) Dudič M., Lhoták P., Stibor I., Lang K., Prošková P.: *Org. Lett.* **2003**, *5*, 149.
5. Stibor I., Dana S. M. H., Lhoták P., Hodačová J., Koča J., Čajan M.: *Gazz. Chim. Ital.* **1997**, *127*, 673.
6. a) Čajan M., Stibor I., Koča J.: *J. Phys. Chem. A* **1999**, *103*, 3778; b) Čajan M., Damborský J., Stibor I., Koča J.: *J. Chem. Inf. Comput. Sci.* **2000**, *40*, 1151.
7. For books on calixarenes see: a) Asfari Z., Böhmer V., Harrowfield J., Vicens J. (Eds): *Calixarenes 2001*. Kluwer Academic Publishers, Dordrecht 2001; b) Mandolini L., Ungaro R.: *Calixarenes in Action*. Imperial College Press, London 2000; c) Gutsche C. D.: *Calixarenes Revisited*. The Royal Society of Chemistry, Cambridge 1998; d) Vicens J., Asfari Z., Harrowfield J. M. (Eds): *Calixarenes 50th Aniversary: Commemorative Issue*. Kluwer Academic Publishers, Dordrecht 1994; e) Vicens J., Böhmer V. (Eds): *Calixarenes: A Versatile Class of Macrocyclic Compounds*. Kluwer Academic Publishers, Dordrecht 1991.
8. a) Scheerder J., Fochi M., Engbersen J. F. J., Reinhoudt D. N.: *J. Org. Chem.* **1994**, *59*, 7815; b) Scheerder J., Engbersen J. F. J., Casnati A., Ungaro R., Reinhoudt D. N.: *J. Org. Chem.* **1995**, *60*, 6448; c) Pelizzi N., Casnati A., Friggeri A., Ungaro R.: *J. Chem. Soc., Chem. Commun.* **1998**, 1307; d) Nam K. Ch., Kang S. O., Jeong H. S., Jeon S.: *Tetrahedron Lett.* **1999**, *40*, 7343; e) Pelizzi N., Casnati A., Ungaro R.: *Chem. Commun.* **1998**, 2607; f) Casnati A., Massera C., Pelizzi N., Stibor I., Pinkhassik E., Ugozzoli F., Ungaro R.: *Tetrahedron Lett.* **2002**, *43*, 7311; g) Sidorov V., Kotch F. W., Abdrakhmanova G., Mizani R., Fettinger J. C., Davis J. T.: *J. Am. Chem. Soc.* **2002**, *124*, 2267; h) Tongraung P., Chantarasiri N., Tuntulani T.: *Tetrahedron Lett.* **2003**, *44*, 29.
9. a) Lin J., Hu Q. S., Xu M.-H., Pu L.: *J. Am. Chem. Soc.* **2002**, *124*, 2088; b) Albrecht M., Zauner J., Burgert R., Roettele H., Froehlich R.: *Mater. Sci. Eng., C* **2001**, *18*, 185.
10. Myiano S., Nawa M., Mori A., Hashimoto H.: *Bull. Chem. Soc. Jpn.* **1984**, *57*, 2171.
11. Brueggemann R., Schmidt G.: *ORTEP 3.21*, PC adaptation, Ulm 1991.
12. Yabuuchi K., Marfo-Owusu E., Kato T.: *Org. Biomol. Chem.* **2003**, *1*, 3464.
13. a) Sessler J. L., Andrievsky A., Kral V., Lynch V.: *J. Am. Chem. Soc.* **1997**, *119*, 9385; b) Alfonso I., Dietrich B., Robolledo F., Gotor V., Lehn J. M.: *Helv. Chim. Acta* **2001**, *84*,

280; c) Rossi S., Kyne G. M., Turner D. L., Wells N. J., Kilburn J.: *Angew. Chem., Int. Ed.* **2002**, *41*, 4233.
14. Connors K. A.: *Binding Constants*, p. 294. Wiley, New York 1987.
15. Altomare A., Cascarano G., Giacovazzo G., Guagliardi A., Burla M. C., Polidori G., Camalli M.: *SIR92 – A Program for Automatic Solution of Crystal Structures by Direct Methods*. *J. Appl. Crystallogr.* **1994**, *27*, 435.
16. Watkin D. J., Prout C. K., Carruthers J. R., Betteridge P. W., Cooper R. I.: C*rystals*, Issue 11. Chemical Crystallography Laboratory, Oxford 2001.
17. Kývala M., Lukeš I.: Presented at *Chemometrics 1995, Pardubice (Czech Republic), 1995*. Book of Abstracts, p. 63 (http://www.natur.cuni.cz/~kyvala/opium.html).
18. Okada M., Mizutani M., Nishimura J.: *Tetrahedron Lett.* **1998**, *39*, 8467.
19. Gleich A., Schmidtchen F. P., Mikulcik P., Müller G.: *J. Chem. Soc., Chem. Commun.* **1990**, 55.
20. Galán A., Andreu D., Echavarren A. M., Prados P., de Mendoza J.: *J. Am. Chem. Soc.* **1992**, *114*, 1511.