ring cavity by three $OH^+\cdots O$ hydrogen bonds. The pyramidal geometry found for the hydronium ion in these complexes indicates that this conformation is probably the most stable in an ion-solvating environment.[11] The molecular structure of monohydrate complex **1a** offers a possible ligand for proton solvation.

The results of preliminary solvent polymeric membrane transport studies conducted with **1** indicate that crown ether alcohol **1** is selective for protons.[44] Among the alkali metal and alkaline earth cations, there is a slight preference for K^+. The observed selectivity sequence of the liquid anion-exchanger membrane electrodes based on ionophore **1** follows the Hofmeister lyotopic series.[65] Formation of monohydrate complex **1a** provides an explanation of the solvent polymeric membrane selectivity measurements for crown ether alcohol **1**, since the monohydrate complex should strongly bind protons. Furthermore, the encapsulated water molecule would hinder coordination of metal cations. Such spatial hindrance explains the relatively poor binding and poor selectivity among alkali and alkaline earth cations. The poor selectivity toward anions can also be attributed to the formation of monohydrate complex **1a**, which prevents possible specific interaction between the crown ether alcohol and anions.

Synthetic attempts are now underway to prepare coronands with longer pendant hydroxyl-containing arms and crown ether diols. Potential applications for a polymerized network of units of **1** are the drying of organic solvents by water complexation, the selective transport of water in reverse osmosis membrane devices, and the formation of hydrophilic pores in biological bilayers.

Acknowledgment. We thank W. Simon for testing the selectivity of **1** when incorporated in synthetic membranes. G.S. thanks the Bat-Sheva Foundation of Israel for financial support. Research conducted at Texas Tech University was supported by a grant from the Robert A. Welch Foundation.

Registry No. **1**, 78328-81-1; **1a**, 123567-47-5; 1,3-bis(2-hydroxyphenoxy)propane, 42397-72-8; epichlorohydrin, 106-89-8.

Supplementary Material Available: Table SI listing anisotropic temperature factors, Table SII listing hydrogen atom coordinates, and Table SIII listing torsion angles (3 pages); Table SIV listing observed and calculated structure factors (9 pages). Ordering information is given on any current masthead page.

(65) Simon, W., personal correspondence.

X-ray Crystallographic Support of a Chiral Recognition Model

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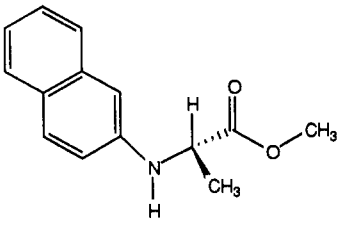
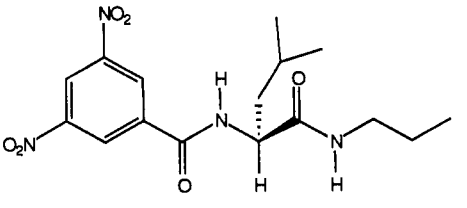
Abstract: Both *N*-(3,5-dinitrobenzoyl)leucine n-propylamide, **1**, and methyl (2-naphthyl)alaninate, **2**, are close models of the chiral selectors incorporated into commercial chiral stationary-phase HPLC columns. Each selector is capable of "recognizing" the stereochemistry of the other. A structure for the homochiral solution complex formed from (*S*)-**1** and (*S*)-**2** has been postulated from experimental data. Structures for both the homochiral and heterochiral complexes have been suggested on the basis of a computational approach. The structure of a crystalline 1:1 complex of (*S*)-**1** and (*S*)-**2** has been determined by X-ray crystallography and found to be in basic agreement with that originally postulated for the analogous complex in solution and with that from the computational study.

The development of chiral stationary phases (CSPs) for the chromatographic separation of enantiomers has altered modern-day approaches to stereochemical analysis and enantiomer separation.[1] In some instances, the development of these phases has been aided by hypotheses concerning the mechanisms of chiral recognition.[2] This is particularly true for those chiral phases derived from *N*-(3,5-dinitrobenzoyl)-α-amino acids and from *N*-aryl-α-amino acids.[3] High-performance liquid chromatography columns with CSPs derived either from *N*-(3,5-dinitrobenzoyl)-leucine or from *N*-(2-naphthyl)alanine show the ability to separate the enantiomers of a wide variety of compounds. Owing to their commercial availability,[4] such columns are finding ready acceptance by the chemical community. Consequently, rationales purporting to account for the ability of these chiral phases to differentiate between the enantiomers of client substances are of interest to the users of such columns.

Chiral recognition models pertaining to the mode of operation of these CSPs have been advanced and are founded upon a body of experimental data.[3] Several such models have attracted the attention of workers who have attempted to define the origin of chiral recognition in these systems by computational methods.[5] Of present relevance is the recent report[5b] by Topiol et al. of a study of the interaction of *N*-(3,5-dinitrobenzoyl)leucine *n*-propyl amide, **1**, with methyl *N*-(2-naphthyl)alaninate, **2**. To quantitate



2



1

the energy difference between two computer-generated structures, one must know the energy of each. The computed structure for

† Correspondence concerning the X-ray structure should be directed to this author.

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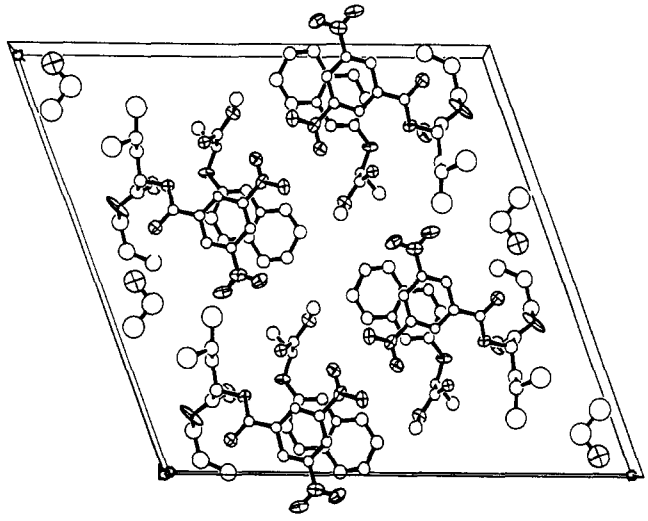

Figure 1. Unit cell of the 1:1 complex of **1** and **2**. Note that the two components are interacting in pairs, and no intercomplex interactions are observed. The hydrogen and disordered carbon atoms have been omitted for clarity.

the more stable of the two 1:1 complexes, the homochiral complex, corresponds closely to that previously advanced on the basis of ultraviolet–visible adsorption spectroscopy studies and ^{1}H nuclear magnetic resonance studies including intermolecular nuclear Overhauser effect studies.[3b] Cautiously, Topiol et al. state "it is conceivable that the model of the (*SS*)-complex studied herein is incorrect and that, say, other intermolecular interactions are responsible for chiral separation".[5] They go on to indicate that they are investigating this possibility. In view of the interest in the structure of this complex, we report the structure of a 1:1 complex of the two components as crystallized from ethanol.[6]

Experimental Section

A solution of 75 mg of the methyl ester of (*S*)-*N*-(2-naphthyl)alanine, **1**, and 50 mg of the *n*-propylamide of (*S*)-*N*-(3,5-dinitrobenzoyl)leucine, **2**, in 20 mL of hot absolute ethanol, was allowed to cool to room temperature. The red solution was placed in a refrigerator and stored for 2 weeks at 4 °C. One of the reddish-orange needles that had formed was selected for X-ray analysis. This needle was removed from the mother liquor, placed under oil, and mounted on a glass fiber. The crystalline complex of (*S*)-**1** and (*S*)-**2** contains one disordered ethanol molecule per molecule of complex. The crystal system was monoclinic with space group *C*2 and unit cell dimensions as follows: a = 22.595 (6) Å, b = 7.061 (4) Å, c = 23.858 (12) Å, β = 110.40 (3)°, V = 3568 (5) Å^3, Z = 4. The data were collected using Mo Kα radiation on an Enraf-Nonius CAD 4 automated κ-axis diffractometer at 223 K. The structure was determined by direct methods using SHELXS-86 with least-squares Fourier difference calculations to reveal the disordered positions. Hydrogen atoms for the unambiguous atoms are in idealized positions. The final refinement of 1455 reflections [$I > 2.58\sigma(I)$] has agreement values, R, of 0.12 and R_w = 0.14. The *n*-propyl side chain and ethanol solvate were disordered in two positions with the major site occupancies of 0.715 (11) and 0.583 (10), respectively. Hydrogen atoms on the disordered groups were not included in structure factor calculations.

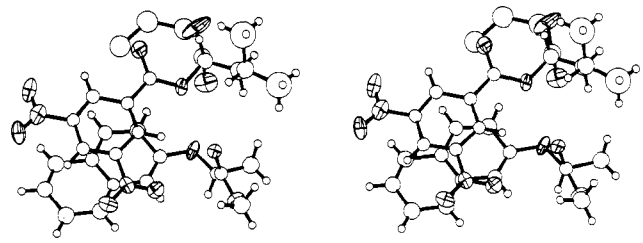

Figure 2. Stereoview of the molecular structure of the 1:1 complex of (*S*)-**1** and (*S*)-**2**. The ethanol of solvation is not shown.

Results

X-ray analysis of one of these crystals affords the unit cell and the structure shown in Figures 1 and 2. The crystal contains a disordered ethanol molecule loosely hydrogen bonded to the dinitrobenzoyl carbonyl oxygen of **2**. The *n*-propyl portion of the C-terminal amide of **2** is also disordered. Each homochiral complex is well separated from its neighbors, suggesting that no "network" of lattice interactions occurs to cause appreciable differences in the solid-state and solution structures of the complex. The two aromatic systems are stacked parallel, the 3.38 Å interplanar distance being indicative of relatively strong π–π bonding.[7] Although the three N–H's are not located, the closeness of the approach and the angle of approach of the dinitrobenzamide nitrogen of **2** to the carbonyl oxygen of **1** and the nitrogen of **1** to the C-terminal carbonyl oxygen of **2** (2.84 and 2.93 Å, respectively) indicate that relatively strong hydrogen bonds are present.

Discussion

The relative positions of the two components provide strong support for the occurrence of the three simultaneous bonding interactions initially advocated as being present on the basis of chromatographic structure–activity relationships[3a] and subsequently affirmed by a study of ^{1}H NMR intermolecular nuclear Overhauser effects.[3b] Note that the conformations of the two components in the solid state are essentially those proposed earlier from studies of molecular models and the belief that low-energy conformations of the uncomplexed species were apt to be little altered in the more stable diastereomeric complex. Later molecular mechanics calculations are in basic agreement as to which conformations of the isolated species are of lowest energy.[8] The similarity between the demonstrated solid-state structure of the (*S*)-**1**–(*S*)-**2** complex and the postulated structure of the solution complex is striking and lends strong support to the notion that most of the affinity between these compounds in solution stems from the formation of such a complex.

Acknowledgment. This work has been supported by a grant from the National Science Foundation.

Registry No. (*S*)-**1**/(*S*)-**2** complex, 123411-83-6.

Supplementary Material Available: Structure showing crystallographic details including atom-numbering scheme and tables listing atomic coordinates, thermal parameters, bond lengths, and bond angles (6 pages). Ordering information is given on any current masthead page.

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