The Preparation of New Chiral Diphenyl-Substituted Macrocyclic Polyether-Diester Compounds and their Enantiomeric Recognition of Chiral Organic Ammonium Salts

Jerald S. Bradshaw*, Patricia K. Thompson and Reed M. Izatt*

Department of Chemistry and Contribution No. 339 from the Institute for Thermochemical Studies,
Brigham Young University, Provo, Utah 84602

Frederick G. Morin and David M. Grant*

Department of Chemistry, University of Utah,
Salt Lake City, Utah 84112
Received January 3, 1984

A series of chiral diphenyl-substituted macrocyclic polyether-diester ligands have been prepared from the chiral diphenyl-substituted tetraethylene glycol. Enantiomeric recogntion by the chiral diphenyl-substituted pyridino-diester-18-crown-6 compound (7) was studied by temperature dependent ¹H NMR spectroscopy in deuteriodichloromethane. This ligand exhibited chiral recognition when complexed with the hydrogen perchlorate salts of (R)- and (S)-α-(1-naphthyl)ethylamine and (R)- and (S)-methyl phenylalaninate.

Introduction

The design and synthesis of host chiral macrocyclic ligands which are able to distinguish between the enantiomers of guest organic ammonium salts is of interest in many areas involving the design of molecules capable of molecular recognition. Such areas include synthetic enzymes, electrodes for specific ions or molecules, drugs targeted for specific sites, and enantiomer separation [1]. The preparation of synthetic chiral macrocyclic crown ethers has been reviewed [2] and a partial literature review of chiral host-guest chemistry pertinent to this study has been given [3].

Enantiomeric recognition by the dimethyl-substituted ligands 2-4 (Figure 1) for chiral organic ammonium salts has been studied by temperature-dependent ¹H nmr spectroscopy in deuteriodichloromethane, titration calorimetry in methanol, and selective crystallization [3]. Ligand (S,S)-2 formed a more stable complex with the hydrogen perchlorate salt of (R)-α-(1-naphthyl)ethylamine, (R)-NapEt, than with the (S)-NapEt salt as shown by all three techniques [3]. Ligands (S,S)-3 and (S,S)-4 also formed more stable complexes with (R)-NapEt than with (S)-NapEt as shown by ¹H nmr spectroscopy. The structures of the (S,S)-2·(R)-NapEt and (S,S)-2·(S)-NapEt complexes have been determined by an X-ray crystallographic procedure [3,4]. The methyl groups of the crown are closer to the naphthyl groups of the guest cation in the complex with the (S)-NapEt salt suggesting the possibility of steric hindrance in this case [4]. Chiral diphenyl-substituted macrocyclic ligand (S,S)-5 [5] exhibited no enantiomeric recognition when complexed with chiral organic ammonium salts [3,6]. The larger phenyl substituents of 5 are in the less rigid polyether portion of the macrocycle while the methyl substituents of 2 are next to the rigid diester-pyridine groups.

In an effort to study chiral macrocyclic compounds with larger groups in the more rigid diester-pyridine portion of the molecule, we have prepared the new diphenyl-substituted compounds 6-12. This paper reports the synthesis of these compounds and a temperature-dependent ¹H nmr spectroscopy study of the complexation of (S,S)-7 with chiral organic ammonium salts.

Results and Discussion.

Compounds 6-12 shown in Figure 1 were prepared from the appropriate dimethyl ester and diphenyl-substituted glycol in benzene using sodium methoxide as the catalyst as shown for the preparation of compound 7 below. The transesterification process has been shown to be very effective for the preparation of diester- and dithiono-crown compounds [7,8]. The reaction can be driven to completion

(S,S)-(+)-13

(S,S)-7
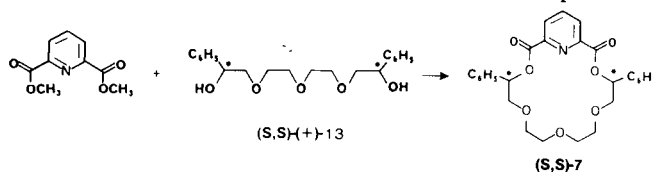
by the removal of the methanol byproduct using molecular sieves. The yields ranged from 4-25% for the macrocylcic diester compounds (see Table I). The starting dimethyl esters were prepared from the commercially available diacid or diacid chlorides [9,10].

These new diphenyl-substitued macrocyclic compounds could not be made from the appropriate diacid chlorides and diphenyl-substituted glycol as has been done previously [10]. Secondary glycols have been found to be less reactive towards the diacid chloride than primary glycols in the preparation of macrocyclic diesters [11]. Diphenyl-substituted glycol 13 (see Scheme I) was particularly unreactive towards the diacid chloride [7]. Thus, we have used the transesterification reaction for these preparations.

Table I

Physical Properties of Chiral and Achiral Macrocyclic Compounds.

Compound	mp (bp), °C	$[\alpha]_D^{25}$	Yield (%)	Ref
6	124-142		25.5	[a]
7	171-173	-81.1	16.8	[a]
18 [b]	81-83		19.0	13
2	94	-13.7	48.5	12
9	169-170.5		15.0	[a]
10	168.5-170.5	-243.1	8.7	[a]
19 [b]	80	-27.3	23.5	12
11	128-129.5		16.1	[a]
12	131-133	+149.3	48.0	[a]
20 [b]	(170-172/1 mm)		32.2	13
21 [b]	(170-172/1 mm)	+46.5	22.0	12
8	123-143		4.1	[a]

[a] This study. [b] Compound 18 is the dimethyl analog of 6; 19 is the dimethyl analog of 10; 20 is the dimethyl analog of 11 and 21 is the dimethyl analog of 12

FIGURE 1
MACROCYCLIC COMPOUNDS
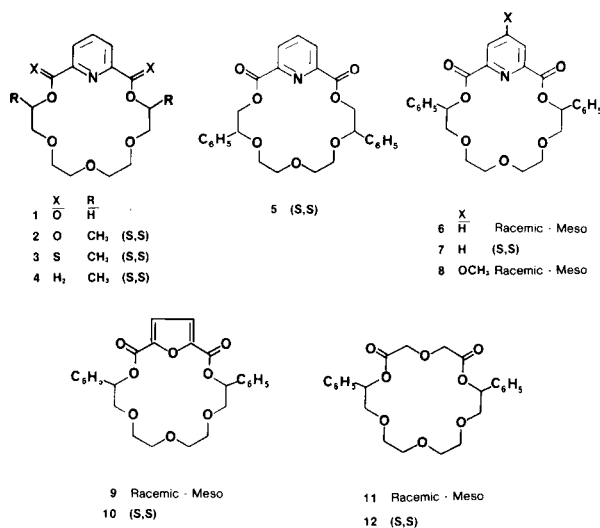
Glycol (S,S)-$(+)$-13 was prepared from (S)-$(+)$-mandelic acid (14) as shown in Scheme I. (S)-$(+)$-Mandelic acid was

SCHEME I
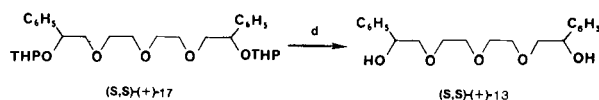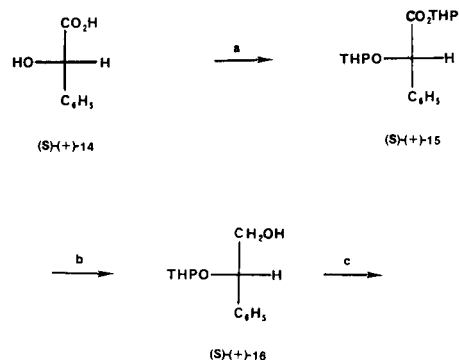
(a) 2,3-Dihydropyran, H$^+$; (b) LiAlH$_4$; (c) NaH, TsOCH$_2$CH$_2$OCH$_2$CH$_2$OTs; (d) CH$_3$OH, H$^+$.

first blocked with dihydropyran and then reduced using lithium aluminum hydride. Mono-blocked glycol 16 was reacted with sodium hydride and diethylene glycol ditosylate to form (S,S)-$(+)$-17. The blocking groups were removed in methanol in the presence of acid to form the chiral glycol (S,S)-$(+)$-13. A racemic-meso mixed glycol 13 was prepared in the same manner from racemic 14. The racemic 13 (S,S and R,R) could not be separated from the meso form (R,S). Thus all macrocycles prepared from racemic-meso mixture 13 are also a mixture of racemic and meso forms. Elemental analyses were not obtained for any intermediates or for the glycols, but good analyses were obtained for all crowns made from these glycols.

Table II

Free Energies of Activation ($\triangle G_c^{\ddagger}$, kcal/mol) in deuteriodichloromethane [a] for the Interaction of Chiral Macrocyclic Ligands with Chiral Alkylammonium Salts

Ligand	Value	Bnz [b]	(S)-NapEt [b]	(R)-NapEt [b]	(S)-PheOMe [b]	(R)-PheOMe [b]
(S,S)-7	T_c,°C	5	-26	10	-45	-21
	$\triangle G_c^{\ddagger}$	12.9	12.3	13	10.8	11.9
(S,S)-2 [c]	T_c,°C	-25	-19	12	-36	-25
	$\triangle G_c^{\ddagger}$	12.4	12.3	13.4	11.8	12.1
(S,S)-3 [c]	T_c,°C	-33	-30	0	-61	-38
	$\triangle G_c^{\ddagger}$	12.1	11.8	13.0	11.0	11.4
(S,S)-4 [c]	T_c,°C	-29	-86	-56	-73 -40	
	$\triangle G_c^{\ddagger}$	11.7	8.7	10.3	10.0	11.3
4 [d]	T_c,°C	10				
	$\triangle G_c^{\ddagger}$	13.0				

[a] A Varian SC-300 spectrometer was used to record all ^{1}H nmr spectra. The benzyl CH on the macrocycle was used as the ^{1}H nmr probe for 7. T_c = coalescence temperature. $\triangle G_c^{\ddagger}$ values are ±0.2. [b] Bnz = the hydrogen perchlorate salt of benzylamine; NapEt = the hydrogen perchlorate salt of (R)- or (S)-α-(1-naphthyl)ethylamine; PheOMe = the hydrogen perchlorate salt of (R)- or (S)-methylphenylalanate. [c] Reference [3]. [d] Reference [9].

The structures proposed for the diphenyl-substituted macrocyclic compounds are consistent with data obtained from ir and ^{1}H nmr spectra, combustion analyses, and molecular weight determinations. Table I compares the physical properties of compounds 6-12 with the dimethyl substituted analogs. Compounds 18-21 listed in Table I are the dimethyl analogs of 6, 10, 11 and 12, respectively [12].

In general, the diphenyl-substituted macrocyclic compounds had higher melting points than the corresponding dimethyl compounds. The racemic-meso mixed diphenyl-substituted compounds have lower melting points than their chiral analogs except for compound 9. The wide melting range for compounds 6 (124-142°) and 8 (123-143°) is due to the presence of both the *syn* (meso) and *anti* (racemic) isomers. Chiral compounds 7 and 10 which contain an aromatic subcyclic unit exhibited a different sign in the rotation of polarized light than that shown by the parent glycol. Optical rotations at five wave lengths for all new optically active compounds are given in table III. It is interesting to note that racemic-meso mixed compounds 8, 9 and 11 exhibited two carbonyl bands in the ir spectra indicative of the *syn* and *anti* forms of those macrocycles. Compound 8 also exhibited singlet peaks at δ 3.88 and 3.90 attributable to the methoxy hydrogen atoms of the *syn* and *anti* forms of the macrocycle.

Complexes of ligand 7 with chiral alkylammonium salts gave ^{1}H nmr spectra with temperature dependent characteristics [3,9]. The free energy of activation ($\triangle G_C^{\ddagger}$) values were determined for the complexes of 7 with the hydrogen perchlorate salts of benzylamine Bnz, (R)- and (S)-NapEt, and (R)- and (S)-methyl phenylalaninate (PheOMe) [3,9,14]. Table II lists the coalescence temperature and $\triangle G_C^{\ddagger}$data for complexes of 7 and its dimethyl analog 2. Data for dithiono compound 3 and polyether 4 are also listed in Table II for comparison purposes.

The $\triangle G_C^{\ddagger}$values in Table II show that compound (S,S)-7 forms more stable complexes with the salts of (R)-NapEt and (R)-PheOMe than it does with the corresponding (S)-salts. The degree of chiral recognition of (S,S)-7 for the enantiomers of NapEt salts is a little less than that observed for the dimethyl ligands 2-4 (see data in Table II). This result was a surprise because we expected the larger phenyl substituents to have a greater steric role in the association between host and guest in these systems. The diphenyl-substituted ligand (S,S)-7 did show greater chiral recognition for the enantiomers of PheOMe than did (S,S)-2 (a difference of 1.1 kcal/mole for the complexes of (S,S)-7 with (R)- and (S)-PheOMe vs 0.3 kcal/mole for 2). Since we have no structural information for these complexes, we can only surmise that the steric role of the larger phenyl substituents is greater in the case of the (S,S)-7-PheOMe complexes than in that of the (S,S)-2-PheOMe complexes. It is interesting that complexes with

Table III

Optical Rotations For All Chiral Compounds [a]

Compound	$[\alpha]_D^{25}$	$[\alpha]_{578}^{25}$	$[\alpha]_{546}^{25}$	$[\alpha]_{436}^{25}$	$[\alpha]_{365}^{25}$
(S)-(+)-15	+65.2	+68.7	+79.1	+149.1	+271.1
(S)-(+)-16	+71.9	+82.8	+94.3	+163.7	+263.7
(S)-(+)-17	+67.8	+70.8	+80.5	+139.3	+224.9
(S,S)-(+)-13	+74.1	+77.2	+87.9	+150.0	+235.4
(S,S)-(-)-7	-77.7	-82.1	-96.3	-200.6	-415.6
(S,S)-(-)-10	-243.1	-257.3	-308.0	-706.1	-1708.8
(S,S)-(+)-12	+149.3	+156.0	+178.2	+313.0	+514.0

[a] c 0.01, chloroform.

(S,S)-4 are less stable kinetically than those with (S,S)-7 (for example, 8.7 kcal/mole for the complex of (S,S)-4 with (S)-NapEt vs 12.3 kcal/mole for the complex of (S,S)-7 with (S)-NapEt) and yet (S,S)-4 exhibited greater chiral recognition for the NapEt salts (Table II). It is possible that in the diester-crowns (*i.e.* 7) the pyridine nitrogen is held in a position that readily accepts a hydrogen bond from the ammonium cation while in the less rigid crown 4, the macrocyclic ring must be reoriented to have the pyridine in the proper position to accept the hydrogen bond. This would account for the fact that complexes with (S,S)-4 are kinetically less stable than those with (S,S)-7. The greater chiral recognition by (S,S)-4 is probably due to factors other than steric.

EXPERIMENTAL

The diester starting materials were prepared from the commercially available diacids or diacid chlorides [9,10]. The starting diphenyl substituted glycols were prepared as outlined below.

(S,S)-(+)-1,11-Diphenyl-3,6,9-trioxaundecane-1,11-diol [(S,S)-(+)-13. Scheme I)].

(S)-(+)-Mandelic acid [(S)-(+)-14, Aldrich, 61.46 g, 0.404 mole)] was blocked by treatment with 180 ml of 2,3-dihydropyran in the presence of p-toluenesulfonic acid to give 116 g (90%) of an impure viscous oil [(S)-(+)-15, $[\alpha]_D^{25}$ +65.2° (c 0.011, chloroform)]; ir (neat): 1750 cm^{-1}, compound (S)-(+)-15 was not further purified.

Compound (S)-(+)-15 (116 g, 0.364 mole) was reduced by treatment with 21.10 g (0.0556 mole) of lithium aluminum hydride in anhydrous diethyl ether. The product was isolated by a countercurrent extraction to give 75.7 g (94%) of monoblocked compound (S)-(+)-16 as an oil, $[\alpha]_D^{25}$ +71.9° (c 0.01, chloroform); ir (neat): 3425 cm^{-1}; ^{1}H nmr: (δ) 1.63 (m, 6H, CH$_2$), 3.10 (s, 1H, OH), 3.50 (m, 2H, OCH$_2$), 3.75 (d, 2H, OCH$_2$), 4.5-5.0 (m, 2H, OCH) and 7.35 (m, 5H).

Compound (S)-(+)-16 (75.7 g, 0.341 mole) and sodium hydride (12.30 g, 0.511 mole) were dissolved in 300 ml of dry dimethylformamide. Diethyl-

ene glycol ditosylate (70.68 g, 0.171 mole) was slowly added to the solution. The resulting mixture was stirred overnight at 80°. The solvent was removed, and 330 ml of distilled water were added. The crude product was obtained by extraction with diethyl ether. The product was purified on a preparatory HPLC column using a 11% acetone/hexane solution as the eluant. The product [(S)-(+)-17] was a yellow oil (49.96 g, 57%), $[\alpha]_D^{25} + 67.8°$ (c 0.0102, chloroform); ^{1}H nmr: (δ) 1.60 (m, 12H, CH_2), 3.60 (m, 16H, OCH_2), 4.5-5.0 (m, 4H, OCH), 7.30 (m, 10H,).

Compound (S)-(+)-17 (49.96 g, 0.097 mole) was deblocked in methanol in the presence of p-toluenesulfonic acid to give compound (S)-(+)-13 (35.77 g) as an impure light brown oil, $[\alpha]_D^{25} + 74.1°$ (c 0.010, chloroform); ir (neat): 3420 cm^{-1}; ^{1}H nmr: (δ) 3.65 (m, 12H, OCH_2), 4.3 (broad, 2H, OH), 4.85 (dd, 2H, OCH), 7.33 (m, 10H).

Racemic-meso mixed diol 13 was prepared in the same manner as reported above using racemic mandelic acid (14). The product was also a light brown oil which gave essentially the same ^{1}H nmr and ir spectra as did (S,S)-(+)-13. Carbon and hydrogen analyses were not performed on the intermediates or on the glycols, but good analyses were obtained on all new crowns made from these glycols.

General Procedure for the Synthesis of Macrocyclic Compounds.

The macrocyclic compounds were prepared from the diphenyl-substituted glycol and the appropriate dimethylester by transesterification as has been reported [7]. In Method A, the molecular sieves were placed in a Soxhlet apparatus and the methanol byproduct was removed using refluxing benzene. In Method B, the molecular sieves were in the stirring reaction mixture. Optical rotations were taken at five wavelengths for all optically active compounds and are listed in Table III.

4,14-Diphenyl-3,6,9,12,15-pentaoxa-21-azabicyclo[15.3.1]heneicosa-1(21),17,19-triene-2,16-dione (6).

Method B was followed using 2.81 g (0.014 mole) of dimethyl 2,6-pyridinedicarboxylate, 5.0 g (0.014 mole) of racemic-meso mixed glycol 13 and 18 g of 4A molecular sieves with sodium methoxide as the catalyst. The product was isolated by a hot hexane extraction and recrystallized from methanol containing one drop of glacial acetic acid to give 1.75 g (26%) of a white solid, mp 124-142°; ir (potassium bromide): 1720 cm^{-1}; ^{1}H nmr: (δ) 3.60-4.10 (m, 12H, OCH_2), 6.20 (m, 2H, OCH), 7.3-7.6 (m, 10H, phenyl), 8.2-8.4 (m, 3H, pyridine).

Anal. Calcd. for $C_{25}H_{27}NO_7$: C, 67.91; H, 5.70; mol wt, 477.5. Found: C, 68.02; H, 5.66; mol wt, 491.

(4S,14S)-(-)-4,14-Diphenyl-3,6,9,12,15-pentaoxa-21-azabicyclo[15.3.1]-heneicosa-1(21),17, 19-triene-2,16-dione (7).

Method A was followed using 2.82 g (0.014 mole) of dimethyl 2,6-pyridinedicarboxylate and 5.02 g (0.014 mole) of glycol (S,S)-(+)-13 with sodium methoxide as the catalyst. The product was isolated by a hot heptane extraction and was recrystallized from methanol containing one drop of glacial acetic acid to give 0.59 g (8.5%) of a white solid, mp 171-173°, $[\alpha]_D^{25}-81.1°$ (c 0.0100, chloroform); ir (potassium bromide): 1720 cm^{-1}; ^{1}H nmr: (δ) 3.60-4.20 (m, 12, OCH_2), 6.20 (m, 2H, OCH), 7.2-7.6 (m, 10H, phenyl), 7.9-8.3 (m, 3H, pyridine).

Anal. Calcd. for $C_{25}H_{27}NO_7$: C, 67.91; H, 5.70; mol wt, 477.5. Found: C, 67.85; H, 5.73; mol wt, 501.

The Method A transesterification process was repeated on the above heptane extraction residue. The product was again isolated by a hot heptane extraction and recrystallized from acidified methanol to give 0.57 g (an additional 8.3% yield) of a white solid with the same mp, ir, and ^{1}H nmr as above.

19-Methoxy-4,14-diphenyl-3,6,9,12,15-pentaoxa-21-azabicyclo[15.3.1]-heneicosa-(21),17,19-triene-2,16-dione (8).

Method B was followed using 3.24 g (0.0144 mole) of dimethyl 4-methoxy-2,6-pyridinedicarboxylate, 5.0 g (0.0144 mole) of racemic-meso mixed glycol 13, and 20 g of 4A molecular sieves with sodium methoxide as the catalyst. The product was isolated by a hot hexane extraction followed by recrystallization from acidified methanol to give 0.3 g (4.1%) of a white solid, mp 123-143°; ir (potassium bromide): 1708 and 1720 cm^{-1}; ^{1}H nmr:

(δ) 3.6-4.2 (m, 12H, OCH_2), 3.88 and 3.90 (two s, 3H, OCH_3), 6.10 (m, 2H, OCH), 7.38 (m, 10H, phenyl), 7.64 and 7.74 (two s, 2H, pyridine).

Anal. Calcd. for $C_{26}H_{29}NO_8$: C, 66.26; H, 5.76; mol wt, 507. Found: C, 66.09; H, 5.58; mol wt, 457.

4,14-Diphenyl-3,6,9,12,15,20-hexaoxabicyclo[15.2.1]eicosa-17,19-diene--2,16-dione (9).

Method B was followed using 2.65 g (0.014 mole) of dimethyl 2,5-furandicarboxylate, 5.0 g (0.014 mole) of racemic-meso mixed glycol 13 and 20 g of 4A molecular sieves with sodium methoxide as the catalyst. The product was isolated by a hot hexane extraction followed by recrystallization from acidified methanol to give 1.02 g (15%) of a white solid, mp 169-170.5°; ir (potassium bromide): 1710 and 1722 cm^{-1}; ^{1}H nmr: (δ) 3.70 (m, 12H, OCH_2), 6.0 (dd, 2H, OCH), 7.2 (s, 2H, furan), 7.4 (m, 10H, phenyl).

Anal. Calcd. for $C_{26}H_{26}O_8$: C, 66.94; H, 5.62; mol wt, 466.46. Found: C, 66.71; H, 5.84; mol wt, 471.

(4S,14S)-(-)-4,14-Diphenyl-3,6,9,12,15,20-hexaoxabicyclo[15.2.1]eicosa-17,19-diene-2,16-dione (10).

Method B was followed using 1.59 g (0.0086 mole) of dimethyl 2,5-furandicarboxylate, 3.0 g (0.0086 mole) of glycol (S,S)-(+)-13 and 20 g of 4A molecular sieves with sodium methoxide as the catalyst. The product was isolated by a hot hexane extraction followed by recrystallization from acidified methanol to give 0.2 g (5.0%) of a white solid, mp 168.5-170.5°, $[\alpha]_D^{25}-243.1°$ (c 0.0102, chloroform); ir (potassium bromide): 1710 cm^{-1}; ^{1}H nmr: (δ) 3.6-4.1 (m, 12H, OCH_2), 5.92 (dd, 2H, OCH), 7.20 (s, 2H, furan), 7.32 (m, 10H, phenyl).

Anal. Calcd. for $C_{26}H_{26}O_8$: C, 66.94; H, 5.62; mol wt, 466.46. Found: C, 66.98; H, 5.59; mol wt, 462.

The Method A transesterification process was followed with the above hexane extraction residue. The product was again isolated by a hot hexane extraction and recrystallized from acidified methanol to give 0.15 g (an additional 3.7% yield) of a white solid with the same mp, ir, and ^{1}H nmr as that given above.

4,14-Diphenyl-1,4,7,10,13,16-hexaoxacyclooctadecane-2,6-dione (11).

Method A was followed using 2.33 g (0.0144 mole) of dimethyl diglycolate and 5.0 g (0.0144 mole) of racemic-meso mixed glycol 13 with sodium methoxide as the catalyst. The product was isolated by a hot hexane extraction followed by recrystallization from acidified methanol to give 1.03 g (16%) of a white crystalline material, mp 128-129.5°; ir (potassium bromide): 1735 and 1752 cm^{-1}; ^{1}H nmr: (δ) 3.68 (s, 8H, OCH_2), 3.76 (d, 4H, J = 1.7 Hz, COOCHCH_2), 4.20 (AB, 2H, J = 6.5 Hz, COCH_2O), 4.56 (AB, 2H, J = 6.5 Hz, COCH_2O), 6.14 (dd, 2H, J = 1.7 Hz, OCH), 7.34 (s, 10H).

Anal. Calcd. for $C_{24}H_{28}O_8$: C, 64.85; H, 6.35; mol wt, 444.46. Found: C, 64.61; H, 6.45; mol wt, 417.

(4S,14S)-(-)-4,14-Diphenyl-1,4,7,10,13,16-hexaoxacyclooctadecane-2,16-dione (12).

Method A was followed using 1.40 g (0.0086 mole) of dimethyl diglycolate and 3.0 g (0.0086 mole) of glycol (S,S)-(+)-13 with sodium methoxide as the catalyst. The product was isolated by recrystallization from acidified methanol to give 3.84 g (48%) of a white crystalline material, mp 131-133°, $[\alpha]_D^{25} + 149.3°$ (c °.0100, chloroform); ir (potassium bromide): 1735 cm^{-1}; ^{1}H nmr: (δ) 3.68 (s, 8H, OCH_2), 3.76 (d, 4H, J = 1.7 Hz, COOCHCH_2), 4.20 (AB, 2H, J = 6.5 Hz, COCH_2O), 4.56 (AB, 2H, J = 6.5 Hz, COCH_2O), 6.14 (dd, 2H, J = 1.7 Hz, OCH), 7.34 (s, 10H).

Anal. Calcd. for $C_{24}H_{28}O_8$: C, 64.85; H, 6.35; mol wt, 444.46. Found: C, 64.80; H, 6.51; mol wt, 425.

Determination of the Free Energy of Activation ($\triangle G_C^{\neq}$) Values.

The free energy of activation ($\triangle G_C^{\neq}$) values for the complexation of compounds (S,S)-7 with various alkylammonium salts were obtained as reported [3]. The $\triangle G_C^{\neq}$ values based on the coalescence of the benzylic hydrogen atoms are listed in Table I.

REFERENCES AND NOTES

[1] R. M. Kellogg, "Topics in Current Chemistry", F. Vögtle, ed, Springer-Verlag, New York, 1982.

[2] S. T. Jolley, J. S. Bradshaw, and R. M. Izatt, *J. Heterocyclic Chem.*, **19**, 3 (1982).

[3] R. B. Davidson, J. S. Bradshaw, B. A. Jones, N. K. Dalley, J. J. Christensen, R. M. Izatt, F. G. Morin, and D. M. Grant, *J. Org. Chem.*, **49**, 353 (1984).

[4] R. B. Davidson, N. K. Dalley, R. M. Izatt, and J. S. Bradshaw, *Israel J. Chem.*, in press.

[5] J. S. Bradshaw, S. T. Jolley, and R. M. Izatt, *J. Org. Chem.*, **47**, 1229 (1982).

[6] J. S. Bradshaw, B. A. Jones, R. B. Davidson, J. J. Christensen, J. D. Lamb, R. M. Izatt, F. G. Morin, and D. M. Grant, *J. Org. Chem.*, **47**, 3362 (1982).

[7] J. S. Bradshaw, B. A. Jones, R. B. Nielsen, N. O. Spencer, and P. K. Thompson, *J. Heterocyclic Chem.*, **20**, 957 (1983).

[8] B. A. Jones, J. S. Bradshaw, P. R. Brown, J. J. Christensen, and R. M. Izatt, *J. Org. Chem.*, **48**, 2635 (1983).

[9] J. S. Bradshaw, G. E. Maas, J. D. Lamb, R. M. Izatt, and J. J. Christensen, *J. Am. Chem. Soc.*, **102**, 467 (1980).

[10] J. S. Bradshaw, R. E. Asay, G. E. Maas, R. M. Izatt, and J. J. Christensen, *J. Heterocyclic Chem.*, **15**, 825 (1978).

[11] S. T. Jolley, and J. S. Bradshaw, *J. Org. Chem.*, **45**, 3554 (1980).

[12] B. A. Jones, J. S. Bradshaw, and R. M. Izatt, *J. Heterocyclic Chem.*, **19**, 551 (1982).

[13] J. S. Bradshaw, and S. T. Jolley, *J. Heterocyclic Chem.*, **16**, 1157 (1979).

[14] I. O. Sutherland, *Annu. Rep. NMR Spectrosc.*, **4**, 71 (1971).