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# Alkali Metals Dissolved in Optically Active Solvents

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Alkali metals dissolve in amines and ethers to give visible and infrared absorption bands. The visible band is believed to be due to absorption by the alkali metal anion and the infrared band to absorption of light by the solvated electrons. The visible and circular dichroism spectra of sodium-potassium alloy dissolved in several optically active ethers and amines were examined. In all cases, no circular dichroism could be detected corresponding to the alkali anion transition. An excellent synthetic route for the formation of a variety of chiral polyethers and cyclic polyethers is described. The method uses the readily available, chiral ethyl (*S*)-(+)-lactate.

Since the initial discovery by Weyl[1] that alkali metals dissolve in liquid ammonia to give deep blue solutions, several other solvents have also been shown capable of dissolving alkali metals,[2,3] including amines and ethers. Generally there are only two absorption bands in these solutions, one or both of which are invariably detected.[4] The bands occur in the visible and infrared spectrum, with the solutions appearing blue regardless of which absorption is present. Substantial effort has been made since the discovery of these solutions to elucidate the structures of the species present in them and explain their behavior.[5] The infrared absorption is believed to be due to the solvated electron, and the visible absorption is thought to be due to the alkali metal anion.[6]

According to Moscowitz, optically active chromophores can be classified into two distinctly different types: the inherently dissymmetric chromophore or the inherently symmetric but asymmetrically perturbed chromophore.[7] The purpose of this study was to ascertain whether or not the species present (solvated electron or anion) in dissolved metal solutions would behave as optically active chromophores, of the latter category, when solvated by chiral molecules.

A suitable probe for this type of optically active chromophore is circular dichroism (CD) or optical rotary dispersion (ORD). From an experimental point of view, CD allows better resolution and shows a higher sensitivity for the detection of small Cotton effects embedded in stronger ones, and so it is increasingly used in place of ORD.[8] We are confined to the examination of only the visible absorption band of dissolved metal solutions, since currently available commercial circular dichroism spectrophotometers are incapable of reaching the infrared region.

The general phenomenon of asymmetry induced in an achiral or racemic molecule by an external medium, which does not absorb light in the same region, is known.[9] However, this effect has not been examined for dissolved alkali metal solutions to our knowledge.

## Results and Discussion

**Synthetic Aspects.** The solvents for this study were designed to satisfy three basic requirements: (1) they must be stable to reduction by solvated electrons; (2) they must be chiral, preferably of high optical purity; (3) they must be capable of dissolving alkali metals to give the visible absorption band. Those factors which could influence the latter condition have been determined to be:[3] (1) the more oxygen or nitrogen atoms in the molecule the more likely the solvent will dissolve the metal; (2) placing bulky groups near the oxygen or nitrogen atom should be avoided; (3) it would appear to be beneficial if the molecule has the ability to chelate positive charge; (4) it would seem that a solvent is more successful if it is of reasonably low molecular weight.

It has been shown that cyclic polyethers, or crowns, complex alkali metal cations.[10] It was also recognized that crowns could also increase the solubility of alkali metals in dissolved metal solutions.[11] With this solubility enhancement it was possible to study many solvents in which alkali metals had shown limited or no solubility if unassisted.

We found that a great variety of polyethers and cyclic polyethers could easily be made from the readily available, optically active ethyl (*S*)-(+)-lactate, as shown in Schemes I and II.

Racemic and (*S*)-(+)-2-pyrrolidinemethanol were prepared by the method of Kostyanovsky[15] from racemic and (*S*)-(−)-proline. Racemic and (*S*)-(+)-2-(methoxymethyl)pyrrolidine, (±)-**20** and (*S*)-(+)-**20**, respectively, were prepared by the method of Seebach.[16] Tetra-

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[1] W. Weyl, *Ann. Phys. (Leipzig)*, 121, (1863).

[2] (a) G. E. Gibson and T. E. Phipps, *J. Am. Chem. Soc.*, **48**, 312 (1926); (b) F. Cafasso and B. P. Sundheim, *J. Chem. Phys.*, **31**, 809 (1959); (c) F. S. Dainton, D. M. Wiles, and A. N. Wright, *J. Chem. Soc.*, 4283 (1960); (d) H. Normant, *Angew. Chem., Int. Ed. Engl.*, **6**, 1046 (1967); (e) H. Normant, T. Cavigny, J. Normant, and B. Angelo, *Bull. Soc. Chim. Fr.*, 1561 (1956); (f) G. Fraenkel, S. H. Ellis and D. T. Dix, *J. Am. Chem. Soc.*, **87**, 1406 (1965); (g) J. Jortner and G. Stein, *Nature (London)*, **175**, 893 (1955).

[3] J. L. Down, J. Lewis, B. Moore, and G. Wilkinson, *J. Chem. Soc.*, 3767 (1959).

[4] (a) H. Blades and J. W. Hudgins, *Can. J. Chem.*, **33**, 411 (1955); (b) G. W. A. Fowles, W. R. McGregor, and M. C. R. Symons, *J. Chem. Soc.*, 3329 (1957).

[5] (a) G. Lepoutre and M. J. Sienko, "Metal-Ammonia Solutions, Colloque Weyl I", W. A. Benjamin, New York, 1964; (b) J. J. Lagowski and M. J. Sienko, "Metal-Ammonia Solutions, Colloque Weyl II", Butterworths, London, 1970; (c) J. Jorter and N. R. Kestner, "Electrons in Fluids, Colloque Weyl III", Springer-Verlag, West Berlin, 1973; (d) *J. Phys. Chem.*, **79**, 26 (1975); (e) *Can. J. Chem.*, **55**, 1796 (1977); (f) references cited in the above collections.

[6] (a) J. L. Dye, *Angew. Chem., Int. Ed. Engl.*, 18, 587 (1979); (b) J. L. Dye, *Pure Appl. Chem.*, **49**, 3 (1977).

[7] A. Moscowitz in C. Djerassi, "Optical Rotatory Dispersion: Application to Organic Chemistry", McGraw-Hill, New York, 1960.

[8] L. Velluz and M. Legrand, *Bull. Soc. Chim. Fr.*, 1785 (1970).

[9] M. Legrand and M. J. Rougier, "Application of the Optical Activity to Stereochemical Determinations", Georg Thieme Verlag, Stuttgart, 1977.

[10] C. J. Pedersen, *J. Am. Chem. Soc.*, **89**, 7017 (1967); **92**, 386 (1970).

[11] J. M. Ceraso and J. L. Dye, *J. Chem. Phys.*, **61**, 1587 (1974).

[12] R. G. Ghirardelli, *J. Am. Chem. Soc.*, **95**, 4987 (1973).

[13] (a) R. N. Green, *Tetrahedron Lett.*, 1793 (1972); (b) F. L. Cook, T. C. Caruso, M. P. Byrne, C. W. Bowers, D. H. Speck, and C. L. Liotta, *ibid.*, 4029 (1974); (c) G. W. Gokel, D. J. Cram, C. L. Liotta, H. P. Harris, and F. L. Cook, *J. Org. Chem.*, **39**, 2445 (1974).

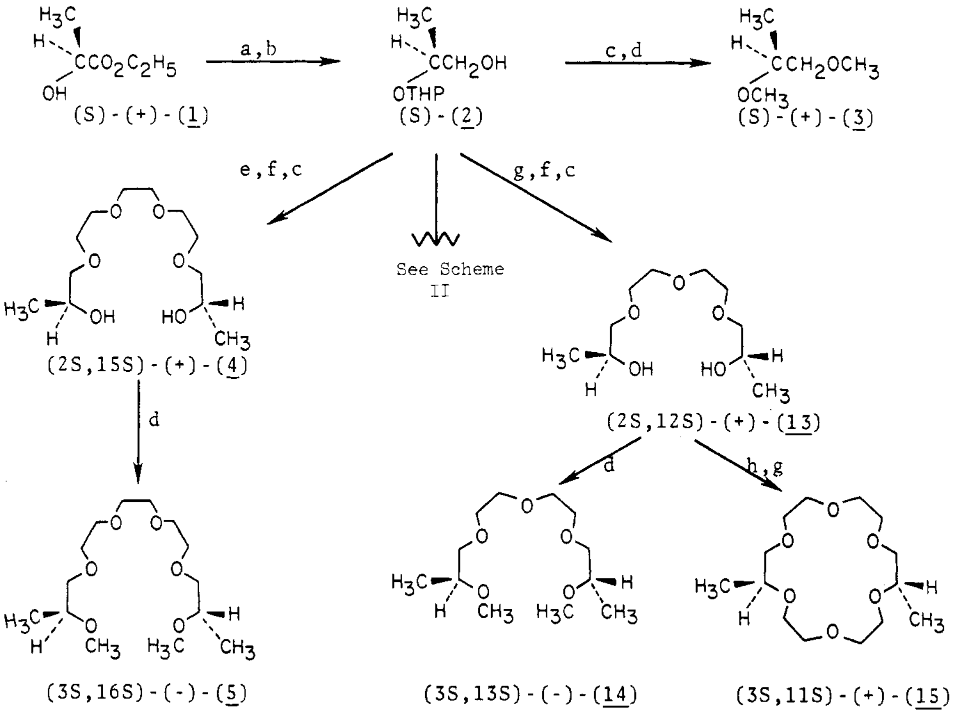
[14] M. P. Mack, R. R. Hendrixson, R. A. Palmer, and R. G. Ghirardelli, *J. Am. Chem. Soc.*, **98**, 7830 (1976).

[15] R. G. Kostyanovsky, I. M. Gella, J. V. Markov, and Z. E. Samojlova, *Tetrahedron*, **30**, 39 (1974).

[16] D. Seebach, H.-O. Kalinowski, B. Bastani, G. Cross, H. Daum, H. Dörr, N. P. DuPreez, V. Ehrig, W. Langer, C. Nossler, H.-A. Oei, and M. Schmidt, *Helv. Chim. Acta*, **60**, 301 (1977).

0022-3263/81/1946-2110$01.25/0

Scheme I[a]



[a] (a) DHP, $H_3O^+$; (b) $LiAlH_4$; (c) $H_3O^+$, $CH_3OH$; (d) NaH, $CH_3I$; (e) $TsOCH_2CH_2OCH_2CH_2OTs$; (f) NaH; (g) $TsOCH_2CH_2OCH_2CH_2OTs$; (h) KH; (i) $CH_3CH(OTHP)CH_2OTs$.

hydrofurfurylamine (**21**) was resolved by using (2*S*,3*S*)-(+)-tartaric acid, and (2*S*,3*S*)-(−)-2,3-dimethoxy-1,4-bis(dimethylamino)butane, (2*S*,3*S*)-(−)-**22**, was commercially available.

**Strategies for Preparing the Dissolved-Metal Solutions.** Special care had to be taken to ensure that the solvents were of high purity, since the presence of easily reducible substances such as acids, alcohols, aromatic compounds, water, etc. would be expected to react with the solvated electron or metal anion. The contamination of samples by decomposition is a serious limitation to reliable studies of dissolved-metal solutions.[6] It would pose a serious problem in this study if the decomposition products were optically active and had an absorption in the region of interest.

When sodium–potassium alloy was dissolved in some of the solvents used, no appreciable color could be generated. In situations of this type, a cosolvent was added to increase the metal solubility. 1,2-Dimethoxyethane and 18-crown-6 were found to be the most successful. In other instances, the chiral solvent of interest was so proficient at dissolving the alloy that light was unable to pass through the solution in a 0.2-mm path length cell. When this occurred, a cosolvent was added which was incapable of dissolving the metal. 1,2-Dimethoxypropane and triethylamine were found to be the most useful. The proportion of solvent and cosolvent was designed so that the dissolved-metal solution gave an optical density between 1.5 and 2.0, since this was the maximum absorption range for the circular dichroism spectrophotometer used.

**Visible Spectra.** The visible spectra were obtained at −50 °C in 0.2-mm path length Pyrex cells. Only the visible absorption band was observed for all of these solutions. All of the dissolved-metal solutions had optical densities of between 1.5 and 2.0. No attempt was made to accurately

Table I. Band Maximum for Sodium–Potassium Alloy in Various Solvents

| solvent system[a] | $\lambda_{max}$, nm |
|---|---|
| (±)-**3**$^{g}$ | *b* |
| (±)-**3**, ~5 × $10^{-3}$ M in 18-crown-6$^{g}$ | 670 |
| (±)-**3**, ~5 × $10^{-3}$ M in 18-crown-6$^{g}$ | 828$^{c}$ |
| (±)-**3**, ~$10^{-2}$ M in **19** | 665 |
| (±)-**3**, ~$10^{-2}$ M in (3*S*,13*S*)-(−)-**14** | 661 |
| (±)-**3**, ~$10^{-2}$ M in (3*S*,16*S*)-(−)-**15** | 666 |
| (±)-**3**, ~7.5 × $10^{-3}$ M in (2*S*,6*S*)-(+)-**8** | 668 |
| (±)-**3**, ~7.5 × $10^{-3}$ M in (2*S*,6*S*)-(+)-**10** | 668 |
| (±)-**3**, ~7.5 × $10^{-3}$ M in (3*S*,11*S*)-(+)-**15** | 669 |
| (+)-**3**, ~7.5 × $10^{-3}$ M in (3*S*,11*S*)-(+)-**15** | 670 |
| (3*S*,6*S*,10*S*,13*S*)-(−)-**11** | |
| 20% (±)-**3**, 80% (3*S*,6*S*,10*S*,13*S*)-(−)-**11**, $10^{-3}$ M in 18-crown-6 | *b* |
| (±)-**3**, ~$10^{-2}$ M in (2*S*,5*S*,9*S*,12*S*)-(+)-**12** | 668 |
| (+)-**3**, ~$10^{-2}$ M in (2*S*,5*S*,9*S*,12*S*)-(+)-**12** | 670 |
| (2*S*,2′*S*)-(+)-**7** | *b* |
| (2*S*,2′*S*)-(+)-**7**, 5 × $10^{-3}$ M in 18-crown-6 | 668 |
| (±)-**21**$^{g}$ | 675$^{d,e}$ |
| 50% (±)-**21**, 50% THF$^{g}$ | 666 |
| 75% (±)-**21**, 25% $(C_3H_5)_3N$$^{g}$ | 650 |
| 80% (±)-**21**, 20% (+)-**3** | 650 |
| 80% (+)-**21**, 20% (+)-**3** | 646 |
| 80% (−)-**21**, 20% (+)-**3** | 650 |
| (±)-**20**$^{h}$ | *b* |
| 50% (±)-**20**, 50% DME$^{h}$ | 660 |
| (±)-**20**, ~$10^{-2}$ M in 18-crown-6$^{h}$ | 668 |
| (2*S*,3*S*)-(−)-**22**, 20% (±)-**3** | *f* |
| 80% (2*S*,3*S*)-(−)-**22**, 20% (±)-**3** | 664 |
| 80% (2*S*,3*S*)-(−)-**22**, 20% (+)-**3** | 666 |

[a] The numbers refer to those for the compounds in Schemes I and II, except that when the sign (±) occurs, it refers to the corresponding racemic compound. [b] Blue only on metal surface. [c] With potassium metal. [d] At ambient temperature. [e] Very intense color. [f] Metal dispersion, but no color detected. [g] The same $\lambda_{max}$ was observed for both enantiomers. [h] The same $\lambda_{max}$ was observed for the (−) enantiomer.

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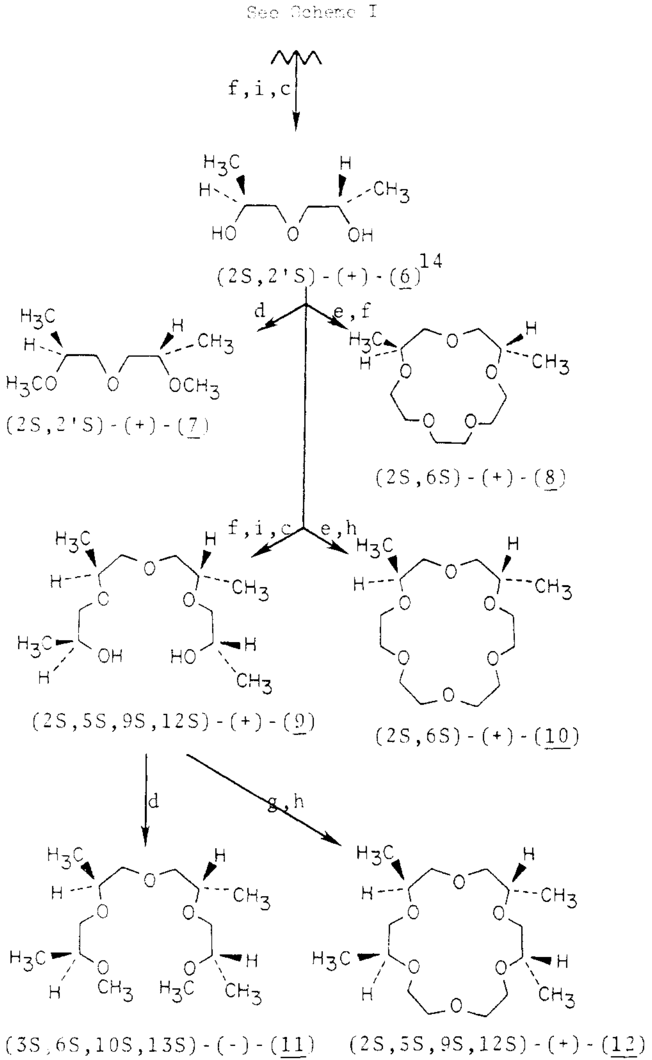
(17) The formation of sodium anions by extraction of sodium from Pyrex may be avoided by using quartz vessels, as shown by I. Hurley, T. R. Tuttle, and S. Golden, *J. Chem. Phys.*, 48, 2818 (1968). This is not of importance in this study, since sodium–potassium alloy was used, and the formation of sodium anions was anticipated.

Scheme II[a]



[a] (a) DHP, $H_3O^+$; (b) $LiAlH_4$; (c) $H_3O^+$, $CH_3OH$; (d) NaH, $CH_3I$; (e) $TsOCH_2CH_2OCH_2CH_2OTs$; (f) NaH; (g) $TsOCH_2CH_2OCH_2CH_2OTs$; (h) KH;[13] (i) $CH_3CH(OTHP)$-$CH_2OTs$.

record the intensity of the band, since the concentration of the metal in solution (and so the optical density) was easily changed by shaking, cooling, or slightly warming the mixture. A summary of those solvent systems examined appears in Table I.

The polyethers which structurally resemble 1,2-dimethoxypropane, (3*S*,6*S*,10*S*,13*S*)-(−)-3,6,10,13-tetramethyl-2,5,8,11,14-pentaoxapentadecane [(3*S*,6*S*,10*S*,13*S*)-(−)-**11**] and (2*S*,2′*S*)-(−)-1,1′-oxybis(2-methoxypropane) [(2*S*,2′*S*)-(−)-**7**], were unable to dissolve the alloy unassisted. This same lack of solubility was shown by 1,2-dimethoxypropane. Apparently the steric interactions introduced by the methyl group are not overcome by the presence of many oxygen atoms in close proximity. The cyclic polyether with four methyl groups, (2*S*,5*S*,9*S*,12*S*)-(+)-**12**, demonstrated a decreased ability to dissolve the alloy as compared to the other crown ethers and therefore required a larger concentration to give a comparable optical density. It is also interesting to note the difference between tetrahydrofurfurylamine (**21**) and 2-(methoxymethyl)pyrrolidine (**20**). The former gave a very intense color when neat, and the latter showed virtually no ability to dissolve the metal. These two solvents are structurally very similar, with the positions of the ether and amine group switched. (2*S*,3*S*)-(−)-**22** was so successful at dissolving the alloy that a solution of highly dispersed metal was obtained with no metal anions present, as demonstrated by its lack of color. Only by the addition of a cosolvent which was unable to dissolve the metal, 1,2-dimethoxypropane, was this solvent capable of showing the visible absorption band.

All of these solutions absorbed in the red (ca. 660 ± 10 nm) as would be expected. In the case of (±)-**3** with potassium metal, the absorption maximum occurred at 828 nm. This would infer that in the solutions in which sodium–potassium alloy was used, the sodium was almost exclusively present. Only when the pure potassium metal was used could the absorption of potassium anions be appreciably detected.[6]

**Circular Dichroism Spectra.** The circular dichroism spectra were obtained at temperatures between 0 and −50 °C. Temperatures much lower than −50 °C were deemed unwise, since, in general, the solutions began to solidify at approximately −70 °C. Crystallization or microcrystallization could give rise to false circular dichroism spectra. Temperatures higher than 0 °C were avoided, since some solutions were found to begin decomposing after 1 or 2 h at room temperature. Repeated examination of these solutions took a significant length of time, and, in general, it was found that solutions kept at 0 °C were stable for long periods of time. Samples were examined at several different temperatures, since it is known that circular dichroism can vary with temperature.[9,18] This may be especially important for these solutions if aggregates are formed, with the type or even the existence of the aggregate dependent upon the temperature.

The solutions were examined for a circular dichroism between about 500 and 850 nm. Curves as small as 1 mdeg would have been detected with the instrument and instrumental settings used. The corresponding racemic samples were used to determine if the spectrophotometer or some property of the solutions would give rise to a false circular dichroism, but none was ever detected for these solvents. The visible spectra of these solutions were examined before and after their circular dichroism spectra were investigated, in order to determine if these solutions were decomposing. After repeated preparation of fresh solutions of varying optical densities and extensive examination of their dichroism spectra, it was concluded that the species absorbing in the visible did not demonstrate any circular dichroism.

The failure of the alkali metal anion to exhibit a solvent-induced circular dichroism would infer that the solvent–metal anion interaction should be classified as weak. It is our intention to investigate, as the instrumentation becomes available, the infrared absorption band of dissolved-metal solutions for circular dichroism.

## Experimental Section

**General Methods.** All chemicals were reagent grade unless otherwise specified. Tetrahydrofuran (THF) was distilled from sodium/benzophenone prior to use. Dimethylformamide (DMF) was distilled from barium oxide prior to use. The polyethylene glycols were commercially available. The di-*p*-toluenesulfonyl derivatives of these glycols were prepared by a modification of the procedures previously described for their synthesis.[19] The modification was that they were not purified but were used in the reactions described below subsequent to their initial isolation.

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(18) M. Legrand In F. Ciardelli and P. Salvadori, "Fundamental Aspects and Recent Developments in Optical Rotatory Dispersion and Circular Dichroism", Heydon and Son, London, 1973, p 269.

(19) (a) S. Z. Perry and H. Hibbert, *Can. J. Res., Sect. B*, 14, 77 (1936); (b) E. P. Kyba, R. C. Helgeson, K. Madan, G. W. Gokel, T. L. Tarnowski, S. S. Moore, and D. J. Cram, *J. Am. Chem. Soc.*, **99**, 2564 (1977).

The preparation of ethyl (*S*)-2-[(tetrahydro-2-pyranyl)oxy]-propanoate, (*S*)-2-[(tetrahydro-2-pyranyl)oxy]-1-propanol and (*S*)-1-(*p*-toluenesulfonoxy)-2-[(tetrahydro-2-pyranyl)oxy]propane have previously been described.[12] A modification of the procedure of Gilman and Young[20] was used to prepare sodium–potassium alloy, since the alloy was prepared in the absence of any solvent.

Melting points were determined with a Mel-Temp apparatus with open capillaries. Melting points and boiling points are uncorrected. Infrared spectra were measured with Perkin-Elmer Model 257 spectrophotometer; band positions are reported in wavenumbers (cm$^{-1}$). Ultraviolet spectra were recorded with a Cary 14 or Cary 219 spectrophotometer; band positions are reported in nanometers. Circular dichroism spectra were recorded with a JASCO Model 5 or Model J-500C spectrophotometer. Proton nuclear magnetic resonance spectra were recorded on a Varian Associates Model A-60 or JEOL Model C-60 spectrometer; chemical shifts are reported in $\delta$ units downfield from internal tetramethylsilane and coupling constants are in hertz. Mass spectral analyses were recorded on an AEI MS902. The spectra were obtained by using electron impact or positive chemical ionization. Microanalyses were performed by Beller Laboratories.

Optical rotations were measured at either the 546.1-nm mercury line or the 589.3-nm sodium line by using a Bendix-Ericsson Model 987 ETL/NPL polarimeter equipped with a Bendix Model DR-1 digital display. The cell length was 0.4 dm, and all solvents used were of spectrophotometric grade. Error limits for rotations were calculated by multiplying the relative standard deviation by the specific rotation. The relative standard deviation was determined by dividing the standard deviation by the observed rotation. Percent optical purity was determined as the observed specific rotation divided by the maximum specific rotation multiplied by 100.

Qualitative GLC analyses were performed on a Hewlett-Packard Model 5710A gas chromatograph (thermal-conductivity detector with helium as carrier gas) using packed columns (15% Lexan on acid-washed 60/80 Chromosorb P, 4 ft × 1/8 in., 15% SE-30 on acid-washed 80/100 Chromosorb P, 10 ft × 1/8 in., and 10% UCW 982 on 80/100 Chromosorb W-HP, 20 in. × 1/8 in.).

Thin-layer chromatography (TLC) was performed by using glass plates coated with Merck silica gel 60 PF-254 + 366. Flash chromatography[21] was carried out by using silica gel 60 F$_{254}$ (70–230 mesh, E. Merck No. 10757).

**Racemic 4,7,10-Trioxatridecane-2,12-diol. Method A.** To a solution of 14.4 g (0.6 mol) of sodium hydride in 400 mL of dry DMF, under a nitrogen atmosphere, was added 29.6 g (0.28 mol) of 2-hydroxyethyl ether in 200 mL of dry DMF over a 0.5-h period. After the mixture was stirred an additional 0.5 h, 175.3 g (0.56 mol) of racemic 1-(*p*-toluenesulfonoxy)-2-[(tetrahydro-2-pyranyl)oxy]propane in 400 mL of dry DMF was added over a 0.5-h period. The mixture was stirred at 55–60 °C for 12 h, and then 1 L of water was added to the cooled solution. This mixture was extracted twice with 250-mL portions of ether. The organic layers were combined, washed once with 100 mL of water, and dried over anhydrous magnesium sulfate, and the majority of the solvent was removed to yield 88.2 g (81%) of a yellow liquid. The infrared spectrum showed some absorption in the 3200–3600-cm$^{-1}$ range and no absorption at 1600 cm$^{-1}$.

The liquid was dissolved in 250 mL of dry methanol, and 3 mL of 12 N hydrochloric acid was added. After 2 h, enough *tert*-butylamine was added to bring the solution to neutral pH. The mixture was concentrated on a rotary evaporator and the remaining oil with suspended salts diluted with 250 mL of ether. The solution was filtered, and the solvent was removed to give a yellow liquid having two phases. The liquid was shaken with 40 mL of pentane, and the top layer was discarded; this procedure was performed twice. Distillation of the remaining liquid through a short Vigreux column from calcium hydride gave 23 g (37%) of the racemic 4,7,10-trioxatridecane-2,12-diol: bp 122–124 °C (0.4 mm); IR (neat film) 3040–3700 (s, br), 2610–3040 (s), 1455 (w), 1370 (w), 1350 (w), 1330 (w), 1295 (w), 1250 (w), 1110 (s), 1040 (w), 1000 (w), 930 (w), 880 (w), 840 (w) cm$^{-1}$; NMR (CDCl$_3$) $\delta$ 1.12 (6 H, d, $J$ = 6 Hz), 3.2–4.03 (14 H, m with a clear s at 3.68), 4.15 (2 H, br s); mass spectrum (electron impact), *m/e* 222 (parent ion).

Anal. Calcd for $C_{10}H_{22}O_5$: C, 54.04; H, 9.98. Found: C, 54.19; H, 9.64.

**Racemic 4,7,10-Trioxatridecane-2,12-diol. Method B.** To a solution of 7.9 g (0.33 mol) of sodium hydride in 200 mL of dry THF, under a nitrogen atmosphere, was added 47.5 g (0.3 mol) of racemic 2-[(tetrahydro-2-pyranyl)oxy]-1-propanol in 100 mL of dry THF over a 0.5-h period. After the mixture was stirred an additional 0.5 h, 62.2 g (0.15 mol) of 2,2′-oxybis[1-(*p*-toluenesulfonoxy)ethane] in 200 mL of dry THF was added over a 0.5-h period. The mixture was refluxed for 12 h, and then enough water was added to the cooled solution to dissolve all of the suspended salts. The majority of the solvent was removed and the remaining mixture extracted once with 150 mL of dichloromethane. The organic layer was dried over anhydrous magnesium sulfate and the solvent removed on a rotary evaporator to yield 55.3 g of the crude THP ether. The infrared spectrum showed some absorption in the 3200–3600-cm$^{-1}$ region and no absorption at 1600 cm$^{-1}$.

The liquid was treated as in the experiment above with acid and methanol. The product was worked up in the same manner and distilled through a short Vigreux column from calcium hydride to yield 20 g (60%) of the racemic 4,7,10-trioxatridecane-2,12-diol: bp 122–124 °C (0.4 mm); $[\alpha]^{25}_{\mathrm{Hg}}$ −0.25 ± 0.20° (*c* 2.49, CHCl$_3$). The proton NMR, infrared, and mass spectra were identical with those of the product generated by method A.

**(2*S*,12*S*)-(+)-4,7,10-Trioxatridecane-2,12-diol.** By use of the procedure above, 35.2 g (0.22 mol) of (*S*)-2-[(tetrahydro-2-pyranyl)oxy]-1-propanol in 100 mL of dry THF was added to a solution of 6.0 g (0.25 mol) of sodium hydride in 200 mL of dry THF. After 0.5 h, 45.7 g (0.11 mol) of 2,2′-oxybis[1-(*p*-toluenesulfonoxy)ethane] in 200 mL of dry THF was added. After refluxing for 12 h, the mixture was worked up in the usual manner to yield 43 g of the crude THP ether.

The liquid was treated as in the procedure above with acid and methanol. The product was worked up in the same manner and distilled through a short Vigreux column from calcium hydride to yield 15.3 g (63%) of (2*S*,12*S*)-(+)-4,7,10-trioxatridecane-2,12-diol: bp 123-126 °C (0.45 mm); $[\alpha]_{\mathrm{Hg}}^{26}$ +50.15 ± 0.30° (*c* 1.65, CHCl$_3$); IR (neat film) 3040–3700 (s, br), 2610–3040 (s), 1455 (w), 1370 (w), 1350 (w), 1330 (w), 1295 (w), 1250 (w), 1110 (s), 1040 (w), 1000 (w), 930 (w), 880 (w), 840 (w) cm$^{-1}$; NMR (CDCl$_3$) $\delta$ 1.15 (6 H, d, $J$ = 6 Hz), 3.50 (4 H, m), 3.72 (8 H, s), 4.0 (2 H, br m), 4.30 (2 H, br d, $J$ = 3 Hz); mass spectrum (electron impact), *m/e* 222 (parent ion).

Anal. Calcd for $C_{10}H_{22}O_5$: C, 54.04; H, 9.98. Found: C, 54.24; H, 10.01.

**(2*S*,15*S*)-(+)-4,7,10,13-Tetraoxahexadecane-2,15-diol.** As above, 38.5 g (0.24 mol) of (*S*)-2-[(tetrahydro-2-pyranyl)oxy]-1-propanol in 100 mL of dry THF was added to a solution of 6.7 g (0.28 mol) of sodium hydride in 200 mL of dry THF. After 0.5 h, 55.1 g (0.12 mol) of 1,8-bis(*p*-toluenesulfonoxy)-3,6-dioxaoctane in 200 mL of dry THF was added. After refluxing for 12 h, the mixture was worked up in the usual manner to yield 57 g of the crude THP ether.

The liquid was treated with acid and methanol, worked up in the same manner, and distilled through a short Vigreux column from calcium hydride to yield 23 g (72%) of (2*S*,15*S*)-(+)-4,7,10,13-tetraoxahexadecane-2,15-diol: bp 150–158 °C (0.55–0.60 mm); $[\alpha]_{\mathrm{Hg}}^{26.5}$ +37.69 ± 0.20° (*c* 2.45, CHCl$_3$); IR (neat film) 3020–3620 (s, br), 2620–3020 (s), 1460 (w), 1210–1390 (w), 1100 (s), 1040 (w), 1000 (w), 940 (w), 880 (w), 845 (w) cm$^{-1}$; NMR (CDCl$_3$) $\delta$ 1.12 (6 H, d, $J$ = 6 Hz), 3.23–4.10 (20 H, m with a clear s at 3.62); mass spectrum (electron impact), *m/e* 222 (parent ion).

Anal. Calcd for $C_{12}H_{26}O_6$: C, 54.12; H, 9.64. Found: C, 54.21; H, 9.64.

**(2*S*,2′*S*)-1,1′-(+)-Oxybis(2-propanol).** (2*S*,2′*S*)-1,1′-(+)-Oxybis(2-propanol) was prepared by the outline given by Ghirardelli and Palmer.[14]

By use of the procedure above, 56.2 g (0.351 mol) of (*S*)-2-[(tetrahydro-2-pyranyl)oxy]-1-propanol in 150 mL of dry THF was added to a solution of 9.6 g (0.4 mol) of sodium hydride in 300 mL of dry THF. After 0.5 h, 110.3 g (0.351 mol) of (*S*)-1-(*p*-toluenesulfonoxy)-2-[(tetrahydro-2-pyranyl)oxy]propane in 300 mL of dry THF was added. After refluxing for 12 h, the mixture

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[20] H. Gilman and R. V. Young, *J. Org. Chem.*, 1, 315 (1936).

[21] For a description of this method see W. C. Still, M. Kahn, and H. Mitra, *J. Org. Chem.*, 43, 2929 (1978).

was worked up in the usual manner to yield 119 g of the crude THP ether.

The liquid was treated as in the procedure above with acid and methanol. The product was worked up in the same manner and distilled through a short Vigreux column from calcium hydride to yield 41 g (87%) of (2*S*,2′*S*)-(+)-1,1′-oxybis(2-propanol): bp 70–78 °C (0.35–0.40 mm) [lit.[14] bp 52–57 °C (0.10–0.15 mm)]; $[\alpha]_{\mathrm{Hg}}^{26}$ +57.62 ± 0.20° (*c* 2.505, $CHCl_3$); IR (neat film) 3010–3650 (s, br), 2500–3010 (s), 1455 (w), 1375 (w), 1335 (w), 1285 (w), 1120 (s), 975 (w), 940 (w), 850 (w), 835 (w), 810 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.13 (6 H, d, *J* = 6 Hz), 3.38 (4 H, m), 3.95 (2 H, br m), 4.55 (2 H, br d, *J* = 3 Hz); mass spectrum (positive chemical ionization), *m/e* 135 (m + 1).

**(2*S*,5*S*,9*S*,12*S*)-(+)-5,9-Dimethyl-4,7,10-trioxatridecane-2,12-diol.** To a solution of 10.8 g (0.45 mol) of sodium hydride in 100 mL of dry DMF, under a nitrogen atmosphere, was added 26.8 g (0.2 mol) of (2*S*,2′*S*)-1,1′-oxybis(2-propanol) in 100 mL of dry DMF over a 0.5-h period. After the mixture was stirred an additional 1 h, 125.8 g (0.4 mol) of (*S*)-1-(*p*-toluenesulfonoxy)-2-[(tetrahydro-2-pyranyl)oxy]propane in 300 mL of dry DMF was added over a 0.5-h period. The mixture was stirred at 55–60 °C for 24 h, and then 1 L of water was added to the cooled solution. This mixture was extracted twice with 250-mL portions of ether. The organic layers were combined, washed twice with 100-mL portions of water, and dried over anhydrous magnesium sulfate, and the majority of the solvent was removed on a rotary evaporator to yield 86 g of a yellow liquid. The infrared spectrum showed some absorption in the 3200–3600-$cm^{-1}$ region, no absorption at 1600 $cm^{-1}$, and a moderate absorption at 1680 $cm^{-1}$ (DMF). This mixture was separated by flash chromatography (pentane bed). Elution first with pentane and then with 10% ether in pentane gave 70 g of a clear liquid whose infrared spectrum showed no absorption in the 3200–3600-$cm^{-1}$ region or at 1680 $cm^{-1}$. Elution was continued with ether to give 5.6 g of a clear liquid whose infrared spectrum showed no absorption at 1680 $cm^{-1}$ but a small absorption in the 3300–3500-$cm^{-1}$ region. This last fraction was discarded.

The liquid from the first fraction was treated as in the procedure above with acid and methanol. After, the solution was brought to neutral pH with *tert*-butylamine, the solvent removed, ether added, the mixture filtered, and the ether removed on a rotary evaporator, there remained a light yellow liquid having two phases. This mixture was separated by flash chromatography (pentane bed). Elution first with pentane and then with 10% ether in pentane gave 10 g of a clear liquid which exhibited a weak absorption in the 3200–3600-$cm^{-1}$ region of the infrared spectrum. This fraction was discarded. Elution continued with ether and then 10% methanol in ether to give 23.4 g of a clear liquid. Distillation of this from calcium hydride through a short Vigreux column gave 20.4 g (41%) of (2*S*,5*S*,9*S*,12*S*)-(+)-5,9-dimethyl-4,7,10-trioxatridecane-2,12-diol: bp 116–120 °C (0.20–0.25 mm); $[\alpha]_{\mathrm{Hg}}^{26.5}$ +112.07 ± 0.19° (*c* 2.588, $CHCl_3$), $[\alpha]_{\mathrm{Hg}}^{26}$ +109.95 ± 0.20° (*c* 2.496, $CHCl_3$); IR (neat film) 3020–3640 (s, br), 2400–3020 (s), 1450 (w), 1370 (s), 1210–1350 (w), 1100 (s), 1015 (w), 955 (w), 940 (w), 860 (w), 935 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.12, 1.10 (12 H, dd, *J* = 6, 6 Hz), 3.23–4.23 (14 H, m); mass spectrum (positive chemical ionization), *m/e* 251 (m + 1).

Anal. Calcd for $C_{12}H_{26}O_5$: C, 57.58; H, 10.47. Found: C, 57.69; H, 10.35.

**(3*S*,13*S*)-(−)-3,13-Dimethyl-2,5,8,11,14-pentaoxapentadecane.** To a solution of 3.6 g (0.15 mol) of sodium hydride in 300 mL of dry THF, under a nitrogen atmosphere, was added 14.65 g (66 mmol) of (2*S*,12*S*)-(+)-4,7,10-trioxatridecane-2,12-diol in 100 mL of dry THF over a 0.5-h period. After being stirred an additional 1 h, the mixture was cooled in an ice bath while 28.4 g (0.20 mol) of methyl iodide was added over a 0.5-h period. The mixture was allowed to return to ambient temperature as the stirring was continued for 12 h. Enough water was added to the mixture to dissolve all suspended salts, and then the majority of the solvent was removed on a rotary evaporator. The remaining liquid was extracted twice with 100-mL portions of dichloromethane, the organic layers were combined and dried over anhydrous magnesium sulfate, and the solvent was removed. The light yellow liquid remaining was distilled from lithium aluminum hydride to yield 14.4 g (87.3%) of (3*S*,13*S*)-(−)-3,13-dimethyl-2,5,8,11,14-pentaoxapentadecane: bp 90–95 °C (0.30–0.40 mm); $[\alpha]_{\mathrm{Hg}}^{25.5}$ −2.31 ± 0.19° (*c* 2.582, $CHCl_3$); IR (neat film) 2500–3080 (s), 1460 (s), 1380 (s), 1355 (s), 1295 (w), 1255 (w), 1205 (s), 1100 (s), 1035 (w), 995 (w), 905 (w), 880 (w), 830 (w), 815 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.13 (6 H, m), 3.30–3.85 (20 H, m with clear singlets at 3.35 and 3.62); mass spectrum (electron impact), *m/e* 250 (parent ion).

Anal. Calcd for $C_{12}H_{26}O_5$: C, 57.57; H, 10.47. Found: C, 57.73; H, 10.53.

**(3*S*,16*S*)-(−)-3,16-Dimethyl-2,5,8,11,14,17-hexaoxaoctadecane.** Following the procedure above, 14.9 g (56 mmol) of (2*S*,15*S*)-(+)-4,7,10,13-tetraoxahexadecane-2,15-diol in 100 mL of dry THF was added to a solution of 3.6 g (0.15 mol) of sodium hydride in 300 mL of dry THF. After 1 h, 28.4 g (0.2 mol) of methyl iodide was added to the ice-cooled solution. At the end of 12 h, the mixture was worked up in the same manner, and the product was distilled from lithium hydride to yield 13.2 g (80%) of (3*S*,16*S*)-(−)-3,16-dimethyl-2,5,8,11,14,17-hexaoxaoctadecane: bp 128–130 °C (0.45 mm); $[\alpha]_{\mathrm{Hg}}^{26.5}$ −2.13 ± 0.20° (*c* 2.49, $CHCl_3$); IR (neat film) 2600–3090 (s), 1460 (s), 1375 (s), 1350 (s), 1290 (w), 1250 (w), 1200 (s), 1110 (s), 1035 (w), 1000 (w), 905 (w), 880 (w), 830 (w), 815 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.13 (6 H, m), 3.30–3.83 (24 H, m with clear singlets at 3.35 and 3.63); mass spectrum (positive chemical ionization), *m/e* 295 (m + 1).

Anal. Calcd for $C_{14}H_{30}O_6$: C, 57.12; H, 10.27. Found: C, 57.28; H, 10.15.

**(2*S*,2′*S*)-(−)-1,1′-Oxybis(2-methoxypropane).** By use of the procedure above, 13.2 g (0.1 mol) of (2*S*,2′*S*)-(+)-1,1′-oxybis(2-propanol) in 100 mL of dry THF was added to a solution of 6 g (0.25 mol) of sodium hydride in 300 mL of dry THF. After 1 h, 56.8 g (0.4 mol) of methyl iodide was added to the ice-cooled solution. At the end of 12 h, the mixture was worked up in the same manner, and the product was distilled from lithium aluminum hydride to yield 14.6 g (90%) of (2*S*,2′*S*)-(−)-1,1′-oxybis(2-methoxypropane): bp 84–88 °C (34 mm), 172–176 °C (atmosphereic pressure); $[\alpha]_{\mathrm{Hg}}^{26}$ −7.60 ± 0.20° (*c* 2.514, $CHCl_3$); IR (neat film) 2600–3100 (s), 1455 (s), 1370 (s), 1350 (s), 1310 (w), 1260 (w), 1200 (s), 1110 (s), 990 (w), 970 (w), 920 (w), 900 (w), 830 (w), 810 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.16 (6 H, m), 3.43–3.80 (12 H, m with a clear s at 3.47); mass spectrum (electron impact), *m/e* 162 (parent peak).

Anal. Calcd for $C_8H_{18}O_3$: C, 59.23; H, 11.18. Found: C, 59.47; H, 11.13.

**(3*S*,6*S*,10*S*,13*S*)-(−)-3,6,10,13-Tetramethyl-2,5,8,11,14-pentaoxapentadecane.** By use of the procedure above, 3.75 g (15 mmol) of (2*S*,5*S*,9*S*,12*S*)-(+)-5,9-dimethyl-4,7,10-trioxatridecane-2,12-diol in 50 mL of dry THF was added to a solution of 0.96 g (40 mmol) of sodium hydride in 150 mL of dry THF. After 1 h, 8.52 g (60 mmol) of methyl iodide was added to the ice-cooled solution. At the end of 12 h, the mixture was worked up in the same manner, and the product was distilled from lithium hydride to yield 3.3 g (79%) of (3*S*,6*S*,10*S*,13*S*)-(−)-3,6,10,13-tetramethyl-2,5,8,11,14-pentaoxapentadecane: bp 98–104 °C (0.65–0.70 mm); $[\alpha]_{\mathrm{Hg}}^{26.5}$ −12.23 ± 0.20° (*c* 2.537, $CHCl_3$); IR (neat film) 2520–3050 (s), 1460 (w), 1375 (w), 1345 (w), 1315 (w), 1295 (w), 1270 (w), 1200 (w), 1110 (s), 1015 (w), 965 (w), 915 (w), 850 (w), 810 (w) $cm^{-1}$; NMR ($CDCl_3$) δ 1.15 (12 H, m), 3.33–3.80 (18 H, m with a clear s at 3.36); mass spectrum (positive chemical ionization), *m/e* 279 (m + 1).

Anal. Calcd for $C_{14}H_{30}O_5$: C, 60.40; H, 10.86. Found: C, 60.67; H, 10.95.

**(*S*)-(+)-1,2-Dimethoxypropane.** (*S*)-2-[(Tetrahydro-2-pyranyl)oxy]-1-propanol (32 g, 0.2 mol) was dissolved in 250 mL of dry methanol, and 3 mL of 12 N hydrochloric acid was added. After being allowed to stand 12 h, the solution was brought to neutral pH with *tert*-butylamine, and the majority of the solvent was removed on a rotary evaporator. The remaining liquid was diluted with 250 mL of ether and filtered, and the solvent was removed. The material was distilled from calcium hydride to yield 12.1 g (80%) of (*S*)-(+)-1,2-propanediol: bp 70–75 °C (5–6 mm) [lit.[22] 76–78 °C (6 mm)]; $[\alpha]^{25}_{\mathrm{D}}$ +4.2 ± 0.07° (*c* 6.509, absolute ethanol) [lit.[22] $[\alpha]^{22}_{\mathrm{D}}$ +4.2° (*c* 6.6, absolute ethanol)]. The proton NMR, infrared, and mass spectra were all consistent with the assigned structure.

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[22] E. Baer and H. O. L. Fischer, *J. Am. Chem. Soc.*, **70**, 609 (1948).

By use of the procedure above, 7.6 g (0.1 mol) of (*S*)-(+)-1,2-propanediol in 25 mL of dry DMF was added to a solution of 5.3 g (0.22 mol) of sodium hydride in 200 mL of dry DMF. After 1 h, 62.4 g (0.44 mol) of methyl iodide was added to the cooled solution. At the end of 12 h, the mixture was worked up in the same manner as above to yield 6 g (58%) of (*S*)-(+)-1,2-dimethoxypropane: bp 90–96 °C; $[\alpha]^{26.5}_{\mathrm{Hg}}$ +8.84 ± 0.20° (*c* 2.509, $CHCl_3$); the proton NMR and infrared spectra were indentical with those for the racemic 1,2-dimethoxypropane; mass spectrum (electron impact), *m/e* 104 (parent ion).

Anal. Calcd for $C_5H_{12}O_2$: C, 57.66; H, 11.61. Found: C, 57.94; H, 11.67.

**(*R*)-(−)-1,2-Dimethoxypropane.** (*R*)-(−)-1,2-Propanediol was prepared by the method of Levene and Walti.[23] The proton NMR, infrared, and mass spectra were all consistent with the assigned structure; $[\alpha]^{25}_{\mathrm{D}}$ −4.3 ± 0.07° (*c* 6.53, absolute ethanol) [lit.[22] $[\alpha]^{22}_{\mathrm{D}}$ −4.2° (*c* 6.6, absolute ethanol)].

Following the procedure above, 7.6 g (0.1 mol) of (*R*)-(−)-1,2-propanediol in 25 mL of dry DMF was added to a solution of 5.3 g (0.22 mol) of sodium hydride in 200 mL of dry DMF. After 1 h, 62.4 g (0.44 mol) of methyl iodide was added to the cooled solution. At the end of 12 h, the mixture was worked up in the same manner as above to yield 5.8 g (56%) of (*R*)-(−)-1,2-dimethoxypropane: bp 96–98 °C; $[\alpha]^{26.5}_{\mathrm{Hg}}$ −9.07 ± 0.20° (*c* 2.54, $CHCl_3$); the proton NMR and infrared spectra were identical with those for the racemic 1,2-dimethoxypropane; mass spectrum (electron impact), *m/e* 104 (parent ion).

Anal. Calcd for $C_5H_{12}O_2$: C, 57.66; H, 11.61. Found: C, 58.17; H, 11.69.

**(3*S*,11*S*)-(+)-3,11-Dimethyl-1,47,10,13,16-hexaoxacyclooctadecane.** To a solution of 13.2 g (0.33 mol) of potassium hydride in 300 mL of dry THF, under a nitrogen atmosphere, was added 34 g (0.153 mol) of (2*S*,12*S*)-(+)-4,7,10-trioxatridecane-2,12-diol in 300 mL of dry THF over a 0.5-h period. After the mixture was stirred an additional 1 h, 63.6 g (0.153 mol) of 2,2′-oxybis[1-(*p*-toluenesulfonoxy)ethane] in 300 mL of dry THF was added to the solution as quickly as possible through an addition funnel. The mixture was refluxed for 12 h, and then enough water was added to the cooled solution to dissolve all of the suspended salts. The majority of the solvent was removed on a rotary evaporator and the remaining mixture extracted three times with 100 mL portions of dichloromethane. The organic layers were combined and dried over anhydrous magnesium sulfate, and the solvent was removed. Distillation through a short Vigreux column from lithium hydride gave 10.9 g (24%) of (3*S*,11*S*)-(+)-3,11-dimethyl-1,4,7,10,13,16-hexaoxacyclooctadecane: bp 130–132 °C (0.4 mm); $[\alpha]^{26.5}_{\mathrm{Hg}}$ +20.50 ± 0.19° (*c* 2.595, $CHCl_3$); IR (neat film) 2660–3020 (s), 1455 (w), 1370 (w), 1350 (w), 1295 (w), 1250 (w), 1120 (s), 985 (w), 940 (w), 885 (w), 835 (w) cm$^{-1}$; NMR ($CDCl_3$) $\delta$ 1.10 (6 H, d, *J* = 6 Hz), 3.35–3.86 (22 H, m with a clear singlet at 3.65); mass spectrum (electron impact), *m/e* 292 (parent ion).

Anal. Calcd for $C_{14}H_{28}O_6$: C, 57.51; H, 9.65. Found: C, 57.69; H, 9.47.

**(2*S*,6*S*)-(+)-2,6-Dimethyl-1,4,7,10,13,16-hexaoxacyclooctadecane.** By use of the procedure above, 10.7 g (80 mmol) of (2*S*,2′*S*)-(+)-1,1′-oxybis(2-propanol) in 200 mL of dry THF was added to 8.02 g (0.2 mol) of potassium hydride in 200 mL of dry THF. After 1 h, 40.2 g (80 mmol) of 1,11-bis(*p*-toluenesulfonoxy)-3,6,9-trioxaundecane in 300 mL of dry THF was added quickly. At the end of 12 h, the mixture was worked up in the same manner as above to yield 5.8 g (25%) of (2*S*,6*S*)-(+)-2,6-dimethyl-1,4,7,10,13,16-hexaoxacyclooctadecane: bp 124–130 °C (0.45–0.50 mm); $[\alpha]^{26}_{\mathrm{Hg}}$ +20.74 ± 0.19° (*c* 2.621, $CHCl_3$); IR (neat film) 2660–3010 (s), 1455 (w), 1370 (w), 1350 (w), 1295 (w), 1250 (w), 1120 (s), 985 (w), 940 (w), 875 (w), 840 (w) cm$^{-1}$; NMR ($CDCl_3$) $\delta$ 1.11 (6 H, d, *J* = 6 Hz), 3.40–3.90 (22 H, m with a clear s at 3.67); mass spectrum (electron impact), *m/e* 292 (parent ion).

Anal. Calcd for $C_{14}H_{28}O_6$: C, 57.51; H, 9.65. Found: C, 57.78; H, 9.75.

**(2*S*,5*S*,9*S*,12*S*)-(+)-2,5,9,12-Tetramethyl-1,4,7,10,13,16-hexaoxacyclooctadecane.** By use of the procedure above, 6 g (24 mmol) of (2*S*,5*S*,9*S*,12*S*)-(+)-5,9-dimethyl-4,7,10-trioxatridecane-2,12-diol in 100 mL of dry THF was added to 2.4 g (60 mmol) of potassium hydride in 200 mL of dry THF. After 1 h, 9.96 g (24 mmol) of 2,2′-oxybis[1-(*p*-toluenesulfonoxy)ethane] in 150 mL of dry THF was added quickly. At the end of 12 h, the mixture was worked up in the same manner as above to yield 2.1 g (27%) of (2*S*,5*S*,9*S*,12*S*)-(+)-2,5,9,12-tetramethyl-1,4,7,10,13,16-hexaoxacyclooctadecane: bp 138–142 °C (0.65–0.75 mm); $[\alpha]^{26.5}_{\mathrm{Hg}}$ +22.21 ± 0.19° (*c* 2.57, $CHCl_3$); IR (neat film) 2560–3080 (s), 1455 (w), 1370 (s), 1340 (w), 1295 (w), 1255 (w), 1120 (s), 1035 (w), 1015 (w), 970 (w), 930 (w), 890 (w), 835 (w) cm$^{-1}$; NMR ($CDCl_3$) $\delta$ 1.15 (12 H, m), 3.30–3.90 (20 H, m with clear s at 3.66); mass spectrum (electron impact), *m/e* 320 (parent ion).

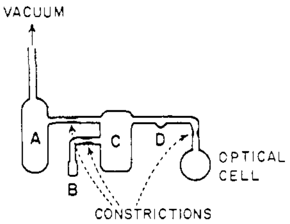

**Figure 1.** Vacuum apparatus.

Anal. Calcd for $C_{16}H_{32}O_6$: C, 59.98; H, 10.07. Found: C, 59.97; H, 10.10.

**(2*S*,6*S*)-(+)-2,6-Dimethyl-1,4,7,10,13-pentaoxacyclopentadecane.** By use of the general procedure above, 10.7 g (80 mmol) of (2*S*,2′*S*)-(+)-1,1′-oxybis(2-propanol) in 200 mL of dry THF was added to 4.8 g (0.2 mol) of sodium hydride in 200 mL of dry THF. After 1 h, 36.7 g (80 mmol) of 1,8-bis(*p*-toluenesulfonoxy)-3,6-dioxaoctane in 300 mL of dry THF was added quickly. At the end of 12 h, the mixture was worked up in the same manner as above to yield 6.2 g (31%) of (2*S*,6*S*)-(+)-2,6-dimethyl-1,4,7,10,13-pentaoxacyclopentadecane: bp 108–118 °C (0.60–0.70 mm); $[\alpha]^{26.5}_{\mathrm{Hg}}$ +41.65 ± 0.19° (*c* 2.61, $CHCl_3$); IR (neat film) 2620–3010 (s), 1450–1475 (w), 1370 (w), 1350 (w), 1340 (w), 1295 (w), 1250 (w), 1125 (s), 980 (w), 940 (w), 875 (w), 840 (w) cm$^{-1}$; NMR ($CDCl_3$) $\delta$ 1.10 (6 H, d, *J* = 6 Hz), 3.26–3.90 (18 H, m with clear s at 3.66); mass spectrum (electron impact), *m/e* 248 (parent ion).

Anal. Calcd for $C_{12}H_{24}O_5$: C, 58.04; H, 9.74. Found: C, 58.29; H, 9.99.

**Resolution of Tetrahydrofurfurylamine.** To a solution of 75 g (0.5 mol) of L-(+)-tartaric acid in 4 L of ethanol was added 50.5 g (0.5 mol) of tetrahydrofurfurylamine. The mixture was heated to reflux for 0.5 h, filtered, and then allowed to cool overnight. The solid was filtered and dissolved in 3 L of ethanol. After 12 h, the salt was filtered (ca. 37 g, mp 84.5–86 °C) and decomposed[24] with dilute sodium hydroxide solution. After a continuous extraction with ether, distillation from barium oxide gave 15 g of (−)-tetrahydrofurfurylamine: bp 154–157 °C; $[\alpha]^{26}_{\mathrm{Hg}}$ −12.32 ± 0.06° (*c* 5.043, $CHCl_3$); the proton NMR and infrared spectra were identical with those for the racemic compound.

The combined filtrates from above were concentrated to 1 L, filtered, and placed in a refrigerator overnight. The solid was filtered off (discarded) and the filtrate taken to dryness on a rotary evaporator. The remaining solid was decomposed with dilute sodium hydroxide solution. After a continuous extraction with ether, distillation from barium oxide gave 20 g of partially resolved (+)-tetrahydrofurfurylamine; bp 154–157 °C; $[\alpha]^{26}_{\mathrm{Hg}}$ +9.84 ± 0.10° (*c* 5.09, $CHCl_3$); the proton NMR and infrared spectra were identical with those for the racemic compound.

**General Procedure for the Reaction of Sodium–Potassium Alloy with Amines and Ethers.** With the exception of 18-crown-6, all solvents and cosolvents were stirred with sodium–potassium alloy for 2–4 h and then distilled just prior to their use.

Solutions were prepared in a Pyrex apparatus such as that shown in Figure 1.

The glassware was cleaned first with 5% HF solution, rinsed with conductance water, immersed in aqua regia for 12 h, rinsed thoroughly with conductance water, and finally dried in an oven

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[23] P. A. Levene and A. Walti, "Organic Syntheses", Collect. Vol. II, Wiley, New York, 1946, p 454.

[24] The melting point of the salt was not changed by further recrystallizations.

overnight. The apparatus was flame dried and kept under an argon atmosphere while the solvent or solution was placed in vessel A, the alloy or metal was placed in vessel B, and high boiling liquids or solids, if any, were placed in vessel D. The solutions were degassed on a high-vacuum apparatus, the metal distilled from vessel B to vessel C, and the apparatus closed with a flame at the constriction. The solution was distilled from vessel A to vessel C and the apparatus closed with a flame at the constriction. Agitation with cooling produced the typical blue color. The saturated solution with a small excess of metal was poured into the optical cell and the apparatus closed with a flame at the constriction. Samples were stored under liquid nitrogen until just prior to the examination of their spectra.

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**Registry No.** (±)-**2**, 3539-39-7; (±)-**2** *p*-toluenesulfonate ester, 42274-61-3; (*S*)-**2**, 76946-21-9; (*S*)-**2** *p*-toluensulfonate ester, 42274-61-3; (±)-**3**, 76900-31-7; (*R*)-(−)-**3**, 76946-22-0; (*S*)-(+)-**3**, 76946-23-1; (2*S*,15*S*)-(+)-**4**, 76900-32-8; (2*S*,15*S*)-(+)-**4** bis(tetrahydropyran-2-yl) ether, 76900-33-9; (3*S*,16*S*)-(−)-**5**, 76915-09-8; (2*S*,2′*S*)-(+)-**6**, 61217-63-8; (2*S*,2′*S*)-(+)-**6** bis(tetrahydropyran-2-yl) ether, 76946-24-2; (2*S*,2′*S*)-(−)-**7**, 76900-34-0; (2*S*,6*S*)-(+)-**8**, 76900-35-1; (2*S*,5*S*,9*S*,12*S*)-(+)-**9**, 76900-36-2; (2*S*,5*S*,9*S*,12*S*)-(+)-**9** bis(tetrahydropyran-2-yl) ether, 76900-37-3; (2*S*,6*S*)-(+)-**10**, 76946-25-3; (3*S*,6*S*,10*S*,13*S*)-(−)-**11**, 76915-14-5; (2*S*,5*S*,9*S*,12*S*)-(+)-**12**, 76900-38-4; (±)-**13**, 76900-39-5; (±)-**13** bis(tetrahydropyran-2-yl) ether, 76900-40-8; (2*S*,12*S*)-(+)-**13**, 76946-26-4; (2*S*,12*S*)-(+)-**13** bis(tetrahydropyran-12-yl) ether, 76984-82-2; (3*S*,13*S*)-(−)-**14**, 76900-41-9; (3*S*,11*S*)-(+)-**15**, 76900-42-0; (±)-**20**, 76946-27-5; (*S*)-(+)-**20**, 63126-47-6; (±)-**21**, 13346-01-5; (*R*)-(−)-**21**, 7202-43-9; (*S*)-(+)-**21**, 7175-81-7; (*S*)-(+)-**21** (L)-(+)-tartrate, 33002-02-7; (2*S*,3*S*)-(−)-**22**, 26549-21-3; 2-hydroxyethyl ether, 111-46-6; 2,2′-oxybis[1-(*p*-toluenesulfonoxy)ethane], 7460-82-4; 1,8-bis(*p*-toluenesulfonoxy)-3,6-dioxaoctane, 19249-03-7; (*S*)-(+)-1,2-propanediol, 4254-15-3; (*R*)-(−)-1,2-propanediol, 4254-14-2; 1,11-bis(*p*-toluenesulfonoxy)-3,6,9-trioxaundecane, 37860-51-8.

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# Kinetics of the Thermal Skeletal Inversion of Bicyclo[2.1.0]pentane and Methylbicyclo[2.1.0]pentanes

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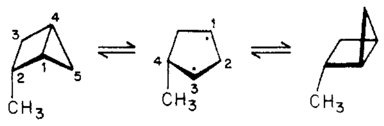
*cis-exo*-2,3-Dideuteriobicyclo[2.1.0]pentane, *cis-exo*-2,3-dideuterio-1-methylbicyclo[2.1.0]pentane, and the endo and exo isomers of 5-methylbicyclo[2.1.0]pentane have been prepared; rate constants for the gas-phase equilibrations between these substrates and the corresponding ring-inverted isomers have been determined between 153 and 208 °C. The parent hydrocarbon and 1-methylbicyclo[2.1.0]pentane have equal or nearly equal activation energies, 37.8 ± 0.1 and 38.0 ± 0.4 kcal/mol; the 2-methyl and 5-methyl systems have slightly higher $E_a$ values, 38.7 to 39.2 kcal/mol. These data and related information from the literature are assessed in terms of electronic and steric substituent effects on ground-state bicyclopentanes and transition states leading to planar 1,3-cyclopentadiyl diradicals.

Thermal interconversion of *endo*- and *exo*-2-methylbicyclo[2.1.0]pentane (**1** $\rightleftarrows$ **3**) was observed by Chesick in 1962.[1] Tentative structural assignments for the isomers were suggested, and the activation parameters log $A = 14.45$ and $E_a = 38.9 \pm 0.8$ kcal/mol for the gas-phase approach to equilibrium were determined. The reaction was presumed to involve incomplete cleavage of the C(1)–C(4) bond at the transition state and the planar cyclic diradical intermediate **2**. An analogy between this isomerization and the geometric isomerization of the 1,2-dideuteriocyclopropanes[2,3] was noted.



1 2 3

The 2-methylbicyclo[2.1.0]pentane eluted first on a silicone oil or Carbowax GLC column has been shown to be the exo isomer,[4,5] as Chesick provisionally suggested.[1] Other bicyclo[2.1.0]pentanes undergo thermal stereomutations consistent with C(1)–C(4) bond cleavage and skeletal inversion but incompatible with alternative formulations involving C(2)–C(3) or C(1)–C(5) cleavage.[6-9]

Direct experimental observations on the 4-methyl-1,3-cyclopentadiyl diradical **2**, the parent diradical **5**, and several other representatives of this novel class of localized 1,3-diradicals have been reported.[10] Generation of these diradicals under matrix-isolation conditions at 5.5 K gave rise to strong ESR signals attributable to triplet diradicals. The barrier for formation of bicyclopentane **4** from the triplet diradical was estimated to be 2.3 ± 0.2 kcal/mol. In a revealing CIDNP experiment, triplet-sensitized photolysis of 2,3-diazabicyclo[2.2.1]hept-2-ene, precursor to

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[1] J. P. Chesick, *J. Am. Chem. Soc.*, **84**, 3250 (1962).

[2] B. S. Rabinovitch, E. W. Schlag, and K. B. Wiberg, *J. Chem. Phys.*, **28**, 504 (1958).

[3] E. W. Schlag and B. S. Rabinovitch, *J. Am. Chem. Soc.*, **82**, 5996 (1960).

[4] K. B. Wiberg and K. C. Bishop, III, *Tetrahedron Lett.*, 2727 (1973).

[5] M. D. Harmony, C. S. Wang, K. B. Wiberg, and K. C. Bishop, III, *J. Chem. Phys.*, **63**, 3312 (1975).

[6] J. A. Berson, W. Bauer, and M. M. Campbell, *J. Am. Chem. Soc.*, **92**, 7515 (1970).

[7] J. P. Grosclaude, H. U. Gonzenbach, J. C. Perlberger, and K. Schaffner, *Chimia*, **29**, 528 (1975); *J. Am. Chem. Soc.*, **97**, 4147 (1975); *Helv. Chim. Acta*, **59**, 2919 (1976).

[8] K. Schaffner, *Tetrahedron*, **32**, 641 (1976).

[9] J. J. Tufariello, J. H. Chang, and A. C. Bayer, *J. Am. Chem. Soc.*, **101**, 3315 (1979).

[10] S. L. Buchwalter and G. L. Closs, *J. Am. Chem. Soc.*, **97**, 3857 (1975); *ibid.*, **101**, 4688 (1979).

0022-3263/81/1946-2116$01.25/0