to yield 0.84 g (97%) of O-acetyl 4-nitrocatechol; identical with the material prepared as described previously.

Reaction of 4 with BF_3 Etherate and NaI. To a solution of 4 (0.3 g, 0.6 mmol) in methylene chloride (2 mL) were added an anhydrous solution of NaI in acetone (3 equiv) and freshly distilled boron trifluoride etherate (1.33 equiv) under nitrogen. After 1 h at room temperature, the reaction was worked up as described for 2 and yielded 0.26 g (93%) of O-acetyl-tetrabromocatechol.

Acknowledgment. Financial support from Research Corp., the College of the Holy Cross, and the National Institutes of Health (Grant 5R01GM13453-14) is gratefully acknowledged.

Registry No. 2, 7555-18-2; 3, 77400-20-5; 4, 77400-21-6; 5, 77400-22-7; 6, 61627-35-8; 7, 77400-23-8; 8, 77400-24-9; 9, 77400-25-0; 10, 77400-26-1; 11, 77400-27-2; 14, 77400-28-3; triethyl arthoacetate, 78-39-7; catechol, 120-80-9; 4-nitrocatechol, 3316-09-4; tetrabromocatechol, 488-47-1; 3-methoxycatechol, 934-00-9; 1,2,3-trihydroxybenzene, 87-66-1; alizarin, 72-48-0; 4-methylesculatin, 529-84-0; ethyl acetate, 141-78-6; acetylcatechol, 2848-25-1; 2,2,2-trichloroethanol, 115-20-8; methyl glycolate, 623-50-7; acetyl-4-nitrocatechol, 77400-64-7; acetyl-4,5-dinitrocatechol, 77400-29-4; 4,5-dinitrocatechol, 77400-30-7; acetyltetrabromocatechol, 77400-31-8.

One-Step Spiroannelation. Synthesis of Spiro γ- and δ-Lactones

Persephone Canonne,* Denis Bélanger, Gilles Lemay, and Georges B. Foscolos

Department of Chemistry, Laval University, Quebec, Canada G1K 7P4

Received September 17, 1980

Carbocyclic acid anhydrides can be converted to spiro γ- and δ-lactones by addition of di-Grignard reagents in tetrahydrofuran solution. Five- and six-membered rings have been formed in one-step reactions. Possible mechanistic pathways for this reaction are discussed. The conversion of spirolactones to 1-(ω-hydroxyalkyl)-cycloalkanols was accomplished by reduction with LAH to illustrate the versatility of these substances giving (after or upon treatment with tosyl chloride) the corresponding spiroethers.

Introduction

Considerable progress has been made in the development of various procedures for the elaboration of synthetic routes to γ- and δ-lactones.

A general method was the halogen–metal exchanges in esters of haloaryl acids.[1-9] Moreover, a variety of synthons containing carbanions at the convenient position has been developed[10-15] and their addition to aldehydes and ketones provided the skeletal arrangement which ultimately has been converted into γ- and δ-lactones.

Another method using the reaction of the lithium salt of 2,4,4-trimethyl-2-oxazoline with epoxides at low temperature after hydrolysis of the resulting hydroxypropyloxazolines produced the expected δ-butyrolactones.[16,17]

Recently, a direct synthesis was reported involving the addition of lithium β-lithiopropionate to aldehydes or ketones, followed by lactonization of the γ-hydroxy acid,[11] but according to the authors, the yield was low, especially in cases involving ketones as the carbonyl component. Within the past decade much research has been directed toward the formation of spirolactones, using general methods of lactonization.[5,18-23] Many of those methods were limited to the synthesis of spirolactones which often appeared in the literature (1-oxaspiro[4.4]nonan-2-one and 1-oxaspiro[4.5]decan-2-one); cyclohexanone and cyclopentanone were inevitably selected as substrates.[5,6,9-12,19-21,23-25,37]

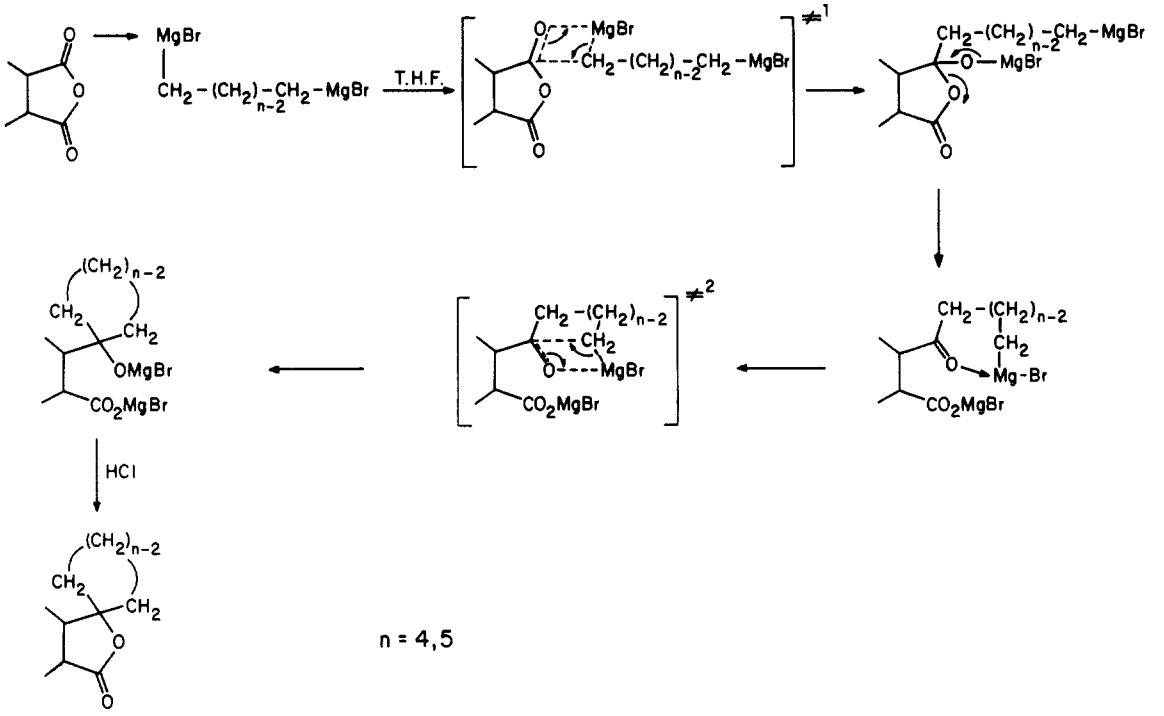
In a previous article,[25] we described a new one-step synthesis of 1-(ω-hydroxyalkyl)cycloalkanols involving the reaction of bis(bromomagnesio)alkanes with lactones. Oxidation of these diols by Jones reagent provided a high yield of the corresponding spirolactones. This method was simple, versatile, and general for preparation of spirolactones.

The use of organodimagnesium compounds has now been extended to the reactions of cyclic anhydrides. As our preliminary note[26] showed, this facile one-step synthesis led to a variety of spirolactones. The great advantage of this method is that the intermediate carboxylate is stable under the reaction conditions and thus does not give byproducts.

(1) W. H. Puterbaugh and C. R. Hauser, *J. Org. Chem.*, **29**, 853 (1964).
(2) B. M. Trost, G. T. Rivers, and J. M. Gold, *J. Org. Chem.*, **45**, 1835 (1980).
(3) E. K. Raunio and H. A. Schroeder, *J. Org. Chem.*, **22**, 570 (1957).
(4) L. K. Dalton, B. C. Elmes, and B. V. Kolczynski, *Aust. J. Chem.*, **25**, 633 (1972).
(5) P. E. Eaton, G. F. Cooper, R. C. Johnson, and R. H. Mueller, *J. Org. Chem.*, **37**, 1947 (1972).
(6) W. Sucrow and U. Klein, *Chem. Ber.*, **108**, 48 (1975).
(7) W. E. Parham and L. D. Jones, *J. Org. Chem.*, **41**, 2704 (1976).
(8) W. E. Parham, D. C. Egberg, Y. A. Sayed, R. W. Thraikill, G. E. Keyser, M. Neu, W. C. Montgomery, and L. D. Jones, *J. Org. Chem.*, **41**, 2628 (1976).
(9) R. M. Jacobson, G. P. Lahm, and J. W. Clader, *J. Org. Chem.*, **45**, 395 (1980).
(10) G. Sturtz, B. Corbel, and J. P. Paugam, *Tetrahedron Lett.*, 47 (1976).
(11) D. Caine and A. S. Frobese, *Tetrahedron Lett.*, 883 (1978).
(12) T. K. DasGupta, D. Felix, U. M. Kempe, and A. Eschenmoser, *Helv. Chim. Acta*, **55**, 2198 (1972).
(13) D. A. Evans, J. M. Takacs, and K. M. Hurst, *J. Am. Chem. Soc.*, **101**, 371 (1979).
(14) R. M. Jacobson and J. W. Clader, *Tetrahedron Lett.*, 1205 (1980).
(15) A. P. Kozikowski and Yon-Yih Chen, *J. Org. Chem.*, **45**, 2236 (1980).
(16) A. I. Meyers, E. D. Mihelich, and R. L. Nolen, *J. Org. Chem.*, **39**, 2783 (1974).
(17) A. I. Meyers, D. L. Temple, D. Haidukewych, and E. D. Mihelich, *J. Org. Chem.*, **39**, 2787 (1974).
(18) J. M. Surzur and P. Teissier, *Bull. Soc. Chim. Fr.*, 653 (1970).
(19) D. H. Aue, M. J. Meshishnek, and D. F. Shellhamer, *Tetrahedron Lett.*, 4799 (1973).
(20) B. M. Trost and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **95**, 5321 (1973).
(21) P. Picard and J. Moulines, *Bull. Soc. Chim. Fr.*, 3377 (1973).
(22) O. S. Bhanot, T. K. Das, H. S. Suri, and P. C. Dutta, *J. Org. Chem.*, **42**, 1623 (1977).
(23) H. Christol, F. Plénat, and C. Reliaud, *Bull. Soc. Chim. Fr.*, 1566 (1968).
(24) J. J. Eisch and J. E. Galle, *J. Organomet. Chem.*, **160**, C8 (1978).
(25) P. Canonne, G. B. Foscolos, and D. Bélanger, *J. Org. Chem.*, **45**, 1828 (1980), and references cited therein.
(26) P. Canonne and D. Bélanger, *J. Chem. Soc., Chem. Commun.*, 125 (1980).

0022-3263/81/1946-3091$01.25/0

Scheme I



Results and Discussion

The addition of 1,4-bis(bromomagnesio)butane and 1,5-bis(bromomagnesio)pentane to a cyclic and bicyclic or aromatic anhydride provides the corresponding spiro γ- and δ-lactones.

The starting anhydrides were conveniently selected in order to extend the scope and limitations of our method of spiroannelation. The results are summarized in Table I.

As indicated, the yields extend generally from good to excellent. Exceptionally, in the case of 1,8-naphthalenecarboxylic anhydride, the spirolactones were obtained in less satisfactory yields, particularly with pentane-1,5-diyldimagnesium bromide (the spirolactone was formed only in traces); chromatographic analysis shows unexpected byproducts such as dimeric and polymeric ketoacidic compounds and recovered starting anhydride.

Similar results were observed with reaction of both bis(bromomagnesium) compounds with maleic anhydride.

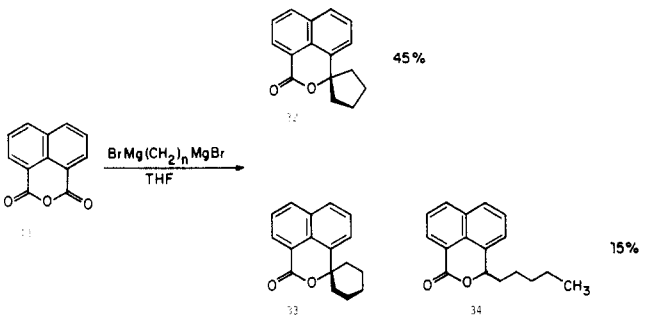
A study of IR and ^{1}H NMR spectra shows the formation of keto acids via a competing 1,4-addition process. The results obtained in the case of maleic anhydride are in contrast with those found through the reaction of the unsaturated bicyclic anhydride **6** which gave almost the same yields as the saturated bicyclic anhydrides (**4** and **5**, Table I).

The spiroannelation process based on the ability of 1,4-bis(bromomagnesio)butane and 1,5-bis(bromomagnesio)pentane to react with one of the carbonyls of the anhydride and the subsequent transformations to the spiro γ- and δ-lactones are represented in Scheme I.

It is not known with certainty whether the di-Grignard reagent exists in tetrahydrofuran solution as a monomeric or a dimeric species.[27,28]

Whereas Blomberg et al.[27] suggested that the 1,5-bis(bromomagnesio)pentane in tetrahydrofuran solution is monomeric, they established the existence of equilibrium 1. This observation of the existence of Schlenk's equilibrium was confirmed qualitatively during our experiments with this dimagnesium compound: preparing the 1,5-bis(bromomagnesio)pentane at lower temperature precipitated the insoluble $MgBr_2$ from tetrahydrofuran di-Grignard solution. The formation of $MgBr_2$ was not observed when we prepared, under the same conditions, the 1,4-bis(bromomagnesio)butane which remains as a clear green solution under these conditions. However at room temperature the two organomagnesium compounds showed the same physical aspects. The mechanism of the addition of organodimagnesium compounds to cyclic anhydrides has not yet been studied, either a four- or six-membered cyclic process being possible.

Scheme II



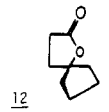
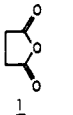
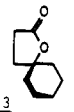
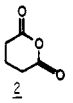
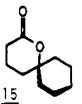
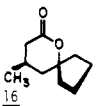
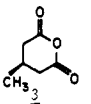
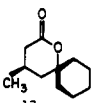
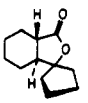
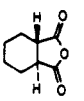
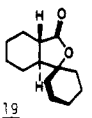
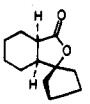
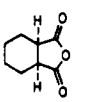
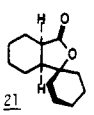
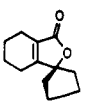
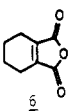
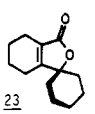
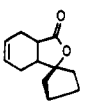
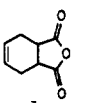
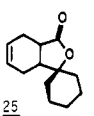
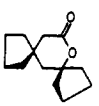
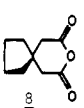
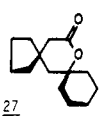
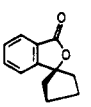
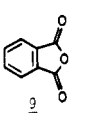
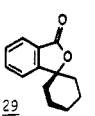
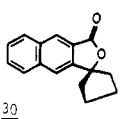
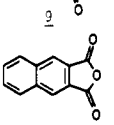
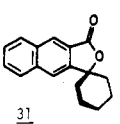
$$BrMg(CH_2)_5MgBr \rightleftharpoons (CH_2)_5Mg + MgBr_2 \quad (1)$$

To simplify Scheme I, we have retained only the mechanism based on a four-membered cyclic process. Furthermore, for the same reason, we have omitted the coordination step.

As it is presented in the Scheme I, the keto acid is the intermediate compound formed from the first attack on the carbonyl of the carboxylic anhydride. An intramolecular subsequent attack on the carbonyl of the keto carboxylate leads to the formation of the new ring. Our results suggest that a four-centered cyclic transition state (2) is involved. This particular case and those previously

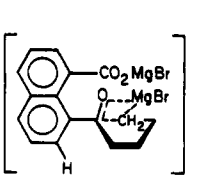
(27) H. C. Holtkamp, C. Blomberg, and F. Bickelhaupt, *J. Organomet. Chem.*, **19**, 279 (1969).
(28) B. Denise, J. Ducom, and J. F. Fauvarque, *Bull. Soc. Chim. Fr.*, 990 (1972).

Table I. Spirolactones from the Action of Dimagnesium Compounds with Cyclic Dicarboxylic Acid Anhydrides

% yield	products with $BrMg(CH_2)_4MgBr$	cyclic anhydride	products with $BrMg(CH_2)_5MgBr$	% yield
86	 12	 1	 13	77
80	 14	 2	 15	75
80	 16	 3	 17	74
76	 18	 4	 19	70
76	 20	 5	 21	70
70	 22	 6	 23	70
75	 24	 7	 25	70
75	 26	 8	 27	75
76	 28	 9	 29	76
75	 30	 10	 31	50

described in reactions with lactones[25] lend credence to a four-membered cyclic process for the intramolecular addition of functionalized Grignard reagents to ketones.

In Scheme II we summarize the reaction of bis(bromomagnesio)alkanes with the 1,8-naphthalenecarboxylic anhydride. The steric factors have an important effect on the two steps involved in this reaction. In the case of 1,5-bis(bromomagnesio)pentane, the second attack is controlled largely by steric factors as was noted for the formation of compound **34** (Figure 1). IR and NMR spectroscopic data revealed the presence of the δ-lactone **34** and only traces of the expected spiro δ-lactone **33**. The inclusion of this example permits the establishment of the limits of the synthetic possibilities of this method. The low yield of **34** and **33** can be explained by the peri steric effects, absent in 2,3-naphthalenecarboxylic anhydride for which results are more satisfactory. The present method



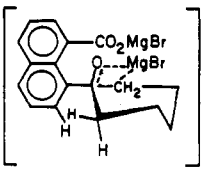
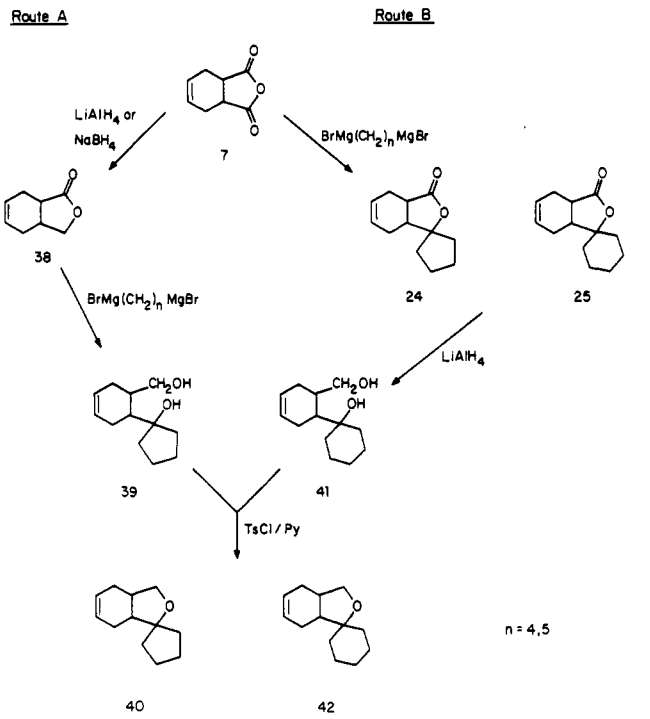


Figure 1.

Scheme III

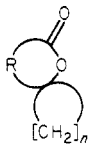


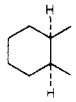
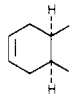
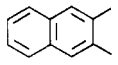
also offers a new route for the synthesis of hindered 1-(ω-hydroxyalkyl)cycloalkanols. To compare the two possible methods for the synthesis of diols from anhydrides and their subsequent transformation into corresponding spiroethers (not previously described), we followed the two alternative routes (A and B) which are illustrated in Scheme III. Experimentation shows in fact that route B is easier than route A: the partial reduction of the cyclic anhydride to the corresponding lactone **38** is a more complicated reaction, requiring more experimental ability than the reduction of spirolactones **24** and **25** to the corresponding 1-(ω-hydroxyalkyl)cycloalkanols. The other steps are similar.

The spiro δ-lactones reported in the present paper were less studied than the spiro γ-lactones. The general classical methods which have been used for their synthesis are the oxidation of the corresponding spirocyclanones[23] and the direct lactonization of the corresponding alkenes.[18,29] Recently, a new route involving the addition of allyl

(29) I. D. Rae and B. N. Umbrasas, *Aust. J. Chem.*, **28**, 2669 (1975).

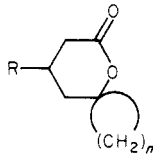
Table II. ^{13}C NMR Chemical Shifts for Spiro γ-Lactones[a]



compd	R	n	C_1	C_3	C_4	C_5
12	$(CH_2)_2$	4	94.9	176.6	32.7	29.9
13	$(CH_2)_2$	5	86.3	176.6	33.0	28.6
18		4	96.8	176.9	49.6	45.3
19		5	86.9	177.0	53.0	43.9
20		4	95.7	177.8	43.7	41.4
21		5	85.6	177.7	41.8	39.6
22		4	96.1	171.8	164.9	125.9
23		5	87.4	172.2	167.9	125.2
24		4	96.5	178.5	40.1	38.9
25		5	86.7	178.8	40.1	37.8
28		4	95.5	169.9	152.9	126.4
29		5	86.9	170.0	155.1	125.1
30		4	95.7	169.8	147.2	136.6
31		5	87.1	170.0	149.1	136.5

[a] Chemical shifts are in δ from Me_4Si.

Table III. ^{13}C NMR Chemical Shifts for Spiro δ-Lactones[a]



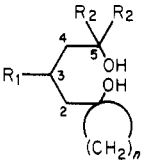
compd	R	n	C_1	C_3	C_4	C_5
14	H	4	93.1	171.4	32.4	29.4
15	H	5	83.0	171.4	32.7	29.6
16	CH_3	4	92.8	171.3	41.3	39.3
17	CH_3	5	82.9	171.3	41.9	38.4
26	$(CH_2)_4$	4	92.0	171.7	42.0	44.9
27	$(CH_2)_4$	5	82.6	172.0	41.6	40.0

[a] Chemical shifts are in δ from Me_4Si.

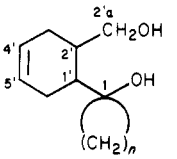
Grignard reagent to the appropriate carbonyl substrate was reported.

The classical oxidation method was used for the synthesis of a bis spiro γ-lactone, from the appropriate 2,2,4,4-bis(tetramethylene)cyclobutanone.[30] In consideration of the difficulty in obtaining the tetramethylenecyclanones, we wished to extend our method to a new series of compounds and to apply it to the synthesis of the bis(tetramethylene) δ-lactone **26** and the tetramethylene pentamethylene δ-lactone **27**. Since the diols **35** and **37** have not been described, we also realized their syntheses (Scheme IV). The lactone **26** was treated with 1,4-bis(bromomagnesio)butane to afford the diol **37** and with $LiAlH_4$ to give the diol **35**. Both reactions permitted excellent yields.

Table IV. ^{13}C NMR Chemical Shift Comparative Study for Diols[a]



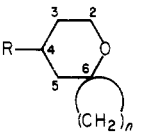
compd	C_1	C_2	C_3	C_4	C_5	C_{Me}
35	83.6	39.5	45.6	48.8	60.3	
37	83.6	47.3	47.0	47.3	83.6	
43	72.3	39.1	26.0	48.5	60.8	22.5
45	83.0	40.0	26.6	48.0	60.7	22.6



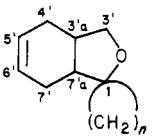
compd	C_1	$C_{1'}$	$C_{2'}$	$C_{2'\alpha}$	$C_{4'}$	$C_{5'}$
39	84.1	47.0	37.0	63.4	127.0	125.1
41	72.2	45.0	34.0	63.2	127.1	124.9

[a] Chemical shifts are in δ from Me_4Si.

Table V. ^{13}C NMR Chemical Shift Comparative Study for Spiroethers[a]



compd	C_2	C_3	C_4	C_5	C_6	C_{Me}
36	60.1	37.2	41.0	47.0	83.6	
44	59.8	48.1	26.5	41.7	72.8	22.5



compd	C_1	$C_{3'}$	$C_{3'a}$	$C_{4'}$	$C_{5'}$	$C_{6'}$	$C_{7'}$	$C_{7'a}$
40	94.5	71.3	35.9	24.1	125.8	125.3	25.0	42.0
42	84.5	71.3	35.4	23.9	126.2	125.7	25.2	42.4

[a] Chemical shifts are in δ from Me_4Si.

Table VI. IR Data Characterizing Intramolecular Hydrogen Bonding of Diols[a]

diol	ν_F, cm^{-1}	ν_B, cm^{-1}	$\Delta\nu$
35	3650	3510	140
37	3625	3485	140
39	3640	3485	155
41	3645	3475	170
43	3650	3520	130
45	3648	3505	143

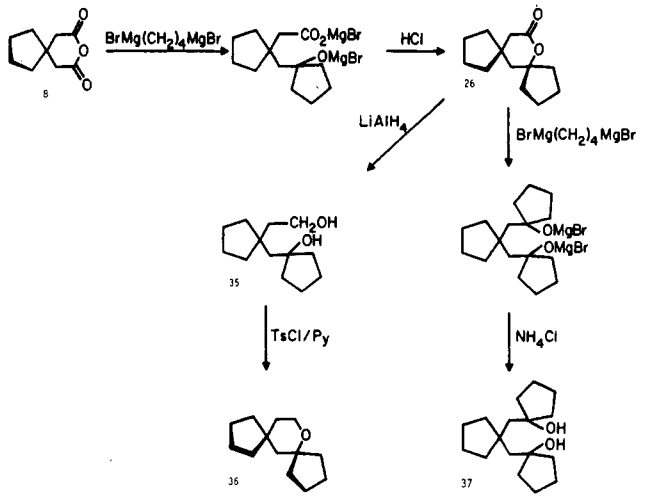
[a] ν_F = free hydroxyl stretching frequencies. ν_B = intramolecular hydroxyl stretching frequencies. Spectra were recorded in 0.5×10^{-3} M CCl_4 solution.

The compound **35**, so formed, presents another point of interest. It was subjected to intramolecular cyclization according to the tosylate technique[25,31] in order to readily obtain the desired spiroether **36**, which has not been prepared previously. Also, a second example serves to

(30) R. Jeanne-Carlier and F. Bourelle-Wargnier, *Bull. Soc. Chim. Fr.*, 297 (1976).

(31) P. Picard, D. Leclercq, and J. Moulines, *Tetrahedron Lett.*, 2731 (1975).

Scheme IV



illustrate other applications of our spiroannelative method (Tables IV and V).

The spirolactones, spiroethers, and diols were found to be, by chromatography and microanalysis, pure compounds, after distillation or recrystallization. The IR, NMR, and mass spectral data confirmed the assignments of structures (see Experimental Section).

It seemed interesting to investigate some conformational aspects of the compounds presented in this paper, as an extension of our previous work.[25] IR and ^{13}C NMR data show general findings throughout the series. The results are recorded in Tables II–VI.

In ^{13}C NMR spectra, we noted that the value of chemical shifts for the spiranic carbon varies according to the size of the spiranic ring (Tables II and III). For the five-membered ring, the cited carbon is much more deshielded than for the six-membered ring (8.5 to 10 ppm) and this same trend was noted when comparing spiro γ-lactones and spiro δ-lactones (4–5 ppm). The carbonyl carbon nuclear shielding is not affected by the size of the spiranic ring, but only by the size of the lactonic ring (5.5 ppm, from γ- to δ-lactones) and by the presence of an α-unsaturation (5.5 to 7 ppm). In the case of the dispirolactones **26** and **27**, it is interesting to point out that the second spiranic carbon (C_5) is similarly affected by the size of the other spiranic ring (4.9 ppm; Table III).

For the diols (Table IV), we observed the same difference of chemical shift values of the potentially spiranic carbon; it is deshielded from a cyclohexanol to a cyclopentanol. The diol **37** presents an evident symmetry, since the C_1–C_5 and C_2–C_4 values are identical.

Table V shows the ^{13}C data for spiroethers, and again, the same particularity about the spiranic carbon is observed (10–11 ppm). The effect is similar for spirolactones and spiroethers.

A study of the IR spectra of diols in solution showed the degree intramolecular OH bonding (Table VI). The difference ($\Delta\nu$) between ν_F and ν_B bands indicates that the OH groups are close together and that the hydrogen bond is relatively strong. In the case of diols **35**, **37**, **43**, and **45**, such intramolecular OH bonding gets some consideration because the corresponding diols without substituents (1-(4-hydroxybutyl)cyclopentanol and -cyclohexanol)[25] do not show any ν_B band. It is also clear that the population of the pseudospiranic chelated conformation of such compounds has definitely increased with the presence of substituents in the aliphatic chain. For the pair of diols **39** and **41**, we noted from IR spectra the same chelated cyclic conformation.

Likewise in the NMR spectra, H_a and H_m of these diols (**39** and **41**) manifest a notable difference in chemical shift, as already reported previously for the corresponding hexahydro derivatives (see ref 25). It appears that H_a is affected by the paramagnetic zone of the oxygen, since the conformation is similar in both cases.

In summary, this method should find considerable use for the preparation of a variety of spiro γ- and δ-lactones and spiroethers, as well as for the conformational study of a serie of resulting 1-(ω-hydroxylalkyl)cycloalkanols.

Experimental Section

Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Boiling points are uncorrected. Analytical thin-layer chromatography was performed on EM silica gel 60 F 254 plates (0.25 mm). Column chromatography was carried out on silica gel 60 F 254 (70–230-mesh ASTM) for dry-column chromatography. Infrared spectra were obtained on a Beckman IR-12 spectrophotometer. ^1H NMR spectra were determined on a Bruker HX-90 spectrometer and are reported in δ units downfield from Me_4Si. ^{13}C NMR spectra were determined on a Bruker-WP-80 (20.1 MHz) apparatus in $CDCl_3$ solution (0.75 mol/L), using Me_4Si as an internal standard. Mass spectra were obtained in a Varian M-66 spectrometer and microanalyses were performed by Chemalytics Inc.

Starting Materials. Tetrahydrofuran was distilled from lithium aluminum hydride into oven-dried flasks and kept over sodium wire. Magnesium turnings, 1,4-dibromobutane, 1,5-dibromopentane, 1,6-dibromohexane, and all anhydrides (1–11), except **10**, were commercially available. 2,3-Naphthalenedicarboxylic acid anhydride (**10**) was prepared by the method of Friedman,[32] by oxidation of 2,3-dimethylnaphthalene with sodium dichromate and treatment of the corresponding diacid with acetic anhydride.

Preparation of Spirolactones 12–34. General Method. The corresponding anhydride 1–11 (0.06 mol) in anhydrous THF (~50 mL) was added dropwise with stirring under nitrogen to 0.065 mol of the organodimagnesium compound in the same solvent (150 mL).[25] The reaction mixture was stirred overnight under an atmosphere of nitrogen. After hydrolysis with dilute (5–10%) hydrochloric acid and stirring an additional hour at 40 °C, the organic layer was separated, the aqueous layer was extracted with ether, and the combined organic layers were dried over anhydrous sodium sulfate. The solution was concentrated in vacuo and the residue was purified, either by distillation, crystallization or column chromatography.

1-Oxaspiro[4.4]nonan-2-one (12):[25,26] bp 59–61 °C (0.7 mmHg); 86% yield; ^1H NMR δ 1.56–2.0 (m, 8 H), 2.1–2.31 (m, 2 H), 2.5–2.75 (m, 2 H); IR (neat) 1770 cm^{-1}.

1-Oxaspiro[4.5]decan-2-one (13):[9,25,26] bp 51–52 °C (0.3 mmHg); 77% yield; ^1H NMR δ 1.2–1.93 (m, 10 H), 1.93–2.15 (m, 2 H), 2.5–2.73 (m, 2 H); IR (neat) 1775 cm^{-1}.

6-Oxaspiro[4.5]decan-7-one (14):[25,26] bp 69–71 °C (0.4 mmHg); 80% yield; ^1H NMR δ 1.48–2.07 (m, 12 H), 2.45–2.69 (m, 2 H); IR (neat) 1730 cm^{-1}.

1-Oxaspiro[5.5]undecan-2-one (15):[25,26] bp 92–94 °C (0.4 mmHg); recrystallized from pentane; mp 45–46 °C; 75% yield; ^1H NMR δ 1.22–2.05 (m, 14 H), 2.35–2.6 (m, 2 H); IR (neat) 1730 cm^{-1}.

9-Methyl-6-oxaspiro[4.5]decan-7-one (16): bp 71–72 °C (0.02 mmHg); 80% yield; ^1H NMR δ 1.03 (d, 3 H, J = 6 Hz), 1.44–2.20 (m, 12 H), 2.64 (dd, 1 H, J = 2, 12 Hz); IR (neat) 1727 cm^{-1}; mass spectrum (70 eV), m/e (relative intensity) 168 (M^+, 100), 140 (52), 126 (44), 112 (59). Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.23; H, 9.67.

4-Methyl-1-oxaspiro[5.5]undecan-2-one (17): bp 82–84 °C (0.02 mmHg); 74% yield; ^1H NMR δ 1.01 (d, 3 H, J = 6 Hz), 1.22–2.29 (m, 14 H), 2.63 (dd, 1 H, J = 2, 12 Hz); IR (neat) 1730 cm^{-1}; mass spectrum (70 eV), m/e (relative intensity) 182 (M^+, 100), 154 (38), 140 (51), 126 (40). Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.38; H, 10.04.

(32) L. Friedman, *Org. Synth.*, 43, 80 (1963).

3′a,7′a-*trans*-3′a,4′,5′,6′,7′,7′a-Hexahydrospiro[cyclopentane-1,1′(3′*H*)-isobenzofuran]-3′-one (18):[25] recrystallized from ether/pentane; mp 61.5–62 °C; 76% yield; ^{1}H NMR δ 1.02–2.34 (complex m); IR (KBr) 1755 cm^{-1}.

3′a,7′a-*trans*-3′a,4′,5′,6,7′,7′a-Hexahydrospiro[cyclohexane-1,1′(3′*H*)-isobenzofuran]-3′-one (19):[25,33] recrystallized from ether/pentane; mp 99–100 °C; 70% yield; ^{1}H NMR δ 1.0–2.4 (complex m); IR (KBr) 1760 cm^{-1}.

3′a,7′a-*cis*-3′a,4′,5′,6′,7′,7′a-Hexahydrospiro[cyclopentane-1,1′(3′*H*)-isobenzofuran]-3′-one (20):[25,26] bp 74–76 °C (0.02 mmHg); recrystallized from ether/pentane; mp 80.5–81 °C; 76% yield; ^{1}H NMR δ 1.0–2.45 (m, 17 H), 2.81–3.11 (m, 1 H); IR (KBr) 1775 cm^{-1}.

3′a,7′a-*cis*-3′a,4′,5′,6′,7′,7′a-Hexahydrospiro[cyclohexane-1,1′(3*H*)-isobenzofuran]-3′-one (21):[25,26,33] bp 106–109 °C (0.04 mmHg); recrystallized from ether–pentane; mp 55–56 °C; 70% yield; ^{1}H NMR δ 1.0–2.35 (m, 19 H), 2.85–3.06 (m, 1 H); IR (neat) 1775 cm^{-1}.

4′,5′,6′,7′-Tetrahydrospiro[cyclopentane-1,1′(3′*H*)-isobenzofuran]-3′-one (22):[26] bp 82–84 °C (0.02 mmHg); recrystallized from ether/pentane; mp 39–39.5 °C; 70% yield; ^{1}H NMR δ 1.55–2.07 (m, 12 H), 2.22 (m, 4 H); IR (KBr) 1740, 1675 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 192 (M$^+$, 100), 164 (64), 122 (31), 108 (21), 79 (20). Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.96; H, 8.39. Found: C, 74.81; H, 8.45.

4′,5′,6′,7′-Tetrahydrospiro[cyclohexane-1,1′(3*H*)-isobenzofuran]-3′-one (23):[26,33] bp 114–115 °C (0.02 mmHg); recrystallized from ether/pentane; mp 74–75 °C; 70% yield; ^{1}H NMR δ 1.41–2.00 (m, 14 H), 2.21 (m, 4 H); IR (KBr) 1750, 1680 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 206 (M$^+$, 100), 178 (14), 163 (47), 150 (55), 135 (31). Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.68; H, 8.79. Found: C, 75.52; H, 8.43.

3′a,7′a-*cis*-3′a,4′,7′,7′a-Tetrahydrospiro[cyclopentane-1,1′(3*H*)-isobenzofuran]-3′-one (24):[26] bp 118–120 °C (0.02 mmHg); recrystallized from ether/pentane; mp 51–51.5 °C; 75% yield: ^{1}H NMR δ 1.83 (m, 10 H), 2.38 (t, 1 H, *J* = 4.5 Hz), 2.47 (m, 2 H), 3.02 (m, 1 H), 5.74 (m, 2 H); IR (KBr) 1780, 1660 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 192 (M$^+$, 100), 163 (64), 147 (50), 124 (26), 107 (30), 79 (76). Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.96; H, 8.39. Found: C, 74.79; H, 8.46.

3′a,7′a-*cis*-3′a,4′,7′,7′a-Tetrahydrospiro[cyclohexane-1,1′-(3′*H*)-isobenzofuran]-3′-one (25):[26] recrystallized from ether/pentane; mp 46.5–47 °C; 70% yield; ^{1}H NMR δ 1.22–1.90 (m, 10 H), 2.03 (dt, 1 H, *J* = 1.5, 4.5 Hz), 2.16–2.58 (m, 4 H), 3.11 (m, 1 H), 5.78 (m, 2 H); IR (KBr) 1775, 1660 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 206 (M$^+$, 86), 163 (100), 124 (30), 108 (31), 79 (37). Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.68; H, 8.79. Found: C, 75.47; H, 8.56.

12-Oxadispiro[4.1.4.3]tetradecan-13-one (26): bp 106–109 °C (0.01 mmHg); 75% yield; ^{1}H NMR δ 1.11–2.11 (m, 16 H), 1.85 (s, 2 H), 2.28 (s, 2 H); IR (neat) 1715 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 208 (M$^+$, 100), 180 (71), 166 (37), 152 (44). Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.79; H, 9.69.

13-Oxadispiro[4.1.5.3]pentadecan-14-one (27): bp 129–130 °C (0.02 mmHg); 75% yield; ^{1}H NMR δ 1.17–1.87 (m, 18 H), 1.78 (s, 2 H), 2.34 (s, 2 H); IR (neat) 1728 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 222 (M$^+$, 100), 194 (50), 180 (43), 166 (47). Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.98. Found: C, 75.54; H, 10.08.

Spiro[cyclopentane-1,1′(3′*H*)-isobenzofuran]-3′-one (28):[25,26] bp 108–110 °C (0.08 mmHg); recrystallized from ether/pentane; mp 75 °C; 75% yield; ^{1}H NMR δ 1.86–2.23 (m, 8 H), 7.3–7.92 (m, 4 H); IR (KBr) 1752, 1622, 1605, 747 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 188 (M$^+$, 82), 160 (100). Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.36; H, 6.48.

Spiro[cyclohexane-1,1′(3′*H*)-isobenzofuran]-3′-one (29):[25,26,34] bp 106–108 °C (0.02 mmHg); recrystallized from ether/pentane; mp 78–79 °C; 76% yield; ^{1}H NMR δ 1.56–2.02 (m, 10 H), 7.29–7.89 (m, 4 H); IR (KBr) 1770, 1620, 1608 cm^{-1}.

Spiro[cyclopentane-1,1′(3*H*)-isonaphthofuran]-3′-one (30): recrystallized from ether/pentane; mp 135–136 °C; 75% yield; ^{1}H NMR δ 2.18 (m, 8 H), 7.51–7.74 (m, 2 H), 7.79–8.11 (m, 3 H), 8.4 (s, 1 H); IR (CCl_4) 1770, 1648 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 238 (M$^+$, 68), 209 (100), 198 (18), 126 (17). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H, 5.92. Found: C, 80.57; H, 6.10.

Spiro[cyclohexane-1,1′(3′*H*)-isonaphthofuran]-3′-one (31): recrystallized from ether/pentane; mp 127–127.5 °C; 50% yield; ^{1}H NMR δ 1.87 (m, 10 H), 7.43–7.69 (m, 2 H), 7.70–8.12 (m, 3 H), 8.43 (s, 1 H); IR (CCl_4) 1770, 1650 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 252 (M$^+$, 79), 223 (100), 210 (29), 126 (13). Anal. Calcd for $C_{17}H_{16}O_2$: C, 80.92; H, 6.39. Found: C, 80.80; H, 6.33.

Spiro[cyclopentane-1,1′(3′*H*)-2′-oxaphenalen]-3′-one (32): recrystallized from ether/pentane; mp 86.5–87.5 °C; 45% yield; ^{1}H NMR δ 1.6–2.6 (m, 8 H), 7.2–7.57 (m, 3 H), 7.66 (dd, 1 H, *J* = 1.5, 7 Hz), 7.92 (dd, 1 H, *J* = 1.5, 8.5 Hz), 8.22 (dd, 1 H, *J* = 1, 7 Hz) IR (KBr) 1725, 1638 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 238 (M$^+$, 75), 209 (100), 196 (12), 126 (20). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H, 5.92. Found: C, 80.44; H, 6.04.

Reaction of 1,8-Naphthalic Anhydride and Pentane-1,5-diyldimagnesium Dibromide. The usual procedure was employed to obtain the crude material (as described above for compounds **12–32**). Workup of the reaction mixture gave a brown oil. Separation of the products was accomplished by flash chromatography[35] of 20 g of the mixture on 32–63-μm silica gel, with 5% ethyl acetate/petroleum ether. Elution with 750 mL gave 290 mg (15%) of a lactonic product (**34**) and several fractions of impure material from which no spirolactone (**33**) could be isolated. An analytical sample of **34** was prepared by successive recrystallizations and it was found to be 1-*n*-pentyl-2(3*H*)-oxaphenalen-3-one: recrystallized from ether/ligroin; mp 107–107.5 °C; 15% yield; ^{1}H NMR δ 0.90 (m, 3 H), 1.39 (m, 6 H), 2.11 (m, 2 H), 4.23 (m, 1 H), 6.94–7.34 (m, 6 H); IR (CCl_4) 1735 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intesnity) 254 (M$^+$, 71), 225 (100), 211 (21). Anal. Calcd for $C_{17}H_{18}O_2$: C, 80.28; H, 7.13. Found: C, 80.10; H, 7.29.

1-(4-Hydroxy-2,2-tetramethylenebutyl)cyclopentanol (35). The spirolactone **26** (0.03 mol) in anhydrous ether (75 mL) was added dropwise at 0 °C to a stirred suspension of lithium aluminium hydride (0.03 mol) in the same solvent (45 mL). The mixture was stirred an additional hour at room temperature, after which time it was hydrolyzed with saturated ammonium chloride, followed by the usual workup. Recrystallization of the crude material from heptane affords the pure diol **35**: mp 52.5–53.5 °C; 90% yield; ^{1}H NMR δ 1.29–1.80 (m, 16 H), 1.78 (t, 2 H, *J* = 6 Hz), 1.80 (s, 2 H), 3.67 (m, 2 H, OH), 3.72 (t, 2 H, *J* = 6 Hz); IR (neat) 3320 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 212 (M$^+$, 11), 194 (22), 166 (100). Anal. Calcd for $C_{13}H_{24}O_2$: C, 73.54; H, 11.39. Found: C, 73.61; H, 11.52.

12-Oxadispiro[4.1.4.3]tetradecane (36). The following procedure gave the most consistent results. To a stirred solution of the diol **35** (0.02 mol) in dry pyridine (50 mL) was added 20 mmol of *p*-toluenesulfonyl chloride (TsCl) in small portions with cooling. After being stirred for 2 h at 0 °C, the resulting mixture was poured into water, extracted with ether, washed with water, and dried with anhydrous sodium sulfate. After removal of the solvent, the residual tosylate was dissolved in hexamethylphosphoric triamide (HMPT) (20 mL)[25,31] and heated at 80 °C for 6 h. The mixture was treated with water and extracted with chloroform. The combined extracts were washed with water and 5% HCl and dried (Na_2SO_4). The solvent was removed in vacuo and the residual oil distilled: bp 66–68 °C (0.02 mmHg); 78% yield; ^{1}H NMR δ 1.24–2.04 (m, 20 H), 3.60 (t, 2 H, *J* = 6 Hz); IR (neat) 1260, 1060 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 194 (M$^+$, 100). Anal. Calcd for $C_{13}H_{22}O$: C, 80.35; H, 11.41. Found: C, 80.52; H, 11.35.

1,1,3,3,5,5-Tris(tetramethylene)-1,5-pentanediol (37). This diol **37** was prepared from lactone **26** and butane-1,4-diyldimagnesium dibromide, according to the method of Canonne.[25] The product was obtained by treatment with pentane and recrystallized from ether/pentane, mp 111–112 °C; 75% yield; ^{1}H

(33) C. G. Overberger and P. Kabasakalian, *J. Am. Chem. Soc.*, **79**, 3182 (1957).

(34) G. M. Pogosyan, A. A. Saakyan, E. S. Avanesyan, and S. G. Matsoyan, *Zh. Org. Khim.*, **3**, 1165 (1967).

(35) W. C. Still, M. Kahn, and A. Mitra, *J. Org. Chem.*, **43**, 2923 (1978).

NMR δ 1.42–1.96 (m, 24 H), 1.93 (s, 4 H), 3.44 (s, 2 H, OH); IR (KBr) 3325 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 266 (M$^+$, 18), 248 (100). Anal. Calcd for $C_{17}H_{30}O_2$: C, 76.64; H, 11.35. Found: C, 76.83; H, 11.33.

3a,7a-*cis*-3a,4,7,7a-Tetrahydroisobenzofuran-3(3*H*)-one (38). This lactone was prepared by $LiAlH_4$ reduction of the corresponding anhydride **7**, according to the method of Bloomfield and Lee:[36] bp 69–71 °C (0.01 mmHg); 74% yield; ^{1}H NMR δ 1.78–3.02 (br m, 7 H), 4.31 (m, 1 H), 5.75 (m, 2 H); IR (neat) 1775, 1660 cm^{-1}.

1-[1,2-*cis*-(2-Hydroxymethyl)cyclohex-4-enyl]cyclopentanol (39). This diol **39** was prepared from spirolactone **24**, as described above for compound **35**: recrystallized from ether/ligroin; mp 86–87 °C; 83% yield; ^{1}H NMR δ 1.72 (m, 9 H), 2.22 (m, 4 H), 2.38 (m, 1 H), 3.43 (dd, 1 H, AMX, J_{AM} = 10, J_{MX} = 3 Hz, 2′-methylenic H), 3.67 (br m, 2 H, OH), 3.89 (t, 1 H, AMX, J_{AM} = J_{AX} = 10 Hz, 2′-methylenic H), 5.61 (m, 2 H); IR (KBr) 3210, 3025, 1660 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 196 (M$^+$, 16), 178 (25), 150 (100). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.33; H, 10.39.

3′a,7′a-*cis*-3′a,4′,7′,7′a-Tetrahydrospiro[cyclopentane-1,1′(3′*H*)-isobenzofuran] (40). This spiroether was prepared from diol **39** as described above for compound **36**: bp 70–72 °C (0.01 mmHg); 84% yield; ^{1}H NMR δ 1.46 (m, 8 H), 2.04 (m, 4 H), 2.59 (dd, 2 H, *J* = 9 Hz), 3.46 (t, 1 H, *J* = 8 Hz), 3.80 (t, 1 H, *J* = 8 Hz), 5.69 (m, 2 H); IR (neat) 1045 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 178 (M$^+$, 100). Anal. Calcd for $C^{12}H^{18}O$: C, 80.85; H, 10.18. Found: C, 80.69; H, 10.19.

1-[1,2-*cis*-(2-Hydroxymethyl)cyclohex-4-enyl]cyclohexanol (41). This diol **41** was prepared from spirolactone **25**, a described above for compound **35**: recrystallized from ether/ligroin; mp 93–93.5 °C; 85% yield; ^{1}H NMR δ 1.54 (m, 11 H), 2.00 (m, 4 H), 2.24 (m, 1 H), 3.39 (dd, 1 H, AMX, J_{AM} = 10, J_{MX} = 3 Hz, 2′-methylenic H), 3.84 (t, 1 H, AMX, J_{AM} = J_{AX} = 10 Hz, 2′-methylenic H), 3.89 (br m, 2 H, OH), 5.60 (m, 2 H); IR (KBr) 3230, 3030, 1660 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 210 (M$^+$, 11), 192 (29), 164 (100). Anal. Calcd for $C_{13}H_{22}O_2$: C, 74.24; H, 10.55. Found: C, 74.21; H, 10.45.

3′a,7′a-*cis*-3′a,4′,7′,7′a-Tetrahydrospiro[cyclohexane-1,1′-(3′*H*)-isobenzofuran] (42). This spiroether was prepared from diol **41** as described above for compound **36**: bp 66–68 °C (0.01 mmHg); 82% yield; ^{1}H NMR δ 1.51 (m, 10 H), 2.01 (m, 4 H), 2.64 (d, 2 H, *J* = 9 Hz), 3.53 (t, 1 H, *J* = 8 Hz), 3.89 (t, 1 H, *J* = 8 Hz), 5.71 (m, 2 H); IR (neat) 1050 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 192 (M$^+$, 100). Anal. Calcd for $C_{13}H_{20}O$: C, 81.20; H, 10.48. Found: C, 81.28; H, 10.35.

1-(4-Hydroxy-2-methylbutyl)cyclohexanol (43). This diol **43** was prepared from spirolactone **17**, as described above for compound **35**. After fractional distillation, it had bp 98–100 °C (0.01 mmHg): 92% yield; ^{1}H NMR δ 0.98 (d, 3 H, *J* = 6 Hz), 1.05–1.96 (m, 15 H), 2.78 (br m, 2 H, OH), 3.67 (2 H, t, *J* = 6 Hz); IR (KBr) 3335, 1360, 1110 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 186 (M$^+$, 12), 168 (29), 140 (100). Anal. Calcd for $C_{11}H_{22}O_2$: C, 70.92; H, 11.91. Found: C, 70.78; H, 12.08.

4-Methyl-1-oxaspiro[5.5]undecane (44). This spiroether was prepared from diol **43** as described above for compound **36**: bp 75–77 °C (8 mmHg); 84% yield: ^{1}H NMR δ 1.00 (d, 3 H, *J* = 6 Hz), 1.21–1.91 (m, 15 H), 3.42 (2 H, t, *J* = 7 Hz); IR (neat) 1255, 1050 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 168 (M$^+$, 100). Anal. Calcd for $C_{11}H_{20}O$: C, 78.51; H, 11.98. Found: C, 78.45; H, 12.12.

1-(4-Hydroxy-2-methylbutyl)cyclopentanol (45). This diol **45** was prepared from spirolactone **16**, as described above for compound **35**. After fractional distillation, it had bp 95–97 °C (0.01 mmHg): 93% yield; ^{1}H NMR δ 0.97 (d, 3 H, *J* = 7 Hz), 1.25–1.91 (m, 13 H), 2.33 (br s, 2 H, OH), 3.46 (2 H, t, *J* = 6 Hz); IR (KBr) 3315, 1360, 1100 cm^{-1}; mass spectrum (70 eV), *m/e* (relative intensity) 172 (M$^+$, 16), 154 (38), 126 (100). Anal. Calcd for $C_{10}H_{20}O_2$: C, 69.72; H, 11.70. Found: C, 66.79; H, 11.79.

Acknowledgment. We thank the National Research Council of Canada and le Ministère de l'éducation du Gouvernement du Québec for support of this work and Professor R. H. Burnell for helpful discussions.

Registry No. **1**, 108-30-5; **2**, 108-55-4; **3**, 4166-53-4; **4**, 14166-21-3; **5**, 13149-00-3; **6**, 2426-02-0; **7**, 85-43-8; **8**, 5662-95-3; **9**, 85-44-9; **10**, 716-39-2; **11**, 81-84-5; **12**, 33448-80-5; **13**, 699-61-6; **14**, 20127-07-5; **15**, 4481-78-1; **16**, 77520-32-2; **17**, 77520-33-3; **18**, 73090-08-1; **19**, 73090-10-5; **20**, 73090-07-0; **21**, 73090-09-2; **22**, 74279-79-1; **23**, 74279-81-5; **24**, 74279-80-4; **25**, 74279-82-6; **26**, 77520-34-4; **27**, 77520-35-5; **28**, 73090-06-9; **29**, 5651-49-0; **30**, 77520-36-6; **31**, 77520-37-7; **32**, 77520-38-8; **34**, 77520-39-9; **35**, 77520-40-2; **36**, 77520-41-3; **37**, 77520-42-4; **38**, 2744-05-0; **39**, 77520-43-5; **40**, 77520-44-6; **41**, 77520-45-7; **42**, 77520-46-8; **43**, 77520-47-9; **44**, 62809-36-3; **45**, 77520-48-0; 1,4-dibromobutane, 110-52-1; 1,5-dibromopentane, 111-24-0; 1,6-dibromohexane, 629-03-8.

(36) J. J. Bloomfield and S. L. Lee, *J. Org. Chem.*, **32**, 3919 (1967).
(37) M. J. Bogdanowicz, T. Ambelang, and B. M. Trost, *Tetrahedron Lett.*, 923 (1973).

Synthesis of Carboxylic Acids and Esters Using Polymer-Bound Oxazolines

Arthur R. Colwell, Louis R. Duckwall, Reda Brooks, and Samuel P. McManus*

Department of Chemistry, The University of Alabama in Huntsville, Huntsville, Alabama 35899

Received December 30, 1980

2,4-Dimethyl-4-(hydroxymethyl)-2-oxazoline was attached to cross-linked polystyrene, giving the polymer-bound oxazoline **3**. Alkylation of **3**, followed by hydrolysis or ethanolysis, provided α and α,α′ mono- and dialkylated acetic acids or their ethyl esters in 68–81% yields. The recovered polymer-bound amino alcohol was recycled to **3** with some reduced capacity. The chiral polymer-bound oxazoline **10** was prepared for use in the asymmetric synthesis of optically active carboxylic acids and other functional derivatives. Although chemical and optical yields similar to those of solution reactions were obtained, the insensitivity of α-substituted 2-oxazolines to hydrolysis greatly reduces the promise of the solid-phase method.

Asymmetric synthesis with chiral polymer-bound templates is an important topic for study for economic reasons and because of possible similarities with enzyme-directed synthesis. Leznoff[1] recently described the asymmetric solid-phase synthesis of 2-alkylcyclohexanones claiming demonstration of the practical reality of this approach. Independently, we have sought to demonstrate the feasibility of using solid supports for binding substrates for use in the asymmetric synthesis of some simple organic functional types.

Meyers[2] has shown that the oxazoline ring system possesses considerable utility in synthesis. By careful defi-

(1) Worster, P. M.; McArthur, C. R.; Leznoff, C. C. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 221.
(2) Meyers, A. I.; Mihelich, E. D. *Angew. Chem., Int. Ed. Engl.* **1976**, *15*, 270. Meyers, A. I. *Acc. Chem. Res.* **1978**, *11*, 375.

0022-3263/81/1946-3097$01.25/0