A Highly Stereoselective Synthesis of Trans-1,2-Disubstituted Cycloalkanols[1]

P. Canonne* and M. Bernatchez

Département de Chimie, Université Laval, Québec, Québec, Canada G1K 7P4

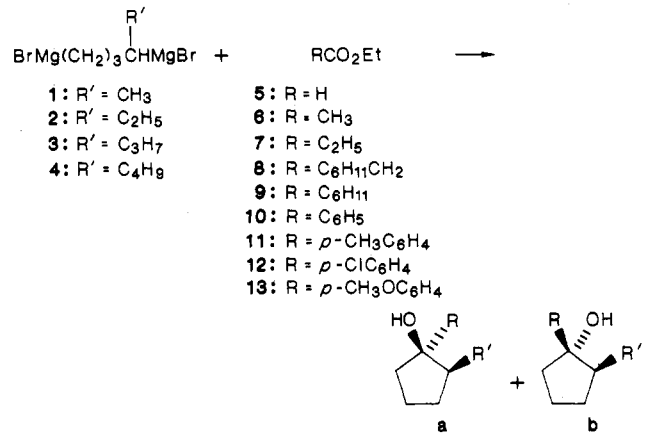
Received November 3, 1986

The study of the reactions of 1,4-bis(bromomagnesio)pentane, 1,4-bis(bromomagnesio)hexane, 1,4-bis(bromomagnesio)heptane, and 1,4-bis(bromomagnesio)octane with aliphatic and aromatic carboxylic acid esters in tetrahydrofuran solution was undertaken in order to ascertain which factors influence isomer distribution. The yields of these annelation processes are in the range of 68–88%. The formation of trans OH 1,2-disubstituted cyclopentanols having the alkyl groups cis is generally observed with yields of 77–96%. The reaction of 1,5-bis(bromomagnesio)hexane with carboxylic acid esters is less stereoselective and is more influenced by steric effects.

The remarkably facile reactions of 1,4-bis(bromomagnesio)butane and 1,5-bis(bromomagnesio)pentane with carboxylic acid derivatives as annelation reagents with esters, lactones, and dicarboxylic acid anhydrides have opened up a new highly convenient route to a large variety of cyclic and spiro compounds.[2-7] The ability of the bis Grignard reagents to perform versatile transformations provides increasing possibilities in organic synthesis. Thus lactones, isoxazolones, and coumarins have been transformed into the corresponding diols, hydroxy oximes, and (hydroxyalkyl)phenols. These compounds easily give spiro lactones, spiroisoxazolines, and spirochromens.

Our work with di-primary bis Grignard reactions has prompted a systematic study using various primary–secondary bis Grignard reagents. It appeared desirable to undertake such as a study using dicarboxylic acid esters as substrates. In a recent preliminary paper we reported on the reactions of 1,4-bis(bromomagnesio)pentane (1) with carboxylic acid esters.[8] We have observed that they lead to the formation of 1-substituted *trans*-2-methylcyclopentanols and show a greater stereoselectivity than the reactions of 1,5-bis (bromomagnesio)hexane. We report here results of the reaction of 1,4-bis(bromomagnesio)-pentane (1), 1,4-bis(bromomagnesio)hexane (2), 1,4-bis-(bromomagnesio)heptane (3), and 1,4-bis(bromomagnesio)octane (4) with various carboxylic acid esters 5–13 in tetrahydrofuran solution (Scheme I). The reaction of 1,4-bis(bromomagnesio)pentane under various experimental conditions was also investigated in order to determine factors that affect the diastereoselection, such as the nature of substitutents in positions 1 and 2 of tertiary 1-substituted 2-alkylcyclopentanols 14–27, the size of the ring, and the nature of the solvent. The latter effect will be reported later.

Scheme I



14: R = R′ = CH_3
15: R = C_6H_5; R′ = CH_3
16: R = C_6H_5; R′ = C_2H_5
17: R = p-$CH_3C_4H_5$; R′ = C_2H_5
18: R = C_6H_5; R′ = C_3H_7
19: R = C_6H_5; R′ = C_4H_9
20: R = CH_3; R′ = C_4H_9
21: R = H; R′ = CH_3
22: R = C_2H_5; R′ = CH_3
23: R = $C_6H_{11}CH_2$; R′ = CH_3
24: R = C_6H_{11}; R′ = CH_3
25: R = p-$CH_3C_6H_4$; R′ = CH_3
26: R = p-ClC_6H_4; R′ = CH_3
27: R = p-$CH_3OC_6H_4$; R′ = CH_3

The 1,4-bis(bromomagnesio)alkanes 1–4 have been prepared in good yields from the corresponding 1,4-dibromoalkanes[9] by using an excess of magnesium turnings in tetrahydrofuran, instead of ether, as previously reported for the preparation of 1,4-bis(bromomagnesio)pentane.[10]

The structure of diprimary bis Grignard reagents has been extensively studied.[11-15] These organomagnesium compounds can exist as monomeric and dimeric species

(1) The nomenclature of the stereochemistry of these alcohols follows the 1974 IUPAC Commission. The hydroxyl group of the alcohol is used as the reference and is indicated by *r* before its locant. The steric relationship of the methyl substituent to the hydroxyl group is affixed by a cis (*c*) or trans (*t*), followed by the locant of the methyl group. For the ketone, the carbonyl group is used as the starting point of the numbering system, and the plane of the ring is the reference of the stereochemistry. Affixes cis (*c*) or trans (*t*) are used to indicate the stereochemistry of the methyl substituent in the ring.

(2) Canonne, P.; Foscolos, G. B.; Bélanger, D. *J. Org. Chem.* **1980**, *45*, 1828.

(3) Canonne, P.; Bélanger, D.; Lemay, G. *Tetrahedron Lett.* **1981**, *22*, 4995.

(4) Canonne, P.; Bélanger, D.; Lemay, G.; Foscolos, G. B. *J. Org. Chem.* **1981**, *46*, 3091.

(5) Canonne, P.; Bélanger, D.; Lemay, G. *J. Org. Chem.* **1982**, *47*, 3953.

(6) Canonne, P.; Fytas, G.; Thibeault, D. *Tetrahedron Lett.* **1983**, *24*, 2991.

(7) Canonne, P.; Caron, H.; Foscolos, G. B. *Tetrahedron* **1984**, *40*, 865.

(8) Canonne, P.; Bernatchez, M. *J. Org. Chem.* **1986**, *51*, 2147.

(9) Dibromoalkanes are obtained from corresponding diols by reaction with PBr_3.

(10) Wolcott, J. M.; Cartledge, F. K. *J. Organomet. Chem.* **1976**, *111*, C-35.

(11) Holtkamp, H. C.; Blomberg, C.; Bickelhaupt, F. *J. Organomet. Chem.* **1969**, *19*, 279.

(12) Spek, A. L.; Schat, G.; Holtkamp, H. C.; Blomberg, C.; Bickelhaupt, F. *J. Organomet. Chem.* **1977**, *131*, 331.

(13) Denise, B.; Ducom, J.; Fauvarque, J. F. *Bull. Soc. Chim. Fr.* **1972**, 990.

(14) Holtkamp, H. C.; Schat, G.; Blomberg, C.; Bickelhaupt, F. *J. Organomet. Chem.* **1982**, *240*, 1.

(15) Freijee, F. J. M.; Schat, G.; Akkerman, O. S.; Bickelhaupt, F. *J. Organomet. Chem.* **1982**, *240*, 217.

0022-3263/87/1952-4025$01.50/0

Table I. Reactions of 1,4-Bis(bromomagnesio)alkanes 1–4 with Carboxylic Acid Esters. Isomer Distribution

bis Grignard	R′	ester	R	yield, %	*cis*-OH (%)	*trans*-OH (%)
1	CH_3	6	CH_3	77	**14a** (4)	**14b** (96)
1	CH_3	10	C_6H_5	78	**15a** (11)	15b (89)
2	C_2H_5	10	C_6H_5	72	**16a** (17)	16b (83)
3	C_3H_7	10	C_6H_5	69	**18a** (8)	**18b** (92)
4	C_4H_9	10	C_6H_5	68	**19a** (16)	**19b** (84)
4	C_4H_9	6	CH_3	69	**20a** (18)	**20b** (82)

Table II. Preparation of Trans-1-Substituted 2-Methylcyclopentanols from the Reaction of Bis(bromomagnesio)pentane with Carboxylic Acid Esters

ester	R	yield, %	*cis*-OH (%)	*trans*-OH (%)
5	H	88	**21a** (23)	**21b** (77)
6	CH_3	77	**14a** (4)	**14b** (96)
7	C_2H_5	76	**22a** (7)	**22b** (93)
8	$C_6H_{11}CH_2$	81	**23a** (6)	**23b** (94)
9	C_6H_{11}	75	**24a** (5)	**24b** (95)
10	C_6H_5	78	**15a** (11)	**15b** (89)
11	p-$CH_3C_6H_4$	70	**25a** (22)	**25b** (78)
12	p-ClC_6H_4	74	**26a** (18)	**26b** (82)
13	p-$CH_3OC_6H_4$	75	**27a** (23)	**27b** (77)

in equlibrium. The position of Schlenk's equilibrium is dependent on the nature of R and the temperature.[16] However the structures of primary–secondary bis Grignard reagents have not yet been studied. During our experiments, we observed a spontaneous precipitation of $MgBr_2$ at different temperatures, which leads us to believe that the same factors influence their structures.

Accordingly, the reactions of ethyl acetate (**6**) and ethyl benzoate (**10**) were carried out at 25 °C in order to avoid precipitation of the $MgBr_2$ from the bis Grignard solutions.

The reaction mixture was kept at room temperature during 1 h. Hydrolysis of an aliquot at appropriate intervals showed that the cyclization of all bis Grignard reagents **1–4** is extremely fast with both esters **6** and **10**. This raised the question as to whether or not a given carboxylic acid derivative would react with the same diastereoselectivity for the various bis Grignard reagents.

As shown in Table I, we have not observed a noticeable difference in the reaction of bis Grignard reagents with ethyl benzoate. Each of the four organodimagnesium compounds gives the corresponding 1-phenyl-1-alkylcyclopentanol in good yields, with a similar diastereoisomer distribution. Also, it seems that the nature of esters has little effect on the formation of the trans-OH isomers. Both ethyl acetate and ethyl benzoate lead to the formation of the trans-OH 1,2-disubstituted cyclopentanols as the major product. These results are very important for synthetic applications because the trans-OH 1,2-disubstituted cyclopentanols are difficult to obtain by direct addition of organometallic compounds to the corresponding 2-alkylated cyclopentanones.[16]

In Table II, we gathered results on the synthesis of trans-1-substituted 2-methylcyclopentanols[17] using aliphatic and aromatic carboxylic acid esters **5–13**. It appears that the steric effect of ethyl cyclohexanecarboxylate (**9**) does not influence the annelation process as observed previously in the case of 1,5-bis(bromomagnesio)pentane.[18] Indeed, we have not observed any important amount of open chain secondary alcohols produced by an intramolecular reduction process.

Scheme II

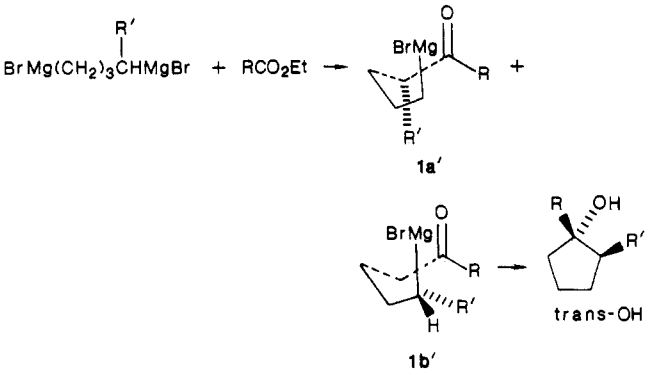


Table III. Isomer Distribution in the Reactions of 1,4-Bis(bromomagnesio)pentane with Ethyl Benzoate under Varying Experimental Conditions

T, °C	reacn time	*cis*-OH **15a**, %	*trans*-OH **15b**, %
25	16 h	11	89
25	1 h	13	87
25	16 s	10	90
0	3 h	12	88
0	1 h	11	89
−178	1 min	9	91

Therefore, this result suggests that the transition state of this cyclization step leading to the trans-OH cyclopentanol would arise from the **1a′** intermediate which is favored over **1b′** (Scheme II).

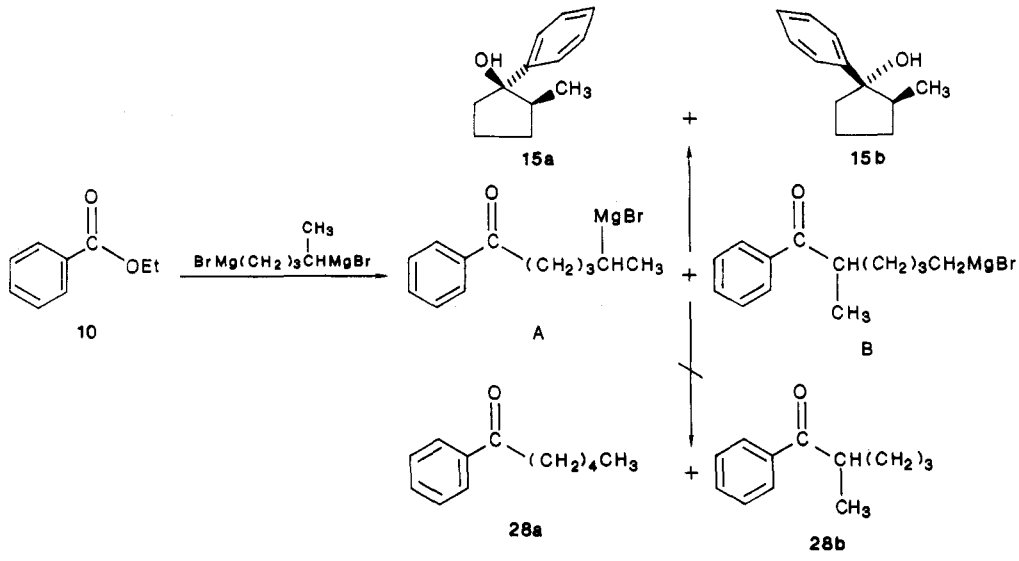
A systematic study of the reaction of 1,4-bis(bromomagnesio)pentane with ethyl benzoate under various conditions was undertaken to ascertain the mechanism. The solutions obtained after hydrolysis were analyzed by GLC with the results shown in Table III.

In each case, the annelation process is favored and the trans-OH isomer is the major reaction product, even at lower temperatures[19] and with short reaction times. Thus, no alkylphenyl ketones were isolated when either the primary or the secondary function of the Grignard reagent initiated the first attack on the ester carbonyl (Scheme III). It is noteworthy that the experiments carried out at low temperatures give the same results as those at 25 °C (Table III). It seems that the position of Schlenk's equilibrium or the structure of bis Grignard reagent does not influence the stereoselectivity of this reaction.

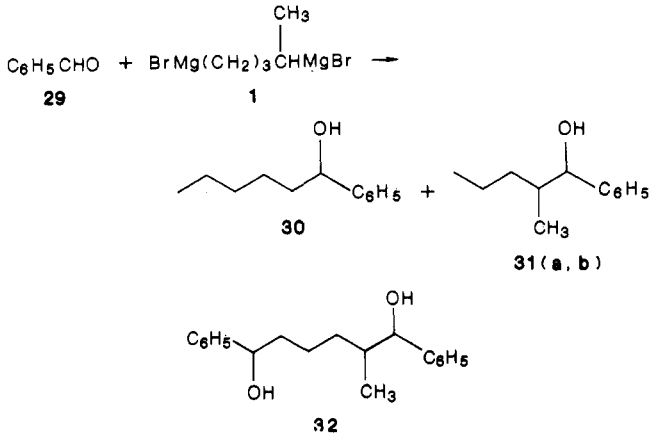
Furthermore, it is difficult to determine the relative selectivity of primary vs. secondary functions of the 1,4-bis(bromomagnesio)pentane (**1**) with esters. To this end, we studied its reaction with benzaldehyde (**29**) using a large excess of 1,4-bis(bromomagnesio)pentane with the purpose of favoring the formation of the secondary alcohols **30** and **31(a,b)**. The experiments were carried out at various temperatures. The solutions obtained after hydrolysis were analyzed by GLC and ^1H NMR spectroscopy, using the chemical shifts of benzylic protons. The results showed

(16) Ashby, E. C.; Laemmle, J. T. *Chem. Rev.* **1975**, *75*, 521.
(17) The yields reported in Tables I and II are given after purification by column chromatography fractional distillation on recrystallization as stated in the Experimental Section.
(18) Canonne, P.; Bélanger, D.; Lemay, G. *Tetrahedron Lett.* **1981**, *22*, 4995.
(19) Brady, S. F.; Ilton, M. A.; Johnson, W. S. *J. Am. Chem. Soc.* **1968**, *90*, 2882.

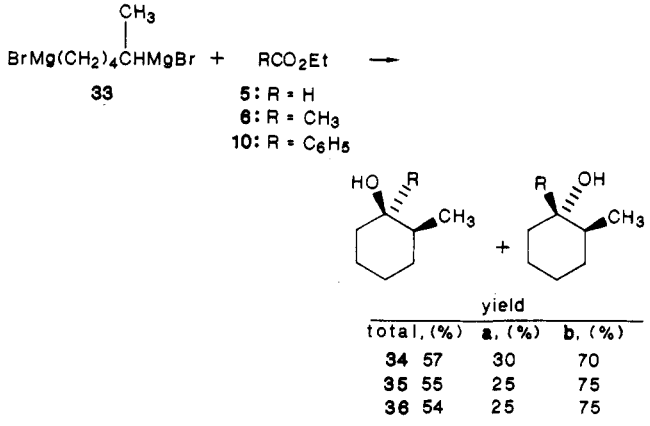
Scheme III



Scheme IV



Scheme V



	yield		
	total, (%)	a, (%)	b, (%)
34	57	30	70
35	55	25	75
36	54	25	75

that the reaction mixture contains three secondary alcohols **30** and **31(a,b)** and a small amount of diol **32** (Scheme IV). The secondary alcohols **30** and **31(a,b)** were separated from the diol **32** by column chromatography; but the separation of **30a** and **31b** was difficult to achieve. The ^1H NMR analysis based on the chemical shifts of benzylic protons showed an equal amounts of isomeric alcohols, without no anticipated chemioselectivity.

Another series of experiments using benzophenone as the substrate, yielded, by reduction, a large amount of benzyl alcohol. We attributed this transformation to the secondary Grignard function rather than to the primary Grignard function. This hypothesis is supported by a comparative reaction of diprimary bis Grignard reagents with benzophenone which led predominantly to the formation of tertiary alcohols. Similarly the reaction of 1,5-bis(bromomagnesio)hexane (**33**) with carboxylic esters **5**, **6**, and **10** led also preferentially to the formation of trans-OH 1,2-disubstituted cyclohexanols **34–36** (Scheme V).

An examination of intramolecular reactions shows that the cyclization of 6-iodo-2-hexanone[20] and 6-bromo-2-hexanone[21] was studied in presence of a magnesium amalgam and mercuric chloride in tetrahydrofuran. In order to compare the diastereoselection of this reaction, the cyclization of the two isomeric bromo ketones: 1-bromo-3-methyl-2-pentanone and 5-bromo-2-hexanone was also studied. It was observed that in both cases the trans-OH 1,2-dimethylcyclobutanol is formed. It was proposed that this reaction involves a process at the surface of the magnesium.

Copper reagents have also been used for the intramolecular reaction of δ- and ε-halo ketones.[22] Moreover it was noted that this cyclization is remarkably sensitive to the solvent and to temperature effects, while in our experiments, the temperature had no noticeable effect.

The analysis of the diastereomeric 1,2-disubstituted cycloalkanols was obtained from ^1H and ^{13}C NMR spectroscopy and GLC. Published data for certain isomeric 1-substituted 2-methylcyclopentanols[23] and cyclohexanols[24] arising from previous studies of organometallic reactions of 2-methylcycloalkanones greatly facilitated this aspect of the study. GLC analysis is very informative. As previously established, we also observed that the retention time of the cis isomer is shorter than the retention time of the trans isomer. In ^1H NMR spectroscopy the chemical

(20) Zelinsky, N.; Moser, A. *Ber.* **1902**, *35*, 2684.
(21) Leroux, Y. *Bull. Soc. Chim. Fr.* **1968**, 359.

(22) Corey, E. J.; Kuwajima, I. *J. Am. Chem. Soc.* **1970**, *92*, 395.
(23) (a) Rei, M. H. *J. Org. Chem.* **1978**, *43*, 2173. (b) Battioni, J. P.; Capmau, M. L.; Chodkiewicz, W. *Bull. Soc. Chim. Fr.* **1969**, 976. (c) Battioni, J. P.; Chodkiewicz, W. *Bull. Soc. Chim. Fr.* **1969**, 981. (d) Lemière, G. L.; Dommisse, R. A.; Alderweirelt, F. C. *Bull. Soc. Chim. Belg.* **1977**, *86*, 737. (e) Shono, T.; Nishiguchi, I.; Ohmizu, H.; Mitani, M. *J. Am. Chem. Soc.* **1978**, *100*, 545.
(24) (a) Eliel, E. L.; Schroeter, S. H.; Brett, T. J.; Biros, F. J.; Richer, J. C. *J. Am. Chem. Soc.* **1966**, *88*, 3327. (b) Ludera, J. R.; Woodall, J. E.; Pyle, J. L. *J. Org. Chem.* **1971**, *36*, 2909. (c) Ficini, J.; Maujean, A. *Bull. Soc. Chim. Fr.* **1971**, 219.

Table IV. ^{13}C NMR Chemical Shifts of 1-Substituted 2-Methylcyclopentanols (Cis and Trans)[a,b]

compd	R	C-1	C-2	C-3	C-4	C-5	CH_3
21a	H	75.98	40.07	31.14	22.28	34.55	13.68
21b	H	80.41	42.24	31.99	21.74	34.05	18.29
14a	CH_3	81.10	44.03	31.80	21.82	42.77	12.73
14b	CH_3	83.71	45.07	32.12	20.78	40.46	15.58
22a	C_2H_5	81.10	42.83	31.94	21.22	37.80	12.75
22b	C_2H_5	84.22	44.27	32.19	20.85	36.80	16.34
23a	$C_6H_{11}CH_2$	82.46	38.93	31.82	21.14	35.34	12.58
23b	$C_6H_{11}CH_2$	84.44	45.58	31.83	20.78	34.16	16.68
24a	C_6H_{11}	84.29	39.36	31.97	21.20	35.41	12.58
24b	C_6H_{11}	87.00	43.02	31.68	20.41	35.12	17.48
15a	C_6H_5	83.85	45.44	31.97	21.80	43.42	12.00
15b	C_6H_5	85.90	45.44	31.97	21.22	36.80	18.29
25a	p-$CH_3C_6H_4$	83.67	45.31	31.85	21.73	43.25	12.11
25b	p-$CH_3C_6H_4$	85.31	44.76	31.60	20.75	36.25	18.29
26a	p-ClC_6H_4	83.71	45.66	31.97	21.80	43.46	12.00
26b	p-ClC_6H_4	85.26	45.21	31.71	21.01	36.67	18.22
27a	p-$CH_3OC_6H_4$	83.56	45.07	31.83	21.58	43.17	12.07
27b	p-$CH_3OC_6H_4$	85.70	44.88	31.65	21.00	36.72	18.31

[a] **a** = cis; **b** = trans. [b] Chemical shifts are in δ from Me_4Si.

Table V. ^{13}C NMR Chemical Shifts (in δ) of Trans-1-Substituted 2-Alkylcyclopentanols

compd	R	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9
14b	CH_3	83.71	45.07	32.12	20.78	40.46	15.58			
15b	C_6H_5	85.90	45.44	31.97	21.22	36.80	18.29			
16b	C_6H_5	85.68	53.49	29.12	21.58	38.49	25.10	12.66		
17b	p-$CH_3C_6H_4$	85.46	53.27	28.97	21.44	38.34	25.02	12.58		
18b	C_6H_5	86.68	51.22	29.56	21.36	38.49	34.32	21.58	14.19	
19b	C_6H_5	85.61	51.29	29.49	21.51	38.34	30.44	31.68	22.68	13.97
20b	CH_3	83.78	50.41	29.71	20.56	41.41	22.90	30.95	20.90	14.12

shifts of the methyl or alkyl groups in position 2 of the trans isomers appear at higher fields than those of the cis isomers. Finally in ^{13}C NMR spectroscopy the methyl carbon and carbinol carbon can be used to distinguish the cis from the trans isomers. The alkyl signal of the trans consistently appears at about 4 ppm downfield from that of the cis diastereoisomers. The carbinol carbon signal of the cis isomer also showed appreciably lower values than the trans isomers (Tables IV and V).

Conclusion. The efficacy of this method was demonstrated by the synthesis of trans-1,2-disubstituted cycloalkanols with greater than 77% stereoselectivity. We have made some improvements in the bis Grignard annelation process by operating at lower temperatures and with shorter reaction times.

The high stereoselectivity of this reaction suggests a two-step process involving initial attack by the secondary part of the bis Grignard reagent on the carbonyl of the carboxylic ester.

Experimental Section

Analysis by GLC. Determination of the composition of pairs of cyclic alcohols was achieved from crude products in solution in *n*-pentane. A Varian Model 3700 gas chromatograph fitted with 8-ft column of DEGS 10% on Chromosorb W AW 80-100 was used. Diastereomeric alcohols were assumed to have equal area response in the GLC analysis using a flame ionization detector.

Melting points were determined in capillary tubes with a Thomas-Hoover apparatus and are uncorrected. All boiling points are uncorrected. Analytical thin-layer chromatography was performed on EM silica gel 60F 254 plates (0.25 mm). Separation of products was achieved either by flash chromatographyy on Woelm silica 32-63 with ethyl acetate–petroleum ether (0–5% gradient) as the eluant or by HPLC Waters 500A with silica cartridge with ethyl acetate–hexanes (10%) as the eluant. Infrared spectra were obtained on a Beckman IR-12 spectrophotometer. ^1H NMR spectra were determined on a Bruker XP-90 spectrophotometer or on a Varian XL-200 in $CDCl_3$ solution and are reported in δ units downfield from Me_4Si. ^{13}C NMR spectra were determined on a Brucker WP-80 or on a Varian XL-200 in $CDCl_3$ by using Me_4Si as internal standard. Mass spectra were obtained with a Hewlett-Packard 5995A GC/MS.

Starting Materials. Tetrahydrofuran was distilled from lithium aluminum hydride into a oven-dried flask and kept over sodium wire. Carboxylic acid esters and dibromides were distilled before use. Because 1,4-dibromopentane is commercially available we repeated reactions until isolate enough minor cyclic cis-OH alcohols were isolated to permit us spectroscopic assignments.

All glassware used in these experiments was flamed out in a stream of dry nitrogen before use. A positive pressure of nitrogen was kept above solutions at all times. All reactions were carried out in a two-necked, 200-mL, round-bottomed flask, with a pressure-equalizing funnel, a water-cooled reflux condenser, and a Teflon-coated magnetic stirring bar.

Preparation of 1,4-Bis(bromomagnesio)alkanes 1–5 and 1,5-Bis(bromomagnesio)hexane (33). In a typical reaction, 33 mmol of magnesium turnings was introduced in the system described above and was flame heated under nitrogen. The magnesium was covered by 5 mL of anhydrous THF, and a solution of 15 mmol of dibromide in 30 mL of THF was added dropwise at room temperature at such a rate that the temperature did not rise above 30 °C. The reaction mixture was stirred for 2–4 h. Yields of formation of bis Grignard was determined by Gilman test.

Preparation of 1,2-Disubstituted Cyclopentanols 14–27 and 1,2-Disubstituted Cyclohexanols 34–36. A solution of 12.75 mmol for five-membered cyclization or 12.0 mmol for six-membered cyclization of ester in 20 mL of anhydrous ether was added over a period of 20 min to a stirred bis Grignard solution. The temperature of the reaction mixture was maintained at 0 or 25 °C during the addition and for another 1 or 2 h afterwards. Saturated ammonium chloride solution (at 0 °C) was added, and the mixture was extracted with ether. The combined organic layers were washed with saturated sodium chloride solution and dried over anhydrous magnesium sulfate. The residue obtained on evaporation of the solvent at reduced pressure was chromatographed. The vapor-phase chromatography of the residue on a 8 ft 10% DEGS showed two completely resolved peaks corresponding to the cis and trans isomers. In the case of isomers **27a,b** the two peaks were not resolved, and therefore the ^1H NMR spectrum was utilized from isomer determination. These residues

chromatographed by flash chromatography or on HPLC afforded pure cis and trans isomers.

1,2-Dimethylcyclopentanols 14a,b.[23a,b] GLC analysis revealed that 1,*t*-2-dimethylcyclopentan-*r*-1-ol (**14b**) was the major isomer (96%). The overall yield was 77%. The major product was separated by flash chromatography.

1,*t*-2-Dimethylcyclopentan-*r*-1-ol (14b): distillation bp 58–59 °C (12 mmHg); ^{1}H NMR δ 0.88 (d, 3 H, J = 6.37 Hz), 1.11 (s, 3 H), 1.35–2.30 (m, 8 H); ^{13}C NMR δ 83.71, 45.07, 40.46; 32.12, 23.05, 20.78, 15.58; IR (neat) 3370, 2960, 2870, 1460, 1115 cm^{-1}.

1,*c*-2-Dimethylcyclopentan-*r*-1-ol (14a): ^{1}H NMR δ 0.92 (d, 3 H, J = 6.33 Hz), 1.22 (s, 3 H), 1.45–2.10 (m, 8 H); ^{13}C NMR δ 81.10, 44.03, 42.77, 31.80, 24.59, 21.82, 12.73; IR (neat) 3465, 2965, 2875, 1455, 1117 cm^{-1}.

1-Phenyl-2-methylcyclopentanols 15a,b.[23b] Analysis by GLC indicated 89% of 1-phenyl-*t*-2-methylcyclopentan-*r*-1-ol (**15b**). Products were separated by flash chromatography, and the overall yield was 78%.

1-Phenyl-*t*-2-methylcyclopentan-*r*-1-ol (15b): distillation bp 72–73 °C (0.2 mmHg); ^{1}H NMR δ 0.51 (d, 3 H, J = 6.98 Hz), 1.39 (m, 2 H), 1.85–2.20 (m, 6 H), 7.30 (m, 5 H); ^{13}C NMR δ 144.95. 128.49, 128.12, 127.54, 127.10, 126.51, 85.90, 45.44, 36.80, 31.97, 21.22, 18.29; IR (neat) 3380, 3075, 3045, 3015, 2950, 2920, 2865, 1595, 1490, 1458, 1445, 1030, 755, 692 cm^{-1}; mass spectrum, m/e (relative intensity) 177 (M^+ + 1, 5), 176 (M^+, 35), 120 (42), 105 (65), 113 (100), 77 (39).

1-Phenyl-*c*-2-methylcyclopentan-*r*-1-ol (15a): distillation bp 68–70 °C (0.2 mmHg); ^{1}H NMR δ 0.82 (d, 3 H, J = 6.67 Hz), 1.50–2.30 (m, 8 H), 7.15–7.55 (m, 5 H); and ^{13}C NMR δ 146.34, 128.19 (2 C), 126.58, 125.19 (2 C), 83.85, 45.44, 43.42, 31.97, 21.80, 12.00; IR (neat) 3465, 3085, 3055, 3025, 2960, 2930, 2870, 1600, 1490, 1460, 1445, 1030, 755, 697 cm^{-1}; mass spectrum, m/e (relative intensity) 177 (M^+ + 1, 9), 176 (M^+, 33), 133 (100), 120 (46), 105 (76), 77 (62).

1-Phenyl-2-ethylcyclopentanols 16a,b. GLC analysis revealed that 1-phenyl-*t*-2-ethylcyclopentan-*r*-1-ol (**16b**) was the major product. Overall yield was 69%, and the major product was separated by flash chromatography.

1-Phenyl-*t*-2-ethylcyclopentan-*r*-1-ol (16b): recrystallized as white powder from *n*-pentane, mp 75–77 °C; ^{1}H NMR δ 0.65 (m, 1 H), 0.75 (t, 3 H, J = 7 Hz), 1.02 (m, 1 H), 1.48 (m, 1 H), 1.68 (s, 1 H), 1.70–2.25 (m, 6 H), 7.4 (m, 5 H); ^{13}C NMR δ 145.39, 128.12 (2 C), 127.02, 126.58 (2 C), 85.68, 53.49, 38.49, 29.12, 25.10, 21.58, 12.66; IR (KBr) 3370, 3075, 3050, 3015, 2950, 2930, 2865, 1595, 1495, 1450, 1025, 750, 695 cm^{-1}; mass spectrum, m/e (relative intensity) 190 (M^+, 35), 147 (13), 134 (13), 133 (100), 120 (64), 77 (44). Anal. Calcd for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 82.08; H, 9.51.

1-Phenyl-*c*-2-ethylcyclopentan-*r*-1-ol (16a): distillation, bp 70–75 °C (0.2 mmHg); ^{1}H NMR δ 0.80 (d, 3 H, J = 7 Hz), 0.87–2.10 (m, 10 H), 7.4 (m, 5 H); IR (neat) 3430, 3070, 3055, 3010, 2950, 2920, 2860, 1595, 1492, 1465, 1440, 1020, 747, 692 cm^{-1}; mass spectrum, m/e (relative intensity) 190.0 (31.3), 147.1 (6.2), 134.0 (9.1), 133.0 (100), 119.9 (54.2), 105.0 (75.8), 91.0 (9.8), 78.0 (15.8), 77.0 (42.0), 55.0 (23.7). Anal. Calcd for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 82.02; H, 9.49.

1-(*p*-Methylphenyl)-2-ethylcyclopentanols 17a,b. GLC analysis revealed that 1-(*p*-methylphenyl)-*t*-2-ethylcyclopentan-*r*-1-ol (**17b**) was the major product (93%). The overall yield was 62%. Products were separated by HPLC.

1-(*p*-Methylphenyl)-*t*-2-ethylcyclopentan-*r*-1-ol (17b): distillation bp 95–97 °C (0.16 mmHg); ^{1}H NMR δ 0.60 (m, 1 H) 0.75 (t, 3 H, J = 6.96 Hz), 0.90 (m, 1 H), 1.26 (s, 1 H), 1.48 (m, 2 H), 1.65–2.15 (m, 5 H), 2.26 (m, 1 H), 2.31 (s, 3 H), 7.19 (m, 4 H); ^{13}C NMR δ 142.32, 136.42, 128.71 (2 C), 126.44 (2 C), 85.46, 53.27, 38.34, 28.97, 25.02, 21.44, 20.93, 12.58; IR (neat) 3370, 3075, 3050, 3015, 2950, 2930, 2865, 1595, 1495, 1470, 1450, 1025, 750, 695 cm^{-1}; mass spectrum, m/e (relative intensity) 204.3 (M^+, 27.8), 147.2 (100), 134.1 (87.0), 121.1 (87.8), 119.2 (99.5), 93.1 (30.7), 91.1 (80.3), 77.1 (25.3), 55.1 (54.2), 41.1 (30.0). Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.25; H. 9.85.

1-(*p*-Methylphenyl)-*c*-2-ethylcyclopentan-*r*-1-ol (17a): distillation bp 96–98 °C (0.17 mmHg); ^{1}H NMR δ 0.75 (t, 3 H, J = 6.96 Hz), 0.90–2.10 (m, 10 H), 2.26 (s, 3 H), 7.07 (m, 2 H), 7.27 (m, 2 H); IR (neat) 3425, 3080, 3045, 3018, 2950, 2920, 2865, 1607, 1508, 1455, 1020, 812, 730 cm^{-1}; mass spectrum, m/e (relative intensity) 204.3 (M^+, 15.9), 147.2 (100), 134.1 (74.8), 121.1 (80.3), 119.2 (92.5), 93.1 (29.2), 91.1 (68.4), 77.1 (88.1), 55.1 (37.7), 41.1 (24.7). Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.26; H, 9.81.

1-Phenyl-2-propylcyclopentanols 18a,b. GLC analysis revealed that the major product was 1-phenyl-*t*-2-propylcyclopentan-*r*-1-ol (**18b**) (96%). The overall yield was 67%, and the major product was isolated by flash chromatography.

1-Phenyl-*t*-2-propylcyclopentan-*r*-1-ol (18b): distillation bp 86–88 °C (0.15 mmHg); ^{1}H NMR δ 0.62 (m, 1 H) 0.73 (t, 3 H, J = 7.30 Hz), 0.90 (m, 1 H), 1.18 (m, 1 H), 1.24 (m, 1 H), 1.45 (m, 1 H), 1.70–2.10 (m, 6 H), 2.30 (m, 1 H), 7.30 (m, 5 H); ^{13}C NMR δ 145.39, 128.12 (2 C), 127.02, 126.58 (2 C), 86.68, 51.22, 38.49, 34.32, 29.56, 21.58, 21.36, 14.19; IR (neat) 3360, 3075, 3050, 3015, 2945, 2915, 2855, 1595, 1475, 1050, 753, 690 cm^{-1}; mass spectrum, m/e (relative intensity) 204.3 (M^+, 17.9), 133.15 (100), 120.0 (73.2), 107.1 (13.1), 105.1 (77.4), 91.1 (14.2), 78.1 (20.1), 77.1 (39.8), 41.1 (19.3). Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.29; H, 9.85.

1-Phenyl-*c*-2-propylcyclopentan-*r*-1-ol (18a): distillation bp 85–86 °C (0.15 mmHg); ^{1}H NMR δ 0.80–1.05 (m, 7 H), 1.88 (m, 7 H), 2.25 (m, 1 H), 7.40 (m, 5 H); IR (neat) 3390, 3080, 3058, 3022, 2950, 2922, 2870, 1600, 1490, 1455, 1022, 755, 695 cm^{-1}; mass spectrum, m/e (relative intensity) 204.3 (M^+, 16.5), 133.1 (100), 120.0 (63.7), 107.1 (31.3), 105.1 (69.5), 78.1 (14.6), 77.1 (33.1), 55.1 (32.4), 43.1 (14.2), 41.1 (20.7). Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.26; H, 9.84.

1-Phenyl-2-butylcyclopentanols 19a,b. Analysis of crude products by GLC revealed that the major alcohol was 1-phenyl-*t*-2-butylcyclopentan-*r*-1-ol (**19b**) (84%). The overall yield was 62%. The major product was isolated by flash chromatography.

1-Phenyl-*t*-2-butylcyclopentan-*r*-1-ol (19b): distillation bp 51–52 °C (0.09 mmHg); ^{1}H NMR δ 0.81 (t, 3 H, J = 6.67 Hz), 0.55–1.55 (m, 6 H), 1.70–2.25 (m, 7 H), 2.32 (m, 1 H), 7.35 (m, 5 H); ^{13}C NMR δ 145.24, 128.05 (2 C), 126.95, 126.51 (2 C), 85.61, 51.29, 38.34, 31.68, 30.44, 29.49, 22.68, 21.51, 13.97; IR (neat) 3370, 3080, 3058, 3022, 2950, 2922, 2865, 2852, 1595, 1485, 1445, 1022, 755, 692 cm^{-1}; mass spectrum, m/e (relative intensity) 218.2 (M^+, 32.3) 133.1 (100), 120.0 (83.8), 105.1 (83.7), 91.1 (20.0), 78.1 (22.0), 77.1 (47.2), 55.1 (41.8), 43.1 (18.8), 41.1 (34.0). Anal. Calcd for $C_{15}H_{22}O$: C, 82.51; H, 10.16. Found: C, 82.48; H, 10.03.

1-Phenyl-*c*-2-butylcyclopentan-*r*-1-ol (19a): distillation bp 49–50 °C (0.09 mmHg); ^{1}H NMR δ 0.87 (t, 3 H, J = 7.07 Hz), 1.23 (m, 6 H), 1.50–2.20 (m, 5 H), 7.37 (m, 5 H); IR (neat) 3430, 3080, 3060, 3025, 2950, 2925, 2865, 2855, 1598, 1488, 1447, 1026, 758, 695 cm^{-1}; mass spectrum, m/e (relative intensity), 219.2 (M^+, 4.4), 218.3 (M^+, 21.8), 134.1 (12.1), 133.1 (100), 120.0 (67.9), 105.1 (63.4), 91.1 (13.6), 78.1 (11.7), 77.1 (27.5), 55.1 (22.0), 41.1 (17.3). Anal. Calcd for $C_{15}H_{22}O$: C, 82.51; H, 10.16. Found: C, 82.47; H, 10.12.

1-Methyl-2-butylcyclopentanols 20a,b. Analysis by GLC revealed that 1-methyl-*t*-2-butylcyclopentan-*r*-1-ol (**20b**) was the major product (82%). The overall yield was 60%. The major product was isolated by flash chromatography.

1-Methyl-*t*-2-butylcyclopentan-*r*-1-ol (20b): distillation bp 68–71 °C (1 mmHg); ^{1}H NMR δ 0.92 (t, 3 H, J = 6.45 Hz), 0.85–1.40 (m, 6 H), 1.15 (s, 3 H), 1.45–2.1 (m, 8 H); ^{13}C NMR δ 83.78, 50.41, 41.41, 30.95, 30.73, 29.71, 22.90 (2 C), 20.90, 14.12; IR (neat) 3385, 2965, 2935, 2865, 1460, 1117 cm^{-1}. Anal. Calcd for $C_{10}H_{20}O$: C, 76.86; H, 12.90. Found: C, 76.81; H, 12.85.

2-Methylcyclopentanols 21a,b.[22a] GLC analysis revealed that *t*-2-methylcyclopentan-*r*-1-ol (**21b**) was the major isomer and constituted 77% of mixture of alcohols. The overall yield was 88%. No attempt was made to separate the isomers: distillation (mixture) bp 87–88 °C (71 mmHg); ^{1}H NMR δ (mixture) [***c*-2-methylcyclopentan-*r*-1-ol (21a)**] 1.01 (d, 3 H, J = 6.9 Hz), 3.96 (m, 1 H), [***t*-2-methylcyclopentan-*r*-1-ol (21b)**] 0.97 (d, 3 H, J = 6.9 Hz), 3.60 (m, 1 H); ^{13}C NMR δ (mixture) [*c*-2-methylcyclopentan-*r*-1-ol (**21a**)] 75.98, 40.07, 34.55, 31.14, 22.28, 13.68, [*t*-2-methylcyclopentan-*r*-1-ol (**21b**)] 80.41, 42.24, 34.05, 31.99, 21.74, 18.29; IR (neat, mixture) 3340, 2945, 2920, 2900, 2865, 1460, 1075 cm^{-1}.

1-Ethyl-2-methylcyclopentanols 22a,b.[23b] GLC analysis revealed that the major alcohol was 1-ethyl-*t*-2-methylcyclopentan-*r*-1-ol (**22b**) (93%). The overall yield was 76%. Products were separated by flash chromatography.

1-Ethyl-*t*-2-methylcyclopentan-*r*-1-ol (22b): distillation bp 75–77 °C (15 mmHg); ^{1}H NMR δ 0.85 (d, 3 H, J = 7.48 Hz), 0.88 (t, 2 H, J = 4.22 Hz), 1.20–2.00 (m, 9 H), 2.09 (s, large, 1 H); ^{13}C NMR δ 84.22, 44.27, 36.80, 32.19, 28.68, 20.85, 16.34, 8.19; IR (neat) 3380, 2950, 2930, 2870, 1455, 1110 cm^{-1}.

1-Ethyl-*c*-2-methylcyclopentan-*r*-1-ol (22a): distillation bp 72–73 °C (16 mmHg); ^{1}H NMR δ 0.89 (d, 3 H, J = 7.26 Hz), 0.94 (t, 2 H, J = 7.18 Hz), 1.40–2.00 (m, 10 H); ^{13}C NMR δ 81.10, 42.83, 37.80, 31.94, 23.28, 21.22, 12.75, 8.40; IR (neat) 3460, 2955, 2935, 2875, 1455, 1112 cm^{-1}.

1-(Cyclohexylmethyl)-2-methylcyclopentanols 23a,b. GLC analysis revealed that trans-OH **23b** was major product. The overall yield was 81%. The major compound was separated by flash chromatography.

1-(Cyclohexylmethyl)-*t*-2-methylcyclopentan-*r*-1-ol (23b): distillation bp 72–74 °C (0.30 mmHg); ^{1}H NMR δ 0.83 (d, 3 H, J = 6.68 Hz), 1.05–2.20 (m, 21 H); ^{13}C NMR δ 84.44, 45.58, 43.54, 37.46, 35.61, 35.49, 34.16, 31.83, 26.71, 20.78, 16.68; IR (neat) 3440, 2950, 2915, 2865, 2845, 1447, 1132 cm^{-1}. Anal. Calcd for $C_{13}H_{24}O$: C, 79.53; H, 12.32. Found: C, 79.51; H, 12.27.

1-(Cyclohexylmethyl)-*c*-2-methylcyclopentan-*r*-1-ol (23a): distillation bp 61–62 °C (0.25 mmHg); ^{1}H NMR δ 0.90 (d, 3 H, J = 6.21 Hz), 1.05–2.21 (m, 19 H); ^{13}C NMR δ 82.46, 47.05, 43.83, 38.93, 35.56, 35.34, 34.54, 31.82, 26.56, 21.14, 12.58; IR (neat) 3480, 2950, 2915, 2865, 2850, 1450, 1120 cm^{-1}. Anal. Calcd for $C_{13}H_{24}O$: C, 79.53; H, 12.32. Found: C, 79.42; H, 12.28.

1-Cyclohexyl-2-methylcyclopentanols 24a,b. GLC analysis revealed that 1-cyclohexyl-*t*-2-methylcyclopentan-*r*-1-ol (**24b**) constituted 95% of the mixture of cyclic alcohols. The overall yield was 75%. The major product was separated by flash chromatography.

1-Cyclohexyl-*t*-2-methylcyclopentan-*r*-1-ol (24b): distillation bp 45–47 °C (0.22 mmHg); ^{1}H NMR δ 0.79 (d, 3 H, J = 7.20 Hz), 1.00–2.30 (m, 19 H); ^{13}C NMR δ 87.00, 43.02, 42.58, 35.12, 31.68, 27.80, 27.29, 26.71, 20.41, 17.48; IR (neat) 3430, 2942, 2918, 2860, 2840, 1445, 1138 cm^{-1}; mass spectrum, m/e (relative intensity) 182.2 (M$^+$, 7.8), 111.0 (40.3), 99.2 (91.0), 98.1 (42.9), 83.1 (78.1), 81.1 (45.8), 71.1 (27.6), 69.0 (27.8), 67.0 (32.3), 57.0 (31.2), 55.0 (100). Anal. Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.17. Found: C, 79.02; H, 12.12.

1-Cyclohexyl-*c*-2-methylcyclopentan-*r*-1-ol (24a): distillation bp 41–43 °C (0.22 mmHg); ^{1}H NMR δ 0.87 (d, 3 H, J = 7.12 Hz), 1.00–2.30 (m, 19 H); ^{13}C NMR δ 84.29, 42.12, 39.36, 35.41, 31.97, 26.90, 27.60, 26.15, 21.20, 12.58; mass spectrum, m/e (relative intensity) 182.2 (M$^+$, 7.8), 111.0 (37.1), 99.2 (82.2), 98.1 (35.3), 83.1 (67.9), 81.1 (38.4), 71.1 (24.6), 69.0 (24.5), 67.0 (33.1), 57.0 (31.8), 55.0 (100). Anal. Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.17. Found: C, 78.98; H, 12.11.

1-(*p*-Methylphenyl)-2-methylcyclopentanols 25a,b. GLC analysis revealed that trans-OH **25b** constituted 78% of the pair of cyclic alcohols. The overall yield was 70%. The products were separated by flash chromatography.

1-(*p*-Methylphenyl)-*t*-2-methylcyclopentan-*r*-1-ol (25b): distillation bp 69–71 °C (0.11 mmHg); ^{1}H NMR δ 0.54 (d, 3 H, J = 6.98 Hz), 1.40 (m, 2 H), 1.92 (m, 3 H), 2.19 (m, 2 H), 2.38 (s, 3 H), 7.16 (m, 2 H), 7.24 (m, 2 H) ($J_{AA'} = J_{BB'}$ = 2.16 Hz, $J_{AB} = J_{A'B'}$ = 8.32 Hz); ^{13}C NMR δ 141.56, 136.01, 128.35, (2 C), 128.30 (2 C), 85.31, 44.76, 36.25, 31.60, 20.75, 20.87, 18.29; IR (neat) 3385, 3080, 3050, 3020, 2950, 2920, 2870, 1605, 1505, 1030, 815 cm^{-1}; mass spectrum, m/e (relative intensity) 190.1 (M$^+$, 36.4), 147.1 (93.3), 134.2 (50.8), 119.1 (82.7), 91.0 (52.7), 85.0 (62.5), 83.0 (100), 55.0 (31.5), 47.0 (25.8), 43.1 (30.1). Anal. Calcd for $C_{13}H_{18}O$: 82.06; H, 9.53. Found: C, 81.97; H, 9.45.

1-(*p*-Methylphenyl)-*c*-2-methylcyclopentan-*r*-1-ol (25a): distillation bp 62–65 °C (0.10 mmHg); ^{1}H NMR δ 0.84 (d, 3 H, J = 6.66 Hz), 1.45–2.35 (m, 8 H), 2.33 (s, 3 H), 7.14 (m, 2 H), 7.32 (m, 2 H); ^{13}C NMR δ 142.11, 136.14, 128.18 (2 C), 126.49 (2 C), 83.67, 45.31, 43.25, 31.85 21.73, 20.91, 12.11; IR (neat) 3445, 3082, 3050, 3020, 2950, 2920, 2870, 1602, 1505, 1450, 1035, 812 cm^{-1}; mass spectrum, m/e (relative intensity) 190.1 (M$^+$, 36.6), 147.1 (82.3), 134.2 (52.1), 119.1 (61.8), 91.0 (45.4), 85.0 (57.3), 83.0 (100), 55.0 (33.6), 47.0 (26.9), 43.1 (32.7). Anal. Calcd for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 82.04; H, 9.50.

1-(*p*-Chlorophenyl)-2-methylcyclopentanols 26a,b. GLC analysis of crude products revealed that trans-OH **26b** constituted 82% of a pair of cyclic alcohols. The overall yield was 79%. The isomers were separated by HPLC.

1-(*p*-Chlorophenyl)-*t*-2-methylcyclopentan-*r*-1-ol (26b): distillation bp 79–81 °C (0.09 mmHg); ^{1}H NMR δ 0.54 (d, 3 H, J = 6.99 Hz), 1.37 (m, 1 H), 1.85 (m, 3 H), 1.98 (s, 1 H), 2.14 (m, 2 H), 2.32 (m, 1 H), 7.26 (d, 2 H), 7.33 (d, 2 H) ($J_{AA'} = J_{BB'}$ = 8.89 Hz, $J_{AB} = J_{A'B'}$ = 13.64 Hz); ^{13}C NMR δ 143.11, 132.57, 127.91 (2 C), 127.79 (2 C), 85.26, 45.21, 36.67, 31.71, 21.01, 18.22; IR (neat) 3365, 3075, 3045, 3020, 2950, 2920, 2865, 1595, 1485, 1448, 1097, 1015, 812 cm^{-1}; mass spectrum, m/e (relative intensity) 212.1 (M$^+$ + ^{37}Cl, 7.8), 210.1 (M$^+$ + ^{35}Cl, 24.6), 169.1 (31.5), 167.1 (100), 154.1 (59.7), 141.0 (41.2), 139.0 (94.5), 111.0 (40.4), 77.0 (31.5), 75.0 (26.4), 55.0 (42.1), 41.0 (39.4). Anal. Calcd for $C_{12}H_{15}ClO$: C, 68.40; H, 7.18. Found: C, 68.37; H, 7.17.

1-(*p*-Chlorophenyl)-*c*-2-methylcyclopentan-*r*-1-ol (26a): distillation bp 71–73 °C (0.12 mmHg); ^{1}H NMR δ 0.82 (d, 3 H, J = 6.67 Hz), 1.50–2.28 (m, 7 H), 1.60 (s, 1 H), 7.29 (m, 2 H), 7.41 (m, 2 H); ^{13}C NMR δ 144.95, 132.51, 128.41 (2C), 126.84 (2C), 83.71, 45.66, 43.46, 31.97, 21.80, 12.00; IR (neat) 3460, 3075, 3045, 3020, 2950, 2920, 2865, 1495, 1480, 1450, 1095, 1012, 812 cm^{-1}; mass spectrum, m/e (relative intensity) 212.2 (M$^+$ + ^{37}Cl, 10.6), 210.2 (M$^+$, 33.3), 169.1 (35.9), 167.1 (100), 154.2 (60.0), 141.1 (33.1), 139.1 (86.3), 111.0 (36.7), 77.1 (28.2), 75.0 (24.9), 55.0 (57.1). Anal. Calcd for $C_{12}H_{15}ClO$: C, 68.40; H, 7.18. Found: C, 68.32; H, 7.16.

1-(*p*-Methoxyphenyl)-2-methylcyclopentanols 27a,b. Examination of ^{1}H NMR spectra of crude products revealed that trans-OH **27b** constituted 77% of a pair of cyclic alcohols. The overall yield was 75%. Products were separated by flash chromatography.

1-(*p*-Methoxyphenyl)-*t*-2-methylcyclopentan-*r*-1-ol (27b): distillation bp 85–86 °C (0.10 mmHg); ^{1}H NMR δ 0.53 (d, 3 H, J = 6.97 Hz), 1.40 (m, 1 H), 1.90 (m, 3 H), 2.16 (m, 2 H), 3.26 (s, 3 H), 7.24 (m, 2 H), 7.32 (m, 2 H); ^{13}C NMR δ 159.84, 134.11, 128.77 (2 C), 127.98 (2 C), 85.70, 54.22, 44.88, 36.72, 31.65, 21.00, 18.31; IR (neat) 3370, 3050, 3020, 2935, 2920, 2860, 1612, 1502, 1550, 1023, 822 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.79. Found: C, 75.62; H, 8.77.

1-(*p*-Methoxyphenyl)-*c*-2-methylcyclopentan-*r*-1-ol (27a): distillation bp 78–79 °C (0.13 mmHg); ^{1}H NMR δ 0.88 (d, 3 H, J = 6.5 Hz), 1.45–2.20 (m, 8 H), 3.27 (s, 3 H), 7.14 (m, 2 H), 7.31 (m, 2 H); ^{13}C NMR δ 158.49, 134.25, 128.22 (2 C), 126.67 (2 C), 83.56, 54.16, 45.07, 43.17, 31.83, 21.58, 12.07; IR (neat) 3470, 3050, 3020, 2938, 2920, 2860, 1615, 1505, 1550, 1445, 1025, 825 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.79. Found: C, 75.64; H, 8.75.

2-Methylcyclohexanols 34a,b.[24c] GLC analysis revealed that *t*-2 methylcyclohexan-*r*-1-ol (**34b**) was the major isomer and constituted 70% of the mixture of the alcohols. The overall yield was 54%. Products were purified by distillation, and no further attempt was made to separate the isomers: distillation (mixture) bp 108 °C (88 mmHg); ^{1}H NMR δ (mixture) [***c*-2-methylcyclohexan-*r*-1-ol (34a)**] 0.93 (d, 3 H, J = 6.5 Hz) 3.48 (ddd, 1 H, J = 6, 2 Hz and J < 1 Hz), [***t*-2-methylcyclohexan-*r*-1-ol (34b)**] 1.00 (d, 3 H, J = 6.5 Hz), 3.12 (ddd, 1 H, J = 9, 8, 4 Hz); IR (neat, mixture) 3380, 2925, 2858, 2955, 1375 cm^{-1}.

1,2-Dimethylcyclohexanols 35a,b.[24] Analysis by GLC revealed that 1,*t*-2-dimethylcyclohexan-*r*-1-ol (**35b**) was the major product (75%). The isomers were separated by HPLC. The overall yield was 53%.

1,*c*-2-Dimethylcyclohexan-*r*-1-ol (35a): distillation bp 87 °C (33 mmHg); ^{1}H NMR δ 0.92 (d, 3 H, J = 6.6 Hz), 1.09 (s, 3 H), 1.45–2.10 (m, 11 H); ^{13}C NMR δ 71.12, 40.58, 40.19, 30.78, 28.85, 26.25, 22.12, 15.47; IR (neat) 3450, 2950, 2920, 2850, 1455, 1375 cm^{-1}.

1,*t*-2-Dimethylcyclohexan-*r*-1-ol (35b): distillation 82 °C (35 mmHg); ^{1}H NMR δ 0.86 (d, 3 H, J = 6.5 Hz) 1.15 (s, 3 H) 1.50–2.10 (m, 10 H) 2.16 (s, OH); ^{13}C NMR δ 73.10, 42.51, 41.56, 32.27, 25.46, 24.29, 21.00, 15.44; IR (neat) 3380, 2945, 2918, 2840, 1452, 1365 cm^{-1}.

1-Phenyl-2-methylcyclohexanols 36a,b.[24c] Analysis by GLC revealed that 1-phenyl-*t*-2-methylcyclohexan-*r*-1-ol (**36b**) was the major product (75%). The overall yield was 54%. Products were separated by HPLC.

1-Phenyl-*t*-2-methylcyclohexan-*r*-1-ol (36b): mp 61–63 °C; ^{1}H NMR δ 0.81 (d, 3 H, J = 7.02 Hz), 1.10–2.50 (m, 9 H), 2.70 (s, 1 H), 7.41 (m, 5 H); IR (CCl_4) 3600, 3485, 3075, 3055, 3020, 2950, 2930, 2860, 2850, 1630, 1490, 1450, 1365 cm^{-1}.

1-Phenyl-*c*-2-methylcyclohexan-*r*-1-ol (36a): distillation bp 86–89 °C (0.2 mmHg); ^{1}H NMR δ 0.60 (d, 3 H, J = 7.0 Hz), 1.20–2.15 (m, 9 H), 3.20 (s, 1 H), 7.31 (m, 5 H); IR (CCl_4) 3610, 3500, 3080, 3055, 3020, 2925, 2850, 1640, 1490, 1450, 1370, 1025, 750, 710, 695 cm^{-1}.

Acknowledgment. We gratefully acknowledge financial support from the Natural Sciences and Engineering Research Council of Canada and the Fonds F.C.A.R. (Gouvernement du Québec).

Registry No. 1, 626-87-9; 2, 25118-28-9; 3, 42474-23-7; 4, 70690-24-3; 5, 109-94-4; 6, 141-78-6; 7, 105-37-3; 8, 5452-75-5; 9, 3289-28-9; 10, 93-89-0; 11, 94-08-6; 12, 7335-27-5; 13, 94-30-4; 14a, 16467-04-2; 14b, 16467-13-3; 15a, 22865-14-1; 15b, 22865-01-6; 16a, 22865-01-6; 16b, 109433-88-7; 17a, 109433-94-5; 17b, 109433-95-6; 18a, 109433-89-8; 18b, 109433-90-1; 19a, 109466-71-9; 19b, 109433-91-2; 20a, 109433-92-3; 20b, 109433-93-4; 21a, 25144-05-2; 21b, 25144-04-1; 22a, 16467-06-4; 22b, 16467-12-2; 23a, 101934-19-4; 23b, 101934-20-7; 24a, 22865-13-0; 24b, 22862-81-3; 25a, 75968-43-3; 25b, 101934-21-8; 26a, 75968-45-5; 26b, 101934-22-9; 27a, 75968-44-4; 27b, 101934-23-0; 33, 627-96-3; 34a, 7443-70-1; 34b, 7443-52-9; 35a, 19879-11-9; 35b, 19879-12-0; 36a, 30689-79-3; 36b, 30689-80-6.

Studies on the Addition of Allyl Oxides to Sulfonylallenes. Preparation of Highly Substituted Allyl Vinyl Ethers for Carbanionic Claisen Rearrangements

Scott E. Denmark,*[1a] Michael A. Harmata,[1b,c] and Kathleen S. White[†]

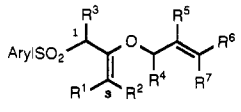
Roger Adams Laboratory, Department of Chemistry, University of Illinois, Urbana, Illinois 61801

Received March 19, 1987

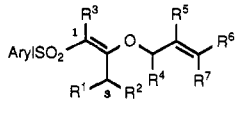
Thirty-five allyl vinyl ethers bearing an arylsulfonyl anion-stabilizing group have been prepared by addition of allylic alkoxides to (arylsulfonyl)allenes. The allyl vinyl ethers are produced as either β,γ-unsaturated or α,β-unsaturated sulfones depending upon the substitution pattern of the allene and the reaction conditions. A wide variety of substitution patterns are available by using this method. Factors that control the position and stereochemistry of the vinyl ether double bond are discussed.

Introduction

In preliminary papers[2] we have reported the carbanion-accelerated Claisen rearrangements (Scheme I) of allyl vinyl ethers with arylsulfonyl-stabilized anions. To investigate the scope of this reaction and its suitability as a general synthetic method we needed an efficient preparation of a variety of allyl vinyl ethers of the type 1 (β,γ-unsaturated) and type 2 (α,β-unsaturated). The



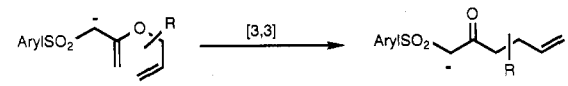
1



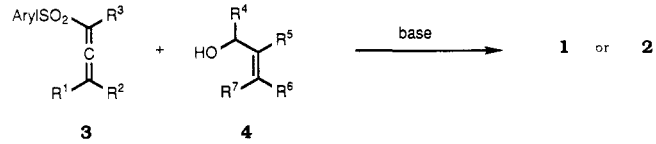
2

disconnection we selected which allowed for good versatility in assembling different substitution patterns involves the combination of (arylsulfonyl)allenes 3 with allylic alcohols 4 activated as their alkoxide salts (Scheme II).[3] The addition of oxygen,[7] nitrogen,[7a,8] and sulfur[7c,9] nucleophiles to sulfonylallenes is well documented.[10] Of particular interest to us were the classic studies by Stirling[7a] who first demonstrated the formation of vinyl ethers by base-catalyzed addition of methanol to (phenylsulfonyl)propadiene. Unfortunately in this and subsequent papers by Stirling et al. the alcohols are inexpensive, expendable, and often used as solvents. For the carbanionic Claisen rearrangement to be of value in more complex syntheses we need to construct the precursors from stoichiometric reagents in good yields. Therefore, the purpose of this study was to develop a reliable protocol for the preparation of 1 and 2 which met the criteria of (1) high yield, (2) versatility, (3) control of double bond position and configuration, and (4) use of minimal amounts of alcohols 4.

Scheme I

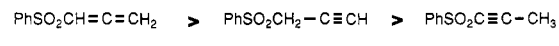


Scheme II



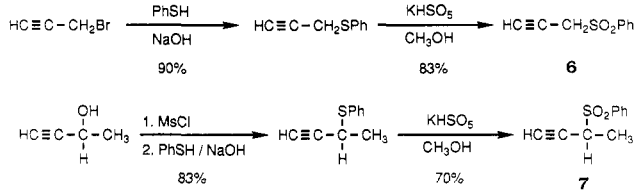
3 4

Scheme III

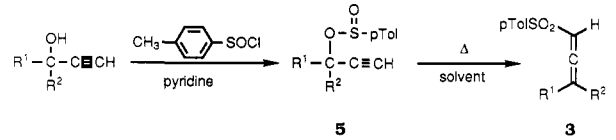


3a 6 6'

Scheme IV



Scheme V



5 3

[†] In part.

0022-3263/87/1952-4031$01.50/0