Articles

Stereochemical Features of the (2 + 2) Cycloaddition Reactions of Chiral Allenes. 3. The Cycloaddition of Enantioenriched 1,3-Dimethylallene with the Symmetrically 1,1-Disubstituted Alkenes 1,1-Dichloro-2,2-difluoroethene and 1,1-Diphenylethene

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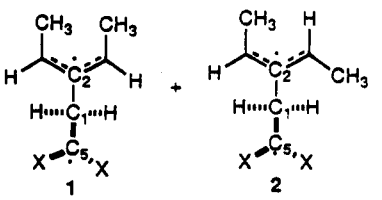
The reaction of enantioenriched (*S*)-(+)-1,3-dimethylallene (13DMA) with 1,1-dichloro-2,2-difluoroethene (1122) produces the two cycloadducts **3** and **4** whose enantiomeric excesses (ee's) have been determined via the tertiary alcohols, formed by hydroboration, and via the dibromides by the use of chiral NMR chemical shift reagents. The major cycloadduct **3** is formed, retaining a higher percentage of the ee of the starting 13DMA (>30%) than does the minor cycloadduct **4** (>10%). The results of molecular modeling calculations on the conformations of the two reactants in approaching the activated complexes for diradical intermediate formation, and on models for the anti,anti and anti,syn diradical intermediates, provide for a most reasonable interpretation of the results involving one major continuous, low-energy reaction pathway via the anti,syn diradical intermediate leading to cycloadduct formation. The reaction of enantioenriched (*S*)-(+)-13DMA with 1,1-diphenylethene (DPE) does not lead to detectable formation of (2 + 2) cycloadducts, but does result in the racemization of 13DMA. The racemization of 13DMA is proposed to occur via the reversible formation of the achiral diradical intermediate **21** and the chiral diradial intermediate **22**.

Introduction

An area of current interest in our laboratories is the detailed investigation of the interesting stereochemical aspects of the (2 + 2) cycloaddition reactions of chiral allenes with variously substituted radicophiles. In the first article in this series the details of the stereochemical features of diradical intermediate formation of symmetrically and unsymmetrically 1,3-disubstituted allenes with 1,1- and 1,2-disubstituted and monosubstituted radicophiles were outlined, and the results of the study of the stereochemistry of the cycloaddition reactions of enantioenriched (*S*)-(+)-1,3-dimethylallene [(*S*)-(+)-13DMA] with acrylonitrile (ACN) and methyl acrylate (MAC) were described.[1] Although no tetrahedral stereogenic atom is generated in the diradical intermediates, a surprisingly large extent of the enantiomeric excess (ee) of the 13DMA is transferred to the diradical intermediates and on to the cycloadducts (31% in one of the cycloadducts derived with ACN, and 39% in one of the cycloadducts derived with MAC). Molecular modeling calculations on the conformations of approach of the two reactants to the activated complexes for diradical intermediate formation and on the conformations of the diradical intermediates have allowed for the correct prediction of the absolute configuration in the cycloadducts formed in the cycloaddition reaction of (*R*)-(−)-13DMA with ACN determined experimentally by Baldwin and Roy.[2]

In the second article of this series the results of a study of the stereochemical features of the cycloaddition reactions of enantioenriched (*S*)-(+)-13DMA with the 1,2-disubstituted radicophiles *N*-phenylmaleimide (NPMI) and dimethyl fumarate (DMFM) were described.[3] These reactions involve the irreversible formation of the diradical intermediates in which a new tetrahedral stereogenic atom is generated. The chirality of these diradical intermediates is "locked in", i.e., there is no mechanism for the racemization of these intermediates. Thus, the extent to which the ee of the 13DMA is transferred to the diradical intermediates is also that which appears in the cycloadducts. The results of extensive molecular modeling calculations have provided interesting insights into the stereochemical features of these cycloaddition reactions. The results of these calculations indicate that three separate, minimum-energy reaction channels are operative, proceeding through different conformations of the reactants in approaching the activated complexes which result directly in the formation of different minimum-energy conformations of the diradical intermediates. These different conformations of the diradical intermediates undergo ring closure to specific cycloadducts. In these reactions an amazingly high degree of transfer of the ee of the starting 13DMA to the diradical intermediates and on to the cycloadducts is observed; ~ 78% in the case of one of the major cycloadducts derived with NPMI, and >97% in the major (>60%) cycloadduct derived with DMFM!

In the present article we describe the results of a study of the stereochemical features of the cycloaddition reactions of enantioenriched (*S*)-(+)-13DMA with the symmetrically 1,1-disubstituted radicophiles 1,1-dichloro-2,2-difluoroethene (1122) and 1,1-diphenylethene (DPE) which proceed via the achiral anti,anti and chiral anti,syn diradical intermediates **1** and **2**.



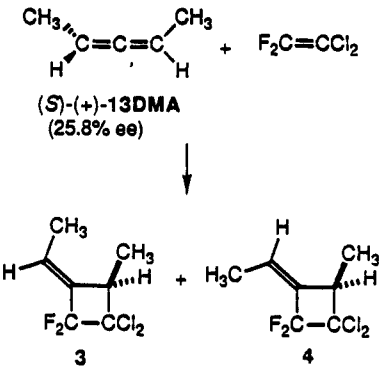
1 2

(1) Pasto, D. J.; Sugi, K. D. *J. Org. Chem.* **1991**, *56*, 3795.
(2) Baldwin, J. E.; Roy, U. V. *J. Chem. Soc., Chem. Commun.* **1969**, 1225.
(3) Pasto, D. J.; Sugi, K. D. *J. Org. Chem.* **1991**, *56*, 6216.

0022-3263/92/1957-0012$03.00/0

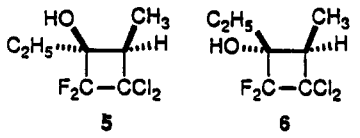
Results and Discussion

Cycloaddition of Enantioenriched (*S*)-(+)-13DMA with 1122. The reaction of (*S*)-(+)-13DMA with 1122, carried out in excess 1122 as solvent in a sealed tube at 160 °C for 48 h, cleanly produced the two cycloadducts **3** and **4** which were isolated by preparative GLPC. It was not possible to recover any unreacted 13DMA to determine its enantiomeric excess (ee) for comparison with that of the starting 13DMA.



The ee's of the cycloadducts could not be determined directly on the cycloadducts by the use of any available chiral NMR shift reagent. The attempted ozonolysis of **3** and **4** to the respective cyclobutanones in methylene chloride/pyridine, which proved to be very effective with the cycloadducts derived from 13DMA and ACN, resulted in the formation of, as yet, an unknown product lacking chlorine and containing a pyridine nucleus. Attempted ozonolysis in methylene chloride in the presence of dimethyl sulfide also did not result in the formation of the desired cyclobutanones.

The hydroboration of the pure cycloadducts **3** and **4** in the presence of a 3-fold excess of borane in THF for one hour at 25 °C followed by oxidative workup resulted in the formation of different diastereomeric tertiary alcohols assigned structures **5** and **6**, respectively.[4] Significant



amounts of unreacted **3** and **4** were also recovered.[5] The 300-MHz ^{1}H NMR spectra of the two alcohols immediately indicated the gross structures of the hydroboration products. The NMR spectra of the two alcohols show very characteristic ABX_3 patterns for the ethyl group in which the diastereotopic methylene protons appeared as a doublet of quartets of doublets with geminal coupling constants of 14.85 and 15.13 Hz, respectively, and also showing vicinal coupling to the methyl group and long-range coupling to one of the fluorine atoms attached to the four-membered ring (see Experimental Section for further details of the NMR spectra). The stereochemistry of **5** and **6** has been assigned on the basis of the relative chemical shifts of the ring methine and methyl protons, and the relative magnitudes of the long-range, cross-ring H–F coupling constants. The methine ring proton of **5** appears at higher field (δ 2.78) than in **6** (δ 3.05), and the ring methyl group of **6** appears at higher field (δ 1.16) than in **5** (δ 1.22). This data suggest that the ring methyl group in **5** is oriented pseudoequatorially with the ring proton oriented pseudoaxially as shown in **5e**, while in **6** the ring methyl group is oriented pseudoaxially with the ring proton oriented pseudoequatorially as shown in **6a**. This is consistent with the further observations that the cross-ring H–F coupling in **6** is larger (9.07 Hz, pseudoequatorial–pseudoequatorial coupling in **6a**) than that in **5** (5.5 Hz, pseudoequatorial–pseudoaxial coupling in **5e**).[6] The percent ee's of the alcohols were determined by the use of the chiral NMR shift reagent Eu(tfc)$_3$ and integration of the ring methyl resonances.

Table I. Enantiomeric Excesses of Alcohols 5 and 6 and Dibromides 7 and 8 and Percent of ee Transferred to 3 and 4[a]

run	% ee start	% ee (% ee transferred) 3	4
1[b]	25.8	10.8[c] (42)	4.1[c] (16)
2[b,d]	47.9	11.1[e] (23)	4.6[e] (10)
3[b,d]	47.9	16.3[e] (34)	3.3[e] (7)
4	47.9	15.0[f] (31)	5.4[f] (11)

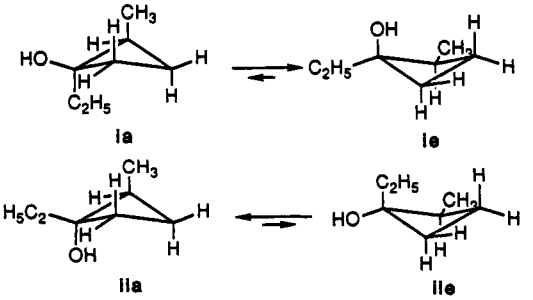
[a] Determined by the use of chiral NMR shift reagents with ±0.8–1.0%. [b] Of alcohol formed on hydroboration for 1 h at 25 °C. [c] Of tertiary alcohol. [d] See ref 5. [e] Of alcohol **5** formed on hydroboration for 3 h at 25 °C. [f] Of dibromide.

In a further attempt to measure the percent ee's of the cycloadducts, **3** and **4** were reacted bromine in aqueous THF exposed to the laboratory light. Under these reaction conditions **3** underwent isomerization to a mixture of **3** and **4** (30:70 ratio), while no change was observed with **4**.[8] When the reaction was carried out in the dark with sonication for 1 h at 25 °C, **4** produced a single product and

(4) The regioselectivity of the hydroboration of **3** and **4** is opposite the normally expected regioselectivity of the hydroboration reaction. However, the presence of allylic halogen induces a reversal in the regioselectivity of the hydroboration of nonsubstituted alkenes (Brown, H. C.; Gallivan, R. M., Jr. *J. Am. Chem. Soc.* **1968**, *90*, 2906. Brown, H. C.; Liotta, R. Scoutin, C. G. *J. Am. Chem. Soc.* **1976**, *98*, 5297). The presence of the two allylic fluorine atoms and the two homoallylic chlorine atoms result in an inductive effect which both reverses the regioselectivity of the hydroboration reaction and results in a significant decrease in the rate of the hydroboration reaction.[5]

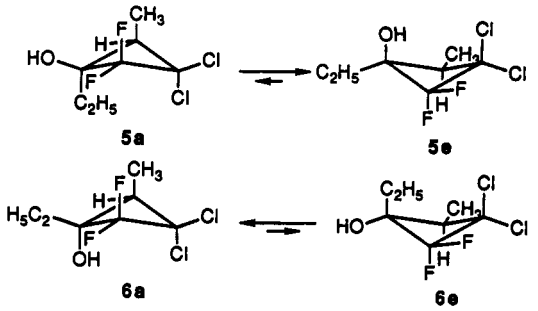
(5) In two other sets of experiments in which the hydroboration reactions were carried out for 3 h at 25 °C in an attempt to drive the hydroboration reaction more toward completion, only alcohol **5** was derived from *both* **3** and **4**, along with small amounts of the unreacted cycloadducts **3** and **4**. It appears that the hydroboration of **3** and **4** occurs reversibly, ultimately producing the more thermodynamically stable product **5**.[1]

(6) In order to estimate the conformational preferences of the two alcohols **5** and **6**, the heats of formation of the two conformations of the parent nonhalogenated systems i and ii of **5** and **6** have been estimated by molecular mechanics calculations with full geometry optimization using the MM3 program,[7] giving heats of formation for ia of 40.80, ie of 39.44, iia of 40.82, and iie of 41.07 kcal mol^{-1}. The results of the calculations indicate that ie is lower in energy than ia by 1.36 kcal mol^{-1} and iia is lower in energy than iie by 0.45 kcal mol^{-1}, with ie being lowest in energy of all of the stereoisomers by 1.36 kcal mol^{-1}. The results of these calculations are consistent with the interpretation of the NMR chemical shift and long-range, cross-ring H–F coupling constant data for the orientations of the ring methine and methyl protons in **5** and **6**.

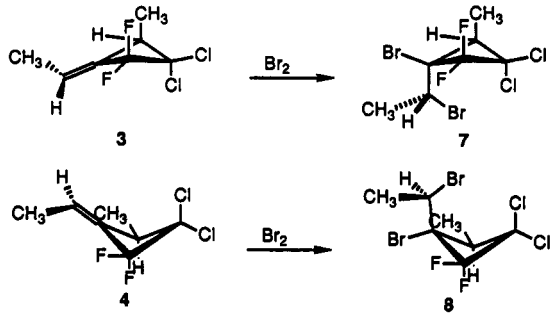


(7) *MM3*, N. L. Allinger, 1989. Parameters not available for **5** and **6** were substituted by the corresponding open-chain parameters.

(8) This observation supports the results of earlier calculations that indicated that (*E*)-2-(methylethylidene)cyclobutane is considerably lower in energy than the *Z* isomer.[1]

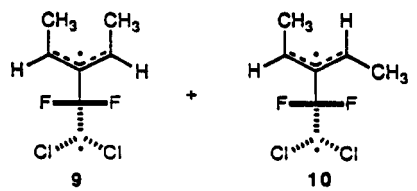


3 produced a mixture of two products in a 88:12 ratio with the minor product being identical with the single product formed from 4. Analysis of the products by mass spectrometry indicated the products to be the dibromides and not the expected bromohydrins. The structures of the two dibromides are assigned as shown in 7 and 8 in which the initial attack by bromine has occurred from the exo face in the lowest energy conformations of 3 and 4.[1] The



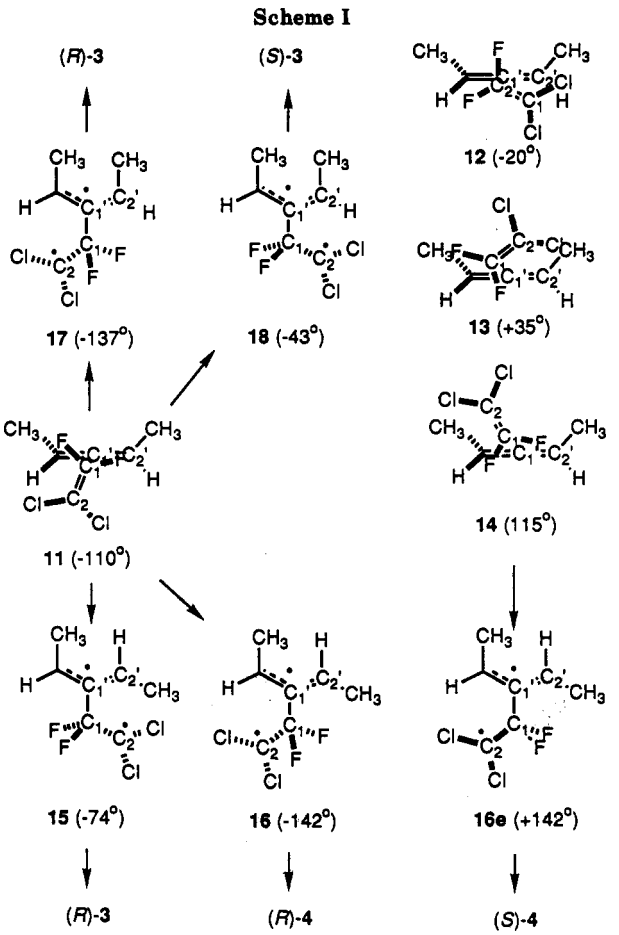
formation of the minor product from 3 probably occurs via the bromine atom induced isomerization of 3 to 4 which was suppressed, but not completely eliminated. The ee's of the two dibromides was determined by the use of a 3:1 mixture of the NMR shift reagents Ag(fod) and Yb(hfc)$_3$.[9] The results are given in Table I.

The observation that cycloadduct 3 is formed retaining a much greater portion of the ee of the starting 13DMA was initially very surprising. The results of ab initio calculations on the parent homotrimethylenemethane,[10] and molecular modeling calculations on the conformational preferences for the approach of ACN to 13DMA leading to the activated complexes for diradical intermediate formation, and on the conformational preferences of the diradical intermediates[1] using the Chem-X program[11] would have suggested that in the reaction of 13DMA with 1122 a perpendicular approach of the two reactants and conformation of the diradical intermdiates is preferred as shown in 9 and 10. However, this scenario is not consistent with the present results.



The results of our earlier studies on the stereochemistry of the cycloaddition reaction of 13DMA with 1122 suggested that the anti,anti diradical intermediate 9 was formed preferentially over the anti,syn diradical intermediate 10. If the anti,anti diradical intermediate prefers

Scheme I



to exist in the perpendicular conformation shown, it is achiral and must give rise to racemic cycloadduct 3. Diradical intermediate 10 is chiral and will result in the formation of nonracemic products. As 9 would have been expected to have been formed preferentially over the formation of 10, and, from steric considerations that diradical intermediate 10 would be expected to ring close to preferentially form 4, the much greater retained ee of 3 compared to that of 4 was totally unexpected. A careful reanalysis of the NMR data originally used to assign the stereochemistry of the cycloadducts confirms our earlier assignments. Furthermore, the isomerization of 3 to 4 on treatment with bromine also supports the stereochemical assignments.[8]

In order to gain an understanding of the observed results, molecular modeling calculations have been carried out on the conformational energy surface for the approach of the two reactants to the activated complexes and on models for the anti,anti and anti,syn diradical intermediates using the Chem-X suite of programs.[11] (To simplify the calculations, all of the anti methyl groups in structures 15–18 in Scheme I were replaced by hydrogen atoms. The anti methyl groups are included in the structures in Scheme I for clarity.) The structures of 1122 and (*S*)-(+)-13DMA were optimized separately and were then "docked" in such a manner that the axes of the 2p AO's on C_1 and $C_{1'}$ were coincident with a separation distance of 2 Å. The conformational potential energy surface for rotation 360° about the C_1–$C_{1'}$ axis was then calculated (see Figure 1). There are four energy-minimum conformations 11–14 which were then geometry optimized (the C_2–C_1–$C_{1'}$–$C_{2'}$ dihedral angles in the conformations are given in parentheses after the structure numbers). None of the minimum energy conformations have the 1122 oriented perpendicular to the C=C=C of the 13DMA (see

(9) Mannschreck, A.; Munninger, W.; Burgemeister, T.; Gore, J.; Cazes, B. *Tetrahedron* **1986**, *42*, 399.
(10) Pasto, D. J.; Benn, D. J. *J. Org. Chem.* **1991**, *56*, 6209.
(11) Chem-X, distributed by Chemical Design, Ltd., Oxford, England.

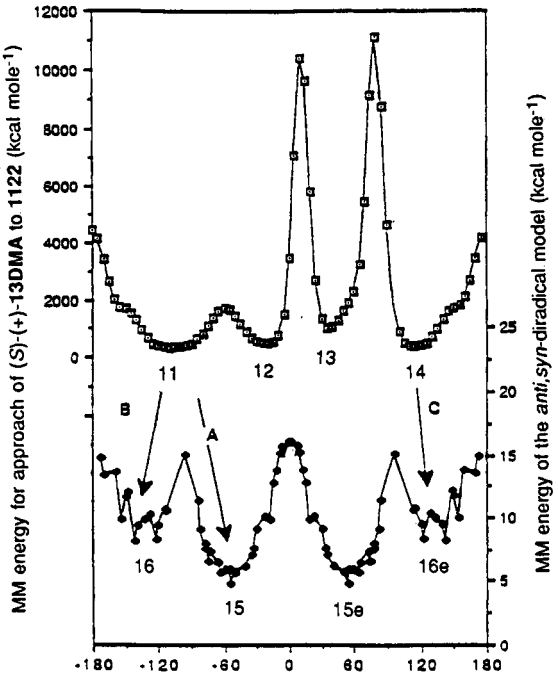


Figure 1. Plots of the conformation energy surfaces for the approach of (*S*)-(+)-13DMA and 1122 to the activated complexes and the anti,syn diradical intermediate model as a function of the C_2–C_1–$C_{1'}$–$C_{2'}$ dihedral angle.

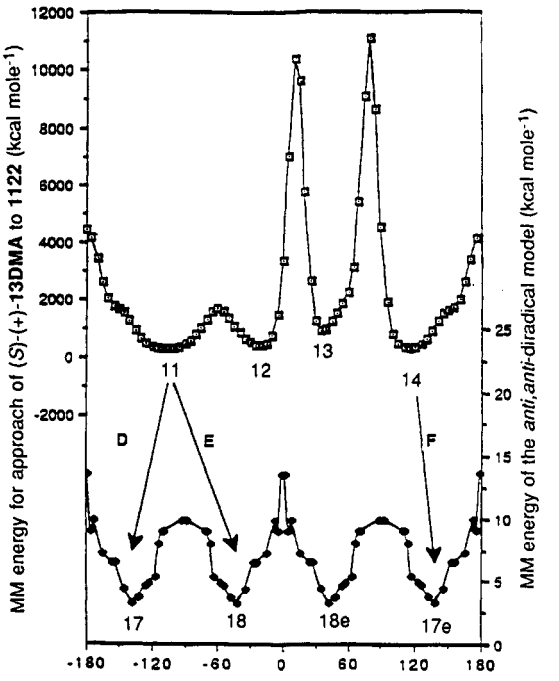


Figure 2. Plots of the conformation energy surfaces for the approach of (*S*)-(+)-13DMA and 1122 to the activated complexes and the anti,anti diradical intermediate model as a function of the C_2–C_1–$C_{1'}$–$C_{2'}$ dihedral angle.

Scheme I). The lowest energy conformation for the approach of the two reactants is shown in structure **11**. The conformational energy calculations on the model of the anti,syn diradical intermediate indicate the existence of two minimum-energy conformations shown as structures **15** and **16** (and their enantiomeric structures **15e** and **16e**) with **15** being lower in energy (see Figure 1). Thus, the lowest energy approach leads, with a slight rotation about the C_1–$C_{1'}$ axis, to the lowest energy conformation of the anti,syn diradical intermediate **15** (pathway A in Figure 1). The direct least motion ring closure of **15** to the right-end of the allyl radical produces the E,R cycloadduct **3** which is the major product retaining the greatest extent of the ee of the starting 13DMA. Conformational isomerization of **15** to either **16** or **15e** would appear to encounter energy barriers that are too high for these processes to compete with ring closure. The approach illustrated in **11** can also lead directly to **16** (pathway B in Figure 1) which is higher in energy than **15** and thus should be formed to a lesser extent. Ring closure of **16** to the left-end of the allyl radical produces the *Z,R* cycloadduct **4**. The second lowest energy approach via **14** would lead to the formation of **16e** which on ring closure would form the *Z,S* cycloadduct **4** (pathway C in Figure 1). These are the only reasonable reaction channels leading to the formation of **4** and, since they produce a product of opposite configuration, will result in a lower ee of **4**.

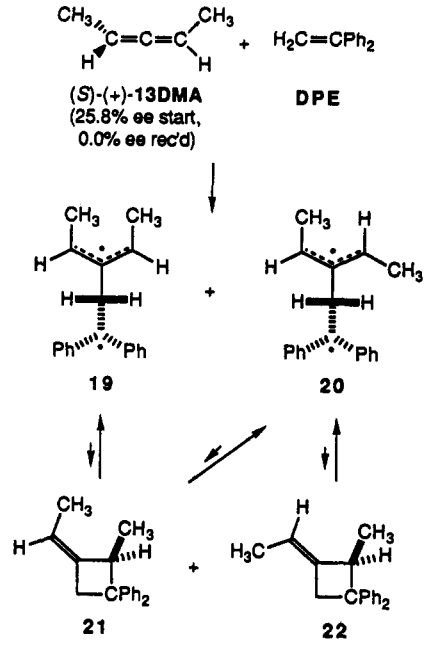
Conformational potential energy surface calculations on the model for the anti,anti diradical intermediate has located the two minimum-energy conformations **17** and **18** which are related as enantiomers (see Figure 2). Both **17** and **18** can be formed via the lowest energy approach shown in **11** which will produce equal amounts of **17** and **18** (pathways D and E in Figure 2). Ring closure of **17** and **18** will produce equal quantities of *E,R* and *E,S* cycloadducts **3**, the net result of which will be an overall reduction in the ee of **3**. The considerably higher energy pathway F should not contribute appreciably to cycloadduct formation. Because of the relatively high observed ee of **3**, it must be concluded that the formation of the anti,syn diradical intermediate must substantially predominate over the formation of the anti,anti diradical intermediate. This is in contrast to our earlier conclusion; however, the current stereochemical results dictate a change in our earlier conclusions.

Attempted Cycloaddition of (*S*)-(+)-13DMA with 1,1-Diphenylethene (DPE). An excess (100%) of (*S*)-(+)-13DMA was reacted with DPE in a sealed NMR tube in toluene-d_8 and heated in a sand bath at 160 °C. The NMR tube was removed periodically and the NMR spectrum was recorded. There was no evidence for the formation of any cycloadduct. After 5 days of heating, the tube was opened and the volatiles were removed on a vacuum line, leaving a very small amount of a residue. The NMR spectrum of the residue indicated the possible formation of cycloadducts or cyclodimers; however, the very small amount of material precluded further characterization. The lack of apparent formation of cycloadducts in the reaction does not mean that they were not formed at all, only that if formed they were formed in quantities too small to be detected. Cycloadducts **21** and **22** are quite sterically congested and could well be formed reversibly in very unfavorable equilibria. The 13DMA was isolated by preparative GLPC and the optical rotation of the sample was recorded. The recovered 13DMA showed *no* optical activity!

These results can be interpreted in terms of the following reaction scheme which involves the reversible formation of the two diradical intermediaes **19** and **20**. Intermediate **19** possesses a plane of symmetry, which if formed reversibly will result in the loss of the optical activity of the 13DMA. Intermediate **20** is chiral, which on cleavage will return to the 13DMA the same extent of chirality as it inherited from the 13DMA. This is the first cycloaddition reaction of 13DMA which has provided evidence for the reversible formation of diradical intermediates.

Experimental Section

Cycloaddition of Enantioenriched (*S*)-(+)-13DMA with 1,1-Dichloro-2,2-difluoroethene (1122). In an NMR tube was



placed 140 mg (2.06 mmol) of (S)-(+)-13DMA (run 1, $\alpha = 0.261 \pm 0.001°$, $c = 1.25$ in diethyl ether, 25.8% ee; runs 2–4, $\alpha = 0.355 \pm 0.001°$, $c = 0.915$ in diethyl ether, 47.9% ee), and 0.6 mL of 1122 was condensed at dry ice temperature. The contents of the tubes were triply freeze–degassed at liquid N_2 temperature, and the tubes were sealed under reduced pressure. The tubes were heated in a sand bath at 160 °C. After 48 h, the tubes were chilled in ice water and carefully opened, and the 1122 was allowed to evaporate at room temperature. The resulting residues were dissolved in $CDCl_3$ and the 300-MHz ^1H NMR spectra were recorded showing the presence of only the two cycloadducts **3** and **4** in a ratio of 66.6:33.4 in run 1, 65.4:34.6 in run 2, 66.4:33.6 in run 3, and 66.4:33.6 in run 4. The cycloadducts **3** and **4** were separated by preparative GLC on a 18 ft × $^1/_4$ in. DEGA on Chromosorb P column at 160 °C. (Insufficient quantities of the cycloadducts were recovered to allow for the accurate determination of their optical rotations.) The 300-MHz ^1H NMR data of the cycloadducts **3** and **4** have been reported and discussed in an earlier publication.[1] 500-MHz ^{19}F NMR ($CDCl_3$) of **3**: δ 54.0 (dqd, J = 200.0, 3.1, 3.1 Hz, 1 F), 56.4 (dqd, J = 197, 2,2, 2.0 Hz, 1 F). **4**: δ 52.3 (dqd, J = 197.0, 3.1, 1.9 Hz, 1 F), 54.7 (d, J = 197.0 Hz, 1 F). HREIMS: calcd for $C_7H_8{}^{35}Cl_2F_2$, 199.9971, found **3**, 199.9970; **4**, 199.9970.

Hydroboration of 3 and 4. In a 25-mL septum-capped vial at 0 °C were added 1 mL of THF, 40 mg (0.112 mmol) of $NaBH_4$, and 30 mg (0.15 mmol) of **3** or **4**. The reaction mixtures were slowly brought up to rt, and 18.4 mL (0.15 mmol) of BF_3-etherate was added dropwise by the use of a syringe. After 1 h of stirring at rt, 0.5 mL of cold 10% NaOH, 0.5 mL of cold 30% H_2O_2, and 5 mL of diethyl ether were sequentially injected into the reaction mixtures. The organic layers were removed and were washed with five 10-mL portions of water. The organic layers were dried ($MgSO_4$), and the diethyl ether was removed under slight reduced pressure. The residues were dissolved in 0.4 mL of $CDCl_3$, and the ^1H NMR spectra were recorded. The NMR spectra of the product(s) derived from the hydroboration of **3** indicated the formation of **5** along with ~50% of unreacted **3** in run 1, and along with ~10% of unreacted **3** in runs 2 and 3; while the NMR spectra of the product(s) derived from **4** indicated the formation of **6** along with ~50% of unreacted **4** in run 1, and the formation of **5** along with ~10% unreacted **4** in runs 2 and 3. The unreacted cycloadducts **3** and **4** were separated from **5** and **6** by column chromatography on a 0.8 mm × 5 cm silica gel column eluting with a 90:10 mixture of pentane–CH_2Cl_2. ^1H NMR ($CDCl_3$) of **5**: δ 1.04 (t, J = 7.43 Hz, 3 H), 1.22 (dt, J = 7.15, 0.69 Hz, 3 H), 1.70 (dqd, J = 14.85, 7.43, 4.26 Hz, 1 H), 1.85 (dqd, J = 14.85, 7.43, 0.93 Hz, 1 H), 2.77 (qdd, J = 7.15, 5.50, 2.06 Hz, 1 H). (The resonance of the hydroxyl proton could not be identified.) **6**: δ 0.98 (t, J = 7.56 Hz, 3 H), 1.16 (dd, J = 7.43, 1.65 Hz, 3 H), 1.56 (dqd, J = 15.13, 7.43, 2.20 Hz, 1 H), 1.85 (dq, J = 15.13, 7.43 Hz, 1 H), 3.05 (dq, J = 9.07, 7.56 Hz, 1 H). (The resonance of the hydroxyl proton could not be identified.) 500-MHz ^{19}F NMR ($CDCl_3$) of **5**: δ 38.70 (dt, J = 189.45, 5.04 Hz, 1 F), 41.44 (d, J = 189.45 Hz, 1 F). **6**: δ 45.77 (ddt, J = 189.73, 25.06, 5.13 Hz, 1 F), 60.36 (d, J = 189.73 Hz, 1 F). MS: No parent ions could be observed by either EIMS or isobutane CIMS.

Determination of the Enantiomeric Excesses of 5 and 6. Aliquots of a solution of 50 mg (0.056 mmol) of tris[3-(trifluoromethylhydroxymethylene)-(+)-camphorato]europium(III) [Eu(tfc)$_3$] dissolved in 500 μL of $CDCl_3$ were added to the NMR solutions of **5** and **6** until suitable resolution of the doublet methyl resonances of the ring methyl group was achieved. The integration of the NMR spectra was accomplished by peak simulation and integration using the GENCAP program on a GE NMR data station. The percent ee's of **5** derived from **3** in runs 1–3 were 10.75%, 11.1%, and 16.3% respectively. The percent ee's of **6** derived from **4** in run 1 was 4.1%, and that of **5** derived from **4** in runs 2 and 3 were 4.6% and 3.3%, respectively.

Isomerization of 3 to 4 on Attempted Reaction with Bromine. In 25-mL septum-capped vials were added 16 mg (0.1 mmol) of Br_2, 0.5 mL of THF, 10 g of ice–water, and a pure sample of **3** or **4**. The vials were shaken for 15 min while exposed to the laboratory light. To the mixtures was added aqueous $NaHSO_3$ until the Br_2 color disappeared, and the reaction solutions were then extracted with 5 mL of $CDCl_3$. The extracts were washed with five 10-mL portions of water, the organic layers were dried ($MgSO_4$), and the $CDCl_3$ was removed under reduced pressure. The residues were dissolved in $CDCl_3$, and the 300-MHz ^1H NMR spectra were recorded, showing the presence of a mixture of **3** and **4** derived from **3** in a ratio of 30:70, while the product derived from **4** indicated the presence of only **4**.

Addition of Bromine to 3 and 4. In 5-mL septum-capped vials were added 50 μL of Br_2, 50 mL of THF, 0.5 g of ice–water, and ~20 mg (~0.10 mmol) of **3** or **4** in the dark. The vials were suspended in a light-protected sonicator, and ultrasound was applied for 1 h. To the reactions mixtures was added aqueous $NaHSO_3$ until the Br_2 color disappeared. The mixtures were extracted with 10 1.5-mL portions of CH_2Cl_2, the combined extracts were dried ($MgSO_4$), and the solvent was removed under reduced pressure. The residues were dissolved in $CDCl_3$, and the 300-MHz ^1H NMR spectra were recorded, indicating the presence of two adducts derived from the reaction of **3** in the ratio of 88:12 and the presence of only one adduct in the reaction of **4**. The 300-MHz ^1H NMR spectrum of the reaction product derived from **3** indicated that the minor adduct is the same as the sole product formed in the reaction of **4**. Separation of the diastereomeric dibromides could not be achieved by chromatographic techniques. 300-MHz ^1H NMR ($CDCl_3$) of the major isomer of product from **3**: δ 1.44 (dt, J = 6.68, 0.64 Hz, 3 H), 1.781 (d, J = 6.47 Hz, 3 H), 2.81 (qdd, J = 6.68, 4.54, 1.38 Hz, 1 H), 4.22 (qd, J = 6.47, 2.66 Hz, 1 H). The product derived from **4**: δ 1.41 (dt, J = 6.68, 0.60 Hz, 3 H), 1.65 (d, J = 6.70 Hz, 3 H), 2.72 (qdd, J = 6.68, 4.08, 1.30 Hz, 1 H), 4.36 (qd, J = 6.70, 1.13 Hz, 1 H). EIMS: Calcd for $C_7H_9{}^{79}Br^{81}Br^{35}Cl_2F_2$, 359.8317, found on mixture of products from **3**, 359.8315; product from **4**, 359.8315. The nominal m/z's for the molecular compositions for the various isotopic compositions of $C_7H_8Br_2Cl_2F_2$ and the calculated (in parentheses) and observed total normalized nominal abundances (in brackets) follow: at m/z 358, $C_7H_8{}^{79}Br_2{}^{35}Cl_2F_2$ (14.2%) [16.1%]; at m/z 360, $C_7H_6{}^{79}Br_2{}^{35}Cl^{37}ClF_2$ and $C_7H_8{}^{79}Br^{81}Br^{35}Cl_2F_2$ (9.3 + 27.8 = 37.1%) [35.5%]; at m/z 362, $C_7H_8{}^{79}Br_2{}^{37}Cl_2F_2$, $C_7H_8{}^{79}Br^{81}Br^{35}Cl^{37}ClF_2$ and $C_7H_8{}^{81}Br_2{}^{35}Cl_2F_2$ (1.5 + 18.1 + 13.6 = 33.2%) [32.4%]; and at m/z 364, $C_7H_8{}^{79}Br^{81}Br^{37}Cl_2F_2$ and $C_7H_8{}^{81}Br_2{}^{35}Cl^{37}ClF_2$ (3.0 + 8.9 = 11.9%) [12.8%].

Determination of the Enantiomeric Excesses of the Bromine Addition Products of 3 and 4. A solution of 50 mg (0.124 mmol) of (6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanedionato)silver [Ag(fod)] and 50 mg (0.041 mmol) of tris[3-(heptafluoropropylhydroxymethylene-(+)-camphorato]ytterbium(III) [Yb(hfc)$_3$] in 500 μL of $CDCl_3$ was prepared and stored in a light-protected container. In NMR tubes were prepared solutions of the mixture of dibromoadducts from **3** and the dibromoadduct from **4**. Microliter aliquots of the Ag(fod)–Yb(hfc)$_3$ solution were added until base-line resolution of the β-bromomethyl resonances was achieved. The methyl resonances were integrated electronically, allowing for the calculation of the ee's,

indicating an ee of 15.0% for the dibromo adduct of the major isomer derived from 3 and 5.4% for the dibromo adduct derived from 4.

Attempted Cycloaddition of Enantioenriched (*S*)-(+)-13DMA with 1,1-Diphenylethene (DPE). In a 9-in. × 5-mm NMR tube were placed 179.7 mg (1.03 mmol) of DPE, 140 mg (2.06 mmol) of (*S*)-(+)-13DMA (α = 0.261 ± 0.001°, c = 1.25 in diethyl ether, 25.8% ee), 300 μL of toluene-d_8, and 5 mg of hydroquinone. The contents of the tube were triply freeze–degassed, and the tube was sealed under reduced pressure. The tube was heated at 160 °C in the sand bath for 5 days, at which time the NMR spectrum of the sample showed only the resonances of 13DMA and DPE. The tube was opened, and the volatiles were removed on a vacuum line. The unreacted 13DMA was isolated from the volatiles by preparative GLC on a 8 ft × $^1/_4$ in. 20% Apiazon L on Chromosorb P column at 110 °C. The optical rotation of the recovered 13DMA was recorded (α = 0.000 ± 0.001°, c = 2.295 in diethyl ether, 0.0% ee). The ^{1}H NMR spectrum of the nonvolatile residue showed no characteristic resonances expected of cycloadducts derived from 13DMA and DPE or cyclodimers of either reactant.

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Registry No. 3, 137396-55-5; 4, 137396-56-6; 5, 137396-57-7; 6, 137491-79-3; 7, 137396-58-8; 8, 137491-80-6; i, 137396-59-9; ii, 137491-81-7; (*S*)-(+)-13DMA, 23190-25-2; DPE, 530-48-3; 1122, 79-35-6.

Supplementary Material Available: 300-MHz ^{1}H NMR spectra for 5, 7, and 8 and 500-MHz NMR spectra for crude 6 (7 pages). Ordering information is given on any current masthead page.

β-Trichlorostannyl Ketones and Aldehydes. Preparation and Facile Amine-Induced Dehydrostannation Leading to α-Methylene Ketones and Aldehydes[1]

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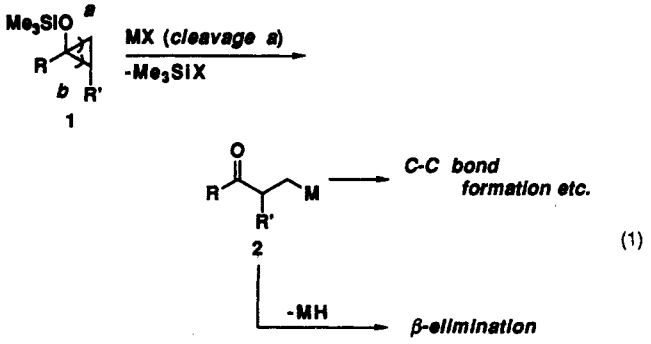
Ring-opening reactions of siloxycyclopropanes 1 with $SnCl_4$ take place under mild reaction conditions and site-selectively to give β-trichlorostannyl ketones and aldehydes 3 in high yields. The β-trichlorostannyl ketones and aldehydes thus obtained readily undergo base-induced dehydrotrichlorostannation at room temperature to give the corresponding α-methylene ketones and aldehydes 4. The reactions are quite general for amines, such as pyridine, triethylamine, *N,N,N′,N′*-tetramethylethylenediamine (TMEDA), and 1,4-diazabicyclo[2.2.2]octane (DABCO), and the yields are good to high. *One-pot* conversion from siloxycyclopropanes 1 to α-methylene ketones or aldehydes 4 by consecutive treatment of 1 with $SnCl_4$ and TMEDA is also successful. The ^{1}H NMR, ^{13}C NMR, ^{119}Sn NMR, and IR spectral properties of β-stannyl ketones and aldehydes are also reported.

In contrast to the extensive applications of metal enolates and α-metallo ketones in organic synthesis, the synthetic potential of β-metallo ketones has long been unexplored. The main limiting factor has been the lack of a convenient and general method for generating these compounds. We have reported a desilylative ring opening of siloxycyclopropanes 1 by metal salts (eq 1) which provides



(1)

a promising method for the generation of β-metallo ketones 2, enabling the development of useful synthetic transformations via 2.[2,3] In general, the ring opening of 2-substituted siloxycyclopropanes 1 occurred site-selectively at the methylene carbon (cleavage *a* in 1), and β-metallo ketones having a methylene group next to the metal were generated selectively by this method.

β-Metal hydride elimination to give alkenes is one of the fundamental and typical reactions of transition-metal alkyls. Accordingly, we thought that the conversion of

(1) A portion of this work has previously appeared; see: Ryu, I.; Murai, S.; Sonoda, N. *J. Org. Chem.* **1986**, *51*, 2389.

(2) A similar approach for β-metallo *esters* from 1-ethoxy-1-siloxycyclopropane has been concurrently developed by Nakamura and Kuwajima at TIT, where they use the term "metal homoenolate". For reviews on the β-metallo ketones and esters, see: (a) Ryu, I.; Sonoda, N. *J. Synth. Org. Chem. Jpn.* **1985**, *43*, 112. (b) Nakamura, E. *J. Synth. Org. Chem. Jpn.* **1989**, *47*, 931. (c) Kuwajima, I.; Nakamura, E. In *Small Ring Compounds in Organic Synthesis IV*; de Meijere, A., Ed.; Springer: Berlin, 1990; pp 1–39.

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