Stereochemistry of the Reaction of Cyclopropanes with Mercuric Trifluoroacetate

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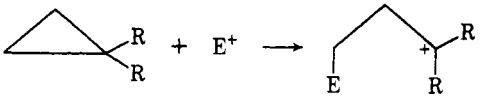
Abstract: The various stereoisomers of 1,2,3-trimethyl-1-phenylcyclopropane, 2,3-dimethyl-1-phenylcyclopropane, and 2,3-dimethylcyclopropanol methyl ether have been reacted with mercuric trifluoroacetate in methanol and the stereochemistry of both electrophilic and nucleophilic attack has been determined. The electrophilic mercury reacts at the least substituted ring bond (for bonds of equal substitution attack at a cis-substituted bond is preferred over attack at a trans-substituted one). Ring opening occurs in the direction of the more stable carbonium ion, which can lead to either retention or inversion at the site of electrophilic substitution. The opening occurs with substantially complete inversion of configuration at the site of nucleophilic attack. If all ring bonds are identically substituted, as is *cis*-1,2,3-trimethylcyclopropane, the ring-opened product arises from 62% inversion and 38% retention of configuration at the site of mercury attack and 100% inversion by the methanol. The results seem best to be accounted for by the formation, in the rate-determining step, of a corner-mercurated cyclopropane which ring opens by nucleophilic substitution by solvent.

Reaction of cyclopropane and its derivatives with various electrophiles leads, in many cases, to ring opening (eq 1). We have been interested for some



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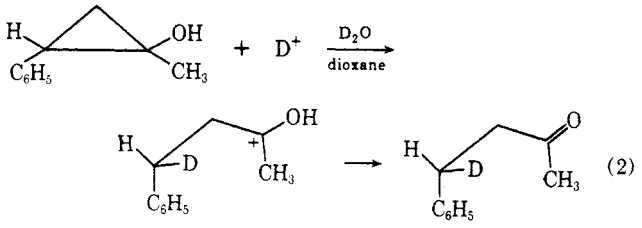
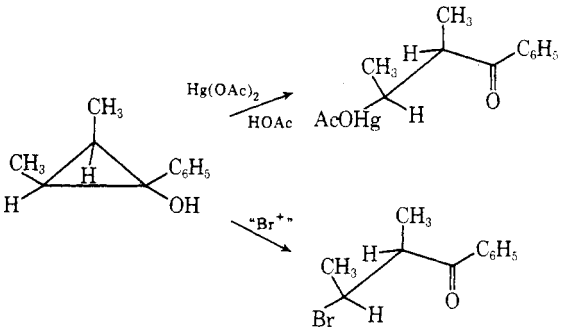
time in the mechanism and stereochemistry of these reactions, since they represent some of the very few examples of the cleavage of a carbon–carbon single bond by an electrophile.[2] Our first experiments in this area utilized cyclopropanols and their derivatives as substrates, since these molecules open readily under mild conditions. We were able to show that ring opening of some of these cyclopropanol derivatives occurs with retention of configuration when D^+ is used as the attacking electrophile[3] (eq 2), and that both mercuric



(2)

acetate and various brominating agents give products resulting from attack with inversion of configuration[4] (eq 3).

Other workers have also studied the stereochemistry of cyclopropane ring opening, particularly that induced by a proton or deuteron. In a reasonably large number of cases retention has been found to be the preferred pathway.[2,5] There are, however, a few examples of protons ring-opening a cyclopropane with inversion. The first of these was discovered by LaLonde and coworkers[6] and is shown in eq 4. Others



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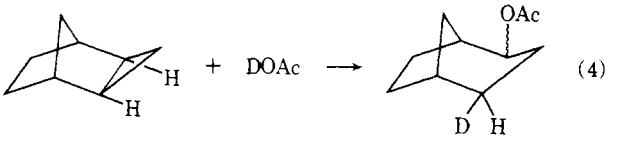


(4)

have been reported by Hogeveen[7] and Wheeler.[8] The remaining possible outcome, a mixture of inversion and retention, has also been reported in cases involving nortricyclene compounds.[9,10]

The present investigation was undertaken in an attempt to answer a number of questions about the electrophilic cleavages of cyclopropanes. In the first place, since all of our previous work had been carried out using cyclopropanols, their ethers, and their acetates as substrates, it might legitimately be asked whether the oxygen atom attached to the ring plays some unique, controlling role in determining the reaction stereochemistry. Secondly, we felt that a comprehensive study of the ring-opening stereochemistry as a function of the substitution pattern of the ring, and in particular the stereochemistry of the ring substituents,

(1) National Science Foundation Trainee, 1969–1971.
(2) For a review, see C. H. DePuy, *Fortschr. Chem. Forschung.*, **40**, 74 (1973).
(3) C. H. DePuy, F. W. Breitbiel, and K. R. DeBruin, *J. Amer. Chem. Soc.*, **88**, 3347 (1966).
(4) (a) C. H. DePuy, W. C. Arney, Jr., and D. H. Gibson, *J. Amer. Chem. Soc.*, **90**, 1830 (1968); (b) A. DeBoer and C. H. DePuy, *ibid.*, **92**, 4008 (1970).
(5) (a) S. J. Cristol, W. Y. Lim, and A. R. Dahl, *J. Amer. Chem. Soc.*, **92**, 4013 (1970); (b) J. B. Hendrickson and R. K. Boeckman, Jr., *ibid.*, **91**, 3269 (1969); (c) A. Nickon, J. L. Lambert, S. J. R. O. Williams, and N. H. Werstiuk, *ibid.*, **88**, 3354 (1966); (d) P. S. Wharton and T. I. Bair, *J. Org. Chem.*, **31**, 2480 (1966).
(6) R. T. LaLonde, J.-Y. Ding, and M. A. Tobias, *J. Amer. Chem. Soc.*, **89**, 6651 (1967).
(7) H. Hogeveen, C. F. Roobeek, and H. C. Volger, *Tetrahedron Lett.*, 221 (1972).
(8) R. J. Warnet and D. M. S. Wheeler, *Chem. Commun.*, 547 (1971).
(9) A. Nickon and J. H. Hammons, *J. Amer. Chem. Soc.*, **86**, 3322 (1964).
(10) J. H. Hammons, E. K. Probasco, L. A. Landers, and E. J. Whalen, *J. Org. Chem.*, **33**, 4493 (1968).

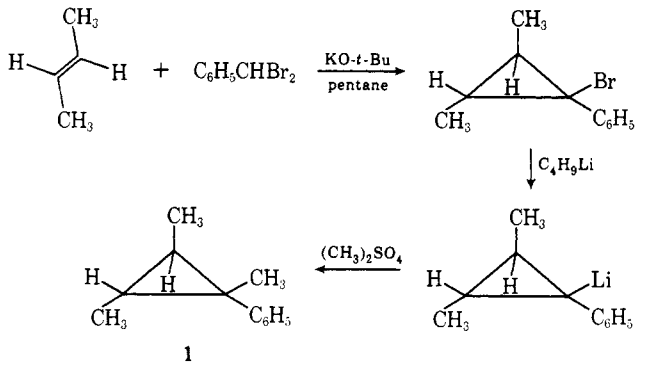
might shed some light on the reaction mechanism. We have, therefore, carried out a detailed study of the mercuration of a number of cyclopropanes, with the results reported in the following section.

Results

Cyclopropanols have the advantage, when used as substrates in electrophilic cleavage reactions, that there exists no problem of stereochemistry at the site of nucleophilic attack since a ketone is the end product of ring opening (eq 3). In moving to cyclopropanes as substrates, the situation becomes more complicated because an additional stereochemical center is introduced; thus, the stereochemistry of the nucleophile as well as the electrophile must be determined. Since our methods of determining the reaction stereochemistry were similar for many of the cyclopropanes investigated, we will describe them in detail for only one example, relegating the essentially similar details for related compounds to the Experimental Section.

1,2,3-Trimethyl-1-phenylcyclopropanes. The first compounds we studied were the three isomeric 1,2,3-trimethyl-1-phenylcyclopropanes. The synthesis of the trans isomer **1** is the most straightforward and could be accomplished in reasonable overall yield by the sequence shown in Scheme I. The same scheme, ap-

Scheme I



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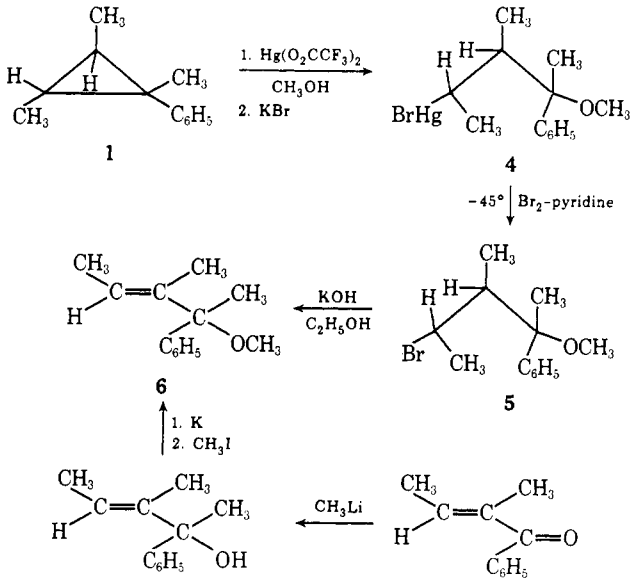
plied to *cis*-2-butene, gives a mixture of *syn*- and *anti*-1-phenyl-1-methyl-*cis*-2,3-dimethylcyclopropane (**2** and **3**, Table IV, respectively) from which the pure stereoisomers were isolated by combination of liquid and gas chromatography.

In separate experiments each of the three isomeric trimethylphenylcyclopropanes was allowed to react with mercuric trifluoroacetate[11] in absolute methanol[12] at 45–50° for about 72 hr, and the resulting organomercuric acetate was converted to the crystalline bromide by treatment with aqueous potassium bromide (see Scheme II). The crude product in each case was examined by nmr, and each displayed a different, relatively simple first-order spectrum that is consistent with a single isomer of the ring-opened product **4**. Evidently, each stereoisomer **1**, **2**, and **3** formed a different diastereomeric product of which **4** is one example, indicating that the reaction occurs with complete stereochemical integrity at both ends of the bond being cleaved.

(11) H. C. Brown and Min Hon Rei, *J. Amer. Chem. Soc.*, **91**, 5647 (1969).

(12) Some reactions were also carried out using mercuric acetate instead of the trifluoroacetate. The reaction times were inconveniently long and the yield considerably less in these cases. However, the stereochemical results were the same.

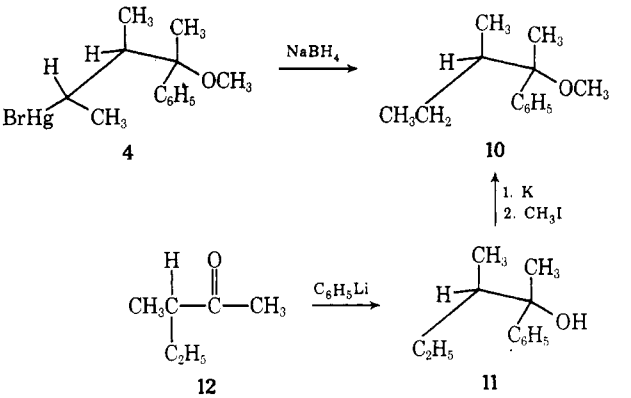
Scheme II



1 4 6 5

To establish the structure of the ring-opened product of **1** and to learn its configuration, the product **4** was converted to compounds of known structure and stereochemistry using the well-studied reactions detailed in Schemes II and III. These same general reactions

Scheme III



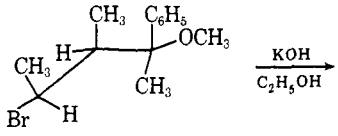
4 10 12 11

were applied to all the cyclopropanes reported here. In order to determine whether the mercury has entered with inversion or retention, the bromomercuri compound **4** formed from **1** was converted stereospecifically with retention to the corresponding bromo compound **5** by using the procedure of Jensen and coworkers[13] who demonstrated that the carbon–mercury bond could be replaced with a carbon–bromine bond with retention of configuration by using pyridine perbromide in pyridine. Again, based on the simple nmr spectra that are observed, only a single diastereomerically pure compound **5** is obtained as a product of this reaction. Upon treatment with alcoholic KOH, a single olefin is formed that was identified as the *E* isomer **6** by comparison with an authentic sample synthesized as shown in Scheme II. Assuming an anti elimination mechanism, which is reasonable in this system,[14] the production of the *E* isomer indicates that the mercuric trifluoroacetate has reacted with cyclopropane **1** with inversion of configuration at the site of electrophilic attack.

(13) F. R. Jensen and L. H. Gale, *J. Amer. Chem. Soc.*, **82**, 148 (1960).

(14) J. F. Bunnett, *Surv. Progr. Chem.*, **5**, 53 (1969).

The reactions detailed in Scheme II were next applied to the cyclopropane **2**. The bromomercuri product from **2** was converted to a bromo compound that is analogous to **5**, but showing significant differences in the nmr spectrum. Elimination of HBr from this isomer, **7**, gives two isomeric olefins **8** and **9**, both of which differ from **6** (eq 5). We did not synthesize an



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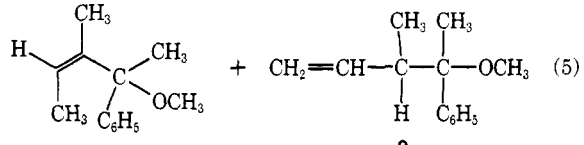


8 **9** (5)

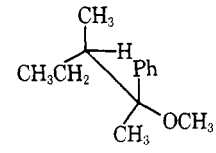
authentic sample of the *Z* isomer, **8**, but comparison between the nmr spectra of **8** and **6** leaves no doubt of its structure and stereochemistry. Thus the homoallylic coupling between the methyl groups is always greater for the trans compound such as **8** than for the cis compound.[15] In addition, the appearance of the terminal olefin **9** from **7** while no analogous terminal olefin is formed from **5** is consistent with the fact that the more sterically crowded *Z* olefin **8** should form at a slower rate than the *E* isomer **6**. Taken as a whole, these results indicate that complete inversion of configuration for the electrophilic mercury can occur in these compounds, in exact accord with the results for the corresponding 2,3-dimethyl-1-phenylcyclopropanols reported earlier,[4] and suggest that the presence of the hydroxyl group in the latter systems does not perturb the stereochemistry of the system.

Next it was necessary to learn whether the nucleophile, $HOCH_3$, had entered with inversion or retention of configuration. To determine this, the mercury was removed from the molecule by sodium borohydride reduction (Scheme III), thus simplifying the stereochemical problem by removing one asymmetric center. A single methyl ether **10** is obtained from **4**. The stereochemistry of **10** was shown to be *RS/SR* (*i.e.*, as that shown in Scheme III and derived from attack of methanol with inversion) by making use of the Cram–Karabatsos rules[16] to predict the major diastereomers to be expected when a new asymmetric center is created adjacent to an asymmetric site already in the molecule. Thus addition of phenyllithium to methyl *sec*-butyl ketone **12** is predicted to give a mixture of alcohols in which the *RS/SR* diastereomer predominates. When we carried out this reaction, a 53:47 mixture of diastereomeric alcohols was formed. This mixture was methylated, purified by glpc, and analyzed by nmr. The isomer present in larger amount was identical with **10**. As a check, phenyl *sec*-butyl ketone was allowed to react with methyllithium. A 58:42 ratio of alcohols was formed. After methylation, the minor isomer was identical by nmr with **10**.

(15) L. M. Jackman and S. Sternhell, "Nuclear Magnetic Resonance in Organic Chemistry," 2nd ed, Pergamon Press, Braunschewig, 1969, p 326.

(16) (a) D. J. Cram and F. A. A. Elhafez, *J. Amer. Chem. Soc.*, **74**, 5828 (1952); (b) G. J. Karabatsos, *ibid.*, **89**, 1367 (1967).

The reactions of Scheme III were repeated with the bromomercuri products formed from cyclopropanes **2** and **3**. Reduction of the bromomercuri compound from **2** gave a single methyl ether, **13**, that was proven



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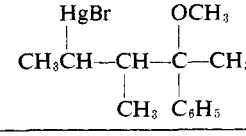
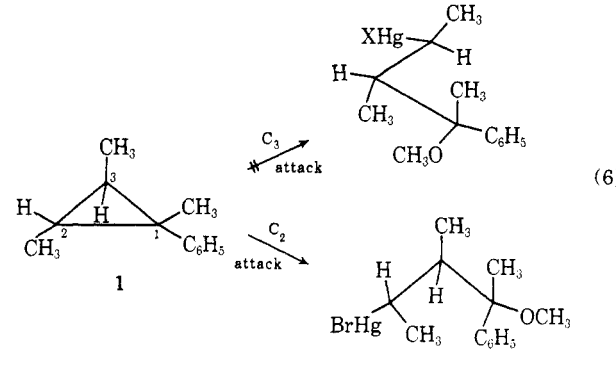
to have the *RR/SS* configuration by comparison of its nmr spectrum with the mixtures of authentic diastereomers. When the bromomercuri compound derived from stereoisomer **3** was reduced with sodium borohydride, the methyl ether was identical with **10**, the *RS/SR* isomer. Thus, the three cyclopropanes incorporate methanol with inversion of configuration when they are cleaved in that solvent. Having established that the electrophile and the nucleophile enter with inversion of configuration, we can assign the configurations of the organomercuric products formed from these cyclopropanes; the assignments appear in Table I.

Table I. Configurations of the Organomercuric Bromides Formed from the Cyclopropanes **1**, **2**, and **3**

Cyclopropane	
1[a]	*SSS/RRR*
2	*RSR/SRS*
3	*RSS/SRR*

[a] Based on C_1–C_2 cleavage only.

Several points need to be made about these results. The finding of complete inversion by the attacking electrophile is not surprising in view of our previous results,[4] but the complete inversion by the nucleophile, CH_3OH, is rather unexpected since the center under attack is tertiary and benzylic. This result would suggest a ring opening initiated by nucleophilic attack rather than ring opening to a cation followed by capture by the nucleophile. Equally surprising is the fact that only a single diastereomer is formed from opening of **1**. Assuming exclusive ring opening by inversion, then attack at each of the two carbons, C_2 and C_3, should have given rise to two diastereomers (eq 6) that



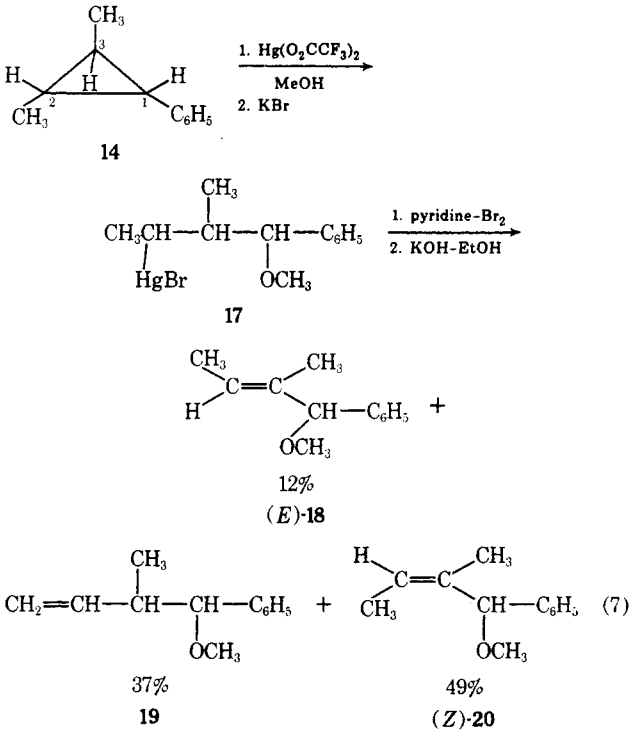
1 (6)

differ only in the configuration of the ring-opened C_1,

the ether carbon. Our results indicate the C_1–C_2 bond is exclusively (>95%) cleaved in this reaction.[17]

1-Phenyl-2,3-dimethylcyclopropanes. We next examined the ring opening of the three isomeric 1-phenyl-2,3-dimethylcyclopropanes. The trans isomer, **14**, is made simply by reduction of the bromide (see Scheme I) with sodium and methanol. When applied to 1-bromo-1-phenyl-*cis*-2,3-dimethylcyclopropane, this method gives a 40:60 mixture of *syn*- and *anti*-1-phenyl-*cis*-2,3-dimethylcyclopropanes (**15** and **16**, respectively), a mixture which is difficult to separate. Equilibration of the syn–anti mixture with potassium *tert*-butoxide in dimethyl sulfoxide gives a 50:1 ratio of the more stable anti isomer,[18] while protonation of the corresponding cyclopropyllithium reagent with a highly hindered proton source such as fluorene gives a 9:1 syn to anti ratio. In this case protonation presumably occurs from the least hindered face of the cyclopropane ring, *i.e.*, trans to the methyl groups.

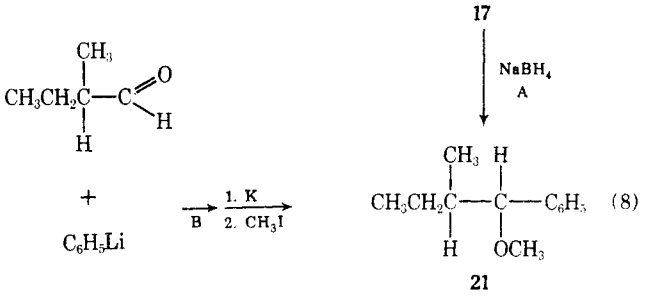
When the trans isomer, **14**, is subjected to ring opening with mercuric trifluoroacetate in methanol followed by bromination and elimination as detailed in Scheme II, a mixture of three olefins **18**, **19**, and **20** (eq 7) is obtained as determined by glpc and nmr analyses.



(7)

An authentic sample of **18** was synthesized by borohydride reduction of (*E*)-2-methylcrotonophenone (see Scheme II) followed by methylation of the alcohol. With an authentic sample of **18** in hand, it was an easy matter to distinguish **19** and **20**. If we assume that, as was the case for the trimethylphenyl system, elimination to furnish the *E* isomer is unaccompanied by elimination to 1-butene (**19**) then the results indicate only 12% inversion of configuration in the mercuration compared with 100% inversion for **1**; the remaining 88% must be retention. Alternatively we might propose that the elimination is not occurring stereospecifically, and both *E* and *Z* isomers are formed on base treatment. To rule out this possibility, one of the four possible diastereomers of 1-methoxy-2-methyl-3-bromo-1-phenylbutane was isolated by chromatography. Upon elimination of HBr by treatment with KOH in ethanol only a mixture of olefins **20** and **19** was found, and no *E* isomer **18**. Finally the same bromo ether was treated with tetrabutylammonium chloride in acetone with the intention of achieving an E2 elimination by a different route.[19] After 72 hr at 65–70° the major product isolated by preparative glpc was the chloro ether, presumably formed by SN2 reaction with inversion of configuration. When this chloro ether was subjected to elimination with KOH in ethanol, only the *E* olefin, **18**, together with a small amount of **19** was formed, and no *Z* olefin. Thus the eliminations occur stereospecifically as predicted.

The stereochemistry of methanol substitution was determined in a manner analogous to Scheme III. Removal of mercury from **17** gives **21**. The stereochemistry of **21** can be established by synthesis from the aldehyde as shown by eq 8 since the predominate isomer



(8)

formed in reaction 8B is predicted to possess a threo or *RS*/*SR* configuration.[16] This assignment is also supported by the magnitude of the vicinal coupling constants in the two diastereomers. The average coupling constant in an erythro isomer tends to be larger than that in a threo isomer.[20] The two diastereomers of **21** were obtained in a 53:47 ratio, and they are readily recognizable by their nmr spectra. The predominant isomer (predicted to be threo by Cram–Karabatosos rules) does indeed have the smaller coupling constant (5.9 Hz) while the minor isomer has J_{vic} = 6.9 Hz. The methoxy protons are well separated in the two diastereomers, so that analysis of the relative amounts of each isomer can be carried out accurately by nmr. The results are summarized in Table II.

The usual sequence of mercuration, bromination, and elimination were carried out on cyclopropanes **15** and

Table II. Relative Amounts of Olefins and Ethers Formed from Each Cyclopropane after Elimination (eq 7) and Reduction (eq 8)

Cyclopropane	Olefins, %			Ethers, %	
	18	**19**	**20**	*threo*-**21**	*erythro*-**21**
14	12	49	37	90	10
15	18	52	30	9	91
16	28	43	29	75	25

(17) High regioselectivity has also been found in the reductive cleavage of *cis*- and *trans*-1-methyl-2-phenylcyclopropane; see S. W. Staley and J. J. Rocchio, *J. Amer. Chem. Soc.*, **91**, 1565 (1969).

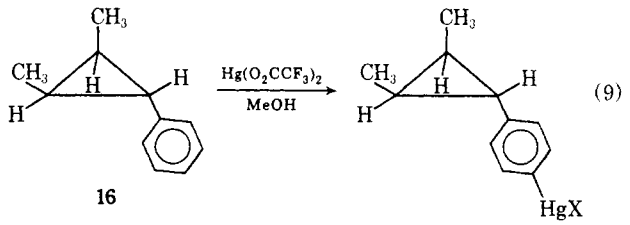
(18) G. L. Closs and R. A. Moss, *J. Amer. Chem. Soc.*, **86**, 4042 (1964).

(19) G. Biale, A. J. Parker, S. G. Smith, I. D. R. Steven, and S. Winstein, *J. Amer. Chem. Soc.*, **92**, 115 (1970).

(20) See ref 15, p 291.

16 as well. A mixture of olefins as in eq 7 was obtained, and the relative amounts detected in each case are summarized in Table II. Likewise the mercurated compounds **17** were reduced with sodium borohydride; the relative amounts of threo and erythro isomers of **21** are shown in Table II.

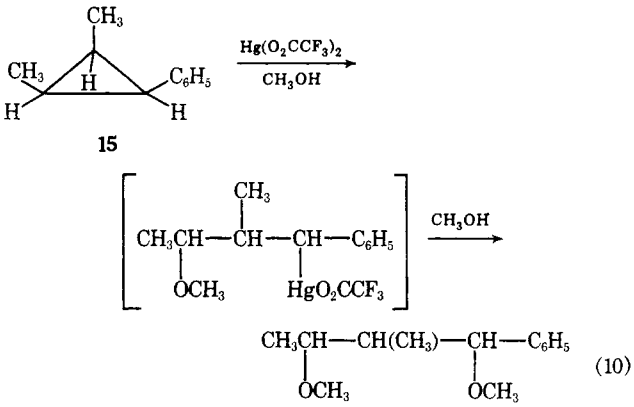
Some special problems arose in the ring opening of these isomers. Although mercuration into the aromatic ring of the phenyl group might have been anticipated in any of these compounds, or indeed in compounds **1**, **2**, and **3** as well, only in the *cis-anti*-cyclopropane **16** did it occur, and then to the extent of 40–45% (eq 9). Models show that only in this isomer can



16 (9)

the aromatic and cyclopropane rings freely adopt the bisected conformation that allows the cyclopropane ring to stabilize the transition state for aromatic substitution.[21] The nonbonded interactions of the methyl groups of **14** and **15** with the ortho hydrogens of the phenyl ring prevent the bisected conformation from being favored, thus inhibiting aromatic substitution for these cases.

One unexpected product also appeared in the ring opening of **15**, the cis-syn isomer. This was the dimethoxy compound shown in eq 10. We postulate



(10)

that it arises by attack of mercury at the benzylic carbon, leading to ring opening in the reverse sense to that previously observed.[22] The initially formed benzylic mercuric trifluoroacetate would be expected to solvolyze under the reaction conditions much more rapidly than secondary mercuric acetates.[23] Perhaps interference between the phenyl and methyl groups prevents the phenyl from adopting the most favorable conformation to facilitate ring opening in the normal direction. In any event this dimethyl ether accounts for 25% of the reaction product.

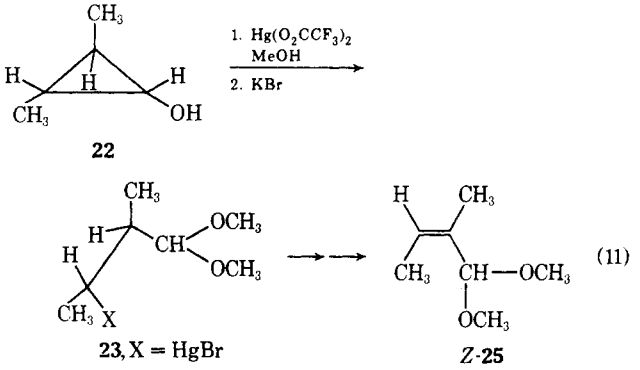
Ring opening of the cyclopropanes **14**, **15**, and **16** can give four possible diastereomers of **17**. All four isomers were distinguishable by nmr (particularly after treatment with pyridine–Br_2) and the relative amounts of each are summarized in Table III. Their configurations are assigned based on the results found for elimination and reduction (Table II).

Table III. Relative Amounts of the Diastereomers of 1-Methoxy-3-bromo-2-methyl-1-phenylbutane Formed from the Cyclopropanes[a,b]

Cyclopropane	Diastereomers A *RSS/SRR*	B *RRS/SSR*	C *RRR/SSS*	D *RSR/SRS*
14[c]	83	2	8	7
15	~5	12	~5	78
16	54	6	20	20

[a] Relative yields determined by nmr. Four distinct methoxy signals are observed (Table V). [b] Configurations were assigned based on the information in Table II. [c] Assumes C_1–C_2 cleavage predominates as in **1**.

2,3-Dimethylcyclopropanols and Methyl Ethers. From the results of the ring-opening studies for 1-phenyl-2,3-dimethylcyclopropanes it was obvious that substitution patterns on the cyclopropane ring can influence the stereochemistry of the ring cleavage. We, therefore, decided to examine some cyclopropanol derivatives which were less substituted than those we had investigated earlier.[4] Our first choice for study was the known cyclopropanol **22**.[24] Ring opening leads initially to the aldehyde which is converted to the dimethyl acetal under longer reaction times (eq 11).

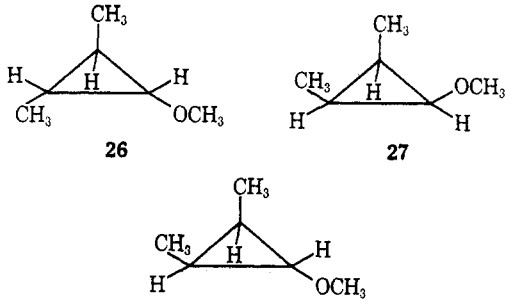


(11)

Conversion to the *Z* olefin **25** was accomplished by the method of Scheme II. That the *Z* olefin **25** is present was established by preparing an authentic sample of the *E* olefin from tiglic aldehyde, thus making a distinction between the two isomers possible. The formation of **25** establishes that ring opening occurs with at least 90% retention of configuration.

Because there seemed to us some chance that the first-formed aldehyde might undergo enolization, and so destroy in part the stereochemical integrity of the experiment, we decided to examine the three isomeric 2,3-dimethylcyclopropyl methyl ethers **26**, **27**, and **28**, which can be prepared by the procedure of Schöllkopf.[25] Each of these isomers undergoes ring opening very rapidly in mercuric trifluoroacetate–methanol. The organomercuric bromide formed from **26** was

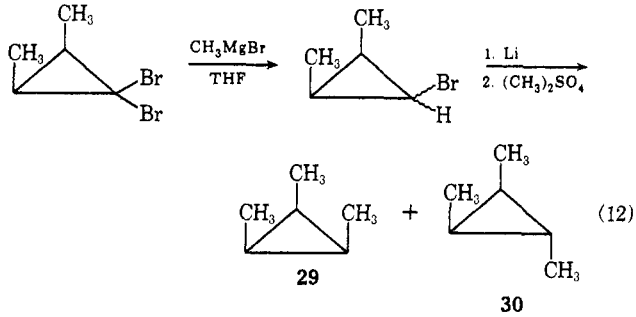
(21) H. C. Brown and J. D. Cleveland, *J. Amer. Chem. Soc.*, **88**, 2051 (1966).
(22) M. Y. Lukina, *Russ. Chem. Rev.*, **31**, 419 (1962).
(23) (a) F. R. Jensen and R. J. Ouellette, *J. Amer. Chem. Soc.*, **83**, 4477 (1961); F. R. Jensen and R. J. Ouellette, *ibid.*, **83**, 4478 (1961); (b) B. G. van Leuwen and R. J. Ouellette, *ibid.*, **90**, 7056 (1968).
(24) D. T. Longone and W. D. Wright, *Tetrahedron Lett.*, 2859 (1969).
(25) U. Schöllkopf, *Angew. Chem., Int. Ed. Engl.*, **7**, 588 (1968).



26 27 28

identical with the product obtained from cyclopropanol **22**. Since elimination gives mostly olefin **25**, the stereochemistry of ring opening must be retention and the intermediate compound **23** must have a threo configuration. Ether **28** also gives predominately the threo isomer **23** showing that ring opening occurs mostly with inversion of configuration. Finally isomer **27** yields a 60:40 ratio of the two diastereomers. That the major isomer present has the erytho configuration was confirmed by elimination to the *E* olefin. Approximately 5–10% of *erythro*-**23** was also detected in the ring openings of **22**, **26**, and **28**.

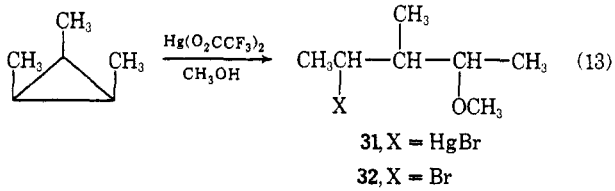
1,2,3-Trimethylcyclopropane. Lastly, we have examined the stereochemical consequences of the ring opening of *all-cis*-1,2,3-trimethylcyclopropane (**29**), prepared as outlined in eq 12. In this completely sym-



29 30 (12)

metrical molecule all ring bonds are identically substituted, so that the stereochemistry of ring opening cannot be imposed by steric factors on the bond which is attacked.

Ring opening of **29** is slow, and only a 55% yield of **31** as a mixture of diastereomers could be obtained (eq 13). Unchanged starting material was still pres-

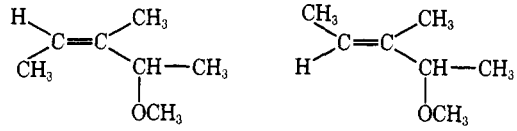


31, X = HgBr
32, X = Br

(13)

ent after 3 days, but its volatility made an exact material balance impossible. The nmr spectrum of the crude product after removal of solvent showed that the only organic product was a mixture of the two diastereomers of **31**. If the nmr spectrum of **31** is determined in pyridine, two distinct methoxy singlets are observed in a 62:38 ratio of relative peak heights.

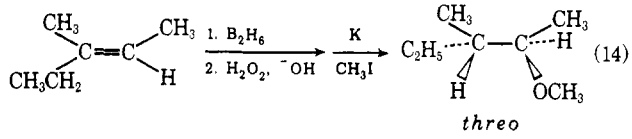
Confirmation that two diastereomers of **31** are formed from the cis isomer comes from a fractional crystallization of the crude organomercurial. After standing in the refrigerator overnight, a hexane solution of **31** deposited white crystals that corresponded to the major (62%) constituent of the mixture. When this pure isomer was converted to olefin by Scheme II, the *Z* olefin, **33**, was produced. From the mother liquors of



33 34

the recrystallization a pure sample of the second diastereomer of **31** was isolated that was identical with that of the minor (38%) constituent of the crude reaction mixture. This pure isomer was converted to the *E* olefin **34** in the usual manner. In this way *cis*-1,2,3-trimethylcyclopropane has been shown to give 62% inversion and 38% retention when attacked by mercury.

The stereochemistry of nucleophilic substitution by methanol was determined by two methods. First, the Cram–Karabatsos rules were applied to predict that erythro alcohol should be the major diastereomer formed from the addition of methyllithium to 2-methylbutyraldehyde.[16] A second approach, serving as a check on this method, involved hydroboration of *trans*-3-methyl-2-pentene and conversion to the threo alcohol (eq 14). The alcohols from both approaches



threo (14)

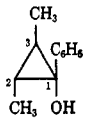
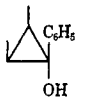
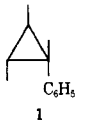
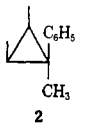
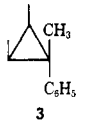
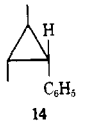
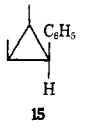
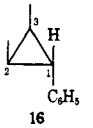
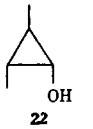
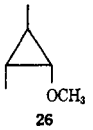
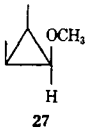
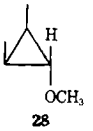
were converted to the methyl ethers, and their nmr spectra were compared with the spectrum of the methyl ether obtained by sodium borohydride reduction of **31**. The conclusion is that methanol attacks with complete inversion of configuration.

Discussion

The stereochemical outcome of cyclopropane ring opening by mercuric trifluoroacetate in methanol for the systems we have studied in this investigation and those reported previously[4] are summarized in Table IV. It is obvious that depending upon the substitution pattern of the cyclopropane, the carbon–mercury bond of the ring-opened product may be formed either with retention or inversion of configuration. The stereochemical results can be accounted for in the following way. In the first place the cyclopropane ring always undergoes ring opening so that the nucleophile becomes attached to the carbon which can best stabilize a positive charge, although there can be exceptions as with **15** (eq 10).[5b,26] In the systems reported here, this carbon is benzylic, or adjacent to an oxygen atom, or both. The stereochemistry can then be accounted for if we assume that the electrophilic mercury attacks the least hindered bond in the molecule, with opening taking place toward the benzylic or oxygen substituted carbon. To determine which ring bond is least hindered, we assume that disubstituted bonds are more accessible than trisubstituted ones, and that among the former cis disubstitution is more reactive than trans. The first five examples in the table then give opening exclusively

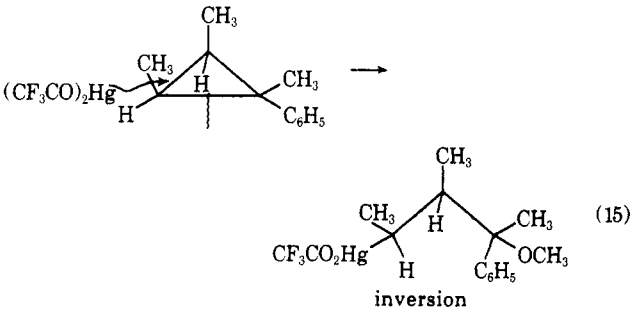
(26) Another exception has been reported by J. B. Hendrickson and R. K. Boeckman, Jr., *J. Amer. Chem. Soc.*, **93**, 4491 (1971).

Table IV. Summary of the Stereochemistry of Cyclopropane Ring Opening with Mercuric Acetates

Cyclopropane	Hg^{2+} ret : inv	CH_3OH ret : inv
	0 100[a]	
	0 100[a]	
 1	0 100	0 100
 2	0 100	0 100
 3	0 100	0 100
 14	88 12	10 90[b]
 15	18 82	9 91
 16	28 72	25 75
 22	95 5	
 26	90 10	
 27	60 40	
 28	5 95	
 29	38 62	0 100

[a] Reference 4. [b] Only C_1–C_2 cleavage is assumed.

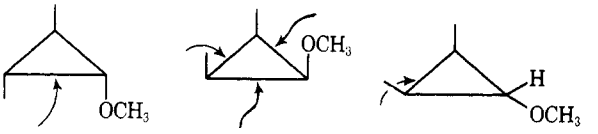
with inversion by mercury because attack occurs through the disubstituted 2,3 bond in preference to the trisubstituted 1,2 or 1,3 bonds (eq 15).



(15)

inversion

If we look next at the three isomeric 2,3-dimethylcyclopropyl methyl ethers, **26**, **27**, and **28**, we can ac-

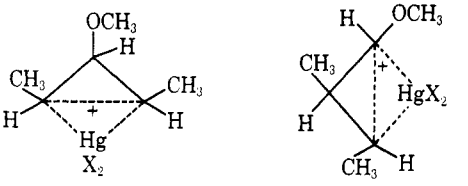


90% retention 60% retention 90% inversion

26 **27** **28**

count for the stereochemical outcome easily using this principle. Thus, in **26** attack at the only cis disubstituted bond leads predominately to retention, in **27** an essentially statistical stereo outcome results from the fact that all three bonds are cis disubstituted, while in **28** attack at the *cis*-dimethyl bond leading to mostly inversion is preferred. The results for opening of the three 1-phenyl-2,3-dimethylcyclopropanes **14**, **15**, and **16** are qualitatively in agreement with the same generalization. The outcome for **15** is complicated by the formation of the anti-Markovnikov product (eq 10) which probably results from attack at the C_1–C_2 bond, but even so attack at the bond substituted with two methyls should be sterically more favorable than attack at the bonds substituted by one methyl and one phenyl.

In view of the fact that substituents at both ends of the ring bond seem to effect the ease with which it is attacked by mercury, it is tempting to postulate an "edge mercurated" intermediate, **34** or **35**, for these reactions.



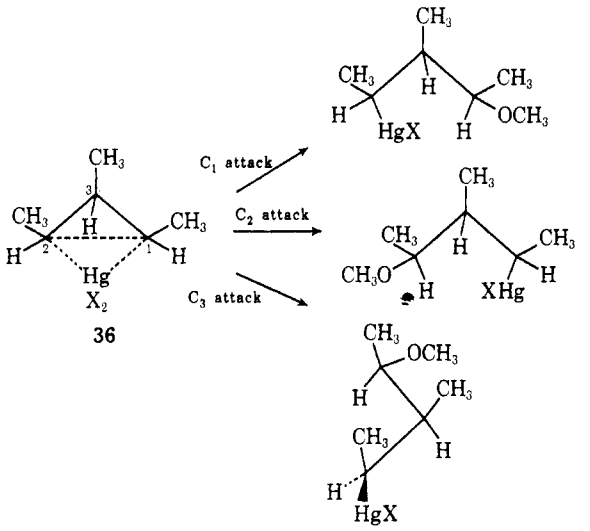
34 **35**

If the formation of such an intermediate were rate determining, we could account for the steric results straightforwardly. Yet we find this picture unconvincing, and a comparison of **34** and **35** shows why. For while these two structures are sterically similar, they are not so electronically. Admittedly, we know little about the electronic structure of such a species, but the reaction is, after all, an electrophilic substitution, positive charge is being introduced into the cyclopropane ring, and the whole direction of opening is controlled by the ability of the methoxy group to stabilize an adjacent positive charge. Ouellette,[27] in fact,

(27) R. J. Ouellette, R. D. Robins, and A. South, Jr., *J. Amer. Chem. Soc.*, **90**, 1619 (1968).

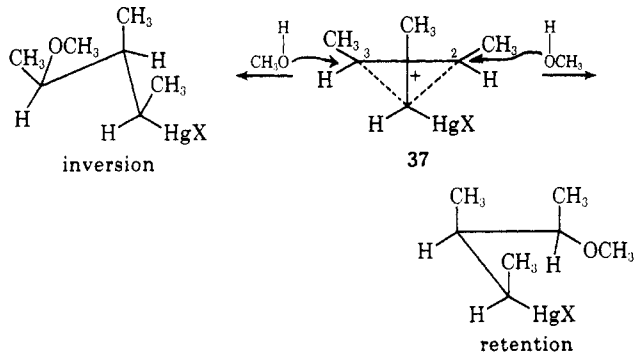
has shown that the rate of cleavage of phenylcyclopropane by mercuric acetate in acetic acid is strongly influenced by substituents on the benzene ring, with $\rho = -3.2$. It is hard to see how this can be reconciled with the stereochemical results if edge mercuration is rate determining.

In an effort to solve this problem, we carried out the stereochemical studies on *cis*-1,2,3-trimethylcyclopropane. This molecule has all ring bonds equally substituted, so that even if edge mercuration or something like it were rate determining, the stereochemistry of the opening would be determined later in the reaction. The results show that inversion of configuration by the electrophile is about twice as probable as retention in this system. This result is exceedingly hard to understand if an edge-mercurated cyclopropane **36** is the sole



36

intermediate from which products come, for retention, which can arise by attack of nucleophile at C_1 or C_2, seems much more likely than inversion, which requires attack of nucleophile at C_3, the re-formation of the C_1–C_2 bond, the breaking of C_1–C_3 or C_2–C_3, and a relatively large movement of the mercury. On the other hand, a corner-mercurated intermediate, **37**, can



account for the stereochemical results admirably. In such an intermediate the positive charge should be shared equally at C_2 and C_3. The reaction from **37** to product is essentially a methanolysis, with the nucleophile entering with inversion and with the rate at C_2 and C_3 being similar, but not necessarily exactly the same because of the different stereochemical outcomes. If the substituents on C_2 and C_3 are not the same, if, for example, one is methyl and the other methoxyl, then ring opening will naturally occur more readily in the direction of the substituent which can best stabilize a positive charge, as in all solvolysis reactions. The observation that the nucleophile enters exclusively, or nearly so, with inversion is also in accord with such an intermediate.

How can the idea of a corner-mercurated cyclopropane intermediate be reconciled with the steric effects which are so pronounced in determining which bond is attacked? Since the electron density of a cyclopropane ring lies along its edge, attack of an electrophile undoubtedly occurs from that direction. An edge-mercurated cyclopropane might then be a useful steric model for the transition state of the rate-determining step, which we feel leads to a corner-mercurated cyclopropane. This picture leads to a number of predictions about the stereochemical consequences of opening variously substituted cyclopropanes, and a number of them are being explored.

Experimental Section

Boiling points are uncorrected. All melting points were taken on a Fisher-Johns melting point apparatus and are uncorrected. Infrared spectra were measured with a Beckman IR-10 spectrophotometer. The nmr spectra were recorded with Varian A-60A or HA-100 instruments using tetramethysilane as internal standard. Mass spectra were obtained using a Varian CH-7 spectrometer. All glpc analyses were performed on an F&M Scientific Model 700 or an Aerograph Model 200 gas chromatograph.

Synthesis of Cyclopropanes. 1-Phenyl-1-methyl-*trans*-2,3-dimethylcyclopropane (1). A 250-ml flask equipped with a mechanical stirrer, condenser, and rubber serum cap was charged with 10.0 g of *cis,trans*-2,3-dimethyl-1-phenylcyclopropyl bromide[4a] and 100 ml of anhydrous ether and immersed in a Dry Ice–acetone bath. Under nitrogen 29 ml of 23.1 wt % *n*-butyllithium in hexane was injected with a syringe. After the mixture was stirred for 15 min, 5.5 ml of dimethyl sulfate in 15 ml of ether was injected. After 15 min the mixture was allowed to warm to room temperature and hydrolyzed with water; the ether layer was separated and stirred with NH_4OH, washed with brine, and dried over $MgSO_4$. Distillation afforded 3.7 g (53%) of product, bp 42–44° (1.2 mm). The nmr spectrum agreed with the previously published one.[28]

1-Phenyl-1-methyl-*cis*-2,3-dimethylcyclopropanes (2 and 3). These cyclopropanes were prepared in the same manner as described for **1**. Starting with 10.0 g of *cis,cis*- and *trans,trans*-2,3-dimethyl-1-phenylcyclopropyl bromide[4a] afforded 3.97 g (58%) of cyclopropanes, a mixture of **2** and **3** with **2** predominating,[28] bp 40° (0.8 mm). Liquid chromatography (neutral alumina, hexane) was used to isolate **2**. Preparative glpc with a SE-30 column furnished pure **3**.

1-Phenyl-*trans*-2,3-dimethylcyclopropane (14). The reduction procedure of Doering and Hoffmann[29] was used with only slight modification. *cis,trans*-2,3-Dimethyl-1-phenylcyclopropyl bromide (22 g)[4a] in 200 ml of ether was reduced with 55 g of sodium and moist methanol (360 ml containing 10 ml of H_2O). Concentration of the solvent and distillation of the residue afforded 9.75 g of product, bp 63–66° (5.5 mm). The nmr spectrum agreed with the previously published one.[18]

***syn*- and *anti*-1-Phenyl-*cis*-2,3-dimethylcyclopropane (15 and 16).** A mixture of these cyclopropanes was prepared in a manner analogous to the one described for **14**. Starting with 21.4 g of *cis,cis*- and *trans,trans*-2,3-dimethyl-1-phenylcyclopropyl bromide[4a] afforded 12.4 g (89%) of cyclopropanes, bp 66–75° (4 mm). The nmr spectrum indicated[18] that the anti isomer predominated (57:43).

The anti isomer **16** was obtained by the equilibration procedure of Closs and Moss.[18]

A 500-ml flask equipped with a mechanical stirrer, reflux condenser, nitrogen inlet, and an addition funnel was charged with 13.5 g of a mixture of *trans,trans*- and *cis,cis*-2,3-dimethyl-1-phenylcyclopropyl bromide[4a] and 75 ml of anhydrous ether. The flask

(28) G. L. Closs and J. J. Coyle, *J. Org. Chem.*, **31**, 2759 (1966).
(29) W. E. von Doering and A. K. Hoffmann, *J. Amer. Chem. Soc.*, **76**, 6162 (1954).

was cooled in a Dry Ice–acetone bath and 33 ml of 23.1 wt % *n*-butyllithium in hexane was added. The yellow suspension was stirred for 10 min before adding 15 g of fluorene dissolved in anhydrous ether. An orange color soon developed, and this solution was stirred for another 30–45 min at −70°. After hydrolysis with water, the ether layer was separated and dried over $MgSO_4$. Evaporation of most of the ether produced a white solid (fluorene) which was filtered and washed with hexane. The mother liquor was concentrated to give a viscous liquid which was distilled to give 4–6 g (45–68%) of product, bp 60–64° (3 mm), in which the syn isomer predominated by at least 9:1. Liquid chromatography (alumina, hexane) gave **15** that was at least 97% pure syn isomer.

cis,trans-**2,3-Dimethylcyclopropanol (22).** The alcohol was prepared from *cis,trans*-2,3-dimethylcyclopropyl bromide by the procedure of Longone and Wright.[24] The ir and nmr spectra were in agreement with those reported.[30]

cis,cis- **and** *trans,trans*-**2,3-Dimethylcyclopropyl Methyl Ether (27 and 28).** A mixture of the two ethers was obtained from 18.5 g of dichloromethyl methyl ether[31] and 50 ml of *cis*-2-butene by the procedure of Schöllkopf.[25] The isomers were separated by fractional distillation through a spinning band column.

cis,trans-**2,3-Dimethylcyclopropyl Methyl Ether (26).** This compound was prepared from *trans*-2-butene in the same manner as described for **27** and **28**.

cis- **and** *trans*-**1,2,3-Trimethylcyclopropane (29 and 30).** Following the procedure of Seyferth and Prokai,[32] *cis*-2,3-dimethyl-1,1-dibromocyclopropane (60 g)[33] was reduced to a mixture of *cis,cis*- and *trans,trans*-2,3-dimethylcyclopropyl bromide with 8.5 g of magnesium, 26 ml of methyl bromide, and 210 ml of anhydrous tetrahydrofuran.

In a 500-ml flask equipped with a mechanical stirrer, condenser, dropping funnel, and nitrogen inlet was placed 3.5 g of lithium wire, cut in small pieces, and 75 ml of anhydrous ether. The flask was cooled in an ice bath and 30 g of 2,3-dimethylcyclopropyl bromide was added dropwise under a nitrogen atmosphere over a 1-hr period. After the mixture was stirred another 30 min, the reaction flask was cooled in a Dry Ice–acetone bath, and 20 ml of dimethyl sulfate in 15 ml of ether was added dropwise. (Warning: the last time this step was carried out, pressure buildup after adding only a few drops of dimethyl sulfate caused the dropping funnel to fly off and shatter.) After another 45 min, the Dry Ice–acetone bath was removed and a saturated NH_4Cl solution was added. The ether layer was separated and dried over $MgSO_4$. Removal of the ether was accomplished by distillation through a spinning band column. The concentrate was fractionally distilled through the same spinning band column using glpc to monitor the distillation. Approximately 5 g of **30** and 4 g of **29** can be obtained. The ir and nmr spectra were consistent with the previously reported ones.[34]

Reaction of Cyclopropanes with Mercuric Trifluoroacetate. General Procedure. A weighed amount of mercuric trifluoroacetate[11] (15–20% excess) was placed in a reaction vessel equipped with a magnetic stirrer and condenser. The mercuric trifluoroacetate was dissolved in absolute methanol, cyclopropane was added, and the clear solution was heated in an oil bath at 45–50° for 72 hr. After this time, the methanol was stripped off under reduced pressure and a saturated solution of KBr in water was added to the viscous residue. Chloroform was added and the two-phase solution was stirred for 30 min. After filtering to remove the insoluble inorganic salts, the chloroform layer was separated, dried over $MgSO_4$, and stripped off on a rotary evaporator to afford the organomercuric bromide.

1-Phenyl-1-methyl-*trans*-**2,3-dimethylcyclopropane (1).** From 1.95 g (12.2 mmol) of cyclopropane, 6.25 g (14.7 mmol) of mercuric trifluoroacetate, and 35 ml of absolute methanol was obtained 4.9 g (85%) of a white solid. The nmr spectrum of the crude product was consistent with one diastereomer of 4-methoxy-3-methyl-4-phenyl-2-pentylmercuric bromide together with a trace of starting cyclopropane. Recrystallation from $CHCl_3$–hexane gave 3.65 g of white crystals: mp 161–164°; nmr ($CDCl_3$) τ 2.69 (s, 5), 6.73 (s, 3), 7.16 (m, 1), 7.92 (m, 1), 8.45 (s, 3), 8.58 (d, 3, J = 7, Hz), 9.17 (d, 3, J = 6.5 Hz).

syn-**1-Phenyl-1-methyl-***cis*-**2,3-dimethylcyclopropane (2).** A 1.5-g (9.4 mmol) sample of **2** was reacted with 5.8 g (13.6 mmol) of mercuric trifluoroacetate dissolved in 25 ml of absolute methanol. Work-up afforded 4.0 g (90%) of a white solid. The nmr spectrum of the crude product showed a trace of starting cyclopropane and was otherwise consistent with that expected for a second diastereomer of 4-methoxy-3-methyl-4-phenyl-2-pentylmercuric bromide. Recrystallization from $CHCl_3$–hexane gave 3.56 g of white crystals: mp 118–122; nmr ($CDCl_3$) τ 2.64 (s, 5), 6.93 (s, 3), 7.6–8.3 (m, 2), 8.48 (s, 3), 8.6 (d, 3, J = 7.0 Hz), 9.36 (d, 3, J = 6.5 Hz).

anti-**1-Phenyl-1-methyl-***cis*-**2,3-dimethylcyclopropane (3).** Reacting 0.72 g (4.5 mmol) of **3** with 2.5 g (5.9 mmol) of mercuric trifluoroacetate in 15 ml of absolute methanol gave 1.85 g (87%) of a white solid. The nmr spectrum of the crude product was consistent with that of a third diastereomer of 4-methoxyl-3-methyl-4-phenyl-2-pentylmercuric bromide. Recrystallization from $CHCl_3$–hexane gave 1.4 g of white crystals: mp 107–110°; nmr ($CDCl_3$) τ 2.63 (s, 5), 6.76 (s, 3), 7.4–8.3 (m, 2), 8.33 (s, 3), 8.58 (d, 3, J = 6.58 Hz), 9.08 (d, 3, J = 6.8 Hz).

1-Phenyl-*trans*-**2,3-dimethylcyclopropane (14).** From 3.0 g (20.5 mmol) of **14**, 10.4 g (24.4 mmol) of mercuric trifluoroacetate, and 30 ml of absolute methanol was obtained 8.33 g (88%) of a white solid. The nmr spectrum of the crude product was recorded using $CDCl_3$ and pyridine as solvents. One diastereomer of **17** clearly predominated. Close scrutiny of the methoxy region of the nmr spectrum in pyridine showed three other closely spaced singlets that can be assigned to the other diastereomers. A small amount of the crude product was recrystallized from $CHCl_3$–hexane to give white crystals: mp 112–114°; nmr ($CDCl_3$) τ 2.74 (s, 5), 5.63 (d, 1, J = 2.5 Hz), 6.66 (s, 3), 7.2–8.1 (m, 2), 8.43 (d, 3), 9.15 (d, 3).

syn-**1-Phenyl-***cis*-**2,3-dimethylcyclopropane (15).** Reacting 1.0 g (6.8 mmol) of **15** (containing 4% or less of **16**) with 3.6 g (8.3 mmol) of mercuric trifluoroacetate in 20 ml of absolute methanol afforded 2.2 g (64%) of a viscous liquid. The nmr spectrum of the crude product was determined. The methoxy region of the spectrum was quite complicated with several sharp singlets present. Column chromatography was carried out on a 12 in. × 3/8 in. column packed with Florisil. The crude product was eluted with Skelly B, then with benzene, and finally dichloromethane. Fraction 4, taking 20–30-ml cuts, contained 60 mg of starting cyclopropane. Fractions 7–9 contained 1.43 g of a solid that exhibited nmr bands consistent with structure **17**. Several diastereomers were present, but one clearly predominated: nmr ($CDCl_3$) τ 2.70 (s, 5), 6.04 (d, 1, J = 7.5 Hz), 6.85 (s, 3), 7.3–8.2 (m, 2), 8.58 (d, 3), 9.23 (d, 3). Fractions 10 and 11 contained 78 mg of a liquid. The nmr spectrum was consistent with the dimethyl ether of 2-methyl-1-phenyl-1,3-butanediol: nmr ($CDCl_3$) τ 2.67 (s, 5), 5.6 (d, 1, J = 4.3 Hz), 6.68 (s, 3), 6.75 (s, 3), 6.62–6.9 (m, 1), 8.0–8.6 (m, 1), 8.93 (d, 3), 9.22 (d, 3); mass spectrum *m/e* (rel intensity) 208 (0.75), 176 (3.5), 161 (3), 122 (10), 121 (100), 105 (7), 91 (9), 77 (13). Reexamining the original spectra of the crude product showed that about 25% of the total reaction was the dimethyl ether (eq 10) and the remainder was the anticipated organomercuric bromide.

anti-**1-Phenyl-***cis*-**2,3-dimethylcyclopropane (16).** A 1.0-g (6.8 mmol) sample of **16** was reacted with 3.5 g (8.2 mmol) of mercuric trifluoroacetate in 20 ml of absolute methanol to give 3.01 g (95%) of a semisolid. The nmr spectrum of the crude product indicated that 40% of the product was from aromatic substitution. The remainder of the product was **17** which was present as three or four of the possible diastereomers. The principal diastereomer present was identical with the one from **14.** Attempts to separate the aromatic substituted product from the ring-opened product by recrystallization and liquid chromatography failed.

cis,trans-**2,3-Dimethylcyclopropanol (22).** A 50-ml flask charged with 1.01 g (11.7 mmol) of cyclopropanol, 5.05 g of mercuric trifluoroacetate, and 20 ml of absolute methanol was sealed and stirred for 48 hr at room temperature. Work-up afforded 4.0 g (88%) of a white solid: mp 53–56°; mass spectrum *m/e* (rel intensity) 416 (10), 415 (5), 414 (55), 413 (42), 412 (100), 410 (67), 409 (50), 408 (28). The nmr spectrum showed that two diastereomers of **23** were present in a 95:5 ratio. The major one was subsequently shown to possess the threo configuration: nmr ($CDCl_3$) τ 5.75 (d, 1, J = 3.3 Hz), 6.55 (s, 3), 6.58 (s, 3), 7.5–8.1 (m, 1), 8.52 (d, 3), 8.98 (d, 3). The minor isomer (5%), *erythro*-**23**,

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Table V. Nmr Data for the Four Diastereomers of CH_3—CH(Br)—CH(CH_3)—CH(OCH_3)—C_6H_5[a]

Diastereomers Protons	A *RSS/SRR*	B *RRS/SSR*	C *RRR/SSS*	D *RSR/SRS*
CH_3–C(C)H–C	55 (d, J = 7)	37.5 (d, J = 7)	71 (d, J = 6.2)	46 (d, J = 7)
CH_3–CH–Br	100 (d, J = 7)	102.5 (d, J = 7)	95 (d, J = 7)	100 (d, J = 7)
OCH_3	195.5 (s)	189 (s)	188 (s)	187 (s)
O–CH–Ph	273 (d, J = 4)	233 (d, J = 9.7)	240 (d, J = 8.3)	237.5 (d, J = 9)
CH_3–C(Br)H–C	258 (quin, J = 7)	302 (qd, J = 2, 7)	224.5 (qd, J = 2.5, 7)	276 (qd, J = 4, 7)
Ph	437 (s)	437 (s)	439 (s)	437 (s)
C–C(C)H–C	7.2–8.1 (m)			

[a] Chemical shifts are given in hertz downfield from TMS on a 60-MHz instrument. The coupling constants J are in hertz. The solvent was $CDCl_3$.

showed the following nmr spectrum in $CDCl_3$: τ 5.82 (d, 1, J = 4.0 Hz), 6.55 (s, 3), 6.58 (s, 3), 7.18 (quartet of doublets, 1), 7.5–8.1 (m, 1), 8.58 (d, 3), 8.95 (d, 3).

cis,trans-**2,3-Dimethylcyclopropyl Methyl Ethers (26–28).** The ether was reacted with a 5% excess of mercuric trifluoroacetate in absolute methanol for 1 hr at room temperature. Work-up proceeded as usual. From **26**, a white solid (68%, mp 55–56°) was obtained that was shown to be a 90:10 mixture of *threo*- and *erythro*-**23** by nmr. A mixture of 90% of **28** and 10% of **27** afforded a 90:10 ratio of *threo*- and *erythro*-**23**, and from 96% of **27** and 4% of **28** was obtained a ratio of *threo*- and *erythro*-**23** of 40:60, respectively. The mass spectra of the products were identical with **23** as obtained from **22**.

cis-**1,2,3-Trimethylcyclopropane (29).** From 1.37 g (16.3 mmol) of **29**, 7.0 g (16.4 mmol) of mercuric trifluoroacetate, and 20 ml of absolute methanol was obtained 3.67 g (57%) of a crystalline solid, mp 67–82°. The nmr spectrum in pyridine showed two methoxy bands, the largest at 195 Hz and the other at 192.5 Hz, and two methyl doublets centered at 84.5 and 79 Hz. The HA-100 spectrum in $CDCl_3$ showed a triplet from the overlapping of two doublets and four other doublets due to the other two methyl groups. Hence, two diastereomers of **31** are present in a ratio of 62:38. The mass spectrum showed the correct parent ion for **31**: *m/e* (rel intensity) 392 (23), 393 (37), 394 (62), 395 (61), 396 (100), 397 (29), 398 (67), 399 (8), 400 (15).

The two diastereomers were separated by fractional recrystallization from hexane. The major diastereomer separated out first: nmr ($CDCl_3$) τ 6.63 (s, 3), 6.89 (quin, 1), 7.5–8.4 (m, 2), 8.51 (d, 3), 8.79 (d, 3), 9.08 (d, 3). The mother liquor contained mostly the minor diastereomer: nmr ($CDCl_3$) τ 6.64 (s, 3), 7.22 (quartet of doublets, 1), 7.6–8.4 (m, 2), 8.59 (d, 3), 8.88 (t, 6). A HA-100 spectrum showed the triplet to be two overlapping doublets.

Bromine Cleavage of the Organomercuric Bromide. General Procedure. The general procedure was adopted from the work of Jensen.[35] The organomercuric bromide was placed in a 50-ml, three-necked flask equipped with a magnetic stirrer and a dropping funnel and dissolved in dry pyridine. After cooling the reaction flask to −45° by a Dry Ice–acetone bath, a pyridine–Br_2 complex, prepared by cautiously adding bromine to pyridine, was added dropwise over a 5-min period to the organomercuric bromide. The light orange solution was stirred another 15–30 min at −45° before pouring the reaction mixture into a mixture of water and pentane. After filtering to remove the mercury salts, the pentane layer was separated, and the aqueous phase was extracted with more pentane. The combined pentane extracts were washed successively with 10% HCl, water, saturated $NaHCO_3$ solution, and water. After drying over $MgSO_4$, the pentane was stripped off on a rotary evaporator to yield the bromo compound.

1-Phenyl-1-methyl-*trans*-**2,3-dimethylcyclopropane (1).** The organomercuric bromide (1.0 g, 1.08 mmol) prepared from **1** was dissolved in 20 ml of pyridine and reacted with pyridine–Br_2 prepared from 0.4 g of bromine and 2 ml of pyridine. Work-up gave 0.34 g (59%) of **5**: nmr ($CDCl_3$) τ 2.64 (m, 5), 6.28 (quartet of doublets, 1, J = 1.3 Hz, 7.0 Hz), 7.0 (s, 3), 8.22 (m, 1), 8.33 (s, 3), 8.52 (d, 3, J = 7.0 Hz), 8.8 (d, 3, J = 6.5 Hz). No further purification was necessary.

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syn-**1-Phenyl-1-methyl-***cis*-**2,3-dimethylcyclopropane (2).** Reaction of 1.0 g (2.08 mmol) of the organomercuric bromide prepared from **2** with the pyridine–Br_2 gave 0.40 g (69%) of **7**. The nmr spectrum of the crude product showed the following bands: nmr ($CDCl_3$) τ 2.69 (s, 5), 5.38 (quartet of doublets, 1, J = 2.0, 7.0 Hz), 6.92 (s, 3), 7.55 (quartet of doublets, 1), 8.37 (d, 3, J = 7.0 Hz), 8.5 (s, 3), 8.98 (d, 3, J = 7.0 Hz).

anti-**1-Phenyl-1-methyl-***cis*-**2,3-dimethylcyclopropane (3).** Reaction of 1.2 g (2.5 mmol) of the organomercuric bromide obtained from **3** with the pyridine–Br_2 yielded 0.51 g (73%) of bromo compound: nmr ($CDCl_3$) τ 2.67 (s, 5), 5.78 (quartet of doublets, 1, J = 2.0 Hz, 7.0 Hz), 6.86 (s, 3), 7.55 (quartet of doublets, 1), 8.4 (s, 3), 8.57 (d, 3, J = 7.0 Hz), 9.0 (d, 3, J = 7.0 Hz).

Identification of the Four Diastereomers of 3-Bromo-1-methoxy-2-methyl-1-phenylbutane. The organomercuric bromide obtained from reacting a mixture of **15** and **16** was brominated in the usual manner to afford the bromo compound. The nmr spectrum of the crude product was quite complicated. Liquid chromatography was carried out with 20 g of Florisil to 1 g of crude product. After several blank fractions, the first compound to appear was shown to be *p*-bromo-*trans*-(*cis*-2,3-dimethylcyclopropyl)benzene by the nmr spectrum in $CDCl_3$; a typical A_2B_2 pattern for the aromatic protons and a pattern (strong singlet at τ 8.8, 9) similar to **16** for the alkylprotons was seen. The 100-MHz spectrum of the next component to emerge was consistent with a mixture of two diastereomers, A and D, of 3-bromo-1-methoxy-2-methyl-1-phenylbutane in a 2:1 ratio. A later fraction contained all four diastereomers, A, B, C, and D, in a ratio of 10:17:31:43. From the 100-MHz spectrum the assignment of chemical shifts for each diastereomer was possible. Their nmr bands are summarized in Table V. Using a high-pressure liquid chromatography system, separation of diastereomers A and D from B and C was possible. This helped to confirm the nmr assignments.

1-Phenyl-*trans*-**2,3-dimethylcyclopropane (14).** A 1.5-g (3.22 mmol) sample of organomercuric bromide prepared from **14** was reacted with pyridine–Br_2 to give 0.58 g (68%) of product. The nmr spectrum in $CDCl_3$ indicated that diastereomers A, B, C, and D of the bromo compound were present (see Table III for the relative amounts).

syn-**1-Phenyl-***cis*-**2,3-dimethylcyclopropane (15).** A 1.05-g sample of organomercuric bromide from **15** was reacted with pyridine–Br_2 in the usual manner. The nmr spectrum of the crude product showed that diastereomers D and the dimethyl ether of 2-methyl-1-phenyl-1,3-butanediol accounted for 48 and 25% of the total reaction, respectively. Diastereomers A, B, and C were also present (Table III) and account for 14% of the reaction. The remaining 13% was not identified.

anti-**1-Phenyl-***cis*-**2,3-dimethylcyclopropane (16).** A 1.65-g sample of crude organomercuric bromide, prepared from **16**, in 10 ml of pyridine was reacted with 0.69 g of bromine in 1.5 mol of pyridine to yield 0.54 g of product. The nmr spectrum of the crude product was determined in $CDCl_3$. Integration indicated that 43% of *p*-bromo-*trans*-(*cis*-2,3-dimethylcyclopropyl)benzene was present. The four diastereomers A, B, C, and D were also present (Table III). Separation of the aromatic-substituted product from the ring-opened product was possible by liquid chromatography over Florisil. The ratio of diastereomers did not change.

cis,trans-**2,3-Dimethylcyclopropyl Methyl Ether (26).** The organomercuric bromide prepared from **26** was reacted with pyridine–

Br_2 in the usual manner. The nmr spectrum of the crude product clearly indicated that the threo isomer of **24** predominated (*post hoc*): nmr ($CDCl_4$) τ 5.55 (quartet of d, 1, J = 2 and 7.0 Hz), 5.75 (d, 1, J = 6.5 Hz), 6.70 (s, 6), 7.6–8.3 (m, 1), 8.40 (d, 3), 9.03 (d, 3). Approximately 7% of the erythro isomer was present. The threo isomer of **24** was also the major product formed in the pyridine–Br_2 reaction of the organomercuric bromides prepared from **22** and **27**.

cis,cis-**2,3-Dimethylcyclopropyl Methyl Ether (27).** The 60:40 mixture of *erythro*- and *threo*-**23** prepared from **27** was brominated in the usual manner to give a 53:47 mixture of *threo*- and *erythro*-**24**, respectively (the two isomers react slightly different). The erythro isomer of **24** shows the following nmr bands in CCl_4: τ 5.5 (quartet of d, 1, J = 2.5 Hz and 7.0 Hz), 5.84 (d, 1, J = 8.0 Hz), 6.66 (s, 3), 6.75 (s, 3), 7.6–8.3 (m, 1), 8.37 (d, 3), 9.06 (d, 3).

cis-**1,2,3-Trimethylcyclopropane (29).** A 1.9-g (4.7 mmol) sample of organomercuric bromide prepared from **29** that was a mixture of two diastereomers (62:38) was reacted with pyridine–Br_2. The crude product weighed 0.58 g (66%) and its nmr spectrum in CCl_4 still showed the presence of two diastereomers of **32** in a ratio of 70:30.

Each of the two diastereomers that were separated by fractional recrystallization at the organomercuric stage was reacted with pyridine–Br_2 in the usual manner to give **32**. The predominate diastereomer of **31** gave a single stereoisomer of **32** having the following nmr spectrum in CCl_4: τ 5.55 (quartet of d, 1, J = 6.0 Hz, 7.0 Hz), 6.74 (s, 3), 6.72–6.76 (m, 1), 6.7–8.3 (m, 1), 8.42 (d, 3), 8.93 (d, 3), 9.15 (d, 3). The minor diastereomer of **31** gave a product that was contaminated with 18% of the diastereomer just described. A different stereoisomer of **32** made up the remaining 82% and showed the following nmr bands in CCl_4: τ 6.23 (quartet of d, 1, J = 2.0 Hz, 7.0 Hz), 6.68 (s, 3), 6.86 (m, 1), 7.8–8.2 (m, 1), 8.35 (d, 3), 8.91 (d, 3), 9.12 (d, 3).

Synthesis of Compounds with Known Configuration. (*E*)-**2-Methoxy-3-methyl-2-phenyl-3-pentene (6).** (*E*)-2-Methylcrotonophenone[4a] was dissolved in 25 ml of anhydrous ether and reacted with 20 ml of 2.29 *M* methyllithium. Work-up in the usual way and distillation (80–90° (0.1 mm)) afforded 1.4 g (33%) of alcohol: ir (neat) 3400–3600 cm^{-1} (broad, OH); nmr (CCl_4) τ 2.8 (m, 5), 4.32 (qq, 1, J_{H,CH_3gem} = 6.5 Hz, J_{H,CH_3trans} = 1.0 Hz), 7.4 (s, 1, OH), 8.33 (dq, 3, J_{CH_3,CH_3} = 1.0 Hz), 8.42 (s, 3), 8.55 (quin, 3, J = 1.0 Hz).

The alcohol (1.4 g, 8.0 mmol) was reacted with 0.4 g (10 mmol) of potassium in refluxing toluene. After 2 hr of reflux, the reaction was cooled to 30° and 5 ml of methyl iodide was added, and the reaction solution was stirred for another 2 hr at 40°. Excess potassium was destroyed with isopropyl alcohol, water was added, and pure **6** was obtained by preparative glpc: ir (neat) 2820 cm^{-1} (m, OCH_3), 1601 (w), 1495 (m), 1450 (s), 1385 (m), 1090 (s); nmr (CCl_4) τ 2.5–3.0 (m, 5), 4.3 (qq, 1, J_{H,CH_3gem} = 6.5 Hz, J_{H,CH_3trans} = 1.0 Hz), 6.86 (s, 3), 8.33 (dq, 3, J_{CH_3,CH_3} = 1.0 Hz), 8.5 (s, 3), 8.65 (quin, 3, J = 1.0 Hz); mass spectrum *m/e* (rel intensity) 190 (50, parent ion), 135 (100).

(*E*)-**1-Methoxy-2-methyl-1-phenyl-2-butene (18).** A 3.0-g (0.019 mol) sample of (*E*)-2-methylcrotonophenone[4a] was reduced with 0.3 g of $NaBH_4$ in 10 ml of 95% ethanol by standard procedures. This alcohol has also been prepared by the addition of tiglic aldehyde to phenyllithium. Nmr and ir spectra were identical.

The crude alcohol (3.2 g) was reacted with 1.0 g (20% excess) of potassium in refluxing benzene (100 ml) followed by methyl iodide. After work-up a pure sample of **18** was obtained by preparative glpc: ir (neat) 2820 cm^{-1} (m, OCH_3), 1601 (w), 1495 (m), 1450 (s), 1380 (m), 1095 (s); nmr (CCl_4) τ 2.82 (m, 4), 4.44 (quartet with broaden peaks, 1), 5.55 (s, 1), 6.78 (s, 3), 8.39 (broad d, 3, J_{R,CH_3gem} = 6.5 Hz), 8.61 (quin, 3, J = 1.0 Hz); mass spectrum *m/e* (rel intensity) 176 (78%), 161 (55%), 121 (100%).

Dimethyl Acetal of Tiglic Aldehyde. A mixture of 7.5 g of tiglic aldehyde and 11 g of trimethyl orthoformate was reacted as described.[36] The product (5.3 g) was isolated by fractional distillation through a 12-in. Vigreux column: bp 120–128° (625 mm); nmr (CCl_4) τ 4.42 (quartet with fine splitting, 1, J_{H,CH_3} = 7.0 Hz), 5.61 (s, 1), 6.83 (s, 6), 8.39 (dq, 3, J_{CH_3,CH_3} = 1.0 Hz), 8.59 (m, 3).

(*E*)-**3-Methyl-2-methoxy-3-pentene (34).** The commercially available 3-methyl-3-penten-2-one was shown to have the *E* configuration by comparing its nmr spectrum with those reported in the literature.[37] This ketone (3.62 g) was reduced with sodium borohydride and methylated, and the desired **34** was obtained by preparative glpc: ir (neat) 2830 cm^{-1} (OCH_3) and 1090 (s); nmr (CCl_4) τ 5.62 (quartet broaden by fine splitting, 1, $J_{CH_3,H}$ = 7.0 Hz), 6.46 (q, 1), 6.93 (s, 1), 8.41 (dq, 3, J_{CH_3,CH_3} = 1.0), 8.47 (s, 3), 8.88 (d, 3); mass spectrum *m/e* (rel intensity) 114 (80%, parent ion).

(*RS/SR*)-**2-Methoxy-3-methyl-2-phenylpentane (10).** To a solution of phenyllithium in ether prepared from 4.0 g of bromobenzene was added 3.0 g of methyl *sec*-butyl ketone. Work-up and removal of the solvent gave 4.17 g of alcohol. In the nmr spectrum, the C-1 methyl protons appeared as two singlets in a ratio of 53:47, indicating the presence of both stereoisomers. The largest signal is assigned to **11**, the *RS/SR* isomer

Methylation (potassium and methyl iodide) gave, after removal of solvent, 1.65 g of product. Glpc analysis with a XF-1150 column showed three major products. The one with the longest retention time was identified as starting alcohol. The other two products were isolated by preparative glpc. The nmr spectrum of the first compound indicated that it was 3-methyl-2-phenylpentane: nmr (CCl_4) τ 7.44 (quin, 1), 8.78 (dd, 3, diastereomeric methyls), 8.9–9.4 (m, 9). The second peak was identified as the methyl ether. With C_6D_6 as solvent, distinguishing the two stereoisomers **10** and **13** was possible. The ratio was 52:48, respectively, and the major one is assigned the *RS/SR* configuration: nmr (100 MHz, C_6D_6) τ 2.75 (m, 5), 7.06 (s, 3), 8.67 (two singlets separated by 0.7 Hz; the largest of the two was upfield, C-1 methyl), other peaks at 8.93, 9.05, 9.15, 9.22, 9.3, 9.43; ir (neat) 2825 (m, OCH_3), 1601 (w), 1495 (m), 1370 (s), 1105 (s), 1065 (s) cm^{-1}; mass spectrum *m/e* (rel intensity) 177 (10), 135 (100), 121 (100).

(*RR/SS*)-**2-Methoxy-3-methyl-2-phenylpentane (13).** In a small flask cooled in an ice bath and purged with nitrogen, 8 ml of 2 *M* methyllithium in ether was added slowly to 3.01 g of *sec*-butyl phenyl ketone. Work-up and removal of the solvent gave 2.01 g of alcohol. Two sharp singlets were seen in the nmr spectrum for the C-1 methyl. Their ratio was 58:42. The minor one was identical with **11**.

The methyl ether **13** was prepared as described for **10**. The nmr spectrum of the glpc collected methyl ether was determined in C_6D_6 at 100 MHz: τ 8.67 (two singlets separated by 0.7 Hz in a ratio of 55:45, largest peak was downfield, C-1 methyl), other peaks at 8.94, 9.07, 9.15, 9.23, 9.3, 9.42. The largest peaks are assigned to the *RR/SS* isomer **13**. The ir spectrum was identical with that of **10**.

(*RS/SR*)-**1-Methoxy-2-methyl-1-phenylbutane (21).** A phenyllithium solution was prepared from 4.0 g of bromobenzene, 0.52 g of lithium, and 20 ml of dry ether. This solution was cooled in an ice bath and an excess of 2-methylbutyraldehyde was added dropwise. After hydrolysis and work-up, 2.3 g of alcohol was obtained. The crude alcohol was methylated *via* the potassium salt in the usual manner. Glpc analysis of the crude product with a XF-1150 column showed two major product. These were isolated by preparative glpc. The minor peak was identified as 2-methyl-1-phenylbutane by comparing the 100-MHz spectrum with that reported.[38] The major product was identified as **21**. The two stereoisomers of **21** were easily distinguished by the nmr spectrum in $CDCl_3$. The benzylic proton appeared as a triplet at τ 6.16. The 100-MHz nmr spectrum showed the triplet to be a pair of overlapping doublets. The methoxy protons appeared as two singlets separated by 1.5 Hz. The ratio of diastereomers was 53:47, and the major one was assigned the *RS/SR* configuration: ir (neat) 2820 (m, OCH_3), 1601 (w), 1490 (m), 1372 (m), 1088 (s) cm^{-1}; mass spectrum *m/e* 178 (3%) and 121 (100%).

erythro- **and** *threo*-**2-Methoxy-3-methylpentane.** To a solution of 10 g of 2-methylbutyraldehyde in 50 ml of ether and cooled in an ice bath was added dropwise 65 ml of 2 *M* methyllithium in ether. The crude alcohol (3.0 g) obtained was reacted with potassium and methyl iodide in the usual manner. The methyl ether was purified by preparative glpc: nmr (CCl_4) τ 6.77 (s, 3), 6.9 (m, 1), 8.29–9.0 (m), 8.97 (d), 9.01 (d), 9.17 (d), 9.18 (d); ir (CCl_4) 2820 (m, OCH_3), 1460 (s), 1380 (s), 1095 (s) cm^{-1}. The major diastereomer should have the erythro configuration, but the complexity of the nmr spectrum made distinction of the two isomers difficult.

Commercially available *trans*-3-methyl-2-pentene was hydroborated with diborane generated from 1.01 g of sodium borohydride in 50 ml of diglyme and 5.06 g of $BF_3 \cdot Et_2O$. After 1 hr, water was added to kill the excess hydride and followed with 6 ml of 6 *N*

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sodium hydroxide and 6.5 ml fo 30% hydrogen peroxide. After another hour, the reaction mixture was diluted with water and extracted with ether. The ether extracts were washed with water and brine, and dried over $MgSO_4$. Removal of the ether by distillation gave 2.0 g of alcohol, bp 47° (33 mm).

This alcohol (2.0 g) was methylated in the usual manner. The product was purified by preparative glpc: nmr (CCl_4) τ 6.77 (s, 3), 6.94 (qd, 1, $J_{H,H}$ = 4.5 Hz), 8.2–9.0 (m), 9.02 (d, 3), 9.2 (d, 3). The absolute configuration should be threo.

Elimination of HBr from the Bromo Compounds. 1-Phenyl-1-methyl-2,3-dimethylcyclopropanes. A 0.60-g sample of **5** prepared from **1** was heated at 60° for 24 hr in a 5 ml solution of 2 *M* potassium hydroxide in absolute ethanol. The reaction mixture was diluted with water and extracted with ether. The combined ether layers were washed with dilute HCl, a saturated $NaHCO_3$ solution, and finally with brine. After drying over $MgSO_4$, the ether was removed to afford the product. The nmr and ir spectra of the crude product were identical with the authentic sample of **6**.

The bromo ether **7** prepared from **2** was reacted with 2 *M* potassium hydroxide in absolute ethanol in a manner similar to that just described. The nmr spectrum of the product was consistent with two olefins (60%) and starting material (40%) being present. The nmr spectrum of one of the olefins was consistent with the *Z* isomer **8**: nmr (CCl_4) τ (2.5), 4.38 (qq, 1, $J_{H,CH_{3gem}}$ = 7.0 Hz, $J_{H,CH_{3cis}}$ = 1.3 Hz), 6.92 (s, 3), 8.45 (s, 3), other protons were not distinguishable. The nmr spectrum of the other olefin was identified as **9**: nmr (CCl_4) τ 2.74 (s, 5), 3.8–4.4 (m, 1), 4.95 (t, J = 1 Hz), 4.86 (dd J = 1.0 Hz, 2.5 Hz), 5.24 (dd, J = 1.0 Hz, 2.5 Hz), 6.98 (s, 3), 7.52 (q, 1), 8.55 (s, 3), 9.25 (d, 3). The ratio of olefins was 1:1. Further treatment of this product mixture with 10 ml of 1.0 *M* potassium *tert*-butoxide in *tert*-butyl alcohol at 60° for 40 hr caused most of **7** that was still present to eliminate to give mostly olefin **9**.

1-Phenyl-2,3-dimethylcyclopropanes. A sample of the bromo compound from each of the 1-phenyl-2,3-dimethylcyclopropanes was reacted with 2 *M* potassium hydroxide in absolute ethanol at 55–60° for 24 hr. The reaction mixture was then diluted with water and extracted with ether. The combined ether extracts were washed with water, dried, and concentrated to give the product. In all three cases, glpc showed two large peaks. These were collected by preparative glpc using a SE-30 column. The first peak was shown to be **19**: nmr (CCl_4) τ 2.83 (s, 5), 4.0–4.85 (m, 1), 4.9–5.4 (m, 2), 6.15 (d, 1, J = 6.0 Hz), 6.84 (s, 3), 7.56 (m, 1), 8.97 (d, 3), 9.15 (d, 3, second diastereomer); ir (neat) 3040 (m), 2820 (m, OCH_3), 1640 (w), 1601 (w), 1090 (s), 905 (s), 750 (s), 690 (s) cm^{-1}; mass spectrum *m/e* 176 (1) and 121 (100).

The second peak that was collected had the same retention time as an authentic sample of **18**, but the nmr spectrum indicated it had to be a mixture of **18** and **20**. The *Z* olefin **20** exhibited the following bands in CCl_4: τ 2.83 (s, 5), 4.47 (quartet with further splitting, 1), 4.86 (s, 1), 6.73 (s, 3), 8.2 (dq, 3, J_{CH_3,CH_3} = 1.4 Hz, $J_{H,CH_{3gem}}$ = 7.0 Hz), 8.57 (quin, 3), J = 1.4 Hz). The ir and mass spectra matched very closely with those of the *E* olefin **18**. The product ratios for the three olefins detected are summarized in Table II.

A 0.13-g sample of bromo compound, which by nmr was only the *RSS/SRR* diastereomer, was reacted with 2 *M* potassium hydroxide in absolute ethanol by the usual procedure. The nmr spectrum of the product showed that **20** and **19** were present in a 59:41 ratio, respectively; no **18** was detected.

A 1.0-g sample of bromo compound, 90% of the *RSS/SRR* diastereomer, was reacted with 4.0 g of tetra-*n*-butylammonium chloride in 180 ml of dry acetone containing 1.0 g of collidine. After 72 hr at 65–70°, the reaction was worked up. Glpc analysis showed about 10% of the expected olefinic products and mostly a new major product. This was collected by preparative glpc and shown to be 3-chloro-1-methoxy-2-methyl-1-phenylbutane: nmr (CCl_4) τ 2.7 (s, 5), 5.96 (d, 1, J = 8.0 Hz), 6.35 (qd, $J_{H,H}$ = 3.0 Hz), 6.96 (s, 3), 7.9–8.5 (m, 1), 8.62 (d, 3), 8.87 (d, 3). This chloromethyl ether (0.20 g) was reacted with 2 *M* potassium hydroxide in absolute ethanol in the usual manner. The nmr spectrum of the product showed that **18** and **19** were present in a 83:17 ratio, respectively.

2,3-Dimethylcyclopropanol and Methyl Ethers. Elimination of HBr from **24** was carried out in the usual manner using KOH in absolute ethanol. The product from **24** which was prepared from **12** gave a mixture of two olefins. The major product (84%) was identified as the dimethyl acetal of angelic aldehyde **25**: nmr (CCl_4) τ 4.55 (quartet with fine splitting, 1), 5.08 (s, 1), 6.74 (s, 6), 8.3 (dq, J_{CH_3,CH_3} = 1.3 Hz, $J_{H,CH_{3gem}}$ = 7.0 Hz), 8.38 (m), A minor product was 3-methyl-4-pentenal which could be recognized by the now characteristic olefin pattern.

The elimination of HBr from a 53:47 mixture of *threo*- and *erythro*-**24** (prepared from **27**) gave both **25** and tiglic dimethyl acetal in a 58:42 ratio, respectively.

1,2,3-Trimethylcyclopropane. The two diastereomers formed from **29** were separated and each was brominated separately. The bromo compound **32** of the major diastereomer was subjected to 2 *M* potassium hydroxide in absolute ethanol by the usual procedure. After work-up, the ether was removed by fractional distillation and the concentrate was distilled in a bulb to bulb apparatus. Glpc analysis of the product showed two peaks in a 83:17 ratio. The nmr spectrum of the product showed that the major product was **33** plus about 17% of 2-methoxy-3-methyl-4-pentene. The *Z* isomer **33** showed nmr bands in CCl_4 at τ 4.67 (quartet with further splitting, I), 5.82 (q, 1), 6.86 (s, 3), 8.35 (dq, 3, J_{CH_3,CH_3} = 1.3 Hz; the other half of the doublet was buried under a multiplet at 8.43), and 8.88 (d, 3). The vinyl olefin is believed to be the side product because of the complexity of the olefinic region of the nmr spectrum.

The minor diastereomer formed from **29** was treated in analogous fashion. The nmr of the product obtained after HBr elimination was identical with authentic **34**. A small amount (10%) of the vinyl olefin was present plus some 17% of **33** due to contamination when the two diastereomers were separated by fractional recrystallization.

Sodium Borohydride Reduction of Organomercuric Bromides. 1-Phenyl-1-methyl-2-3-dimethylcyclopropanes. A 1.0-g sample of the organomercuric bromide prepared from **1** was placed in a small flask fitted with a magnetic stirrer, and 15 ml of methanol was added. To the rapidly stirred mixture, 0.24 g of sodium borohydride dissolved in 10 ml of 3.5 *M* sodium hydroxide in water was added. Free mercury appeared immediately. After 30 min, the reaction solution was filtered through Celite and the filtrate was extracted with ether. After washing the combined ether extracts with water and brine solution, and drying over $MgSO_4$, the ether was stripped off to afford 0.26 g (64%) of product. Glpc analysis with a XF-1150 column showed one peak. The nmr spectrum was determined in C_6D_6 at 100 and 60 MHz. Comparison of this spectrum with the authentic mixtures of the two diastereomers **10** and **13** established that only one diastereomer could be present and its configuration was *RS/SR* (**10**). The 60-MHz nmr pattern was quite complex and showed bands at τ 2.75 (m, 5), 7.06 (s, 3), 8.67 (s, 3), 9.0 (d), 9.25 (m). The ir spectrum was essentially identical with the authentic samples.

The organomercuric bromide from **2** was treated with sodium borohydride in a similar manner. The product consisted of one component by glpc. The 100-MHz nmr spectrum in C_6D_6 showed that only one diastereomer **13** was present when compared with the authentic mixtures of *RR/SS* and *RS/SR* isomers. The 60-MHz spectrum had bands at τ 2.75 (m, 5), 7.06 (s, 3), 8.67 (s, 3), 9.12 (d), and 9.38 (d).

Reduction of the organomercuric bromide prepared from **3** gave a single product that was identical with **10** as prepared from **1**.

1-Phenyl-2,3-dimethylcyclopropanes. The organomercuric bromide (1.0 g) from each cyclopropane was reduced with sodium borohydride by the procedure previously described above. The product was analyzed by glpc. Some starting cyclopropane was detected, but the major component had the same retention time as authentic **21**. The product from **15** showed a small peak (27%) emerging several minutes after the major one (73%). This was shown to be the dimethyl ether of 2-methyl-1-phenyl-1,3-butanediol by retention time. The ratio of two possible diastereomers of **21** was determined from the nmr spectrum of a glpc collected sample by measuring the relative peak heights or areas of the benzylic protons and methoxy protons. The configurations were decided by comparison with the nmr spectrum of the authentic compound. The results are summarized in Table III.

1,2,3-Trimethylcyclopropane. A 4.0-g sample of the organomercuric bromide (both diastereomers present in a 62:38 ratio) prepared from **29** was reduced with 1.14 g of sodium borohydride by the usual procedure. The ether was removed by careful distillation, and the residue was distilled in a short path distillation apparatus. The fraction collected between 75 and 80° contained the product. Its nmr and ir spectra were identical with the authentic threo isomer of 2-methoxy-3-methylpentane. The erythro isomer was not detected.

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