Cleavage of Cyclopropanols and Cyclopropanol Methyl Ethers by Mercury(II) Acetate[1]

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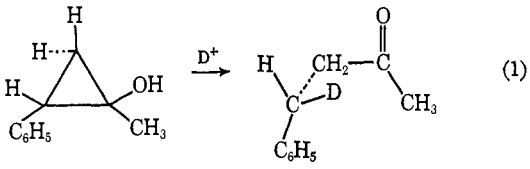
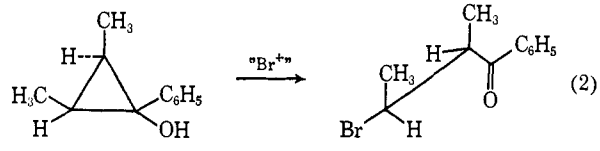
Abstract: Cyclopropanols and cyclopropanol methyl ethers react readily with mercury(II) acetate in acetic acid at room temperature to give β-acetoxymercuri ketones. Cyclopropyl acetates are relatively inert to these reaction conditions. In the case of unsymmetrically substituted cyclopropanols the ratio of 1,2 to 1,3 bond cleavage was determined and, in general, mercury(II) becomes attached to the least substituted carbon atom. The reaction of mercury(II) acetate with 1-phenyl-*cis*,*trans*-2,3-dimethylcyclopropanol methyl ether and 1-phenyl-*cis*,*trans*-2,3-dimethyl- and 1-phenyl-*trans*,*trans*-2,3-dimethylcyclopropanol proceeded with inversion of configuration at the point of electrophilic attack. Based upon the above results and kinetic studies it is postulated that the electrophile approaches the 2,3 bond with possible complexation followed by partitioning to cleave either the 1,2 or 1,3 bond.

The high reactivity of cyclopropanols makes them suitable substrates for the study of bimolecular electrophilic cleavage reactions. Indeed, cyclopropanes are the only compounds which, at the present time, readily lend themselves to an examination of the fission of a carbon–carbon single bond. It appears, however, that there is as yet no single factor which permits one to predict the mode of cleavage of substituted cyclopropanes, as evidenced by the results of several recent publications.[3] The recent work of Ouellette,[3d] who examined the reaction of phenylcyclopropane with mercury(II) acetate, illustrated the bimolecular electrophilic nature of the cleavage process. The question of the stereochemistry of electrophilic attack and the effect of additional substitution on the cyclopropane ring remained unanswered.

Our continued interest in the cleavage of cyclopropanols with electrophilic reagents was reinforced by recent work which showed that there are basic stereochemical differences between cleavage by a proton and by electropositive halogen; *e.g.*, the former occurs with retention[4] (eq 1) and the latter with inversion of configuration[5] (eq 2). We thought it profitable then to investigate the behavior of other electrophilic reagents toward cyclopropanols. This paper deals with the results obtained from the cleavage of cyclopropanols with mercury(II) acetate.



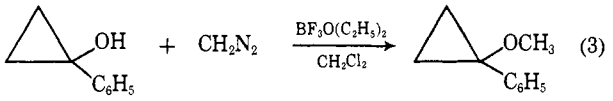
(1)



(2)

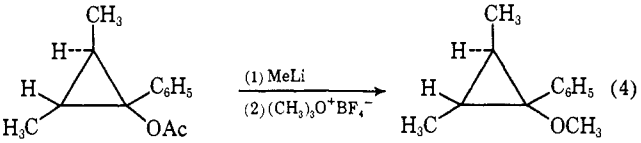
Results

The Synthesis of Cyclopropanol Methyl Ethers. Since a variety of cyclopropanols was already available,[6] we decided that the corresponding methyl ethers could best be made by simple alkylation. Two methods proved generally useful. First, alkylation of the cyclopropanol was affected using the boron trifluoride catalyzed addition of diazomethane (eq 3). Aluminum



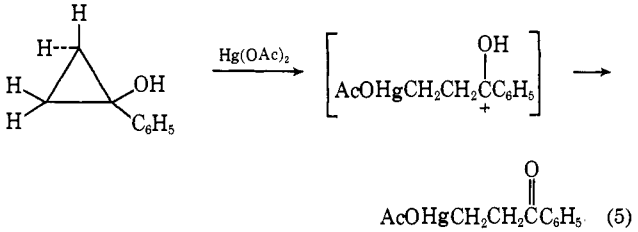
(3)

trichloride proved to be a better catalyst.[7] Second, because we use the cyclopropyl acetates as precursors for many cyclopropanols, a method of greater utility is shown in eq 4.



(4)

Reactions of Cyclopropanols and the Corresponding Methyl Ethers with Mercury(II) Acetate. Mercury(II) acetate reacts rapidly with a number of cyclopropanols and their corresponding methyl ethers at room temperature in glacial acetic acid (a medium in which cyclopropanols are stable). An example of the reaction is shown in eq 5. Cyclopropyl acetates react only very



(5)

(1) Presented in part at the 157th National Meeting of the American Chemical Society, Minneapolis, Minn., April 1969, Abstracts ORGN-62.

(2) National Institutes of Health Postdoctoral Fellow, 1967–1969.

(3) (a) S. J. Cristol and R. T. LaLonde, *J. Amer. Chem. Soc.*, **80**, 4355 (1958); (b) W. G. Dauben and W. T. Wipke, *Pure Appl. Chem.*, **9**, 539 (1964); (c) R. T. LaLonde, J. Ding, and M. A. Tobias, *J. Amer. Chem. Soc.*, **89**, 6651 (1967); (d) R. J. Ouellette, R. D. Robins, and A. South, Jr., *ibid.*, **90**, 1619 (1968); (e) K. B. Wiberg and G. Szeimies, *ibid.*, **90**, 4195 (1968).

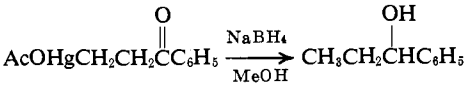
(4) C. H. DePuy, F. W. Breitbeil, and K. R. DeBruin, *ibid.*, **88**, 3347 (1966).

(5) C. H. DePuy, W. C. Arney, Jr., and D. H. Gibson, *ibid.*, **90**, 1830 (1968).

(6) C. H. DePuy, *Accounts Chem. Res.*, **1**, 33 (1968).

(7) Unpublished results of R. J. Van Lanen, University of Colorado, 1969. This procedure was suggested by Professor Th. J. DeBoer, University of Amsterdam, Amsterdam, The Netherlands.

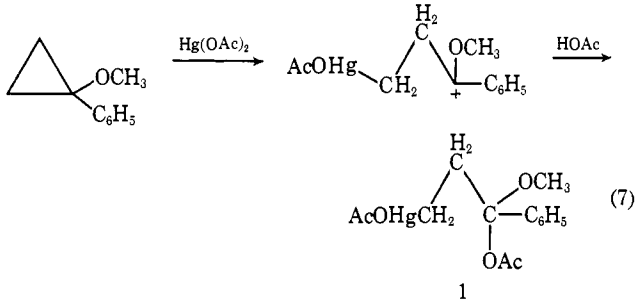
slowly under these conditions. Treatment of both 1-phenylcyclopropanol and its methyl ether with mercury(II) acetate (1:1 molar ratio) for 10 min at room temperature followed by removal of the solvent under reduced pressure gave a quantitative yield of 1-phenyl-3-acetoxymercuri-1-propanone. Sodium borohydride reduction[8] of this product gave 1-phenyl-1-propanol (eq 6), whose ir and nmr spectra were identical with those of authentic material prepared by reduction of propiophenone. This reaction was especially useful in



(6)

determining the ratio of the direction of ring cleavage in the case of unsymmetrically substituted cyclopropanols (*vide infra*).

1-Phenylcyclopropanol methyl ether reacts more slowly than the alcohol, and the initial product of ring opening appears to be the methoxy acetate (**1**) (eq 7). Thus when the reaction is carried out in an nmr tube in acetic acid-d_4, the spectrum obtained is consistent with

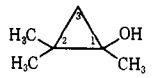
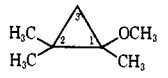
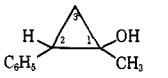
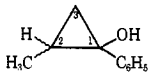


(7)

structure **1** which on work-up affords the ketonic product. A similar product was observed in the reaction of 1,2,2-trimethylcyclopropanol methyl ether with mercury(II) acetate.

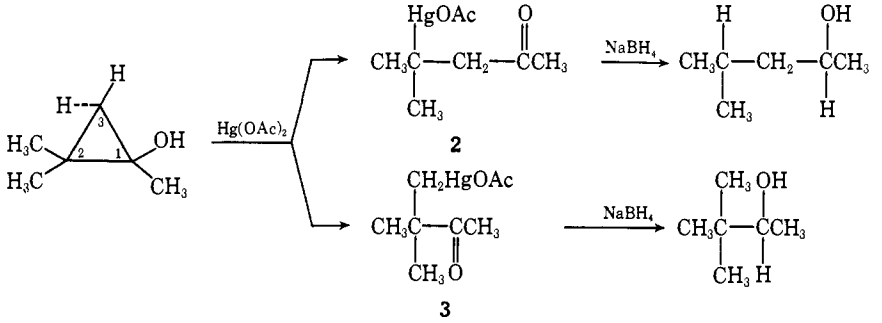
Direction of Ring Cleavage. Unsymmetrically substituted cyclopropanols, *e.g.*, 1,2,2-trimethylcyclopropanol, can give rise to two products upon cleavage with mercury(II), that resulting from 1,2 bond cleavage (**2**) and that resulting from 1,3 bond cleavage (**3**). The product ratio, which is a measure of the effect of substituents on rate, was determined by glpc analysis of the alcohol mixture obtained from sodium borohydride reduction of the crude product mixture. The results of several cyclopropane ring cleavage reactions are shown in Table I. Previously published results with other electrophilic reagents are listed for comparison.

Table I. Direction of Ring Cleavage of Cyclopropanols with Various Electrophiles

	H^+/H_2O 1,2:1,3	OH^-/H_2O 1,2:1,3	Br^+ 1,2:1,3	Hg^{2+} 1,2:1,3
	25:75[a]	0:100[a]	0:100[b]	3:97
				3:97
	40:60[a]	100:0[a]	100:0[b]	23:77
	47:53	17:83		1:99

[a] See ref 4. [b] See ref 5.

Stereochemistry of Ring Opening. The stereochemistry of the cleavage reaction with mercury(II) can be ascertained by a study of the reaction of mercury(II) acetate with 1-phenyl-*cis,trans*-2,3-dimethyl- (**4**) and 1-phenyl-*trans,trans*-2,3-dimethylcyclopropanol (**5**). The possibilities are outlined in Scheme I. The stereochemistry of the starting cyclopropanols is known. The stereochemistry of the intermediate organomercurials is unknown, but these can be determined by stereospecific conversion to the known bromo ketones whose stereochemistries were previously determined by mild, *trans* elimination to *cis*- and *trans*-2-benzoyl-2-butene.[5] The stereospecific conversion of the acetoxymercuri ketones to bromo ketones follows the work of Jensen, who demonstrated that the carbon–mercury bond could be replaced by a carbon–bromine bond with retention of configuration by using pyridine perbromide in pyridine.[9] *erythro*- and *threo*-bromo ketones were formed by cleavage of **4** and **5**, respectively. The methyl ether corresponding to **4** also gave the *erythro*-β-acetoxymercuri ketone. These results then show that cleavage with mercury(II) occurs with *inversion* of configuration at the point of electrophilic attack.



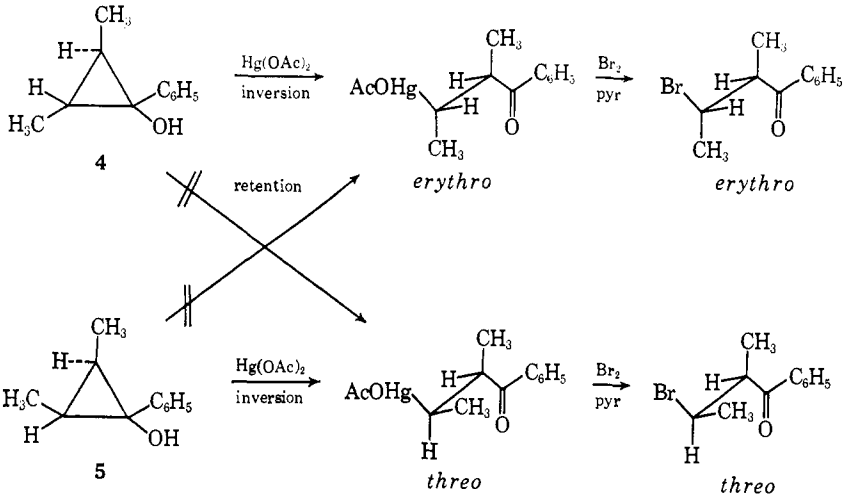
Kinetic Studies. For the moderately reactive cyclopropyl derivatives, the standard Volhard method for the determination of mercury[10] was used to obtain the

(8) (a) F. G. Bordwell and M. L. Douglass, *J. Amer. Chem. Soc.*, **88**, 993 (1966); (b) H. C. Brown and P. Geoghegan, Jr., *ibid.*, **89**, 1522 (1967).

(9) F. R. Jensen and L. H. Gale, *ibid.*, **82**, 148 (1960). It should be emphasized that Jensen's work involved cleavage of 4-methylcyclohexylmercuric bromides. The conclusions regarding the mode of ring opening of cyclopropanols are based upon the assumption that the cleavage of carbon–mercury bonds in the acetoxymercuriketones also occurs with complete retention of configuration.

(10) I. M. Kolthoff and E. B. Sandell, "Textbook of Quantitative Inorganic Analysis," 3rd ed, The Macmillan Co., New York, N. Y., 1952, p 547.

Scheme I



total concentration of mercury(II) and alkylmercuric acetate. Mercury(II) acetate reacts with 2 equiv of thiocyanate ion and the product of the reaction, the organomercurial, reacts with only 1 equiv. By appropriate mathematical manipulation,[3d] the desired concentrations of mercury(II) and/or product can be determined. Reactions were carried out by dissolving the reagents in acetic acid which had previously been brought to temperature in a constant-temperature bath.

The reactions were carried out as a 0.02 *M* solution in each component and were found to be second order, first order in mercury(II) and first order in cyclopropanol. The reactions were followed to at least three half-lives. The rate constant was obtained by plotting the reciprocal of concentration *vs.* time. Generally, equivalent molar concentrations were used to simplify the mathematical calculations although reactions in which an excess of one reagent was used were also carried out. Aliquots were withdrawn periodically and added to a known amount of excess aqueous thiocyanate solution. The excess thiocyanate was then back-titrated with standardized Ag(I) solution using Fe(III) as indicator. In this way accurate bimolecular rate constants were obtained for 1-phenyl-*trans*,*trans*-2,3-dimethyl- and 1-phenyl-*cis*,*trans*-dimethylcyclopropanol. 1-Phenylcyclopropanol reacts extremely rapidly with mercury(II) at 20°, and a precise rate constant could not be determined. However, a fairly accurate rate constant was obtained by the simultaneous and rapid addition of solutions of the reagents, *via* two syringes, to a test tube with vigorous stirring at room temperature (25°). The reaction was then quenched by rapid addition of excess thiocyanate solution. The excess thiocyanate was then analyzed as usual. The half-life of the reaction under these conditions was about 8 sec. Attempts to slow down the reaction by carrying out the process at higher dilutions presented difficulty in the analysis. On the other hand 1,2,2,3,3-pentamethylcyclopropanol reacts so slowly that rate constants could not be obtained. Complications arise because mercury(II) attacks acetic acid.[3d,11]

In some cases relative rates were determined by competition experiments which were carried out in an nmr tube. Equivalent amounts of two cyclopropyl derivatives in acetic acid-d_4 were added to an nmr tube followed by 0.9 equiv of mercury(II) acetate.

(11) W. Kitching and P. R. Wells, *Aust. J. Chem.*, 18, 305 (1965).

After the reaction was complete, relative amounts of starting materials could be determined by nmr spectrometry. It was then a simple matter to obtain values for eq 8, where (a_f) and (a_i) are final and initial concentrations of component a, respectively.

$$\frac{k_a}{k_b} = \frac{\ln[(a_f)/(a_i)]}{\ln[(b_f)/(b_i)]} \quad (8)$$

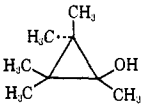
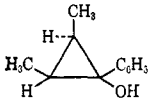
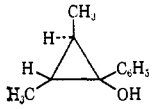
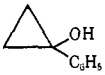
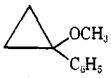
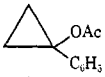
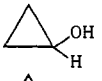
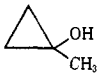
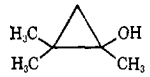
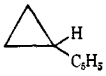
Activation parameters were determined for the reaction of 1-phenyl-*trans*,*trans*-2,3-dimethylcyclopropanol and are as follows: $\Delta H^{\pm} = 14.7$ kcal mol^{-1}, $\Delta S^{\pm} = -21$ eu, and $\Delta F^{\pm} = 21.1$ kcal mol^{-1}. The results of our kinetic studies are listed in Table II.

Discussion

The second-order kinetics of the reaction of mercury(II) acetate with cyclopropanols and cyclopropanol methyl ethers complements the results of Ouellette[3d] and allows the reaction to be classified as electrophilic cleavage of a carbon–carbon single bond. The stereochemical result of inversion of configuration is the same as that found for bromination.[5] It is now becoming clear that both inversion and retention pathways for these cleavages may be observed, although it is far from clear under just what reaction conditions or patterns of substitution which stereochemical process will be favored.

Our kinetic studies and studies of the direction of cleavage in unsymmetrically substituted cyclopropyl compounds allow for the first time a quantitative assessment to be made of the effect of substituents on the rate of ring opening. In the first place, by comparing our results of the rate of cleavage of 1-phenylcyclopropanol with mercury(II) acetate and Ouellette's results[3d] with phenylcyclopropane and mercury(II) acetate (see Table II), we see that the hydroxyl group increases the rate by a factor of 10^4. The nature of groups attached to the oxygen atom also has a definite effect on the rate of ring cleavage. Based on competitive rate studies, cyclopropanols react some 10 to 20 times faster than their corresponding methyl ethers, and the acetates are estimated to react some 10^3 to 10^4 slower than the ethers. This is not too difficult to understand when one considers that the transition state for ring opening undoubtedly involves a good deal of carbon–carbon bond rupture with concomitant stabilization of the developing positive charge on the

Table II. Rate Constants for the Reaction of Cyclopropyl Derivatives with Mercury(II) Acetate

	T, °C	k, M^{-1} sec^{-1}
	25	10^{-5}–10^{-6} [a]
	29.95	4.04×10^{-3}
	40.45	9.24×10^{-3}
	50.60	2.05×10^{-2}
	29.95	1.4×10^{-3}
	25	3.5
	25	2.2×10^{-1} [b]
	25	10^{-4} [c]
	25	1 [d]
	25	1 [d]
	25	1
	25	10^{-1} [e]
	25.0	1.6×10^{-4} [f]

[a] Estimated rate constant based on disappearance of alcohol as monitored by nmr. [b] Based on competition experiment with 1-phenylcyclopropanol. [c] Rate constant based on the half-life as determined by nmr. [d] Based on competition experiment with 1-phenylcyclopropanol. 1-Phenyl- and 1-methylcyclopropanol and cyclopropanol all react at about the same rate. [e] Based on competition experiment with 1,2,2-trimethylcyclopropanol. [f] This value is taken from ref 3d.

carbon bearing the oxygen atom. In the case of cyclopropanols the positive charge can readily be stabilized by the partial formation of a carbon–oxygen double bond and cleavage of the oxygen–hydrogen bond resulting in effective dispersal of the positive charge to the reaction medium *via* hydrogen bonding of the proton with solvent. This pathway is not available to the other cyclopropyl derivatives under discussion but in the case of the methyl ethers considerable stabilization is still available with most of the positive charge on the oxygen atom. However, charge stabilization by the acetate group results in considerable positive charge on an atom adjacent to an already electron deficient center, hence, the tremendous rate difference between the alcohols and ethers on the one hand and the acetates on the other. A similar explanation has been invoked to explain the differences in the rate of α-hydrogen atom abstraction from alcohols, ethers, and esters which are postulated to proceed *via* a polarized transition state.[12]

(12) E. S. Huyser and K. L. Johnson, *J. Org. Chem.*, 33, 3972 (1968).

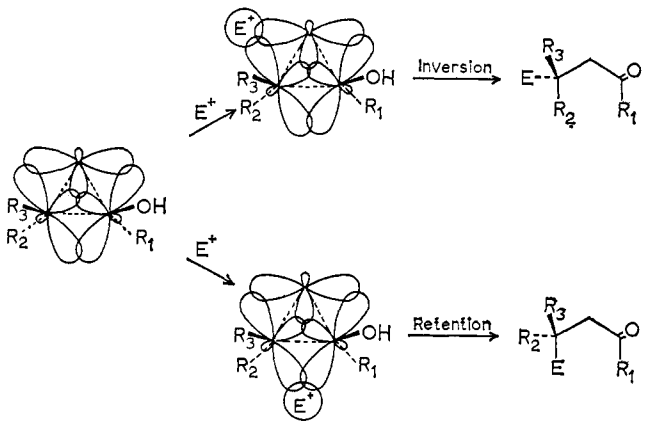


Figure 1.

Introduction of a single methyl group at the site of substitution, as, for example, in 1-phenyl-*cis*,*trans*-2,3-dimethyl- and 1-phenyl-*trans*,*trans*-2,3-dimethylcyclopropanol, decreases the rate of ring opening by a factor of 10^3, and complete replacement of all hydrogen atoms by methyl groups, as in 1,2,2,3,3-pentamethylcyclopropanol, results in an additional rate depression of 10^3. These large rate effects upon substitution of methyl for hydrogen are similar to those observed in SN2 reactions, and are most likely due to steric effects. Yet, the comparison with the SN2 reaction must not be carried too far since electrophilic cleavage is not accelerated by a 2-phenyl group, as the product studies in the cleavage of 2-phenyl-1-methylcyclopropanol show (see Table I).

The data on electrophilic ring openings of cyclopropanes presently available are best rationalized, in our opinion, by attack on one of the cyclopropane bonds, followed by, or perhaps concerted with, ring opening to give the most stable carbonium ion. It should be emphasized that if we adopt the "bent-bond" picture for the bonding in cyclopropane, attack at C_2 on the rear of the C_1–C_2 bond does not mean attack along the C_1–C_2 internuclear axis but rather attack at or near the C_2–C_3 bond. This is most clearly illustrated in the Walsh model for cyclopropane[13] (Figure 1). Some support for this picture is gained from an examination of the products of mercury(II) attack on 1,2,2-trimethylcyclopropanol and its methyl ether. Rate studies from methylated cyclopropanols show that the rate of reaction at a dimethylated center should be less than at an unsubstituted center by a factor of 10^6. Yet, the products from cleavage of this unsymmetrical compound show only a factor of 32 in the rate of attack at C_2 and C_3. A great deal more must be known about the reaction before firm conclusions can be drawn since there may be presently unknown pathways which will give rise specifically to 1,2-cleavage. It is hoped that studies now in progress will shed further light on the factors responsible for the various types of cleavage, and will show how the stereochemistry can be manipulated for synthetic and mechanistic purposes.

Experimental Section

Boiling points are uncorrected. All melting points were taken on a Fisher-Johns melting point apparatus and are corrected.

(13) For a more complete description of bonding in cyclopropanes, see W. A. Bernett, *J. Chem. Educ.*, 44, 17 (1967).

Infrared spectra were measured with a Beckman IR-10 spectrophotometer. The nmr spectra were recorded with a Varian A-60A instrument using $CDCl_3$ or CCl_4 as solvents and tetramethylsilane as internal standard. Mass spectra were determined using Varian M-66 or Varian MAT CH-7 spectrometers. An F & M Model 700 gas chromatograph was used for the glpc analyses. Reagents used were obtained from regular commercial sources. References to synthetic procedures for the cyclopropyl derivatives used in this study may be found in ref 6. $MgSO_4$ was the drying agent used. Elemental analyses were performed by Huffman Laboratories, Inc., Wheatridge, Colo.

Preparation of Cyclopropanol Methyl Ethers. Method I. 1-Phenylcyclopropanol (1.0 g, 0.0075 mol) was dissolved in 5 ml of methylene chloride and cooled in an ice bath, and 0.1 g of boron trifluoride etherate was added. A solution of diazomethane (prepared from Du Pont's EXR-101) in methylene chloride was then added dropwise until no more of the cyclopropanol remained as indicated by periodic examination of the reaction mixture by tlc. The reaction mixture was then filtered and concentrated. Distillation afforded 0.6 g (54%) of 1-phenylcyclopropanol methyl ether: bp 50° (2.0 mm); δ 0.85 (m, 2), 1.05 (m, 2), 3.10 (s, 3), 7.22 (m, 5); mass spectrum *m/e* 148.

Method II. This example is illustrative for converting cyclopropanol acetates to cyclopropanol methyl ethers. 1-Phenyl-*cis,trans*-2,3-dimethylcyclopropanol acetate (2 g, 0.0098 mol) was dissolved in 10 ml of anhydrous ether under N_2 and cooled to 0–5° in an ice bath. To this solution 9 ml of 2.35 *M* solution of methyllithium (2 equiv) in ether was added dropwise. After stirring for 0.5 hr, 4 g (0.0027) of trimethyloxonium fluoroborate[14] was carefully added and the mixture stirred at room temperature overnight. The reaction mixture was poured onto ice. The organic layer was separated and the aqueous phase extracted with ether. The ether solutions were combined, dried, and concentrated to give 1.77 g. Distillation yielded 1.27 g, bp 35° (0.05 mm), of moderately pure material. Elution chromatography (20 × 270 mm, silica gel using petroleum ether, bp 45–60°, as eluent) afforded 0.8 g (46%) of 1-phenyl-*cis,trans*-2,3-dimethylcyclopropanol methyl ether: δ 0.55–1.45 (m, 8), 3.08 (s, 3), 7.30 (m, 5); mass spectrum *m/e* 176.

1,2,2-Trimethylcyclopropanol methyl ether, bp *ca.* 50° (130 mm), was prepared in 40% yield: δ 0.18 (AB q, 2), 1.03 (s, 3), 1.13 (s, 3), 1.30 (s, 3), 3.16 (s, 3); mass spectrum *m/e* 114.

Reaction of 1-Phenylcyclopropanol with Mercury(II) Acetate. Mercury(II) acetate (1.41 g, 0.00443 mol) was added to a solution of 0.593 g (0.00443 mol) of 1-phenylcyclopropanol in 10 ml of glacial acetic acid. The solution was stirred at room temperature for 1 hr and the solvent was removed at reduced pressure (aspirator) to give 1.7 g of 1-phenyl-3-acetoxymercuri-1-propanone as a pale yellow, viscous oil: δ 1.87 (t, 2), 1.95 (s, 3), 3.38 (t, 2), 7.48 (m, 3), 7.93 (m, 2). The addition of 5 ml of saturated aqueous potassium bromide resulted in the formation of crystalline material which was collected by filtration. The crude product was recrystallized from chloroform–hexane to give 1.25 g (68%) of 1-phenyl-3-bromomercuri-1-propanone: mp 90–90.5°; $\nu_{C=O}^{CDCl_3}$ 1680 cm^{-1}; δ 1.97 (t, 2), 3.58 (t, 2), 7.59 (m, 3), 8.00 (m, 2); mass spectrum *m/e* (relative intensity) 410 (19), 411 (32), 412 (63), 413 (57), 414 (100), 415 (25), 416 (70), 418 (13).

Anal. Calcd for C_9H_9BrHgO: C, 26.13; H, 2.19. Found: C, 26.33; H, 2.20.

Reaction of 1-Phenylcyclopropanol Methyl Ether with Mercury(II) Acetate. The cleavage reaction was carried out in a manner identical with that described for 1-phenylcyclopropanol. The product was also identical with 1-phenyl-3-acetoxymercuri-1-propanone. However, when the reaction was carried out in an nmr tube in acetic acid-d_4 the nmr spectrum obtained after the reaction was completed was consistent with either 1-acetoxy-1-methoxy-1-phenyl-3-acetoxymercuripropane (**1**) or a mixture of 1-phenyl-3-acetoxymercuri-1-propanone and methyl acetate. Addition of methyl acetate showed that the $-OCH_3$ resonance was 13 Hz downfield from that obtained for the reaction product which implies that **1** is the initially formed adduct.

Reduction of 1-Phenyl-3-acetoxymercuri-1-propanone. Sodium borohydride (an excess) was added in small portions to 1.2 g (0.003 mol) of 1-phenyl-3-acetoxymercuri-1-propanone in 20 ml of methanol while keeping the reaction cooled by means of an ice bath. After addition was complete, the reaction was stirred at room temperature for 3 hr. The reaction solution was diluted with water and acidified with HCl, and the product was extracted with pentane. The pentane extract was dried and concentrated to give 1-phenyl-1-propanol whose nmr and ir spectra were identical with those of an authentic sample which was prepared by reduction of propiophenone with sodium borohydride.

Reaction of 1,2,2-Trimethylcyclopropanol with Mercury(II) Acetate. This procedure is illustrative of those used for the cleavage of unsymmetrically substituted cyclopropanol derivatives. The reaction was carried out in the manner described for 1-phenylcyclopropanol. The crude adduct (1.5 g) was reduced as described for 1-phenyl-3-acetoxymercuri-1-propanone. The alcohols obtained from the reduction were analyzed by glpc on an 8 ft × 0.25 in. 20% Carbowax 20,000 on 60–80 Chromosorb W at 100° and a flow rate of 60 ml/min. Only two products could be detected. Admixture with the known 4-methyl-2-pentanol and 3,3-dimethyl-2-butanol showed that they were present in the alcohol mixture, obtained from reduction of the organomercurial adduct, in the proportion 3:97, respectively. Authentic samples of the alcohols were obtained by reduction of the corresponding ketones with sodium borohydride.

Reaction of 1-Phenyl-*cis,trans*-2,3-dimethylcyclopropanol with Mercury(II) Acetate. Mercury(II) acetate (2.2 g, 0.0069 mol) was dissolved in 75 ml of water and the cyclopropanol (1.0 g, 0.062 mol) was dissolved in 75 ml of dioxane. These two solutions were simultaneously added to a reaction flask and stirred at room temperature for 24 hr. The solvent was removed under reduced pressure (aspirator) and the resulting residue was triturated with methylene chloride and filtered. The filtrate was concentrated to give 2.2 g (85%) of *erythro*-α-methyl-β-acetoxymercuributyrophenone as a viscous oil: δ 1.34 (d, 3), 1.46 (d, 3), 2.02 (s, 3), 2.88 (m, 1), 3.70 (m, 1), 7.5 (m, 3), 7.95 (m, 2).

Reaction of 1-Phenyl-*trans,trans*-2,3-dimethylcyclopropanol with Mercury(II) Acetate. The reaction was carried out as described for the *cis,trans* isomer to give *threo*-α-methyl-β-acetoxymercuributyrophenone: δ 1.26 (d, J = 7.0 Hz, 3), 1.28 (d, J = 6.5 Hz, 3), 2.03 (s, 2), 2.63 (m, 1), 3.88 (m, 1), 7.5 (m, 3), 8.05 (m, 2).

Reaction of 1-Phenyl-*cis,trans*-2,3-dimethylcyclopropanol Methyl Ether Mercury(II) Acetate. The reaction was carried out in acetic acid using the procedure described for 1-phenylcyclopropanol to give *erythro*-α-methyl-β-acetoxymercuributyrophenone.

Conversion of *erythro*-α-Methyl-β-acetoxymercuributyrophenone to Its Corresponding Bromo Ketone. The mercurial (2 g, 0.0047 mol) was dissolved in 10 ml of pyridine. Pyridine perbromide (prepared by adding 0.784 g (0.0049 mol) of bromine to 1.5 ml of pyridine) in pyridine was added dropwise over a period of 10 min.[9] The reaction mixture was stirred at room temperature for 1 additional hr and poured into a pentane–water mixture. The organic layer was removed and the aqueous layer was extracted with pentane. The combined extracts were successively washed with 10% HCl, water, dilute $NaHCO_3$, and water, and then dried. Removal of the solvent under reduced pressure afforded *erythro*-α-methyl-β-bromobutyrophenone whose nmr spectrum was identical with that of the known material.[5] The product was contaminated with some 2-benzoyl-*cis*-2-butene which resulted from the ready elimination of HBr from the bromo ketone.[5]

Conversion of *threo*-α-Methyl-β-acetoxymercuributyrophenone to Its Corresponding Bromo Ketone. The method used was that described for the *erythro* mercurial. The product of this reaction was *threo*-α-methyl-β-bromobutyrophenone whose nmr spectrum was identical with that of the known material.[5]

Kinetic Analysis. Method I. A solution of mercury(II) acetate (0.05 *M*) in acetic acid which had previously been equilibrated at the desired temperature was added to a known amount of the cyclopropanol in a volumetric flask also at the desired temperature. Aliquots were removed periodically and quenched by addition to a known amount of aqueous potassium thiocyanate (excess). Benzene was then added to separate the unreacted cyclopropanol from the aqueous phase. Determination of excess thiocyanate in this two-phase system proved to be satisfactory. If the benzene is not added, the cyclopropanol reacts with the iron(III) indicator. After acidification with 6 *N* HNO_3, the excess thiocyanate was determined by titration with standardized silver nitrate at 0–5° (ice bath) using ferric ammonium nitrate as indicator.[10] Rate constants were obtained from the data plots using the method of least squares.

Method II. A slight modification of method I was used to obtain the rate constant for the reaction of 1-phenylcyclopropanol with mercury(II) acetate. Solutions of the cyclopropanol and mercury(II) acetate in acetic acid were prepared. Aliquots of each solution were simultaneously and rapidly added with rapid stirring to the reaction vessel at room temperature. The reaction was quenched at appropriate intervals by the rapid addition of excess

(14) H. Meerwein, *Org. Syn.*, **46**, 120 (1966).

potassium thiocyanate followed by analysis as in method I. In this manner four points could be obtained during the first three half-lives of the reaction. Attempts to slow down the reaction by carrying it out at lower concentrations failed due to complications in the analyses. In our solvent system one is, of course, limited in that lower temperatures are not accessible.

Method III. Relative rates were determined by means of competition experiments which were carried out in nmr tubes. The desired amounts of cyclopropanol substrates (a and b) were weighed out and dissolved in acetic acid-d_4. Mercury(II) acetate (c) was then added and the solution shaken until the reaction was complete. (The initial molar ratio of a:b:c was 1:1:0.9). The sample was then analyzed by nmr to determine the ratio of starting cyclopropyl compounds. From the known initial amounts of starting materials and the stoichiometry of the reaction the relative rate, k_a/k_b, could be determined using eq 8.

Acknowledgments. We wish to thank the National Science Foundation for a grant (No. GP 6536X) in support of this work. This investigation was also supported in part by a National Institutes of Health Fellowship (5-FO2-GM 37548) from the National Institutes of General Medical Sciences to A. D.

Bridged Polycyclic Compounds. LXII. Stereochemistry and Mechanisms of Electrophilic Additions to Cyclopropane Rings[1]

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Abstract: A number of electrophilic additions to the cyclopropane ring of dibenzotricyclo[3.3.0.0^{2,8}]octadiene (**4**) have been scrutinized. These include addition of bromine, the elements of methyl hypobromite (bromine in methanol), and hydrogen bromide. In addition, the latter reagent has been added to the dideuterio analog (**15**) of **4**. All reagents add to the bond between the benzylic carbon atoms. This system allows for study of the stereochemistry of attack by both electrophile and nucleophile. The results and those available in the literature are discussed in terms of plausible mechanisms for additions to cyclopropanes.

There has been much interest recently in the stereochemistry of additions to cyclopropane rings. Electrophilic additions recently described include: addition of deuterioacetic acid to nortricyclene,[2] which proceeds with 50% retention and 50% inversion at the site of electrophilic attack, and complete inversion at the site of nucleophilic attack, presumably *via* norbornyl cation; addition of deuterioacetic acid to 1-methylnortricyclene,[3] which occurs with 60% retention and 40% inversion at the site of electrophilic attack and 100% inversion by nucleophile; and addition of deuterioacetic acid to tricyclo[3.2.1.0^{2,4}]octane,[4] which gives largely inversion at each reaction site.

Addition of deuterioacetic acid to bicyclobutane[5a] proceeded with retention by the deuteron, a result opposite to that of addition of deuterium oxide to a more complex bicyclobutane,[5b] where inversion by both electrophile and nucleophile was observed.

Very recently it was reported[6] that deuterioacetic acid and deuterium bromide both add to a tricyclo[3.2.2.0^{2,4}]nonene with retention at the site of electrophilic attack. This is similar to additions of protic species to cyclopropanols and to cyclopropyl acetates, which appear to go largely (if not stereospecifically) with retention of configuration.[7-9] On the other hand, treatment of cyclopropanols with bromine appears to involve electrophilic attack with inversion.[7]

This confusing situation with respect to electrophilic ring cleavage is not paralleled by nucleophilic ring opening, where all of the cases studied[10,11] showed complete inversion by nucleophile.

Interest in this laboratory in the question of electrophilic attack upon cyclopropane rings began with our studies[12a] on the addition of bromine to quadricycloheptanedicarboxylic acid (**1**), where it was shown that addition of bromine led to **2**, a reaction involving inversion at both sites.[13] A similar situation obtained[12b] in addition of water to **1**, leading to **3**. The availability[14] of dibenzotricyclo[3.3.0.0^{2,8}]octadiene (**4**) made this an interesting candidate for studies of electrophilic additions, as, in general, it would be

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