ozone content between 3 and 6% by weight were employed. The ozonolyses were run to about 75% completion on solutions of concentrations and at temperatures shown in Tables II–IV.

With the experiments included in Table III, only the *cis–trans* ratios and the relative yields of normal and cross ozonides, but not actual total ozonide yields, were determined, by direct injection on the gas chromatograph. In some cases *cis–trans* ratios were verified by nmr.

In most of the other cases a 25-ml solution of the olefin was ozonized. The solvent, unreacted starting material, and volatile products were removed under reduced pressure and condensed in a cold trap. This was diluted to a definite volume with pentane and analyzed by vpc. The residue was diluted with pentane and the ozonide determined both for yield and *cis–trans* ratio by vpc or nmr. Yields were generally based on the ozone reacting. In some instances, the ozonides were then removed by distillation and the yield of polymeric peroxides obtained by weight. The procedures were the same whether or not the ozonolyses were carried out in the presence of an added aldehyde.

Gas Chromatography. Ozonide *cis–trans* ratios and relative yields of cross and normal ozonides were determined on an Aerograph A-90-P3 gas chromatograph, using a 20 ft × $^3/_8$ in. column packed with 20% cyanosilicone fluid on Chromosorb P; injector temperature 63°, column temperature 68°, detector temperature 190°, flow rate 150 cc/min. Peak areas were determined by a K and E compensating polar planimeter, making three successive determinations on each of three separate injections. In some cases determinations were made on two or more separate ozonolysis mixtures; the values shown in Tables II–IV are average values. Checks made in this way and with solutions of *cis* and *trans* ozonides of known concentrations, as well as by means of nmr, showed the determinations to have a maximum variation of ±0.5 for a given ozonolysis reaction mixture, or ±2.0 for different ozonolysis reaction mixtures. In those cases where total ozonide yields were determined by vpc (*cis*- and *trans*-1,2-diisopropylethylenes) peak areas were compared with those of standard solutions of the ozonides. *cis* and *trans* ozonide assignments were based on the *cis* isomer having the longer vpc retention time, as done by previous investigators.[16,21]

Unreacted olefin and aldehyde determinations were done with an F & M Model 500 gas chromatograph equipped with a disk integrator, and using a 20 ft × 0.25 in. column packed with 20% Carbowax 20M on Chromosorb P; yields were determined by comparing with standard solutions of the known compounds.

Nmr spectra were obtained with a Varian Associates A-60 spectrometer. *cis–trans* ozonide ratios were determined by integrating the methine hydrogen peak areas. These were τ 4.68 (*cis*-2-butene ozonide), 4.72 (*trans*-2-butene ozonide), 5.18 (*cis*-di-*t*-butylethylene ozonide), and 5.25 ppm (*trans*-di-*t*-butylethylene ozonide). The total yields of the di-*t*-butylethylene ozonides and of pivaldehyde were also determined by nmr; the integrated *t*-butyl proton peak areas were compared with that of a known amount of *t*-butyl bromide. These were τ 8.23 (*t*-butyl bromide), 8.95 (pivaldehyde), and 9.04 ppm (*cis* and *trans* ozonides).

Acknowledgments. This work was supported by grants from the Robert A. Welch Foundation (F-042), the Petroleum Research Fund of the American Chemical Society (792 A_4), and the National Science Foundation (GP-4613).

Chemistry of Cyclopropanols. VI. Cleavage by Electrophilic Halogen

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Abstract: It has been shown that both *cis,trans*- and *trans,trans*-2,3-dimethyl-1-phenylcyclopropanols and their corresponding acetates react stereospecifically with a variety of brominating agents to form bromo ketones with complete *inversion* of configuration at the site to which the bromine becomes attached. Thus the *cis,trans* isomer gives only *erythro*-α-methyl-β-bromobutyrophenone and the *trans,trans* isomer gives exclusively the corresponding *threo* isomer. Chlorinating agents react with both cyclopropanols and the same 50:50 mixture of *threo*- and *erythro*-chloro ketones is produced from either isomer. The direction of ring opening with halogenating agents has been studied for 1,2,2-trimethylcyclopropanol and *trans*-2-phenyl-1-methylcyclopropanol and compared with the direction found for ring opening with protons. Halogenating agents are more specific with both compounds, giving exclusively 1,3 bond breaking in the former compound and exclusively 1,2 bond breaking in the latter. This is to be contrasted with openings with protons in which 1,3 bond breaking predominates (75–25% and 60–40%, respectively).

The acid- and base-catalyzed isomerization reactions of *trans*-2-phenyl-1-methylcyclopropanol to 3-phenyl-2-butanone and 4-phenyl-2-butanone were extensively explored in an earlier study.[1] The base-catalyzed reaction was assigned an SEl mechanism based on the observation that, in deuterated solvents, 4-deuterio-4-phenyl-2-butanone was formed from the optically active cyclopropanol with inversion of configuration at the benzylic carbon atom. The exclusive C-1–C-2 bond cleavage may be rationalized by assuming that an intermediate cyclopropoxide ion rearranges, with ring opening, to produce the more stable carbanion. The acid-catalyzed reaction was assigned an SE2 mechanism based on the formation of 4-deuterio-4-phenyl-2-butanone, in deuterated solvent, in which the stereochemistry of the benzylic carbon atom had been retained. In contrast to the base-catalyzed reaction, however, this material accounted for only 40% of the product mixture, the remainder being 4-deuterio-3-phenyl-2-butanone resulting from C-1–C-3 bond cleavage (see Figure 1). This product ratio suggests that the potential stability of charge at the benzylic position is not the determining factor in directing ring opening under acidic conditions. In order to examine the possible steric requirements of the reaction, the concept of replacing the protonating species by elec-

(1) C. H. DePuy, F. W. Breitbeil, and K. R. DeBruin, *J. Am. Chem. Soc.*, 88, 3343 (1966).

trophilic halogen has been explored.[2] It was envisaged that halogenating agents such as N-halosuccinimides, *t*-butyl hypohalites, and hypohalous acids were potential sources of positive halogen when used under conditions unfavorable to free-radical processes. The results of these studies are reported herein.

Results and Discussion

A. 1,2,2-Trimethylcyclopropanol (Ia). The first system chosen for study was 1,2,2-trimethylcyclopropanol. This choice was based on two considerations. First, information concerning the acid- and base-catalyzed isomerizations of alkyl-substituted cyclopropanols was meager, and this system, which may yield different products depending on the direction of ring opening, should serve as an interesting contrast of the aforementioned arylcyclopropanol. Second, the quaternary C-2 carbon atom is sterically hindered with respect to the secondary C-3 carbon atom. Thus, differences in the steric requirements of substitution by proton and halogen should be reflected in the product ratios.

The cyclopropanol Ia was prepared from the corresponding acetate[3] in the usual manner through the use of methyllithium.[4] Initially the base-catalyzed reactions of this cyclopropanol and its corresponding acetate were examined. Previous studies[1] of the acid- and base-catalyzed reactions of cyclopropanols were conducted in dioxane–water, but in order to simplify product isolation, the present work employed a heterogeneous reaction with water alone as solvent. Reactions were complete within 48 hr, and the resulting organic material was analyzed by gas phase chromatography (gpc). Comparison of the product obtained from either the acetate or the cyclopropanol with synthetic mixtures of the expected products, pinacolone and isobutyl methyl ketone, revealed only pinacolone; the analysis conditions employed would have easily indicated the second ketone present to the extent of 1%. The identity of the product was further confirmed by comparison of its spectral properties (ir, nmr) with those of an authentic sample of pinacolone. The exclusive formation of this product is in agreement with the expected rearrangement of an intermediate cyclopropoxide to the primary, rather than the tertiary, carbanion (Chart I). Freeman[5] has recently postulated that this cyclopropoxide is an intermediate in the basic decomposition of 3-acetoxy-3,5,5-trimethyl-1-pyrazoline and also finds that pinacolone is the major product.

A product study of the acid-catalyzed reaction of the cyclopropanol and its acetate was conducted in a manner similar to that used in the reactions with base. Gpc analysis, after a reaction time of 48 hr in 3 *M* H_2SO_4, revealed the presence of 76 ± 2% pinacolone and 24 ± 2% isobutyl methyl ketone (Chart I). After the completion of this study, Davis and Woodgate[6] reported a similar product ratio from reaction of the cyclopropanol effected by 6 *N* HCl. As in the acid-catalyzed isomerization of *trans*-2-phenyl-1-methylcyclopropanol, substantial ring opening occurs away from the carbon atom that is, potentially, the more stable carbonium ion.

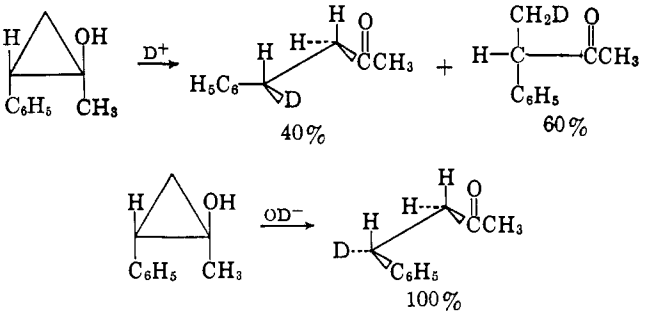
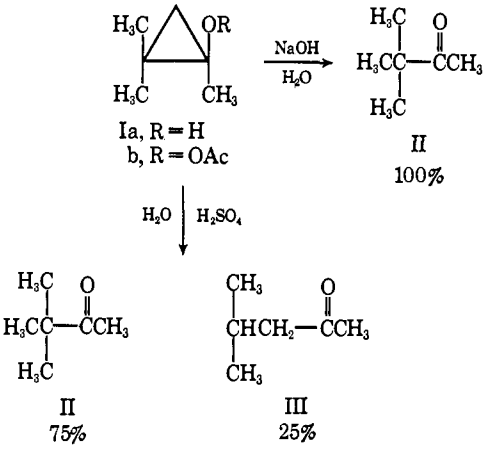


Figure 1. The stereochemical courses of acid- and base-catalyzed ring opening of *trans*-2-phenyl-1-methylcyclopropanol.

Chart I



Determination of the product ratios in the acid- and base-catalyzed reactions provided the information desired for comparison with the halogen-induced ring openings. The first reactions of this type employed HOCl and *t*-butyl hypochlorite as the chlorinating agents. A standardized solution of HOCl was treated with an equivalent amount of the cyclopropanol at room temperature. Examination of the product by nmr spectroscopy (before or after preparative gpc) revealed three singlets in the ratio 2:3:6 at τ 6.38, 7.89, and 8.74. Identical spectra were obtained from reactions accomplished in carbon tetrachloride and *t*-butyl alcohol. The latter two reactions were conducted between 0° and ambient in the dark and under nitrogen. These reactions effected quantitative conversion of the cyclopropanol to one product (see Experimental Section) and appeared to be almost instantaneous. The reaction conducted in carbon tetrachloride was subjected to nmr analysis before work-up; the only product derived from *t*-butyl hypochlorite was found to be *t*-butyl alcohol. The expected products, by analogy to the acid- and base-catalyzed reactions, are 4-chloro-4-methyl-2-pentanone (C-1–C-2 bond cleavage) and 4-chloro-3,3-dimethyl-2-butanone (C-1–C-3 bond cleavage). The nmr spectrum was in general accord with either of these compounds; however, the former compound is known to lose HCl spontaneously at room temperature.[7] The product obtained in these reac-

(2) Deno and Lincoln have recently reported the results of a study of cyclopropane ring openings induced by electrophilic bromine; see N. C. Deno and D. N. Lincoln, *J. Am. Chem. Soc.*, 88, 5357 (1966).

(3) J. P. Freeman, *J. Org. Chem.*, 29, 1379 (1964).

(4) C. H. DePuy, G. M. Dappen, K. L. Eilers, and R. A. Klein, *ibid.*, 29, 2813 (1964).

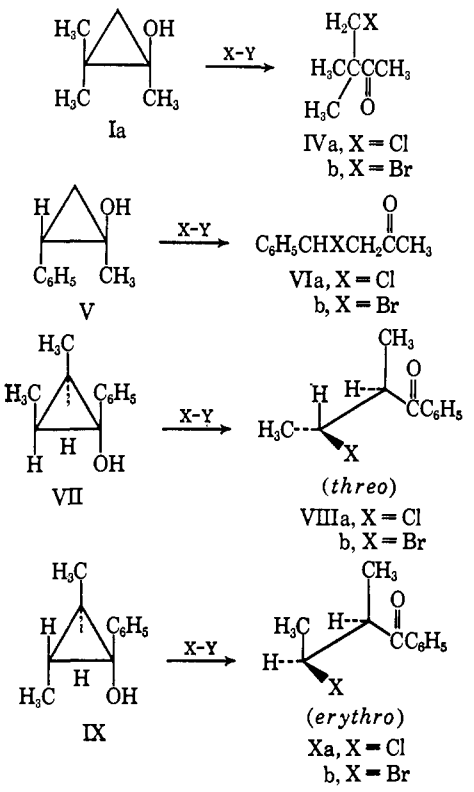
(5) J. P. Freeman and J. H. Plonka, *J. Am. Chem. Soc.*, 88, 3662 (1966).

(6) B. R. Davis and P. D. Woodgate, *Chem. Commun.*, 65 (1966).

(7) M. Richard, M. Minjolet, and P. Geschwind, *Compt. Rend.*, 233, 1007 (1946).

tions was unchanged by treatment with refluxing ethanolic KOH or preparative gpc. Reaction with 2,4-dinitrophenylhydrazine, under acidic conditions, produced the appropriate derivative in good yield (see Experimental Section). These considerations leave little doubt that the reaction has cleaved the C-1–C-3 bond to produce 4-chloro-3,3-dimethyl-2-butanone (IVa; see Chart II).

Chart II



With the successful cleavage of Ia by chlorinating agents an examination of brominating agents was deemed desirable. Both N-bromosuccinimide and *t*-butyl hypobromite effected rapid reaction in chloroform or *t*-butyl alcohol. The reactions were conducted in the dark, at or below ambient and under nitrogen. The material resulting from these reactions produced nmr spectra ($CDCl_3$) displaying three singlets (ratio 2:3:6) at τ 6.5, 7.8, and 8.7. An identical spectrum was obtained after the material had been treated with ethanolic KOH, indicating that C-1–C-3 bond cleavage had again occurred to produce the unreactive halo ketone (4-bromo-3,3-dimethyl-2-butanone; IVb in Chart II).

The reactions examined to this point revealed that the halogenating agents were quite specific in effecting only C-1–C-3 bond cleavage with 1,2,2-trimethylcyclopropanol, resulting in substitution of the least hindered carbon atom. However, it was also recognized that the carbon atom eventually substituted by halogen was also that which could best accommodate a negative charge (recall 100% C-1–C-3 bond breaking in the base-catalyzed isomerization of the cyclopropanol). Thus, the direction of ring opening could be a function either of the steric requirements of the incoming halogen or the relative stability of the incipient carbanion, if such intermediates are involved.

B. *trans*-2-Phenyl-1-methylcyclopropanol (V). In order to examine the latter two considerations further, studies were undertaken with *trans*-2-phenyl-1-methylcyclopropanol. In this compound it was anticipated that the steric and electronic factors would be in opposition. Preliminary experiments indicated that the elements of HX were rapidly lost from the products. The reactions were therefore conducted in nmr tubes, with $CDCl_3$ as solvent, to allow inspection of the initial products. The nmr spectra were thus obtained after reaction times of less than 5 min.

Reaction of V with *t*-butyl hypochlorite was complete within the time required to obtain the first nmr spectrum. The new signals observed could all be assigned to 4-chloro-4-phenyl-2-butanone (VIa, expected from C-1–C-2 cleavage). The acyl methyl group occurred as a singlet at τ 7.85 and the aryl proton as a multiplet centered at τ 2.60. The methylene protons, which are adjacent to an asymmetric center, constitute the AB portion of an ABX system that includes the benzylic proton. The AB portion of the system was visible as a three-line multiplet centered at τ 6.70 and the X portion occurred as a pair of doublets centered at τ 4.40. Support for this structural assignment derives from subsequent spectra obtained during the succeeding 90 min. During this time, the initial signals diminished and were replaced by peaks identical with those obtained from an authentic sample of benzalacetone. This is the product to be expected from spontaneous loss of HCl from VIa. Reaction of benzalacetone (in CCl_4) with gaseous HCl provided a solution that reproduced exactly the nmr spectrum (excepting *t*-butyl alcohol) obtained from V and *t*-butyl hypochlorite and which contained a 50:50 mixture of VIa and benzalacetone.

A similar reaction was conducted with V and N-bromosuccinimide (as a slurry in $CDCl_3$). The resulting solution produced an nmr spectrum directly analogous to that from 4-chloro-4-phenyl-2-butanone (VIa). The product was thus assigned the structure 4-bromo-4-phenyl-2-butanone (VIb in Chart II). Support for this assignment was derived from the appearance of signals due to benzalacetone in the nmr spectra obtained from the reaction mixture during the following hour.

C. *trans,trans*- and *cis,trans*-2,3-Dimethyl-1-phenylcyclopropanol (VII and IX). The method chosen to probe the stereochemistry of halogen substitution employed geometric isomers of 2,3-dimethyl-1-phenylcyclopropanol. It was noted that, if retention of configuration occurred, the *cis,trans* isomer would produce a *threo*-α-methyl-β-halobutyrophenone (VIII), whereas the *cis,cis* or *trans,trans* isomer would provide the corresponding *erythro* isomer X. Conversely, if the reaction proceeded with inversion, opposite members of the diastereomeric pair would be produced. The diastereomeric halo ketones were easily distinguishable through their nmr spectra, and, in the case of the bromo ketones, the identity of each diastereomer was determined. The structural assignments of the latter compounds will be considered in section D.

The isomers of 2,3-dimethyl-1-phenylcyclopropanol were prepared through metal–halogen interchange between the corresponding cyclopropyl bromides[8] and

(8) R. A. Moss and R. Gerstl, *Tetrahedron Letters*, 3445 (1965); *Tetrahedron*,, 12, 2637 (1966).

n-butyllithium. Carbonation, followed by acidification, afforded the cyclopropanecarboxylic acids. The *cis,cis* and *trans,trans* isomers were separated by fractional crystallization and the latter, as well as the isomeric *cis,trans* compound, was converted to the corresponding cyclopropanol in the usual manner.[4]

The reactions of *cis,trans*- and *trans,trans*-2,3-dimethyl-1-phenylcyclopropanols with several brominating agents were examined; the results of these studies are summarized in Table I. With N-bromosuccinimide in chloroform, the *trans,trans* isomer VII was converted exclusively, after 24 hr, to *threo*-α-methyl-β-bromobutyrophenone (VIIIb) indicating that ring opening had occurred with inversion of configuration. Identical results were obtained from reaction of the cyclopropanol with bromine in HOAc (buffered with NaOAc); also, the corresponding cyclopropyl acetate reacted with bromine in carbon tetrachloride (with NaOAc) to give the *threo*-bromo ketone, although the reaction required more than 3 days.

Table I. Summary of the Cleavage Reactions of *trans,trans*- and *cis,trans*-2,3-Dimethyl-1-phenylcyclopropanols (VII and IX) Effected by Halogenating Agents

Cyclopropanol	Halogenating agent	Solvent	Stereochemistry
VII	NBS	$CHCl_3$	100% *threo* (inv)
	Br_2	HOAc–NaOAc	100% *threo* (inv)
	t-BuOCl	$CHCl_3$	50:50 mixtures of diastereomers
	$FeCl_3$	Ether	50:50 mixtures of diastereomers
IX	NBS	*t*-BuOH	100% *erythro* (inv)
	t-BuOBr	*t*-BuOH	100% *erythro* (inv)
	Br_2	*t*-BuOH	100% *erythro* (inv)
	NBS	$CHCl_3$	65% *erythro* (inv), 35% *threo* (ret)
	t-BuOCl	*t*-BuOH	50:50 mixtures of diastereomers
	Cl_2	*t*-BuOH	50:50 mixtures of diastereomers

Similar reactions were examined with the *cis,trans*-cyclopropanol IX. In *t*-butyl alcohol, N-bromosuccinimide effected complete reaction within an hour and only the *erythro* isomer Xb (corresponding to inversion of configuration) was visible in the nmr spectrum of the product. Identical results were obtained in reactions of the cyclopropanol with *t*-butyl hypobromite or bromine (with KOAc) conducted in *t*-butyl alcohol. In chloroform, N-bromosuccinimide effected complete ring opening of the cyclopropanol, although the reaction required 48 hr and produced 65% *erythro*-bromo ketone and 35% of the *threo* isomer. The corresponding cyclopropyl acetate was also treated with bromine in carbon tetrachloride. In this case the α,β-dibromo ketone was formed; however, the *erythro* compound Xb is readily converted to dibromide under these conditions whereas the *threo* isomer does not react further. The implication is that stereospecific ring opening has again occurred.

In contrast to the stereospecificity observed in the bromination reactions, both the *cis,trans*- and *trans,trans*-cyclopropanols produced identical mixtures of diastereomeric chloro ketones with several chlorinating agents. The reactions examined are indicated in Table I. The products of these reactions were identified by comparison of their nmr spectra with those of the corresponding bromo compounds, although the separate isomers were not characterized.

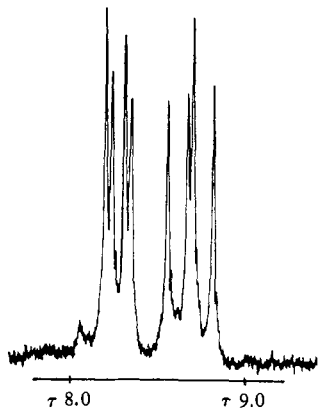


Figure 2. Methyl peaks from the nmr spectrum of a mixture of *erythro*- and *threo*-α-methyl-β-bromobutyrophenones.

D. *threo*- and *erythro*-α-Methyl-β-bromobutyrophenones (VIIIb, Xb). A mixture of these bromo ketones was prepared by a modification of the procedure previously employed to prepare the corresponding chloro compounds. Formerly, the reaction involved benzoyl chloride, 2-butene, and zinc or aluminum chloride together with ether as solvent.[9] In the present work, the use of ether with benzoyl bromide resulted in a high yield of ethyl benzoate. This problem was easily surmounted by using pentane as a reaction solvent, and the resulting products were tentatively assigned as a mixture of *erythro* and *threo* isomers on the basis of their nmr spectra. In $CDCl_3$, eight sharp signals occurred in the region τ 8.1–8.8 (two doublets for the methyl groups of each isomer), two complex multiplets were observed at τ 5.64 and 6.18 (methinyl protons), and two further multiplets were centered at τ 2.04 and 2.50 (aromatic protons). The signals for the methyl groups of the two diastereomers are quite distinct, as may be seen in Figure 2.

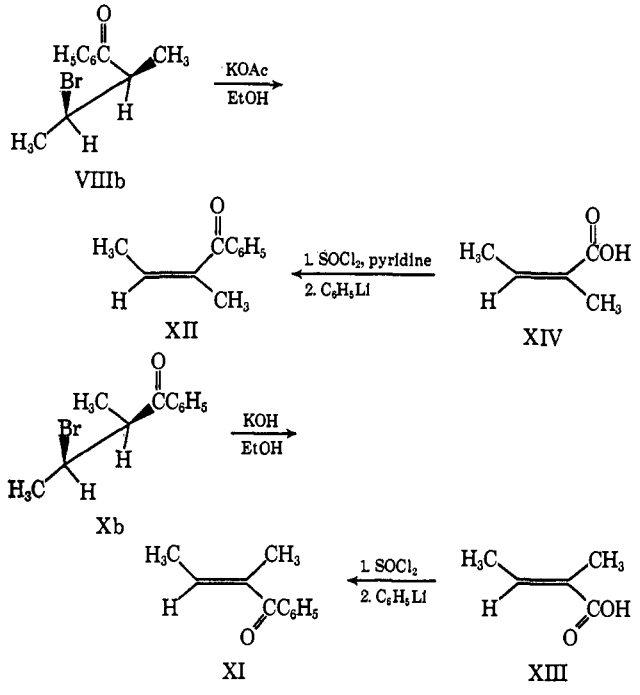
Efforts to separate the isomers by elution chromatography were not completely successful; however, fractions were obtained which were enriched in the separate components. The nmr spectra of these allowed the doublets at τ 8.26 and 8.78 (J = 7 cps in each case) to be assigned to one bromo ketone while those at τ 8.30 and 8.63 (J = 7 cps in each case) could be assigned to the second. Absolute confirmation of the structure of each bromo ketone was required, and it was envisaged that a study of their elimination reactions might provide such information. In the event of stereospecific *trans* elimination, the *threo* compound would produce *trans*-2-benzoyl-2-butene whereas the *erythro* isomer would afford the corresponding *cis* compound.

A mixture of the bromo ketones, containing 60% of the *threo* isomer, was treated with 1 equiv of KOAc in ethanol. The resulting material produced an nmr spectrum ($CDCl_3$) that revealed the presence of a single

(9) L. P. Petrenko and Yu. L. Smol'yaninova, *Zh. Obshch. Khim.*, **33**, 2041 (1963); *Chem. Abstr.*, **59**, 8639*d* (1963).

bromo ketone together with an approximately equal amount of *cis*-2-benzoyl-2-butene (XI, *vide infra*). Thus, if *trans* elimination is assumed,[10] the bromo ketone whose nmr spectrum exhibits signals for the methyl groups at τ 8.30 and 8.63 must be the *erythro* isomer Xb (Chart III). The product mixture was subsequently treated with 1 equiv of KOH in ethanol and the nmr spectrum of the resulting mixture then indicated the presence of equal amounts of *cis*- and *trans*-2-benzoyl-2-butenes (XI and XII). Again, if *trans* elimination is assumed, the bromo ketone whose nmr spectrum displays methyl signals at τ 8.26 and 8.78 must be the *threo* diastereomer (see Chart III). The identification of the α,β-unsaturated ketones was established by stereospecific synthesis of the separate isomers from tiglic (XIII) and angelic (XIV) acids (the configurations of these have been determined from X-ray studies[11]), as outlined in Chart III.

Chart III



The nmr spectra ($CDCl_3$) of the α,β-unsaturated ketones were quite distinct. The *trans*-2-butene derivative displayed an A_3B_3X pattern composed of the C-4 (terminal) methyl group (τ 8.51), the C-1 methyl group (τ 8.10) and the vinyl proton (τ 4.21). The terminal methyl group exhibits primary splitting (7 cps) by the vinyl proton and additional splitting (1.6 cps) by the remaining methyl group. The C-1 methyl signal is further split (1.5 cps) by the vinyl proton. The observed splitting factors are within the limits reported[12] for coupling constants in similar systems. The aromatic protons occur as two multiplets centered at τ 2.00 and 2.40 (relative ratios 2:3). The *cis*-2-butene derivative displayed a similar pattern; however, in this case the C-4 methyl–C-1 methyl splitting was observed to be 1.0 cps. The chemical shift parameters for this isomer are τ 8.20 (C-4 methyl group), 8.05 (C-1 methyl group), 3.60 (vinyl proton), and 2.70 (aromatic protons). Noting the differences in chemical shift values in the two compounds and, particularly, the separation of the aromatic protons in the *trans* isomer, it seemed possible to rationalize these observations in terms of the following considerations. The *ortho* protons of aromatic systems are often found to be deshielded when the aromatic nucleus is conjugated with an unsaturated group.[13] In the present systems, such an effect might reduce the conjugative interaction between the double bond and the carbonyl group. In this event protons at the terminal position of the double bond would not be further deshielded and should occur at relatively higher field. It is therefore suggested that, in the *trans* isomer, the conjugative interaction usually observed in α,β-unsaturated ketones is reduced and that the nonaromatic protons appear at higher field as a result of this effect.

Conclusions

Although the halogenating reagents employed in this study are best known for their free-radical reactions, these reactions usually require initiation. Furthermore, there have been recent studies that convincingly demonstrate that, in the absence of such conditions, ionic paths are possible. For example, *t*-butyl hypochlorite has effected ring expansion during chlorination of 1-methyl-1-(1-hydroxycyclopentyl)ethene to yield 2-chloromethyl-2-methylcyclohexanone.[14] The 1,2-alkyl shift involved in this reaction would be unusual for a radical intermediate.

Reactions of alkyl-substituted aromatic systems with N-bromosuccinimide generally lead to both side chain and nuclear bromination. That these results are explicable in terms of competing radical and ionic pathways was suggested some years ago.[15] Support for this rationale has been presented with a systematic study of the variation in product ratios in several systems as a function of radical initiators or inhibitors and solvent polarity.[16] The amount of nuclear bromination was found to increase with the absence of initiators, the presence of inhibitors, and/or increased solvent polarity.

The reaction conditions employed in the present work (dark, low temperatures) were not conducive to homolysis of the halogenating agents; yet, in most cases, reactions were quite rapid. Furthermore, the stereospecificity of the reactions of the 2,3-dimethyl-1-phenylcyclopropanols with brominating agents is suggestive of an ionic or concerted mechanism rather than a free-radical chain process. The lack of stereochemical preference in reactions of these systems with chlorinating agents and the fact that *t*-butyl hypochlorite affords the same product mixture as ferric chloride, a reagent known[17] to induce free-radical ring openings in cyclopropanols, suggest that these latter reactions may not proceed through ionic paths.

(10) Stereospecific *trans* elimination has been shown to occur in similar systems under analogous conditions; see S. J. Cristol and P. Pappas, *J. Org. Chem.*, 28, 2066 (1963), and references cited therein.

(11) A. L. Porte and J. M. Robertson, *Nature*, 176, 116 (1955).

(12) J. W. Emsley, J. Feeney, and L. H. Sutcliffe, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Vol. 2, Pergamon Press Inc., New York, N. Y., 1966, p 723 ff.

(13) See ref 12, pp 719 and 752, for a discussion of similar observations.

(14) C. D. Johnson, C. J. Cheer, and D. J. Goldsmith, *J. Org. Chem.*, 29, 3320 (1964).

(15) C. Djerassi, *Chem. Rev.*, 43, 271 (1948).

(16) S. D. Ross, M. Finkelstein, and R. C. Petersen, *J. Am. Chem. Soc.*, 80, 4327 (1958).

(17) S. E. Schaafsma, H. Steinberg, and Th. J. DeBoer, *Rec. Trav. Chim.*, 85, 73 (1966).

Experimental Section

Spectral Data. All infrared spectra were recorded on a Beckman IR-10 spectrophotometer using 0.1-mm sodium chloride cells, unless otherwise indicated. The mass spectra were obtained on a modified Consolidated Electrodynamics Corporation Type 21-103C spectrometer at 70 eV. Nuclear magnetic resonance (nmr) spectra were recorded on a Varian A-60 spectrometer at 60 Mc; peak positions are given in τ units.

Gas-Phase Chromatography (gpc). All gas-phase chromatographic analyses were performed on an Aerograph Model 202 or an F & M Scientific Corporation Model 700. The columns employed are referred to by letter, with the temperature being specified for each individual analysis: A, 5 ft × 0.25 in. stainless steel column containing 20% Carbowax 20M on 60–80 mesh Chromosorb W; B, 5 ft × 0.25 in. stainless steel column containing 20% β,β'-oxydipropionitrile on 60–80 mesh Chromosorb W; C, 5 ft × $^3/_8$ in. aluminum column containing 20% Carbowax 20M on 60–80 mesh Chromosorb W; D, 5 ft × 0.25 in. stainless steel column containing 20% Apiezon L on 60–80 mesh Chromosorb W; E, 5 ft × 0.25 in. stainless steel column containing 20% XF-1150 on 60–80 mesh Chromosorb W.

Elemental Analyses. Elemental analyses were performed by A. Bernhardt (Mulheim, Germany); Galbraith Laboratories, Inc., Knoxville, Tenn.; or M-H-W Laboratories, Garden City, Mich.

Synthetic Reactions. Reactions involving alkyllithium or Grignard reagents were conducted in equipment that had been flamed out under nitrogen, and the reaction flasks were subsequently equipped with drying tubes containing $CaSO_4$. Preparations of cyclopropanols were conducted in glassware which had been washed with dilute HF solution, rinsed with distilled water, and then thoroughly dried. The cyclopropanols were stored in similarly treated glassware under nitrogen at −20°.

Synthesis of *t*-BuOCl. The hypohalite was prepared according to the method of Walling.[18] In a 50-ml erlenmeyer flask, 29 ml of 0.697 *M* NaOCl was cooled to 0°; with stirring, 1.2 g (0.02 mol) of glacial acetic acid was added slowly. Immediately, 1.48 g (0.02 mol) of *t*-BuOH was introduced slowly, and stirring was continued at 0° for 20 min. After transference to a separatory funnel, the aqueous layer was removed and the yellow hypohalite was washed three times with equal volumes of water. The product was dried over $MgSO_4$ and stored at −20°. The hypohalite was routinely used within 24 hr of its preparation.

Preparation of *t*-BuOBr. The hypobromite was prepared by a modification of the procedure of Geneste and Kergomard.[19] In a 1-l. flask equipped with a magnetic stirrer and immersed in an ice bath, 500 ml of 0.67 *M* NaOCl was cooled to 0°. To the stirred solution of NaOCl, 19.2 g (1 equiv) of HOAc and 38.2 g (1 equiv) of KBr were added. After the salt had dissolved, 23.6 g (1 equiv) of *t*-BuOH was added, and the solution was transferred to a separatory funnel. The lower layer was removed after 15 min and extracted with a small volume of H_2O. Distillation through an 8-in. Vigreux column, taking the fraction boiling at 40–50° (85 mm), produced 3.0 g of the *t*-BuOBr.

Synthesis of 1,2,2-Trimethylcyclopropyl Acetate (Ib). In the manner of Freeman,[20] 78.8 g (0.814 mol) of mesityl oxide was cooled to 0° and treated with 48 ml (0.814 mol) of 85% aqueous hydrazine. After 1 hr at room temperature, CH_2Cl_2 was added and the organic layer separated and dried over $MgSO_4$. Filtration, followed by removal of solvent at reduced pressure, afforded 69.7 g (73%) of crude 3,5,5-trimethyl-2-pyrazoline which was used without further purification. Treatment of 63.1 g (0.55 mol) of crude pyrazoline with 248 g (0.563 mol) of $Pb(OAc)_4$ afforded crude 3-acetoxy-3,5,5-trimethyl-1-pyrazoline which was thermally decomposed at atmospheric pressure. Distillation through a spinning-band column afforded 47 g (60%) of a pale yellow liquid, bp 126–128° (atmospheric pressure). Analysis of this material on gpc column A at 120° indicated a single component and the spectral properties (ir (neat) $\nu_{C=O}$ 1725 cm^{-1}, ν_{C-O} 1220 cm^{-1}, ν_{C-H} (cyclopropyl) 3050 cm^{-1}) were in agreement with those reported by Freeman for 1,2,2-trimethylcyclopropyl acetate. The nmr spectrum ($CDCl_3$) of this material displayed four singlets of equal area at τ 8.02 (CH_3CO_2), 8.51, 8.88, and 8.93 and a pair of doublets at τ 9.37 and 9.64 (cyclopropyl protons).

Synthesis of 1,2,2-Trimethylcyclopropanol (Ia). A quantity of 1,2,2-trimethylcyclopropyl acetate, 10 g (0.08 mol), was diluted with 20 ml of anhydrous ether, and 100 ml of methyllithium solution (1.62 *M* in ether) was added at such a rate that a gentle reflux was maintained. The resulting mixture was stirred for 30 min, then transferred to an addition funnel and rapidly added to a large excess of H_3BO_3 in 50 ml of water. Immediately the mixture was filtered under vacuum and the ether layer separated. The aqueous layer was extracted with ether, and the combined ether portions were washed with saturated brine and then dried over $MgSO_4$. After filtration, ether was removed by distillation through an 8-in. column packed with tantalum coils. The residual material was then distilled at reduced pressure affording 3.9 g (52%) of colorless oil, bp 54–57° (35 mm). Analysis on gpc column A at 150° revealed three components which accounted for 1, 3, and 96% of the mixture, respectively. The small impurities were identified as *t*-BuOH and 1,2,2-trimethylcyclopropyl acetate by comparative retention times, and efforts to remove these impurities by distillation at higher temperatures led to cyclopropanol ring opening (to pinacolone and isobutyl methyl ketone). The spectral data, however, are in agreement with those expected for 1,2,2-trimethylcyclopropanol: ir (CCl_4) ν_{O-H} 3320 and 3600 cm^{-1} (intermolecular H bonded and free), ν_{C-H} (cyclopropyl) 3060 cm^{-1}; nmr (CCl_4) methyl singlets at τ 8.97, 8.82, and 8.61, cyclopropyl protons as doublets at τ 9.86 and 9.56, broad s nglet at τ 5.82 (relative area 1, position variable with concentration). The tosylate of the cyclopropanol was prepared by the method of Tipson.[21] Recrystallization from CH_2Cl_2 afforded white plates, mp 25.0–25.8°, which had the following elemental analysis.

Anal. Calcd for $C_{13}H_{18}O_3S$: C, 61.39; H, 7.13; S, 12.61. Found: C, 61.76; H, 7.21; S, 12.25.

Reactions of 1,2,2-Trimethylcyclopropanol. A. H_2SO_4. The cyclopropanol (2.0 g) was treated with 21 ml of 3 *M* H_2SO_4 in a stoppered 50-ml erlenmeyer flask. The solution was stirred for 24 hr, and the organic layer was separated and dried with $MgSO_4$. The peak areas of a standard solution containing 20.9% isobutyl methyl ketone and 79.1% pinacolone (by weight) were analyzed (column B at 90°) and the areas were determined with a disk chart integrator (Disc Instruments, Inc. Model 204). The average values obtained, for three injections, were 21.8 ± 0.8% and 78.2 ± 0.8%, respectively. The product ratios were determined by gpc and found to be 75.0 ± 0.5% pinacolone (average of two injectons) and 25.0 ± 0.5% isobutyl methyl ketone.

B. HOCl. A 5% NaOCl solution ("Index" bleach) was standardized iodometrically[22] and found to be 0.697 *M* in NaOCl. To 17 ml of this solution (0.012 mol of NaOCl), 0.7 g (0.012 mol) of glacial acetic acid was added at 0° with magnetic stirring. A mixture containing approximately 75% of the cyclopropanol and 25% pinacolone (peak areas from column A at 150°) was introduced, and the mixture was stirred rapidly for 20 min at 0°. The organic layer was separated and dried. An nmr spectrum (CCl_4) of the product revealed the expected signals from the pinacolone: $(CH_3)_3C$ at τ 8.78 (S) and CH_3CO at 7.82 (S). There were three additional singlets at τ 6.38, 7.89, and 8.74 whose ratios were 2:3:6, respectively. Analysis by gpc (column D at 150°) revealed the presence of two components in approximately a 60:40 ratio. These were isolated by preparative gpc (column D at 150°) and the first was identified as pinacolone through comparison of its spectral properties with an authentic sample; an nmr spectrum ($CDCl_3$) of the second component displayed the three singlets previously observed. This was assigned the structure $(CH_3)_2C(CH_2Cl)COCH_3$ on the basis of this spectrum, its ir spectrum ($\nu_{C=O}$ 1718 cm^{-1}, ν_{C-Cl} 693 cm^{-1}), and its lack of reactivity toward 1 *N* NaOH during 1 hr at room temperature. A 2,4-dinitrophenylhydrazone was prepared (red plates from aqueous ethanol, mp 105–105.5°) which was submitted for elemental analysis.

Anal. Calcd for $C_{12}H_{14}ClN_4O_4$: C, 45.94; H, 4.82. Found: C, 45.76; H, 4.84.

C. *t*-BuOCl in CCl_4. The cyclopropanol (1.0 g) was dissolved in 5 ml of CCl_4 in a 10-ml erlenmeyer flask immersed in an ice bath. With magnetic stirring, 1.08 g of *t*-BuOCl was added dropwise and stirring was continued for 1 hr. After concentration to about 2 ml, the nmr spectrum of the solution was examined. Signals from the cyclopropanol were absent and two singlets appeared, in a ratio of

(18) C. Walling, private communication.
(19) J. Geneste and A. Kergomard, *Bull. Soc. Chim. France*, 470 (1963).
(20) J. P. Freeman, *J. Org. Chem.*, 29, 1379 (1964).
(21) R. S. Tipson, *J. Org. Chem.*, 9, 235 (1944).
(22) N. H. Farmer, "Standard Methods of Chemical Analysis," Vol. 1, 6th ed, D. Van Nostrand Co., Inc., Princeton, N. J., 1962, p 341.

2:3 at τ 6.38 and 7.89, which were identical with those observed from the HOCl reaction product. The third signal expected was visible but overlapped that of *t*-BuOH at τ 8.72. The remaining solvent was stripped and the residue was distilled, at atmospheric pressure, through a 1-in. column packed with glass beads. The largest fraction (0.92 g) was distilled at 160–165°. This material produced nmr (CCl_4) and ir (CCl_4) spectra identical with those observed from the HOCl reaction, and the 2,4-dinitrophenylhydrazone was similarly in agreement (mp 106–106.5°).

D. *t*-BuOCl in *t*-BuOH. The reaction was performed as in A except that the reaction flask was covered with aluminum foil, flushed with nitrogen, and sealed with a serum cap. With stirring at room temperature, 1 equiv (0.54 g) of *t*-BuOCl was slowly injected into a solution of 0.53 g of the cyclopropanol dissolved in 8 ml of *t*-BuOH. After 30 min the solvent was distilled (100 mm) and the residue was taken up in $CDCl_3$. The nmr spectrum of the solution was identical with that produced by the reaction discussed in part B. The solvent was stripped under vacuum, and the residue was dissolved in 10 ml of EtOH saturated with KOH. After stirring overnight, the solvent was removed under vacuum; the residue was taken up in $CDCl_3$ and filtered through glass wool. The nmr spectrum of the resulting material was identical with that obtained before base treatment.

E. NBS in CCl_4. The cyclopropanol (0.155 g, 0.150 mol) was dissolved in 0.5 ml of CCl_4, and the resulting solution was poured into a slurry of 0.276 g (0.15 mol) of NBS in 1 ml of CCl_4 in a beaker. The mixture was then filtered through glass wool into an nmr tube. The resulting solution displayed three singlets (in addition to the signal from succinimide at τ 7.32) in a ratio of 2:3:6 at τ 6.5, 7.8, and 8.7, respectively. The product was assigned the structure $(CH_3)_2C(CH_2Br)COCH_3$ on the basis of this spectrum, its ir spectrum (in $CHCl_3$: $\nu_{C=O}$ 1718 cm^{-1}, no O–H or cyclopropyl C–H), its lack of reaction with saturated ethanolic KOH (during 1 hr), and the analysis of its 2,4-dinitrophenylhydrazone (mp 83.0–83.5°).

Anal. Calcd for $C_{12}H_{15}BrN_4O_4$: C, 40.15; H, 4.21; N, 15.61; Br, 22.22. Found: C, 39.75; H, 4.15; N, 15.42; Br, 22.28.

F. NBS in *t*-BuOH. The cyclopropanol (1.25 g, 0.0125 mol) in 5 ml of *t*-BuOH was injected into a flask (equipped to stir magnetically, covered with aluminum foil, flushed with nitrogen, and sealed with a serum cap) containing 2.22 g (1 equiv) of NBS dissolved in 15 ml of *t*-BuOH. After stirring for 1 hr, the solvent was removed under vacuum, and the residue was taken up in $CHCl_3$. This solution was passed through about 1 in. of silica gel in a dropping pipet with elution by about 8 ml of $CHCl_3$. The nmr spectrum of the resulting material was identical with that obtained in E.

G. *t*-BuOBr in $CDCl_3$. An nmr tube containing 0.183 g of the cyclopropanol in 1 ml of $CDCl_3$ was cooled to 0°, and 0.286 g of freshly prepared *t*-BuOBr (1 equiv) was added dropwise. An exothermic reaction ensued, accompanied by immediate loss of the orange-red color of the hypobromite. The nmr spectrum of the resulting solution displayed the three singlets assigned to $(CH_3)_2C(CH_2Br)COCH_3$ (see part E) in addition to peaks from *t*-BuOH at τ 8.72 and 6.00 (the latter of which is variable with concentration).

Reactions of 1,2,2-Trimethylcyclopropyl Acetate (Ib). A. NaOH. In a stoppered, 25-ml erlenmeyer flask, 1.35 g of the acetate was magnetically stirred overnight with 10 ml of 1 *N* NaOH at room temperature. The organic layer was separated and dried over $MgSO_4$; gpc analysis (column A at 100°) revealed components having retention times corresponding to those of pinacolone, starting material, and 1,2,2-trimethylcyclopropanol in ratios of 1.0:2.0:*ca.* 0.2. The material was then treated with 1 *N* NaOH solution overnight at reflux temperature and examined a second time. The sole component now had a gpc retention time and ir spectrum identical with those of pinacolone. A synthetic mixture of pinacolone and isobutyl methyl ketone demonstrated that 1% of the latter would have been easily detected under the analysis conditions.

B. H_2SO_4. H_2SO_4 (20 ml, 3 *M*) and 2.0 g of the acetate were mixed in a 50-ml, round-bottomed flask equipped with a condenser. After refluxing for 24 hr, the organic layer was dried, and gpc analysis (column B at 90°) revealed that the acetate had been consumed. The acid-catalyzed ring opening produced pinacolone (78.2 ± 0.8%) and isobutyl methyl ketone (21.8 ± 0.8%); these percentages were obtained as average values of three gpc injections.

C. *t*-BuOCl. Samples of the acetate weighing 2.2, 2.8, and 2.8 g were dissolved in 5 ml of CCl_4, 5 ml of H_2O in 15 ml of *p*-dioxane, and 5 ml of H_2O in 18 ml of HOAc, respectively. The solutions were stirred magnetically while 1 equiv of *t*-BuOCl was added to each solution. After 24 hr, the latter two solutions were extracted with ether and dried over $MgSO_4$. After stripping the solvent, these residues were diluted with CCl_4. The resulting solutions and the CCl_4 reaction mixtures were examined by gpc (column A at 150°). In addition to solvent, the major component in each of these was unreacted starting material, and there was no peak suggesting the presence of $(CH_3)_2C(CH_2Cl)COCH_3$.

D. NCS. The reaction was performed as in part B of the preceding section. After recovery of the material, an nmr spectrum identical with that of starting material was obtained.

Reactions of *trans*-2-Phenyl-1-methylcyclopropanol (V).[23] A. *t*-BuOCl. In an nmr tube, 0.15 g of the cyclopropanol was dissolved in 0.5 ml of $CDCl_3$. The tube was immersed in an ice bath and 0.11 g (1 equiv) of *t*-BuOCl was added with shaking. After 5 min, the nmr spectrum was obtained. The signals of the cyclopropanol had been greatly reduced, and the spectrum displayed new peaks which were all assigned to $C_6H_5CHClCH_2COCH_3$ (using the methyl signal of *t*-BuOH to determine τ values). The assignments were as follows: singlet at τ 7.85 (CH_3CO), multiplet at 6.70 (methylene protons), two doublets at 4.40 (methinyl proton), and a further multiplet at 2.60 (aromatic protons). Subsequent spectra, obtained during the next 90 min, showed a gradual decrease in these peaks with new peaks appearing at τ 8.70, 3.40, and 3.10 which were identical with those from an authentic sample of benzalacetone. The latter compound was expected from spontaneous loss of HCl by the chloro ketone; furthermore, a spectrum analogous to that of the product mixture (after 1 hr, loss of HCl was half complete) was produced by bubbling HCl through a 20% solution of benzalacetone in CCl_4 at 0° for 30 min.

B. NBS. To a solution of 0.105 g (0.71 mmol) of the alcohol and 0.5 ml of $CDCl_3$ in an nmr tube cooled to 0–5°, 1 equiv of NBS was added in small portions. The initial nmr spectrum (obtained within 10 min) indicated complete consumption of the alcohol; in addition to the signal from succinimide (τ 7.32), the prominent peaks were assigned to $C_6H_5CHBrCH_2COCH_3$ as follows: a singlet at τ 7.91 (acyl methyl), unsymmetrical triplets centered at 6.52 (methylene protons) and 4.40 (methinyl proton), and a singlet at 2.57 (aromatic protons). During the succeeding hour, the original signals diminished in proportion to the increase in those due to benzalacetone (assigned by comparison to an authentic sample).

Synthesis of *threo*- and *erythro*-α-Methyl-β-bromobutyrophenones (VIIIb and Xb).[24] Approximately 200 ml of pentane (dried with $MgSO_4$) was cooled in a pressure bottle to −78° under nitrogen. A quantity, 23.5 g (0.42 mol), of *trans*-2-butene was condensed in the bottle followed by addition of 5 g (0.022 mol) of zinc bromide (dried overnight at 110°). After adding 39 g (0.21 mol) of freshly distilled benzoyl bromide, the bottle was sealed and stirred at 65° for 3 days. After recooling to −78°, the bottle was opened, and the contents were transferred to a separatory funnel. The solution was washed with water, saturated $NaHCO_3$, and finally water again. The organic layer was dried over $MgSO_4$ and the solvent subsequently stripped under vacuum. The residue was then eluted through silica gel with a 50:50 mixture of pentane and $CHCl_3$. The eluent was then examined in the carbonyl region of the ir spectrum; the first few fractions, containing 6 g of product, possessed an intense band at 1690 cm^{-1}. The remaining fractions, comprising a total of 12 g, showed this band and progressively increasing amounts of absorption at 1650 cm^{-1}. An nmr spectrum of the first material exhibited peaks centered at τ 2.04 and 2.50 (aromatic protons), 5.64 and 6.18 (methinyl protons), and eight sharp peaks at *ca.* 8.50 (methyl protons), in agreement with the expectations for a mixture of the diastereomeric α-methyl-β-bromobutyrophenones.

Some separation of the pair of isomers was effected by passing the mixture very slowly through silica gel a second time. The first eluted material contained a 2:1 predominance of the bromo ketone whose nmr spectrum showed methyl doublets centered at τ 8.26 and 8.78. The spectra of the remaining fractions revealed increasing amounts of the diastereomer having methyl doublets centered at τ 8.30 and 8.63; the aromatic and methinyl proton signals of the two isomers overlap extensively.

Attempts to further separate the bromo ketones by elution chromatography on neutral alumina ($CHCl_3$) or by distillation (1.5 mm; the major fraction boiled at 92–96°) led to a material containing two components as revealed by gpc analysis (column C at 100°). These compounds, present in a ratio of 1:9, were isolated

(23) The alcohol was prepared in 20% over-all yield from *trans*-2-phenyl-1-methylcyclopropanecarboxylic acid according to the method of DePuy, *et al.*[4]

(24) This synthesis represents a modification of the method[9] employed for the corresponding chloro ketones.

by preparative gpc (same conditions); the minor component eluted first. Later it was shown that these products had nmr spectra identical with *trans*- and *cis*-2-benzoyl-2-butenes, respectively (*vide supra*).

Synthesis of *cis*-2-Benzoyl-2-butene (XI). Tiglic acid was prepared using the procedures of Bordwell[25] and House.[26] Condensation of 50 g (0.89 mol) of *trans*-2-butene into a 500-ml flask immersed in a Dry Ice–acetone bath was followed by dropwise addition, with stirring, of 135 g (0.85 mol) of bromine. Stirring was continued until the flask reached room temperature. The resulting dibromide was placed under vacuum until the pressure reached 50 mm. The yield of crude *meso*-2,3-dibromobutane was 182.4 g. The product was dissolved in 150 ml of ethylene glycol in a 1-l. flask equipped with a stirring rod, an addition funnel, and a condenser arranged for distillation. The mixture was heated to 120° by an oil bath, and a solution of 68.5 g of KOH in 250 ml of ethylene glycol was added, over 45 min, to the rapidly stirred solution. During the addition, material boiling at 84–87° was removed. This distillate, after drying overnight with anhydrous $MgSO_4$, afforded 109 g of 2-bromo-*cis*-2-butene.

A solution of 40.6 g (0.30 mol) of the vinyl bromide in 100 ml of anhydrous ether was added to a stirred mixture of 4.2 g (0.61 g-atom) of lithium chips in 150 ml of anhydrous ether contained in a 500-ml flask. After completion of the addition, the solution was stirred for 30 min at room temperature and poured into a large excess of crushed Dry Ice. After the mixture attained room temperature, 6 *N* HCl was added with vigorous stirring until the aqueous layer was faintly acidic. The ether layer was separated and extracted with saturated $NaHCO_3$ solution until CO_2 evolution ceased. The combined aqueous portions were neutralized with 6 *N* HCl and extracted three times with ether. Removal of ether under vacuum left a solid which was taken up in hot Skellysolve B. This solution, after standing at −20° overnight, produced 2.76 g of tiglic acid which was collected and dried under vacuum (mp 64–65°; lit.[26] 64–65°; nmr in $CDCl_3$: methyl groups at τ 8.34 (S) and 8.20 (S), vinyl proton at 3.16 (M), CO_2H at −1.26 (S)).

In a 10-ml flask equipped with a condenser, 2.75 g of tiglic acid was dissolved in 4 ml of $SOCl_2$ (*ca.* 2 equiv) and refluxed for 1 hr. Distillation through a 3-in. Vigreux column produced 2.27 g of the acid chloride (bp 64–65°; nmr in $CDCl_3$: methyl groups centered at τ 8.10 (M), vinyl proton at 2.84 (M)).

The acid chloride (1.824 g, 15.4 mmol) was dissolved in 10 ml of anhydrous ether in a 25-ml flask and cooled to −78° in a Dry Ice bath. Dropwise, 4 ml of 1.87 *M* phenyllithium in hexane was added during 30 sec to the rapidly stirred solution. Within 5 min, the solution was poured into about 10 ml of water. After separation of the two layers, excess acid chloride was destroyed by extracting the ether with saturated $NaHCO_3$ solution (0.77 g of tiglic acid recovered). The ether solution was dried with $MgSO_4$; solvent was removed under vacuum, and the residue was taken up in $CHCl_3$. Analysis by gpc (column D at 190°) revealed that the major peak corresponded in retention time to the major component isolated from thermal decomposition of the bromo ketones and indicated that the minor component resulting from this decomposition was absent. A second peak (*ca.* 30% of the mixture) having a longer retention time (9.4 min as compared to 1.4 min for the major product) was not characterized. The major component was isolated by elution chromatography on silica gel with $CHCl_3$ (followed by preparative gpc on column D at 190°). This had an nmr spectrum identical with that of the major product from decomposition of the bromo ketones, thus allowing both to be assigned as *cis*-2-benzoyl-2-butene.

Synthesis of *trans*-2-Benzoyl-2-butene (XII). This synthesis exactly paralleled the preparation of the *cis* isomer; *cis*-2-butene (50.0 g, 0.89 mol) produced 182.0 g of crude *dl*-2,3-dibromobutane. This was converted to 87.0 g of 2-bromo-*trans*-2-butene by treatment with KOH. The bromobutene (40.6 g, 0.30 mol) produced 6.3 g of angelic acid (mp 41–43°; lit.[26] 40–43°); nmr in $CDCl_3$: methyl groups as overlapping multiplets centered at τ 8.01, vinyl proton as a multiplet at 3.72, and CO_2H as a singlet at −1.75. The conversion of 0.063 mol of the acid to the acid chloride was accomplished by dissolving the acid in 25 ml of benzene and 5 ml (1 equiv) of pyridine. The solution was cooled to 0–5° and 5 ml (0.064 mol) of $SOCl_2$ in 5 ml of benzene was added, dropwise, with stirring. The reaction mixture was maintained at this temperature and stirring was continued for 1 hr. The mixture was then filtered and 4 g of crude angeloyl chloride was obtained (nmr in $CDCl_3$: methyl groups as overlapping multiplets centered at τ 8.03, vinyl proton at 3.71 as a multiplet; relative ratios 6:1, respectively).

The acid chloride (1.82 g) was converted to the α,β-unsaturated ketone with 4 ml of 1.87 *M* phenyllithium as before. Analysis by gpc (column D at 190°) revealed that the major component had a retention time equivalent to the minor product from thermal decomposition of the bromo ketones.

Elimination Reactions of *erythro*- and *threo*-α-Methyl-β-bromobutyrophenones. A. *t*-BuOK–*t*-BuOH. Two mixtures, one with 65% of the *threo*-bromo ketone and one with 20% of this diastereomer (percentages estimated from nmr spectra), were examined. A sample of this first mixture, 0.39 g, was dissolved in 10 ml of *t*-BuOH and a sample of the second, 0.0436 g, was dissolved in 5 ml of *t*-BuOH. Each was then treated with 1 equiv of *t*-BuOK. After 30 min, solvent was removed under vacuum, and a small amount of $CHCl_3$ was added to the residue. After filtration, the mixtures were examined by gpc (column E at 150°). The bromo ketones were not visible, and peaks corresponding to the α,β-unsaturated ketones were present in the same ratio as from the thermal decomposition of the bromo ketones (90% *cis*-2-benzoyl-2-butene).

B. KOAc–EtOH. In 5 ml of absolute EtOH, 0.2614 g of a mixture of bromo ketones (60% *threo* isomer) was treated with 0.2130 g (2 equiv) of KOAc. The mixture was then stirred for 3 hr at room temperature. After this time, 10 ml of $CHCl_3$ was added, and the mixture was extracted twice with water and then dried over $MgSO_4$. Solvent was removed under vacuum and the residue taken up in $CDCl_3$. The nmr spectrum of the resulting solution revealed that the signals from the predominant (*threo*) bromo ketone were still present, but those of the minor isomer had been replaced by peaks from *cis*-2-benzoyl-2-butene. Comparison of the vinyl proton region with that of the methinyl protons indicated that the two components were present in approximately equal amounts.

Solvent was removed and the residue was taken up in 5 ml of EtOH. To this solution, 0.041 g of KOH was added, and the mixture was stirred for 30 min. The reaction mixture was worked up as before and the nmr spectrum reflected approximately equal amounts of *cis* and *trans* isomers (as estimated from vinyl proton signals).

Synthesis of *cis,trans*-2,3-Dimethyl-1-phenylcyclopropanol (IX). *cis,trans*-2,3-Dimethyl-1-phenylcyclopropyl bromide was prepared by a modification of the procedure of Moss and Gerstl.[8] A pressure bottle was flushed with nitrogen and placed in a Dry Ice bath. In the bottle, 25 g of *t*-BuOK was covered with pentane and 10 g of *trans*-2-butene was condensed into the mixture. After addition of 20 g of benzal bromide, the bottle was sealed and allowed to stand for 3 days with occasional shaking. After this time, the bottle was cooled and opened. The material was filtered under vacuum, and the collected solid was thoroughly washed with pentane. This solution was then extracted with water five times and subsequently dried over $MgSO_4$. After stripping the solvent, the product was passed through a 2-cm pad of anhydrous $MgSO_4$ to complete the drying. Average yields of 80–90% of crude cyclopropyl bromide were obtained, and the product was used without further purification.

In a typical conversion of the bromide to the acid, 26.03 g (0.116 mol) of the bromide in 20 ml of anhydrous ether was added to 35.5 g of 22.2% *n*-butyllithium (in hexane) contained in a 250-ml flask that had been flamed under nitrogen and then cooled in a Dry Ice–acetone bath. (*Note:* Reactions in which there was not immediate formation of a dark coloration in the solution inevitably gave poor yields.) A siphon tube was then fitted to the reaction flask and the solution was forced, under nitrogen, onto well-crushed Dry Ice that was vigorously stirred. After coming to room temperature, the solution was treated with 6 *N* HCl until the aqueous layer remained faintly acidic. The ether layer was separated and extracted with 1 *N* NaOH, and the aqueous extracts were again acidified with HCl. After drying over $MgSO_4$, ether was removed from the solution, and the resulting solid was taken up in hexane and crystallized upon standing at −20°. The yields of cyclopropanecarboxylic acid ranged up to 45% but 30% was more typical. The product had mp 105–106° and the nmr spectrum ($CDCl_3$) exhibited doublets at τ 8.60 and 9.20 (methyl groups), multiplets at 8.80 and 9.20 (cyclopropyl protons), a multiplet centered at 2.80 (aromatic protons), and a singlet at −2.80 (CO_2H). The ir spectrum exhibited ν_{-OH} 3540 cm^{-1} and $\nu_{C=O}$ 1695 cm^{-1}.

(25) F. G. Bordwell and P. S. Landis, *J. Am. Chem. Soc.*, 79, 1593 (1957).

(26) H. O. House and G. H. Rasmusson, *J. Org. Chem.*, 26, 4278 (1961).

Anal. Calcd for $C_{12}H_{14}O_2$: C, 75.85; H, 7.62; O, 16.65. Found: C, 75.76; H, 7.42; O, 16.82.

In a representative synthesis of *cis,trans*-2,3-dimethyl-1-phenylcyclopropyl methyl ketone, 17.16 g (90.20 mmol) of the acid was dissolved in 200 ml of anhydrous ether in a 500-ml flask immersed in an ice bath. A condenser was attached to the flask and fitted with a tube leading (through a cold trap) to a water bubbler. Approximately 1 equiv of a methyllithium solution in ether was placed in the addition funnel and added, dropwise, until methane evolution ceased. A volume of methyllithium solution equal to that already added was then slowly dropped into the mixture. Stirring was continued overnight and approximately 100 ml of a saturated NH_4Cl solution, followed by sufficient 6 *N* HCl to reduce the pH to <1, was added. The ether layer was separated, washed with saturated $NaHCO_3$, and dried over $MgSO_4$. The solvent was stripped and 14.17 g of crude ketone was obtained. Analysis by gpc (column E at 160°) indicated >95% purity. An nmr spectrum ($CDCl_3$) of the product exhibited multiplets centered at τ 8.88 and 9.25 (methyl groups), 8.20 and 8.60 (cyclopropyl protons), a singlet at τ 8.18 (CH_3CO), and a singlet at 2.70 (aromatic protons).

A typical preparation of acetate involved 14.17 g (0.076 mol) of the ketone in 100 ml of CH_2Cl_2 (dried over $MgSO_4$) with 175 g of anhydrous Na_2HPO_4 in a 1-l. flask. Small portions of a cold solution of peracid, prepared from the addition of 90% H_2O_2 (10.8 g, 0.38 mol) to 80.0 g (0.38 mol) of $(CF_3CO)_2O$ in 200 ml of dry CH_2Cl_2, was added to the ketone solution at such a rate that the reaction could be maintained below 10°. This amount of peracid is somewhat different from that used by earlier workers[4] and represents the use of 5 equiv of peracid. The mixture was stirred vigorously for 4 hr at 0° (in order to reduce foaming) and then at room temperature until gpc analysis[27] indicated that reaction was complete. The mixture was then filtered, washed thoroughly with saturated $NaHCO_3$ solution, and finally washed with water. After stripping the solvent, the acetate was purified by preparative gpc (column C at 200°). Yields of crude product averaged about 80%. An nmr spectrum ($CDCl_3$) of the material exhibited singlets at τ 8.78 and 9.18, multiplets at 8.70 and 9.20 (cyclopropyl protons), a singlet at 8.08 (CH_3CO), and a singlet at 2.75 (aromatic protons); the ir spectrum (CCl_4) exhibited $\nu_{C=O}$ 1765 cm^{-1} and ν_{C-O} 1240 cm^{-1}.

The cyclopropanol was usually prepared on a 1–2-g scale by dissolving 1.5–2.5 g of the acetate in 10 ml of dry ether in a 50-ml flask at 0–5°. Methyllithium (1 equiv, in ether) was then added and the solution stirred for 30 min. After transference to an addition funnel, the solution was added, with stirring, to a large excess of boric acid in an equivalent volume of water. The mixture was filtered, the layers were separated, and the aqueous layer was extracted twice with ether. The combined ether extracts were then washed with water and, finally, dried over $MgSO_4$. Solvent was removed at reduced pressure and the residue was placed under vacuum (0.5 mm) at 50° for 30 min. The recovered material represented, on the average, a 70% yield of cyclopropanol. Efforts to purify the product by preparative gpc (several columns at 100–200°), elution chromatography (silica gel–$CHCl_3$), or distillation (8-in. Vigreux column, 0.5 mm) resulted in large losses of material and produced mixtures whose nmr spectra were complex. Therefore, the crude cyclopropanol was used without further purification; the nmr spectrum ($CDCl_3$) of this product showed a doublet and a singlet at τ 8.75 and 9.29, respectively (methyl groups), multiplets at 8.70 and 9.30 (cyclopropyl protons), a broad singlet at 6.90 (OH), and a singlet at 2.80 (aromatic protons).

Reactions of *cis,trans*-2,3-Dimethyl-1-phenylcyclopropanols (IX) with Halogenating Agents. The following reactions were all conducted in the same manner unless otherwise specified. The alcohol was dissolved in the appropriate solvent and injected, dropwise, through a serum cap into a solution of the halogenating agent, magnetically stirred in an erlenmeyer flask covered with aluminum foil and flushed with N_2. After the specified reaction time, the solvent was removed under vacuum. In the reactions with NBS or NCS, the residue was taken up in $CHCl_3$ and passed through 1 in. of silica gel contained in a dropping pipet (with elution by about 8 ml of $CHCl_3$). The solvent was again stripped and the residue was taken up in $CDCl_3$ prior to nmr spectral examination. In all other cases, after the solvent was stripped, the residue was simply taken up in $CDCl_3$ and the nmr spectrum was obtained.

(27) This ketone proved to be more difficult to convert to the acetate than others examined in this laboratory; the progress of the reaction was therefore monitored by gpc (column E at 190°). The rate of the reaction was severely retarded if efficient agitation of the heterogeneous mixture was not maintained.

A. NBS in $CHCl_3$. Weighed samples (about 0.1 g) of the alcohol were each treated with 1 equiv of NBS in $CHCl_3$ according to the general scheme above and the products were examined after 30 min, 1 hr, 54 hr, and 72 hr (each time representing a different reaction). In the first two cases, the lowest field methyl doublets of the bromo ketones and the methinyl proton signals were evident although remaining starting material covered the upfield doublets. The lower field doublets could be approximately integrated and a value of 65% *erythro*- and 35% *threo*-α-methyl-β-bromobutyrophenones was obtained. After 1 hr the reaction appeared to be about 20% complete. After 54 hr, the product ratio was about 55:45 but unidentified signals in the area τ 8.5–9.5 were present. After 72 hr, an extremely complex spectrum was obtained, and the solution had become quite opaque. In several cases the spectra of the reaction mixtures were examined before passage through silica gel. Except for the signals from NBS and succinimide, chromatography effected no changes.

B. NBS in *t*-BuOH. The general procedure was employed with 0.122 g of the alcohol in 2 ml of *t*-BuOH and 0.134 g (1 equiv) of NBS (dried in a desiccator over P_2O_5) in 10 ml of *t*-BuOH. After 1 hr, work-up gave a product whose nmr spectrum indicated exclusive conversion of the alcohol to *erythro*-α-methyl-β-bromobutyrophenone.

C. Br_2 in *t*-BuOH. The reaction was run as in B with 0.120 g of cyclopropanol and 0.1186 g of Br_2. After 1 hr, the usual work-up produced a mixture with an extremely complex nmr spectrum but no signals were evident that could be assigned to the bromo ketones. Reaction of the cyclopropanol with bromine in *t*-BuOH a second time, in the presence of an equivalent of KOAc, afforded the *erythro*-bromo ketone contaminated with a small amount of unreacted starting material.

D. *t*-BuOBr in *t*-BuOH. The usual procedure was employed and after 1 hr an nmr spectrum was obtained that reflected exclusive formation of *erythro* isomer (the *threo* isomer could not be detected in less than about 10% concentration in this experiment). The spectrum contained some signals in the region τ 8.5–9.5 that could not be unequivocally assigned to starting material.

E. *t*-BuOCl in *t*-BuOH. The reaction was performed in the usual manner using 0.11 g of cyclopropanol and 0.075 g (1 equiv) of *t*-BuOCl. The reaction time was 1 hr, and after work-up, the nmr spectrum ($CDCl_3$) indicated that the starting material had reacted almost completely. The prominent peaks were assigned to the diastereomeric α-methyl-β-chlorobutyrophenones and one diastereomer was present in about 5% excess: methyl groups as a pair of doublets centered at τ 8.79 and 8.42, methinyl protons centered at τ 5.57 and 6.18, aryl protons centered at τ 2.07 and 2.57. The minor isomer had significantly different chemical shifts of the methyl doublets (τ 8.52 and 8.66) but the methinyl protons and aryl protons appeared to have essentially the same chemical shifts as those of the major product.

F. Cl_2 in *t*-BuOH–KOAc. In a 10-ml erlenmeyer flask equipped as usual, 0.12 g of the cyclopropanol and 0.47 g of KOAc (1 equiv) were mixed with 5 ml of *t*-BuOH. Chlorine gas was bubbled through the stirred solution for 1 hr. The solvent was removed, and the residue was taken up in $CDCl_3$ and filtered through glass wool. The nmr spectrum of the resulting material indicated predominantly unreacted alcohol, but four upfield doublets (approximately equal intensities) could be assigned to the chloro ketones. However, the presence of starting material and some unidentified components made this assignment tentative.

G. NCS in *t*-BuOH. The reaction was performed as usual. After a reaction time of 4 hr, an nmr spectrum ($CDCl_3$) indicated only unreacted starting material.

Synthesis of *trans,trans*-2,3-Dimethyl-1-phenylcyclopropanol (VII). This cyclopropanol was prepared in a manner directly analogous to that described for the *cis,trans* isomer. Room temperature reaction (2.5 days) of benzal bromide, 40 g, potassium *t*-butoxide, 50 g, and *cis*-2-butene, 10 ml, with pentane as a diluent afforded 32 g (89%) of *trans,trans*- and *cis,cis*-2,3-dimethyl-1-phenylcyclopropyl bromides[8] (37 and 63%, respectively, of the mixture). The crude product, devoid of benzal bromide and *t*-butyl alcohol, was used without further purification.

The mixture of cyclopropyl bromides, 10 g, was diluted with 10 ml of anhydrous ether and added dropwise, with stirring and under a nitrogen blanket, to 25 ml of 2.18 *M* *n*-butyllithium (in hexane) which had been diluted with 24 ml of anhydrous ether.[28] The

(28) *Note:* The reaction flask had been flamed under nitrogen before use.

reaction mixture was maintained at −78° for a further 10 min after addition of the bromides was complete and then poured, with vigorous stirring, onto an excess of crushed Dry Ice which had been covered with ether. After the mixture had attained room temperature, it was acidified with 6 *N* HCl and the ether layer separated, washed with brine, and dried over $MgSO_4$. After removal of ether, the residue (4.2 g, 50%) was taken up in hexane and allowed to stand at −20° for several hours. (The crude mixture contained approximately a 90:10 ratio of the two isomers, with the higher melting isomer predominating. However, the relative amounts of the two acids produced in this reaction have been shown to be variable.[29]) The crystals obtained were further enriched in the predominant isomer, and after several recrystallizations from CCl_4 the pure isomer had mp 190–191° and its nmr spectrum ($CDCl_3$) exhibited multiplets at τ 9.03 (methyl groups), 8.16 (cyclopropyl protons), and 2.50 (aromatic protons), and a singlet at τ −2.30 (COOH) with relative areas 6:2:5:1, respectively.

Anal. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42; O, 16.82. Found: C, 76.00; H, 7.45; O, 16.84.

The lower melting isomer was obtained from the combined mother liquors after a number of crystallizations from CCl_4. The pure material had mp 161–162° and its nmr spectrum ($CDCl_3$) exhibited multiplets at τ 8.75 (methyl groups) and 8.42 (cyclopropyl protons) and singlets at τ 3.02 (aromatic protons) and −1.10 (COOH), with relative areas 6:2:5:1.

Anal. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42; O, 16.82. Found: C, 76.03; H, 7.46; O, 16.80.

The structural assignments of the two isomers were made on the basis of their nmr spectra. The higher melting isomer is assigned as the *trans,trans* isomer since the methyl groups, which are *cis* to the aromatic ring, would be expected to be shielded and thus occur at higher field than those of the *cis,cis* compound.[30]

A sample of *trans,trans* acid, 3.0 g, was dissolved in 30 ml of anhydrous ether and treated with 2 equiv of methyllithium in the usual manner.[4] The crude ketone thus obtained was taken up in Skellysolve B and the resulting solution extracted with saturated sodium bicarbonate solution to remove traces of unreacted acid. The pure ketone was then obtained by successive crystallizations from Skellysolve B (average yield: 85%) and had mp 101–102°. A 2,4-dinitrophenylhydrazone derivative of the ketone was prepared which crystallized as deep-red plates from 95% ethanol and had mp 143–144°. The nmr spectrum ($CDCl_3$) of the ketone exhibited a multiplet centered at τ 9.06 (methyl groups), a singlet at 8.14 (acyl methyl), and two additional multiplets centered at 8.08 (cyclopropyl protons), and 2.70 (aromatic protons), with relative areas 6:3:2:5; the ir spectrum (CCl_4) showed $\nu_{C=O}$ at 1700 cm^{-1}.

Baeyer–Villiger reaction of the ketone, 2.5 g in 40 ml of CH_2Cl_2, with peroxytrifluoroacetic acid[4] (prepared from 8.1 g of trifluoroacetic anhydride in 15 ml of CH_2Cl_2 and 1.3 ml of 90% hydrogen peroxide) in the presence of 28 g of Na_2HPO_4 afforded, after a reaction time of 8 hr, 2.0 g (75%) of crude acetate. The product was purified by repeated crystallizations from Skellysolve B and had mp 60–61°. The nmr spectrum (CCl_4) of the acetate showed multiplets centered at τ 9.05 (methyl groups) and 8.68 (cyclopropyl protons), a singlet at 8.27 (CH_3CO_2), and a final multiplet at 2.62 (aromatic protons) with relative areas 6:2:3:5; the ir spectrum (CCl_4) showed $\nu_{C=O}$ at 1760 cm^{-1} and ν_{C-O} at 1240 cm^{-1}.

The *trans,trans*-cyclopropanol was usually prepared on a relatively small scale in the following manner. The cyclopropyl acetate, 2.0 g, was diluted with 10 ml of anhydrous ether and placed in a 100-ml flask which had been flamed under nitrogen before use. To this solution was added 2 equiv of methyllithium (in ether); the resulting solution was then transferred to a dropping funnel and added slowly, with vigorous stirring, to a cold (0–5°) slurry of 12.4 g of boric acid in 50 ml of water. The mixture was transferred to a separatory funnel, with sufficient water to dissolve the remaining boric acid, and the ether layer separated (hereafter, all glassware used with the cyclopropanol had been rinsed in dilute HF solution followed by distilled water and then thoroughly dried).

After drying over $MgSO_4$ and filtration, the ether was removed on a rotary evaporator and the resulting semisolid triturated with cold hexane. The white solid thus obtained was collected on a filtering funnel and washed with cold hexane. The crude product, 1.0 g (63%), was recrystallized from hexane and had mp 101–102°. The nmr spectrum (CCl_4) of the cyclopropanol exhibited multiplets centered at τ 9.12 (methyl groups) and 8.75 (cyclopropyl protons) and singlets at 7.76 (–OH) and 2.70 (aromatic protons), with relative areas 6:2:1:5; the ir spectrum ($CHCl_3$) showed ν_{-OH} at 3590 (sharp) and 3420 (broad) cm^{-1}.

Reactions of *trans,trans*-2,3-Dimethyl-1-phenylcyclopropanol (VII). A. *t*-BuOCl in $CDCl_3$. The cyclopropanol, 0.30 g, was dissolved in 0.5 ml of $CDCl_3$ and cooled to 0–5°. Freshly prepared (*vide supra*) *t*-butyl hypochlorite, 0.20 g, was then slowly added and the mixture allowed to stand, with occasional shaking, for 10 min. The mixture was then transferred to an nmr tube and its spectrum obtained. Examination of the spectrum showed that reaction was substantially complete and product peaks were observed as follows: doublets centered at τ 8.79, 8.66, 8.52, and 8.46; multiplets centered at τ 6.18, 5.57, and 2.30, with relative areas 6:2:5, respectively. In similar manner to the products described for the *cis,trans* isomer (see section E of reactions), one diastereomeric ketone was present in slight excess (approximate ratio 56:44).

B. $FeCl_3$ in Ether. The alcohol, 0.27 g, was dissolved in 10 ml of anhydrous ether and cooled to 0–5°. Anhydrous ferric chloride, 0.28 g in 15 ml of anhydrous ether, was then added slowly and the mixture maintained at 0–5° for an additional 0.5 hr with stirring. The mixture was then filtered, extracted with water, saturated $NaHCO_3$ solution, and water again, and finally dried over $MgSO_4$. After filtration and removal of solvent, the residual oil was taken up in $CDCl_3$ and its nmr spectrum obtained. The resulting spectrum was virtually identical with that obtained for the products described in part A; the isomer composition was approximately 60:40 (same isomer predominant).

C. NBS in $CDCl_3$. A solution of 0.25 g of the cyclopropanol in 0.5 ml of $CDCl_3$ was cooled to 10° and then 0.28 g of N-bromosuccinimide was added in small portions during 10 min. The mixture was filtered through glass wool, and the filtrate was transferred to an nmr tube and its spectrum obtained. Examination of this spectrum indicated that the solution contained predominantly unreacted cyclopropanol. Subsequent reactions, accomplished in similar manner, showed that the cyclopropanol required approximately 24 hr to react completely with NBS. After this time, examination of the nmr spectrum showed doublets at τ 8.78 and 8.26 and multiplets at 6.18, 5.64, and 2.50, and 2.04, consistent with exclusive formation of *threo*-α-methyl-β-bromobutyrophenone (*vide supra*).

D. Br_2 in HOAc–NaOAc. The cyclopropanol, 0.17 g, was dissolved in 10 ml of a saturated solution of NaOAc in glacial HOAc and a solution of 0.20 g of bromine in 2 ml of HOAc was then added dropwise with stirring. The bromine color disappeared virtually as fast as the solution was added; when addition was complete the mixture was allowed to stand an additional 5 min. After this time, the mixture was poured into water and extracted with ether, and the ether extract was washed with water, saturated $NaHCO_3$, and water and finally dried over $MgSO_4$. Ether was removed after filtration and the residue taken up in $CDCl_3$. The nmr spectrum again indicated exclusive formation of the *threo* compound VIIIb.

Reactions of *cis,trans*- and *trans,trans*-2,3-Dimethylcyclopropyl Acetates with Brominating Agents. A. *trans,trans* Isomer. 1. NBS in CCl_4. The cyclopropyl acetate, 0.20 g, was dissolved in 10 ml of CCl_4 and allowed to stir at room temperature for 5 days with 0.18 g of N-bromosuccinimide. After this time, the mixture was filtered, solvent removed, and the residue taken up in $CDCl_3$. The nmr spectrum of the solution indicated that ring opening had occurred to the extent of *ca.* 10% and that product(s) appeared to be α-methyl-β-bromobutyrophenone; however, it was not possible to determine the stereoselectivity of the reaction.

2. Br_2 in CCl_4. A solution of 0.20 g of the acetate in 10 ml of CCl_4 was mixed with 0.18 g of bromine in 2 ml of CCl_4 and allowed to stir at room temperature until the bromine color had disappeared (3.5 days). Solvent was then removed and the residual oil taken up in $CDCl_3$. The nmr spectrum of this solution indicated that it was a mixture of *threo*-bromo ketone (*ca.* 65%) and unreacted acetate (*ca.* 35%).

B. *cis,trans* Isomer. 1. Br_2 in CCl_4. The acetate, 0.20 g, was dissolved in 10 ml of CCl_4 and mixed with 0.16 g of bromine diluted with 2 ml of CCl_4. This solution was allowed to stand at room temperature, with stirring, for 16 hr; after this time, the bromine color had disappeared. Solvent was then removed and the residue taken up in $CDCl_3$; the nmr spectrum of this solution indicated that it contained approximately equal amounts of unreacted acetate and a second compound whose spectral pattern was in agreement with that expected for α-methyl-α,β-dibromobutyrophenone: a doublet centered at τ 8.06, a singlet at 7.95, a quartet at 5.11, and two multiplets centered at 2.66 and 2.10.[31]

(29) H. Barda, unpublished results.

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(31) Reaction of *cis*-2-benzoyl-2-butene or the corresponding *trans* isomer with bromine in CCl_4 produced a single α,β-dibromo ketone

2. NBS in CCl_4. A solution containing 0.20 g of the acetate in 10 ml of CCl_4 was placed in a Pyrex flask with 0.18 g of N-bromosuccinimide and irradiated with a GE 275-W sunlamp for 16 hr; the reaction mixture was maintained at 26° during this time. The mixture was then filtered and solvent removed, and the residue was dissolved in $CDCl_3$. The nmr spectrum of this solution indicated that it contained only starting material.

whose nmr spectrum was identical with the compound obtained from bromine and the *cis,trans*-acetate. The geometry of this product has not been determined. A competition experiment in which a 55:45 mixture of *threo*- and *erythro*-bromo ketones was treated (during 12 hr) with a limited quantity of bromine showed that dibromide resulted at the expense of the *erythro* isomer; also, it will be recalled that *no* dibromide resulted from reaction of *trans,trans*-acetate with bromine.

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The Norrish Type II Process in α-Keto Acids. Photolysis of α-Ketodecanoic Acid in Benzene[1]

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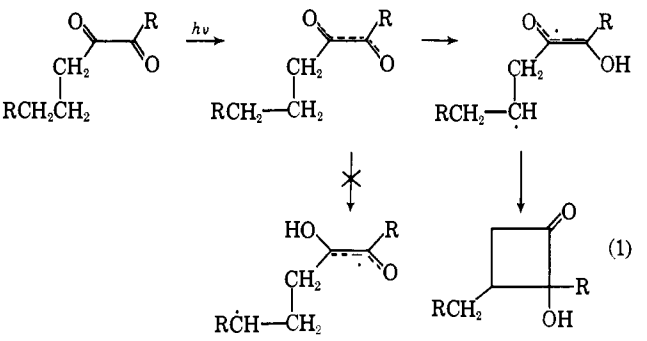
Abstract: Irradiation of α-ketodecanoic acid in benzene affords 1-heptene and pyruvic acid *via* a Norrish type II elimination (this being the first demonstrated example of the type II process in α-keto acids). The quantum yield for the process is 0.2. Quenching experiments indicate that α-ketodecanoic acid reacts only in the triplet state and has about the same reactivity in the photoelimination as an aliphatic ketone. A consequence of this fact demands a very fast rate of intersystem crossing in this compound. Relative rate constants for intersystem crossing and triplet hydrogen abstraction have been compared with other classes of carbonyl compounds, revealing the unique character of the excited states of α-keto acids.

In the condensed phase the major reaction pathway for aliphatic and aromatic ketones with γ-hydrogens is the Norrish type II photoelimination.[3] A minor, competing, pathway is cyclization to form a cyclobutanol.[3,4] The present evidence suggests that the initial abstraction is reversible and can occur from either the first excited singlet state or from the triplet state.[5-10] Although there are some ambiguities concerning the processes leading to cyclobutanol formation,[7,11-13] the elimination reaction apparently proceeds directly from the diradical intermediate.

In contrast α-diketones give only products of cyclization and no observable photoelimination.[14,15] The most striking thing about this reaction is that abstraction occurs by the "distant" keto group to yield hydroxycyclobutanones rather than abstraction by the "near" keto group to give 1-alkanoylcyclobutanols (eq 1). The reaction most probably occurs through the triplet state but there may be some radical chain reaction since the unsensitized quantum yield is 1.0 or higher and the quantum yield for the benzophenone-sensitized reaction is about 1.6.[15]



(1)

Although several types of photoreactions have been reported for α-keto acids and α-keto esters,[16-19] no examples of Norrish type II photoelimination or cyclobutanol formation are known.

Photolysis of α-ketodecanoic acid in benzene could lead to several types of products (Chart I). Photoelimination and/or cyclization, path a, would be analogous to that found for aliphatic and aromatic ketones. Photoreaction by path b would parallel the photochemistry of α-diketones. Although hydrogen atom abstraction by the acid group, as required in path b, is not well known, it has been observed in the photolysis of *n*-butyric acid.[20]

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