maleic acids.[7] Previous consideration of these decreases in K_1/K_2 ratios have "emphasized" an interference with intramolecular hydrogen bonding.[6,7] However, if the suggestion is accepted that for $K_1/K_2 \leqslant 10^4$ intramolecular hydrogen bonding is negligible as a factor contributing to that ratio,[8] then some other explanation must be found.

Electrostatic interaction between the two carboxyl groups is a useful starting point. Such interaction varies with the dielectric constant of the medium. To account for some large K_1/K_2 ratios, and generally to give reasonable correlation between spacing of carboxyl groups and the K_1/K_2 ratio, a cavity of low dielectric constant, the molecule itself, may be considered to be buried in a medium of high dielectric constant, the solvent.[2] On the basis of this model, the relationship

$$\log K_1/4K_2 = \frac{e^2}{2.303kT}\,\frac{1}{r}\,\frac{1}{D_E} \qquad (1)$$

may be formulated where r equals the "distance" between the carboxyl groups and D_E is an "effective" dielectric constant.[2] In order to calculate r and D_E, the carboxyl groups must be "buried" in a spherical or ellipsoidal cavity of low dielectric constant, usually assumed as 2 (hydrocarbon), and in the ellipsoidal case, the carboxyl groups must be located at the foci. In actual molecules where the carboxyl groups may lie at opposite ends of the cavity as in *trans* conformations of acyclic 1,2-dicarboxylic acids or in long straight-chain diacids, or they lie within a spherical cavity as in some disubstituted malonic acids or racemic di-*t*-butylsuccinic acid, then the theory works reasonably well. However, in some *cis*-1,2-dicarboxylic acids, the carboxyl groups clearly project from the hydrocarbon cavity and lie very close to each other; *i.e.*, there is no medium of low dielectric constant between the two carboxyl groups, nor do they lie within the cavity. The compounds do not resemble the spheres or ellipsoids necessary for quantitative application of the theory, and qualitative application is of dubious value since it leaves open the question of what effective dielectric constant should be used. Using K_1 and K_2 for *cis*-1,2-cyclobutanedicarboxylic acid and r equal to 4.00 Å., about a 15° bend in the cyclobutane ring, in eq. 1 gives D_E as 37. This is appreciably larger than values of D_E usually "found" with this "shape" and size of hydrocarbon residue, but it might not be unreasonable if the acid molecule, the cavity, is considered to be divided into a hydrocarbon portion, $D = 2$, and a carboxyl portion, $D \sim 58$, all buried in the solvent, $D \sim 80$. The rationale for the carboxyl region is that two very closely spaced carboxyl groups might be looked upon as comparable to a small volume of formic acid, $D = 58$. To the extent that any of these values have any real meaning at the molecular (or very small volume) level, it suggests that very careful examination must be made of the orientation of closely spaced carboxyl groups with regard to the attached "hydrocarbon cavity." That is, for *cis*-1,2-diacids, as the groups come closer together, the "medium" between them might be expected to change in nature from hydrocarbon to carboxyl and solvent with attendant rise in "effective" dielectric constant. From eq. 1, then, for some ranges of change in molecular structure of the *cis*-1,2-diacids, D_E might be expected to increase more rapidly than r decreased. The net result would be a decrease in K_1/K_2 ratio as the spacing between groups decreases.[9]

Acknowledgment.—This work was supported in part by a grant from the National Science Foundation.

[7] L. Eberson, *Acta Chem. Scand.*, **18**, 1276 (1964).

[8] L. Eberson and I. Wadsö, *ibid.*, **17**, 1552 (1963). This lower limit for intramolecular hydrogen bonding as a contributing factor could be lowered to 10^3 without effecting the present discussion. The range of K_1/K_2 ratios in which the decreases have been observed in the examples cited is about 10^1–10^2.

[9] Presumably, if the groups could be forced closer together, a minimum would be reached and then the K_1/K_2 ratio again would rise, probably very rapidly. However, sufficiently close approach to reach such a minimum undoubtedly would raise a variety of other problems.

The Stereochemistry of Free-Radical Addition of Thiolacetic Acid to Cyclohexenes[1,2]

FREDERICK G. BORDWELL, PHILIP S. LANDIS, AND GEORGE S. WHITNEY

Chemistry Department, Northwestern University, Evanston, Illinois

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Free-radical addition of thiolacetic acid to 4-*t*-butyl-1-methylcyclohexene resulted in about 80% of *trans*-diaxial adduct (SAc group axial) and 20% of *cis* adduct (SAc· group equatorial). This is explained by assuming that in each instance the AcS·radical initiates a perpendicular attack on the C=C bond, but that attack from the "top" side of the cyclohexene molecule is preferred for steric reasons. The radical intermediates formed from addition of the AcS· radical to 4-*t*-butyl-, 3-methyl-, and 2-methyl-1-methylenecyclohexanes were found to abstract a hydrogen atom from AcSH preferentially into an axial position.

Free-radical addition of hydrogen bromide, thiolacetic acid, and the like to 1-substituted cyclohexenes has been shown to proceed to give predominantly the *cis* product.[3] It has been suggested that the major (*cis*) product is formed by *trans*-diaxial addition,[3] but its origin, and that of the smaller amount of *trans* product, is rendered uncertain by the possibility of chair–chair interconversion preceding the hydrogen

[1] Abstracted in part from the Ph.D. Dissertation of G. S. Whitney, Northwestern University, 1962.

[2] These results were reported at the Fifth Annual Conference on Organic Chemistry at the U. S. Army Natick Laboratories, Natick, Mass., Oct. 1961, and in part at 142nd National Meeting of the American Chemical Society, Atlantic City, N. J., Sept. 1962; Abstracts, p. 64Q.

[3] (a) H. L. Goering, D. I. Relyea, and D. W. Larsen, *J. Am. Chem. Soc.*, **78**, 348 (1956); (b) F. G. Bordwell and W. A. Hewett, *ibid.*, **79**, 3493 (1957).

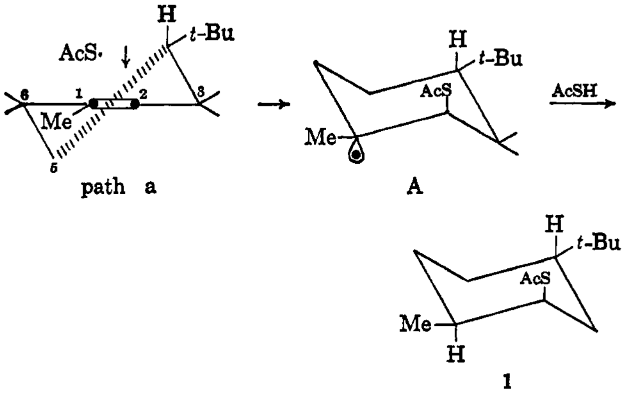
atom abstraction step. A number of other cyclohexenes have now been studied in order to obtain additional evidence on this point.

Preliminary experiments were first carried out with 1-methylcyclohexene to test the sensitivity of the stereochemical result to changes in reaction conditions. Gas–liquid partition chromatographic (g.l.p.c.) analysis proved to be an excellent method of determining the relative amounts of stereoisomeric thiolacetates. Two well-resolved peaks were obtained; the area of the peak with the longer retention time was four times as large as that with shorter retention time. The 1:4 ratio agrees well with the earlier analysis,[3b] and the relative order of retention times was that expected, since with the corresponding thiols *cis*-2-methylcyclohexanethiol is known to have the higher boiling point.[3b] The *trans* to *cis* ratio was but little affected by changing either the reaction temperature or the concentration of reactants.[4]

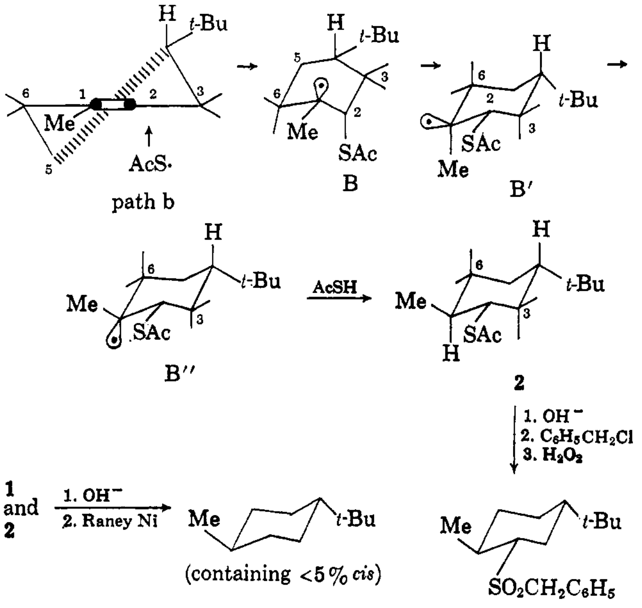
Addition of thiolacetic acid to 4-*t*-butyl-1-methylcyclohexene gave a mixture of thiolacetates in a ratio of 1:4 (in order of g.l.p.c. retention times). Hydrolysis of the thiolacetate mixture and careful fractional distillation gave two thiols, the higher boiling thiol predominating. The benzyl sulfone derivative prepared from the higher boiling thiol was isomerized to that of the benzyl sulfone derivative of the lower boiling thiol by the action of base. This result showed that the major product has the SAc group in an axial position and that the minor product has the SAc group in an equatorial position. The steric relationship of the methyl and *t*-butyl groups was established by desulfurizing portions of the original thiol mixture with Raney nickel and with triethyl phosphite. The desulfurized product was 95% *trans*-4-*t*-butyl-1-methylcyclohexane (less than 5% of the *cis* isomer was present). This result showed that the major product of addition was *trans*-5-*t*-butyl-*cis*-2-methylcyclohexyl thiolacetate (1), and that the minor product was *cis*-5-*t*-butyl-*trans*-2-methylcyclohexyl thiolacetate (2).

Addition of thiolacetic acid to 1,4-dimethylcyclohexene gave similar results. Four thiolacetates in amounts of 15, 76, 3, and 5% (in order of g.l.p.c. retention times) were formed. The major and secondary products were shown to have the methyl groups *trans* to one another by hydrolysis to the thiols and desulfurization. Over 95% of *trans*-1,4-dimethylcyclohexane resulted from the thiol mixture, as shown by g.l.p.c. analysis.

In the addition of thiolacetic acid to 4-*t*-butyl-1-methylcyclohexene about 80% of the product has the SAc group in an axial position and 20% has the SAc group in an equatorial position. Evidently the double bond in the alkene can be attacked from either side. Axial attack by the AcS· radical from the "top" side (path a) is favored sterically since only the axial hydrogen atom at C-4 offers any appreciable interference (the hydrogen atom at C-6 is pseudo-axial). Furthermore, the chain intermediate A can be formed with very little molecular readjustment of the original alkene conformation. Abstraction of a hydrogen atom by A (from AcSH) into an axial position will then give 1 (over-all *trans*-diaxial addition).



On the other hand, axial attack of the AcS· radical from the "bottom side" (path b) is opposed by a hydrogen atom on an adjacent carbon atom, the pseudo-axial hydrogen atom at C-3. If the addition is to follow a path comparable with that shown for the formation of 1, it will have to go through a twist-boat intermediate (B), which then goes to B′, then to B″, and finally to 2.



(obtained also by
base-catalyzed
isomerization of a
comparable derivative
prepared from 1)

Since the twist-boat intermediate B is less stable than the chair intermediate A, this representation offers an explanation for the preference of path a over path b on the grounds of the relative stability of the intermediates, as well as on the grounds of steric accessibility.

The preferential abstraction of the hydrogen atom from AcSH by A or B″ into an axial position in the second step is not so readily explained, since the preferred steric approach of the AcSH molecule would be such as to place the hydrogen atom in an equatorial

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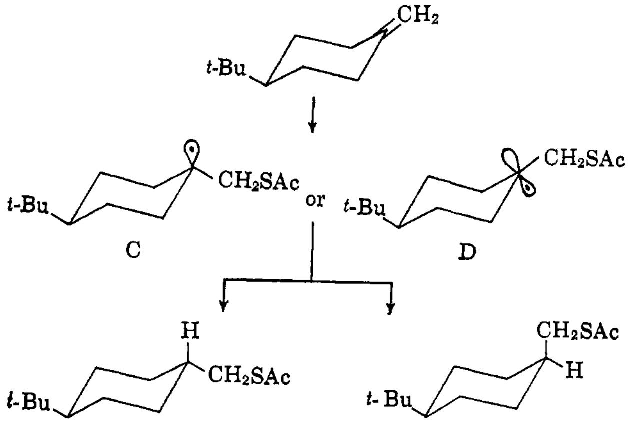
[4] Extension of this investigation to other 1-alkylcyclohexenes indicated that the *trans/cis* ratio changed but little when R = Me, Et, *i*-Pr, or *t*-Bu. Addition to 3-*t*-butylcyclohexene gave *trans*- and *cis*-3-*t*-butylcyclohexyl thiolacetates in a 4 : 1 ratio. Addition to 4-*t*-butylcyclohexene gave these same two products in about the same ratio plus a mixture of *cis*- and *trans*-4-*t*-butylcyclohexyl thiolacetates in which the *cis* isomer is believed to predominate. Structure assignments were made principally on the basis of g.l.p.c. retention times and must be considered tentative. Details are given in ref. 1.

position. Further information on this point was obtained by investigating the addition of thiolacetic acid to 4-*t*-butyl-, 2-methyl-, and 3-methyl-1-methylenecyclohexanes. Assignment of structures to the thiolacetates was made by hydrolysis to the thiol, followed by desulfurization. The relative amounts of *cis*- and *trans*-dialkylcyclohexanes formed in the desulfurization were determined by g.l.p.c. analysis, using known mixtures as standards. The relative amounts of isomers revealed by this analysis agreed well with the relative amounts suggested by g.l.p.c. analysis of the thiolacetate mixtures. For example, g.l.p.c. analysis of the adduct from 4-*t*-butyl-1-methylenecyclohexane and thiolacetic acid indicated the presence of two isomeric thiolacetates in amounts of 92 and 8%. Hydrolysis to the thiols and desulfurization gave a mixture of 94% *trans*- and 6% *cis*-4-*t*-butyl-1-methylcyclohexanes. The additions to 2-methyl-1-methylenecyclohexane and 3-methyl-1-methylenecyclohexane proceeded in a comparable manner in that in each instance the major product was the one formed by abstraction of the hydrogen atom into an axial position. A similar steric result has been observed recently for abstraction of a chlorine atom.[5]



3 (92%) 4 (8%)

Although the methyl radical and certain other radicals have been shown to be planar,[6] it is not easy to rationalize the present result in terms of a planar radical. One would expect a planar radical to be attacked from the less hindered side, but in the case of hydrogen atom abstraction from AcSH this would lead to the placing of the hydrogen atom in an equatorial position. For example, intermediate D should give rise primarily to **4**, not **3**. An explanation for preferential abstraction of a chlorine atom into an axial position by a planar cyclohexyl radical has recently been advanced.[7] According to this hypothesis electron delocalization involving the axial protons "will result in an asymmetric distribution of charge such that the electron-rich chlorine atom (from ROCl) should attack on the side opposite to the axial protons." It would seem, however, that according to this line of reasoning the relatively electron-poor hydrogen atom (from AcSH) should approach from the side of the axial protons (which is also the least hindered side). But this would lead to the wrong stereochemistry. For this reason we prefer to use a representation showing the radical as pyramidal.

Experimental Section[8]

Addition of Thiolacetic Acid and Analysis of Thiolacetate Mixtures.—Thiolacetic acid (practical grade) was distilled under vacuum in a nitrogen atmosphere prior to use. Most additions were carried out by adding a 10% molar excess of thiolacetic acid to the alkene (with stirring or shaking) as rapidly as the volatility of the alkene and the capacity of the reflux condenser permitted. Irradiation was usually with a Hanovia Type 16200 ultraviolet source. After 30 to 60 min. the reaction mixture was either subjected directly to vacuum distillation or was distilled after washing with aqueous bicarbonate.

Most of the thiolacetate mixtures were well resolved by use of an 8 ft. × 0.25 in. copper column (column A) packed with 8% Dow-Corning Silicone Oil 550 on 60-mesh Chromosorb P. Analyses using this column were carried out on an F and M 300 chromatographic unit using helium as the carrier gas. A comparable column 15 ft. in length (column B) was used for more difficult separations. Areas of peaks were determined from the width at half-height. In most instances the analyses are judged to be accurate to ±2%. In establishing identity by g.l.p.c. analysis, comparisons were made both by retention times and by simultaneous injection of a standard with the mixture to observe peak enhancement.

Additions to 1-Methylcyclohexene.—1-Methylcyclohexene, obtained by the method of Arnold, Smith, and Dodson,[9] was analyzed by g.l.p.c. analysis on a 6-ft. silver nitrate on triethylene glycol column, and found to consist of 96% of the desired olefin and 4% of methylenecyclohexane.

G.l.p.c. analysis of the thiolacetic acid adduct revealed two peaks in a ratio of 17 : 83 accounting for about 95% of the thiolacetates, and a peak at considerably longer residence time identified by direct comparison as arising from cyclohexylmethyl thiolacetate. An authentic sample of the latter was prepared from 1-methylenecyclohexane[10] and thiolacetic acid.

In experiments carried out under conditions where the temperature of the reaction was moderated by the use of suitable cooling baths, the following ratios of major peaks were recorded: 99°, 20:80; 80°, 22:78; 30°, 20:80; 0°, 16:84; −30°, 9:91; and −70°, 11:89. Similar experiments were also carried out at all of these temperatures, except 30°, in which a 20:1 ratio of a diluent such as hexane was used with reactants; no significant change in isomer ratio from those with no diluent was observed. These results point to a higher stereoselectivity for the reaction at lower temperatures, but the effect is not far outside experimental uncertainty.

4-*t*-Butyl-1-methylcyclohexene.—4-*t*-Butyl-1-methylcyclohexanol, prepared from 4-*t*-butylcyclohexanone and methylmagnesium iodide, was heated with iodine for 2 hr. at 200°. Water was removed; the oil remaining was dried over calcium chloride and distilled at 53° (2.5 mm.) and also 180–182° (752 mm.), $n^{20}\text{D}$ 1.4599. The yield based on ketone was better than 90%. The infrared showed a trace of carbonyl but no evidence for the *exo*-alkene. Analysis on the silver nitrate column showed only one peak.

Anal. Calcd. for $C_{11}H_{20}$: C, 86.76; H, 13.24. Found: C, 87.14; H, 13.22.

Hydrogenation of 4-*t*-Butyl-1-methylcyclohexene.—Eight grams of 4-*t*-butyl-1-methylcyclohexene was hydrogenated on a Parr apparatus using 0.14 g. of Pd–C catalyst and 15 ml. of ethanol. The residue was distilled to give 6.1 g. (73%) of an oil, b.p. 183–185°, $n^{25}\text{D}$ 1.4026. G.l.p.c. analysis showed 75% *trans*-4-*t*-butyl-1-methylcyclohexane and 23% of the *cis* isomer. (Hydrogenation carried out with platinum in acetic acid gave a 63 : 37 ratio of *trans* to *cis*.)

Anal. Calcd. for $C_{11}H_{22}$: C, 85.63; H, 14.37. Found: C, 86.05; H, 14.04.

***cis*- and *trans*-5-*t*-Butyl-2-methylcyclohexyl Thiolacetates.**—A mixture of 15.2 g. (0.1 mole) of 4-*t*-butyl-1-methylcyclohexene and 7.6 g. (0.1 mole) of thiolacetic acid (practical grade) was

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[5] F. D. Greene, C. Chu, and J. Walia, *J. Am. Chem. Soc.*, **84**, 2463 (1962).

[6] H. M. McConnell and R. W. Fessenden, *J. Chem. Phys.*, **31**, 1688 (1959).

[7] M. C. R. Symons, *Nature*, **198**, 1196 (1963).

[8] Microanalyses were by Miss Hilda Beck.

[9] R. T. Arnold, G. G. Smith, and R. M. Dodson, *J. Org. Chem.*, **15**, 1256 (1950).

[10] Kindly furnished by Robert L. Arnold.

stirred rapidly for 3 hr. at 40–55° while being irradiated with a 100-w. lamp. Distillation gave a forerun of 9.3 g., b.p. 48–92° (1.2 mm.), and 8.9 g. (39%) of thiol esters, b.p. 92–93° (0.9 mm.).

Anal. Calcd. for $C_{13}H_{24}OS$: C, 68.36; H, 10.58. Found: C, 68.25; H, 10.38.

The forerun was largely recovered olefin, since subsequent additions with thiolacetic acid of higher purity—and 10% molar excess—pushed the yield as high as 83%: 11.4 g. of acid and 22.8 g. of olefin gave 28 g. of thiolacetates, b.p. 123° (3 mm.), $n^{25}D$ 1.4897. Analysis of this mixture on column A at 200° revealed two peaks 21 : 79 in order of emergence.

5-*t*-Butyl-2-methylcyclohexanethiol.—To 27 g. (0.12 mole) of 5-*t*-butyl-2-methylcyclohexyl thiolacetate in 20 ml. of ethanol was added a cooled solution of 20 g. of potassium hydroxide in 60 ml. of 50% water–ethanol. The mixture was heated for 1 hr. under nitrogen atmosphere (to minimize disulfide formation); 40 ml. of acetic acid was added and the thiols were extracted with hexane and distilled. Foaming was minimized with Dow Antifoam; 16.2 g. (70% yield) of thiol mixture was obtained, b.p. 81–83° (2 mm.), $n^{20}D$ 1.4848.

The fractionation of 13.7 g. of the mixture on a Nester–Faust 3-ft. whirling-band column afforded 1.0 g. of lower boiling fraction, b.p. 53–54° (0.65 mm.), $n^{20}D$ 1.4828; 0.4 g. of a between fraction; and 12.3 g. boiling at 55–56° (0.63 mm.), $n^{20}D$ 1.4850.

Anal. Calcd. for $C_{11}H_{22}S$: C, 70.89; H, 11.90; S, 17.20. Found (lower boiling thiol): C, 71.09; H, 11.78. Found (higher boiling thiol): C, 71.25; H, 11.83; S, 17.10.

***trans*-5-*t*-Butyl-*cis*-2-methylcyclohexyl benzyl sulfone** was obtained from the higher boiling thiol as a white solid melting at 127–128° after crystallization from ethanol.

Anal. Calcd. for $C_{13}H_{29}O_2S$: C, 70.08; H, 9.15. Found: C, 70.33; H, 9.12.

***cis*-5-*t*-Butyl-*trans*-2-methylcyclohexyl benzyl sulfone**, m.p. 87–91°, was obtained from the lower boiling thiol. Recrystallization from hexane gave material melting at 93–94°.

Anal. Calcd. for $C_{18}H_{24}O_2S$: C, 70.08; H, 9.15. Found: C, 69.81; H, 9.19.

Separation of Mixed 5-*t*-Butyl-2-methylcyclohexyl Benzyl Sulfones.—From 1.9 g. of unfractionated 5-*t*-butyl-2-methylcyclohexanethiol mixture, 1.5 g. of crude sulfone melting 119–125° was prepared. Silica gel chromatography on a column 50 × 2 cm. with 7% ether in hexane separated the mixture into two parts. Fourteen liters of solvent was required (fractions of 500 ml.). The first 17 fractions contained a solid melting at 123–125° and weighing 1.09 g. and the last six fractions melted between 78 and 92° and weighed 0.31 g. Recrystallizing successively from ethanol and twice with hexane gave materials melting at 132.0–133.0° and 94.0–99.0°. The ratio of isomers determined in this way was about 4 : 1.

Isomerization of *trans*-5-*t*-Butyl-*cis*-2-methylcyclohexyl Benzyl Sulfone.—A solution of 0.13 g. of the sulfone, m.p. 132–133°, dissolved in 15 ml. of propanol containing 0.4 g. of sodium propoxide was refluxed on the steam bath overnight. Upon acidification a solid was recovered which melted at 96–98° after two recrystallizations from hexane. The infrared spectrum of this sulfone was identical with that of *cis*-5-*t*-butyl-*trans*-2-methylcyclohexyl benzyl sulfone.

Desulfurization of Mixed 5-*t*-Butyl-2-methylcyclohexanethiol.—Triethyl phosphite (16.6 g., 0.1 mole) and 9.3 g. (0.05 mole) of mixed thiols were allowed to stand in sunlight for 7 hr.[11] Upon distillation 16 g. of material boiling at 167–185° was collected; this was percolated through a silica gel column with pentane eluent. Pentane solvent was removed and 5.2 g. of product was collected by distillation at 184–185°, $n^{25}D$ 1.4027. G.l.p.c. analysis on a 20-ft. tricresyl phosphate column showed that the material was at least 95% one product, and identical with the major product of the hydrogenated 4-*t*-butyl-1-methylcyclohexene.[12] It was, therefore, *trans*-4-*t*-butyl-1-methylcyclohexane. This result was confirmed in a desulfurization by Raney nickel which showed 95.6% of the *trans* isomer.

1,4-Dimethylcyclohexene.—1,4-Dimethylcyclohexanol was prepared from 4-methylcyclohexanone and dehydrated with iodine. G.l.p.c. analysis on a silver nitrate on triethylene glycol column showed two peaks, 8 and 92%. The first peak was assumed to be 4-methyl-1-methylenecyclohexane.

2,5-Dimethylcyclohexyl Thiolacetate.—The adduct of 1,4-dimethylcyclohexene and thiolacetic acid was formed in 67% yield and distilled at 81–88° (0.6 mm.), $n^{25}D$ 1.4865. G.l.p.c. analysis on column A at 190° showed three peaks: two major peaks (20:80 ratio) were obtained together with a trailing peak (4% of the total) which was assigned to (4-methylcyclohexyl)-methyl thiolacetate. Another g.l.p.c. analysis was carried out on this material by Dr. A. W. Weitkamp[13] on an Apiezon grease column, which showed four peaks: 15.4:76.4:3.2:5.0. The ratio of the major peaks was thus 17:83.

Anal. Calcd. for $C_{10}H_{18}SO$: C, 64.46; H, 9.74. Found: C, 63.99; H, 9.66.

2,5-Dimethylcyclohexanethiol.—Hydrolysis of 12.5 g. of mixed thiolacetates was carried out, and distillation gave 60 g. of 2,5-dimethylcyclohexanethiol (71% yield), b.p. 57° (2.2 mm.), $n^{25}D$ 1.4813. Chromatographic analysis[13] of this thiol mixture revealed four peaks: 22:71.3:4.5:2.2. The ratio of the two major isomers was again 23.5:76.5. The smaller amounts either represent (4-methylcyclohexyl)methanethiol or 2,5-dimethylcyclohexanethiols in which the methyl groups are axial.

Anal. Calcd. for $C_8H_{16}S$: C, 66.59; H, 11.18. Found: C, 67.19; H, 11.09.

Desulfurization of 2,5-Dimethylcyclohexanethiol.—The thiol mixture was treated with triethyl phosphite and distilled. A cut of 3.6 g. (70% yield) was made between 120 and 130°, $n^{25}D$ 1.4190. A sample of 1,4-dimethylcyclohexane from hydrogenation of the alkene containing 70% *trans*-1,4-dimethylcyclohexane had a boiling point of 120–124°, $n^{25}D$ 1.4275. Chromatographic comparison over a tricresyl phosphate column at 100° showed that the desulfurized material contained only 5–7% of the higher boiling *cis*-1,4-dimethylcyclohexane.[13]

Preparation of Substituted Methylenecyclohexanes.—Preparation of 2-methyl-, 3-methyl-, and 4-*t*-butyl-1-methylenecyclohexanes was accomplished by the reaction of triphenylphosphinemethylene[14] on the suitable cyclohexanone. The physical properties are summarized in Table I.

TABLE I
PHYSICAL PROPERTIES OF METHYLENECYCLOHEXANES

Methylenecyclohexane	n_D (°C.)	Lit. n_D (°C.)
4-*t*-Butyl-	1.4592 (27)	1.4604 (25)[a]
3-Methyl-	1.4450 (25)	1.4461 (20)[b]
2-Methyl-	1.4490 (25)	1.4514 (25)[c]

[a] S. Siegel and B. Dmuchovsky, *J. Am. Chem. Soc.*, **84**, 3132 (1962). [b] O. Wallach, *Ann.*, **347**, 337 (1906). [c] G. S. Hammond and T. D. Nevitt, *J. Am. Chem. Soc.*, **76**, 4121 (1954).

The synthetic samples of 4-*t*-butyl- and 3-methyl-1-methylenecyclohexanes exhibited strong infrared bands in the 885–890-cm.$^{-1}$ region which were absent in 4-*t*-butyl-1-methyl- and 1,3-dimethylcyclohexenes. Mixtures of these *endo* and *exo* isomers were in each instance incompletely resolved by column B. However, g.l.p.c. analysis on column B cleanly resolved a mixture of 2-methyl-1-methylenecyclohexane, 2,3-dimethylcyclohexene, and 1,2-dimethylcyclohexene, the isomers appearing in that order. The synthetic sample of 2-methyl-1-methylenecyclohexane gave a single sharp peak under comparable conditions.

Thiolacetates of Methylenecyclohexanes, Their Hydrolysis and Desulfurization.—In a typical experiment, 3 ml. of thiolacetic acid was added to about 2 g. of alkene and shaken 15 min. in a quartz tube before an ultraviolet source. After it was treated to remove excess thiolacetic acid, the sample was analyzed by g.l.p.c. on column B at 190 or 220°. Structures were assigned to peaks in these analyses by hydrolysis of the thiolacetate mixtures in warm base and ethanol (followed by neutralization) to form thiols, which were desulfurized by treating with equimolar amounts of triethyl phosphite[11] for 0.5 hr. (with radiation).

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[11] F. W. Hoffman, R. J. Ess, T. C. Simmons, and R. S. Hanzel, *J. Am. Chem. Soc.*, **78**, 6414 (1956).

[12] J. F. Sauvage, R. H. Baker, and A. S. Hussey, *ibid.*, **82**, 6094 (1960).

[13] We are grateful to Dr. A. W. Weitkamp, Standard Oil of Indiana (now American Oil Co.), Research Division, Whiting, Ind., for checking this result.

[14] G. Wittig and W. Haag, *Chem. Ber.*, **88**, 1654 (1955).

TABLE II

ANALYSIS OF THIOLACETATE ADDUCTS BY DESULFURIZATION

Methylene-cyclohexene	Thiolacetate adducts	Alkane from desulfurization, *trans* to *cis*	Alkene hydrogenated	*trans* to *cis*	Lit.
2-Methyl-	73:27	74:26	1,2- and 2,3-Dimethylcyclohexene	27:73	70–80% *cis*[a]
3-Methyl-	17:83	15:85	1,3-Dimethylcyclohexene	26:74	70–80% *cis*[a]
4-*t*-Butyl-	91:9	88:12	4-*t*-Butyl-1-methylcyclohexene	63:37	37% *cis*[b]

[a] See ref. 12. [b] See ref. 14.

Washing with water removed excess phosphite. The dried hydrocarbon mixtures were compared chromatographically to authentic sample mixtures of known composition (column B at 100°) prepared by hydrogenation of the corresponding cyclohexenes over platinum in acetic acid. The chromatographic columns employed failed to separate the mixtures of thiols. The results are summarized in Table II.

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Solvent Effects in the Base-Catalyzed Oxidation of Ketones to Mono- and Dicarboxylic Acids

THOMAS J. WALLACE, HARVEY POBINER, AND ALAN SCHRIESHEIM

Esso Research and Engineering Company, Process Research Division, Exploratory Research Section, Linden, New Jersey

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The base-catalyzed autoxidation of acetophenone and C_5 to C_{12} cyclic aliphatic ketones was studied in hexamethylphosphoramide (HMPA) at 23.5 and 80°. The cyclic ketones were autoxidized to their corresponding dibasic acids in moderate to excellent yields in the presence of either potassium or sodium hydroxide. Evidence is presented which indicates that the choice of solvent for these reactions is a critical factor. The ease of oxidation with respect to the solvent was HMPA $>$ *t*-butyl alcohol $>>>$ water. Potassium and sodium hydroxide were equally effective catalysts but lithium hydroxide was extremely poor. Structural variations indicated that the ketone containing the most acidic α-carbon–hydrogen bonds was most readily oxidized. These facts are consistent with a carbanion oxidation, and a mechanistic path involving formation of an unstable peroxy anion intermediate has been postulated. Results were obtained which indicate that the selectivity to acidic products can be controlled by the use of an HMPA–water mixture as the solvent medium.

The ability of alkali to accelerate the oxidation of ketones by molecular oxygen was first reported in the literature many years ago for ketones containing highly acidic α-carbon–hydrogen bonds.[1-5] The base-catalyzed acceleration of the autoxidation of cyclic aliphatic ketones was initially reported by Harries[6,7] who found that carvone, an α,β-unsaturated ketone, was autoxidized to a 1,3-diketone in the presence of hydroxide ion. The mechanism of the alkaline autoxidation of cyclic, α,β-unsaturated ketones was subsequently studied in great detail by Treibs[8] who suggested that an unstable peroxide intermediate is initially formed and then decomposes to yield condensation products and hydrogen peroxide. The hydrogen peroxide subsequently reacts with the unsaturated ketone to form an epoxide which is unstable to base and decomposes to the observed products. Rigaudy[9] has found that certain enolizable ketones, such as 9-benzoylfluorene, do not oxidize under neutral conditions but in the presence of alkali a rapid reaction occurs which leads to the formation of scission products. The autoxidation of a variety of ketones under strongly alkaline conditions has been studied by Doering and Haines,[10] who used potassium *t*-butoxide in *t*-butyl alcohol and an oxygen pressure of 2 atm., and by Elkik,[11] who employed sodium *t*-pentoxide in benzene at room temperature as the reaction medium. Many reactions were exothermic and gave acidic products resulting from attack at the position α to the carbonyl group. However, Doering found that, even with the fairly basic system that he employed, certain structural limitations existed for these reactions. Cyclic aliphatic ketones such as cyclohexanone gave mainly tars and not the expected cleavage products.

From the above discussion, two fairly general conclusions can be made. First, the use of alkali metal hydroxides as catalysts for these reactions is limited to ketones having fairly acidic α-carbon–hydrogen bonds, *e.g.*, $PhCH_2COPh$. Second, the base-catalyzed oxidation of cyclic aliphatic ketones to dicarboxylic acids does not proceed readily even in the presence of a strong base. Based on our previous studies on solvent effects in the anionic oxidation of sulfur compounds[12] it was felt that these limitations with respect to base and ketone could be overcome by the proper choice of solvent, *i.e.*, a solvent that was dipolar,

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(1) W. Miller and Rohde, *Ber.*, **25**, 2095 (1892).

(2) A. H. Salway and E. S. Kipping, *J. Chem. Soc.*, **95**, 166 (1909).

(3) V. Bogdanowska, *Ber.*, **25**, 1271 (1892).

(4) C. Graebe and E. Gfeller, *Ann.*, **276**, 12 (1893).

(5) C. Graebe and J. Jequier, *ibid.*, **290**, 199 (1896).

(6) C. Harries, *Ber.*, **34**, 2105 (1901).

(7) C. Harries and A. Stähler, *Ann.*, **330**, 264 (1904).

(8) (a) W. Treibs, *Ber.*, **63**, 2423 (1930); (b) *ibid.*, **64**, 2178 (1931); (c) *ibid.*, **65**, 163 (1932); (d) *ibid.*, **66**, 1483 (1933); (e) *ibid.*, **64**, 2545 (1931); (f) *ibid.*, **66**, 610 (1933); (g) *ibid.*, **65**, 1314 (1932); (h) *ibid.*, **68**, 1049 (1935).

(9) J. Rigaudy, *Compt. rend.*, **228**, 253 (1949).

(10) W. v. E. Doering and R. M. Haines, *J. Am. Chem. Soc.*, **76**, 482 (1954).

(11) E. Elkik, *Bull. soc. chim. France*, 933 (1959).

(12) (a) T. J. Wallace and A. Schriesheim, *Tetrahedron Letters*, **No. 17**, 1131 (1963), and references therein; (b) T. J. Wallace, H. Pobiner, and A. Schriesheim, *J. Org. Chem.*, **29**, 888 (1964); (c) T. J. Wallace, N. Jacobson, and A. Schriesheim, *Nature*, **201**, 609 (1964); (d) T. J. Wallace and A. Schriesheim, *Tetrahedron*, to be published.