Anal. Calcd. for $C_9H_{19}NO_3S$: C, 48.84; H, 8.66; N, 6.33; S, 14.49. Found: C, 48.65; H, 8.58; N, 6.20; S, 14.38.

The infrared spectrum showed $\lambda_{\max}^{CHCl_3}$ 2.74 (m), 3.37 (s), 6.82 (m), 7.50 (s), 7.84 (m), 8.46 (s), 8.72 (s), 9.40 (m), 10.10 (s), and 10.35 (m) μ. The n.m.r. spectrum ($CDCl_3$) showed multiplets centered at τ 8.40 (ten protons), a singlet at 7.10 (six protons), a singlet at 6.93 (two protons), and a singlet at 6.50 (one proton).

Dimethylaminosulfonylmethyl Cyclohexyl Ketone. Lithium dimethylaminosulfonyl carbanion was prepared under nitrogen in 50 ml. of dry tetrahydrofuran from 7.4 g. (0.06 mole) of N,N-dimethylmethanesulfonamide and 0.06 mole of *n*-butyllithium in hexane (38 ml.). The mixture was cooled in an ice bath during the addition, with stirring, of 4.68 g. (0.03 mole) of ethyl cyclohexanecarboxylate in 10 ml. of dry tetrahydrofuran. The ice bath was removed and after 30 min. most of the tetrahydrofuran was removed at the water aspirator. The residue was diluted with 75 ml. of water and acidified with dilute hydrochloric acid to pH 3–4 (pH paper); the white precipitate of the β-ketosulfonamide V was filtered, washed with water, and dried (6.75 g., 96.6%). A sample was recrystallized from ethyl acetate to give colorless needles, m.p. 94°.

Anal. Calcd. for $C_{10}H_{19}NO_3S$: C, 51.48; H, 8.21; N, 6.00; S, 13.74. Found: C, 51.44; H, 8.27; N, 5.96; S, 13.67.

The infrared spectrum showed $\lambda_{\max}^{CHCl_3}$ 3.45 (s), 5.87 (s), 6.93 (m), 7.46 (s), 8.66 (s), and 10.28 (s) μ. The n.m.r. spectrum ($CDCl_3$) showed multiplets in the region τ 8.0–8.9 (ten protons), a multiplet centered at 7.3 (one proton), a singlet at 7.12 (six protons), and a singlet at 5.98 (two protons).

Acknowledgment. We thank the National Institutes of Health for support of this research both in the form of postdoctoral fellowships (to M. C.) and a research grant.

Dimethyloxosulfonium Methylide ($(CH_3)_2SOCH_2$) and Dimethylsulfonium Methylide ($(CH_3)_2SCH_2$). Formation and Application to Organic Synthesis

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Contribution from the Converse Laboratory of Harvard University, Cambridge, Massachusetts 02138. *Received October 16, 1964*

The generation of dimethyloxosulfonium methylide (II) and dimethylsulfonium methylide (XIII) as reactive intermediates is described. Both ylides are nucleophiles and both function to transfer methylene to certain electrophilic unsaturated linkages, including C=O, C=N, C=S, and in certain cases C=C. The less reactive oxosulfonium ylide interacts with the carbonyl function of aromatic and nonconjugated aldehydes and ketones to form oxiranes and with α,β-unsaturated ketones which are Michael receptors to form cyclopropyl ketones. The sulfonium ylide reacts with the same substrates to give oxiranes exclusively even with the α,β-unsaturated carbonyl systems. These reactions are quite general and, therefore, of considerable practical value. The stereochemistry of carbonyl addition to cyclohexanones varies depending on the ylide; the oxosulfonium ylide reacts by equatorial addition (i.e., of methylene) and the sulfonium ylide shows a preference for axial addition. A number of other reactions of these ylides are described including "over-all methylene insertion," and a differential comparison of their chemical properties is made.

This investigation originated from the idea that a moderately stable ylide (II) might result from deprotonation of the recently discovered[1,2] trimethyloxosulfonium[3] ion (I) and that this ylide might possess useful chemical properties. In particular, the reaction of the ylide II with carbonyl compounds, especially ketones, was of interest in connection with certain synthetic problems being studied in these laboratories and other investigations of carbanions stabilized by sulfur-containing functions. It was considered that II might function in a manner comparable to diazomethane, for example, to convert cyclic ketones to homo analogs by ring expansion or oxiranes by methylene transfer. Alternatively II might react in the manner of "Wittig" reagents. From the facile exchange of hydrogen in I with hydroxylic media[4,5] and from the similarity of

$$\underset{\text{I}}{(CH_3)_3\overset{+}{S}O\,X^-} \qquad \underset{\text{II}}{(CH_3)_2\overset{\delta^+}{S}O\overset{\delta^-}{C}H_2} \qquad \underset{\text{III}}{(CH_3)_2\overset{+}{S}OCH_2Y}$$

certain of the molecular orbitals of II with those of the highly stable sulfone function, the possibility of generating the ylide II, at least as a transient, metastable reagent, seemed good. In the first section of this article the details of our study of the generation and

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(1) R. T. Major and H. J. Hess, *J. Org. Chem.*, **23**, 1563 (1958).

(2) R. Kuhn and H. Trischmann, *Ann.*, **611**, 117 (1958).

(3) In this paper the compounds having the functional group of type $R_1R_2R_3\overset{+}{S}O$ as in I will be referred to as oxosulfonium derivatives rather than sulfoxonium[1,2] derivatives. The former term seems preferable, especially in view of possible confusion of the word sulfoxonium with the related word sulfonium for compounds of the type $R_1R_2R_3S^+$, which are also discussed in this paper.

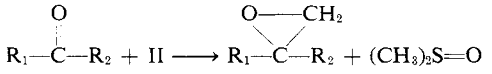
(4) S. G. Smith and S. Winstein, *Tetrahedron*, **3**, 317 (1958).

(5) F. A. Cotton, J. H. Fassnacht, W. D. Horrocks, Jr., and N. A. Nelson, *J. Chem. Soc.*, 4138 (1959).

chemistry of II are described.[6] This work led to further investigations of the related sulfonium ylide class as reactive and useful species in synthesis, and this work is considered in the following section.[7] Finally, a differential comparison of these ylides is presented.

Chemistry of Dimethyloxosulfonium Methylide. The reaction of trimethyloxosulfonium chloride or iodide in dry dimethyl sulfoxide with sodium hydride (under nitrogen) proceeds rapidly with hydrogen evolution to give the ylide II and sodium halide. The ylide can also be produced in tetrahydrofuran or dioxane solution using sodium hydride and trimethyloxosulfonium chloride. The chloride of I has sufficient solubility in tetrahydrofuran and dioxane to interact with the insoluble sodium hydride.[8] Furthermore, the sodium chloride produced is insoluble and can be removed by filtration. Solutions of the ylide II in tetrahydrofuran are stable for several months if kept under an inert atmosphere (dry nitrogen or argon) at 0° and the concentration of ylide is easily determined by titration with standard acid in water. At room temperature decomposition becomes appreciable after about a week. The nuclear magnetic resonance (n.m.r.) spectrum of the ylide in dioxane supports the formulation II since two peaks appear at τ 6.86 and 8.30 with a relative intensity of 3:1. The ylide reacts as a nucleophile with boron trifluoride and carbon dioxide to give zwitterionic 1:1 adducts III, Y = BF_3^- and COO^-. These experiments on the generation of dimethyloxosulfonium methylide represent the first synthesis of a sulfur-functional ylide derived from a nonstabilized carbanion.

One of the most striking properties of II is its reactivity toward ketones and aldehydes which in many instances takes the form

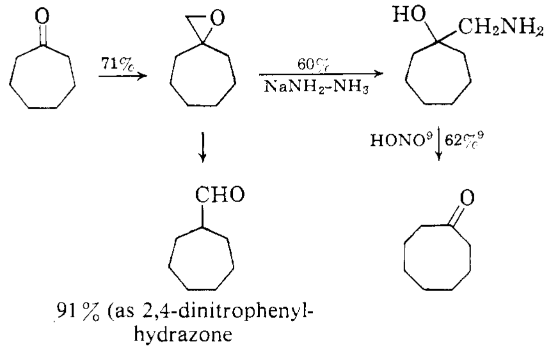


$$R_1-\overset{\overset{O}{\|}}{C}-R_2 + II \longrightarrow R_1-\overset{O-CH_2}{C}-R_2 + (CH_3)_2S{=}O$$

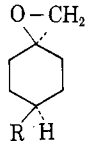
Epoxides have been produced by this process from benzophenone (90%), cycloheptanone (71%), and benzaldehyde (56%). Most of these reactions were carried out with a small excess of II at 25° for 1 hr., then an additional hour at 50°. Certain ketones appear resistant to the transformation, in particular desoxybenzoin and Δ^4-cholestenone, probably as a consequence of an enhanced tendency to form enolate ions by proton transfer to II. Thus, the predominant mode of reaction of the ylide II with nonconjugated aldehydes and ketones is neither the carbonyl addition–carbon rearrangement process as exemplified by the ketone–diazoalkane transformations, nor the methylene–oxygen exchange with olefin formation as exemplified by the Wittig olefin synthesis.

The oxiranes which are available from ketones by reaction with II are in many instances useful synthetic intermediates. For example, in the case of cycloheptanone, routes to cycloheptanecarboxaldehyde and cyclooctanone have been developed (see Scheme I).

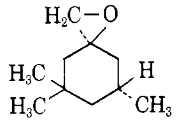
Scheme I



The stereochemistry of addition of the ylide II to ketones is a matter of considerable interest. The reaction of II with 4-*t*-butylcyclohexanone is stereospecific and produces the oxirane IV, (R = *t*-Bu) in *ca.* 90% yield. Reduction of the oxirane affords *trans*-4-*t*-butyl-1-methylcyclohexanol free of the *cis* isomer. 4-Phenylcyclohexanone behaves similarly with II and



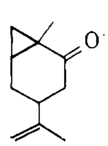
IV



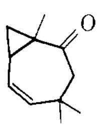
V

only the oxirane IV (R = C_6H_5) is formed. The assignment of stereochemistry is based upon analysis of the tertiary alcohol(s) produced by reduction with lithium aluminum hydride (see Experimental). Transfer of methylene from II to 3,3,5-trimethylcyclohexanone is also stereospecific since only the oxirane V results. Reduction of V with lithium aluminum hydride afforded the same alcohol which is formed from 3,3,5-trimethylcyclohexanone with methyllithium. It is evident that methylene transfer from the ylide II to the above cyclohexanones occurs selectively in such a way that the newly formed carbon–carbon linkage is equatorial. It is reasonable to expect that this tendency will be general, although the degree of stereospecificity may not always be as high as for the cases reported here.[10]

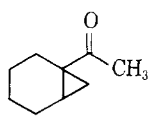
The reaction of 1 equiv. of dimethyloxosulfonium methylide with α,β-unsaturated ketones (which are susceptible to Michael addition) results in selective methylene transfer to the α,β-carbon–carbon double bond to form cyclopropyl ketones rather than addition to the carbonyl group. Thus, benzalacetophenone reacts with II to form 1-phenyl-2-benzoylcyclopropane in 95% yield (as a mixture of *cis* and *trans* isomers). Carvone, eucarvone, and 1-acetylcyclohexene are converted efficiently by II into the cyclopropyl ketones VI, VII, and VIII, respectively. These structures are indicated by spectroscopic and chemical data. It is



VI



VII



VIII

noteworthy that the product from eucarvone (VII) involves methylene transfer to the α,β- rather than the

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(6) For a preliminary discussion, see E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, **84**, 867 (1962).

(7) Preliminary results were given in E. J. Corey and M. Chaykovsky, *ibid.*, **84**, 3782 (1962); *Tetrahedron Letters*, **No. 4**, 169 (1963).

(8) See the Experimental part for an improved preparation of the chloride of I.

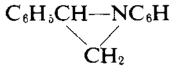
(9) F. F. Blicke, J. Azura, N. J. Doorenbos, and E. B. Hotelling, *J. Am. Chem. Soc.*, **75**, 5418 (1953).

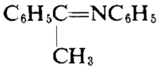
(10) For a review of the stereochemistry of addition of various carbon nucleophiles to cyclohexanones, see A. V. Kamernitzky and A. A. Akhrem, *Tetrahedron*, **18**, 705 (1962).

γ,δ-double bond. This selectivity may be due partly to a shielding effect of the *gem*-dimethyl groups which inhibits attack at C_δ. The hydrogenation of the eucarvone adduct VII with palladium–charcoal in methanol affords a mixture of 2,2,6,6-tetramethylcycloheptanone and 3,3,8-trimethylcyclooctanone (ratio 3:1) and the sequence methylene transfer–hydrogenation represents still another kind of ring expansion.

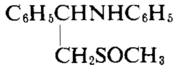
The reaction of the ylide II with reactive carboxylic acid derivatives, *e.g.*, esters and acid chlorides, is discussed in another paper on stable oxosulfonium ylides.[11] However, it should be noted here that either Michael addition or carbonyl attack or both can occur in the reactions of II with α,β-unsaturated carboxylic acid derivatives. In the case of α,β-unsaturated acid chlorides (or other "activated" carboxylic acid derivatives) carbonyl attack can be expected to predominate. Methylene transfer to the α,β-double bond is more favorable with amides, *e.g.*, dimethylamides, however.[12] The methyl or ethyl esters of carboxylic acids show intermediate behavior and three types of products may result: (1) cyclic ylides from attack at C_β followed by intramolecular carbonyl addition, (2) cyclopropyl esters, or (3) α,β-unsaturated ketooxosulfonium ylides.[11] The last reaction course is relatively unimportant with these esters but assumes greater weight with "activated esters."[11]

Methylene transfer has also been observed between the oxosulfonium ylide II and the thiono function. Thus, thiobenzophenone was converted in good yield to 1,1-diphenylthiirane. The ylide II attacks the C=N bond of benzalaniline to give in this instance three products: 1,2-diphenylaziridine (IX, 44%), acetophenone anil (X, 22%), and the aminosulfoxide XI (19%).[13] The constitution of the last product follows from its identity with the compound XI prepared by the addition of methylsulfinylcarbanion to benzalaniline. (Although it had been isolated and identified from the initial experiment, the formation of XI was not included in our preliminary note[14] which was primarily concerned with a comparison of methylene transfer from sulfonium and oxosulfonium ylides to benzalaniline.) The formation of IX, X, and XI can be rationalized on the basis of an intermediate formed by attachment of the ylide II to the electrophilic carbon of benzalaniline. The process which leads to acetophenone anil is especially interesting, and possible routes are indicated by XIIa and b. Formally similar reactions have been described recently for certain aromatic compounds which are susceptible to nucleophilic attack at the ring by two groups.[15,16] For example, nitrobenzene is transformed by the oxosulfonium ylide II into a mixture of *o*-nitrotoluene (major product) and *p*-nitrotoluene.[15,16]

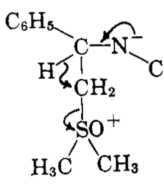

IX


$C_6H_5\underset{CH_3}{C}{=}NC_6H_5$

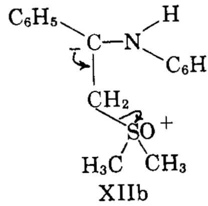
X


$C_6H_5\underset{CH_2SOCH_3}{CH}NHC_6H_5$

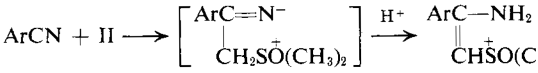
XI


XIIa

or


XIIb

The reaction of dimethyloxosulfonium methylide with aromatic nitriles proceeds by nucleophilic addition followed by prototropic rearrangement (dimethyl sulfoxide is not eliminated[17]).


$$ArCN + II \longrightarrow \left[\underset{CH_2\overset{+}{S}O(CH_3)_2}{ArC{=}N^-}\right] \xrightarrow{H^+} \underset{CH\overset{+}{S}O(CH_3)_2}{ArC\text{—}NH_2}$$

Chemistry of Dimethylsulfonium Methylide. As the synthetic utility of dimethyloxosulfonium methylide became apparent, a study of the related dimethylsulfonium methylide (XIII) seemed indicated and was undertaken despite indications that sulfonium ylides derived from nonstabilized carbanions are subject to rapid spontaneous decomposition.[18] It seemed likely to us that under the proper circumstances the sulfonium ylide XIII could be generated as a reactive intermediate and applied in synthesis. At the time of our work, knowledge of sulfonium ylides was restricted to the classical preparation of dimethylsulfonium fluorenylide,[19] a stabilized, isolable ylide, and the study of its reaction with nitrosobenzene and benzaldehydes.[20,21] The products obtained from the interaction of the fluorenylide with the various substituted benzaldehydes included oxiranes, olefins corresponding to a Wittig-type process, and rearranged hydroxy sulfides.[21]

Solutions of dimethylsulfonium methylide[14] were prepared successfully by addition of a solution of trimethylsulfonium iodide with stirring to a solution of methylsulfinyl carbanion in equivalent amount under nitrogen, as was the case with the oxosulfonium ylide II except that it was necessary to conduct the reaction at lower temperatures (0 to −10° in dimethyl sulfoxide containing enough tetrahydrofuran to prevent freezing) because of the marked thermal instability of XIII. In contrast to the oxosulfonium ylide II which can be stored in tetrahydrofuran solution (under nitrogen) for several days at 25° without appreciable decomposition, the sulfonium ylide XIII decomposes with a half-life of a few minutes at room temperature with formation of ethylene (see Experimental). At 0° or below, the stability of XIII is much greater, and since the process of ylide formation appears to be instantaneous, it is possible to conduct subsequent reactions without significant loss of the reagent by the immediate addition of the appropriate substrate with continued cooling.

The ylide XIII reacts with a wide variety of aldehydes and ketones by over-all methylene transfer to form oxiranes, a process observed previously in many

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(11) E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, **86**, 1640 (1964).

(12) See P. T. Izzo, *J. Org. Chem.*, **28**, 1713 (1963), for an example of this type of process.

(13) Similar results have been obtained by H. Metzger and K. Seelert, *Z. Naturforsch.*, **18b**, 335 (1963). These workers also report methylene transfer to benzaldazine, *ibid.*, **18b**, 336 (1963).

(14) E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, **84**, 3782 (1962).

(15) H. Metzger, H. Konig, and K. Seelert, *Tetrahedron Letters*, No. **15**, 867 (1964).

(16) V. J. Traynelis and J. V. McSweeney, Abstracts, 148th National Meeting of the American Chemical Society, Sept. 1964, p. 12S.

(17) H. Konig and H. Metzger, *Z. Naturforsch.*, **18b**, 976 (1963).

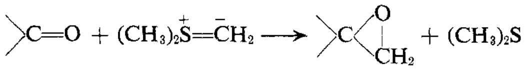
(18) *Cf.* V. Franzen, H.-J. Schmidt, and C. Mertz, *Ber.*, **94**, 2942 (1961).

(19) C. K. Ingold and J. A. Jessop, *J. Chem. Soc.*, 713 (1930).

(20) For a summary, see A. W. Johnson and R. B. LaCount, *J. Am. Chem. Soc.*, **83**, 417 (1961).

(21) S. Trippett, *Quart. Rev.* (London), **17**, 406 (1963).

instances with the oxosulfonium ylide II. After a standard reaction time of 10 min. at 0° and 30–60 min. for warming to room temperature, the carbonyl compounds studied were consumed completely using 1.1 to 1.2 equiv. of ylide. Thus several compounds were converted to the corresponding oxiranes by selective addition of methylene to the carbonyl group: benzophenone (84% yield), benzaldehyde (75%), cycloheptanone (97%), carvone (89%), eucarvone (93%), benzalacetophenone (87%), and pulegone (90%). The only case studied in which the ketone–epoxide conversion was not observed with XIII was desoxybenzoin (enolate formation).


XIII

It should be noted here that the oxosulfonium ylide II and the sulfonium ylide XIII differ with respect to the mode of reaction with α,β-unsaturated ketones; the former reagent produces cyclopropyl ketones as indicated in the previous section for the cases of carvone, eucarvone, and benzalacetophenone.[22]

The oxosulfonium ylide II and the sulfonium ylide XIII also manifest major differences in the stereochemistry of addition to the ketonic function in rings. The principal manner of addition of XIII to 4-*t*-butylcyclohexanone is that which yields the oxirane with *cis-t*-butyl and oxirane methylene groups (ratio of *cis* to *trans* 83:17). The preference for axial methylene transfer, also noted for 4-phenylcyclohexanone, persists even with 3,3,5-trimethylcyclohexanone (ratio of axial CH_2 to equatorial CH_2, 55:45), though not as strongly because of the strong adverse steric effect of the axial 3-methyl group. The differences between the ylides II and XIII (compare previous sections) in the cases studied indicated that the two ylides are complimentary in stereoselective synthesis.[23]

Dimethylsulfonium methylide (XIII) reacts smoothly with benzalaniline to give the aziridine IX in 91% yield[14]; this transformation is not complicated by the side reactions which attend the corresponding reaction of the oxosulfonium ylide II (see preceeding section). A number of other examples of methylene transfer from XIII to the imino group have been reported by Franzen and Driessen.[22]

As expected from relative stabilities of II and XIII and from data on rates of base-catalyzed hydrogen–deuterium exchange for the corresponding conjugate acids,[24,25] the sulfonium ylide is a far more powerful methylene transfer agent than the oxosulfonium ylide. Thus, the reaction of 5 equiv. of XIII with 1,1-diphenylethylene effects 60% conversion to 1,1-diphenylcyclopropane, whereas there is no methylene transfer from II under the same conditions. Neither ylide reacts with tolane or *trans*-stilbene.[14] In our opinion formation of 1,1-diphenylcyclopropane from the ylide XIII and 1,1-diphenylethylene is probably a direct methylene-transfer reaction rather than a reaction of free methylene with the olefin. Free methylene would not be expected to show the specificity which has been observed.

In independent studies, Johnson and Hruby have reported the preparation of diphenylsulfonium benzylide and its reaction with acenapthylene to form a cyclopropane derivative.[26]

More recent papers both from Johnson's laboratory and ours deal with the transfer of substituted methylenes from unstable ylides to carbonyl groups.[27,28] The conditions which are used for the generation of alkyl-substituted ylides are far more critical than for the unsubstituted dimethylsulfonium methylide; low temperatures (−70 to −50°) must be used[27,28] and for good results a strong, bulkyl base, *e.g.*, *t*-butyllithium[28] or lithium diethylamide,[28] must be employed. With care, high yields of oxiranes can be obtained from many carbonyl compounds with the substituted ylides.[28]

Contrasts between Dimethyloxosulfonium and Dimethylsulfonium Methylides. At this point a synopsis of the outstanding differences in chemical behavior of the oxosulfonium ylide II and the sulfonium ylide XIII may be helpful. First of all the former is much more stable than the latter against spontaneous thermal decomposition in inert media. The oxosulfonium ylide is also a less reactive nucleophile, as shown, for example, for the test case of 1,1-diphenylethylene in which XII reacts but II does not. Neither ylide will transfer methylene to a normal nonconjugated carbon–carbon double bond.

Whereas the oxosulfonium ylide tends to attack the α,β-double bond of α,β-unsaturated carbonyl compounds, the sulfonium ylide prefers addition to the carbonyl group, at least for α,β-unsaturated ketones.

In methylene-transfer reactions with cyclohexanones, the oxosulfonium ylide II strongly tends to form an equatorial carbon–carbon bond, but the sulfonium ylide preferentially give an axial carbon–carbon bond.

In methylene-transfer reactions with imines the sulfonium ylide reacts much more cleanly than the oxosulfonium ylide; the latter frequently yields considerable amounts of methylene "insertion" product (*cf.* X from benzalaniline).

Other differences between the ylides II and XIII may well be uncovered by further research. One is tempted to believe that differences in the detailed reaction mechanisms for the two ylides may also emerge, but a consideration of this possibility should await the acquisition of mechanistically relevant knowledge.

The outstanding mechanistic questions at present would seem to be the following: (1) the problem of reaction intermediates, for example, zwitterionic adducts such as $R_2CO^--CH_2SO^+(CH_3)_2$ or charge-transfer

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(22) The reaction of dimethylsulfonium methylide with carbonyl compounds has also been studied by V. Franzen and H. E. Driessen, *Chem. Ber.*, **96**, 1881 (1963). Some of the preliminary results reported by these authors which appeared after the submission of our note on dimethylsulfonium methylide[14] [see V. Franzen and H. E. Driessen, *Tetrahedron Letters*, **No. 15**, 661 (1962)] were incorrect in that formation of cyclopropyl ketones rather than oxiranes were reported for α,β-unsaturated ketones. For a correction see E. J. Corey and M. Chaykovsky, *ibid.*, **No. 4**, 169 (1963), later confirmed by Dr. Franzen (personal communication, June 1963).

(23) For a recent application of dimethylsulfonium methylide to the synthesis of the natural product helminthosporal, see E. J. Corey and S. Nozoe, *J. Am. Chem. Soc.*, **85**, 3527 (1963).

(24) S. G. Smith and S. Winstein, *Tetrahedron*, **3**, 317 (1958).

(25) W. von E. Doering and A. H. Hoffman, *J. Am. Chem. Soc.*, **77**, 521 (1955).

(26) V. J. Hruby and A. W. Johnson, *ibid.*, **84**, 3586 (1962). These workers have interpreted their results as indicating a carbene intermediate, but it is clear that direct transfer of phenylcarbene is a possibility.

(27) A. W. Johnson, V. J. Hruby, and J. L. Williams, *ibid.*, **86**, 918 (1964).

(28) E. J. Corey and W. Oppolzer, *ibid.*, **86**, 1900 (1964).

complexes such as $[R_2C{=}O]^- [CH_2S(CH_3)_2]^+$ (this includes the problem of whether the two reagents produce different intermediates); (2) the problem of reversibility of the initial interaction between reagent and substrate; (3) the definition of circumstances under which a direct and concerted methylene transfer is possible (without any intermediates); and (4) the question of other modes for ylide decomposition including bimolecular decomposition to form olefin or dissociation to form carbenes. At present these elements of the mechanistic problem can be recognized and one can regard their resolution as a useful, though by no means simply attainable, goal.

Experimental[29]

Trimethyloxosulfonium Iodide. The procedure of Kuhn and Trischmann[2] was followed. A solution of 96 g. (1.23 moles) of dimethyl sulfoxide and 180 ml. of methyl iodide was refluxed under nitrogen for 3 days, during which time a solid precipitated. The solid was filtered off, washed with chloroform, dried, and found to weigh 145 g. (53.6%). Recrystallization from water gave large colorless prisms which were crushed and dried in a vacuum desiccator over phosphorus pentoxide.

Trimethyloxosulfonium Chloride.[1,2] Trimethyloxosulfonium iodide (30 g., 0.136 mole) was dissolved in 300 ml. of distilled water by stirring and heating to 50°. Chlorine gas was bubbled into the solution until no more iodine precipitated. The mixture was cooled, the aqueous portion decanted from the iodine, and the iodine washed with two 50-ml. portions of distilled water. The combined aqueous solutions were washed with ether until colorless and then evaporated at the water pump to leave a white crystalline residue. The residue was dissolved in 45 ml. of hot methanol, 45 ml. of benzene added, and the solution allowed to cool to room temperature and then placed in a refrigerator. Filtration yielded 12 g. of chloride as colorless needles. The filtrate was diluted with 100 ml. of benzene and cooled in a refrigerator to yield another 2 g. of colorless needles. The total yield was 80%. The chloride was dried under vacuum at 85° for 5 hr. before use and had m.p. 220–222° dec.

Dimethyloxosulfonium Methylide. General Method of Preparation in Dimethyl Sulfoxide. A weighed amount of sodium hydride (50% mineral oil dispersion) was placed in a three-necked, round-bottomed flask and washed three times with light petroleum ether, by swirling and decanting the liquid portion, in order to remove the mineral oil. The flask was immediately fitted with a mechanical stirrer, a reflux condenser, and a rubber stopple through which reagents were introduced *via* hypodermic syringe (a pressure-compensated dropping funnel may also be used). A three-way stopcock, connected to the top of the reflux condenser, was connected to a water aspirator and a source of dry nitrogen. The system was evacuated until the last traces of petroleum ether were removed from the sodium hydride, the vacuum broken, and 1 equiv. of powered trimethyloxosulfonium iodide or chloride introduced through one of the side arms of the flask. The system was placed under nitrogen by evacuating and filling with nitrogen several times. The aspirator hose was removed and this arm of the stopcock was connected to a mercury-sealed U-tube to which the system was opened. Dimethyl sulfoxide (distilled from calcium hydride, b.p. 64° (4 mm.)) was introduced slowly *via* hypodermic syringe or dropping funnel, the stirrer was started, and a vigorous evolution of hydrogen ensued, which ceased after 15–20 min. to give a milky-white reaction mixture.

Preparation of Dimethyloxosulfonium Methylide in Tetrahydrofuran. Sodium hydride (0.32 mole) as a 50% mineral oil dispersion (Metal Hydrides, Inc.) was placed in a 1-l., three-necked, round-bottomed reaction vessel and washed three times with 100-ml. portions of petroleum ether (b.p. 40–60°) by swirling, allowing the hydride to settle, and decanting, in order to remove the mineral oil. The flask was immediately fitted with a sealed mechanical stirrer, reflux condenser, and a glass stopper, and evacuated to remove the last traces of petroleum ether. The vacuum was broken, 38.4 g. (0.30 mole) of trimethyloxosulfonium chloride and 500 ml. of dry tetrahydrofuran (distilled from lithium aluminum hydride) were introduced, and the system was placed under nitrogen. With stirring, the mixture was heated to reflux. The evolution of hydrogen gas was fairly rapid at first, but after several minutes it ceased. After 2–3 hr., rapid hydrogen evolution again began and after 3–4 hr. the reaction was finished as was evidenced by lack of hydrogen evolution and a milky-white suspension of finely divided sodium chloride. The mixture was cooled and filtered with suction (preerably in a drybox) through a large Büchner funnel containing a matting of filter paper and dried Celite filter-aid, directly into a storage flask. The flask was sealed with rubber stopples and placed under nitrogen; the solution can be stored at 0° or below for several weeks without appreciable decomposition of the ylide. Before use, samples of the solution may be withdrawn *via* hypodermic syringe, added to distilled water, and titrated with standard hydrochloric acid to the phenolphthalein end point to determine the exact concentration of ylide (equivalent ratio 1:1). A hypodermic syringe may be used to withdraw samples for use in reactions. Solutions of the ylide have been prepared in dioxane by the same method.

Nuclear Magnetic Resonance Spectrum of Dimethyloxosulfonium Methylide. A solution of 0.03 mole of the ylide in 40 ml. of dioxane was concentrated under vacuum to a volume of about 8 ml. and placed under nitrogen. A sample was withdrawn *via* hypodermic syringe and placed in an n.m.r. tube under nitrogen with tetramethylsilane as standard. In addition to dioxane peaks at 6.4, the spectrum showed the ylide methyl hydrogens as a sharp peak at τ 6.86 and the methylene hydrogens as a broader peak at τ 8.30 (integral ratio 3:1).

A solution of the ylide in dioxane was evaporated under vacuum, to leave the ylide as an almost colorless oil. An attempt was made to dissolve the ylide in deuteriochloroform at room temperature in order to measure the n.m.r. spectrum in that solvent, but a violent reaction took place producing a black tar.

Reaction of Dimethyloxosulfonium Methylide with

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(29) Melting points are corrected; boiling points are uncorrected. N.m.r. spectra were obtained with a Varian A-60 spectrometer using tetramethylsilane as internal standard. Microanalyses were performed by the Scandinavian Microanalytical Laboratories, Herlev, Denmark.

Benzophenone. A solution of the ylide was prepared under nitrogen from 0.03 mole of sodium hydride, 6.6 g. (0.03 mole) of trimethyloxosulfonium iodide, and 30 ml. of dimethyl sulfoxide. A solution of 4.55 g. (0.025 mole) of benzophenone in 10 ml. of dimethyl sulfoxide was added with stirring and the reaction mixture heated to 50° for 1 hr. After cooling and adding 60 ml. of water, the mixture was extracted with ether, and the combined extracts were washed twice with water, dried over anhydrous sodium sulfate, and evaporated to yield 4.4 g. (89.9%) of 1,1-diphenylethylene oxide as a white crystalline solid, m.p. 52–56°. The infrared spectrum showed no carbonyl absorption. Recrystallization from absolute ethanol afforded white crystals, m.p. 55–56° (lit.[30] m.p. 56°). The n.m.r. spectrum ($CDCl_3$) showed signals at τ 2.64 (ten protons) and 6.88 (two protons).

Reaction of Dimethyloxosulfonium Methylide with Benzaldehyde. The ylide was prepared by refluxing a mixture of 0.04 mole of sodium hydride, 5.12 g. (0.04 mole) of trimethyloxosulfonium chloride, and 30 ml. of dry tetrahydrofuran under nitrogen until the evolution of hydrogen ceased (2 hr.). With the reaction mixture held at 55°, a solution of 3.18 g. (0.03 mole) of benzaldehyde in 30 ml. of dry tetrahydrofuran was slowly added dropwise with stirring over a period of 1.5 hr. and the reaction mixture then stirred at 55° for an additional hour. The mixture was concentrated under reduced pressure (water aspirator) to a volume of about 10 ml., 50 ml. of water added, and the mixture extracted with pentane (some resinous material remained in the aqueous phase). The combined pentane extracts were dried over anhydrous sodium sulfate and evaporated; the pale yellow residue was evaporatively distilled at 80° (5.0 mm.) to yield 2.0 g. (55.6%) of colorless styrene oxide, whose infrared spectrum was identical with that of an authentic sample.

Reaction of Dimethyloxosulfonium Methylide with 4-Phenylcyclohexanone. A solution of the ylide was prepared under nitrogen from 0.012 mole of sodium hydride, 2.64 g. (0.012 mole) of trimethyloxosulfonium iodide, and 20 ml. of dimethyl sulfoxide. A solution of 1.74 g. (0.01 mole) of 4-phenylcyclohexanone in 5 ml. of dimethyl sulfoxide was added with stirring and the reaction mixture stirred at room temperature for 15 min. and then at 50° for 1 hr. After cooling and adding 30 ml. of water, the mixture was extracted with ether, and the combined extracts were washed twice with water, dried over anhydrous sodium sulfate, and evaporated; the residue was evaporatively distilled at 75° (0.03 mm.) to yield 1.35 g. (71.7%) of the oxide as a colorless liquid. After standing for several days the oxide crystallized, m.p. 30–32°.

Anal. Calcd. for $C_{13}H_{16}O$: C, 82.94; H, 8.57. Found: C, 83.16; H, 8.66.

The infrared spectrum showed λ_{max}^{neat} 3.28 (w), 3.39 (s), 6.24 (w), 6.69 (m), 6.95 (m), 10.13 (m), and 10.88 (s) μ. The n.m.r. spectrum (neat) showed multiplets centered at τ 8.78 and 8.17 (nine protons), a singlet at 7.50 (two protons), and a peak at 2.70 (five protons).

Reaction of Dimethyloxosulfonium Methylide with Cycloheptanone. A solution of the ylide was prepared under nitrogen from 0.30 mole of sodium hydride, 66 g. (0.30 mole) of trimethyloxosulfonium iodide, and 200 ml. of dimethyl sulfoxide. Cycloheptanone (22.4 g., 0.2 mole) was added dropwise at room temperature, with stirring, over a period of 20 min. and stirring was continued at room temperature for 18 hr. and then at 50° for 1 hr. After cooling, the reaction mixture was poured into 400 ml. of cold water and the product extracted with seven 100-ml. portions of ether. The combined extracts were washed once with 50 ml. of water, dried over anhydrous sodium sulfate, and evaporated; the yellow residue was distilled at reduced pressure to yield 17.9 g. (71.1%) of colorless methylenecycloheptane oxide, b.p. 63° (14 mm.).

Anal. Calcd. for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 76.05; H, 11.17.

The infrared spectrum showed λ_{max}^{neat} 3.35 (s), 3.45 (m), 6.85 (m), 9.95 (w), 10.55 (w), and 11.25 (w) μ. The n.m.r. spectrum (neat) showed signals at τ 8.38 (twelve protons) and 7.57 (two protons).

Rearrangement of Methylenecycloheptane Oxide with Boron Trifluoride Etherate. To a stirred solution of 1.0 g. (7.93 mmoles) of the oxide in 25 ml. of dry ether, cooled in an ice bath, was added 0.5 ml. of boron trifluoride etherate. After removing the ice bath and stirring for 15 min., the solution was diluted with 50 ml. of ether, washed twice with 5-ml. portions of 10% aqueous sodium bicarbonate, and evaporated. The liquid residue, 1.98 g. (0.01 mole) of 2,4-dinitrophenylhydrazine, and 4 ml. of concentrated hydrochloric acid were dissolved in 60 ml. of 95% ethanol and heated on a steam bath for 5 min. After cooling in a refrigerator, the crystalline precipitate was filtered off to give 2.2 g. (90.5%) of crude cycloheptanecarboxaldehyde 2,4-dinitrophenylhydrazone, m.p. 125–131°. Two recrystallizations from 95% ethanol gave long orange-yellow needles, m.p. 134.5–135.5° (lit.[31] m.p. 134.5–135.5°).

1-Methylaminocycloheptanol. A mixture of 2.0 g. (0.0159 mole) of methylenecycloheptane oxide, 3.12 g. (0.08 mole) of powdered sodium amide, 40 ml. of liquid ammonia, and 5 ml. of dry ether was placed in a stainless steel Kunzel bomb and allowed to stand at room temperature for 24 hr. The bomb was opened, 10 ml. of water added dropwise, and the residual ammonia allowed to evaporate. The aqueous mixture was extracted with ether, and the combined extracts were washed once with water and once with saturated salt solution, dried over anhydrous sodium sulfate, and evaporated to yield 2.1 g. of a yellow liquid. Rapid evaporative distillation at 80° (0.2 mm.) gave 1.37 g. (60%) of the aminohydrin as a colorless liquid. The hydrochloride (from isopropyl alcohol–ether) had m.p. 220–221° (lit.[32] m.p. 217–218°, 223°[33]).

Reaction of Dimethyloxosulfonium Methylide with Benzalacetophenone. A solution of the ylide was prepared under nitrogen from 0.032 mole of sodium hydride, 7.05 g. (0.032 mole) of trimethyloxosulfonium iodide, and 35 ml. of dimethyl sulfoxide. The reaction mixture was cooled in a cold water bath (*ca.* 10°) and a solution of 6.24 g. (0.03 mole) of benzalacetophenone in 15 ml. of dimethyl sulfoxide was added

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[30] A. Klages and J. Kessler, *Chem. Ber.*, **39**, 1753 (1906).

[31] A. C. Cope, N. A. Nelson, and D. S. Smith, *J. Am. Chem. Soc.*, **76**, 1100 (1954).

[32] F. F. Blicke, J. Azura, N. J. Doorenbos, and E. B. Hotteling, *ibid.*, **75**, 5418 (1953).

[33] B. Tchoubar, *Bull. soc. chim. France*, **16**, 160 (1949).

rapidly with stirring. After 5 min. the water bath was removed and stirring continued at room temperature for 2 hr. and at 50° for 1 hr. The reaction mixture was poured into 100 ml. of cold water and the aqueous mixture extracted with ether; the combined extracts were washed twice with water and once with saturated salt solution, dried over anhydrous sodium sulfate, and evaporated to yield 6.7 g. of a pale yellow oil which solidified after standing at room temperature for a few hours. The solid was chromatographed on 75 g. of Merck alumina using 15% benzene in pentane as the eluent. The first fraction, which was not further investigated, contained about 50 mg. of colorless oil which showed only weak carbonyl absorption in its infrared spectrum. Seven additional fractions contained almost colorless oils whose infrared spectra were identical and which showed intense carbonyl absorption at 5.98 μ. The combined oils (6.3 g., 94.6%) solidified, after standing in a refrigerator, to a white crystalline solid, m.p. 35–41°, identified as 1-benzoyl-2-phenylcyclopropane. A sample recrystallized twice from petroleum ether (b.p. 66–75°) gave colorless needles, m.p. 45.5–50°, and probably was a mixture of isomers (lit.[34] m.p. 32–34°).

Anal. Calcd. for $C_{16}H_{14}O$: C, 86.46; H, 6.35. Found: C, 86.39; H, 6.45.

The infrared spectrum showed $\lambda_{max}^{CHCl_3}$ 3.25 (m), 5.98 (s), 6.22 (m), 6.3 (m), 9.65 (s), 9.72 (s), 9.92 (m), and 10.1 (s) μ. The ultraviolet spectrum showed $\lambda_{max}^{n\text{-hexane}}$ 242 mμ (ϵ 18,200). The n.m.r. spectrum ($CDCl_3$) showed three multiplets in the regions τ 7.0–7.5, 8.0–8.3, and 8.4–8.8 in the integral ratio 2:1:1. Multiplet phenyl peaks occurred in the regions τ 2.0–2.3 and 2.6–3.1.

Attempted Reaction of Dimethyloxosulfonium Methylide with Deoxybenzoin. A solution of the ylide was prepared under nitrogen from 0.020 mole of sodium hydride, 4.4 g. (0.020 mole) of trimethyloxosulfonium iodide, and 20 ml. of dimethyl sulfoxide. A solution of 2.94 g. (0.015 mole) of deoxybenzoin in 7 ml. of dimethyl sulfoxide was added with stirring and the reaction mixture stirred at room temperature for 2 hr. and at 50° for 1 hr. After cooling and adding 50 ml. of water, the mixture was extracted with ether and the combined extracts were washed once with water, dried over anhydrous sodium sulfate, and evaporated to yield 2.78 g. (94.5% recovery) of a pale yellow oil whose infrared spectrum was identical with that of desoxybenzoin.

Attempted Reaction of Dimethyloxosulfonium Methylide with Δ^4-Cholesten-3-one. The ylide was generated by refluxing a mixture of 9.15 mmoles of sodium hydride, 1.17 g. (9.15 mmoles) of trimethyloxosulfonium chloride, and 20 ml. of dry tetrahydrofuran until hydrogen evolution ceased (2 hr.). A solution of 1.73 g. (4.5 mmoles) of Δ^4-cholesten-3-one in 10 ml. of dry tetrahydrofuran was added with stirring to the refluxing reaction mixture and stirring was continued at the reflux temperature for 12 hr. After cooling and adding 50 ml. of water, the mixture was extracted with ether, and the combined extracts were washed twice with water, dried over anhydrous sodium sulfate, and evaporated to yield 1.70 g. (98% recovery) of a pale yellow viscous oil which crystallized after scratching with a glass rod. The infrared spectrum of the solid was identical with that of Δ^4-cholesten-3-one.

Reaction of Dimethyloxosulfonium Methylide with Carvone. A solution of the ylide was prepared under nitrogen from 0.021 mole of sodium hydride, 4.62 g. (0.021 mole) of trimethyloxosulfonium iodide, and 25 ml. of dimethyl sulfoxide. A solution of 3.0 g. (0.02 mole) of freshly distilled carvone (b.p. 104–105° (10 mm.)) in 5 ml. of dimethyl sulfoxide was added, with stirring and slight cooling in a water bath. The reaction mixture was stirred at room temperature for 2 hr., then at 50° for 1 hr., poured into 80 ml. of cold water, and extracted with ether. The ether extracts were washed twice with water, dried over anhydrous sodium sulfate, and evaporated to leave a pale yellow liquid. Distillation gave 2.65 g. (81.3%) of the cyclopropyl ketone VI as a colorless liquid, b.p. 109–110° (10 mm.). Vapor phase chromatographic analysis (6-ft. 20% silicone rubber on Chromosorb, 225°, helium flow rate 40 ml./min. at 20 p.s.i.g.) showed the presence of only one compound (retention time 6 min., 15 sec.).

Anal. Calcd. for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.25; H, 9.78.

The infrared spectrum showed λ_{max}^{neat} 3.38 (m), 5.90 (s), 6.06 (m), 6.84 (m), 7.27 (m), 7.50 (m), 8.90 (m), and 11.18 (m) μ. The n.m.r. spectrum (neat) showed a multiplet centered at τ 9.2 (one proton), a sharp methyl singlet at 8.85 (three protons), and a sharp methyl singlet at 8.32 with less intense overlapping multiplets at 7.40–8.75 (total of ten protons), and a singlet at 5.30 (two protons).

Reaction of Dimethyloxosulfonium Methylide with Eucarvone. Under the same conditions described above, 0.021 mole of the ylide and 3.0 g. (0.02 mole) of eucarvone gave 2.9 g. (88.4%) of the cyclopropyl ketone VII as a colorless liquid, b.p. 89–90° (10 mm.), which was shown to be homogeneous by vapor phase chromatographic analysis.

Anal. Calcd. for $C_{11}H_{16}O$: C, 80.43; H, 9.82. Found: C, 80.38; H, 9.86.

The infrared spectrum showed λ_{max}^{neat} 3.31 (s), 5.92 (s), 6.84 (m), 7.23 (m), 7.31 (m), 7.40 (m), 7.68 (m), 8.00 (w), 8.25 (w), 8.52 (m), 8.72 (w), 9.05 (m), 9.39 (m), 10.98 (m), and 11.60 (m) μ. The ultraviolet spectrum showed $\lambda_{max}^{95\%\ alc}$ 207 and 272 mμ (ϵ 3710 and 266). The n.m.r. spectrum (neat) showed three sharp singlets at τ 9.10, 8.98, and 8.82 (three protons each), multiplets at 7.92–8.70 (four protons), peaks at 7.33 and 7.13 (one proton), and multiplets at 4.14–4.78 (two protons).

Hydrogenation of the Cyclopropyl Ketone VII. A mixture of 534 mg. (3.26 mmoles) of the ketone, 150 mg. of 10% palladium-on-carbon catalyst (saturated with hydrogen before the ketone was introduced), and 10 ml. of methanol was hydrogenated with stirring at room temperature under hydrogen at atmospheric pressure. The hydrogen uptake ceased after 75 min. when slightly over 2 equiv. had been absorbed. The mixture was filtered, the filtrate evaporated, and the residue evaporatively distilled at 100° (10 mm.) to yield 470 mg. (86%) of colorless liquid. Vapor phase chromatographic analysis (6-ft. 20% silicone rubber, 200°, helium flow rate 44 ml./min. at 20 p.s.i.g.) showed the presence of two compounds (retention times 6 min., 55

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(34) R. J. Mohrbacher and N. H. Cromwell, *J. Am. Chem. Soc.*, 79, 401 (1957).

sec. and 9 min., 12 sec.) in the ratio 3:1. The compounds were shown to be 2,2,6,6-tetramethylcycloheptanone and 3,3,8-trimethylcyclooctanone, respectively, by the following physical data obtained from v.p.c. collected samples.

Anal. Calcd. for $C_{11}H_{20}O$ (2,2,6,6-tetramethylcycloheptanone): C, 78.51; H, 11.98. Found: C, 78.57; H, 12.10.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{CCl_4}}$ 3.32 (s), 5.88 (s), 6.45 (m), 6.84 (s), 7.23 (m), 7.32 (m), 7.48 (w), 7.65 (w), 7.78 (w), 8.10 (m), 8.28 (m), 8.42 (m), and 9.35 (s) μ. The n.m.r. spectrum (CCl_4) showed the geminal dimethyl groups as two sharp singlets at τ 9.10 and 9.00 (six protons each), a multiplet at 8.2–8.65 (six protons), and a peak at 7.68 (two protons).

Anal. Calcd. for $C_{11}H_{20}O$ (3,3,8-trimethylcyclooctanone): C, 78.51; H, 11.98. Found: C, 78.70; H, 11.99.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{CCl_4}}$ 3.32 (s), 5.88 (s), 6.45 (m), 6.80 (s), 6.91 (m), 7.20 (w), 7.31 (m), 8.15 (m), 8.31 (m), 8.58 (m), 8.98 (m), 9.25 (w), 9.50 (w), and 9.90 (m) μ. The n.m.r. spectrum (CCl_4) showed the geminal dimethyl group as a sharp singlet at τ 9.03, a methyl doublet with peaks at 9.08 and 8.96 (J = 7.5 c.p.s.) (nine protons total integration), multiplets at 8.1–8.9, and a sharp peak at 7.83 with less intense overlapping multiplets (eleven protons total integration).

Reaction of Dimethyloxosulfonium Methylide with Thiobenzophenone. A solution of 10.5 mmoles of the ylide in 20 ml. of tetrahydrofuran was added dropwise, with stirring, under nitrogen to a solution of 1.98 g. (10 mmoles) of thiobenzophenone[35] in 20 ml. of dry tetrahydrofuran, cooled in an ice bath, over a period of 5 min. Toward the end of the addition, the blue color of the thiobenzophenone was discharged and the solution became pale yellow. After stirring for 10 min. with the ice bath removed, the solvent was evaporated at room temperature with a water aspirator; the residue was dissolved in 50 ml. of pentane, washed with water, dried over anhydrous sodium sulfate, and concentrated under vacuum at room temperature to a volume of about 20 ml. Cooling the solution in a Dry Ice–acetone bath caused the product to crystallize. The mixture was warmed slightly and the pentane decanted from the crystals. Recrystallization twice, in the same manner, and filtering gave 1.5 g. (70.7%) of 1,1-diphenylethylene episulfide as a white crystalline solid, m.p. 39–42°. The compound decomposed slowly at room temperature and rapidly upon heating into 1,1-diphenylethylene and sulfur. The analytical sample was prepared by recrystallizing a sample several times from pentane in the same manner, drying under vacuum at room temperature for 30 min., and having the white crystals analyzed immediately.

Anal. Calcd. for $C_{14}H_{12}S$: C, 79.20; H, 5.70; S, 15.10. Found: C, 78.86; H, 5.85; S, 15.41.

The n.m.r. spectrum (CCl_4) showed a singlet at τ 7.19 (two protons) and multiplets centered at 3.05 (ten protons).

Reaction of Dimethyloxosulfonium Methylide with Benzalaniline. A solution of the ylide was prepared under nitrogen from 0.03 mole of sodium hydride, 6.6 g. (0.03 mole) of trimethyloxosulfonium iodide, and 30 ml. of dimethyl sulfoxide. With stirring, a solution of 5.06 g. (0.028 mole) of benzalaniline in 10 ml. of dimethyl sulfoxide was added at room temperature over a period of 3 min. After stirring at room temperature for 1 hr. and then at 60° for 2 hr., the mixture was poured into 150 ml. of cold water and extracted with 75 ml. of pentane. After the extraction, white crystals began separating from the aqueous phase. Cooling in an ice bath and filtering gave 1.4 g. (19.3%) of the sulfoxide XI, m.p. 160–177°. Recrystallization from ethyl acetate gave colorless needles, m.p. 180–184°. The infrared spectrum was identical with that of the product obtained from the reaction of methylsulfinyl carbanion with benzalaniline.

The pentane extracts were washed twice with water, dried over anhydrous potassium carbonate, and evaporated to yield 3.6 g. (66%) of a yellow oil which was shown by its n.m.r. spectrum to be a mixture of 1,2-diphenylaziridine (IX) and acetophenone anil (X), in the ratio 2:1. A sample of the oil was dissolved in 95% alcohol and cooled in a cold room to −15° for several days. The precipitated acetophenone anil was filtered and recrystallized again from the same solvent to give pale yellow crystals, m.p. 38–39.5° (lit.[36] m.p. 41°). The infrared and n.m.r. spectra were identical with those of authentic sample.[37]

Reaction of Dimethyloxosulfonium Methylide with 1-Acetylcyclohexene. A solution of the ylide was prepared under nitrogen from 0.053 mole of sodium hydride, 11.7 g. (0.053 mole) of trimethyloxosulfonium iodide, and 50 ml. of dimethyl sulfoxide. With stirring, 6.2 g. (0.05 mole) of 1-acetylcyclohexene was added with slight external cooling of the reaction flask. After stirring at room temperature for 3 hr., the mixture was poured into 150 ml. of cold water and extracted with ether; the extracts were washed twice with water, dried over anhydrous sodium sulfate, and evaporated to leave an almost colorless liquid. Distillation gave 3.7 g. (53.6%) of colorless liquid, b.p. 78–85° (9 mm.). Vapor phase chromatographic analysis (8 ft., 10% fluorosilicone on Chromosorb, 175°, helium flow rate 50 ml./min. at 20 p.s.i.g.) showed the presence of two components (retention times 9 min. and 10 min., 24 sec.) in the ratio 1:9. Samples were collected and the major component found to be the cyclopropyl ketone VIII.

Anal. Calcd. for $C_9H_{14}O$: C, 78.22; H, 10.21. Found: C, 78.05; H, 10.15.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{CCl_4}}$ 3.40 (m), 5.80 (s), 6.87 (w), 7.21 (w), 7.39 (w), 7.66 (w), 7.82 (w), 7.96 (w), 8.04 (w), and 8.53 (m) μ. The n.m.r. spectrum (CCl_4) showed a multiplet centered at τ 9.40 (one proton), multiplets at 8.08–8.92 (nine protons), a sharp peak at 8.05 (three protons), and multiplets at 7.3–7.75 (one proton).

The structure of the minor product is not known with certainty but is probably the aldehyde formed by rearrangement of the epoxide resulting from methylene transfer to the carbonyl of 1-acetylcyclohexene. The infrared spectrum (CCl_4) showed carbonyl absorption at 5.75 and the characteristic aldehyde carbon–hydrogen stretching peak at 3.69 μ. The n.m.r. spectrum (CCl_4) showed a doublet with peaks at τ 9.04 and 8.92 with

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(35) "Organic Syntheses," Coll. Vol. IV, John Wiley and Sons, Inc., New York, N. Y., 1963, 927.

(36) L. Claisen, *Chem. Ber.*, **29**, 2931 (1896).

(37) G. Reddelien, *Ann.*, **388**, 165 (1912).

overlapping multiplets at 7.5–8.9, an olefinic hydrogen multiplet at 4.62, and a doublet with peaks at 0.10 and 0.25.

Reaction of Dimethyloxosulfonium Methylide with Carbon Dioxide. A solution of 0.03 mole of dimethyloxosulfonium methylide in 75 ml. of tetrahydrofuran was placed in a 250-ml. round-bottomed flask fitted with a gas-inlet tube which extended to the bottom of the flask, and an outlet tube connected to a mercury-sealed U-tube. Dry carbon dioxide was bubbled through the solution until the exothermic reaction had subsided and the flask began to cool (*ca.* 20 min.). The precipitated white solid was filtered, washed with dry tetrahydrofuran, and dried under vacuum over phosphorus pentoxide. The dried 1:1 adduct (III, Y = CO_2) weighed 3.8 g. (93%) and had m.p. 135–137°. The product was extremely hygroscopic.

The infrared spectrum showed $\lambda_{\max}^{\text{Kaydol}}$ 6.05 (m), 6.64 (s), 8.09 (s), 8.72 (s), 9.38 (m), 9.60 (m), 10.0 (w), and 10.25 (w) μ.

Reaction of Dimethyloxosulfonium Methylide with Boron Trifluoride. A solution of 0.01 mole of the ylide in 30 ml. of tetrahydrofuran was placed in a 100-ml. round-bottomed flask under nitrogen. Boron trifluoride gas was introduced through an inlet tube extending below the surface of the solution until no more solid precipitated. The mixture was cooled and filtered; the solid was washed with dry tetrahydrofuran and dried to give 1.50 g. (93.7%) of the 1:1 adduct (III, Y = BF_3) as a white crystalline solid. Recrystallization from ethanol–water gave colorless flat prisms, m.p. 245–270°.

Anal. Calcd. for $BC_3F_3H_8OS$: C, 22.52; H, 5.04; S, 20.04 Found: C, 22.03; H, 5.16; S, 20.65.

The infrared spectrum showed $\lambda_{\max}^{\text{Kaydol}}$ 7.48 (m), 7.52 (m), 8.14 (s), 8.45 (m), 9.60 (s, broad), 10.05 (s, broad), and 10.50 (s, broad) μ.

Attempted Reactions of Dimethyloxosulfonium Methylide with Olefins. Cyclohexene and *trans*-stilbene were treated with the ylide in dimethyl sulfoxide and in tetrahydrofuran at 60–70° for several hours. In all cases only unchanged olefin was isolated.

Reaction of Dimethyloxosulfonium Methylide with 4-t-Butylcyclohexanone. A solution of 1.54 g. (10 mmoles) of 4-*t*-butylcyclohexanone in 5 ml. of dry tetrahydrofuran was added, with stirring under nitrogen, to a solution of 10.5 mmoles of the ylide in 21 ml. of tetrahydrofuran. The mixture was heated at reflux for 1 hr. followed by removal of most of the tetrahydrofuran at the water aspirator. Water (20 ml.) was added and the mixture extracted with pentane; the extracts were washed with water, dried over anhydrous sodium sulfate, and evaporated to leave 1.66 g. (98.6%) of the oxirane as a colorless oil. Evaporative distillation at 110° (13 mm.) gave IV (R = *t*-Bu), 1.5 g. (89.2%) as a colorless oil.

Anal. Calcd. for $C_{11}H_{20}O$: C, 78.51; H, 11.98. Found: C, 78.68; H, 11.98.

The infrared spectrum showed $\lambda_{\max}^{CCl_4}$ 3.32 (s), 6.80 (m), 6.95 (m), 7.20 (w), 7.34 (m), 7.60 (w), 8.20 (m), 10.15 (w), 10.90 (m), and 11.80 (w) μ. The n.m.r. spectrum (CCl_4) showed a singlet at τ 9.10 (nine protons), multiplets at 7.9–9.0 (nine protons), and a singlet at 7.57 (two protons).

Reduction of the Oxirane. A solution of 600 mg. (3.57 mmoles) of the oxirane in 5 ml. of dry ether was added dropwise to a stirred suspension of 95 mg. (2.5 mmoles) of lithium aluminum hydride in 5 ml. of dry ether. The mixture was refluxed for 1 hr., the excess hydride was destroyed with a few drops of water, and 30 ml. of 5% aqueous potassium hydroxide was then added. The mixture was extracted with ether and the extracts were washed with water, dried over anhydrous sodium sulfate, and evaporated to leave 572 mg. (94%) of *trans*-1-methyl-4-*t*-butylcyclohexanol as a white crystalline solid, m.p. 61–65°. Vapor phase chromatographic analysis of the crude product showed the presence of only one isomer. Sublimation gave the pure compound as colorless needles, m.p. 69–70°. The reported[38] melting point for the *trans* isomer (*trans*-methyl and *t*-butyl) is 70.5–71°.

Reaction of Dimethylsulfonium Methylide with 4-t-Butylcyclohexanone. A solution of *n*-butyllithium (11 mmoles) in 8 ml. of pentane was added dropwise over several minutes to a stirred suspension of 2.45 g. (12 mmoles) of powered trimethylsulfonium iodide in 30 ml. of dry tetrahydrofuran under nitrogen at 0°. After stirring for 5 min. a solution of 1.54 g. (10 mmoles) of 4-*t*-butylcyclohexanone in 5 ml. of dry tetrahydrofuran was added. Stirring was continued for 30 min. at 0° and then for 1 hr. at room temperature, followed by removal of most of the tetrahydrofuran at the water aspirator. Water (20 ml.) was added and the mixture extracted with pentane; the extracts were washed with water, dried over anhydrous sodium sulfate, and evaporated to leave 1.69 g. of colorless oil. Evaporative distillation at 120° (12 mm.) gave 1.3 g. (77.3%) of oxirane as a colorless liquid. The infrared and n.m.r. spectra indicated that the product was a mixture of isomers. A trace of unchanged ketone was also present.

Reduction. In the same manner as described above, 644 mg. (2.5 mmoles) of the oxirane mixture was reduced using 95 mg. (2.5 mmoles) of lithium aluminum hydride to yield 650 mg. (99.5%) of a mixture of alcohols as a white oily solid. Vapor phase chromatographic analysis (8 ft., 10% fluorosilicone on KOH-washed Chromosorb, 165°, helium flow rate 40 ml./min. at 20 p.s.i.g.) showed the presence of 17% *trans*-1-methyl-4-*t*-butylcyclohexanol (axial hydroxyl) and 83% of the *cis* isomer (equatorial hydroxyl) with retention times 8 min., 50 sec. and 11 min., 22 sec., respectively. A sample of the *cis* isomer was collected from the v.p.c. column and sublimed to give colorless crystals, m.p. 95–97° (lit.[38] m.p. 97.5–98°).

Reaction of Dimethyloxosulfonium Methylide with 3,3,5-Trimethylcyclohexanone. The ketone (1.4 g., 10 mmoles) and 20 mmoles of the ylide in 50 ml. of tetrahydrofuran was refluxed for 16 hr. under nitrogen. Processing gave 1.33 g. of colorless liquid. Evaporative distillation at 90° (13 mm.) yielded 1.2 g. (78%) of the pure oxirane V.

Anal. Calcd. for $C_{10}H_{18}O$: C, 77.86; H, 11.76. Found: C, 77.71; H, 11.75.

The infrared spectrum showed $\lambda_{\max}^{CCl_4}$ 3.40 (s), 6.75 (w), 6.90 (m), 7.08 (w), 7.25 (w), 7.38 (m), 7.62 (w), 7.80 (w), 7.95 (w), 8.15 (w), 8.50 (w), 9.12 (w), 10.50 (m), 10.71 (m), 10.90 (m), 11.32 (m), and 11.90 (m) μ.

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[38] C. H. DePuy and R. W. King, *J. Am. Chem. Soc.*, **83**, 2743 (1961).

The n.m.r. spectrum (CCl_4) showed methyl peaks at τ 9.15, 9.08, 9.05, and 8.96 with overlapping less intense multiplets (total of eleven protons), multiplets at 8.20–8.88 (five protons), and a singlet at 7.68 (two protons).

Reduction. The oxirane V (524 mg., 3.40 mmoles) was reduced with 95 mg. (2.5 mmoles) of lithium aluminum hydride in ether. Processing gave 500 mg. (94%) of 1,3,3,5-tetramethylcyclohexanol (1-hydroxy axial, 1- and 5-methyls equatorial and *cis*) as a white crystalline solid, m.p. 80–81.5° (lit.[39] m.p. 80–81°). The infrared spectrum was identical with the same compound prepared from 3,3,5-trimethylcyclohexanone and methyllithium, and there was no melting point depression upon mixing the two samples.

Reaction of Dimethylsulfonium Methylide with 3,3,5-Trimethylcyclohexanone. The ketone (1.40 g., 10 mmoles) and 20 mmoles of the ylide (generated as described above) in tetrahydrofuran under nitrogen yielded, after processing, a pale yellow liquid. Evaporative distillation at 110° (13 mm.) gave 1.36 g. (88.2%) of colorless product whose infrared spectrum indicated a mixture of isomeric oxiranes.

Reduction. The oxirane mixture (568 mg., 3.69 mmoles) was reduced with 95 mg. (2.5 mmoles) of lithium aluminum hydride in ether to yield 542 mg. (94%) of a mixture of isomeric 1,3,3,5-tetramethylcyclohexanols as a colorless oil. Vapor phase chromatographic analysis (12 ft., 10% fluorosilicone on Diatoport S, 135°, helium flow rate 43 ml./min. at 20 p.s.i.g.) showed the presence of 45% of the isomer with axial 1-hydroxyl and *cis* equatorial 1- and 5-methyl, and 55% of the 1-epimer with equatorial hydroxyl (a collected sample had m.p. 66–66.5°). Retention times were 7 min., 25 sec. and 9 min., 20 sec. respectively.

Reaction of Dimethyloxosulfonium Methylide with 4-Phenylcyclohexanone. The ketone (1.74 g., 10 mmoles) and 12 mmoles of the ylide in 40 ml. of tetrahydrofuran were refluxed for 1 hr. under nitrogen. Processing gave a colorless oil which was evaporatively distilled at 100° (1.0 mm.) to yield 1.38 g. (73.4%) of the oxirane as a colorless oil. Cooling and scratching gave colorless crystals of IV, R = C_6H_5, m.p. 32–33.5°, undepressed upon admixture with a sample of the same compound prepared in dimethyl sulfoxide as solvent.

The infrared spectrum showed $\lambda_{\max}^{CCl_4}$ 3.28 (m), 3.38 (s), 6.14 (w), 6.71 (m), 6.98 (m), 7.16 (w), 7.63 (w), 10.15 (m), 10.88 (s), and 12.03 (m) μ. The n.m.r. spectrum (neat) showed multiplets centered at τ 8.78 and 8.17 (total of nine protons), a singlet at 7.50 (two protons), and a peak at 2.70 (five protons).

Reduction. The oxirane (757 mg., 4.03 mmoles) was reduced with 95 mg. (2.5 mmoles) of lithium aluminum hydride in ether. Processing gave 733 mg. (95.7%) of 1-methyl-*cis*-4-phenylcyclohexanol (axial hydroxyl) as a white crystalline solid, m.p. 67–71°. Recrystallization from hexane raised the melting point to 71–72° (lit.[40] m.p. 71–72°).

Reaction of Dimethylsulfonium Methylide with 4-Phenylcyclohexanone. The ketone (1.74 g., 10 mmoles) and 20 mmoles of the ylide (generated as described above) in tetrahydrofuran under nitrogen yielded, after processing and evaporative distillation at 110° (1.0 mm.), 1.5 g. of a colorless liquid. The infrared and n.m.r. spectra showed this to be a complex mixture of about 30–40% unchanged 4-phenylcyclohexanone (probably due to enolate anion formation), oxirane, and some alcoholic material (hydroxyl absorption in the infrared). However, there appeared to be little or none of the oxirane IV (R = C_6H_5) formed as described above from dimethyloxosulfonium methylide and 4-phenylcyclohexanone.

Trimethylsulfonium Iodide.[41] Equimolar amounts of dimethyl sulfide and methyl iodide are mixed and allowed to stand at room temperature overnight. The resulting solid white cake of the sulfonium salt was crushed and recrystallized from 95% ethanol.

Dimethylsulfonium Methylide. General Method of Preparation and Reaction with Aldehydes and Ketones. A 1.5 to 2 *M* solution of methylsulfinyl carbanion was prepared in the usual manner, under nitrogen, from sodium hydride and dry dimethyl sulfoxide. The solution was cooled to room temperature, diluted with an equal volume of dry tetrahydrofuran (to prevent freezing), and then cooled in a salt–ice bath. With stirring, a solution of trimethylsulfonium iodide (1 molar equiv. based on sodium hydride) in dimethyl sulfoxide (800 ml. per mole of sulfonium salt) was added over a period of about 3 min. When quantities greater than 0.1 mole were used it was best to insert a thermometer into the reaction mixture and to regulate the addition to maintain the temperature below 5°. After the addition of the salt was complete, the mixture was stirred for 1 min. longer before adding the carbonyl compound (slightly less than 1 equiv.), either neat, if liquid, or dissolved in dimethyl sulfoxide or tetrahydrofuran, if solid, at a moderately rapid rate. Stirring was continued at salt–ice temperature for several minutes and then for 30–60 min. with the bath removed. The reaction mixture was diluted with three volumes of water and the product extracted with an appropriate solvent, washed with water, and dried. Oxiranes formed from α,β-unsaturated aldehydes or ketones should be dried over potassium carbonate and the liquids, if required pure, should be distilled over a small amount of potassium carbonate at low temperatures.

Benzophenone. The ylide (0.03 mole) and 4.55 g. (0.025 mole) of benzophenone gave, after work-up with ether, 4.9 g. (quantitative yield) of the oxirane as a crystalline solid. Recrystallization from 15 ml. of 95% ethanol gave 4.1 g. (83.6%) of colorless crystals, m.p. 54–56° (lit.[30] m.p. 56°).

Benzaldehyde. The ylide (0.03 mole) and 2.65 g. (0.025 mole) of benzaldehyde gave, after work-up with ether and evaporative distillation at 110° (20 mm.), 2.26 g. (75.4%) of styrene oxide, identical in all respects with an authentic sample.

Cycloheptanone. The ylide (0.03 mole) and 2.24 g. (0.02 mole) of cycloheptanone gave, after work-up with ether and evaporative distillation at 100° (24 mm.), 2.45 g. (97.2%) of the oxirane, identical (infrared and n.m.r.) with the product formed from dimethyloxosulfonium methylide and cycloheptanone.

Benzalacetophenone. The ylide (0.032 mole) and 6.24 g. (0.03 mole) of benzalacetophenone yielded, after

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(39) G. Chiurdoglu and A. Maquestiau, *Bull. soc. chim. Belges*, **63**, 357 (1954).

(40) D. Y. Curtin and R. J. Harder, *J. Am. Chem. Soc.*, **82**, 2357 (1960).

(41) H. J. Emeleus and H. G. Heal, *J. Chem. Soc.*, 1126 (1946).

work-up with pentane, 6.7 g. (quantitative yield) of the oxirane as a pale yellow oil. A sample (1.23 g.) was evaporatively distilled at 130° (0.05 mm.) from 50 mg. of potassium carbonate to yield 1.07 g. (87% recovery) of pale yellow oil.

Anal. Calcd. for $C_{16}H_{14}O$: C, 86.44; H, 6.35. Found: C, 86.22; H, 6.23.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{CHCl_3}}$ 3.28 (s), 5.90 (w), 5.98 (m), 6.20 (m), 6.30 (w), 6.66 (s), 6.88 (s), 7.45 (m), 7.65 (m), 9.28 (m), 9.69 (m), 10.25 (s), 1.70 (s), and 10.93 (m) μ; ultraviolet spectrum: $\lambda_{\max}^{\mathrm{cyclohexane}}$ 256 mμ (ϵ 20,100). The n.m.r. spectrum (CCl_4) showed a pair of doublets centered at τ 7.08 (J = 6.5 c.p.s., two protons), a pair of doublets centered at 3.64 (J = 16.5 c.p.s., two protons), and phenyl multiplets at 2.42–3.0 (ten protons).

Carvone. The ylide (0.032 mole) and 4.5 g. (0.03 mole) of carvone gave, after work-up with pentane and evaporative distillation from 30 mg. of potassium carbonate at 60° (0.2 mm.), 4.38 g. (89.1%) of the oxirane as a colorless liquid.

Anal. Calcd. for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.09; H, 9.90.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{neat}}$ 3.35 (s), 5.90 (w), 6.03 (m), 6.85 (s), 7.23 (m), 7.48 (w), 8.62 (w), 8.72 (w), 9.00 (w), 9.42 (m), 10.65 (s), 10.90 (s), 11.20 (s), 11.95 (s), and 12.45 (m) μ. The n.m.r. spectrum (neat) showed a doublet centered at τ 8.58 (three protons), a singlet at 8.31 (three protons), multiplets at 7.0–8.1 (seven protons), a singlet at 5.32 (two protons), and a multiplet centered at 3.33 (one proton).

Eucarvone. The ylide (0.023 mole) and 3.0 g. (0.02 mole) of eucarvone gave, after work-up with pentane and evaporative distillation from 30 mg. of potassium carbonate at 70° (1.5 mm.), 3.07 g. (93.5%) of the oxirane as a colorless liquid.

Anal. Calcd. for $C_{11}H_{16}O$: C, 80.43; H, 9.82. Found: C, 80.42; H, 9.80.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{neat}}$ 3.32 (s), 6.00 (w), 6.15 (w), 6.78 (m), 6.90 (m), 7.22 (m), 7.32 (m), 7.45 (m), 8.70 (m), 9.12 (m), and 12.45 (s) μ; ultraviolet spectrum: $\lambda_{\max}^{\mathrm{cyclohexane}}$ 256 mμ (ϵ 10,300) and 263 mμ (10,600). The n.m.r. spectrum (neat) showed a singlet at τ 8.98 (six protons), a doublet with peaks at 8.78 and 8.56 (J = 13.5 c.p.s., one proton), a singlet (with a slight shoulder) at 8.45 (three protons), a doublet with peaks at 7.91 and 7.69 (J = 13.5 c.p.s., one proton), a multiplet centered at 7.25 (two protons), and multiplets at 6.2–6.6 (three protons).

Pulegone. The ylide (0.032 mole) and 4.26 g. (0.028 mole) of pulegone gave, after work-up with pentane and evaporative distillation from 30 mg. of potassium carbonate at 60° (1.0 mm.), 4.19 g. (90%) of the oxirane as a colorless liquid.

Anal. Calcd. for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 78.99; H, 11.20.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{neat}}$ 3.38 (s), 5.79 (w), 6.05 (w), 6.85 (m), and 7.25 (m) μ. The n.m.r. spectrum (neat) indicated that the product was a mixture of two isomers in almost equal proportions. The protons of the methyl group located on saturated carbon appeared as two doublets of almost equal intensity centered at τ 9.15 and 9.05. Two intense sharp peaks (olefinic methyl protons) appeared at τ 8.41 and 8.22 in the midst of less intense multiplets.

Δ^4-Cholesten-3-one. The ylide (0.02 mole) and 5.75 g. (0.015 mole) of Δ^4-cholesten-3-one (dissolved in 30 ml. of tetrahydrofuran when added to the ylide solution) gave, after work-up with pentane, a pale yellow solid which was triturated with 20 ml. of cold methanol and filtered to yield 5.4 g. (90.5%) of the oxirane as a white crystalline solid, m.p. 64–77° (mixture of isomers). The analytical sample was prepared by recrystallizing a sample three times from acetone to give colorless flat needles, m.p. 101–109°.

Anal. Calcd. for $C_{28}H_{46}O$: C, 84.35; H, 11.63. Found: C, 84.49; H, 11.61.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{CCl_4}}$ 3.40 (s), 5.80 (w), 5.92 (m), 6.80 (m), and 7.22 (m) μ.

Benzalaniline. The ylide (0.03 mole) and 4.53 g. (0.025 mole) of benzalaniline gave, after work-up with pentane, 4.9 g. (quantitative yield) of 1,2-diphenylaziridine[42,43] as a pale yellow oil. Evaporative distillation from 30 mg. of potassium carbonate at 120° (0.05 mm.) yielded 4.45 g. (91.2%) of the pure product as a pale yellow oil.

Anal. Calcd. for $C_{14}H_{13}N$: C, 86.12; H, 6.71; N, 7.17. Found: C, 86.09; H, 6.73; N, 7.17.

The infrared spectrum showed $\lambda_{\max}^{\mathrm{neat}}$ 3.24 (w), 6.22 (m), 6.68 (m), 6.80 (w), 7.15 (w), 7.58 (w), 7.68 (w), 7.80 (w), and 8.62 (w) μ. The n.m.r. spectrum showed a multiplet centered at τ 7.80 (two protons), a quartet centered at 7.05 (one proton), and phenyl multiplets at 2.55–3.20 (ten protons).

Reaction of Dimethylsulfonium Methylide with 1,1-Diphenylethylene. A solution of the ylide (0.05 mole) was prepared at salt–ice temperature according to the general procedure. 1,1-Diphenylethylene (1.8 g., 0.01 mole) was added *via* hypodermic syringe, and after stirring at salt–ice temperature for 2 hr. and then at room temperature for 2 hr. the reaction mixture was poured into water and worked up with pentane. There was obtained 1.9 g. of colorless liquid which was shown by v.p.c. analysis (6 ft., 20% silicone rubber column, 225°, 34 ml./min. helium flow rate at 20 p.s.i.g.) to be a mixture of 61% 1,1-diphenylcyclopropane and 39% unchanged 1,1-diphenylethylene. Retention times were 14 min., 30 sec. and 11 min., 31 sec., respectively. Samples were collected and their infrared spectra were identical with those of authentic samples. When only a onefold excess of the ylide was used, the product obtained contained only 35% of the cyclopropane in addition to 65% unreacted olefin.

Decomposition of Dimethylsulfonium Methylide. A solution of 0.042 mole of methylsulfinyl carbanion in 30 ml. of dimethyl sulfoxide was prepared under nitrogen in the usual manner in a system which was connected to a gas buret through a water-cooled condenser. With stirring, a solution of 8.16 g. (0.04 mole) of trimethylsulfonium iodide in 30 ml. of dimethyl sulfoxide was added, at room temperature, over a period of 5 min. The temperature of the reaction mixture rose to about 50° and a gas was evolved. Most of the gas was evolved after 5 min. but the reaction was allowed to continue for 1 hr., after which time 440 ml. of gas had been collected in the buret. The gas was slowly

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(42) L. Wolff, *Ann.*, **394**, 68 (1912).

(43) K. Alder and G. Stein, *ibid.*, **501**, 1 (1933).

bubbled through a tube containing a solution of 3.2 g. (0.02 mole) of bromine in 40 ml. of methylene chloride, followed by sweeping the gas remaining in the reaction flask through the same solution with a nitrogen stream. The bromine solution was washed with 10% aqueous sodium thiosulfate to remove the excess bromine, then with saturated salt solution, dried over anhydrous potassium carbonate, and fractionally distilled to yield 2.0 g. (53.4% based on the sulfonium salt) of ethylene dibromide, b.p. 130–132° (lit. 131.6°). The infrared spectrum was identical with that of an authentic sample.

Attempted Reactions of Dimethylsulfonium Methylide. Attempts were made to effect reaction of the sulfonium ylide with desoxybenzoin, *trans*-stilbene, and diphenylacetylene using the general procedure. In each case starting material was recovered almost quantitatively.

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Synthesis of N-Benzoyl-2′-O-tetrahydropyranylguanosine-5′-phosphate, an Intermediate in the Chemical Synthesis of Polyriboguanylic Acid[1]

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The synthesis of N-benzoyl-2′-O-tetrahydropyranylguanosine-5′-phosphate, a suitable monomer for chemical synthesis of 5′-phosphomonoester-terminated polyriboguanylic acid, has been achieved. Starting with guanosine-5′-phosphate, N-benzoylguanosine-3′,5′-cyclic phosphate was synthesized in two steps by known reactions. Acid-catalyzed reaction of this cyclic phosphate with dihydropyran gave, quantitatively, N-benzoyl-2′-O-tetrahydropyranylguanosine-3′,5′-cyclic phosphate which was then specifically hydrolyzed with a partially purified enzyme to give, in high yield, N-benzoyl-2′-O-tetrahydropyranylguanosine-5′-phosphate. Yields of the pure final product, based on starting guanosine-5′-phosphate, were near 50%. Synthesis of 2′-O-tetrahydropyranylguanosine-5′-phosphate by a similar route has also been accomplished. Procedures have been devised for removal of the benzoyl and tetrahydropyranyl protecting groups from these substituted guanosine nucleotides under milder conditions than anticipated. Details of these synthetic reactions and of ancillary studies of protecting group stabilities and the properties of the phosphodiesterase employed are presented.

The chemical polymerization of ribonucleotides has been under investigation for a number of years in several laboratories.[3] The mixed anhydride approach of Michelson[4] and the ethyl polyphosphate method of Schramm, *et al.*[5] bypass the problem of protecting groups, but, consequently, preclude exclusive formation of $C_{3'} \rightarrow C_{5'}$[6] phosphodiester linkages in the polymeric product. On the other hand, Khorana and co-workers, in particular, and others as well, have studied extensively the preparation of specifically blocked ribonucleotides which might be polymerized by the carbodiimide method in order to obtain $C_{3'} \rightarrow C_{5'}$ phosphodiester linkages exclusively.[7] Reaction conditions and many other problems of carbodiimide polymerizations have been worked out for deoxynucleotides, in which case sugar protecting groups are not required.[3b] However, a comparable range of polyribonucleotides has not been synthesized, primarily because of the difficult accessibility of the appropriately blocked intermediates.

A bifunctional intermediate containing both a phosphomonoester group and a hydroxyl group is required for such polymerization. For exclusive $C_{3'} \rightarrow C_{5'}$ phosphodiester linkages in the polymer, the phosphate may be esterified either at the 3′- or the 5′-hydroxyl of a ribonucleoside. The 2′-hydroxyl must be blocked in order to prevent formation of a nucleoside-2′,3′-cyclic phosphate when the 3′-hydroxyl is esterified,[8] and mixed $C_{2'} \rightarrow C_{5'}$ and $C_{3'} \rightarrow C_{5'}$ phosphodiester linkages when the 5′-hydroxyl is esterified.[8] Polymers of the type $(Up)_n$[7a] and $(Ap)_n$[9] have been synthesized utilizing

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[1] This work was supported by grants from the National Institutes of Health.

[2] Established Investigator of the American Heart Association during part of this investigation.

[3] For extensive reviews of this field, see (a) A. M. Michelson, "The Chemistry of Nucleosides and Nucleotides," Adademic Press Inc. (Ltd.), London, 1963, pp. 400–443; (b) H. G. Khorana, "Some Recent Developments in the Chemistry of Phosphate Esters of Biological Interest," John Wiley and Sons, Inc., New York, N. Y., 1961, pp. 93–125.

[4] A. M. Michelson, *J. Chem. Soc.*, 1371 (1959).

[5] G. Schramm, H. Grotsch, and W. Pollman, *Angew. Chem.*, **74**, 53 (1962).

[6] The abbreviations and nomenclature used to describe internucleotide linkage are those proposed by Khorana (see ref. 3b, pp. 93–95). In naming derivatives of guanosine, the abbreviation Guo is used (see IUPAC, Tentative Rules, Abbreviations and Symbols for Chemical Names of Special Interest in Biological Chemistry, *J. Biol. Chem.*, **237**, 1381 (1962), paragraph 5.4). Phosphoesters are referred to by the symbol P, and cyclic phosphate as CP. Other abbreviations include THP for tetrahydropyranyl substituents; DCC for N,N′-dicyclohexylcarbodiimide; DMSO for dimethyl sulfoxide; DEAE for diethylaminoethyl; and Tris for trishydroxymethylaminomethane.

[7] Examples include: (a) D. H. Rammler, Y. Lapidot, and H. G. Khorana, *J. Am. Chem. Soc.*, **85**, 1989 (1963); (b) M. Smith, D. H. Rammler, I. H. Goldberg, and H. G. Khorana, *ibid.*, **84**, 430 (1962); (c) D. H. Rammler and H. G. Khorana, *ibid.*, **84**, 3112 (1962); (d) J. Smrt and F. Sorm, *Collection Czech. Chem. Commun.*, **27**, 73 (1962); (e) F. Cramer and K. H. Scheit, *Angew. Chem.*, **74**, 717 (1962).

[8] M. Smith, J. G. Moffatt, and H. G. Khorana, *J. Am. Chem. Soc.*, **80**, 6204 (1958).

[9] Y. Lapidot and H. G. Khorana, *ibid.*, **85**, 3857 (1963).