tions will be reflected in the ratios of *m/e* 94:56 (**3**:**4**). This ratio is 30.3 for the *cis* isomer and 49.2 for the *trans* isomer, in accord with the postulation of a more twisted *cis* activated complex. Such an analysis is tenuous, however, because it fails to take into account further decomposition pathways. Alternatively an analysis may be made using the kinetic approach of Bursey and McLafferty.[12] Thus the effect of the local molecular environment on the absolute rate of a decomposition reaction can be compared for two similar reactions using the ratio of the abundance of a common product ion to that of its precursor ion if the product ion is formed with the same energy distribution from each molecular ion. The ratio of *m/e* 56:150 is 0.024 for the *trans* isomer and 0.039 or 1.62 times as great for the *cis* isomer;[13] thus the conformation of the propenyl group in the un-ionized molecule is reflected in the relative energies of the activated complexes for the RDA reaction. Since the rate of decomposition of the molecular ion of the *cis* isomer is only 1.24 times as great as that of the *trans* isomer we feel that these data suggest (but do not demand) that the greater rate of formation of *m/e* 56 in the *cis* isomer is due (at least in part) to the maintenance of the stereochemical integrity of the exocyclic double bond upon ionization. It should be noted, however, that the π bond order will be greater in the conjugated dienes studied by us than in simple olefins, thus restricting isomerization to a greater extent.[14]

Acknowledgment. We are pleased to acknowledge the support of this work by the National Science Foundation (Grant GP-5526) and the assistance of Dr. Henry Fales in obtaining several of the mass spectra. We also express appreciation to the National Science Foundation for a grant used for the purchase of a mass spectrometer.

[12] M. M. Bursey and F. W. McLafferty, *J. Am. Chem. Soc.*, **88**, 529 (1966).

[13] The assumption that the *m/e* 56 ions are formed with equal energy distribution from each molecular ion actually sets a lower limit on the higher ratio value for the *cis* isomer since this isomer is the one which is more likely to possess excess energy and thus to have product ions which undergo further decomposition.

[14] Excess vibrational energy would aid in overcoming the barrier to internal rotation about the essential single bond of the diene moiety and may thereby reduce the *cis–trans* difference.[12]

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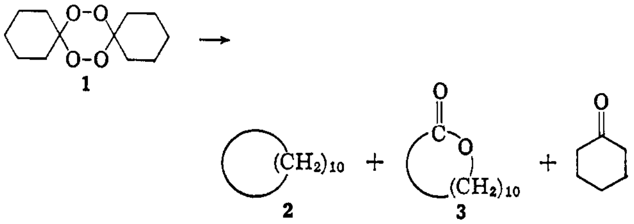
A New General Synthesis of Macrocyclic Compounds

Sir:

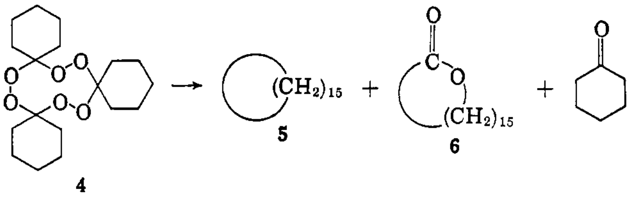
We wish to report the discovery of a general method for the synthesis of macrocyclic compounds from inexpensive and readily available starting materials. The procedure is extremely simple, involving only photolysis or thermolysis of an appropriate ketone peroxide. The desired macrocyclic compound is generated directly in good yield. In this communication we report the synthesis of carbocyclic hydrocarbons and macrocyclic lactones. We shall report subsequently on extension of the method to substituted carbocycles and heterocycles. The reactions of cyclohexanone diperoxide (**1**)[1] serve to illustrate.

Photolysis of **1** (12 g) in methanol (4.5 l.) or in benzene using a standard quartz Hanovia apparatus with a 450-w lamp for 3 hr followed by solvent removal with a rotary evaporator yields cyclodecane (**2**; 14%), 11-undecanolactone (**3**;[2] 10%), and cyclohexanone (~20%).[3]

Thermolysis of **1** gave the same products but in appreciably higher yield. Heating solid peroxide **1** in an evacuated and sealed ampoule for 30 min at 150° yields as the major product cyclodecane (**2**; 44%) along with the lactone (**3**; 23%) and cyclohexanone (21%).[4] Provided the necessary peroxide is available (usually the peroxide is quickly and easily prepared from the appropriate ketone with hydrogen peroxide), the procedure becomes almost trivial, particularly since we have also found that thermolysis of most peroxides can be carried out using a gas-chromatograph injection inlet and/or column heated to about 180°. Pyrolysis occurs instantaneously, and excellent separation of the products is obtained. A variety of chromatographic columns may be used.



Trimeric cyclohexanone peroxide (**4**)[5] reacts in similar fashion to yield cyclopentadecane (**5**), 16-hexadecanolactone (dihydroambrettolide; **6**),[2,6] and cyclohexanone.



The reaction is not limited to six-membered ring ketones. The dimeric peroxide of cycloheptanone,[7] for example, on thermolysis gives cyclododecane in 22% yield. Using appropriately substituted cyclic ketones it appears likely that almost any macrocyclic compound can be synthesized, provided the necessary peroxide percursor can be obtained. The generality and utility of the reactions are illustrated by the data in the tables. We have not yet attempted to maximize the yields; a study of reaction variables is under way.

The thermal or photochemical decomposition of ketone peroxides is most reasonably interpreted as proceeding through homolysis of an oxygen–oxygen bond as indicated here for cyclohexanone diperoxide (**1**). The cleavage should be analogous to that of alkyl

[1] R. Criegee and G. Lohaus, *Ann.*, **583**, 6 (1953); M. S. Kharasch and G. Sosnovsky, *J. Org. Chem.*, **23**, 1322 (1958).

[2] L. Ruzicka and M. Stoll, *Helv. Chim. Acta*, **11**, 1159 (1928); M. Stoll and W. Scherrer, *ibid.*, **13**, 142 (1930).

[3] Products were identified by infrared, nmr, and mass spectral analyses.

[4] Caution! Some peroxides will occasionally explode with considerable violence. Generally if a small amount of solvent such as methanol or benzene is left in the solid, explosions can be avoided.

[5] R. Criegee, W. Schnorrenberg, and J. Becke, *Ann.*, **565**, 7 (1949).

[6] S. D. Sabnis, H. H. Mathur, and S. C. Bhattacharyya, *J. Chem. Soc.*, 4580 (1965).

[7] T. Ledaal, *Acta Chem. Scand.*, **21**, 1656 (1967).

Table I. Reactions of Ketone Diperoxides

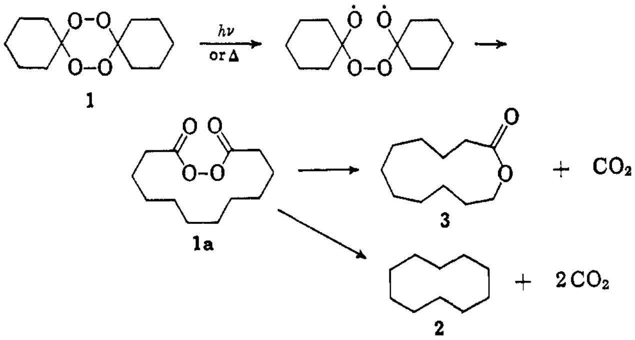
Diperoxide	Method	Products	Yields, %	Regenerated ketone, %
Cyclohexanone[1,7]	hν	Cyclodecane	14	20
	Δ		44	21
	hν	11-Undecanolactone	9	
	Δ		23	
Cycloheptanone[7]	hν	Cyclododecane	32	24
	Δ		22	33
	hν	13-Tridecanolactone	7	
	Δ		<1	
Cyclododecanone[7]	Δ	Cyclodocosane	20	9
		23-Tricosanolactone	11	

Table II. Reactions of Ketone Triperoxides

Triperoxide	Method	Products	Yields, %	Regenerated ketone, %
Cyclopentanone[a]	Δ	Cyclododecane	20	24
		13-Tridecanolactone	2	
Cyclohexanone[5]	hν	Cyclopentadecane	15	20
	Δ		16	15
	hν	16-Hexadecanolactone	25	
	Δ		<1	

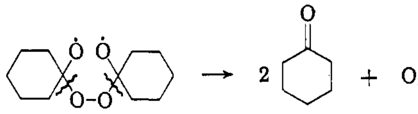
[a] W. Dilthey, M. Inckel, and H. Stephan, *J. Prakt. Chem.*, **154**, 219 (1940).

peroxides[8] and ozonides.[9] For example, we have shown that ozonides on photolysis or thermolysis undergo a double β scission following homolysis of the oxygen–oxygen bond. β Scission to produce alkyl radicals is followed by a very efficient cage recombination to form a new carbon–carbon bond. We envision peroxides reacting in similar fashion. Such a reaction path leads to formation of an intermediate acyl peroxide (**1a**). The cyclic hydrocarbon presumably results from homolytic decomposition[10] of **1a** followed by loss of 2 moles of carbon dioxide and cage recombination of the resulting alkyl radicals.



The observation of lactone in the thermal reactions is probably understandable in terms of a carboxy inversion reaction.[11] It may prove possible to reduce or eliminate lactone formation in the photochemical reaction by the use of sensitizers.[10]

The regeneration of ketone from both the photolysis and thermolysis of peroxides is viewed most simply as a double β scission of carbon–oxygen bonds to generate oxygen (probably singlet) and two molecules of ketone.



Because of the ready availability of the starting materials and the simplicity of the reactions, the procedure described here now constitutes the most generally useful synthesis of macrocyclic systems. In particular, this promises to be the most convenient and inexpensive method for preparation of a wide variety of musk compounds used in perfumes.[12] In fact, some of the lactones described in this communication, particularly dihydroambrettolide (**6**), are important musk compounds. Application of this synthesis to particular substituted macrocyclic compounds such as muscone is in progress. *A priori*, this synthesis also appears applicable to the preparation of oxygen-containing macrocycles (ethers) such as 11-oxa-16-hexadecanolactone[13] *via* γ-pyrone peroxides. In addition to the synthesis of musk compounds, the method appears to hold considerable promise for the preparation of very large ring systems. Ultimately the reaction may find application in the synthesis of antibiotic macrolides.

Acknowledgment. We thank the Public Health Service, National Center for Air Pollution Control, for partial support of this work through Grant AP00580-01.

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[8] J. G. Calvert and J. N. Pitts, Jr., "Photochemistry," John Wiley and Sons, Inc., New York, N. Y., 1966, pp 443–450.

[9] P. R. Story, W. H. Morrison, III, T. K. Hall, J. Farine, and C. E. Bishop, 154th National Meeting of the American Chemical Society, Chicago, Ill., Sept 11–16, 1967, Abstract S-30; to be published.

[10] C. Walling and M. J. Gibian, *J. Am. Chem. Soc.*, **87**, 3413 (1965), and references cited therein.

[11] F. D. Greene, H. P. Stein, C.-C. Chu, and F. M. Vane, *ibid.*, **86**, 2080 (1964); C. Walling and Z. Cekovic, *ibid.*, **89**, 6681 (1967).

[12] P. Z. Bedoukian, *Am. Perfumer Cosmet.*, **80**, 23 (1965); P. Z. Bedoukian, "Perfumery Synthetics and Isolates," D. Van Nostrand, Co., Inc., New York, N. Y. 1951.

[13] W. Berends, *Am. Perfumer Cosmet.*, **80**, 35 (1965).

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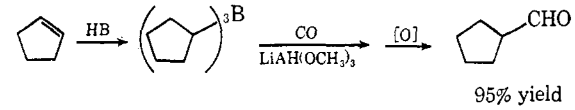
Reaction of Organoboranes with Ethyl Bromoacetate under the Influence of Potassium *t*-Butoxide. A Convenient Procedure for the Conversion of Olefins into Esters *via* Hydroboration

Sir:

The reaction of organoboranes with carbon monoxide in the presence of alkali metal borohydrides[1] or of lithium trimethoxyaluminohydride[2] provides a convenient method for a one-carbon-atom homologation, providing a simple route for the synthesis of aldehydes from the corresponding olefins (1). Similarly, the reaction of trialkylboranes with acrolein provides a convenient procedure for the three-carbon-atom



(1)

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[1] M. W. Rathke and H. C. Brown, *J. Am. Chem. Soc.*, **89**, 2740 (1967).

[2] H. C. Brown, R. A. Coleman, and M. W. Rathke, *ibid.*, **90**, 499 (1968).