date precipitate was removed by filtration and the filter cake was washed with 15 ml of $CHCl_3$. Extraction with $CHCl_3$, drying over anhydrous sodium sulfate, and removal of the solvent at reduced pressure yielded the sulfoxide as a brown oil. Recrystallization from benzene–petroleum ether gave 0.41 g (74%) of the sulfoxide: mp 71–72°; ^1H NMR ($CDCl_3$) δ 6.60 (2 H, s), 3.84 (3 H, s), 2.91 (3 H, s), and 2.60 (6 H, s).

Anal. Calcd for $C_{10}H_{14}O_2S$: C, 60.58; H, 7.12; S, 16.17; O, 16.13. Found: C, 60.46; H, 7.08; S, 16.18; O, 16.28.

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Registry No.—I, 7321-59-7; II, 3517-99-5; III, 55661-07-9; 4-methoxy-2,6-dimethylbenzenesulfonyl chloride, 55661-08-0; chlorosulfonic acid, 7790-94-5; 3,5-dimethylanisole, 874-63-5; 4-methoxy-2,6-dimethylthiophenol, 701-69-9; 4-methoxy-2,6-dimethylphenyl methyl sulfide, 55661-09-1; dimethyl sulfate, 77-78-1.

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Oxidation of Hydrocarbons. VI. Oxidation of Cycloalkanes by Ruthenium Tetroxide[1]

Udo A. Spitzer* and Donald G. Lee

Department of Chemistry, University of Regina, Regina, Saskatchewan, Canada S4S 0A2

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The selective oxidation of saturated hydrocarbons by inorganic oxidants is an important and often difficult procedure because the required vigorous conditions also promote second-stage oxidation accompanied by C–C bond cleavage and subsequent degradation to carbon dioxide. The limited use of various transition metal oxides for such conversions has been recently reviewed.[2] In addition to other known methods we have found ruthenium tetroxide to be a convenient oxidant for cycloalkanes. Its value as a reagent for these reactions is enhanced because of its high solubility in nonpolar hydrocarbon solutions[3] and because it can be used in conjunction with inexpensive cooxidants such as aqueous sodium hypochlorite (household bleach).[4] Furthermore, the products are easily retrievable from the reaction mixture.

Experimental Section

All reactions were carried out as previously described[5] using either sodium metaperiodate or sodium hypochlorite as cooxidants. Since little difference in yields or products could be detected with either of these cooxidants, it would appear that most of the oxidative conversion is by ruthenium tetroxide, although the possibility of some direct oxidation of the intermediates by the cooxidants cannot be eliminated.[6]

Each reaction was initiated by combining 100 ml of cooxidant solution (1.46 *M* NaOCl or 0.46 *M* $NaIO_4$), 0.01 g of $RuO_2 \cdot 2H_2O$, and 5.0 ml of hydrocarbon in a flask. The flask was closed and the heterogenous mixture was agitated on a wrist shaker until all of the cooxidant had been consumed. The hydrocarbon layer was then separated and the remaining aqueous solution was made basic ($pH \geq 10$) by the addition of 6 *M* NaOH and extracted with 3 × 50 ml of ether to recover nonacidic products and starting material. The remaining solution was acidified ($pH \leq 3$) by the addition of concentrated H_2SO_4, saturated with NaCl, and extracted with 3 × 50 ml of ether to recover acidic products. Each set of ether extracts was combined, dried over anhydrous $MgSO_4$, and analyzed by GLC. They were then concentrated to 10 ml or less and the nonacidic products were separated and collected by preparative GLC. The isolated products were identified by GLC, TLC, NMR, ir, and melting points. The results are summarized in Table I. Each reaction was carried out three times and the average yield reported.

In a second series of experiments, the relative rates of reaction of cyclopentane, cyclohexane, cycloheptane, and cyclooctane were compared by subjecting all four compounds to oxidation under identical conditions. To 500 ml of 1.64 *M* NaOCl was added 20 mg of $RuO_2 \cdot 2H_2O$ and the solution was stirred until all of the ruthenium dioxide had been converted into ruthenium tetroxide. Ten milliliters of each substrate was then shaken with 50 ml of this solution and 1.00-ml aliquots were withdrawn and titrated periodically. The results of these experiments are found in Table II.

Results and Discussion

When a two-phase system is used, oxidation of the organic substrates by ruthenium tetroxide takes place in the nonaqueous phase. The ruthenium dioxide precipitate formed in this process then migrates to the interface (as in Scheme I), where it is converted back into ruthenium te-

Table I
Products from the Ruthenium Tetroxide Oxidation of Cycloalkanes

Alkane	Registry no.	Reaction time, days	Products	% yield[a]	Registry no.
Cyclopentane	287-92-3	7	Cyclopentanone	18	120-92-3
			Glutaric acid	63	110-94-1
Cyclohexane	110-82-7	8	Cyclohexanone	26 (23)	108-94-1
			Adipic acid	58 (45)	124-04-9
Cycloheptane	291-64-5	2	Cycloheptanone	68	502-42-1
			Pimelic acid	20	111-16-0
Cyclooctane	292-64-8	1	Cyclooctanone	55 (55)	502-49-8
			Suberic acid	23 (33)	505-48-6
trans-Decahydronaphthalene	493-02-7	1	*trans*-9-Decahydronaphthol	55	1654-87-1
			Decalones	7	21370-71-8 16021-08-2

[a] The yields in parentheses were obtained using sodium periodate as the cooxidant; all other results were obtained using sodium hypochlorite as the cooxidant. In each case the yield calculation was based on the amount of cooxidant used.

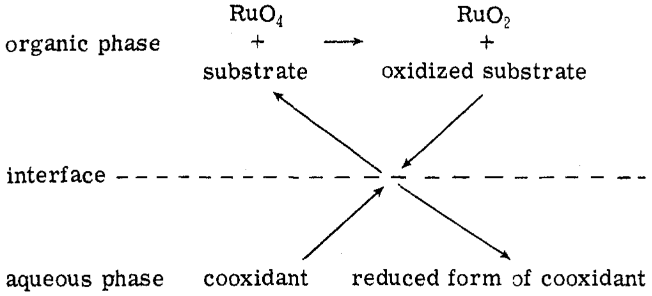
Table II
Relative Ratios for Reactions Involving Cycloalkanes

Reaction	Ring size			
	5	6	7	8
1. RuO_4 oxidation	1.5	1	2.5	8.7
2. Mn(VII) oxidation[b]	1.4	1	5.2	14.5
3. CrO_3 oxidation[c]	2.0	1	6.6	22.4
4. Acetolysis of tosylates[a,d]	14.0	1	25.3	191

[a] It has been proposed that these reactions proceed through carbonium ion intermediates. [b] Reference 10. [c] Reference 11. [d] Reference 9.

troxide by the cooxidant (which remains in the aqueous phase).

Scheme I



Consequently, it is likely that the organic substrates never come into direct contact with the cooxidant. The products (particularly if they are carboxylic acids) would, however, distribute between both phases and some second-stage oxidation could thus be the result of direct contact with the cooxidant. However, the fact that similar results were obtained when different cooxidants were used suggests that such reactions do not contribute significantly to the overall products obtained.

The results indicate that five- and six-membered rings have a greater tendency to undergo ring cleavage than the seven- and eight-membered rings. This may be due, at least in part, to the greater solubility of the corresponding cyclic ketones in aqueous solutions (where they would come into contact with cooxidant) or to the greater tendency for the smaller rings to undergo oxidative cleavage by ruthenium tetroxide. The reactions could be accelerated by working at a higher temperature, but because vigorous shaking is required to bring the two phases into contact, it is most convenient to work at room temperature. Despite the length of time required for a complete reaction, it would appear that this procedure compares favorably with other methods described in the literature for the oxidation of cyclic hydrocarbons.

Of particular interest is the observation that *trans*-decahydronaphthalene could be converted into *trans*-9-decahydronaphthol in about 60% yield. This suggests, as would be expected for an oxidative process, that tertiary carbon–hydrogen bonds are perferentially attacked.

In this work no solvent was used; however, an inert solvent such as carbon tetrachloride could be used if insufficient hydrocarbon was available.[7]

In a second series of experiments, the relative rates of reaction of cyclopentane, cyclohexane, cycloheptane, and cyclooctane were compared by subjecting all four compounds to oxidation under identical conditions and periodically determining the amount of unreduced cooxidant. In Table II, results of these experiments are described and compared with results that have been obtained from the oxidation of the same compounds by permanganate ion and hexavalent chromium. This comparison suggests that the mechanism is similar for all three oxidants and that the rate ratios are certainly different from those for the acetolysis of the corresponding tosylates. Since the latter reactions involve formation of carbonium ion intermediates,[8,9] it would appear that the oxidation reactions all proceed with homolytic carbon–hydrogen bond cleavage.

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Registry No.—Ruthenium tetroxide, 20427-56-9.

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Carbon-13 Nuclear Magnetic Resonance Spectroscopy of Naturally Occurring Substances. XXX. Griseofulvin[1]

Samuel G. Levine and Ronald E. Hicks

Department of Chemistry, North Carolina State University, Raleigh, North Carolina 27607

Hugo E. Gottlieb and Ernest Wenkert*[2]

Department of Chemistry, Indiana University, Bloomington, Indiana 47401

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While the ^1H nuclear magnetic resonance spectra of griseofulvin (**1a**) and its derivatives have been known and used for some time[3,4,5] and their ^{13}C satellites exploited in an analysis of the path of ^{13}C-enriched acetate in griseofulvin biosynthesis,[6] no direct ^{13}C nuclear magnetic resonance data are available for this system. Accordingly a ^{13}C NMR investigation of the spirocyclic antibiotic and four of its derivatives, epigriseofulvin (**1b**), isogriseofulvin (**2a**), 4′-demethoxyisogriseofulvin (**2b**), and dehydrogriseofulvin (**3**), was undertaken.

Proton-decoupled and single-frequency, off-resonance decoupled spectra of compounds **1**–**3** in hexadeuteriodimethyl sulfoxide solution were recorded and the residual coupling information used for the differentiation of the various carbon types. The carbon shifts of the five compounds are listed in Table I.

The *C*-methyl group is represented by the highest field signal in all spectra. The invariancy of the methyl shifts of the ring A methoxy groups permits assignment of the ring C methoxy shift by default. The ring A methoxy groups are distinguished from each other by the difference of the ef-