phthaloylglycyl chloride[29] (**9e**) with triisopropyl phosphite in quantitative yield. Anal. Calcd for $C_{16}H_{20}NO_6P$: C, 54.40; H, 5.66; N, 3.97. Found: C, 54.52; H, 5.45; N, 3.77. ^1H NMR ($CDCl_3$): 7.88 (2 H, m), 7.74 (2 H, m), 4.71 (2 H, d, J = 9 Hz), 4.76 (2 H, m), 1.40 (12 H, m).

X-ray Crystallography. Data collection was performed on a Philips PW 1100 automated diffractometer using a θ–2θ scan mode. The data were corrected for Lorentz polarization but no absorption correction was applied due to the low absorption coefficients. All non-hydrogen atoms were located by the direct methods of SHELX-86 and by subsequent difference maps. The refinement was carried out with SHELX-76.[31] Other pertinent information can be found in Tables S1 and S8 in the supplementary material.

Anticonvulsant Activity. Compounds **17c**, **17d**, and **17e** were screened in mice for their anticonvulsant activity at the Epilepsy Branch of the U.S. National Institute of Health, Bethesda, MD.[26] The screening procedure involved the following: (i) the maximal electroshock (MES) test, which measures seizure spread; (ii) the subcutaneous pentylenetetrazol test (Sc MET test), which measures seizure threshold; and (iii) the rotorod ataxia test, which assesses neurotoxicity.

Acknowledgment. This research was supported, in part, by The Fund for Basic Research, Administered by The Israel Academy of Sciences and Humanities (to E.B.). We thank Mr. James Stables of the NIH Epilepsy Branch for screening our compounds in the anticonvulsant screening project.

Registry No. **5**, 129034-39-5; **6a**, 129034-40-8; **6b**, 129034-41-9; **8a**, 129034-42-0; **8b**, 129034-43-1; **9d**, 10314-06-4; **9e**, 6780-38-7; **11a**, 129034-44-2; **11c**, 129034-45-3; **11d**, 129034-46-4; **12a**, 129034-47-5; **12b**, 129034-48-6; **12d**, 129034-49-7; **12f**, 129034-50-0; **13c**, 129034-51-1; **13d**, 129034-52-2; **14d**, 129034-53-3; **14e**, 129034-54-4; **16a**, 129034-55-5; **16b**, 129034-56-6; **16c**, 129034-57-7; **16d**, 129034-58-8; **16e**, 129034-59-9; **17a**, 129034-60-2; **17b**, 129034-61-3; **17c**, 129034-62-4; **17d**, 129034-63-5; **17d**·HCl, 129034-69-1; **17e**, 129034-64-6; **18a**, 129034-65-7; **18b**, 129034-66-8; **19a**, 129034-67-9; **19b**, 129034-68-0; Cbz-Pro-OH, 1148-11-4; Cbz-Pro-Cl, 61350-60-5; $P(OMe)_3$, 121-45-9; $P(OPr\text{-}i)_3$, 116-17-6.

Supplementary Material Available: Experimental details of the X-ray diffraction studies of **16b** and **16c** (12 pages); observed and calculated structure factors for **16b** and **16c** (27 pages). Ordering information is given on any current masthead page.

---

[31] Sheldrick, G. M. "SHELX-76" in *Computing in Crystallography*; Schenck, H., Olthof-Hazekamp, R., van Koningsveld, H., Bassi, G. C., Eds.; Delft University Press: Delft, The Netherlands, 1978; pp 34–42.

Ozonolysis of Vinyl Ethers in Solution and on Polyethylene

Karl Griesbaum,*[,1a] Woo-Sun Kim,[1a] Norinaga Nakamura,[1b] Mitsuyuki Mori,[1b]
Masatomo Nojima,*[,1b] and Shigekazu Kusabayashi[1b]

Engler-Bunte-Institut, Bereich Petrochemie, Universität Karlsruhe (TH), D-7500 Karlsruhe, Germany, and
Department of Applied Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka 565, Japan

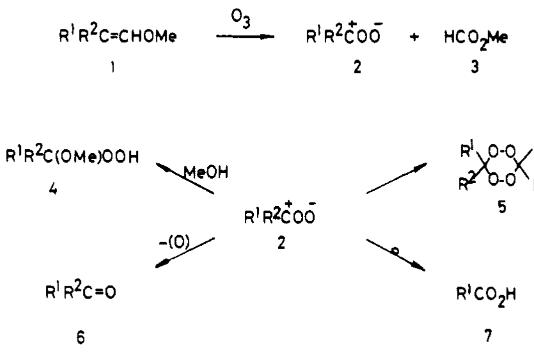
Received February 27, 1990

Ozonolyses of the vinyl ethers **1a–f** in methanol afforded almost exclusively the corresponding α-methoxy hydroperoxides **4**, suggesting the preferred formation of the carbonyl oxides **2**. In aprotic solvents including methyl formate, the predominant modes of decay of the carbonyl oxides **2** were cyclodimerization, reduction, and rearrangement, yet no ozonide formation. By contrast, ozonolyses of **1a–f** on polyethylene gave the α-methoxy-substituted ozonides **14** in fair yields. Ozonolyses of **1a–f** in the presence of added carbonyl compounds **6** in methylene chloride or ether yielded the corresponding cross ozonides. Judged from the ozonide yields, the reactivities of the carbonyl compounds follow the sequence: $(ClCH_2)_2C{=}O > ClCH_2COCH_3 > (CH_3)_2C{=}O$ and $2\text{-}CF_3C_6H_4CHO > PhCHO$.

Introduction

Vinyl ethers, as electron-rich alkenes, exhibit high reactivity toward electrophilic ozone. The ozonolysis of trisubstituted vinyl ethers is well known to yield mainly epoxides and other "partial cleavage" products derived by oxygen atom transfer from ozone.[2] Recently, Kuczkowski discovered that the reaction of unsubstituted vinyl ethers resulted in the exclusive formation of formaldehyde *O*-oxide, which in aprotic solvents cycloadds to the substrate to afford the corresponding 1,2-dioxolanes.[3] When the reaction was carried out in methyl formate, however, α-methoxy-substituted ozonides were obtained in good yields.[4,5] It was, therefore, of interest to investigate the reaction pathways of mono- and disubstituted vinyl ethers. Another interest is the ozonolysis on polyethylene, since we have discovered that this method may be suitable for preparing ozonides which could not be obtained by conventional methods.[6] Hence, if the ozonolysis of mono- and

Scheme I



---

[1] (a) Universität Karlsruhe. (b) Osaka University.

[2] (a) Hoffmann, R. W.; Schneider, J. *Chem. Ber.* **1967**, *100*, 3698. (b) Borowitz, I. J.; Rapp, R. D. *J. Org. Chem.* **1969**, *34*, 1370. (c) Gassman, P.; Creary, X. *Tetrahedron Lett.* **1972**, 4407, 4411. (d) Clark, R. O.; Heathcock, C. H. *J. Org. Chem.* **1976**, *41*, 1396.

[3] Keul, H.; Kuczkowski, R. L. *J. Am. Chem. Soc.* **1984**, *106*, 5370.

[4] (a) Keul, H.; Kuczkowski, R. L. *J. Am. Chem. Soc.* **1984**, *106*, 3383. (b) Wojciechowski, B. J.; Pearson, W. H.; Kuczkowski, R. L. *J. Org. Chem.* **1989**, *54*, 115.

[5] Examples are also known for intramolecular cycloaddition of a carbonyl oxide moiety to an ester group. (a) Bunnelle, W. H.; Meyer, L. A.; Schlemper, E. O. *J. Am. Chem. Soc.* **1989**, *111*, 7612. (b) Bunnelle, W. H. *Ibid.* **1989**, *111*, 7613.

[6] (a) Griesbaum, K.; Volpp, W.; Greinert, R. *J. Am. Chem. Soc.* **1985**, *107*, 5309. (b) Griesbaum, K.; Volpp, W. *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 81. (c) Griesbaum, K.; Volpp, W.; Greinert, R.; Greunig, H.; Schmid, J.; Henke, H. *J. Org. Chem.* **1989**, *54*, 383.

0022-3263/90/1955-6153$02.50/0 © 1990 American Chemical Society

Table I. Ozonolysis of Vinyl Ethers 1a–f in Carbon Tetrachloride, Methanol, or Methyl Formate[a]

vinyl ether	solvent	reaction temp, °C	products (% yield)
1a	CCl_4	0	**5a** (12), **6a** (28), **7a** (21)
1a	CH_3OH	–70	**4a** (63), **6a** (20)
1a	HCO_2CH_3	–70	**5a** (17), **6a** (25), **7a** (20)
1b	CCl_4	0	**5b** (16), **6b** (8), **7b** (24), **11** (10)
1b	CH_3OH	–70	**4b** (95)
1b	HCO_2CH_3	–70	**5b** (10), **6b** (50)
1c	CCl_4	0	**6c** (10), **13c** (12)[b]
1c	CH_3OH	–70	**4c** (90)
1c	HCO_2CH_3	–70	**6c** (31), **13c** (14)[b]
1d	CCl_4	0	**7d** (15)[c]
1d	CH_3OH	–70	**4d** (93)
1d	HCO_2CH_3	–70	**7d** (15)[c]
1e	CCl_4	0	**5e** (44), **6e** (40), **9** (10)
1e	CH_3OH	–70	**4e** (30), **6e** (64), **10** (5)
1e	HCO_2CH_3	–70	**5e** (15), **6e** (70)
1f	CCl_4	0	**5f** (10), **6f** (20)[d]
1f	CH_3OH	–70	**4f** (80)
1f	HCO_2CH_3	–70	**5f** (15), **6f** (40)[d]

[a] Reaction of vinyl ether (1 mmol) with 1 equiv of ozone. [b] Unidentified product, which was labile on silica gel, was obtained in a significant amount. [c] Polymeric products were also obtained in significant amounts. [d] An identified product was produced in considerable amount.

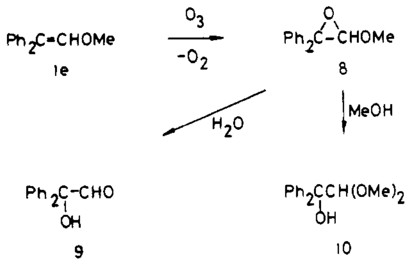
disubstituted vinyl ethers proceeds via carbonyl oxide intermediates,[7] capture of the intermediates by the coproduced alkyl formate could occur on polyethylene. In order to probe these possibilities, we undertook the ozonolysis of vinyl ethers **1a–f** in solution and on polyethylene.

Results and Discussion

Ozonolysis of Vinyl Ethers 1a–f in Solution. Ozonolysis of the vinyl ethers **1b–d,f** in methanol afforded the corresponding α-methoxy hydroperoxides **4b–d,f** as the sole isolable products (Table I). From the ozonolysis of **1a,e**, however, the corresponding reduction products **6a,e** were also obtained in significant amounts, in addition to the α-methoxy hydroperoxides **4a,e** (Table I). Since ^1H NMR spectra of the crude products obtained from the ozonolysis of 1,1-diphenyl-2-methoxyethene (**1e**) indicated the formation of the α-methoxy hydroperoxide **4e** in ca. 80% yield, it is concluded that during column chromatography on silica gel **4e** is partly decomposed to give benzophenone (**6e**). A similar effect was observed for the product derived from the ozonolysis of **1a**. These results suggest that of the two possible reaction pathways, i.e., carbonyl oxide formation and partial cleavage, the former process predominates for vinyl ethers **1a–f** (Scheme I). The additional formation of acetal **10** (5% yield) from vinyl ether **1e** leads us to deduce that in the case of this sterically congested substrate, the partial-cleavage process, i.e., oxygen atom transfer from ozone to **1e**, occurs to a small extent, too (Scheme II).[8] Consistent with this, we previously found that the ozonolysis of 1-(*o*-tolyl)-1-phenyl-2-methoxyethene gives exclusively the corresponding epoxide.[9]

Ozonolyses of **1a–f** in carbon tetrachloride were more complex (Table I): The monosubstituted vinyl ethers **1a,b** gave mixtures of the 1,2,4,5-tetroxanes **5a,b**, the aldehydes **6a,b**, and the carboxylic acids **7a,b**. From **1b** ca. 10% of methyl phenylacetate (**11**) was obtained additionally. 1-(2-(Trifluoromethyl)phenyl)-2-methoxyethene (**1c**) gave 3,5-bis(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (**13c**) in 12% yield, together with the aldehyde **6c**. Vinyl ether **1d** gave a complex mixture of products containing octanoic acid (**7d**). Kuczkowski had found that ozonolysis of (*Z*)-1-ethoxypropene in methylene chloride afforded 46% of 3,6-dimethyl-5-ethoxy-1,2-dioxolane, derived by [3 + 2] cycloaddition between acetaldehyde *O*-oxide and the vinyl ether substrate.[4b] Although the ^1H NMR spectra of the crude products obtained from the ozonolysis of the more bulky 1-methoxy-1-nonene (**1d**) in methylene chloride at –70 °C or in carbon tetrachloride at 0 °C did not show the presence of the corresponding 1,2-dioxolane, we cannot exclude the possibility that it may have been produced in a small amount but was decomposed during column chromatography on silica gel. The disubstituted vinyl ethers **1e,f** gave the 1,2,4,5-tetroxanes **5e,f** and the ketones **6e,f** as the major products. From **1f** were obtained considerable amounts of unidentified products (ca. 40 wt %) also.

Scheme II



The products tetroxane **5**, carbonyl compound **6**, and carboxylic acid **7** are most likely derived from the carbonyl oxide **2**,[10] by cyclodimerization, reduction, and rearrangement,[11] respectively (Scheme I). The formation of 10% of methyl phenylacetate (**11**) from 1-phenyl-2-methoxyethene (**1b**) may have occurred by oxygen atom transfer to the vinyl ether **1b** from the carbonyl oxide **2b** rather than from ozone, since—as shown by the ozonolysis of **1b** in methanol—the reaction proceeds exclusively via the carbonyl oxide **2b**. The following result also seems to support this. When the vinyl ether **1b** was treated with 0.5 equiv of ozone, the tetroxane **5b**, benzaldehyde (**6b**), benzoic acid (**7b**), and methyl phenylacetate (**11**) were isolated in yields of 6%, 13%, 17%, and 9%, respectively, based on the vinyl ether **1b**; the vinyl ether **1b** was also recovered in 22%. Thus, by this variation of the ratio of ozone to **1b** (from 1:1 to 1:2) a remarkable decrease in yield of the tetroxane **5b** was observed (16% → 6%) and in contrast, the yield of the ester **11** was not influenced significantly (10% → 9%).[12]

$PhCH_2CO_2Me$

11

Next, ozonolyses of vinyl ethers **1a–f** were carried out in methyl formate (**3**) in order to test whether carbonyl oxides **2** could capture the poor 1,3-dipolarophile **3** to yield the corresponding 3-methoxy-1,2,4-trioxolanes **14**. In marked contrast to the reaction of unsubstituted vinyl

---

(7) (a) Mori, M.; Nojima, M.; Kusabayashi, S.; McCullough, K. J. *J. Chem. Soc., Chem. Commun.* **1988**, 1550. (b) Mori, M.; Sugiyama, T.; Nojima, M.; Kusabayashi, S.; McCullough, K. J. *J. Am. Chem. Soc.* **1989**, *111*, 6884.

(8) Bailey, P. S.; Hwang, H. H.; Chiang, C. *J. Org. Chem.* **1985**, *50*, 231.

(9) Nakamura, N.; Nojima, M.; Kusabayashi, S. *J. Am. Chem. Soc.* **1987**, *109*, 4969.

(10) Bailey, P. S. *Ozonation in Organic Chemistry*; Academic Press: New York; 1978, Vol. 1; 1982, Vol. 2.

(11) Alternatively, the carboxylic acids **7a,b,d** would be produced by oxidation of the corresponding aldehydes **6a,b,d** with ozone or air.

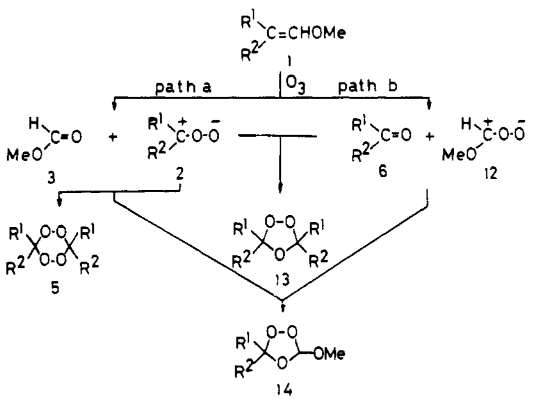
(12) We thank one of the reviewers for his kind suggestion to perform this experiment.

Table II. Ozonolysis of Vinyl Ethers 1a–f on Polyethylene

vinyl ether	products ozonide (% yield)[a]	cis:trans	others (% yield)[a]
1a	**14a** (44)	20:80	**1a** (15), **6a** (11), **3** (23)
	13a (7)	43:57	
1b	**14b** (34)	28:72	**1b** (10), **6b** (4), **11** (6), **3** (4)
	13b (6)	44:56	
1c	**14c** (56)	13:87	**1c** (5), **6c** (13), **3** (3)
	13c (5)	40:60	
1d	**14d** (61)	38:62	**1d** (9), **3** (3)[b]
1e	**14e** (14)		**1e** (6), **5e** (4), **6e** (38), **8** (15), **9** (10), **3** (10)
1f	**14f** (15)		**1f** (11), **5f** (3), **6f** (15), **3** (4)
	13f (53)		

[a] Determined by ^{1}H NMR analysis using 1,1,2,2-tetrachloroethane as internal standard. [b] Polymeric products were also obtained in considerable amounts.

Scheme III



a; R^1=4-MeOC$_6$H$_4$, R^2=H b; R^1=Ph, R^2=H c; R^1=2-CF$_3$C$_6$H$_4$, R^2=H
d; R^1=CH$_3$(CH$_2$)$_6$-, R^2=H e, R^1=R^2=Ph f; R^1,R^2= -(CH$_2$)$_5$-

ethers and of 1-ethoxypropene,[4] no evidence was obtained for the capture of excess methyl formate by the carbonyl oxides **2a–f**. The products were mainly the corresponding 1,2,4,5-tetroxanes **5** and the reduction products **6**. Compared with the reaction in carbon tetrachloride, the yields of the reduction products **6** increase with a concomitant decrease of those of the tetroxanes **5** and of the carboxylic acids **7**. At this stage, we cannot offer an appropriate explanation for the observed solvent effects.

Ozonolyses of Vinyl Ethers 1a–f on Polyethylene. In contrast to the reaction in carbon tetrachloride or methyl formate, ozonolyses of vinyl ethers **1a–f** on polyethylene at −75 °C gave the corresponding α-methoxy-substituted ozonides **14a–f** in fair yields (Table II and Scheme III). Yields of the compounds shown in Table II were determined by NMR spectroscopy of the crude products with 1,1,2,2-tetrachloroethane as internal standard. Since the ozonides **14** are labile on silica gel, the isolated yields were substantially lower than those cited in Table II as reported in the Experimental Section. Starting from **1a–d**, both possible stereoisomeric ozonides **14** were formed in each case.[13]

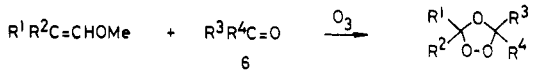
Ozonides **14a–f** were isolated as pure substances and characterized by their ^{1}H and ^{13}C NMR spectra and by reduction to the corresponding carbonyl fragments **3** and **6**. Of the stereoisomeric ozonides, *trans*-**14a**, *cis*- and *trans*-**14b**, *trans*-**14c**, and *cis*-**14d** were isolated as pure samples, whereas others were only obtained in admixture with the corresponding stereoisomer. Ozonides **14a–f** partially decomposed when they were kept at room temperature in CDCl$_3$ for 1 day. As neat samples at room temperature ozonides **14c** and **14f** were stable, ozonides **14b** and **14d** were partially decomposed after 3 days, and **14a** and **14e** after 2 weeks.

The configuration of the vinyl ethers **1** does not appear to affect the stereochemistry of the ozonides **14**. In the ozonolysis of both *cis*- and *trans*-1-(2-(trifluoromethyl)-phenyl)-2-methoxyethene (**1c**) on polyethylene, *cis*- and *trans*-3-methoxy-5-(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (**14c**) were obtained in a ratio of ca. 1:6.

In addition to the "normal" ozonides **14**, ozonolysis of **1a–c,f** afforded also the corresponding "cross" ozonides of structure **13**. They have been isolated and characterized by spectroscopic methods. Cross ozonides *trans*-**13a**[20] and **13c** have been obtained for the first time during this investigation, whereas **13b**[14] and **13f**[15] had been obtained previously from the ozonolysis of the corresponding parent olefins.

Further products were the corresponding fragments **3** and **6** in the ozonolysis of **1a–c,e,f** and fragment **3** from the ozonolysis of **1d**. Ozonolysis of **1e** and **1f** afforded the corresponding tetroxanes **5**, too.

The above results can be rationalized by the reaction sequence outlined in Scheme III. Ozonolyses of **1a–f** in methanol clearly demonstrated that of the two possible fragmentation pathways of the primary ozonide formed by [3 + 2] cycloaddition between **1** and ozone, path a yielding carbonyl oxide **2** and methyl formate **3** predominates. In view of this, it was surprising that the yield of the cross ozonide **13f** was as high as 53%. A possible explanation is that, in contrast to the reaction in methanol, two modes of cleavage of the primary ozonides, viz. path a and path b in Scheme III, could competitively occur on polyethylene, hence providing the cross ozonide **13f** by recombination of **2f** and **6f**.



b; R^3=Ph, R^4=H
c; R^3=2-CF$_3$C$_6$H$_4$, R^4=H
g, R^3=tert-butyl, R^4=H
h; R^3=pentyl, R^4=H
i; R^3=R^4=CH$_3$
j; R^3=CH$_2$Cl, R^4=CH$_3$
k; R^3=R^4=CH$_2$Cl

In the ozonolysis of 1,1-diphenyl-2-methoxyethene (**1e**) on polyethylene the corresponding epoxide **8** and the α-hydroxy aldehyde **9** were also obtained in yields of 15% and 10%, respectively (Scheme II and Table II). The formation of these products is explained by partial oxidation of **1e** to give **8**, which in turn may undergo hydrolysis to give **9**. From **1b** methyl phenylacetate (**11**) was obtained in 6% yield as an additional product.

Ozonolysis of Vinyl Ethers in the Presence of Added Carbonyl Compounds. Since the ozonolyses of vinyl ethers **1** in aprotic solvents were found to yield mainly the corresponding carbonyl oxides **2**, and since methyl formate (**3**), the byproduct from the ozonolyses of **1**, does not intercept carbonyl oxides, the ozonolysis of

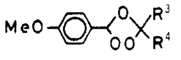
---

(13) The stereochemical assignments of ozonides **14a–d** are tentative. By analogy with previously published results,[4b] trans configuration was assigned to those isomers in which the ^{1}H NMR signals of the ring protons appeared downfield from those of the corresponding isomers. Furthermore, the cis isomer had in each case the longer retention time in column chromatography, and *cis*-**14a** as well as *cis*-**14c** had longer retention times in GLC than the corresponding trans isomers, in line with the previous examples reported in the literature.[10]

(14) Criegee, R.; Korber, H. *Chem. Ber.* **1971**, *104*, 1807.

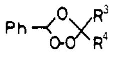
(15) Krieger-Beck, P. Unpublished results.

vinyl ethers **1a–f** was undertaken in the presence of 5 molar equiv of carbonyl compounds **6**. We expected that this could reveal the relative reactivities of the carbonyl compounds **6b**,**c**,**g–k** toward the carbonyl oxides **2a–f**.



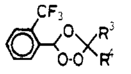
15

a; $R^3 = 2\text{-}CF_3C_6H_4$, $R^4 = H$
b; $R^3 = R^4 = CH_3$
c; $R^3 = CH_2Cl$, $R^4 = CH_3$
d, $R^3 = R^4 = CH_2Cl$



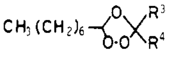
16

a; $R^3 = 2\text{-}CF_3C_6H_4$, $R^4 = H$
b; R^3 = tert-butyl, $R^4 = H$
c; R^3 = pentyl, $R^4 = H$
d; $R^3 = R^4 = CH_3$
e; $R^3 = CH_2Cl$, $R^4 = CH_3$
f; $R^3 = R^4 = CH_2Cl$



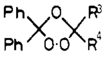
17

a; $R^3 = R^4 = CH_3$
b; $R^3 = CH_2Cl$, $R^4 = CH_3$
c; $R^3 = R^4 = CH_2Cl$



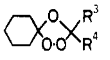
18

a; $R^3 = Ph$, $R^4 = H$
b; $R^3 = 2\text{-}CF_3C_6H_4$, $R^4 = H$



19

a; $R^3 = Ph$, $R^4 = H$
b; $R^3 = 2\text{-}CF_3C_6H_4$, $R^4 = H$
c; R^3 = tert-butyl, $R^4 = H$
d; R^3 = pentyl, $R^4 = H$
e; $R^3 = R^4 = CH_2Cl$



20

a; $R^3 = 2\text{-}CF_3C_6H_4$, $R^4 = H$
b; $R^3 = R^4 = CH_2Cl$

In most cases the corresponding cross ozonides **15–20** were obtained; an exception was the ozonolysis of vinyl ethers **1d**,**e** in the presence of acetone, in which no evidence was obtained for the formation of the corresponding cross ozonide (Table III). Judged from the ozonide yields the following points were clarified. (a) In most cases ether turned out to be a better solvent than methylene chloride; only in the ozonolysis of **1c** in the presence of **6c** the reverse trend was observed. (b) Ozonide yields were markedly dependent on the structure of the carbonyl compounds. Thus, the yields of ozonides decreased in the order **6c** > **6b** and **6k** > **6j** > **6i**. This means that the reactivity of the carbonyl compound increases with the increase in electron-withdrawing ability of the α-substituents.[16] In accordance with this, the ozonolysis of vinyl ether **1b** in the presence of a 1:1 mixture of dichloroacetone (**6k**) and chloroacetone (**6j**) in methylene chloride at 0 °C led to the exclusive formation of the ozonide **16f**, derived from the capture of benzaldehyde *O*-oxide (**2b**) by **6k**. A similar trend was also observed in the reaction of **1b** in the presence of a 4:1 mixture of benzaldehyde (**6b**) and 2-(trifluoromethyl)benzaldehyde (**6c**), which gave **13b** and **16a** in a ratio of 1:2.

Finally, ozonolyses of both *cis*- and *trans*-1-phenyl-2-methoxyethene (**1b**) in the presence of trimethylacetaldehyde (**6g**) gave the same mixture of *cis*- and *trans*-3-phenyl-5-*tert*-butyl-1,2,4-trioxolane (**16b**) in a ratio of ca. 3:7. Consistent with this, Kuczkowski also found that for the reaction of *cis*- and *trans*-1-ethoxypropene in the presence of a variety of carbonyl compounds the configuration of the alkene exerted only a negligible influence on the cis:trans ratio of the cross ozonides formed.[4b]

Experimental Section

General. ^{1}H NMR spectra were recorded on a Bruker WM 250 or a JNM-PS-100 spectrometer in $CDCl_3$ (standard; Me_4Si), ^{13}C NMR spectra on a Bruker WM 250 in $CDCl_3$ (standard; Me_4Si), IR spectra on a Beckman 4260 or Acculab 1, and GC/MS spectra on a Hewlett-Packard 5985B instrument. GLC analysis was performed on a Hewlett-Packard 5880 instrument: 50 m capillary column SE54, 50–180 °C at 7 °C/min. Melting points were determined on an electrothermal capillary melting point apparatus. Elemental analyses were performed by Analytical Laboratories, Gummersbach, or Osaka University.

Vinyl ethers **1a–c**,**e**[17] and **1d**,**f**[18] were prepared by the reported methods. The physical properties are summarized in Table IV. The purity of compounds *cis*-**14a**, *trans*-**14a**, *cis*-**14b**, *trans*-**14b**, *cis*-**14c**, *cis*-**14d**, *trans*-**14d**, and **14e**, for which no or unsatisfactory elemental analyses could be obtained, was judged by ^{1}H NMR analysis. The spectra are available as supplementary material.

Ozonolysis in Solution. Ozonolysis in Methanol. The ozonolysis of 1,1-diphenyl-2-methoxyethene (**1e**) in methanol is representative. To a solution of **1e** (1 mmol) in methanol (20 mL) was passed a slow stream of ozone (1 mmol; Nippon Ozone Model 0-1-2 ozonator) at −70 °C. The mixture was poured into water, extracted with ether, washed with aqueous $NaHCO_3$ and then brine, and dried over anhydrous magnesium sulfate. After evaporation of the solvent, the crude products were column chromatographed on silica gel. The first fraction (elution with benzene) contained benzophenone (**6e**). The second fraction (elution with ether–benzene, 1:50 v/v), contained α-(dimethoxymethyl)benzhydrol (**10**): an oil; ^{1}H NMR δ 3.24 (s, 6 H), 4.49 (s, 1 H), 6.90–8.04 (m, 10 H); EI-MS *m/e* 196 (M^+); IR 3450 cm^{-1}.[19] The third fraction (elution with ether–benzene, 1:10 v/v) contained α-methoxybenzhydryl hydroperoxide (**4e**).

The physical properties of α-methoxy hydroperoxides **4a–f** are summarized in Table V.

Ozonolysis in Carbon Tetrachloride. The ozonolyses of 1-(4-methoxyphenyl)-2-methoxyethene (**1a**) and (methoxymethylene)cyclohexane (**1f**) are representative. A solution of **1a** (1 mmol) in carbon tetrachloride (20 mL) was treated with 1 equiv of ozone at 0 °C. Then the solvent was evaporated, and the residue was column chromatographed on silica gel. The first fraction (elution with benzene–hexane, 1:2 v/v) contained 3,5-bis(4-methoxyphenyl)-1,2,4,5-tetroxane (**5a**): mp 196–198 °C (from methanol); ^{1}H NMR δ 3.80 (s, 6 H), 6.84 (s, 2 H), 6.87–7.50 (m, 8 H); IR 1640, 1600, 1280, 1120 cm^{-1}. Anal. Calcd for $C_{16}H_{16}O_2$: C, 63.15; H, 5.30. Found: C, 62.90; H, 5.32. In analogy to the trans configuration of the relevant 3,6-diphenyl-1,2,4,5-tetroxane (**5b**) (the structure has been unambiguously determined by the X-ray analysis[20]), this cycle peroxide **5a** also would be a trans isomer. The second fraction (elution with ether–benzene, 1:10 v/v), contained *p*-anisaldehyde (**6a**). The third fraction (elution with ether) contained *p*-anisic acid (**7a**).

The ozonolysis of **1f** (1 mmol) was undertaken under the similar conditions. Column chromatography of the crude products on silica gel (elution with benzene–hexane, 1:10) gave first the tetroxane **5f**: mp 126–128 °C (lit.[21] mp 123–126 °C). The melting point and IR spectra were the same as those of the authentic sample prepared by the reported method.[21] The second fraction contained cyclohexanone (**6f**). Subsequent elution with ether–benzene (1:1) gave unidentified oily products having the following physical properties (ca. 40 wt %): IR (film) 3450, 2990, 2775, 1702, 1440, 1350, 1290, 1280, 1150, 1098, 1060, 940, 920 cm^{-1}; ^{1}H NMR δ 1.3–2.1 (m), 2.25 (t, *J* = 6 Hz), 9.42 (s), the ratios of the peak areas being around 26:2:1.

Ozonolysis in Methyl Formate. The ozonolysis of 1-phenyl-2-methoxyethene (**1b**) in methyl formate is representative. To a solution of **1b** (1 mmol) in methyl formate (20 mL) was passed 1 equiv of ozone at −70 °C. After evaporation of methyl formate, the products were column chromatographed on silica gel. Elution with benzene–hexane (1:1 v/v) afforded 3,6-diphenyl-1,2,4,5-tetroxane (**5b**): mp 210–211 °C (from ethanol); ^{1}H NMR δ 6.92 (s, 2 H), 7.10–7.80 (m, 10 H).[22] Subsequent elution afforded benzaldehyde (**6b**).

Ozonolysis on Polyethylene. The reactions have been carried out by a procedure which had been published previously in great detail.[6c]

Ozonolysis of 1-(4-Methoxyphenyl)-2-methoxyethene (1a). A 54:46 mixture (1.417 g, 8.64 mmol) of *trans*- and *cis*-**1a** was

---

[16] Criegee, R.; Bath, S. S.; von Bornhaupt, B. *Chem. Ber.* **1960**, *93*, 2891.

[17] Wittig, G.; Schlosser, M. *Chem. Ber.* **1961**, *94*, 1373.

[18] Earnshaw, G.; Wallis, C. J.; Warren, S. *J. Chem. Soc., Perkin Trans. 1*, **1979**, 3099.

[19] Timmler, H.; Draber, W.; Buechel, H.; Plempel, M. *Ger. Offen.* 2037610; *Chem. Abstr.* **1972**, *76*, P140829w.

[20] Groth, P. *Acta Chem. Scand.* **1967**, *21*, 2695.

[21] Story, P. R.; Lee, B.; Bishop, C. E.; Denson, D. D.; Busch, P. B. *J. Org. Chem.* **1970**, *35*, 3059.

[22] Kharasch, M. S.; Sosnovski, G. *J. Org. Chem.* **1958**, *23*, 1322.

Table III. Ozonolyses of Vinyl Ethers 1a–f in the Presence of Carbonyl Compounds[a]

				products		
vinyl ether	carbonyl compound	solvent	reaction temp, °C	ozonide (% yield)	ratio cis:trans	others (% yield)
1a	**6c**	CH_2Cl_2	0	**15a** (10)	44:56	
1a	**6i**	ether	−70	**15b** (15)		**5a** (19), **6a** (9)
1a	**6j**	CH_2Cl_2	0	**15c** (44)[b]		
1a	**6k**	CH_2Cl_2	0	**15d** (51)		
1b	**6b**	pentane	0	**13b** (35)	30:70	
1b	**6b**	ether	0	**13b** (25)	29:71	
1b	**6b**	CH_2Cl_2	0	**13b** (21)	33:67	
1b	**6c**	CH_2Cl_2	0	**16a** (49)	64:36	
1b	**6g**	pentane	−70	**16b** (27)	30:70	**6b** (8)
1b	**6g**	ether	−70	**16b** (65)	29:71	**5b** (4)
1b	**6g**	CH_2Cl_2	−70	**16b** (17)	33:67	**5b** (1)
1b	**6h**	CH_2Cl_2	−70	**16c** (23)	61:39	**5b** (1)
1b	**6i**	ether	−70	**16d** (32)		**5b** (6), **6b** (21)
1b	**6i**	CH_2Cl_2	−70	**16d** (14)		**5b** (4)
1b	**6j**	CH_2Cl_2	0	**16e** (50)[c]		
1b	**6k**	CH_2Cl_2	0	**16f** (73)		
1c	**6b**	ether	0	**16a** (50)	42:58	
1c	**6b**	CH_2Cl_2	0	**16a** (30)	41:59	
1c	**6c**	ether	0	**13c** (53)		
1c	**6c**	CH_2Cl_2	0	**13c** (74)		
1c	**6i**	ether	−70	**17a** (38)		**6c** (7), **13c** (7)
1c	**6i**	CH_2Cl_2	−70	**17a** (26)		**6c** (21), **13c** (6)
1c	**6j**	CH_2Cl_2	0	**17b** (61)[d]		**13c** (3)
1c	**6k**	CH_2Cl_2	0	**17c** (78)		
1d	**6b**	ether	0	**18a** (31)	56:44	
1d	**6b**	CH_2Cl_2	0	**18a** (28)	44:56	
1d	**6c**	ether	0	**18b** (61)	34:66	
1d	**6c**	CH_2Cl_2	0	**18b** (32)	36:64	
1d	**6i**	CH_2Cl_2	−70			**7d** (39)
1d	**6k**	CH_2Cl_2	0	**18c** (46)		
1e	**6b**	ether	0	**19a** (34)		**5e** (1)
1e	**6b**	CH_2Cl_2	0	**19a** (4)		**5e** (9)
1e	**6c**	CH_2Cl_2	0	**19b** (24)		**5e** (28)
1e	**6g**	ether	−70	**19c** (28)		**5e** (11)
1e	**6g**	CH_2Cl_2	−70	**19c** (4)		**5e** (20)
1e	**6h**	CH_2Cl_2	−70	**19d** (13)		**5e** (9)
1e	**6i**	ether	−70			**5e** (24)
1e	**6i**	CH_2Cl_2	−70			**5e** (10)
1e	**6k**	CH_2Cl_2	0	**19e** (62)		**5e** (1)
1f	**6b**	CH_2Cl_2	0			**5f** (6)
1f	**6c**	CH_2Cl_2	0	**20a** (11)		
1f	**6k**	CH_2Cl_2	0	**20b** (80)		

[a] Reaction of vinyl ether (1 mmol) with 1 equiv of ozone in the presence of 5 mol equiv of a carbonyl compound. [b] The ratio of the major ozonide to the minor one = 64:36. [c] The ratio of the isomeric ozonides = 59:41. [d] The ratio of the isomeric ozonides = 61:39.

loaded on 109 g of polyethylene from an ether solution and ozonized for 7 h at −75 °C. A small sample was extracted with $CDCl_3$. ^1H NMR analysis of the extract showed the presence of 3% of *cis*-**13a**, 4% of *trans*-**13a**, 9% of *cis*-**14a**, and 35% of *trans*-**14a**. The products were extracted with ether, and the ether was evaporated to leave 1.40 g of a semisolid peroxidic residue. From 0.63 g of this residue, 23 mg (2.8%) of *trans*-**14a**, 45 mg (5.5%) of a 1:4.5 mixture of *cis*- and *trans*-**14a**, and trace amounts of *cis*-**13a** and of *trans*-**13a** were isolated by column chromatography (silica gel; pentane–ether, 10:1).

***cis*-3-Methoxy-5-(4-methoxyphenyl)-1,2,4-trioxolane (14a)** (in admixture with 82% of *trans*-**14a**): colorless liquid; ^1H NMR δ 3.52 (s, 3 H), 3.82 (s, 3 H), 5.60 (s, 1 H), 6.12 (s, 1 H), 6.94 (d, J = 8.7 Hz, 2 H), 7.53 (d, J = 8.7 Hz, 2 H); ^{13}C NMR (−20 °C) δ 52.36, 55.37, 104.31, 113.94, 114.08, 124.54, 129.81, 161.24; EI-MS m/e (relative intensity) 152 (36) $[M - HCOOCH_3]^+$, 124 (64), 109 (100), 81 (27), 53 (7); GLC t_R = 18.01 min.

***trans*-3-Methoxy-5-(4-methoxyphenyl)-1,2,4-trioxolane (14a)**: purity >95%; colorless liquid; ^1H NMR δ 3.53 (s, 3 H), 3.82 (s, 3 H), 6.22 (s, 1 H), 6.36 (s, 1 H), 6.93 (d, J = 8.7 Hz, 2 H), 7.44 (d, J = 8.7 Hz, 2 H); ^{13}C NMR (−20 °C) δ 51.64, 55.35, 103.30, 113.75, 113.86, 124.02, 128.85, 160.97; EI-MS m/e (relative intensity) 124 (86), 109 (100), 81 (33), 53 (10); IR (film) 2928, 2896, 2816, 1552, 1520, 1376, 1264, 1216, 1184, 1104, 1072, 928, 832, 752 cm^{-1}; GLC t_R = 17.19 min. Anal. Calcd for $C_{10}H_{12}O_5$: C, 56.60; H, 5.70. Found: C, 55.30; H, 5.38. ^1H NMR analysis of a neat sample which was kept at room temperature showed that it was completely decomposed. This explains the incorrect elemental analysis data.

***cis*-3,5-Bis(4-methoxyphenyl)-1,2,4-trioxolane (13a)**: colorless solid; mp 74–78 °C (lit.[23] mp 76–78 °C); ^1H NMR δ 3.83 (s, 6 H), 6.28 (s, 2 H), 6.94 (d, J = 8.75 Hz, 4 H), 7.49 (d, J = 8.75 Hz, 4 H); ^{13}C NMR (−20 °C) δ 55.37, 104.31, 114.10, 126.25, 128.90, 161.15.

***trans*-3,5-Bis(4-methoxyphenyl)-1,2,4-trioxolane (13a)**:[24] colorless solid; mp 139–140 °C [lit.[24] mp 73.9–74.5 °C; ^1H NMR δ 3.73 (s, 6 H), 6.13 (s, 2 H), 6.83 (d, 4 H), 7.37 (d, 4 H)]; ^1H NMR δ 3.84 (s, 6 H), 6.33 (s, 2 H), 6.96 (d, J = 8.75 Hz, 4 H), 7.55 (d, J = 8.75 Hz, 4 H); ^{13}C NMR (−20 °C) δ 55.34, 105.22, 113.92, 123.46, 129.51, 161.24; EI-MS m/e (relative intensity) 288 (1) $[M]^+$, 256 (2) $[M - O_2]^+$, 152 (24) $[M - C_8H_8O_2]^+$, 135 (100) $[C_8H_7O_2]^+$, 77 (35) $[C_6H_5]^+$, 28 (78) $[CO]^+$. Anal. Calcd for $C_{16}H_{16}O_5$: C, 66.65; H, 5.59. Found: C, 66.16; H, 5.53.

Reduction of *trans*-13a. A solution of *trans*-**13a** and of triphenylphosphine in $CDCl_3$ was heated to 50 °C for 3 h. ^1H NMR analysis showed the presence of *p*-anisaldehyde (**6a**) (δ 3.89 (s), 7.01 (d, J = 8.7 Hz), 7.84 (d, J = 8.7 Hz), 9.89 (s)) as the sole product. It was identified on the basis of the identity of its GLC retention time (18.05 min) with that of an authentic sample.

Decomposition of *cis*-13a. A solution of *cis*-**13a** in $CDCl_3$ was kept at room temperature for 3 days. ^1H NMR analysis

---

(23) Tautomu, M.; Masaki, K. *J. Chem. Soc., Chem. Commun.* **1986**, 1577.

(24) Our assignment of *trans*-**13a** is in contrast to that of Futamura et al. in which the formation of *trans*-ozonide was suggested, yet *cis*-ozonide was probably obtained: Futamura, S.; Kusunose, S.; Ohta, H.; Kamiya, Y. *J. Chem. Soc., Perkin Trans 1* **1984**, 15.

Table IV. Physical Properties of Vinyl Ethers 1a–f

vinyl ether	bp, °C (mmHg)	^{1}H NMR, δ
trans-**1a**[a,h]	170 (10)	3.65 (s, 3 H), 3.77 (s, 3 H), 5.77 (d, *J* = 13.0 Hz, 1 H), 6.93 (d, *J* = 13.0 Hz, 1 H), 6.79–7.53 (m, 4 H)
cis-**1a**[b,h]	170 (10)	3.74 (s, 3 H), 3.78 (s, 3 H), 5.17 (d, *J* = 7.0 Hz, 1 H), 6.04 (d, *J* = 7.0 Hz, 1 H), 6.79–7.53 (m, 4 H)
trans-**1b**[c]	67 (3)	3.68 (s, 3 H), 5.81 (d, *J* = 13.0 Hz, 1 H), 7.05 (d, *J* = 13.0 Hz, 1 H), 7.13–7.29 (m, 5 H)
cis-**1b**[c]	67 (3)	3.78 (s, 3 H), 5.22 (d, *J* = 7.0 Hz, 1 H), 6.14 (d, *J* = 7.0 Hz, 1 H), 7.10–7.59 (m, 5 H)
trans-**1c**[d,h]	70 (4)	3.71 (s, 3 H), 6.13 (dd, *J* = 12.7 and 2.2 Hz, 1 H), 6.98 (d, *J* = 12.7 Hz, 1 H), 7.19–7.61 (m, 4 H)
cis-**1c**[d,h]	70 (4)	3.71 (s, 3 H), 5.54 (dd, *J* = 7.3 and 2.1 Hz, 1 H), 6.20 (d, *J* = 7.3 Hz, 1 H), 7.14–8.16 (m, 4 H)
trans-**1d**[e,h]		0.85–2.05 (m 15 H), 3.50 (s, 3 H), 4.74 (dt, *J* = 12.6 and 7.3 Hz, 1 H), 6.28 (d, *J* = 12.6 Hz, 1 H)
cis-**1d**[f,h]		0.85–2.05 (m, 15 H), 3.58 (s, 3 H), 4.34 (q, *J* = 7.3 Hz, 1 H), 5.86 (d, *J* = 7.3 Hz, 1 H)
1e	134 (1)[g]	3.75 (s, 3 H), 6.45 (s, 1 H), 7.18–7.40 (m, 10 H)
1f	79–84 (15)	1.49–1.50 (m, 6 H), 1.92–1.95 (m, 2 H), 2.15–2.19 (m, 2 H), 3.53 (s, 3 H), 5.74 (s, 1 H)

[a] In admixture with 46% of *cis*-**1a**. [b] In admixture with 54% of *trans*-**1a**. [c] From 0.89 g of a 2:3 mixture of *cis*- and *trans*-**1b** 242 mg of *cis*-**1b** and 286 mg of *trans*-**1b** were isolated by column chromatography (silica gel; pentane–benzene, 1:1). [d] From 5.0 g of a 4:5 mixture of *cis*- and *trans*-**1c** 1.252 g of *cis*-**1c** and 1.445 g of *trans*-**1c** were isolated by column chromatography (silica gel; pentane–ether, 4:1). [e] In admixture with 34% *cis*-**1d**. [f] In admixture with 66% of *trans*-**1d**. [g] Colorless solid, mp 34 °C. [h] Elemental analyses of new compounds; *trans*-**1a** (in admixture with 35% of *cis*-**1a**), calcd ($C_{10}H_{12}O_2$): C, 73.17; H, 7.32. Found: C, 73.30; H, 7.05. *cis*-**1a** (in admixture with 28% of *trans*-**1a**), calcd ($C_{10}H_{12}O_2$): C, 73.17; H, 7.32. Found: C, 73.35; H, 7.05. *trans*-**1c**, calcd ($C_{10}H_9F_3O$): C, 59.41; H, 4.45. Found: C, 59.15; H, 4.50. *cis*-**1c**, calcd ($C_{10}H_9F_3O$): C, 59.41; H, 4.45. Found: C, 59.40; H, 4.35. *trans*-**1d**, calcd ($C_{10}H_{20}O$): C, 76.92; H, 12.82. Found: C, 76.70; H, 12.95. *cis*-**1d**, calcd ($C_{10}H_{20}O$): C, 76.92; H, 12.82. Found: C, 77.01; H, 12.80.

Table V Physical Properties of α-Methoxy Hydroperoxides 4a–f[a]

hydroperoxide	^{1}H NMR, δ[h]
4a[b]	3.15 (s, 3 H), 3.66 (s, 3 H), 5.52 (s, 1 H), 6.60–7.35 (m, 4 H), 9.60 (br s, 1 H)
4b[c]	3.46 (s, 3 H), 5.59 (s, 1 H), 7.00–7.54 (m, 5 H), 9.12 (br s, 1 H)
4c[d]	3.57 (s, 3 H), 5.93 (s, 1 H), 7.13–7.80 (m, 4 H), 9.03 (br s, 1 H)
4d[e]	0.67–1.83 (m, 15 H), 3.43 (s, 3 H), 4.62 (t, *J* = 4.0 Hz, 1 H), 9.00 (br s, 1 H)
4e[f]	3.18 (s, 3 H), 6.90–7.80 (m, 10 H), 8.45 (br s, 1 H)
4f[g]	1.10–1.90 (m, 10 H), 3.27 (s, 3 H), 8.43 (br s, 1 H)

[a] All these hydroperoxides were isolated as oils. [b] Scharp, D. B.; Patrick, T. M. *J. Org. Chem.* **1961**, *26*, 1389. [c] Keaveny, W. P.; Berger, M. G.; Pappas, J. J. *J. Org. Chem.* **1967**, *32*, 1537. [d] Anal. Calcd ($C_9H_9F_3O_3$): C, 48.65; H, 4.05. Found: C, 48.91; H, 4.00. [e] Anal. Calcd ($C_9H_{20}O_3$): C, 61.36; H, 11.36. Found: C, 60.80; H, 11.57. [f] Ogata, Y.; Sawaki, Y.; Shiroyama, M. *J. Org. Chem.* **1977**, *42*, 4061. [g] Tsutsumi, S.; Kida, Y. Japan Kokai 7595215; *Chem. Abstr.* **1976**, *84*, P4506b. [h] Recorded in CCl_4.

showed the presence of *p*-anisaldehyde (**6a**) and of minor byproducts.

Reduction of 14a. A solution of **14a** (trans:cis = 7:3) and triphenylphosphine in $CDCl_3$ was kept at room temperature for 1 h. ^{1}H NMR analysis showed the presence of *p*-anisaldehyde (**6a**) and methyl formate (**3**) (δ 3.77 (d, *J* = 0.8 Hz), 8.06 (q, *J* = 0.8 Hz)) in a molar ratio of 1.1:1. GLC analysis showed the peaks of **6a** (t_R = 18.07 min) and **3** (t_R = 5.81 min), as confirmed by injection of authentic samples.

Ozonolysis of 1-Phenyl-2-methoxyethene (1b). A 1:9 mixture (1.049 g, 7.83 mmol) of *trans*- and *cis*-**1b** was loaded on 84 g of polyethylene from an ether solution and ozonized at –75 °C for 5 h. A small sample was extracted with $CDCl_3$. ^{1}H NMR analysis of the extract showed the presence of 3.9% of **6b**, 2.4% of *cis*-**13b**, 3.1% of *trans*-**13b**, 9.5% of *cis*-**14b**, 24.8% of *trans*-**14b**, and 5.7% of methyl phenylacetate (**11**). The products were extracted with ether, and the ether was evaporated at room temperature at 15 Torr to leave 0.87 g of a liquid residue. From the liquid residue (0.87 g), 37.5 mg (2.1%) of a 2:3 mixture of *cis*- and *trans*-**13b**, 51 mg (3.6%) of *trans*-**14b**, 232 mg (16.3%) of a 52:48 mixture of *cis*- and *trans*-**14b**, and 27 mg (2.3%) of **11** were isolated by column chromatography (silica gel; pentane–ether, 20:1).

***cis*-3,5-Diphenyl-1,2,4-trioxolane (13b)**[25] (in admixture with 60% of *trans*-**13b**): ^{1}H NMR δ 6.33 (s, 2 H), 7.37–7.64 (m, 10 H).

***trans*-3,5-Diphenyl-1,2,4-trioxolane (13b)**[25] (in admixture with 40% of *cis*-**13b**): ^{1}H NMR δ 6.36 (s, 2 H), 7.37–7.64 (m, 10 H).

***cis*-3-Methoxy-5-phenyl-1,2,4-trioxolane (14b)**:[26] purity >90%; colorless liquid; ^{1}H NMR δ 3.53 (s, 3 H), 6.03 (s, 1 H), 6.15 (s, 1 H), 7.43–7.49 (m, 3 H), 7.59–7.62 (m, 2 H); ^{13}C NMR (–20 °C) δ 52.63, 104.18, 113.73, 128.26, 128.74, 129.39, 131.16; IR (film) 2944, 2864, 2384, 2368, 1472, 1344, 1216, 1120, 1088, 912, 864 cm^{-1}. The compound decomposed at room temperature. Hence, no elemental analysis was performed.

***trans*-3-Methoxy-5-phenyl-1,2,4-trioxolane (14b)**: purity >95%; colorless liquid; ^{1}H NMR δ 3.53 (s, 3 H), 6.22 (s, 1 H), 6.43 (s, 1 H), 7.41–7.44 (m, 3 H), 7.48–7.52 (m, 2 H); ^{13}C NMR (–20 °C) δ 51.80, 103.08, 113.51, 126.84, 128.57, 130.38, 133.25; EI-MS *m/e* (relative intensity) 122 (15) $[M - HCOOCH_3]^+$, 106 (34) $[C_6H_5CHO]^+$, 105 (45) $[C_6H_5CO]^+$, 77 (46) $[C_6H_5]^+$, 71(100), 51 (15); IR (film) 2960, 2848, 2432, 1488, 1456, 1376, 1296, 1264, 1216, 1200, 1120, 1040, 784, 768 cm^{-1}; GLC t_R = 19.53 min. The compound decomposed at room temperature. Hence, no elemental analysis was performed.

Methyl phenylacetate (11):[27] viscous liquid; ^{1}H NMR δ 3.63 (s, 2 H), 3.69 (s, 3 H), 7.21–7.38 (m, 5 H).

Reduction of 14b. A solution of **14b** (trans:cis = 4:1) and dimethyl sulfide in $CDCl_3$ was kept at ambient temperature for 3 days. ^{1}H NMR analysis showed the presence of *cis*-**14b** (δ 6.03 (s), 6.15 (s)), benzaldehyde (**6b**) (δ 7.62–7.68 (m), 7.87–7.91 (m), 10.03 (s)), and methyl formate (**3**) in a molar ratio of 2.4:1.0:2.1. The solvent was evaporated at room temperature. From the residue *cis*-**14b** was isolated by column chromatography (silica gel, pentane–ether, 1:1).

Decomposition of 14b. A solution of **14b** (trans:cis = 2:1) in $CDCl_3$ was kept at ambient temperature for 4 days. ^{1}H NMR analysis showed the presence of *trans*-**14b** (δ 6.22 (s), 6.43 (s)), benzaldehyde (**6b**), and methyl formate (**3**) in a molar ratio of 1:1.3:1.4. The mixture was evaporated at room temperature to leave *trans*-**14b** as the residue.

Ozonolysis of *trans*-1-(2-(Trifluoromethyl)phenyl)-2-methoxyethene (1c). Compound *trans*-**1c** (1.27 g, 6.28 mmol) was loaded on 96 g of polyethylene from an ether solution and ozonized for 10 h at –75 °C. A small sample was extracted with $CDCl_3$. ^{1}H NMR analysis of the extract showed the presence of 7% of *cis*-**14c** and 49% of *trans*-**14c** corresponding to a cis–trans ratio of 1:7. The products were extracted with ether, and the extract was evaporated at room temperature and 15 Torr to leave 1.24 g of a peroxidic liquid residue. From the residue (0.8 g) 8 mg (0.4%) of *trans*-**13c**, 6 mg (0.3%) of *cis*-**13c**, 13 mg (0.8%) of *trans*-**14c**, and 75 mg (4.8%) of a 79:21 mixture of *cis*- and

---

(25) Schaap, A. P.; Shahabuddin, S.; Gagnon, D.; Lopez, L. *J. Am. Chem. Soc.* **1983**, *105*, 5149.

(26) From a 1:4 mixture of *cis*- and *trans*-**14b**, *cis*-**14b** could be isolated by reducing the more reactive *trans*-**14b** upon addition of a stoichiometric amount of dimethyl sulfide followed by column chromatograpy.

(27) *The Aldrich Library of NMR Spectra*; Aldrich: Milwaukee, 1974; Vol. 7, p 23.

trans-**14c** were isolated by column chromatography (silica gel, pentane–ether, 30:1).

***cis*-3,5-Bis(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (13c)**: viscous liquid; ^{1}H NMR (−20 °C) δ 6.73 (s, 2 H), 7.54–7.82 (m, 8 H); ^{13}C NMR (−20 °C) δ 100.25, 123.66 (q, J = 274.0 Hz), 126.21, 128.24, 129.15 (q, J = 31.5 Hz), 130.26, 131.49, 132.34. Anal. Calcd for $C_{16}H_{10}F_6O_3$: C, 52.76; H, 2.77. Found: C, 52.84; H, 2.79.

***trans*-3,5-Bis(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (13c)**: viscous liquid; ^{1}H NMR (−20 °C) δ 6.75 (s, 2 H), 7.55–8.03 (m, 8 H); ^{13}C NMR (−20 °C) δ 100.86, 123.53 (q, 274.0 Hz), 125.97, 128.95, 129.51 (q, J = 31.5 Hz), 129.95, 130.83, 132.48. Anal. Calcd for $C_{16}H_{10}F_6O_3$: C, 52.76; H, 2.77. Found: C, 52.55; H, 2.69.

***cis*-3-Methoxy-5-(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (14c)** (in admixture with 70% of *trans*-**14c**): colorless liquid; ^{1}H NMR δ 3.54 (s, 3 H), 6.14 (s, 1 H), 6.40 (s, 1 H), 7.57–8.11 (m, 4 H); ^{13}C NMR (−20 °C) δ 53.19, 99.62, 114.01, 123.40 (q, J = 274.0 Hz), 125.81, 128.29 (q, J = 31.5 Hz), 129.54, 130.97, 132.01, 132.50; EI-MS m/e (relative intensity) 190 (34) $[M - HCOOCH_3]^+$, 174 (45) $[C_8H_5F_3O]^+$, 173 (100) $[C_8H_4F_3O]^+$, 145 (81) $[C_7H_4F_3]^+$, 126 (31), 95 (21), 75 (26) $[C_2H_3O_3]^+$; GLC t_R = 19.56 min.

***trans*-3-Methoxy-5-(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (14c)**: colorless liquid; ^{1}H NMR δ 3.53 (s, 3 H), 6.26 (s, 1 H), 6.82 (s, 1 H), 7.51–7.82 (m, 4 H): ^{13}C NMR δ 52.11, 99.39, 113.21, 123.82 (q, J = 274.0 Hz), 126.27 (q, J = 31.5 Hz), 126.36, 127.86, 130.29, 131.92, 132.12; EI-MS m/e (relative intensity) 190 (61) $[M - HCOOCH_3]^+$, 174 (14) $[C_8H_5F_3O]^+$, 173 (100) $[C_8H_4F_3O]^+$, 145 (61) $[C_7H_4F_3]^+$, 126 (17), 95 (17) $[C_6H_4F]^+$, 75 (19) $[C_2H_3O_3]^+$; IR (film) 2896, 2880, 1552, 1312, 1280, 1216, 1168, 1120, 1072, 1056, 992, 768 cm^{-1}; GLC t_R = 18.48 min.. Anal. Calcd for $C_{10}H_9F_3O_4$: C, 48.01; H, 3.62. Found: C, 48.08; H, 3.50.

Ozonolysis of *cis*-1-(2-(Trifluoromethyl)phenyl)-2-methoxyethene (1c). Compound *cis*-**1c** (1.18 g, 5.84 mmol) on 95 g of polyethylene was ozonized at −75 °C for 11 h, and the product was worked up as described above. ^{1}H NMR analysis showed the presence of 9% of *cis*-**14c** and 53% of *trans*-**14c**, corresponding to a cis–trans ratio of 1:5.9. The remainder of the polyethylene was three times extracted with ether, and the combined extracts were evaporated at room temperature and 15 Torr to leave 0.82 g of a liquid residue. From the residue (0.82 g) 11 mg (0.6%) of *trans*-**13c**, 13 mg (0.7%) of *cis*-**13c**, 18 mg (1.2%) of *trans*-**14c**, and 92 mg (6.3%) of a 79.21 mixture of *cis*- and *trans*-**14c** were isolated by column chromatography (silica gel; pentane–ether, 30:1).

Reduction of 14c. A 7:3 mixture of *trans*- and *cis*-**14c** and dimethyl sulfide in $CDCl_3$ was kept at room temperature for 3 days. ^{1}H NMR analysis showed the presence of 2-(trifluoromethyl)benzaldehyde (**6c**) (δ 7.69–7.83 (m), 8.12–8.16 (m), 10.4 (s)) and methyl formate (**3**) in a molar ratio of 1.7:1.

Ozonolysis of 1-Methoxy-1-nonene (1d). A 66:34 mixture (0.894 g, 5.73 mmol) of *trans*- and *cis*-**1d** was loaded on 80 g of polyethylene from an ether solution and ozonized for 4 h at −75 °C. A small sample was extracted with $CDCl_3$. ^{1}H NMR analysis of the extract showed the presence of 38% of *trans*-**14d** and 23% of *cis*-**14d**. The remainder of the polyethylene was extracted with ether, and the ether was evaporated to leave 0.870 g of a liquid residue. From the liquid residue (0.870 g) 469 mg of a mixture containing *cis*- and *trans*-**14d** (38:62) and polymers was isolated by column chromatography (silica gel; pentane–ether, 30:1). From this 128 mg (11%) of a 34:66 mixture of *cis*- and *trans*-**14d** was distilled at room temperature and 10^{-3} Torr and collected in a trap at −40 °C. The residue (300 mg) consisted of a polymeric material.

***cis*-3-Heptyl-5-methoxy-1,2,4-trioxolane (14d)**:[28] purity >90%; colorless liquid; ^{1}H NMR δ 0.88 (t, J = 6.4 Hz, 3 H), 1.21–1.51 (m, 10 H), 1.80–1.84 (m, 2 H), 3.42 (s, 3 H), 5.13 (t, J = 5.11 Hz, 1 H), 5.99 (s, 1 H); ^{13}C NMR (−20 °C) δ 14.24, 22.64, 23.99, 28.98, 29.06, 29.31, 31.63, 51.99, 104.67, 112.77; IR (film) 2944, 2912, 2848, 1472, 1392, 1200, 1088, 1040, 992, 752 cm^{-1}; GLC t_R = 20.66 min. The compound decomposed when kept at room temperature. Hence, no elemental analysis was performed.

***trans*-3-Heptyl-5-methoxy-1,2,4-trioxolane (14d)** (in admixture with 34% of *cis*-**14d**): colorless liquid; ^{1}H NMR δ 0.88 (t, J = 6.4 Hz, 3 H), 1.28–1.48 (m, 10 H), 1.62–1.72 (m, 2 H), 3.43 (s, 3 H), 5.51 (t, J = 5.26 Hz, 1 H), 5.99 (s, 1 H); ^{13}C NMR (−20 °C) δ 14.03, 22.61, 23.76, 29.02, 29.16, 29.36, 31.70, 51.37, 104.80, 113.00; EI-MS m/e (relative intensity) 144 (3) $[M - HCOOCH_3]^+$, 115 (14), 101 (32), 84 (57), 60 (100) $[HCOOCH_3]^+$, 43 (35), 29 (16); GLC t_R = 20.66 min..

Reduction of 14d. To a stirred solution of 38 mg of ozonide **14d** (trans:cis = 7:3) in 5 mL of $CDCl_3$ was added 22 mg of dimethyl sulfide at room temperature. ^{1}H NMR analysis after 16 days showed the presence of *cis*-**14d** (δ 5.13 (t, J = 5.11 Hz)), octylaldehyde (**6d**) (δ 9.77 (t, J = 1.8 Hz)), and methyl formate (**3**) in a ratio of 1.0:1.8:1.8. The solvent was evaporated at room temperature and 15 Torr to leave 13 mg of a liquid residue. From the residue 4 mg of *cis*-**14d** was isolated by column chromatography (silica gel; pentane–ether, 1:1).

Ozonolysis of 1,1-Diphenyl-2-methoxyethene (1e). Compound **1e** (1.67 g, 7.95 mmol) was loaded on 127 g of polyethylene from an ether solution and ozonized at −75 °C for 24 h. A small sample was extracted with $CDCl_3$. ^{1}H NMR analysis of the extract showed the presence of 3.5% of **5e**, 13.5% of **14e**, 15.2% of **8**, and 9.7% of **9**. The remainder of the polyethylene was three times extracted with ether, and the combined extracts were evaporated at room temperature and ca. 15 Torr to leave 1.47 g of a semisolid residue. From this residue 142 mg (6.9%) of **14e**, 120 mg (4.0%) of **5e**, 23 mg (1.3%) of **8**, and 13 mg (0.8%) of **9** were isolated by column chromatography (silica gel; pentane–ether, 30:1).

3,3,6,6-Tetraphenyl-1,2,4,5-tetroxane (5e): colorless solid; mp 159–162 °C (from MeOH) (lit.[29] mp 155–162 °C); ^{1}H NMR δ 7.29–7.44 (m, 20 H), ^{13}C NMR δ 112.0 (2 C), 127.39 (4 C), 128.05 (8 C), 128.77 (8 C), 139.23 (4 C).

3-Methoxy-5,5-diphenyl-1,2,4-trioxolane (14e): purity >95%; colorless liquid; ^{1}H NMR δ 3.49 (s, 3 H), 6.07 (s, 1 H), 7.31–7.60 (m, 10 H); ^{13}C NMR δ 52.08, 110.76, 114.22, 126.38, 127.80, 128.20, 128.34, 128.58, 128.78, 129.71, 135.42, 139.78; IR (film) 3088, 3056, 2960, 2928, 2848, 1744, 1664, 1616, 1504, 1456, 1328, 1280, 1264, 1120, 1072, 1024, 928, 768, 720, 656 cm^{-1}. Anal. Calcd for $C_{15}H_{14}O_4$: C, 69.75; H, 5.46. Found: C, 70.39; H, 5.71.

2,2-Diphenyl-3-methoxyoxirane (8):[30] colorless liquid; ^{1}H NMR δ 3.54 (s, 3 H), 4.82 (s, 1 H), 7.29–7.60 (m, 10 H).

1,1-Diphenyl-1-hydroxyacetaldehyde (9): viscous liquid; ^{1}H NMR δ 4.40 (br s, 1 H), 6.97–7.98 (m, 10 H), 9.99 (s, 1 H) [lit.[31] ^{1}H NMR δ 6.93–7.98 (m, 10 H), 9.84 (s, 1 H)].

Reduction of 14e. A solution of **14e** and dimethyl sulfide in $CDCl_3$ was kept at room temperature for 2 days. ^{1}H NMR analysis showed the presence of **14e** (δ 6.07 (s, 1 H)), methyl formate (**3**), and benzophenone (**6e**) (δ 7.41–7.82 (m)) in a molar ratio of 4.9:1.0:1.9.

Ozonolysis of (Methoxymethylene)cyclohexane (1f). Compound **1f** (0.73 g, 5.8 mmol) was loaded on 60 g of polyethylene in a stream of nitrogen and ozonized for 5 h at −75 °C. A small sample was extracted with $CDCl_3$. ^{1}H NMR analysis of the extract showed the presence of 14.6% of **14f** and 55.5% of a mixture of **5f** and **13f** in a ratio of 5:95. The remainder of the polyethylene was extracted with ether, and the ether was removed in a rotatory evaporator at ambient temperature and ca. 15 Torr. From the liquid residue (0.51 g) 27 mg (3%) of **14f** and 81 mg of a 1:8 mixture of **5f** and **13f** was isolated by column chromatography (silica gel; pentane–ether, 30:1). The latter were identified on the basis of the identity of their GLC retention times (**5f**, t_R = 28.14 min; **13f**, t_R = 23.62 min) with those of authentic samples.[15]

9-Methoxy-7,8,10-trioxaspiro[5.4]decane (14f): colorless liquid; ^{1}H NMR δ 1.61–1.75 (m, 10 H), 3.41 (s, 3 H), 5.93 (s, 1 H); ^{13}C NMR (−20 °C) δ 23.1, 23.9, 24.5, 31.8, 33.4, 52.3, 110.6, 112.8; EI-MS m/e (relative intensity) 143 (12) $[M - OCH_3]^+$, 114 (41) $[M - HCOOCH_3]^+$, 98 (62) $[C_6H_{10}O]^+$, 69 (85) $[C_4H_5O]^+$, 55 (76) $[C_3H_3O]^+$, 42 (77) $[C_3H_6]^+$, 41 (100) $[C_3H_5]^+$; IR (film) 2960, 2880, 1472, 1360, 1216, 1184, 1136, 1120, 1072, 1024, 896, 816 cm^{-1}; GLC t_R = 16.67 min. Anal. Calcd for $C_8H_{14}O_4$: C, 55.16; H, 8.10. Found: C, 55.17; H, 7.82.

Reduction of 14f. A solution of **14f** and triphenylphosphine

---

(28) From 38 mg of a 3:7 mixture of *cis*- and *trans*-**14d** 4 mg of *cis*-**14d** could be isolated by reducing the more reactive *trans*-**14d** upon addition of dimethyl sulfide followed by column chromatography.

(29) Criegee, R.; Lohaus, G. *Justus Liebigs Ann. Chem.* **1953**, *583*, 6.

(30) Authentic sample of **8** was prepared by epoxidation of **1e**.

(31) Tada, M.; Okabe, M.; Miura, K. *Chem. Lett.* **1978**, 1135; *Tetrahedron Lett.* **1972**, 2681.

Table VI. Physical Properties of the Ozonides 15–20 Obtained from the Ozonolysis of Vinyl Ethers 1 in the Presence of Added Carbonyl Compounds

ozonide[a,b]	^{1}H NMR, δ[f]	anal.
trans-**15a**	3.75 (s, 3 H), 6.15 (s, 1 H), 6.57 (br s, 1 H), 6.72–7.98 (m, 8 H)	calcd ($C_{16}H_{13}F_3O_4$): C, 58.96; H, 4.02 found: C, 58.86; H, 4.11
cis-**15a**	3.72 (s, 3 H), 6.06 (s, 1 H), 6.63 (br s, 1 H), 6.72–7.98 (m, 8 H)	calcd ($C_{16}H_{13}F_3O_4$): C, 58.96; H, 4.02 found: C, 58.90; H, 4.22
15b	1.56 (s, 3 H), 1.59 (s, 3 H), 3.75 (s, 3 H), 5.82 (s, 1 H), 6.78–7.47 (m, 4 H)	calcd ($C_{11}H_{14}O_4$): C, 62.85; H, 6.71 found: C, 62.79; H, 6.77
15c (major isomer)[c]	1.68 (s, 3 H), 3.57 (s, 2 H), 3.74 (s, 3 H), 5.96 (s, 1 H), 6.74–7.37 (m, 4 H)	calcd ($C_{11}H_{13}Cl_3J$): C, 53.99; H, 5.35 found: C, 53.87; H, 5.34
15c (minor isomer)	1.68 (s, 3 H), 3.50 (d, J = 12 Hz, 1 H), 3.62 (d, J = 12 Hz, 1 H), 3.74 (s, 3 H), 5.87 (s, 1 H), 6.74–7.37 (m, 4 H)	calcd ($C_{11}H_{13}ClO_4$): C, 53.99; H, 5.35 found: C, 54.02; H, 5.31
15d[d]	3.67 (d, J = 9 Hz, 2 H), 3.86 (d, J = 9 Hz, 2 H), 3.75 (s, 3H), 6.00 (s, 1 H), 6.81–7.38 (m, 4 H)	calcd ($C_{11}H_{12}Cl_2O_4$): C, 47.32; H, 4.33 found: C, 47.25; H, 4.37
trans-**16a**	6.42 (s, 1 H), 6.75 (br s, 1 H), 7.20–8.16 (m, 9 H)	calcd ($C_{15}H_{11}F_3O_3$): C, 60.82; H, 3.74 found: C, 60.79; H, 3.74
cis-**16a**	6.30 (s, 1 H), 6.75 (br s, 1 H), 7.20–8.01 (m, 9 H)	calcd ($C_{15}H_{11}F_3O_3$): C, 60.82; H, 3.74 found: C, 60.95; H, 3.75
trans-**16b**	0.96 (s, 9 H), 4.92 (s, 1 H), 5.94 (s, 1 H), 7.23–7.53 (m, 5 H)	calcd ($C_{12}H_{16}O_3$): C, 69.21; H, 7.74 found: C, 69.51; H, 7.71
cis-**16b**	1.02 (s, 9 H), 5.01 (s, 1 H), 5.85 (s, 1 H), 7.20–7.57 (m, 5 H)	calcd ($C_{12}H_{16}O_3$): C, 69.21; H, 7.74 found: C, 69.45; H, 7.71
trans-**16c**	0.87 (t, J = 4.5 Hz, 3 H), 1.20–2.10 (m, 8 H), 5.40 (t, J = 4.5 Hz, 1 H), 6.09 (s, 1 H), 7.35–7.65 (m, 5 H)	calcd ($C_{13}H_{18}O_3$): C, 70.27; H, 8.11 found: C, 70.00; H, 8.13
cis-**16c**	0.87 (t, J = 4.5 Hz, 3 H), 1.20–2.10 (m, 8 H), 5.46 (t, J = 4.5 Hz, 1 H), 6.03 (s, 1 H), 7.35–7.65 (m, 5 H)	calcd ($C_{13}H_{18}O_3$): C, 70.27; H, 8.11 found: C, 70.30; H, 8.13
16d	1.59 (s, 3 H), 1.62 (s, 3 H), 6.06 (s, 1 H), 7.20–7.65 (m, 5 H)	
16e (major isomer)	1.71 (s, 3 H), 3.51 (d, J = 12 Hz, 1 H), 3.68 (d, J = 12 Hz, 1 H), 5.97 (s, 1 H), 7.20–7.50 (m, 5 H)	calcd ($C_{10}H_{11}ClO_3$): C, 55.96; H, 5.17 found: C, 55.80; H, 5.17
16e (minor isomer)[e]	1.68 (s, 3 H), 3.54 (d, J = 12 Hz, 1 H), 3.66 (d, J = 12 Hz, 1 H), 6.09 (s, 1 H), 7.20–7.50 (m, 5 H)	calcd ($C_{10}H_{11}ClO_3$): C, 55.96; H, 5.17 found: C, 56.14; H, 5.06
16f	3.69–3.96 (m, 4 H), 6.23 (s, 1 H), 7.26–7.65 (m, 5 H)	calcd ($C_{10}H_{10}Cl_2O_3$): C, 48.22; H, 4.05 found: C, 48.14; H, 4.06
17a	1.62 (s, 6 H), 6.36 (br s, 1 H), 7.32–7.98 (m, 4 H)	calcd ($C_{11}H_{11}F_3O_3$): C, 53.23; H, 4.47 found: C, 53.30; H, 4.53
17b (major isomer)	1.74 (s, 3 H), 3.56 (d, J = 10.5 Hz, 1 H), 3.68 (d, J = 10.5 Hz, 1 H), 6.38 (s, 1 H), 7.20–7.95 (m, 4 H)	calcd ($C_{11}H_{10}F_3ClO_3$): C, 46.74; H, 3.57 found: C, 46.71; H, 3.62
17b (minor isomer)	1.68 (s, 3 H), 3.53 (d, J = 12 Hz, 1 H), 3.69 (d, J = 12 Hz, 1 H), 6.51 (br s, 1 H), 7.38–7.89 (m, 4 H)	calcd ($C_{11}H_{10}F_3ClO_3$): C, 46.74; H, 3.57 found: C, 46.90; H, 3.55
17c	3.73 (d, J = 13.5 Hz, 1 H), 3.89 (d, J = 13.5 Hz, 1 H), 3.87 (s, 2 H), 6.54 (br s, 1 H), 7.47–7.92 (m, 4 H)	calcd ($C_{11}H_9F_3Cl_2O_3$): C, 41.69; H, 2.84 found: C, 41.64; H, 2.85
trans-**18a**	0.69–1.85 (m, 15 H), 5.27 (t, J = 3 Hz, 1 H), 5.94 (s, 1 H), 7.20–7.50 (m, 5 H)	calcd ($C_{15}H_{22}O_3$): C, 71.97; H, 8.86 found: C, 72.09; H, 8.83
cis-**18a**	0.69–1.86 (m, 15 H), 5.31 (t, J = 3.0 Hz, 1 H), 5.88 (s, 1 H), 7.20–7.50 (m, 5 H)	calcd ($C_{15}H_{22}O_3$): C, 71.97; H, 8.86 found: C, 71.80; H, 8.92
trans-**18b**	0.75–1.89 (m, 15 H), 5.19 (t, J = 4.5 Hz, 1 H), 6.42 (br s, 1 H), 7.20–7.86 (m, 4 H)	calcd ($C_{16}H_{21}F_3O_3$): C, 60.37; H, 6.65 found: C, 60.46; H, 6.75
cis-**18b**	0.75–1.89 (m, 15 H), 5.31 (d, J = 4.5 Hz, 1 H), 6.42 (br s, 1 H), 7.20–7.86 (m, 4 H)	calcd ($C_{16}H_{21}F_3O_3$): C, 60.37; H, 6.65 found: C, 60.44; H, 6.68
18c	0.75–1.89 (m, 15 H), 3.53 (d, J = 12 Hz, 1 H), 3.66 (d, J = 12 Hz, 1 H), 3.72 (s, 2 H), 5.28 (t, J = 4 Hz, 1 H)	calcd ($C_{11}H_{20}Cl_2O_3$): C, 48.70; H, 7.43 found: C, 49.12; H, 7.52
19b	6.78 (br s, 1 H), 7.23–7.68 (m, 14 H)	calcd ($C_{21}H_{15}F_3O_3$): C, 67.74; H, 4.06 found: C, 68.06; H, 3.99
19c	0.90 (s, 9 H), 5.04 (s, 1 H), 7.17–7.71 (m, 10 H)	calcd ($C_{18}H_{20}O_3$): C, 76.03; H, 7.09 found: C, 75.83; H, 6.93
19e	3.75 (s, 4 H), 7.20–7.65 (m, 10 H)	calcd ($C_{16}H_{14}Cl_2O_3$): C, 59.10; H, 4.34 found: C, 59.14; H, 4.39
20a	0.63–1.95 (m, 10 H), 6.36 (s, 1 H), 7.35–7.95 (m, 4 H)	calcd ($C_{14}H_{15}F_3O_3$): C, 58.33; H, 5.24 found: C, 59.45; H, 5.75
20b	1.26–1.86 (m, 10 H), 2.10 (d, J = 12 Hz, 2 H), (d, J = 12 Hz, 2 H)	calcd ($C_9H_{14}Cl_2O_3$): C, 44.83; H, 5.85 found: C, 45.01; H, 5.77

[a] Unless otherwise noted, the 1,2,4-trioxolanes were obtained as an oil. [b] The physical properties of the 1,2,4-trioxolanes, **16d**, **19a**, and **19d**, were reported in the literature. **16d**: Criegee, R.; Korber, H. *Adv. Chem. Ser.* **1972**, *112*. **19a**: Castoguay, J.; Bertrand, M.; Carles, J.; Fliszar, S.; Rousseau, Y., *Can. J. Chem.* **1969**, *47*, 919. **19d**: Miura, M.; Nojima, M. *J. Am. Chem. Soc.* **1980**, *102*, 288. [c] MP: 42–46 °C. [d] MP: 60–62 °C. [e] MP: 205–206 °C. [f] Recorded in CCl_4. For the assignment of the configuration see the footnote 13. However, **15a** is not consistent with this agreement and therefore, the stereochemistry of at least this compound is quite tentative.

in $CDCl_3$ was kept at room temperature for 1 h. ^{1}H NMR analysis showed the presence of methyl formate (**3**) and of cyclohexanone (**6f**) (δ 1.71–1.91 (m), 2.32–2.37 (m)) in a molar ratio of 1:1.1.

Reduction of a Mixture of 5f and 13f. A 5:95 mixture of **5f** and **13f** and triphenylphosphine in $CDCl_3$ was kept at room temperature for 1 day. ^{1}H NMR analysis showed the presence of cyclohexanone (**6f**) as the sole product.

Ozonolysis of Vinyl Ethers in the Presence of Added Carbonyl Compounds. The ozonolysis of a vinyl ether (1 mmol) was undertaken in the presence of a carbonyl compound (5 mmol) in an appropriate solvent (20 mL). The physical properties of the ozonides **15–20**, isolated by column chromatography on silica gel, are summarized in Table VI.

Ozonolysis of 1-Phenyl-2-methoxyethene (1b) in the Presence of Chloroacetone (6j) and Dichloroacetone (6k). A mixture of **1b** (1 mmol), **6j** (5 mmol), and **6k** (5 mmol) in methylene chloride (20 mL) was treated with 1 equiv of ozone at 0 °C. Column chromatography of the crude products on silica gel (elution with benzene–hexane, 1:1) afforded 3-phenyl-5,5-bis(chloromethyl)-1,2,4-trioxolane (**16f**) (δ 3.69–3.96 (m), 6.23 (s)) in 60% yield. In ^{1}H NMR spectra of the crude products, no signal was observed assignable to 3-phenyl-5-methyl-5-(chloromethyl)-1,2,4-trioxolane (**16e**).

Ozonolyis of 1b in the Presence of Benzaldehyde (6b) and 2-(Trifluoromethyl)benzaldehyde (6c). To a methylene chloride solution (20 mL) of **1b** (1 mmol), **6b** (4 mmol), and **6c** (1 mmol), was passed 1 mmol of ozone at 0 °C. Column chromatography on silica gel (elution with benzene–hexane, 1:1) afforded 3,5-diphenyl-1,2,4-trioxolane (**13b**) and 3-phenyl-5-(2-(trifluoromethyl)phenyl)-1,2,4-trioxolane (**16a**) in yields of 13% and 25%, respectively.

Ozonolysis of *cis*- and *trans*-1-Phenyl-2-methoxyethene (1b) in the Presence of Trimethylacetaldehyde (6g). When a mixture of *cis*-**1b** (1 mmol) and **6g** (5 mmol) was treated with 1 mmol of ozone in ether at −70 °C, 3-phenyl-5-*tert*-butyl-1,2,4-trioxolane (**16b**) was isolated in 60% yield as a cis–trans mixture, the ratio being 29:71. When *trans*-**1b** was used instead of the cis isomer, a cis–trans mixture of **16b** was obtained in 55% yield, the cis:trans ratio being 30:70.

A similar independence of the ozonide composition on the configuration of the vinyl ether **1b** was found in the reaction in pentane or methylene chloride.

Acknowledgment. Support of part of the work by the Deutsche Forschungsgemeinschaft is greatly acknowledged. M.N. thanks the Deutsche Akademischer Austauschdienst for a travel grant which provided a chance to study the method of ozonolysis on polyethylene at the University of Karlsruhe.

Registry No. *cis*-**1a**, 64304-84-3; *trans*-**1a**, 64304-83-2; *cis*-**1b**, 14371-19-8; *trans*-**1b**, 4110-75-2; *cis*-**1c**, 130011-62-0; *trans*-**1c**, 130011-64-2; *cis*-**1d**, 130011-63-1; *trans*-**1d**, 130011-65-3; **1e**, 40237-72-7; **1f**, 19096-89-0; **3**, 107-31-3; **4a**, 90535-16-3; **4b**, 10027-71-1; **4c**, 130011-66-4; **4d**, 130011-67-5; **4e**, 63704-22-3; **4f**, 16580-35-1; **5a**, 130011-68-6; **5b**, 16204-37-8; **5e**, 16204-36-7; **5f**, 183-84-6; **6a**, 123-11-5; **6b**, 100-52-7; **6c**, 447-61-0; **6d**, 124-13-0; **6e**, 119-61-9; **6f**, 108-94-1; **6g**, 630-19-3; **6h**, 66-25-1; **6i**, 67-64-1; **6j**, 78-95-5; **6k**, 534-07-6; **7a**, 100-09-4; **7b**, 65-85-0; **7d**, 124-07-2; **8**, 79698-42-3; **9**, 4746-86-5; **10**, 35967-47-6; **11**, 101-41-7; *cis*-**13a**, 110003-04-8; *trans*-**13a**, 89902-49-8; *cis*-**13b**, 21072-45-7; *trans*-**13b**, 21072-46-8; *cis*-**13c**, 130011-79-9; *trans*-**13c**, 130011-80-2; **13f**, 129731-36-8; *cis*-**14a**, 130011-69-7; *trans*-**14a**, 130011-75-5; *cis*-**14b**, 130011-70-0; *trans*-**14b**, 130011-76-6; *cis*-**14c**, 130011-71-1; *trans*-**14c**, 130011-77-7; *cis*-**14d**, 130011-72-2; *trans*-**14d**, 130011-78-8; **14e**, 130011-73-3; **14f**, 130011-74-4; *cis*-**15a**, 130011-81-3; *trans*-**15a**, 130011-82-4; **15b**, 130011-83-5; *cis*-**15c**, 130011-84-6; *trans*-**15c**, 130011-85-7; **15d**, 130011-86-8; *cis*-**16a**, 130011-87-9; *trans*-**16a**, 130011-88-0; *cis*-**16b**, 130011-89-1; *trans*-**16b**, 130011-90-4; *cis*-**16c**, 130011-91-5; *trans*-**16c**, 130011-92-6; **16d**, 38481-59-3; *cis*-**16e**, 130011-93-7; *trans*-**16e**, 130011-94-8; **16f**, 130011-95-9; **17a**, 130011-96-0; *cis*-**17b**, 130011-97-1; *trans*-**17b**, 130011-98-2; **17c**, 130011-99-3; *cis*-**18a**, 130012-00-9; *trans*-**18a**, 130012-01-0; *cis*-**18b**, 130012-02-1; *trans*-**18b**, 130012-03-2; **18c**, 130012-04-3; **19a**, 23246-12-0; **19b**, 130012-05-4; **19c**, 130012-06-5; **19d**, 73258-07-8; **19e**, 130012-07-6; **20a**, 130012-08-7; **20b**, 130012-09-8.

Supplementary Material Available: ^{1}H NMR spectra of a mixture of *trans*- and *cis*-**14a**, *trans*-**14a**, *cis*-**14b**, *trans*-**14b**, a mixture of *trans*- and *cis*-**14c**, a mixture of *trans*- and *cis*-**14d**, *cis*-**14d**, and **14e** (8 pages). Ordering information is given on any current masthead page.

A New Chromone and Flavone Synthesis and Its Utilization for the Synthesis of Potentially Antitumorigenic Polycyclic Chromones and Flavones

Ronald G. Harvey,* Jung-Tai Hahn, Maria Bukowska,[†] and Henry Jackson

Ben May Institute, University of Chicago, Chicago, Illinois 60637

Received March 12, 1990

A new synthesis of chromones and flavones based on the ortho-directed metalation of methoxymethyl aryl ethers with alkyllithium reagents is described. It entails reaction of the ortho-lithiated intermediates with a conjugated unsaturated aldehyde followed by oxidation of the allylic alcohol product with "periodinane" to yield an ortho-allylic ketone. The latter on heating in acetic acid undergoes loss of the methoxymethyl protecting group and cyclization to a chromanone (or flavanone, if a β-phenyl substitutent is present). Dehydrogenation by treatment with pyrrolidone hydrotribromide (PHT) in dimethyl sulfoxide yields the corresponding chromones (or flavones). This synthetic approach appears general in its applicability. It has been applied to the synthesis of a series of polycyclic chromone and flavone compounds containing the naphthalene and pyrene ring systems that hold promise as agents for the chemoprevention of cancer.

Coumarins, chromones, and flavones are pharmacologically important classes of plant products. Some compounds of these classes, notably 5,6- and 7,8-benzoflavone and ellagic acid, have been shown to exhibit significant activity as inhibitors of tumor induction by carcinogenic polycyclic aromatic hydrocarbons (PAHs).[1] In contrast to most other types of tumor-inhibitory compounds, many of which exhibit toxicity, mutagenicity, and other undesirable properties, the coumarin and chromone compounds tend to show minimal side effects. Surprisingly, systematic investigations of their structure–activity relationships have not been conducted. With this objective in mind, we recently devised an efficient novel synthesis of coumarins based on the ortho-directed metalation of methoxymethyl phenolic ethers.[2,3] This method was utilized to prepare a series of substituted coumarins and polycyclic coumarin analogues of PAHs. Preliminary assays of biological activity indicate that several of these compounds exhibit significant antitumor activity. In particular, the polycyclic coumarin analogues of benzo[*a*]pyrenes **1a–c** are strong

---

[†] On leave of absence from the Department of Chemistry, Technical University of Warsaw, Warsaw, Poland.

(1) DiGiovanni, J.; Slaga, T. J. In *Modification of Polycyclic Aromatic Hydrocarbon Carcinogenesis*; Gelboin, H. V., Ts'o, P. O. P., Eds.; Academic Press: New York, 1981; pp 259–292.

(2) Harvey, R. G.; Cortez, C.; Ananthanarayan, T. P.; Schmolka, S. *Tetrahedron Lett.* **1987**, *28*, 6137.

(3) Harvey, R. G.; Cortez, C.; Ananthanarayan, T. P.; Schmolka, S. *J. Org. Chem.* **1988**, *53*, 3936.

0022-3263/90/1955-6161$02.50/0 © 1990 American Chemical Society