This neighbor spin detection scheme has been applied to cytidine with irradiation of the 1′-proton and typical results are shown in part c of Figure 1. The up–down pattern of the signals allows direct determination of both $J_{1',2'}$ and $J_{2',3'}$. The pulse sequence used is $90°-t_m/2-180°-t_m/2-90°-90°$–acquisition. The phases of the first two 90° pulses are cycled through $X,Y,-X,-Y$ and the last 90° through $X,-X$ to give double-quantum filtering.[5] The phase of the 180° pulse is Y.

A variation on the scheme is to apply a decoupling field to spin A during the time used for generation of multiple-quantum coherence. When this occurs the efficiency of generation of multiple-quantum coherence between neighbor and remote spins may be altered. For a weakly coupled AMX spin system and for double-quantum filtering the maximum percentage effect occurs when $t_m = {}^1/_2J_{AM}$.[10] This approach has been applied to cytidine with the result shown in part b of the figure. Selective decouploing of the 1′-proton allows detection of the remote 3′-proton. The remote proton multiplet structure corresponds to the difference between the subspectra associated with the two polarizations of the neighbor proton giving an up–down pattern.[11] In general, the phases of the signals from different spins will not be the same.[12] This combination of selective irradiation and multiple-quantum filtering is reminiscent of a one-dimensional approach to allow heteronuclear detection of remote protons.[13]

The use of multiple-quantum filtering is not essential, and analogous procedures based on the simple pulse sequence $90°-t_m-90°$–acquisition with the phase of the first pulse being X and the second pulse cycled through $X,Y,-X,-Y$ have been demonstrated. This approach does not necessarily give the up–down multiple pattern needed for spectral analysis but is adequate for determination of the chemical shifts of neighbor and remote nuclei.

A one-dimensional version of relayed coherence transfer has been proposed which utilizes a selective 90° pulse at the beginning of the experiment.[2a] This approach requires the use of two delay times as well as phase coherence between the selective 90° pulse and the other pulses and is not as versatile or as easy to implement as the selective irradiation methods proposed here.

These two applications indicate some of the utility of combining selective irradiation with multiple-quantum filtering. While the cases presented here utilize only double-quantum filters, weakly coupled spin systems, and homonuclear examples,[14] many variations are possible. The main limitation on the basic approach is that of having *a* resolved signal from which to begin the determination of a coupling network. For the determination of a few coupling networks at high resolution the combination of selective irradiation with multiple-quantum filtering is much less demanding of spectrometer time than two-dimensional methods.

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[9] The pulse sequence used for the experiments is $90°-t_m/2-180°-t_m/2-90°-90°$–acquisition with the phases of the pulses cycled for selective detection of double-quantum coherence. The delay time t_m was 0.1 s for the results shown in Figure 1. The free induction decay obtained with selective irradiation of the 1′-proton was substracted from the one obtained with far off-resonance irradiation and the resulting difference Fourier transformed. The experiments were performed using a Varian XL-200 spectrometer on a 50 mM sample of cytidine which was in 95% deuterated water. A 1-s equilibration delay was used, and the selective saturation was performed over 0.4-s.

[10] To predict the absolute intensities of the remote proton signals one need compare the efficiency of generation of MX double-quantum coherence in the presence and absence of coupling of M to A using the rules presented elsewhere.[3]

[11] In the presence of strong coupling of the irradiated neighbor or remote spins additional signals may be observed.

[12] As discussed in ref 5, the phases of the signals in multiple-quantum filtered spectra for spin systems other than AX are generally not the same.

[13] Bolton, P. H. *J. Magn. Reson.* **1982**, *46*, 91–97.

[14] A heteronuclear experiment can consist of selective irradiation of a heteronucleus during t_m and no 180° pulse. The difference spectrum then consists of either those protons that are neighbors to the heteronucleus or both the neighbors and remote protons depending on the choice of t_m. Selective decoupling of the heteronucleus can be applied during acquisition in both experiments if desired. This approach has been applied to selective decoupling of ^{31}P for oligonucleotide–drug complexes and will be presented elsewhere.[15]

[15] Bolton, P. H.; Gerlt, J. A., manuscript in preparation.

Thermolysis of 7,8-Dioxabicyclo[4.2.2]deca-2,4,9-trienes. An Unusual Decomposition Mode of Endoperoxides

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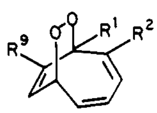
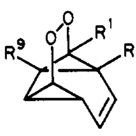
With only few exceptions, the thermolysis of endoperoxides leads to decomposition products derived from initial cleavage of the peroxide bond.[1] Presently we describe a hitherto unprecedented decomposition mode in the case of the endoperoxide of cyclooctatetraene **1a** and derivatives. Instead of affording the expected diepoxides **4a** and **5a**, facile intramolecular cycloaddition led to the isomeric endoperoxide **2a**, which on allowed (4 + 2) retrocyclization generated the intermediary, labile dialdehyde **3a**. Depending on the reaction conditions, the major final products of the latter were 4-(hydroxymethyl)benzaldehyde, terephthalaldehyde, benzaldehyde, or benzene. The product distributions of the solution and gas-phase thermolyses are summarized in Table I.



1a, $R^1 = R^2 = R^9 = H$
b, $R^1 = OMe; R^2 = R^9 = H$
c, $R^1 = R^2 = H; R^9 = OMe$
d, $R^1 = R^2 = H; R^9 = Ph$
e, $R^1 = Me; R^2 = R^9 = H$
f, $R^1 = R^9 = H; R^2 = Me$



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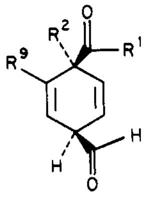

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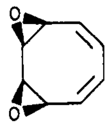

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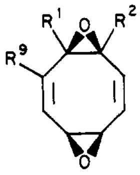

5

The endoperoxides **1** were prepared via tetraphenylporphine (TPP)-photosensitized oxygenation[2] of the respective cyclooctatetraene. The experimental details are described elsewhere.[3] While the photochemical and the cobalt–tetraphenylporphine complex catalyzed reactions of these endoperoxides afforded exclusively the diepoxides **5**, the thermal decomposition did not produce even traces of the diepoxides **4** and **5**. The fact that in the liquid-phase thermolysis of the endoperoxide **1a** in acetonitrile the main product was the 4-(hydroxymethyl)benzaldehyde (Table I, entry 1) provided the first clue that the dialdehyde **3a** could have served as a potential intermediate.

This mechanistic supposition was made plausible through the following experiments. In CCl_4 at 130 °C endoperoxide **1a** gave

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† Research participant in the science teachers program.

‡ Doctoral Dissertation, University of Würzburg, July 1984.

[1] Saito, I.; Nittala, S. S. "The Chemistry of Peroxides"; Patai, S., Ed.; Wiley: New York, 1983; pp 311–374.

[2] Adam, W.; Klug, G. *Tetrahedron Lett.* **1982**, *23*, 3155.

[3] Adam, W.; Klug, G.; Peters, E.-M.; Peters, K.; von Schnering, H. G. *Tetrahedron*, in press.

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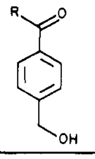
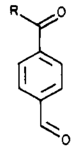
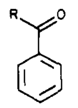
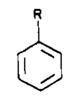
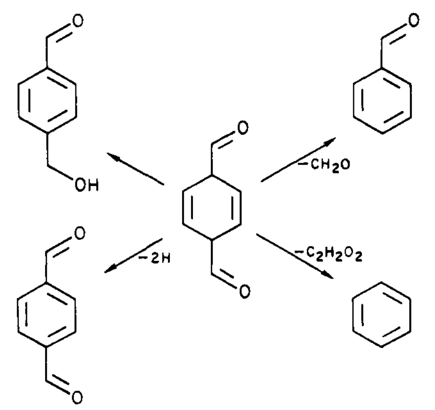
Table I. Product Distributions in the Thermolysis of the Cyclooctatetraene Endoperoxides **1**

endoperoxide				relative product yields, %[b]			
no.	R	phase[a]	temp, °C				
1. **1a**	H	CH_3CN	130	93	3	3	
2. **1a**	H	CCl_4	130		28	72	traces
3. **1a**	H	CH_2Cl_2	40		9 (25)[c]		
4. **1a**	H	gas	320		traces		99
5. **1b**	MeO	gas	320			40	60 (R = H)
6. **1c**	MeO	gas	320				100
7. **1d**	Ph	gas	320				100
8. **1e,f**[d]	Me	gas	320		44	10	27 19 (R = H)

[a] Gas-phase pyrolyses were performed by volatilizing the endoperoxide through a hot tube at a bath temperature of 20–50 °C and 10^{-5}–10^{-6} torr. [b] Determined by quantitative ^{1}H NMR of the thermolysate; error ca. 5% of stated values. [c] In the presence of 0.1 M 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ); only relative yields were determined; remainder unreacted endoperoxide. [d] It was not possible to separate this mixture of endoperoxides.

a mixture of terephthalaldehyde and benzaldehyde, the latter as main product (Table I, entry 2), presumably via oxidation and deformylation, respectively, of the intermediary dialdehyde **3a**. With increasing temperature of thermolysis the proportion of benzaldehyde increased. In fact, at temperatures as low as 40 °C in CH_2Cl_2, the endoperoxide **1a** was converted into terephthalaldehyde (Table I, entry 3) as the only defined product, together with major amounts of undefined high-molecular-weight peroxidic material. In the presence of DDQ as oxidant, the amount of terephthalaldehyde that was produced from endoperoxide **1a** was significantly increased (Table I, entry 3). An authentic sample of dialdehyde **3a**,[4] prepared by sodium amalgam[5a] reduction of terephthalic acid and esterification with diazomethane,[5b] followed by dibutylaluminum hydride[5c] (DIBAH) reduction, was readily converted into terephthalaldehyde on oxidation with molecular oxygen or DDQ. In refluxing acetonitrile in the absence of air, 4-(hydroxymethyl)benzaldehyde and traces of benzaldehyde were formed. Furthermore, under free radical conditions, e.g., in the presence of di-*tert*-butyl peroxide, the 4-(hydroxymethyl)benzaldehyde (tautomer of the dialdehyde **3a**) gave appreciable amounts of terephthalaldehyde.

It is difficult to rationalize these experiments mechanistically without invoking the dialdehyde **3a** as a key intermediate. Thus, in polar solvents such as CH_3CN the dialdehyde **3a** tautomerizes into 4-(hydroxymethyl)benzaldehyde, under oxidative conditions (O_2 and DDQ) in CCl_4 it dehydrogenates into terephthalaldehyde, and under free radical conditions (high temperatures, peroxides) it deformylates into benzaldehyde, as illustrated in eq 1. In fact, even benzene is formed in trace amounts (Table I), presumably via double deformylation (eq 1).



(1)

As to a logical route to the dialdehyde **3a** from the endoperoxide **1a**, we propose, in analogy to bicyclo[4.2.2]deca-2,4,6,8-tetraene,[6] intramolecular (4 + 2) cycloaddition leading to the novel endoperoxide **2**. Retrocyclization through peroxide-bond homolysis affords the dialdehyde **3**. What is surprising and could hardly have been predicted is the fact that the intramolecular cycloaddition **1a** → **2a** is energetically preferred over peroxide bond cleavage to give the expected diepoxide **5a**. This is especially astounding in that the photolysis or treatment with the cobalt complex of tetraphenylporphine gives the diepoxides **5** for all the endoperoxides **1**.

The gas-phase thermolysis of the endoperoxides **1** provided further support for the proposed mechanism. The parent endoperoxide **1a** ($R^1 = R^2 = R^9 = H$) afforded at 320 °C as major product benzene and small amounts of terephthalaldehyde (Table I, entry 4). At these elevated temperatures in the gas phase double deformylation of the dialdehyde **3a** was the course of action.

Control experiments showed that 4-(hydroxymethyl)benzaldehyde, terephthalaldehyde, and cyclooctatetraene were stable under the conditions of the pyrolysis of the endoperoxides. In the case of 4-(hydroxymethyl)benzaldehyde and cyclooctatetraene only at pyrolysis temperatures greater than 500 °C decomposition into benzene could be detected gas chromatographically. The fact that cyclooctatetraene did not afford detectable amounts of benzene[7] under the pyrolysis conditions of the endoperoxide **1a** and that cyclooctatetraene itself could not be seen upon thermolysis of the endoperoxide **1a** excludes the possibility that deoxygenation of the endoperoxide **1a** into cyclooctatetraene serves as feasible route to benzene.

With the 1-methoxy endoperoxide **1b**, as expected on the basis of the proposed mechanism, the major products were benzene and methyl benzoate (Table I, entry 5), produced from **3b** via combined decarbomethoxylation and deformylation, respectively. On the other hand, and again as expected, the isomeric 9-methoxy endoperoxide **1c** gave anisole (Table I, entry 6) via double deformylation of the intermediary dialdehyde **3c**. Similarly, diphenyl was the exclusive gas-phase pyrolysis product (Table I, entry 7) in the case of 9-phenyl endoperoxide **1d**. Finally, pyrolysis of the mixture of methyl endoperoxides **1e,f** afforded a mixture of 4-acetylbenzaldehyde, acetophenone, toluene, and benzene (Table I, entry 8), all rationalizable in terms of the proposed mechanism.

Acknowledgments are made to the Deutsche Forschungsgemeinschaft and the Fonds der Chemischen Industrie for generous financial support of this work. We are grateful to BASF for generous samples of cyclooctatetraene.

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[4] It was not possible to isolate and fully characterize the dialdehyde **3** in view of its high propensity toward autoxidation into terephthalaldehyde.

[5] (a) McDonald, R. N.; Reineke, C. E. *Org. Synth.* **1970**, *50*, 50. (b) Brown, G. W.; Sondheimer, F. *J. Am. Chem. Soc.* **1967**, *89*, 7116. (c) Corey, E. J.; Nicolaou, K. C.; Toru, T. *Ibid.* **1975**, *97*, 2287.

[6] Jones, M., Jr.; Fairless, B. *Tetrahedron Lett.* **1968**, 4881.

[7] (a) Jones, M., Jr.; Schwab, L. O. *J. Am. Chem. Soc.* **1968**, *90*, 6549. (b) Tanaka, J. *J. Chem. Soc. Jpn., Pure Chem. Sect.* **1954**, *75*, 212; *Chem. Abstr.* **1954**, *48*, 4984*b*.