

1,11-oxy steroids listed in Table IV.

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Supplementary Material Available: Atomic coordinates and isotropic thermal parameters for the prednisolone acetate photoproduct ethyl acetate complex 4c (2 pages). Ordering information is given on any current masthead page.

Photochemistry of Nitrodibenzo[*b,e*][1,4]dioxins in the Presence of Primary Amines

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While 1-nitrodibenzo[*b,e*][1,4]dioxin is stable toward irradiation in the presence of amines, the 2-nitro isomer (NDD) reacts to yield two isomeric (alkylamino)hydroxynitrodiphenyl ethers and *N*-(alkylamino)-2-nitrophenoxazine when irradiated in polar solvents containing a primary amine. In apolar solvents, however, only the nitrophenoxazine is obtained. The reaction is established to occur through the triplet state of NDD, which reacts with the amine to form an exciplex. If the medium is sufficiently polar, the exciplex dissociates to the solvated radical ions, from which the diphenyl ethers arise.

In the frame of our studies on the photochemistry of nitro-substituted heterocyclic compounds in the presence of bases,¹ we turned our attention to the nitrodibenzo[*b,e*][1,4]dioxins. Since the latter appear to be rather similar to the nitrodiphenyl ethers, a photochemical reaction with nucleophiles is expected, on the basis of the photochemical behavior of nitroanisoles and nitroveratroles.²

In the present work, it is shown that 1-nitrodibenzo[*b,e*][1,4]dioxin is stable even on prolonged irradiation in the presence of amines, whereas 2-nitrodibenzo[*b,e*][1,4]dioxin (NDD, 1) is consumed on irradiation in the presence of primary amines, although stable in inert solvents. This reaction takes place with various primary amines, although it is not observed when bulky groups are present, as in the case of *tert*-butylamine.

Irradiation of 1 in the presence of *n*-propylamine, followed by chromatographic separation, gave three products in significant yield when the reaction was carried out in polar solvents, while a single product, corresponding to the minor one in the previous case, was obtained on irradiation in cyclohexane (see Scheme I, and Table I).

To the two main products obtained in polar solvents could be attributed the gross structure of (alkylamino)-hydroxynitrodiphenyl ethers, arising from the cleavage of one of the two ethereal bridges, on the basis of analytical and spectroscopic data. However, the choice among the four possible formulas required a closer examination.

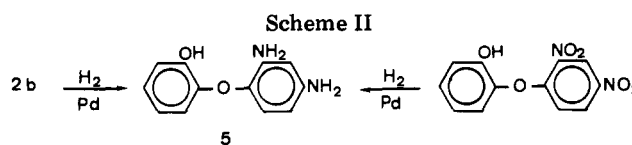
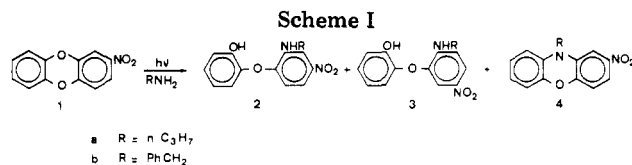


Table I. Percent Yield of the Photoproducts from 2-Nitrodibenzo[*b,e*][1,4]dioxin (1)

solvent	amine (1 M)	product yield, %		
		2	3	4
<i>t</i> -BuOH/H ₂ O (95/5)	<i>n</i> -PrNH ₂	56	24	7
	PhCH ₂ NH ₂	53	24	
MeCN	<i>n</i> -PrNH ₂	30	25	11
C ₆ H ₁₂	<i>n</i> -PrNH ₂			28

Compound 2 was identified by direct comparison. The benzylamino derivative (2a) was prepared and transformed by catalytic hydrogenation into the diamino derivative (5) (Scheme II). This was shown to be identical with authentic 2,4-diamino-2'-hydroxydiphenyl ether, unambiguously prepared by reduction of the corresponding dinitro derivative.

As for compound 3a, the choice was possible on the basis of its ¹H NMR spectrum, which showed that the hydrogen atom in the meta position with respect to the nitro group is vicinal to an amino group and not to a hydroxy group: the corresponding signal, easily identified from its chemical

(1) (a) A. Albini, G. F. Bettinetti, E. Fasani, and G. Minoli, *J. Chem. Soc., Perkin Trans. 1*, 299 (1978); (b) A. Albini, G. F. Bettinetti, and G. Minoli, *J. Chem. Soc., Perkin Trans. 1*, 191 (1980).

(2) (a) E. Kronenberg, A. van der Heyden, and E. Havinga, *Recl. Trav. Chim. Pays-Bas*, 86, 254 (1967); (b) E. Havinga and R. O. DeJongh, *Bull. Soc. Chim. Belg.*, 71, 803 (1962); (c) J. Cornelisse and E. Havinga, *Chem. Rev.*, 75, 353 (1975).

Table II. Relevant Spectroscopic Properties of the Photoproducts

	NMR ^a				IR, ^b cm ⁻¹	UV ^c λ_{\max} , nm (log ϵ)
	3-H	4-H	5-H	6-H		
2a	6.7 (d, $J = 10$)		7.5 (dd)	7.55 (d, $J = 2$)	3530 w, 3440 m, 3400 s	398 (3.61)
2a ^d	7.1 (d)		7.85 (dd)	8.55 (d)		
3a	6.7 (d, $J = 9$)	8 (dd)		7.6 (d, $J = 2$)	3410 s, 3340 br	395 (4.30)
3a ^d	7.75 (d)	8.15 (dd)		7.85 (d)		
2b	6.5 (d, $J = 8$)		<i>e</i>	<i>e</i>	3470 br, 3440 s	393 (3.56)
3b	6.6 (d, $J = 9$)	8 (dd)		7.6 (d, $J = 2$)	3420 s, 3350 br	390 (4.24)
4 ^f	7.75 (dd)	6.85 (d, $J = 9$)			1490 vs	328 (3.65)

^a In CDCl₃; chemical shifts in δ and coupling constants in hertz. ^b In Nujol mull. ^c In MeCN. ^d NMR in the presence of CF₃COOD. ^e Signals submerged under the aromatic signals. ^f For 1-H, δ 7.7 (d, $J = 3$ Hz).

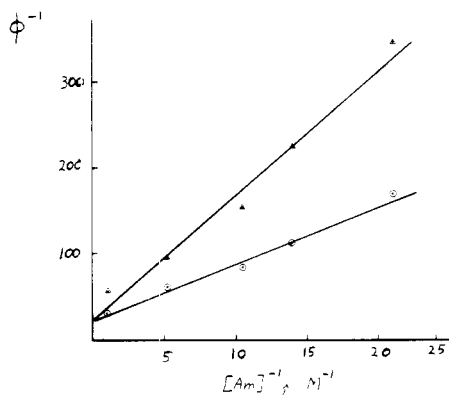


Figure 1. Reciprocal plot of the quantum yield of the photo-reactions from 2-nitrodibenzo[*b,e*][1,4]dioxin (1) in acetonitrile vs. the concentration of *n*-propylamine: O, ϕ_{-1} , slope 6.8 M⁻¹, intercept 20.2 ($r = 0.992$); Δ , ϕ_{2+3} , slope 14.7 M⁻¹, intercept 22.2 ($r = 0.989$).

shift and coupling constants, undergoes a marked downfield shift in acidic medium (Table II).

The structure of compound 4a was recognized as follows. Elemental analysis and spectroscopic characteristics (absence of O-H and N-H signals, UV spectrum similar to that of 1) indicated the formula of *N*-(propylamino)-2- or -3-nitrophenoxazine. As this compound was different from the authentic *N*-(propylamino)-3-nitrophenoxazine, the formula 4a had to be accepted. This conclusion was also supported by the blue shift of the spectrum of compound 4 with respect to 3-nitrophenoxazine ($\lambda_{\max} = 323$ nm for 4a and 460 nm for *N*-(propylamino)-3-nitrophenoxazine).

Hence, the formation of the two diphenyl ethers corresponds to the reaction of the amine on the two ethereal bonds of the nitro-substituted ring, just as in the reaction of 3,4-dimethoxynitrobenzene with amines. However, in the latter case the "meta" substitution is strongly favored,^{2a} while in the present case the difference between "meta" and "para" substitution is rather limited. A further process is observed in the present case, whereby water is formally eliminated and a phenoxazine is produced. The formation of the latter compound is not a secondary process, either thermal or photochemical. In fact, 4 is not formed either from 2 or from 3 under the reaction conditions.

Information about the multiplicity of the reactive excited state and the mechanism of the reaction was obtained through measurements of the reaction quantum yield under different conditions. The quantum yields of formation of compounds 2 and 3 (ϕ_2 and ϕ_3) as well as the yield of disappearance of 1 (ϕ_{-1}) were strongly dependent on the amine concentration (see Figure 1, data in acetonitrile).

A reasonable conversion is obtained only if the amine concentration is relatively high. A possible explanation would be that the reaction requires the excitation of a preformed ground-state complex. However, no modifica-

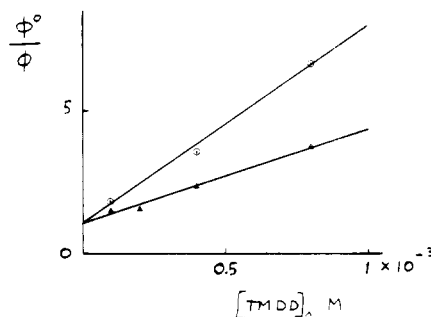


Figure 2. Quenching of the reaction of 2-nitrodibenzo[*b,e*]-[1,4]dioxin (1) with *n*-propylamine (0.1 M) in acetonitrile by means of tetramethyldiazetene 1,2-dioxide: O, ϕ_{-1} , slope 6860 M⁻¹, intercept 1.04 ($r = 0.993$); Δ , ϕ_{2+3} , slope 3330 M⁻¹, intercept 1.05 ($r = 0.992$).

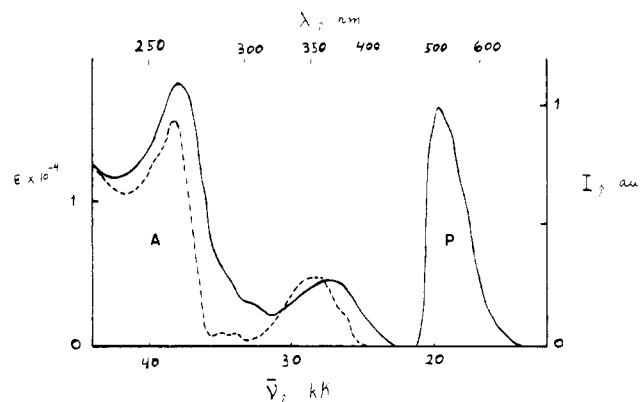


Figure 3. Absorption (A) and phosphorescence (P) spectra of 2-nitrodibenzo[*b,e*][1,4]dioxin (1). A: —, in acetonitrile; ---, in cyclohexane. P: in ether-pentane-ethanol at 77 K, uncorrected.

tion of the absorption spectrum of 1 was observed. This suggests the absence of such a complex. A linear correlation of the reciprocal of the quantum yield vs. the reciprocal of the amine concentration was observed both for the disappearance of the substrate and for the formation of the products. Thus, only one excited state is reactive, and the reaction is exclusively second order.

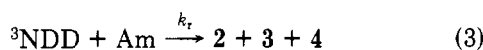
The reaction is efficiently quenched by 3,3,4,4-tetramethyldiazetene 1,2-dioxide, as shown in Figure 2 for the disappearance of 1 and for the formation of products 2 and 3. As for product 4, an accurate measurement of its yield in the low-conversion experiments was impossible due to analytical difficulties (see Experimental Section). However, measurements at higher conversion showed that the effect of the quencher on the formation of 4 is the same as that on the formation of the two other photoproducts. Thus, the entire photochemistry of 1 proceeds through its triplet state (³NDD).

The triplet state of 1 was identified spectroscopically from its phosphorescence (Figure 3).

Table III. Quantum Yields of the Photochemical Reactions of 2-Nitrodibenzo[*b,e*][1,4]dioxin (1)

solvent	amine	quantum yields		
		ϕ_{-1}	ϕ_{2+3}	ϕ_4
<i>t</i> -BuOH/H ₂ O (95/5)	none	$\leq 10^{-4}$		
	<i>n</i> -PrNH ₂ (0.1 M)	0.056	0.043	0.0035
MeCN	none	$\leq 10^{-4}$		
	<i>n</i> -PrNH ₂ (0.1 M)	0.011	0.006	0.001
	<i>n</i> -PrNH ₂ (1 M)	0.037	0.027	0.003
C ₆ H ₁₂	none	$\leq 10^{-4}$		
	<i>n</i> -PrNH ₂ (0.1 M)	0.02		0.0025

The simplest kinetic scheme required is therefore given by eq 1-5.



If γ is the quantum yield of formation of the triplet state, the product quantum yield gives eq 6 or, in the inverse form, eq 7.

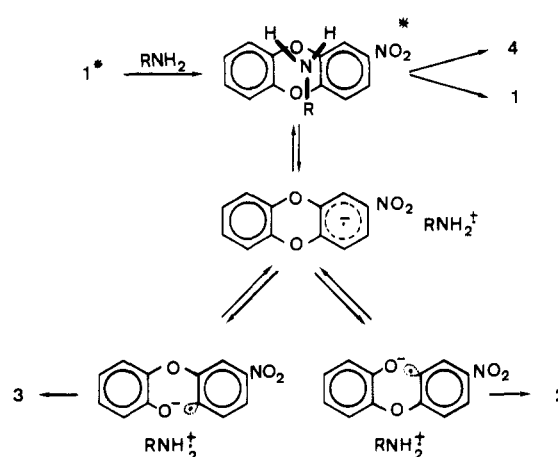
$$\phi = \gamma \frac{k_r[\text{Am}]}{k_d + (k_r + k_d')[\text{Am}] + k_q[\text{Q}]} \quad (6)$$

$$\phi^{-1} = \gamma^{-1} \left(\frac{k_r + k_d'}{k_r} + \frac{k_d}{k_r[\text{Am}]} + \frac{k_q[\text{Q}]}{k_r[\text{Am}]} \right) \quad (7)$$

The relative importance of the different reactions of the triplet state of 1 can be determined from the plots in Figures 1 and 2. In the absence of any quencher, the third term in parentheses in eq 7 is zero, and the ratio of intercept to slope of the straight line in Figure 1 corresponds to the ratio $(k_r + k_d')/k_d$, whose value comes out to be 3 M⁻¹. In the presence of the quencher at a given concentration of the amine, eq 7 requires a linear dependence of ϕ^{-1} on the quencher concentration. This was experimentally verified: the slope of the fit, viz., $\gamma^{-1}(k_q/k_r[\text{Am}])$, comes out to be 5.7×10^5 M⁻¹. The ratio k_q/k_d can be calculated by employing the value of the slope of the fit reported in Figure 1, viz., $\gamma^{-1}k_d/k_r$, so that one obtains $k_q/k_d = 8.8 \times 10^3$ M⁻¹.

Thus the rate of reaction of the triplet state of 1 with the amine is of the same order of magnitude as its rate of intersystem crossing to the ground state but several orders of magnitude lower than its rate of energy transfer to tetramethyldiazetidine dioxide. With the reasonable assumption that the energy transfer occurs at a diffusion-controlled rate ($k_q = k_{\text{diff}} = 1.8 \times 10^{10}$ s⁻¹ in acetonitrile), $k_d \approx 2 \times 10^6$ s⁻¹ and $k_r + k_d' \approx 6 \times 10^6$ M⁻¹ s⁻¹ can be evaluated. The present data do not allow the separate evaluation of the rates of the chemically productive (eq 3, rate k_r) and unproductive (eq 4, rate k_d') reactions of the triplet state of 1 with amines. Insofar as process 4 is negligible in comparison with process 3, the intercept of the fit given in Figure 1, viz., $\gamma^{-1}(k_r + k_d')/k_r$, corresponds to γ^{-1} , which gives $\gamma = 0.05$ as minimum quantum yield of formation for the triplet state of 1. See Table III for

Scheme III



the quantum yields for the reactions of 1. On the other hand, if process 4 competes with process 3, γ has to be larger. Thus, the low quantum yield of this reaction can be due either to inefficient intersystem crossing to the reactive triplet state or to efficient deactivation of the same state through reaction with amines.³

The remarkable solvent effect on the product ratio gives further information about the mechanism of formation of products 2, 3, and 4. The total quantum yield of the NDD reaction is gradually lowered in going from polar to apolar solvents, but, while the quantum yield of formation of product 4 remains practically unchanged, the quantum yield of formation of products 2 and 3 abruptly drops in apolar solvents. In cyclohexane intractable tars are formed, and this is not due to thermal or photochemical decomposition of products 2 and 3, which are stable under these conditions.

The simplest explanation of this effect, remembering that the three products all arise from the triplet state of 1, appears to be that the interaction of triplet 1 with the amine leads initially to an exciplex. This can then dissociate into radical ions which are stabilized in polar medium, while in apolar solvents only reactions from the undissociated exciplex are observed. In fact, it is tempting to conceive the exclusive formation of the 2-nitrophenoxazine 4, with exclusion of the isomeric 3-nitro derivative, as occurring in a more or less concerted fashion from the exciplex (see Scheme III), with simultaneous elimination of water. This fits well with the lack of influence of the solvent polarity on the formation of product 4. On the other hand, it also appears plausible that the NDD radical anion opens to the two possible phenolate forms (see Scheme III), which could be sufficiently stable in polar medium and could undergo further reaction to the diphenyl ethers 2 and 3. This would explain the formation of the latter products only in highly polar solvents. In apolar solvents other reactions, e.g., reduction of the nitro groups, leading eventually to tars, become predominant. Some cases of different behavior between exciplexes and the corresponding radical ions have in effect been reported.⁴

Experimental Section

General Methods. 1-Nitro- and 2-nitrodibenzo[*b,e*][1,4]dioxins were prepared according to the literature procedures^{5,6} and purified

(3) These results may be compared with the total rate of reaction of the triplet state of the fully aromatic 2-nitrophenazine with amines, which we found to be $k_r + k_d' \approx 1 \times 10^7$ M⁻¹ s⁻¹ (see ref 1b).

(4) F. D. Lewis, *Acc. Chem. Res.*, **12**, 152 (1979).

(5) G. Saint-Ruf and B. Lobert, *Bull. Soc. Chim. Fr.*, 183 (1974).

(6) J. D. London and F. McCapra, *J. Chem. Soc.*, 1899 (1959).

Table IV. Analytical Data on New Compounds

compd	mp, °C (cryst solv)	anal.						
		found			formula	calcd		
		C	H	N			C	H
2a	68.5-69 (cyclohexane)	62.3	5.5	9.6	C ₁₅ H ₁₆ N ₂ O ₄	62.5	5.6	9.7
3a	135.5-136 (cyclohexane)	62.3	5.6	9.9	C ₁₅ H ₁₆ N ₂ O ₄			
4a	69-69.5 (EtOH)	67.1	5.3	10.1	C ₁₅ H ₁₄ N ₂ O ₃	66.7	5.2	10.4
2b	164.5-165.5 (EtOH)	68.3	5.0	8.5	C ₁₅ H ₁₆ N ₂ O ₄	67.9	4.8	8.3
3b	135.5-136 (cyclohexane)	67.6	4.6	8.1	C ₁₅ H ₁₆ N ₂ O ₄			

by recrystallization to a constant melting point. Table IV lists melting points and analytical data. The UV spectra were recorded on a Perkin-Elmer 200 spectrophotometer, the IR spectra on a Perkin-Elmer 257 spectrophotometer, and the ¹H NMR spectra on a Perkin-Elmer R-12 instrument using (CH₃)₄Si as internal standard. Mass spectra were obtained by means of a Du Pont 492-B instrument. Melting points are uncorrected.

Irradiation Procedure. Solutions (1 × 10⁻² M) of 2-nitro-dibenzo[*b,e*][1,4]dioxin (1) were brought to a boil in the irradiation vessel and then cooled while being purged with nitrogen. The appropriate amount of amine was added, and the solution was irradiated by means of an immersion medium-pressure mercury arc (Hanau TQ 150) through a Pyrex filter, while maintaining a slow nitrogen bubbling. The conversion was brought to about 50%. The solution was then evaporated at reduced pressure after addition of some toluene in order to avoid concentration of the amine during the evaporation. The residue was chromatographed on a silica gel column, eluting with benzene.

Catalytic Reduction of Compound 2b. A 0.1-g sample of compound 2b in 20 mL of ethanol was hydrogenated in the presence of palladium on charcoal. The catalyst was filtered off, the solution evaporated, and the residue recrystallized from benzene, yielding 0.05 g of 2,4-diamino-2'-hydroxydiphenyl ether (5), identical (spectroscopic properties, no depression of the mixture melting point) with a sample obtained through an unambiguous synthesis (see below).

Catalytic Reduction of Compound 3b. A 0.1-g sample of compound 3b was hydrogenated as above. A clear solution was obtained, which turned to blue on admitting air. This color could be bleached under a hydrogen atmosphere. On evaporation of the solvent an untractable gum was obtained. This suggested that two amino groups, or an amino and a hydroxy group, were para one to another, and therefore the compound could be easily oxidized to the corresponding quinone.

2,4-Diamino-2'-hydroxydiphenyl Ether (5). 2,4-Dinitro-2'-methoxydiphenyl ether (prepared in 85% yield from 2,4-dinitrochlorobenzene and guaiacole with the method of London and McCapra⁶) was heated in melted pyridinium chloride at 200 °C for 10 min to yield 2,4-dinitro-2'-hydroxydiphenyl ether: mp 94 °C (cyclohexane); yield 40% (lit.⁷ mp 98.5-99 °C; yield 10%). This

product (0.8 g) in 50 mL of ethanol was hydrogenated in the presence of palladium on charcoal. Evaporation of the solvent and recrystallization of the residue from benzene yielded 0.35 g (55% yield) of compound 5 as pale pink needles, mp 151.5-152 °C. Anal. Calcd for C₁₂H₁₂N₂O₂: C, 66.7; H, 5.6; N, 13.0. Found: C, 66.8; H, 5.6; N, 13.0.

N-Propyl-3-nitrophenoxazine. This compound was prepared in 58% yield from 2-(propylamino)phenol and 2,4-dinitrochlorobenzene with the method of Roberts and Clark.⁸ Recrystallization from acetic acid yielded bright red crystals, mp 129.5-130 °C. Anal. Calcd for C₁₅H₁₄N₂O₃: C, 66.5; H, 5.2; N, 10.4. Found: C, 66.5; H, 5.3; N, 10.1.

Measurements. The quantum yield of the photoreactions was determined at 313 nm by irradiating dilute solutions contained in spectrophotometric 1-cm cells with a super-high-pressure mercury lamp (Osram 200 W/4, Schott PIL interference filter). The samples were degassed by repeated freeze-pump-thaw cycles prior to irradiation. Potassium ferrioxalate was used as an actinometer. The extent of the NDD reaction and the yield of formation of the diphenyl ethers 2 and 3 were determined by high-pressure liquid-liquid chromatography (column size, 2 mm i.d. × 60 cm; packing, Corasil type 1, from Waters Assoc.; eluant, benzene). The reactions were quenched at ca. 10% conversion. Under these conditions the phenoxazine 4 could not be measured. Therefore, the effect of the diazotized dioxin on the formation of 4 was measured by experiments with more concentrated solutions, as described in the Irradiation Procedure section.

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Registry No. 1, 38178-41-5; 2a, 73262-25-6; 2b, 73262-26-7; 3a, 73274-28-9; 3b, 73262-27-8; 4a, 73262-28-9; 5, 73262-29-0; 2,4-dinitro-2'-methoxydiphenyl ether, 2363-29-3; N-propyl-3-nitrophenoxazine, 73262-30-3; 2-(propylamino)phenol, 4280-56-2; 2,4-dinitrochlorobenzene, 97-00-7.

(7) V. N. Drozd, V. N. Knyazev, and A. A. Klimov, *Zh. Org. Khim.*, 10, 826 (1974).

(8) K. C. Roberts and N. B. Clark, *J. Chem. Soc.*, 1312 (1935).

Photooxidation of Strained Olefins. 4.¹ Cyclopropenes

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The photosensitized oxidation of cyclopropenes 5a-c proceeds rapidly, producing a plethora of products whose formation can be understood in terms of secondary rearrangements of initially formed products hydroperoxide 24 and epoxide 29. However, the reaction does not involve singlet oxygen but is rather a free-radical process.

Introduction

For decades cyclopropene and its derivatives have intrigued the theoretician and challenged the synthetic chemist. The source of this fascination is the approximately 50 kcal/mol of strain energy² stored up in this

petite molecule. Recently we have been studying^{1,3} the effect of strain on the rate, mode, and direction of singlet oxygen (¹O₂) reactions and, of course, cyclopropene de-

(2) See Baird, N. C.; Dewar, M. J. S. *J. Am. Chem. Soc.* 1967, 89, 3966.

(1) For part 3 of this series, see: Frimer, A. A.; Roth, D. *J. Org. Chem.* 1979, 44, 3882.

(3) (a) Frimer, A. A.; Farkash, T.; Sprecher, M. *J. Org. Chem.* 1979, 44, 989. (b) Frimer, A. A.; Rot D.; Sprecher, M. *Tetrahedron Lett.* 1977, 1927.