TABLE I

Amino acid or derivative	Diethyl azodicarboxylate[a]	Solvent system	Time, hr	% yield of sulfoxide
DL-Methionine	3	Water–ethanol	3	97
L-Ethionine	3	Water–dioxane	1.5	>95
Glycyl-DL-methionine	3	Water–dioxane	1.5	>95
L-Methionine amide·HCl	4	Water–ethanol	4	>98
DL-Methionine methyl ester·HCl	4	Water–methanol	5	>98
S-Ethyl-L-cysteine	18[b]	Water–ethanol	24	>98

[a] Given in the ratio of moles of azodicarboxylate ester *vs.* moles of sulfide. [b] The reagent was added to the reaction mixture of six equal portions during 24 hr.

The solution was concentrated *in vacuo* to a volume of 75 ml and the aqueous mixture was extracted several times with ethyl acetate. The extracts were dried over anhydrous sodium sulfate and evaporated to leave 3.4 g (19.3 mmoles) of ethyl hydrazodicarboxylate, identified by its infrared spectrum.

The aqueous portion was lyophilized to leave 1.61 g (97.5%) of DL-methionine sulfoxide, mp 205–215° dec (lit.[12] mp 220–230° dec). The product was shown to be identical with an authentic sample of DL-methionine sulfoxide by infrared spectroscopy and thin layer chromatography. A sample of the product was placed on an automatic amino acid analyzer and was shown to have the same retention time as authentic DL-methionine sulfoxide.

Oxidation of L-Methionine Amide Hydrochloride.—A solution of 0.92 g (5 mmoles) of L-methionine amide hydrochloride, 3.16 g (20 mmoles) of ethyl azodicarboxylate, 30 ml of ethanol, and 20 ml of water was stirred at room temperature for 4 hr. Thin layer chromatography (silica gel; 70% 1-propanol, 30% water) showed the absence of starting material. The reaction mixture was processed as described for the oxidation of DL-methionine to yield 1.96 g (11.1 mmoles) of ethyl hydrazodicarboxylate and 1.0 g (quantitative yield) of L-methionine amide sulfoxide hydrochloride as a colorless hygroscopic powder. The product was triturated with dry ether, filtered, and dried over phosphorus pentoxide to give a colorless crystalline solid, mp 160–175° dec.

Anal. Calcd for $C_5H_{13}ClN_2O_2S$: C, 29.92; H, 6.53; N, 13.96; S, 15.98. Found: C, 29.88; H, 6.46; N, 13.59; S, 15.81.

The infrared spectrum (KBr) showed a strong peak at 10.0 mμ characteristic of a sulfoxide (solid state).

Oxidation of DL-Methionine Methyl Ester Hydrochloride.—A solution of 0.995 g (5.0 mmoles) of DL-methionine methyl ester hydrochloride, 3.162 (20 mmoles) of ethyl azodicarboxylate, 30 ml of methanol, and 10 ml of water was stirred at room temperature for 5 hr. Processing as described above yielded 1.1 g (quantitative yield) of DL-methionine methyl ester sulfoxide hydrochloride as a colorless viscous oil. The infrared spectrum (film) showed a strong sulfoxide peak at 9.85 mμ.

Oxidation of S-Ethyl-L-cysteine.—A solution of 1.49 g (10 mmoles) of S-ethyl-L-cysteine, 4.74 g (30 mmoles) of ethyl azodicarboxylate, 75 ml of ethanol, and 75 ml of water was stirred at room temperature for 4 hr, during which time the solution became colorless. Thin layer chromatography (silica gel, 70% 1-propanol, 30% water) showed a large amount (*ca.* 80%) of unreacted starting material. Every 4 hr another 30 mmoles of the azo ester was added until a total of 180 mmoles had been added. Thin layer chromatography then indicated the absence of starting material. The solution was concentrated *in vacuo* to 50 ml; distilled water (50 ml) was added and the mixture was extracted with ethyl acetate to remove ethyl hydrazodicarboxylate.

The aqueous portion was lyophilized to leave 1.66 g (quantitative yield) of S-ethyl-L-cysteine sulfoxide as a colorless powder, mp 140–150°. Recrystallization from aqueous ethanol gave colorless crystals, mp 157–159° dec.

Anal. Calcd for $C_5H_{11}NO_3S$: C, 36.35; H, 6.71; N, 8.48. Found: C, 36.57; H, 6.66; N, 8.34.

Reaction of Ethylthioacetic Acid with Ethyl Azodicarboxylate.—A solution of 1.20 g (10 mmoles) of ethylthioacetic acid, 4.74 g (30 mmoles) of ethyl azodicarboxylate, 30 ml of acetone, and 10 ml of water was stirred at room temperature for 4 days, after which time the orange solution had become colorless. The solution was concentrated to 10 ml, diluted with a solution of 2.52 g (30 mmoles) of sodium bicarbonate in 30 ml of distilled water, and the mixture was extracted with ethyl acetate to remove ethyl hydrazodicarboxylate.

The aqueous phase was acidified with dilute hydrochloric acid to pH 2 and extracted with chloroform. The extracts were washed with water, dried over anhydrous sodium sulfate, and evaporated to yield 2.35 g (80%) of the 1:1 adduct III as a crystalline solid. Recrystallization from water gave colorless prisms, mp 122–125°.

Anal. Calcd for $C_{10}H_{18}N_2SO_6$: C, 40.80; H, 6.17; N, 9.52; S, 10.89. Found: C, 40.96; H, 6.02; N, 9.43; S, 10.94.

The nmr spectrum ($CDCl_3$) showed a triplet centered at 1.32 (9 protons), a quartet centered at 2.85 (2 protons), a quartet centered at 4.30 (4 protons), a singlet at 6.08 (1 proton), a broad band at 7.35 (1 proton), and a singlet at 9.38 (1 proton) ppm.

Attempted Oxidation of Certain Thioethers with Ethyl Azodicarboxylate.—Attempts were made to oxidize N-acetyl-L-methionine amide, *n*-hexyl sulfide, isobutyl sulfide, and benzyl sulfide with excess ethyl azodicarboxylate in ethanol–water or acetone–water solution at room temperature and at reflux. In all cases only the starting thioether and ethyl hydrazodicarboxylate were isolated.

(12) G. Toennies, *Science*, **88**, 545 (1938).

Photochemical Rearrangement of a γ,δ-Cyclopropyl-α,β-Unsaturated Ketone

PAUL J. KROPP AND HOWARD J. KRAUSS

The Procter & Gamble Company, Miami Valley Laboratories, Cincinnati, Ohio 45239

Received June 13, 1967

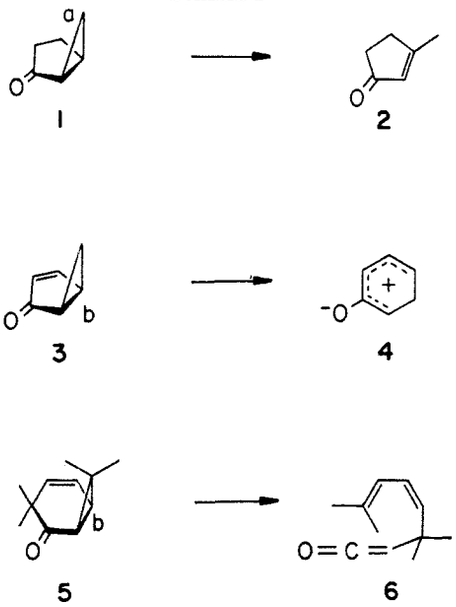
One of the remaining problems concerning conjugated cyclopropyl systems is establishing the factors involved in determining which bond of the cyclopropane ring will undergo cleavage during the course of a photochemical reaction. From a consideration of only the bicyclo[3.1.0]hexan-2-one system (**1**), the situation appears quite simple. Several reports have indicated that derivatives of **1** undergo predominant or exclusive cleavage of the external bond a rather than the internal bond b, to afford products of type **2**.[1] This is not surprising since, within the rigid skeleton of **1**, it is the orbitals of bond a which are more nearly parallel to, and can more effectively overlap with, the π orbitals of the carbonyl group. However, the introduction of a double bond to give the bicyclo[3.1.0]hex-3-en-2-one system **3** dramatically alters the photochemical behavior; derivatives of **3** undergo almost exclusive cleavage of the internal bond b to afford products ultimately derived from an intermediate of type **4**.[2] Parallel behavior is exhibited by the bicyclo[4.1.0]hept-4-en-2-one analog **5**, which undergoes cleavage to **6**[3]

(1) (a) O. L. Chapman, T. A. Rettig, A. A. Griswold, A. I. Dutton, and P. Fitton, *Tetrahedron Letters*, 2049 (1963); (b) O. L. Chapman, J. B. Sieja, and W. J. Welstead, Jr., *J. Am. Chem. Soc.*, **88**, 161 (1966); and (c) J. N. Pitts, Jr., L. D. Hess, E. J. Baum, E. A. Schuck, J. K. S. Wan, P. A. Leermakers, and G. Vesley, *Photochem. Photobiol.*, **4** 305 (1965); L. D. Hess and J. N. Pitts, Jr., *J. Am. Chem. Soc.*, **89**, 1973 (1967).

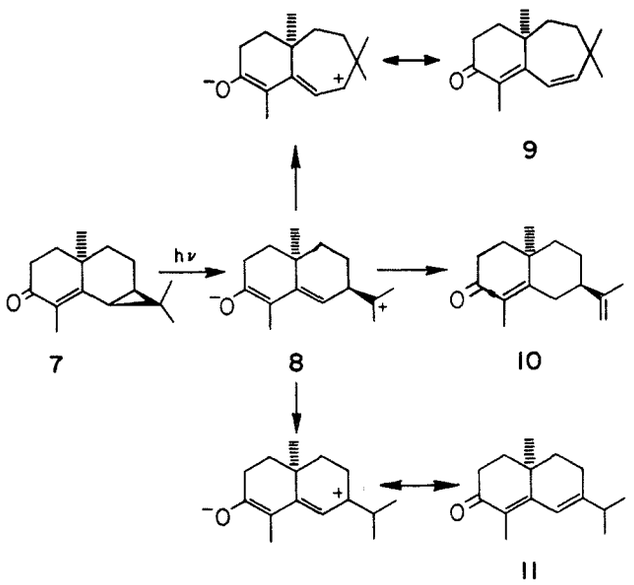
(2) For a discussion of the photochemical behavior of bicyclo[3.1.0]hex-3-en-2-ones, see P. J. Kropp, *Org. Photochem.*, **1**, 1 (1967).

(3) A. J. Bellamy and G. H. Whitham, *J. Chem. Soc.*, 4035 (1964).

SCHEME I



SCHEME II



(Scheme I). It has been suggested that cleavage of bond b in compounds of types **3** and **5** indicates that the controlling factor in these cases is a requirement during the course of cleavage for continuous overlap of the cyclopropyl system with the π orbitals of the carbonyl group on one side and double bond on the other.[2-4] This condition can be met only by bond b. Presumably, removal of the possibility of a cyclic mechanism for cleavage would induce preferential reaction by bond a. We wish now to describe the photochemical behavior of the cyclopropyl ketone **7**, in which the possibility of a cyclic mechanism is absent.

Irradiation of **7**[5] in a variety of solvents afforded three principal photoproducts in varying ratios (Table I). Two of these products were found to be epi-α-cyperone (**10**) and β-cyperone (**11**) by direct comparison with specimens prepared independently as described previously.[6] The third product is tentatively assigned

TABLE I
PHOTOCHEMICAL REARRANGEMENT OF CYCLOPROPYL KETONE **7**[a]

Solvent	Time, hr	Yield,[b] % 7	9	10	11
Benzene	2	11	9	59	12
Ether	1	11	27	25	21
Methanol	1	21	2	45	13

[a] See Experimental Section for details. [b] Determined by gas chromatographic analysis of the crude reaction product after removal of solvent. The results reported are those of a typical run.

the novel structure **9** on the basis of spectral data. The mass spectrum revealed that this photoproduct, too, is isomeric with the starting ketone **7**, while infrared absorption at 6.02 and 6.10 μ indicated the continued presence of an enone chromophore (Scheme II). This was confirmed by ultraviolet absorption at 272 mμ (ϵ 21,000), which further suggested that the unsaturation consists of a linearly conjugated dienone system. The nmr spectrum displayed three singlets attributable to methyl groups located at saturated positions (τ 8.86, 8.97, and 9.05) and a fourth band (8.32) assignable to an allylic methyl group. Absorption by two vinylic protons also appeared (4.12 and 4.52) in the form of a clean AB quartet with J_{AB} = 12 Hz. The magnitude of this coupling constant indicates that the double bond is present in a seven-membered ring.[7] Hydrogenation of the photoproduct afforded a tetrahydro derivative (**12**) having the appropriate infrared absorption at 5.86 μ and no absorption in the nmr spectrum below τ 7.6.

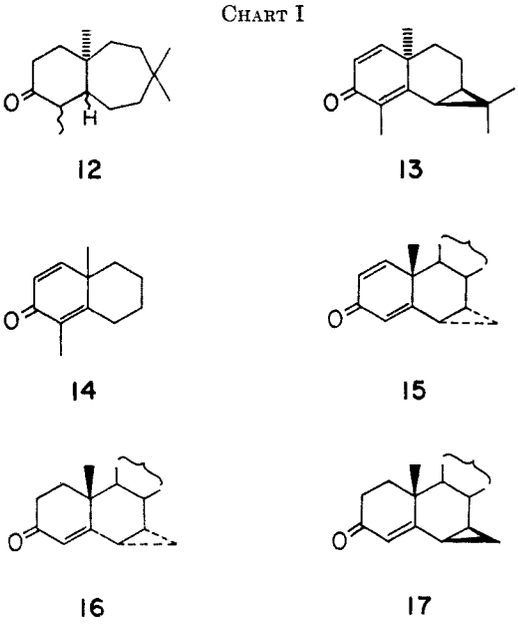
Since control experiments revealed no interconversion of the photoproducts, it is assumed that each is a primary product derived directly from **7**. The formation of **9**, **10**, and **11** apparently involves an initial cleavage of the *external* cyclopropyl bond to afford an intermediate of type **8** which undergoes either an appropriate hydrogen shift to afford the cyperones **10** and **11** or an alkyl shift and concomitant ring expansion to afford **9**.[8] There was no evidence for the presence of any other significant products formed *via* cleavage of the internal cyclopropyl bond and there is no obvious route to the products **9**, **10**, or **11** involving an initial cleavage of that bond. Thus in this system the direction of cleavage is that which is predicted on the basis of maximum parallel overlap with the π system of the enone chromophore and there is apparently nothing special *per se* about the conjugation of a cyclopropane ring with a double bond which favors a bond b type of cleavage in the absence of a cyclic mechanism.

For comparison of its behavior, the corresponding cross-conjugated dienone **13** was prepared by oxidation of the cyclopropyl ketone **7**. In contrast to **7**, which is reasonably photolabile, the dienone **13** was found to be *extraordinarily stable toward ultraviolet light*, at least in benzene or ether solution. Irradiation of **13** at 2537 A or with the broad mercury spectrum under conditions well beyond those normally required for total destruction of **7** or of the analogous dienone

(4) P. J. Kropp, *J. Am. Chem. Soc.*, **87**, 3914 (1965).
(5) R. B. Bates, G. Büchi, T. Matsuura, and R. R. Shaffer, *ibid.*, **82**, 2327 (1960).
(6) R. Howe and F. J. McQuillin, *J. Chem. Soc.*, 2423 (1955).
(7) O. L. Chapman, *J. Am. Chem. Soc.*, **85**, 2014 (1963); G. V. Smith and H. Kriloff, *ibid.*, **85**, 2016 (1963); P. Laszlo and P. von R. Schleyer, *ibid.*, **85**, 2017 (1963).
(8) The representation of ionic intermediates such as **8** is not necessarily intended to have mechanistic significance except insofar as the rearrangement to **9**, **10**, and **11** is more reminiscent of typical cationic than either anionic or radical behavior.

14[4,9] effected no significant rearrangement. This marked difference in lability between **13** and **7**, on one hand, and **13** and **14**, on the other, may be attributable to conformational effects; however, Dreiding models reveal no obvious distortion of the cyclopropylenone chromophore in **7** by the introduction of the second double bond of **13**, or of the dienone chromophore in **14** by the introduction of the cyclopropyl ring of **13** (Chart I). The effect is perhaps due to an alteration of electronic distribution in the excited state and may reflect a difference as to whether the lowest lying excited state is n,π^* or π,π^*.

CHART I



12 **13** **14** **15** **16** **17**

It has recently been reported, subsequent to the completion of this work, that the stereoisomeric cyclopropyl ketones **16** and **17** are photochemically inert.[10] The surprising difference in behavior between **16** and **7** may reflect stabilization of the intermediate **8** by the presence of the *gem*-dimethyl substitution on the cyclopropane ring. In complete analogy with **13**, the dienone **15** was also found to be unreactive toward ultraviolet irradiation.[10]

Experimental Section[11]

Irradiation of (−)-1,1,3a,7-Tetramethyl-1,1a,2,3,3a,4,5,7b-octahydro-6H-cyclopropa[*a*]naphthalen-6-one (7).—Irradiations were conducted with 150-ml solutions containing 200–234 mg of cyclopropyl ketone **7** (mp 65.5–67.5°, prepared from (−)-epi-α-cyperone[5]) using a Hanovia 450-w medium-pressure mercury lamp and a Vycor water-cooled immersion well. Mixing of the solution was attained by the introduction of a stream of nitrogen through a jet opening at the bottom of the apparatus. The results from a series of typical runs are outlined in Table I. Isolation by preparative gas chromatography afforded, in addition to recovered starting material, specimens of the cyperones **10** and **11** which exhibited gas chromatographic, infrared, and nmr properties identical with those of authentic material.[6] Also isolated was a colorless oil tentatively identified as (−)-**1,4a,7,7-tetramethyl-3,4,4a,5,6,7-hexahydro-2H-benzocyclohepten-2-one (9)**: $[\alpha]_{5461}^{27}$ −46° (*c* 0.95); λ_{max} 6.02 and 6.10 μ; λ_{max} 272 mμ (ε 21,000); nmr spectrum, τ 4.12 and 4.52 (2d, 2, J_{AB} = 12 Hz, CH-8 and -9), 8.32 (m, 3, CH_3-1), and 8.86, 8.97, and 9.05 (3s, 9, CH_3-4a, -7, and -7);[12] *m/e* 218.1668 (calcd, 218.1670), 203, 190, 175, 161, 147, 133, and 119.[13]

Further purification by short-path distillation at 115° (0.1 mm) afforded a pale yellow oil.[14]

Anal. Calcd for $C_{15}H_{22}O$: C, 82.51; H, 10.16. Found: C, 81.8; H, 10.4.

Treatment of a solution containing 34 mg of photoproduct **9** in 5 ml of ethanol in an atmosphere of hydrogen resulted in the absorption of 2.2 equiv. Isolation in the usual manner followed by short-path distillation of 94–96° (0.2 mm) afforded (+)-**1,4a,7,7-tetramethyl-2,3,4,4a,5,6,7,8,9,9a-decahydro-1H-benzocycloheptan-2-one (12)** as a colorless liquid: $[\alpha]_{5461}^{27}$ +58° (*c* 1.39); λ_{max} 5.86 μ; nmr spectrum, no absorption below τ 7.6.

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 81.35; H, 11.8.

Control Runs.—Irradiation of 150-ml ether solutions containing 234 mg of epi-α-cyperone (**10**) or β-cyperone (**11**) for 1 hr as described above followed by removal of the solvent at atmospheric pressure and gas chromatographic analysis of the resulting residue afforded only recovered starting material with no evidence for the formation of any of the other photoproducts **9–11**.

(−)-1,1a,2,3,3a,7b-Hexahydro-1,1,3a,7-tetramethyl-6H-cyclopropa[*a*]naphthalen-6-one (13). A. Preparation.—The general procedure of Burn, Kirk, and Petrow[15] was employed. A solution containing 994 mg (4.55 mmoles) of cyclopropyl ketone **7** and 1.13 g (5.00 mmoles) of 2,3-dichloro-5,6-dicyanobenzoquinone in 30 ml of benzene was heated under reflux in an atmosphere of nitrogen for 24 hr. The reaction mixture was cooled to room temperature, filtered, and concentrated under reduced pressure on a rotary evaporator. The resulting amber oil was then filtered through 30 g of activity II alumina with 1 l. of petroleum ether (bp 60–80°) to give 700 mg of a partially crystalline pale yellow oil which was shown by gas chromatography to consist of 56% dienone **13** and 44% recovered starting material. Further purification by preparative gas chromatography followed by recrystallization from petroleum ether afforded a specimen of dienone **13** as colorless rods: mp 85.5–86.5° (slight previous softening); $[\alpha]_{5461}^{27}$ −87° (*c* 1.49); λ_{max} 6.04, 6.16, 6.22, and 12.02 μ; λ_{max} 211 (ε 5100), 240 (ε 6300), and 280 mμ (ε 5500); nmr spectrum, τ 3.34 and 3.84 (2d, 2, J_{AB} = 10 Hz, CH-4 and -5), 8.12 (s, 3, CH_3-7), 8.76 and 8.80 (2s, 6, $2CH_3$-1), and 9.18 (s, 3, CH_3-3a); *m/e* 216, 201, 173, 159, 145, and 131.

Anal. Calcd for $C_{15}H_{20}O$: C, 83.28; H, 9.32. Found: C, 83.35; H, 9.35.

B. Irradiation.—A 314-mg specimen of dienone **13** was irradiated as described above, first in ether solution with a Hanau NK 6/20 low-pressure mercury lamp for 3.5 hr and then with a Hanovia 200-w medium-pressure mercury lamp in ether solution for 1.5 hr and benzene solution for 0.5 hr. Removal of the solvent after each irradiation afforded a pale yellow oil which exhibited no significant changes in the infrared or gas chromatographic spectra. Further irradiation for 7 hr in benzene solution with a Hanovia 450-w lamp followed by removal of solvent afforded a yellow oil which exhibited two unidentified minor peaks by gas chromatography (9 and 4%) and recovered starting material (87%). Collection of the principal peak by preparative gas chromatography afforded a white crystalline solid which exhibited infrared and nmr spectra identical with the starting dienone **13**. A similar irradiation of 265 mg of dienone **13** in ether solution for 2 hr with a 450-w lamp resulted in no detectable change by gas chromatogaphy.

Registry No.—**7**, 2506-71-0; **9**, 14120-56-0; **12**, 14120-57-1; **13**, 14120-58-2.

(9) P. J. Kropp, *J. Org. Chem.*, **29**, 3110 (1964); D. Caine and J. B. Dawson, *ibid.*, **29**, 3108 (1964).

(10) J. Pfister, H. Wehrli, and K. Schaffner, *Helv. Chim. Acta*, **50**, 166 (1967).

(11) Ultraviolet spectra were determined in absolute ethanol with a Cary Model 14 spectrophotometer and infrared spectra were obtained on neat samples with a Perkin-Elmer Infracord spectrophotometer unless otherwise indicated. Melting points were determined on a micro hot stage and are calibrated and corrected. Optical rotations were measured in absolute ethanol. Gas chromatographic analyses were performed on an Aerograph Model A-90P instrument using 5 or 10 ft × 0.25 in. columns packed with 20% Carbowax 20M or ethylene glycol succinate on 60/80 mesh Chromosorb W. Nuclear magnetic resonance spectra were determined in deuterated chloroform solution with a Varian Model A-60 or HA-100 spectrometer, using tetramethylsilane as an internal standard. Mass spectra were obtained using an Atlas Model SM-1 spectrometer.

(12) Indicates multiplicity (s = singlet, q = quartet, m = multiplet), integration, and assignment.

(13) The mass spectral data reported include the parent ion peak and other significantly large peaks appearing above the lowest *m/e* value listed.

(14) Because of a tendency for **9** to undergo some decomposition on distillation, an elemental analysis within the usually accepted limits could not be obtained; however, a correct elemental composition was obtained from the high-resolution mass spectrum.

(15) D. Burn, D. N. Kirk, and V. Petrow, *Proc. Chem. Soc.*, 14 (1960).