Photodecarboxylation of Glutaric Anhydrides. α-Cleaved Cyclobutanone Biradicals[1]

Sir:

The low-pressure Hg($^3P_1$)-photosensitized reaction of glutaric anhydride (GA) in a flow system was reported to yield cyclopropane (yield 53.8%), acetylene (23.5%), ethylene (4.7%), propylene (0.4%), and a trace of ketene in addition to CO and CO_2.[2] The cyclobutanone (CB) biradical was proposed as an intermediate species which subsequently decomposed either to cyclopropane + carbon monoxide, or to ketene + ethylene, but CB was never found in these experiments. Extensive studies in vapor phase CB photochemistry show that CB decomposes in a different manner depending upon its multiplicity; in both the internally converted hot S_0* and S_1 states it decomposes to ketene + ethylene, but in the T_1 state to cyclopropane + carbon monoxide. Above its predissociation threshold, however, the singlet α-cleaved CB biradical is formed in addition to the S_0*, S_1, and T_1 state products.[3] There is no substantial evidence for the triplet α-cleaved CB biradical formation, but the triplet cyclobutanones with methyl substituents generated by the triplet sensitizations decarbonylate very efficiently to yield a trimethylene-like biradical.[4] Liquid-phase photolysis of CB results in both decarbonylation and ethylene formation, probably derived by crossover from CB(S_1) to the repulsive surfaces representing $\cdot CH_2COCH_2CH_2\cdot$ and $\cdot CH_2CH_2CH_2CO\cdot$, the former being responsible for ethylene formation and the latter the source of cyclopropane and propylene.[5] In methanol 2-methoxytetrahydrofuran was observed in addition to those found in other solvents, probably originating from the singlet state or an unquenchable triplet state.[6] The presence of the CB(T_1) in liquid solution is, however, doubtful.[5] On the other hand, photodecarboxylation of benzyl esters has been shown to occur through the triplet state *via* a discrete biradical intermediate.[7] I wish to report here that both sensitized and direct photolyses of glutaric anhydride under sufficiently high vapor pressure at 155 and 260° yield primarily cyclopropane and CB in addition to CO and CO_2. This reaction thus provides a simple novel method for preparation of CB and its derivatives. The photodecarboxylation to yield CB is also found to occur in both neat and crystalline phases of GA.

The Hg($^3P_1$)-photosensitized reaction was carried out in a quartz cylinder which contained GA and a drop of mercury under vacuum. The cylinder was placed inside another quartz tube partially wrapped with heated nichrome wire. After temperature equilibration, the irradiation was carried out with a surrounding bank of low-pressure mercury lamps. For liquid- and solid-phase photolyses, a 1.2-cm diameter quartz tube was used with a 1.0-cm diameter glass rod placed inside, while irradiated with a bank of low-pressure mercury lamps. After irradiation, the products were pumped out through a trap cooled with liquid nitrogen, while measuring the amount of CO formed, which was confirmed by mass spectrometry as the only noncondensable product at liquid nitrogen temperature. The rest of the products were analyzed by gas chromatograph and by mass spectrometry. The CB formed was identified by comparing its ir, mass, and nmr spectra with a sample supplied by Aldrich Chemical Co. The 2,2- and 3,3-dimethylcyclobutanones obtained were identified by comparison with the reported ir and mass spectra.[8] The nmr spectra of the dimethylcyclobutanones matched those of the samples independently prepared according to the reported method.[8,9] The light intensity for the Hg($^3P_1$)-photosensitized reaction was measured using 3-pentanone as an actinometer, and with a mixture of N_2O + ethane. Both measurements agreed fairly well with each other, yielding 9.4 × 10^{-5} einstein/min under the same conditions for photolysis at 155°.

Table I. Photoproducts of Glutaric Anhydride

Phase	Temp, °C	Yields relative to CO_2[a]: CO	C_2H_4	C_3H_6	C_4H_6O	Initial amount of glutaric anhydride, g[b]
Vapor, Hg*	155	0.93	0.00	0.73	0.00	0.054
Vapor, Hg*	155	0.80	0.029	0.78	0.12	2.053
Vapor, Hg*	260	0.56	0.037	0.48	0.41	1.998
Neat	57		0.00	0.040	0.126	
Crystalline	30		Trace	0.066	0.079	

[a] Rate of CO_2 formation at 155° under the saturation vapor pressure was 4.8 × 10^{-5} mol min^{-1} per 9.6 × 10^{-5} einstein min^{-1}. [b] A 602-cm^3 quartz cylinder was used for the vapor phase Hg($^3P_1$) photosensitized reaction.

The results for GA are presented in Table I. Direct photolysis in the absence of mercury with the full power of a medium-pressure mercury lamp or with a zinc lamp yielded essentially the same results as the Hg($^3P_1$)-photosensitized reaction, indicating perhaps the same intermediate species in each case. With a small charge of the anhydride in the reactor, insufficient to establish the saturation vapor pressure, cyclopropane and a trace of propylene were produced together with CO and CO_2, while ethylene, acetylene, and CB were absent. However, in runs at the saturation vapor pressure, CB and a trace of ethylene were formed together with cyclopropane, CO, and CO_2. With an increase of the saturation vapor pressure at high temperature the yield of CB dramatically increased, while the amount of cyclopropane gradually decreased. There was no ethylene formation in the neat form photolysis at 57°, but a trace of ethylene was found in the photolysis of crystalline GA after long irradiation.[10] The photode-

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(1) A part of the paper was presented at the 164th National Meeting of the American Chemical Society, New York, N. Y., Aug 30, 1972.

(2) I. S. Krull and D. R. Arnold, *Tetrahedron Lett.*, 4349 (1969).

(3) J. C. Hemminger, C. F. Rusbult, and E. K. C. Lee, *J. Amer. Chem. Soc.*, **93**, 1867 (1971), and earlier work cited herein.

(4) J. Metcalfe and E. K. C. Lee, *ibid.*, **94**, 7 (1972).

(5) R. F. Klemm, *Can. J. Chem.*, **48**, 3320 (1970).

(6) N. J. Turro, J. C. Dalton, K. Dawes, G. Farrington, R. Hautala, D. Morton, M. Niemczyk, and N. Schore, *Accounts Chem. Res.*, **5**, 92 (1972), and earlier work cited herein.

(7) R. S. Givens and W. F. Oettle, *J. Amer. Chem. Soc.*, **93**, 3301 (1971).

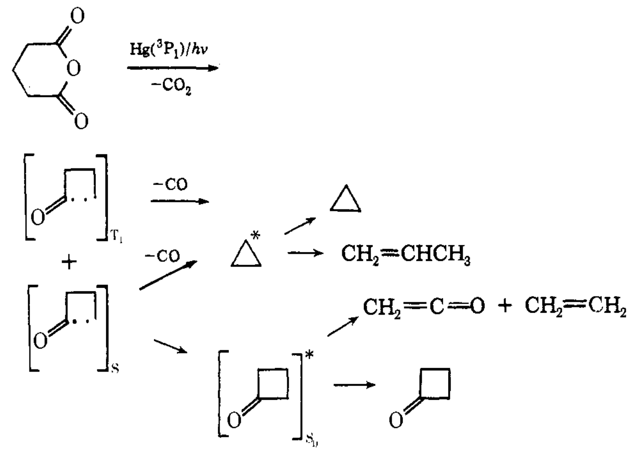
(8) H. Audier, J.-M. Conia, M. Fétizon, and J. Goré, *Bull. Soc. Chim. Fr.*, 787 (1967); J.-M. Conia, J. Goré, J. Salaün, and L. Ripoll, *ibid.*, 1976 (1964).

(9) Dimethylcyclobutanones were prepared by Dr. R. D. Miller. 3,3-Dimethylcyclobutanone, prepared by the present photodecarboxylation, also showed a doublet at 1780 cm^{-1}, which was reported as an abnormal ir absorption in ref 8. 3,3-Tetramethylenecyclobutanone did not show such a doublet of its ν (C=O).

(10) The photolysis of GA in liquid methanol at 254 nm yielded mainly glutaric acid monomethyl ester, glutaric acid dimethyl ester, and *n*-butyric acid methyl ester in addition to CO_2 and traces of other volatile products. However, no trace of 2-methoxytetrahydrofuran was found among the products.

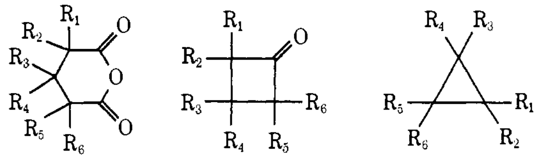
carboxylation of GA may proceed through α-cleaved cyclobutanone biradical, as shown in the mechanism of Scheme I. Because ethylene was only a minor product in the vapor-phase photolysis, and because it was not found in the neat form photolysis, ethylene and possibly ketene were formed only through CB(S_0*). This very minor role of ethylene, a characteristic singlet state product, was first taken to indicate the triplet biradical intermediate, as in the case of benzyl esters.[7,11] However, CB(T_1) and perhaps the triplet biradical decompose with 100% efficiency and do not give rise to CB(S_0) even at 1500 Torr.[3,4] The singlet biradical undergoes the internal conversion to CB(S_0) in addition to decarbonylation as well as ethylene formation.[3,12] The biradical intermediate generated by photodecarboxylation of GA may not be so activated in comparison with the one from CB(S_1) that it undergoes decarbonylation, the energetically preferred process.[13] The absence of ethylene, thus, does not rule out the singlet biradical intermediate. The photodecarboxylation of GA may yield both singlet and triplet biradicals. The Hg($^3P_1$)-photosensitized reaction of CB yielded a significant fraction of the singlet state products.[14] In the Hg($^3P_1$)/GA system, the triplet biradical may have been formed at low pressure, but it decarbonylates. With increase of the saturation vapor pressure of GA, the singlet biradical is formed to yield CB and cyclopropane. In the condensed phases, there may be only the singlet biradical intermediate, which can partly explain the reduced cyclopropane formation relative to CB formed. The intermediacy of the singlet biradical also explains no significant effect on the yield of CB by the presence of O_2.

Scheme I



Photolysis of substituted GA yielded the same results as simple GA. As shown in Table II, upon photodecarboxylation and decarbonylation 2,2-dimethylglutaric anhydride yielded 2,2-dimethylcyclobutanone and 3,3-dimethylglutaric anhydride yielded 3,3-dimethylcyclobutanone in addition to 1,1-dimethylcyclopropane for both cases. In contrast with the present technique, the reported method for preparation of dimethylcyclobutanones by addition of diazomethane to dimethylketene always yields a mixture of 2,2- and 3,3-dimethylcyclobutanones.[8] The present study of photodecarboxylation was extended to a more complicated GA, *i.e.*, 3,3-tetramethyleneglutaric anhydride, which yielded 3,3-tetramethylenecyclobutanone together with spiro[2.4]heptane, CO_2, and CO. 3,3-Tetramethylenecyclobutanone was characterized by ir, mass, and nmr spectra.[15]

Table II. Photoproducts of Substituted Glutaric Anhydrides in the Vapor Phase Hg($^3P_1$) Photosensitized Reaction under the Saturation Vapor Pressure



Substituents	Temp, °C	Products, 10^{-4} mol/9.6 × 10^{-4} einstein Cyclobutanones	Cyclopropanes	$R_3R_4C{=}CR_5R_6$
$R_1 = R_2 = CH_3$; $R_3 = R_4 = R_5 = R_6 = H$	165	0.53	2.86	0.098
$R_1 = R_2 = R_5 = R_6 = H$; $R_3 = R_4 = CH_3$	165	0.51	3.10	0.12
$R_1 = R_2 = R_5 = R_6 = H$; $R_3, R_4 = CH_2CH_2CH_2CH_2$	200	0.19	2.57	

Acknowledgments. The author wishes to thank Dr. H. E. Hunziker for his constant encouragement and helpful discussions and Dr. R. D. Miller for his most useful comments. The referee's comments are specially useful in understanding the mechanism.

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(11) The intermediacy of the singlet biradical was pointed out by a referee.

(12) H. A. J. Carless and E. K. C. Lee, *J. Amer. Chem. Soc.*, **94**, 1 (1972).

(13) The decarbonylation process is preferred by 9.73 kcal mol^{-1} at 25° to the ethylene formation process; *cf.* D. R. Stull, E. F. Westrum, Jr., and G. C. Sinke, "The Chemical Thermodynamics of Organic Compounds," Wiley, New York, N. Y., 1969. A. T. Blades (*Can. J. Chem.*, **47**, 615 (1969)) suggested that α-cleaved cyclobutanone biradical was responsible for decarbonylation, while β-cleaved cyclobutanone biradical led to ethylene + ketene.

(14) D. C. Montague and F. S. Rowland, *J. Amer. Chem. Soc.*, **91**, 7230 (1969).

(15) Ir (CCl_4) carbonyl absorption 1780 cm^{-1}; mol wt by mass 124; nmr (CCl_4) τ 7.20 (s, 4), 8.28 (singlet with a shoulder, 8).

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Received October 3, 1972

Subtilisin Catalysis of Nonspecific Anilide Hydrolyses

Sir:

The hydrolysis mechanism of serine proteases has often been studied using specific and nonspecific ester substrates. The same cannot be said for amide substrates since nonspecific amide substrates have not been observed to be hydrolyzed at all. We wish to report that the bacterial proteinase subtilisin[1] rapidly catalyzes the hydrolysis of two substituted acetanilides: 2,2,2-trifluoro-*N*-methyl-*p*-nitroacetanilide (I) and 2,2,2-trifluoro-*p*-nitroacetanilide (II). However, we were unable to detect subtilisin-catalyzed hydrolysis of *p*-nitroacetanilide.[2]

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(1) The enzyme was purified on carboxymethylcellulose according to the method of L. Polgar and M. L. Bender, *Biochemistry*, **8**, 136 (1969).

(2) Nonproductive complexes cannot be the cause of the inactivity of subtilisin since the k_2/K_s constants quoted in Tables I and II can have no nonproductive component; see M. L. Bender and F. J. Kézdy, *Annu. Rev. Biochem.*, **34**, 49 (1965).