Vinyl Substituent Effects in the Peracid Oxidation of Cyclopropenes

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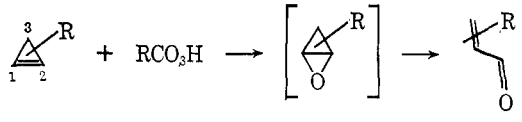
Abstract: The second-order rate constants ($\times 10^3$, M^{-1} sec^{-1}) for oxidation of 1,2-disubstituted 3,3-dimethylcyclopropenes in CCl_4 at 0° with *m*-chloroperbenzoic acid are: R_1 = Me and R_2 = H, 0.93; R_1 = R_2 = Me, 11.24; R_1 = Me and R_2 = Ph, 7.26; R_1 = R_2 = Ph, 0.384. These rate constants show vinyl substituent effects that parallel those for olefins which undergo true epoxidation. The results are consistent with the formation of oxabicyclobutane intermediates which fragment to the observed enone products.

Treatment of cyclopropenes with peracids results in smooth oxidation to unsaturated carbonyl products.[2] If the double bond of the cyclopropene is sufficiently hindered, the peracid will competitively abstract an available allylic C-3 cyclopropenyl hydrogen that leads to an intermediate cyclopropenyl cation.[2d,f]

In order to study the mechanism by which cyclopropenes are oxidized to carbonyl products, we have conducted and already reported on the stereochemistry of product formation with respect to the C-3 allylic substituents on cyclopropenes.[2c,e] Equally important to such product studies, kinetic studies can provide information about any initially formed intermediates.

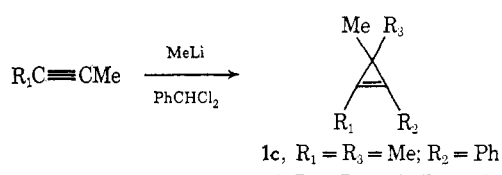
To date, we have studied three rate–structure features of cyclopropene oxidation with peracids. In work reported elsewhere,[2g] we have found that cyclopropenes are oxidized at rates similar to rates of epoxidation for cyclopentenes and cyclobutenes. Also, C-3 allylic substituent effects for cyclopropenes have been compared to the kinetic substituent effects found for epoxidation of allylically substituted cyclopentenes.[2h] In this paper, we report a series of vinyl substituent effects for cyclopropene oxidation and compare the results to the vinyl substituent effects for true epoxidation. These kinetic results are consistent with, if not demanding for, the formation of an oxabicyclobutane intermediate. Such intermediates have been neither isolated nor detected.[2,3]



In order to simplify the study of the kinetic vinyl substituent effects, we selected cyclopropenes which would be relatively stable and easy to handle. For this reason we used geminal dimethyl substituents on the allylic C-3 carbon, since hydrogens in this position may either react with peracids[2d] or lead to an undesirable Alder-ene reaction between two cyclopropene molecules.[4] Furthermore, both alkyl and aryl vinyl substituents were chosen because both types of substituents have been previously used in the kinetic studies of true epoxidations of acyclic olefins.[5] Finally, we have synthesized and studied the oxidation kinetics of analogously substituted cyclopentenes in order to delineate completely both alkyl and aryl vinyl substituent effects in a cyclic system that undergoes true epoxidation.

Results

The olefins in Table I were all prepared by procedures that have been previously described or were developed in our laboratories. Only cyclopropenes **1c**



1c, $R_1 = R_3 = Me$; $R_2 = Ph$
1d, $R_1 = R_2 = Ph$; $R_3 = Me$

Table I. Iodometric Rates of *m*-Chloroperbenzoic Acid Oxidation of Olefins in CCl_4 at 0°

Olefin	$10^3 k_2$, M^{-1} sec^{-1} [a]	Relative k_2
1,2-Disubstituted 3,3-Dimethylcyclopropene[b]		
1a, R_1 = Me; R_2 = H[c]	0.93 ± 0.19 (6)	2.4
1b, R_1 = R_2 = Me	11.24 ± 0.17 (3)	29.3
1c, R_1 = Me; R_2 = Ph	7.26 ± 0.60 (3)	18.9
1d, R_1 = R_2 = Ph	0.384 ± 0.023 (3)	(1.0)
1,2-Disubstituted Cyclopentene[d]		
2a, R_1 = Me; R_2 = H	180.3 ± 5.8 (3)	4.6
2b, R_1 = R_2 = Me	3480 ± 209 (6)	88
2c, R_1 = Me; R_2 = Ph	275 ± 19 (5)	7.1
2d, R_1 = R_2 = Ph	38.8 ± 2.3 (8)	1.0

[a] Errors are standard deviations of independent runs with the indicated degrees of freedom. [b] 4×10^{-2}–2×10^{-3} *M* in olefin, 2×10^{-2}–1×10^{-3} *M* in peracid. [c] Run competitively against **1b**, k_{1b}/k_{1a} = 12.1 ± 2.5 (6). [d] *Ca.* 4×10^{-2}–5×10^{-4} *M* in olefin, 2×10^{-2}–5×10^{-4} *M* in peracid.

(1) Elon Huntington Hooker Graduate Fellow, 1972–1973.

(2) (a) H. Prinzbach and U. Fisher, *Helv. Chim. Acta*, **50**, 1669 (1967); (b) J. Ciabattoni and P. J. Kocienski, *J. Amer. Chem. Soc.*, **91**, 6534 (1969); (c) L. E. Friedrich and R. A. Cormier, *J. Org. Chem.*, **35**, 450 (1970); (d) J. Ciabattoni and P. J. Kocienski, *J. Amer. Chem. Soc.*, **93**, 4902 (1971); (e) L. E. Friedrich and R. A. Cormier, *Tetrahedron Lett.*, 4761 (1971); (f) P. J. Kocienski and J. Ciabattoni, *J. Org. Chem.*, **39**, 388 (1974); (g) L. E. Friedrich and R. A. Fiato, *J. Org. Chem.*, **39**, 416 (1974); (h) L. E. Friedrich and R. A. Fiato, *J. Org. Chem.*, in press.

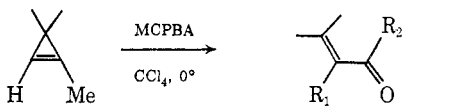
(3) (a) E. J. Corey, J. D. Bass, R. LeMahieu, and R. B. Mitra, *J. Amer. Chem. Soc.*, **86**, 5570 (1964); (b) H. E. Zimmerman, R. G. Lewis, J. J. McCullough, A. Padwa, S. W. Staley, and M. Semmelhack, *ibid.*, **88**, 1965 (1966); (c) O. L. Chapman and T. J. Murphy, *ibid.*, **89**, 3476 (1967); (d) H. E. Zimmerman and W. R. Eiser, *ibid.*, **91**, 887 (1969); (e) N. Furutachi, Y. Nakadaira, and K. Nakanishi, *ibid.*, **91**, 1028 (1969).

(4) (a) F. J. Weigert, R. L. Baird, and J. R. Shapely, *J. Amer. Chem. Soc.*, **92**, 6630 (1970); (b) P. Dowd and A. Gold, *Tetrahedron Lett.*, 85 (1969).

(5) D. Swern in "Organic Peroxides," D. Swern, Ed., Wiley-Interscience, New York, N. Y., 1971, pp 355–535, and references therein.

and **1d** deserve special mention. Using a modification of a procedure described by Closs,[6] cyclopropenes **1c** and **1d** were prepared by the reaction of methyllithium and benzal chloride with either 2-butyne or phenylpropyne, respectively. In this procedure, the methyllithium serves not only as a base to remove a proton from benzal chloride but also as an alkylating agent to react with the intermediate chlorocyclopropene.

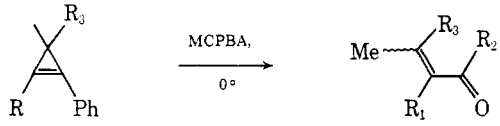
The oxidation reaction conditions were 99+% *m*-chloroperbenzoic acid (MCPBA) in CCl_4 at 0°. Each cyclopentene **2a–d** gave a quantitative yield of epoxide. Cyclopropene **1a** gave a 79:21 kinetic mole ratio of unsaturated carbonyl products **4a** and **4b**. At moderate



1a

4a, R_1 = Me; R_2 = H
4b, R_1 = H; R_2 = Me

conversions, the initial products are gradually destroyed by peracid such that the observed ratio of **4a**:**4b** drops in value.[7] The remaining cyclopropenes all gave essentially quantitative yields of enones throughout greater than 90% conversion (based on peracid initially present) of cyclopropene (see Experimental Section). Only cyclopropene **1c** deserves special comment. The enone product formed was shown by synthesis to be solely enone **5a**. No trace of enone **5b** was detected.



1c, R = Me; R_3 = Me
e, R = *t*-Bu; R_3 = *t*-Bu

5a, R_1 = Ph; R_2 = Me; R_3 = Me
5b, R_1 = Me; R_2 = Ph; R_3 = Me
5c, R_1 = R_3 = *t*-Bu; R_2 = Ph

This result is contrasted by the report of Ciabattoni[2d] who found that when a vinyl *tert*-butyl substituent was used cyclopropene **1e** gave only enone **5c**. This contrasting stereochemical result signifies the importance of steric effects in the overall oxidation which is being investigated further.

Iodometric analysis of peracid disappearance was used for all the olefins except cyclopropene **1a**. The disappearance of this cyclopropene was measured against cyclopropene **1b** in the same reaction flask because of peracid reaction with α,β-dimethylcrotonaldehyde and mesityl oxide **4a** and **4b**. This loss of peracid by secondary oxidation processes is immaterial to the competitive oxidation of cyclopropenes **1a** and **1b**, because peracid concentration drops from the second-order competitive kinetics equation.[8] Unfortunately, this method is only capable of producing small standard deviations in rate constant ratios when the ratios are approximately equal to 1. If the ratio is much greater or less than 1, then the propagated error greatly increases since one of the starting olefins must be measured at a short conversion at which time the other olefin is almost completely reacted. In our case, the rate constant ratio is *ca.* 12 and therefore the propagated error in the rate constant for cyclopropene **1a** is relatively large. We attempted to measure the competitive appearance of products from **1a** and **1b** at short reaction times but ran into other experimental difficulties (see Experimental Section). As a result, due recognition should be given to the stated standard deviation of the rate constant for cyclopropene **1a**.

$$k_2(\mathbf{1b})/k_2(\mathbf{1a}) = \ln [\mathbf{1b}_t/\mathbf{1b}_0]/\ln [\mathbf{1a}_t/\mathbf{1a}_0]$$

In order to be able to compare further the vinyl substituent effects in cyclopropene oxidation with substituent effects in true epoxidations, we have tabulated the data presented in Table II. Some of the kinetics for the compounds in Table II were actually obtained in peracetic–acetic acid solution at 25.8°. In order to interpolate these rate constants to our conditions of *m*-chloroperbenzoic acid–CCl_4 at 0°, we tried several empirical correlations in order to predictably relate rate constants of epoxidation between the two epoxidation conditions. For this purpose, we have measured the rate constants of epoxidation for the compounds in Table III under our conditions. The rates for these compounds have also been reported in peracetic–acetic acid solution at 25.8°.[9] A least-squares log–log plot of the rate constants in Table III gives an excellent linear correlation (r = 0.9999).

Table II. Rate Constants for *m*-Chloroperbenzoic Acid Epoxidation of Acyclic Olefins in CCl_4 at 0°

Olefin	10^3k_2, M^{-1} sec^{-1}	Relative k_2
2-Butene[a,b]	3.44	28.7
1-Phenylpropene[a,b]	1.42	11.8
cis-Stilbene[b]	0.237	1.97
trans-Stilbene[c]	0.120	(1.0)

[a] Presumed trans. [b] Interpolated from data in ref 9. [c] This work.

Table III. Iodometric Rates of Peracid Oxidation of Selected Olefins

Olefin	10^3k_2, M^{-1} sec^{-1} [a] MCPBA–CCl_4, 0°	10^3k_2, M^{-1} sec^{-1} [a] $MeCO_3H$–HOAc, 25.8° [b]
trans-Stilbene	0.120 ± 0.003 (2)	0.112
1,1-Diphenylethylene	1.564 ± 0.022 (2)	0.800
Cyclopentene	9.11 ± 0.20 (3)	3.26
1-Methylcyclopentene	180.3 ± 5.8 (3)	37.1

[a] All errors are standard deviations of independent runs with the indicated degrees of freedom. [b] Reference 9.

$$\log k_2(\text{MCPBA}) = a \log k_2(\text{MeCO}_3\text{H}) + b$$
$$a = 1.259 \pm 0.014\ (2)$$
$$b = 1.073 \pm 0.040\ (2)$$

The theoretical implications of such a correlation between systems with multivariable changes (peracid, solvent, temperature) is presented by Wells.[10] Care

(6) G. L. Closs, L. E. Closs, and W. A. Böll, *J. Amer. Chem. Soc.*, **85**, 3796 (1963); see L. E. Friedrich and R. A. Fiato, *Synthesis*, 611 (1973).

(7) Ciabattoni in ref 2b and 2f reported a 64:36 and 69:31 ratio respectively of **4a**:**4b** under slightly different reaction conditions and for larger per cent conversions of olefin (MCPBA in CH_2Cl_2 at 0°).

(8) G. A. Russell in "Techniques of Organic Chemistry," S. L. Freiss, E. S. Lewis, and A. Weissberger, Ed., Interscience, New York, N. Y., 1961, pp 343–388.

(9) D. Swern, *J. Amer. Chem. Soc.*, **69**, 1692 (1947).

should be taken to interpolate only within the extremes of the rate constants in Table III. Olefins whose rate constants are slower than *trans*-stilbene fail to fit the correlation. For example, the MCPBA calculated rate constant for allylbenzene (0.0317×10^{-3} M^{-1} sec^{-1} in $MeCO_3H$) is 2.56×10^{-5} M^{-1} sec^{-1}. Its measured value under our conditions was 6.53×10^{-5} M^{-1} sec^{-1}, a discrepancy of 61%. The average absolute discrepancy of the calculated to the observed rate constants for the compounds in Table III is only 4%.

Discussion

The results of true epoxidations of the cyclopentene systems in Table I and the acyclic systems in Table II provide a basis to analyze the peracid oxidation of substituted cyclopropenes. In the cyclopentene systems, the gradual substitution of vinyl methyl groups in place of phenyl groups leads to a rate ratio for **2d**:**2c**:**2b** of 1:7:88. In the acyclic systems in Table II, the analogous rate ratios are 1:12:29 or 1:6:15, depending on whether *trans*- or *cis*-stilbene is used in the correlation. In each case, a vinyl methyl substituent is more rate enhancing than a phenyl group. Presumably, the rate retarding inductive effect of a phenyl substituent in an electrophilic epoxidation partially cancels the rate enhancing resonance effect of the phenyl group.

The relative rate ratio of cyclopropenes **1d**:**1c**:**1b** is 1:19:29. If oxabicyclobutanes are being formed, we believe this sequence should be compared with the relative ratios of the acyclic compounds using *trans*-stilbene as a base value, 1:12:29. The reason is that vicinal vinyl substituents of cyclopropenes such as two phenyl groups are probably coplanar with the cyclopropene ring. This type of coplanarity exists in *trans*-stilbene and has been postulated by Battiste[11] for 1,2-diphenylcyclobutene, based on uv and nmr comparisons; see Table IV. In general, it appears that planar vinyl phenyl substituents possess multiplets for their ortho, meta, and para protons in the nmr as well as greater fine structure at longer wavelengths and higher extinction coefficients in the uv. Given the results in Table IV, it appears that the vinyl phenyl substituents in cyclopropenes **1c** and **1d** are probably planar with the ring. As such, the acyclic rate ratios of 1:12:29 using *trans*-stilbene are in good agreement with the observed cyclopropene ratios of 1:19:29. A cyclopropene epoxide-forming transition state is strongly implicated.

The rate ratio of 12:1 for tetramethyl- and trimethylcyclopropene is similarly in line with an epoxidation process when compared to the 19:1 ratio of rates for epoxidation of cyclopentenes **2b**:**2a**.

A final analysis concerns whether the observed results are compatible with other conceivable oxidation mechanisms that circumvent oxabicyclobutanes. Without specifying a complete set of alternate mechanisms, most of these alternate processes do not contain a transition state with C_s symmetry. Some examples of such asymmetrical transition states are structures **6a–c**. These three transition states would initially lead to a 1,3-dipolar cycloadduct,[12] enone product, and protonated enone, respectively.

(10) P. R. Wells, "Linear Free Energy Relationships," Academic Press, London, 1968.

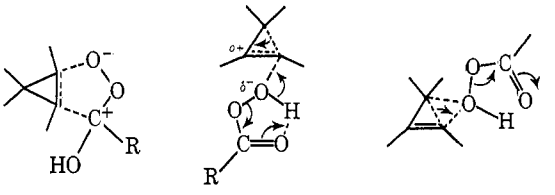
(11) M. A. Battiste and M. Burns, *Tetrahedron Lett.*, 523 (1966).

(12) K. D. Bingham, G. D. Meakins, and G. H. Whitham, *Chem. Commun.*, 445 (1966).

Table IV. Spectral Comparison of Vinyl Phenyl Substituents in Different Olefins

Olefin	Nmr (δ)	Uv nm (ε)
cis-Stilbene	7.2 (s, 10)[a]	202 (25,000), 224 (22,000)[b] 277 (10,400)
1,2-Diphenylcyclopentene (**2d**)	7.0 (s, 10)[c]	220 (16,000), 270 (11,000)[d]
trans-Stilbene	7.1–7.7 (m, 10)[a,c]	203 (24,000), 229 (16,400),[e] 296 (33,800), 308 (28,500)
1,2-Diphenylcyclobutene	7.2–7.6 (m, 10)[c]	228 (24,100), 236 (13,500),[f] 297 (18,400), 307 (17,500), 322 (10,800)
1,2-Diphenylcyclopropene	7.0–7.9 (m, 1)[c,g]	228 (10,200), 236 (8,700),[g] 309 (14,500), 318 (17,000), 335 (12,300)
1,2-Diphenyl-3,3-dimethylcyclopropene (**1d**)	7.0–7.6 (m, 10)[c]	224 (15,000), 230 (16,000),[c] 237 (12,000), 309 (22,000), 319 (28,000), 337 (21,000)

[a] N. S. Bhacca, L. F. Johnson, and J. N. Shoolery "Nmr Spectra Catalog," Varian Associates, 1962. [b] E. V. Blackburn and C. J. Timmons in "UV Atlas of Organic Compounds," Vol. V, Plenum Press, New York, N. Y., 1966, p D 10/75. [c] This work. [d] K. A Muszkat and E. M. Fischer, *J. Chem. Soc. B*, 662 (1967). [e] E. M. F. Roe in footnote *b*, p D 10/76. [f] Reference 11. [g] D. T. Longone and D. M. Stehouwer, *Tetrahedron Lett.*, 1016 (1970).



6a **6b** **6c**

In electrophilic reactions of alkylated π systems, it has been observed that unsymmetrical transition states lead to rates which are fastest for olefins with the greatest number of alkyl groups on one of the vinyl carbon atoms. Beyond that, further alkyl substitution on the other vinyl carbon appears to slow the rate. The relative rates of cyclopropenes **1a** and **1b** are inconsistent with an unsymmetrical transition state when compared to the data in Table V.

Table V. Relative Reactivities of Alkyl-Substituted Ethylenes Toward Electrophilic Reaction[a]

	Unsymmetrical transition states		Symmetrical transition states	
	Tl^{3+} oxidation	Hydroxymercuration	Epoxidation	Br_2 addition
Ethylene	6×10^{-3}	0.051	0.45	0.016
Propene	(1.00)	(1.00)	(1.00)	(1.00)
2-Butene[b]	0.35	0.058	22	43
2-Butene[c]	0.08	0.017		28

[a] Taken from data compiled by Awasthy and Roček, ref 13b. [b] Cis isomer. [c] Trans isomer.

If a series of para-substituted phenyl groups were used as cyclopropene vinyl substituents, the method of Mitsuhashi and Simamura[13a] could be used to test for

(13) (a) T. Mitsuhashi and O. Simamura, *J. Chem. Soc. B*, 705 (1970); (b) A. K. Awasthy and J. Roček, *J. Amer. Chem. Soc.*, 91, 991 (1969).

an unsymmetrical transition state. The method cannot be reliably used for compounds **1b–d** because the steric effects of a phenyl and methyl group are different and may vary depending on their nearest neighbor interactions.

In summary, the vinyl substituent effects reported in this paper are completely in accord with an *epoxidizing* transition state which leads to an oxabicyclobutane. Our results on the allylic substituent effects[2h] and ring size effects[2g] did produce some surprises, but overall do not preclude an oxabicyclobutane intermediate. Product studies[2] are also consistent with an oxabicyclobutane intermediate, although there is a curious lack of stereospecificity in the products.[2c,e] It is still unknown as to what role orbital symmetry effects play in the stereochemistry of oxabicyclobutane fragmentations.

Experimental Section

Olefins. Methylcyclopentene (**2a**),[14] 1,2-dimethylcyclopentene (**2b**),[15] 1-phenyl-2-methylcyclopentene (**2c**),[16] 1,2-diphenylcyclopentene (**2d**),[17] 1,3,3-trimethylcyclopropene (**1a**),[6] 1,2,3,3-tetramethylcyclopropene (**1b**),[18] 1-phenyl-2,3,3-trimethylcyclopropene (**1c**),[2f] and 1,2-diphenyl-3,3-dimethylcyclopropene (**1d**)[2f] were all prepared according to reported procedures. Liquid samples of **2a–c** and **1c** were purified by vpc (0.25 in. × 12 ft 15% Carbowax 20M, 4% KOH on Chromosorb W column). Samples of **1a** and **1b** were also purified by vpc (0.25 in. × 26 ft 20% di-*n*-decyl phthalate column, room temperature). Solids **2d** or **1d** were recrystallized from absolute methanol or 95% aqueous ethanol, respectively, until a constant melting range was obtained.

Samples of 1,1-diphenylethylene (Eastman Kodak) and cyclopentene[19] were purified by vpc. Samples of *trans*-stilbene (Aldrich Chemical Co.) were recrystallized from absolute ethanol until a constant melting range was obtained. These compounds along with cyclopentene **2a** were used to determine a linear free energy relationship between data from this work and that presented by Swern;[9] see Table III.

The final purity of all olefins was established by nmr in conjunction with vpc data (>99% pure) when applicable.

***m*-Chloroperbenzoic Acid.** Commercially available (Aldrich) 85% MCPBA was purified to 99+% purity by treatment with a neutral phosphate buffer solution.[20]

Separate control experiments showed that a stock solution of MCPBA in CCl_4 at 0° was stable for at least 15 hr.

Oxidation Product Studies. Epoxides were formed as the only reaction products from the peracid oxidation of all cyclopentenes and acyclic olefins studied over 50–80% conversion (based on the peracid initially present which was 1.0–0.5 *M* equiv of initial olefin concentration). Trimethylcyclopropene **1a** was shown by vpc (0.125 in. × 10 ft 10% Carbowax column, flame ionization detectors) to give a 79:21 *M* ratio yield of α,β-dimethylcrotonaldehyde **4a** and mesityl oxide **4b** at short reaction time. At longer reaction times, the 3.81:1 *M* ratio of aldehyde–ketone (**4a**:**4b**) decreased; see below for results of a representative run.

Reaction time, sec	Vpc data (area **4a**: area **4b**)
105	3.70
1105	3.29
2075	2.40

Tetramethylcyclopropene **1b** gave quantitative yields of α-methylmesityl oxide when the initial olefin concentration was twice as much as that for MCPBA. Cyclopropene **1c** gave quantitative yields of 3-phenyl-4-methyl-3-penten-2-one (**5a**). Cyclopropene **1d** gave quantitative yields of 1,2-diphenyl-3-methyl-2-buten-1-one which along with **5a** and **5b** were independently prepared.

3-Phenyl-4-methyl-3-penten-2-one (5a). A solution of 3.0 g (18 mmol) of 1-chloro-2,2-dimethylstyrene[21] (freshly distilled, bp 92–94° (15 mm)) and 4 ml of anhydrous THF (distilled from sodium and benzophenone) was added slowly (1 hr) to 2.4 g (0.10 g-atom) of magnesium turnings (dried at 120° for 1 hr) in 3 ml of anhydrous THF with 2 drops of methyl iodide at 40° under nitrogen. The magnetically stirred mixture became dark green in color and was allowed to react for an additional 1 hr at room temperature. At this time, 0.88 g (20 mmol) of acetaldehyde (Eastman Kodak) in 5 ml of anhydrous THF was added dropwise (30 min) to the mixture. The reaction was allowed to proceed for an additional 1 hr at 40° under nitrogen.

After work-up and concentration of the ethereal solution, the crude 3-phenyl-4-methyl-3-penten-2-ol, 3.1 g (80%), was chromatographed on silica gel with isolation of the last major component which was eluted (2.5% ether and 97.5% benzene). The fractions containing this material were concentrated giving a colorless oil: ir (CCl_4) 3500–3300, 1650 cm^{-1}; nmr (CCl_4) δ 7.05 (m, 5), 4.75 (q, J = 6.5 Hz, 1), 1.80 (s, 3), 1.38 (s, 3), 1.02 (d, J = 6.5 Hz, 3), 1.05 (broad s, 1, disappears with addition of D_2O); mass spectrum (70 eV) *m/e* 176 (15, molecular ion), 158 (81).

Samples of the alcohol were oxidized with a 1.5 *M* excess of pyridinium dichromate using the procedure of Coates and Corrigan.[22] Analytical samples of ketone **5a** were finally obtained by vpc (0.25 in. × 8 ft 6% Carbowax 20M, 4% KOH column, 120–150°). This ketone was obtained as a colorless oil: uv max (hexanes) 238 nm (ε 8500); ir (CCl_4) 1670 cm^{-1}; nmr (CCl_4) δ 7.20 (m, 5), 2.00 (s, 3), 1.88 (s, 3), 1.62 (s, 3); mass spectrum (70 eV) *m/e* 174 (82, molecular ion), 131 (100), 43 (20).

Anal. Calcd for $C_{12}H_{14}O$ (mol wt 174.24): C, 82.72; H, 8.10. Found: C, 82.79; H, 8.15.

1-Phenyl-2,3-dimethyl-2-buten-1-one (5b). This ketone was prepared using the procedure of Smith and Holum[23] while the final purification was achieved by vpc (0.25 in. × 8 ft 6% Carbowax 20M, 4% KOH column, 120–150°). Pure enone **5b** was obtained as a colorless oil: $n^{18}D$ 1.5355 (lit.[23] $n^{20}D$ 1.5353); uv_{max} (hexanes) 242 nm (ε 12,200); ir (CCl_4) 1665 cm^{-1}; nmr (CCl_4) δ 7.70 (m, 2), 7.30 (m, 3), 1.85 (broad s, 6), 1.55 (s, 3); mass spectrum (70 eV) *m/e* 174 (94, molecular ion), 159 (90), 105 (100).

Anal. Calcd for $C_{12}H_{14}O$ (mol wt 172.24): C, 82.72; H, 8.10. Found: C, 82.58; H, 8.07.

1,2-Diphenyl-3-methyl-2-buten-1-one. This ketone was prepared in the same manner used to prepare ketone **5a** with the only difference being that benzaldehyde was substituted for acetaldehyde. The 1,2-diphenyl-3-methyl-2-buten-1-ol which was finally isolated was a faint yellow oil: ir (CCl_4) 3500–3400, 1650 cm^{-1}; nmr (CCl_4) δ 7.0 (m, 8), 6.60 (m, 2). 5.70 (broad s, 1), 1.95 (s, 3), 1.70 (broad s, 1, disappears on D_2O addition), 1.50 (s, 3); mass spectrum (70 eV) *m/e* 238 (64, molecular ion), 220 (32), 105 (100).

Pyridinium dichromate oxidation[21] with final purification of the desired ketone by vpc (0.25 in. × 8 ft 6% Carbowax 20M, 4% KOH column, 185°) gave analytical samples of 1,2-diphenyl-3-methyl-2-buten-1-one: uv_{max} (hexanes) 243 (19,600), 273 nm (3000); ir (CCl_4) 1665 cm^{-1}; nmr (CCl_4) δ 7.80 (m, 2), 7.20 (m, 8), 1.82 (s, 3), 1.69 (s, 3); mass spectrum (70 eV) *m/e* 236 (100, molecular ion), 221 (49), 105 (100).

Anal. Calcd for $C_{17}H_{16}O$ (mol wt 236.32): C, 86.41; H, 6.83. Found: C, 86.52; H, 6.85.

Competitive Rate of Loss of Cyclopropenes 1a and 1b. A magnetically stirred solution of *ca.* 0.150 *M* **1a** and *ca.* 0.150 *M* **1b** in CCl_4 (Mallinckrodt SpectrAR grade) at 0° was prepared. The CCl_4 which was used to prepare olefin stock solutions was *ca.* 0.035 *M* in cyclohexane and 0.210 *M* in methylene chloride which were the vpc internal standards.

Small aliquots of the 0° solution were withdrawn with a chilled (0°) 10-μl syringe and quickly injected onto the analytical gas chromatograph (0.125 in. × 20 ft 20% di-*n*-decyl phthalate column, 40–80°) which was equipped with flame ionization detectors. After two or three injections, an equal volume of *ca.* 0.500 *M* MCPBA stock solution was added to the olefin stock solution at 0°. Small (1–2 μl) aliquots were withdrawn periodically with a chilled syringe and injected onto the gas chromatograph. Several runs

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were also performed in which aliquots were withdrawn and quenched by addition to 10% aqueous Na_2SO_3 and 10% aqueous $NaHCO_3$ with subsequent analysis of the CCl_4 layer.

The relative second-order rate constants were calculated with the following equation[8]

$$\ln (\mathbf{1a}_t/\mathbf{1a}_0) = [k_2(\mathbf{1b})/k_2(\mathbf{1a})][\ln (\mathbf{1b}_t/\mathbf{1b}_0)]$$

where $k_2(\mathbf{1b})/k_2(\mathbf{1a})$ is the second-order rate constant ratio for olefins **1a** and **1b**, respectively, $\mathbf{1a}_0$ and $\mathbf{1b}_0$ are the initial areas of olefins **1a** and **1b** normalized to the internal standard area, and $\mathbf{1a}_t$ and $\mathbf{1b}_t$ are the areas of the compounds normalized to the internal standard area at any time (t).

The order of elution for the compounds was olefin **1a**, methylene chloride, olefin **1b**, and cyclohexane.

When the competitive rate of appearance of products was analyzed it was limited to small per cent olefin conversion due to the reactivity of the enone products **4a** and **4b** to peracid. During the course of our studies, we noticed that during the first 3% reaction, olefins **1a** and **1b** reacted in an abnormally fast manner and gave a surprising $k_2(\mathbf{1b})/k_2(\mathbf{1a}) = ca.$ 3.0. This phenomenon is presumably due to a mixing period during which the peracid and olefin concentrations are not homogeneous and the temperature may have fluctuated. A similar situation is indicated in the peracid kinetic results that have been reported by Lynch and Pausaker.[24]

Iodometric Analysis of Peracid Loss.[25] A magnetically stirred solution containing known amounts of olefin and MCPBA was prepared at 0° in a 10-ml volumetric flask. A short time thereafter (1–2 min to allow mixing and thermal equilibration), a 1-ml aliquot was withdrawn in two portions with a calibrated (at 0°) 500-μl syringe which was cooled to 0°. The aliquot was added to a solution of 1 ml of acetic acid and 1 mol of 10% aqueous potassium iodide. The liberated iodine was titrated with $Na_2S_2O_3$ ($ca.$ 1×10^{-3}–1×10^{-4} M) which had been previously normalized with KIO_3. A stopwatch was started during the addition of the reaction solution to the acetic acid–KI solution. The peracid loss during the initial 1–2-min period from the prepared concentration was calculated and an appropriate correction made in the time zero olefin concentration used in subsequent calculations.

The reaction solution was subsequently monitored at recorded times by withdrawing 0.5- or 1.0-ml aliquots with a chilled (0°) 500-μl volumetric syringe. Ice was replaced in the cooling bath as needed to maintain a bath temperature of 0°. The reaction solution was analyzed repeatedly until 20–70% MCPBA loss was noted. Usually, several (5–12) samples were analyzed at various times for each run. For olefins which were relatively unreactive two separate aliquots were analyzed (±10 sec) for each time recorded.

The data were analyzed first by a least-squares program on a Hewlett-Packard Model 9820 A advanced programming calculator. The normal second-order rate equation was rearranged into terms of observables, for conditions of initial olefin concentration greater than initial peracid concentrations

$$\frac{1}{A_\infty}\ln\left(\frac{2V_aA_\infty}{M\mathrm{ml}_t}+1\right) = \frac{1}{A_\infty}\ln\left(\frac{2V_aA_\infty}{M\mathrm{ml}_0}+1\right) + k_2t$$

where A_∞ is the difference in the time zero concentration of olefin and peracid, respectively, V_a is the volume in milliliters of the reaction aliquot analyzed, M is the molarity of the thiosulfate stock solution, and ml_t and ml_0 are the volumes (milliliters) of thiosulfate solution at time t and time zero required to titrate the liberated iodine for the respective samples.

Subsequently, the data were analyzed with a nonlinear iterative least-squares computer program[26] on an IBM-360/65 computer. This program accounts for random errors present in all observables. In all cases, the data gave linear plots with the second-order rate equation and the rate constants were invariant over a range of initial reactant concentrations.

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Carboxy β-Lactams by Photochemical Ring Contraction

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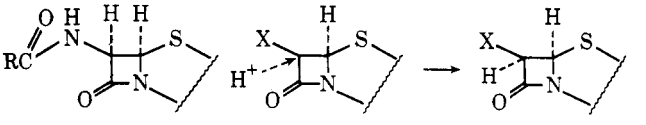
Abstract: The potential and limitations of the photochemical ring contraction of 3-diazo-2,4-pyrrolidinediones as a route to carboxy β-lactams (2-azetidinone-3-carboxylic acids) are explored. Although the method seems to be a fairly general route from α-amino acids to β-lactams, the difficulty of achieving steric control makes the process not especially promising as a route to natural penicillins and cephalosporins.

Considerable ingenuity has been demonstrated over many years in devising syntheses for the β-lactam system which forms the most salient feature of the penicillin and cephalosporin antibiotics.[1]

An intriguing feature which gives additional complexity to the problem is that the amino substituent next to the lactam carbonyl is in the less stable arrangement in these molecules, cis to the sulfur atom. Such an arrangement could, in principle, be the result of kinetic protonation, from the less hindered side, of a trigonal center bearing a substituent X, which could be either an amino group or any other function capable of transformation into an amino group with retention of configuration.[2]



One of the most versatile possibilities would be to have X present as a carboxyl group. Indeed, the conversion of carboxy β-lactams to amino β-lactams has

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