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(9) (a) E. F. Ullman and J. E. Milks, *J. Am. Chem. Soc.*, **86**, 3814 (1964); (b) H. E. Zimmerman and R. D. Simkin, *Tetrahedron Lett.*, 1847 (1964); (c) D. R. Arnold and L. A. Karnischky, *J. Am. Chem. Soc.*, **92**, 1404 (1970).
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(11) A metastable ketal-enol ether formed by addition of ethanol to **1a** has been proposed as a rational intermediate in a mechanistic scheme leading to the ultimate isolable photoproducts obtained from this ylide in ethanol; however, this adduct was characterized solely by chemical transformations conducted without isolation in which ultraviolet spectroscopy served as the only analytical tool. See E. F. Ullman and W. A. Henderson, *J. Am. Chem. Soc.*, **88**, 4943 (1966).
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(13) These results are significant and more extensive studies to be published later demonstrate that the ylides **4a–g** are photolabile and afford dicyanocarbene upon simultaneous radiation in the visible region: G. W. Griffin, K. Ishikawa, and I. J. Lev, *J. Am. Chem. Soc.*, in press.
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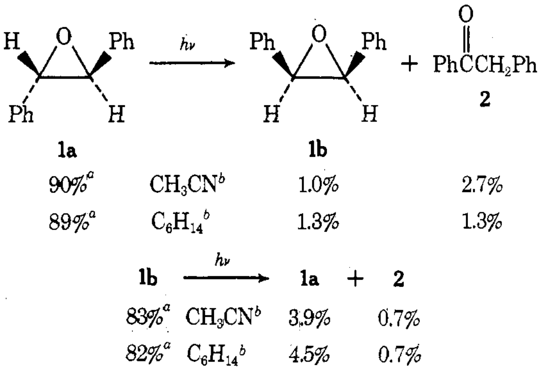
Photochemistry of *cis*- and *trans*-Stilbene Oxides

Summary: Stilbene oxides undergo photochemical ring opening from both singlet and triplet excited states to form carbonyl ylides which have been trapped with electron-deficient olefins; the resulting tetrahydrofuran adducts are formed stereoselectively in moderate yields from the singlet excited oxiranes, but are quantitatively obtained in a novel, synthetically useful fashion from triplet sensitized reaction mixtures.

Sir: The photochemistry of aryloxiranes has attracted considerable synthetic interest and mechanistic scrutiny within recent years.[1] *vic*-Diaryloxiranes have been observed to undergo photochemical [3 → 2 + 1] cycloelimination to produce synthetically useful yields of carbenes and carbonyl compounds.[1a,2] One of the interesting mechanistic features of these reactions is the apparently competitive fission of the oxirane C–C and C–O bond producing reactive intermediates which lead to the observed products.[3-5] Photochemical cleavage of the oxirane C–C bond produces carbonyl ylides which previously had been postulated[6] and more recently detected and characterized by spectroscopic means.[7] While the thermal ring opening of aryl oxiranes is well known to produce carbonyl ylides which were studied and trapped in subsequent 1,3-dipolar cycloaddition reactions,[8,9] the photochemically formed ylides have been less well characterized.[10,11] In the present paper, we wish to describe briefly data pertaining to the mechanistic aspects and synthetic utility of the photochemistry of the parent aryloxiranes, the *cis*- and *trans*-stilbene oxides.

Simultaneous irradiation[12] of the *trans*- and *cis*-stilbene oxide isomers in acetonitrile and in hexane with 2537-Å light at ambient temperature effects photoisomerization as outlined in Scheme I.[13]

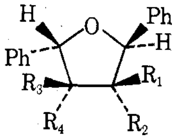
Scheme I

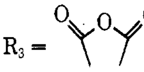


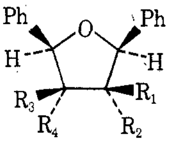
^{a} Indicates amount of unconsumed starting material. ^{b} Solvent.

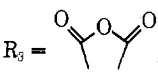
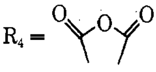
It is evident that *cis*-stilbene oxide photoisomerizes to its trans isomer, **1a**, much more readily than is observed for the reverse process, while the formation of deoxybenzoin (**2**) occurs ~6–7 times more readily from **1a** than from **1b.**

Examination of molecular models suggests that orientation of the phenyl π electrons relative to the C–C or C–O oxirane bond may control which products are preferentially formed. In **1a**, the absence of steric constraints permits aryl π overlap with the cleaving C–O σ bond leading to formation of deoxybenzoin. In **1b** this overlap is sterically hindered and instead aryl π overlap with the oxirane C–C bond appears favored, permitting facile cis–trans isomerization.[14] Similar arguments have been advanced previously to explain photochemical transformations of small-ring carbonyl compounds[15] and arylcyclopropanes.[16] Models also suggest a precedence for orbital participation in oxirane ring opening in the photolysis of 9,10-phenanthrene oxide reported by Griffin[17] and Chapman.[18]



3a, $R_1 = CO_2CH_3$; $R_2 = R_3 = R_4 = H$
b, $R_2 = CO_2CH_3$; $R_1 = R_3 = R_4 = H$
c, $R_1 = R_3 =$  ; $R_2 = R_4 = H$



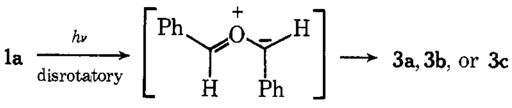
4a, $R_1 = CO_2CH_3$; $R_2 = R_3 = R_4 = H$
b, $R_2 = CO_2CH_3$; $R_1 = R_3 = R_4 = H$
c, $R_1 = R_3 =$  ; $R_2 = R_4 = H$
d, $R_2 = R_4 =$  ; $R_1 = R_3 = H$

When *trans*- or *cis*-stilbene oxide is irradiated directly with 2537-Å light in the presence of methyl acrylate or maleic anhydride, a product mixture containing previously observed photoproducts (vide supra),[1-4] as well as new tetrahydrofuran (THF) adducts **3** and **4**, was obtained. The yields of these adducts are given in Table I.[19] The photocycloaddition of stilbene oxides with electron-deficient olefins can be rationalized by the assumption that the electronically excited oxi-

Table I. Adduct Yields from Photolysis of Stilbene Oxides in the Presence of Dipolarophiles[19]

Stilbene oxide	Dipolarophile	Solvent	Total adduct yield, %	Relative adduct ratios, %	
				3a/3b	**4a/4b**
1a	Methyl acrylate	CH_3CN	23	62/27	8/3
1b	Methyl acrylate	CH_3CN	30	9/2	66/24
1a	Methyl acrylate	C_6H_{12}	18	61/26	6/7
1b	Methyl acrylate	C_6H_{12}	20	17/5	36/42
				3c	**4c/4d**
1a	Maleic anhydride	CH_3CN	26	91	4/5
1b	Maleic anhydride	CH_3CN	31	14	47/39

rane undergoes C–C fission to give carbonyl ylide intermediates, **5** and **6**. In each case it is apparent that the predominant mode of ylide formation is the result of an allowed[21] photochemical disrotatory opening of the stilbene oxide. The stereochemistry of the isolated adducts from **1a** and **1b** confirms the identity of ylides proposed earlier by Trozzolo and Griffin[7] from low temperature spectroscopic studies of oxirane photolyses. With both oxirane isomers, a slightly higher yield of THF adducts was obtainable using the polar acetonitrile than with cyclohexane. Furthermore, photolysis of **1b** in cyclohexane containing methyl acrylate resulted in significantly depressed adduct stereoselectivity, as well as a reversal in the relative amounts of **4a** and **4b**. Additional studies are required to interpret these solvent effects.[22]



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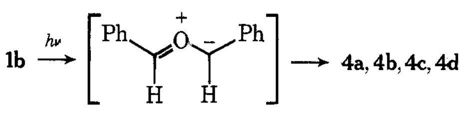

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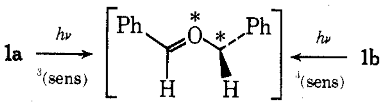
Irradiation of **1a** and **1b**[23] with methyl acrylate in solvents containing sufficient acetone to absorb >99% of the light (hν >300 nm) resulted in much cleaner reaction mixtures and afforded high yields of the THF adducts **3** and **4**. Identical adduct isomer ratios were obtained regardless of the stereochemistry of the starting oxirane. In addition, the ratio and yields of adduct isomers varied depending on whether acetonitrile or benzene was employed as the solvent. These results are given in Table II. It is evident from these data that the use of benzene/acetone as a reaction media provides a very simple and useful new synthetic procedure for making tetra- and dihydrofurans. The identity of photoadduct ratios from either **1a** or **1b** clearly implicates a common intermediate in the reactions. One possible candidate for this intermediate would be the orthogonal biradical, **7**, derived from the triplet excited state of the stilbene oxide.[24] Addition of the olefin to this intermediate would produce another biradical capable of free rotation prior to ring closure. Alternatively, in analogy with Salem's surface for nitrile ylide opening,[26] the triplet excited state of the oxirane may give an open minimum, which deactivates to the same mixture of cis and trans ylides, regardless of the precursor. The sharp contrast between the photosensitized reaction mixtures and those produced by direct irradiation suggests that, in the latter case, singlet excited oxiranes may ring open to planar carbonyl ylides (such as **5** and **6**) which have resonance delocalization to preserve their stereochemical integrity.[27]

Table II. Adduct Yields from Acetone Sensitized Photolysis of Stilbene Oxides with Methyl Acrylate[23]

Stilbene oxide	Solvent	Total adduct yield, %	Relative adduct ratios, %	
			3a/3b	**4a/4b**
1a	CH_3CN	56	19/8	51/22
1b	CH_3CN	50	19/8	51/22
1a	C_6H_6	99	23/10	40/27
1b	C_6H_6	99	23/10	40/27



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Finally, we wish to comment on the role which frontier molecular orbital theory appears to play in the trapping of carbonyl ylides. Based on estimated frontier orbital energies for carbonyl ylides substituted with alkyl or conjugating substituents, Houk[28] has suggested that these ylides will react readily with electron-deficient dipolarophiles, and less readily or not at all with conjugated or electron-rich dipolarophiles. The formation of THF adducts from stilbene oxide and electron-deficient olefins, as well as our inability to detect adducts from **1a** or **1b** and norbornene,[29] supports Houk's conclusions. Additional effort is currently underway to further elucidate the scope and mechanistic implications of the above observations.

Acknowledgment. I wish to express appreciation to Professor A. Padwa for support and encouragement during the early stages of this work, and to Professors G. Griffin and K. Houk for helpful comments. I am indebted to Phil Briggs for mass spectral interpretations.

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(1) For excellent reviews, see G. W. Griffin, *Angew. Chem., Int. Ed. Engl.*, **10**, 537 (1971); G. W. Griffin and A. Padwa, in "Photochemistry of Heterocyclic Compounds", O. Buchardt, Ed., Wiley, New York, N.Y., 1976; N. R. Bertoniere and G. W. Griffin, "Organic Photochemistry", Vol. III, O. L. Chapman, Ed., Marcel Dekker, New York, N.Y., 1973, Chapter 2.

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(9) E. F. Ullman and J. E. Milks, *J. Am. Chem. Soc.*, **86**, 3814 (1964); D. R. Arnold and L. A. Karnischky, *ibid.*, **92**, 1404 (1970); D. R. Arnold and Y. C. Chang, *J. Heterocycl. Chem.*, **8**, 1097 (1971); J. W. Lown and K. Matsumoto, *Can. J. Chem.*, **49**, 3443 (1971).

(10) Photochemically produced carbonyl ylides were trapped in the middle sixties by Ullman, but these ylides were derived from a highly specific, n,π^* singlet excited-state precursor. Cf. E. F. Ullman and W. A. Henderson, Jr., *J. Am. Chem. Soc.*, **88**, 4942 (1966), and references therein.

(11) While this work was in progress, Professor G. Griffin kindly informed me of his group's success in trapping photochemically generated carbonyl ylides. Cf. (a) G. W. Griffin, I. Lev, and K. Ishikawa, Vth IUPAC Symposium on Photochemistry, Enschede, The Netherlands, July 21–27, 1974, Contr. Paper No. 20, p 62; (b) G. W. Griffin, N. E. Brightwell, K. Ishikawa, I. Lev, and S. Satra, VIIIth International Conference on Photochemistry, Edmonton, Canada, Aug. 7–13, 1975, Abstr. I-1; (c) G. W. Griffin, K. Ishikawa, and I. Lev, 27th Southeast-31st Southwest Regional Meeting of the American Chemical Society, Memphis, Tenn., Oct. 29–31, 1975, Abstr. 443; (d) I. J. Lev, K. Ishikawa, N. S. Bhacca, and G. W. Griffin, *J. Org. Chem.*, preceding paper in this issue. Professor R. Huisgen has also recently described trapping of photochemically generated carbonyl ylides.[7c]

(12) Photolyses performed by dissolving 1 mmol of stilbene oxide in 10.0 ml of organic solvent. Solutions were deareated with argon in quartz tubes, capped and irradiated with 2537-Å lamps in a Rayonet reactor (New England Ultraviolet Co.) for 15 min. Analyses were performed by VPC (5% QF-1) using an added external standard. Only trace amounts of benzaldehyde could be detected under these conditions.

(13) Similar photochemical geometric isomerization and rearrangement to vinyl ketones has been noted previously by Paulson with α,β-epoxy olefins: D. R. Paulson, F. Y. N. Tang, and R. B. Sloan, *J. Org. Chem.*, **38**, 3967 (1973).

(14) Our data do not exclude oxirane cis–trans isomerization by cleavage of the C–O bond in addition to the proposed role of orbital overlap control. In the photochemistry of oxirane ring opening, a referee has suggested that van der Waals strain also may play a role in ring cleavage of *cis*-stilbene oxide.

(15) A. Padwa, *Acc. Chem. Res.*, **4**, 48 (1971), and references therein.

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(18) D. M. Jerina, B. Witkop, C. L. McIntosh, and O. L. Chapman, *J. Am. Chem. Soc.*, **96**, 5578 (1974).

(19) The assignment of structure and configuration of adducts **3** and **4** rests on their characteristic spectral properties (NMR, ir, *m/e*) as well as chemical conversion of **3a** to **3b** and **4a** to **4b** with sodium methoxide.[20] Photolyses were performed by irradiating deareated solution containing ~0.75 mmol of stilbene oxide and ~1.9 mmol of olefin in 10.0 ml of solvent with 16–2537-Å lamps in a Rayonet reactor. Complete reaction product analyses will be presented in our full paper.

(20) For similar spectral and chemical analogies, see A. Padwa and J. Smolanoff, *J. Am. Chem. Soc.*, **93**, 548–550 (1971); J. R. Smolanoff, Ph.D. Dissertation, State University of New York at Buffalo, Feb 1974; A. Padwa, M. Dharan, J. Smolanoff, and S. I. Wetmore, Jr., *J. Am. Chem. Soc.*, **95**, 1945–1953 (1973).

(21) R. B. Woodward and R. Hoffmann, "The Conservation of Orbital Symmetry", Academic Press, New York, N.Y., 1970, p 70.

(22) The use of acetonitrile as a solvent for these reactions has been noted previously (cf. ref 11a).

(23) Irradiations were performed on deaerated solutions of ~1 mmol of stilbene oxide, ~2.5 mmol of methyl acrylate, 2.0 ml of acetone, and 10.0 ml of acetonitrile or benzene contained in a Pyrex test tube mounted next to a Hanovia 450-W high pressure mercury arc lamp.

(24) Attempted sensitization of **1a** in the presence of methyl acrylate with acetophenone gave no reaction (capable of producing acrylate triplets only).[25]

(25) G. S. Hammond, J. Saltiel, A. A. Lamola, N. J. Turro, J. S. Bradshaw, D. O. Cowan, R. C. Counsell, V. Vogt, and C. Dalton, *J. Am. Chem. Soc.*, **86**, 3197 (1964).

(26) L. Salem, *J. Am. Chem. Soc.*, **96**, 3486 (1974).

(27) Addition of *trans,trans*-2,4-hexadiene to reaction solutions failed to inhibit THF adduct formation or to change isomer ratios. Although several factors may be responsible for the lack of stereospecificity obtained in ring opening of stilbene oxides upon direct irradiation, one possibility is that the singlet excited oxirane could undergo partial intersystem crossing to the excited triplet state followed by stereorandomization of adduct formation.

(28) K. N. Houk, J. Sims, R. E. Duke, Jr., R. W. Strozier, and J. K. George, *J. Am. Chem. Soc.*, **95**, 7287–7300 (1973); K. N. Houk, J. Sims, C. R. Watts, and L. J. Luskus, *ibid.*, **95**, 7301–7315 (1973).

(29) Similar experiments by earlier workers have apparently also failed to trap carbonyl ylides with simple olefins.[1–4]

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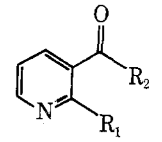
Synthesis of 2,3-Disubstituted Pyridines. Ortho-Formylation and Ortho-Acylation of 2-Alkylpyridines

Summary: A general synthesis of 2-alkyl-3-acylpyridines and 2-alkyl-3-formylpyridines via [2,3]-sigmatropic rearrangements of α-pyrrolidinyl-2-alkylpyridines is described; the initially obtained α-cyanoamine can be hydrolyzed to an aldehyde, reductively cleaved to an amine, or alkylated and hydrolyzed to a ketone.

Sir: As part of our studies involving the structure[1] and reactivity[2] of nicotine and various nicotine analogues, we required a series of 2-alkyl-3-acylpyridines (1). Because of the substituent pattern involved and the well-known resistance of pyridine toward Friedel-Crafts alkylation and acylation, compounds generalized by structure **1** are difficult to prepare. We now report a sequence of reactions involving α-cyanoamines in which the α-cyanoamines (1) are the migrating moiety in a Sommelet–Hauser rearrangement; and (2) are utilized as acyl carbanion equivalents to effect alkylations.



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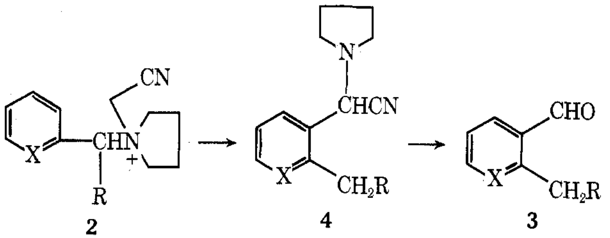
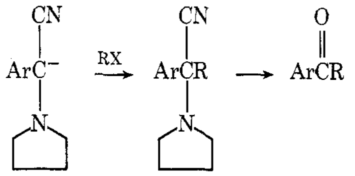


2 **4** **3** (1)

a, X = CH, R = H
b, X = N



(2)

While the synthetic utility of [2,3]-sigmatropic rearrangements is well known in aliphatic and homocyclic chemistry,[3] only one application of this type of reaction in alkylpyridine chemistry has been reported.[4] Recently, Mander and Turner[6] reported the transformation of **2a** with KO-t-Bu to o-methylbenzaldehyde (**3a**) via the α-cyanoamine **4a**. This rearrangement seemed particularly attractive to us because the α-cyanoamine generated in the reaction was considered capable of undergoing alkylation.[7] In addition, as shown in Schemes I and II, the combination of the alkylation–rearrangement reactions adds remarkable versatility toward the general synthesis of **1**.

Treatment of the crystalline quaternary salt **2b** (R = H),[8] prepared via alkylation with cyanomethyl benzenesulfonate[9] (Scheme I), with KO-t-Bu in THF–Me$_2$SO at −10 °C, followed by acid hydrolysis of the crude product, gave (50%) 2-methyl-3-pyridinecarboxaldehyde (**5a**). Treatment of the crude product with semicarbazide hydrochloride gave a 34% yield of semicarbazone **5b**.[10] This procedure represents a considerable improvement over the published synthesis of **5a** which was obtained in 15% yield via a five-step synthesis from ethyl 3-aminocrotonate and 3-ethoxyacrolein diethyl acetal.[10]