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STEREOCONTROL OF PATERNO-BÜCHI PHOTOCYCLOADDITIONS

Steven A. Fleming* and J. Jerry Gao

Department of Chemistry and Biochemistry, Brigham Young University, Provo, UT 84602

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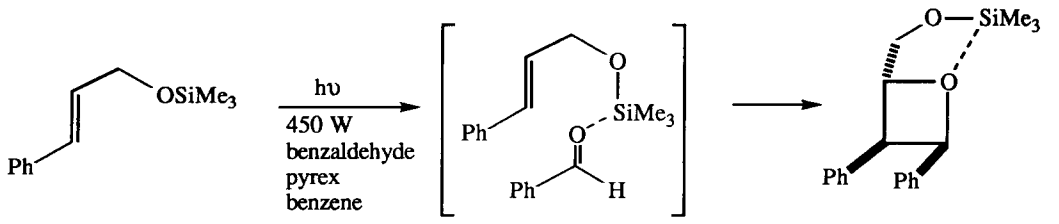
Summary: Diphenyloxetane was synthesized from photocycloaddition of benzaldehyde and styrene. The oxetane products, 2,3 *trans* and 2,3 *cis* isomers, were observed in a 3:1 ratio. Irradiation of 1-phenylpropene and trimethylsilyl cinnamyl ether under the same conditions also gave oxetanes. The silyl group resulted in high stereoselectivity for the oxetane formation. © 1997 Elsevier Science Ltd.

The Paterno-Büchi photocycloaddition is a powerful carbon-carbon bond forming reaction. It is one of the most synthetically useful photochemical reactions. Recently, much attention has been focused on intra- and intermolecular reactions, where regio- and stereoselectivity are essential. We have introduced methodology that provides a means for controlling the regio- and stereochemistry of the cyclobutane forming [2+2] reaction in solution.[1] In our attempt to extend this work to the synthesis of oxetanes, we found that many stereochemical aspects of the simple Paterno-Büchi reaction were absent from the literature.

The use of silicon as a tether for various intramolecular reactions has been explored, including radical cyclization reactions[2] and [4 + 2] reactions.[3] One limitation to this approach is the desilylation after the tethering group has served its function. The hydrolysis of the silicon-oxygen bond is not difficult but this type of tethering requires the extra steps of assembly and removal in addition to a required stoichiometric relationship. A more attractive application of this methodology would allow catalytic use of a tethering group. In our case, the reacting molecules could be coordinated to silicon via a silicon-oxygen expanded sphere coordination, which requires no hydrolysis after reaction (see Scheme 1).

We first examined the use of the silicon in the TMS ether of cinnamyl alcohol as a temporary tether with benzaldehyde in the Paterno-Büchi reaction. We were pleased to find that the reaction was regioselective as predicted[4] *and* appeared to be highly stereoselective. We hoped that silyl control of the photocycloaddition would give oxetane **1a** due to favorable π-π overlap between the aromatic groups of the styryl and benzaldehyde reagents in the tethered complex.[5] However, as we attempted to ascertain the relative stereochemistry of the major product from this reaction, we found little premise for the assignment based on data in the

Scheme 1



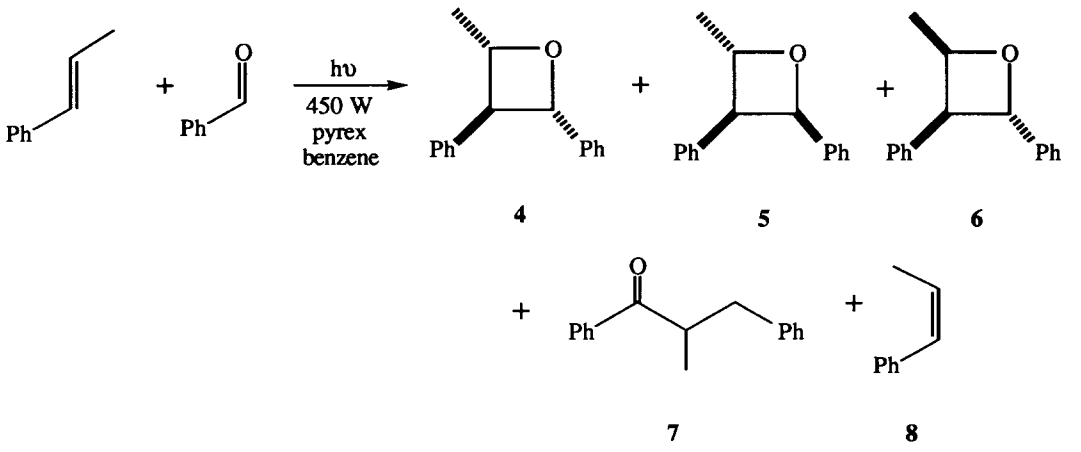
1a

literature. In fact, we were unable to distinguish between the possible stereorelationships in comparison to the previously reported cis-2,3 and trans-2,3 diphenyloxetane.[6] Therefore, we chose to reevaluate the photocycloaddition between styrene and benzaldehyde prior to assigning the stereochemical relationships in our cinnamyl studies.

Irradiation of a styrene:benzaldehyde (10:1) solution (1 M in benzene) gave three products that are easily separated by HPLC.[7] These products included two oxetanes and a styrene polymeric product (<5%). The yield of isolated oxetanes was 32% based on recovered benzaldehyde. The yield is undoubtedly higher, however the volatility of benzaldehyde complicates accurate measurement. NMR analysis allowed stereochemical assignment of the two oxetane products. Compound **2**[8] is the major isomer (*trans*-2,3-diphenyloxetane) and has a characteristic[9] upfield shift for the C-2 hydrogen. Compound **3**[10] is the minor isomer (*cis*-2,3-diphenyloxetane) and has a lower R_f value on silica gel. The original publication describing these oxetanes gave similar ratios (3:1, *trans:cis* respectively) but did not report the NMR data that we have found to allow differentiation of the isomers.

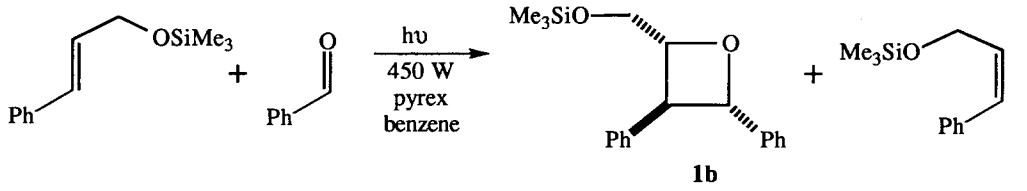
We also have examined the impact of an alkyl group in the β position of the styrene. A study of this analogue was necessary in order to accurately assign the stereochemistry of oxetane **1**. Thus, irradiation of (E)-1-phenylpropene in the presence of benzaldehyde (1:1) gave five products in addition to recovered starting material. Separation of the photoproducts allowed the following assignments: all *trans*-2,3-diphenyl-4-methyloxetane (**4**), *cis,trans*-2,3-diphenyl-4-methyloxetane (**5**), *trans,cis*-2,3-diphenyl-4-methyloxetane (**6**), 2-methyl-3-phenylpropiophenone (**7**), and (Z)-1-phenylpropene (**8**). NMR analysis (including NOE) and comparison to 2,3-diphenyloxetanes **2** and **3** allowed the structural assignment for oxetanes **4-6** as shown in Scheme 2.[11] Oxetane **4**, the major product, was obtained in 25% yield. The minor cycloadducts were found in a 5:1 ratio with a combined yield of less than 3%. Ketone **7** (9%) presumably arises from acyl radical addition to the styrene moiety.[12] Photosensitized double bond isomerization results in approximately 10% yield of (Z)-1-phenylpropene (**8**).

Scheme 2



With this information, we can now return to the initial silyl coordinated study with the ability to ascertain the correct stereochemical relationship in the oxetane **1**. It is clear that the major product is the all *trans* oxetane **1b** (isolated in ca. 20% yield) as shown in Scheme 3.[13] It is interesting to note that no other cycloadducts are detected (detection limit <1%). The *cis* and *trans* alkene isomers of the silyl cinnamyl ether are recovered in a 1.6:1 ratio for a combined yield of 67%.

Scheme 3



1b

In conclusion, it can be argued that the Paterno-Büchi photochemical cycloaddition between styrene and benzaldehyde has π-π overlap which impacts the distribution of products because there is *cis*-2,3-diphenyloxetane obtained from the irradiation. One would not expect any *cis* isomer to be formed if the diradical has sufficient time to relax prior to bond formation. This study implicates noncovalent tethering (but not π-π overlap) for silylated cinnamyl alcohol and benzaldehyde since there is only one stereoisomer obtained and no side-reactions (e.g. ketone **7**). If tethering is involved, then the phenyl groups must be held in opposite directions in the coordinated structure due to steric effects.

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References and notes

1. a) Fleming, S. A.; Ward, S. C.; *Tetrahedron Lett.* **1992**, *33*, 1013-1016; b) Ward, S. C.; Fleming. S. A.; *J. Org. Chem.* **1994**, *59*, 6476-6479; c) Bradford, C. L.; Fleming, S. A.; Ward, S. C.; *Tetrahedron Lett.* **1995**, *36*, 4189-4192.
2. Hutchinson, J. H.; Daynard, T. S.; Gillard, J. W. *Tetrahedron Lett.* **1991**, *32*, 573.
3. Shea, K. J.; Staab, A. J.; Zandi, K. S. *Tetrahedron Lett.* **1991**, *32*, 2715.
4. For a thorough discussion of the mechanism and regioselectivity of the Paterno-Büchi reaction see: Gilbert, A.; Baggott, J. "Essentials of Molecular Photochemistry" Blackwell, 1991, Chapter 7.6, pp 340-353.
5. Our preferred explanation of the stereoselectivity observed in our silyl tethered work (see Ref. 1) is based on the requirement of two π stabilizing groups attached to the styryl moiety and their consistent *cis* relationship in the 4-membered ring that is formed.
6. Carless, H. A. J.; Maitra, A. K.; Trivedi, H. S. *J. Chem. Soc., Chem. Commun.* **1979**, 984.
7. High pressure liquid chromatography was performed using a Microsorb Si-80-199-C5 silica column eluted with 5% EtOAc in hexane at a flow rate of 3 mL/min.
8. The spectral data for **2** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.2-7.4 (m, 10 H), 5.7 (d, J = 6.95 Hz, 1 H), 4.9 (m, 2 H), 4.1 (ddd, J = 7.0, 7.3, 6.9 Hz, 1 H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 128.8, 128.6, 128.1, 127.2, 127.0, 125.2, 90.2, 74.2, 49.7; High Resolution MS $C_{15}H_{15}O$ CI m/z calc. 211.1123, obs. 211.1118.
9. Other phenyl substituted oxetanes have exhibited similar trends. See: a) Beereboom, J. J.; von Wittenau, M. S. *J. Org. Chem.* **1965**, *30*, 1231; b) Turro, N. J.; Wriede, P. A. *J. Am. Chem. Soc.* **1968**, *90*, 6863; c) Yang, N. C.; Eisenhardt, W. *J. Am. Chem. Soc.* **1971**, *93*, 1277; d) Yang, N. C.; Kimura, M.; Eisenhardt, W. *J. Am. Chem. Soc.* **1973**, *95*, 5058.
10. The spectral data for **3** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.9-7.2 (m, 10 H), 6.2 (d, J = 8.71 Hz, 1 H), 5.2 (dd, J = 6.3, 8.3 Hz, 1 H), 4.9 (t, J = 6.4 Hz, 1 H), 4.6 (q, J = 8.3 Hz, 1 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 128.3, 127.9, 127.2, 126.9, 125.5, 86.4, 73.9, 45.5; High Resolution MS $C_{15}H_{15}O$ CI m/z calc. 211.1123, obs. 211.1131.
11. The spectral data for **4** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.2-7.5 (m, 10 H), 5.68 (d, J = 7.6 Hz, 1 H), 5.05 (dq, J = 7.3, 6.0 Hz, 1 H), 3.59 (t, J = 7.6 Hz, 1 H), 1.59 (d, J = 6.0 Hz, 3 H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 142.5, 139.2, 128.8, 128.6, 128.5, 127.9, 127.2, 125.4, 85.0, 80.9, 57.6, 23.2; High Resolution MS $C_{16}H_{17}O$ CI m/z calc. 225.1279, obs. 225.1268.
    The spectral data for **5** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.2-7.5 (m, 10 H), 6.05 (d, J = 9.3 Hz, 1 H), 5.22 (dq, J = 6.4, 6.3 Hz , 1 H), 4.15 (dd, J = 6.84, 8.8 Hz, 1 H), 1.65 (d, J = 6.35 Hz, 3 H).
    The spectral data for **6** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.2-7.5 (m, 10 H), 6.29 (d, J = 7.8 Hz, 1 H), 5.47 (dq, J = 6.3, 6.3 Hz , 1 H), 4.45 (t, J = 7.8 Hz, 1 H), 1.17 (d, J = 6.3 Hz, 3 H).
12. For an example see: Gottschalk, P.; Neckers, D. C. *J. Org. Chem.* **1985**, *50*, 3498.
13. The spectral data for **1b** were: ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.2-7.6 (m, 10), 5.69 (d, J = 7.8 Hz, 1 H), 4.95 (ddd, J = 7.3, 3.3 Hz, J = 4 Hz, 1 H), 3.98 (t, J = 7.5 Hz, 1 H), 3.92 (dd, J = 3.4, 12 Hz, 1 H), 3.83 (dd, J = 4.4, 12 Hz, 1 H) 0.2 (s, 9 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 142.3, 139.2, 130.2, 128.7, 128.5, 128.3, 127.3, 126.0, 85.7, 84.0, 64.8, 50.6, -0.5; High Resolution MS $C_{19}H_{25}O_2Si$ CI m/z calc. 313.1624, obs. 313.1613.

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