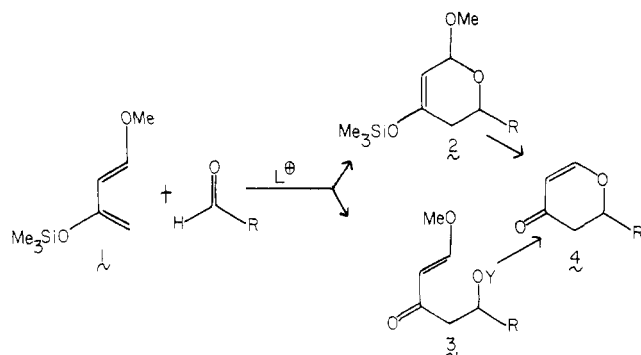


# Communications

## Expedient Routes to Multiply Functionalized Pyrans

**Summary:** The scope of the Lewis acid catalyzed cyclocondensation reaction of activated dienes and aldehydes has been investigated. With a 3-(trialkylsilyloxy) group in the basic diene, the reaction has been shown to be feasible with 1,1-dimethoxy, 1-(silyloxy)-1-alkyl, and 1-alkyl substituents. Rapid and general routes to various derivatives of 4-pyranone are thus available.

**Sir:** We have been exploring the cyclocondensation of 1,3-dioxygenated butadienes such as 1 with aldehydes.<sup>1</sup> Depending on the nature of the Lewis acid catalyst and the nature of the diene, two limiting mechanisms have been recognized. A pericyclic process leading to cycloadduct 2 has been identified.<sup>2</sup> An aldol-like pathway,

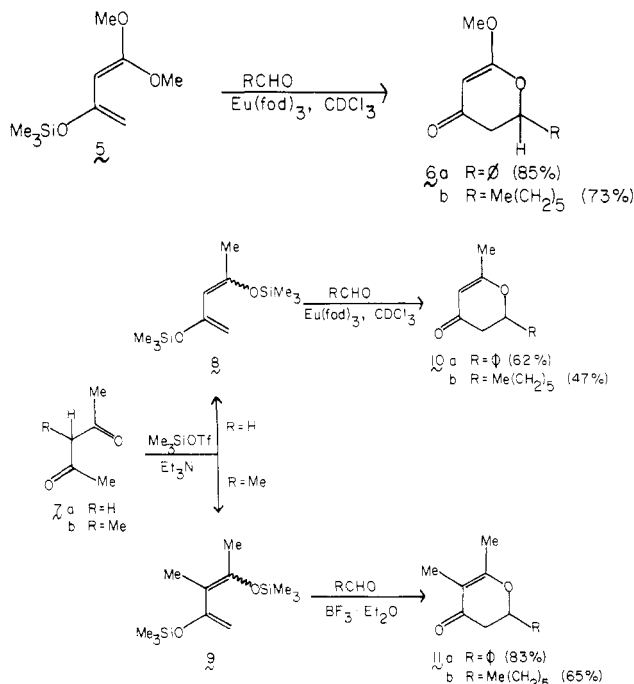


proceeding by way of intermediates related to 3, has also been encountered.<sup>2,3</sup> Under appropriate conditions, 2 and 3 undergo conversion to 4. Because products such as 2 and 4 offer considerable promise for a variety of synthetic objectives, we investigated the consequences of major structural variations in the dienes.

Herein we report some recent findings that demonstrate significant expansions in the scope of the cyclocondensation reaction.

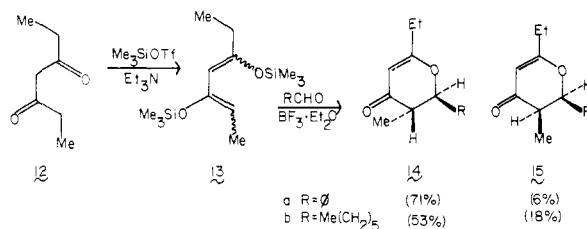
We first examined the case of the 1,1,3-trioxygenated diene 5.<sup>4</sup> Using  $\text{Eu}(\text{fod})_3$  as the Lewis acid catalyst, in chloroform at room temperature,<sup>5</sup> this diene reacts with benzaldehyde and with *n*-heptanal to give the corresponding dihydropyranones 6<sup>a</sup> as shown. There was no evidence for the intermediacy of acyclic products similar to 3, but the matter was not investigated in detail.

We next investigated dienes bearing the 1-alkyl-1,3-dioxygenated substitution pattern. The  $\beta$ -diketones 7<sup>a</sup> and 7<sup>b</sup> were readily converted to the crude bis(silyloxy)diene



8 and 9 as a mixture of *E,Z* stereoisomers.<sup>7a,b</sup> These dienes reacted with benzaldehyde and with *n*-heptanal under the conditions shown to afford, in one step, the 6-substituted 2,3-dihydropyranones 10 and 11 in the indicated yields.<sup>6</sup>

Similarly, bis-silylation of 12 affords a mixture of *E,Z* permutants<sup>8</sup> shown as 13. Reactions of these dienes with



the same aldehydes afford mixtures of 14<sup>6</sup> and 15.<sup>6</sup> We have not determined the stereochemical behavior of the individual dienes in these reactions. However, in synthetic terms, this very rapid access to 2,3,6-trisubstituted pyranones could well prove valuable in the synthesis of avermectin-like compounds.<sup>9</sup>

Of course the symmetries of diketones 7 and 12 are such that only one constitutional isomer can be produced on bis-silylation. It was of interest to apply the reaction sequence to the unsymmetrical diketone 16.<sup>10</sup> Under the

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(3) Larson, E. R.; Danishefsky, S. *Tetrahedron Lett.* 1982, 23, 1975.

(4) (a) Danishefsky, S.; Singh, R. K.; Gammill, R. B. *J. Org. Chem.* 1978, 43, 379. (b) Danishefsky, S.; Yan, C. F.; Singh, R. K.; Gammill, R. B.; McCurry, P. M., Jr.; Fritsch, N.; Clardy, J. *J. Am. Chem. Soc.* 1979, 101, 7001. (c) Danishefsky, S.; Walker, F. J. *Ibid.* 1979, 101, 7018. (d) Banville, J.; Brassard, P. *J. Chem. Soc., Perkin Trans. 1*, 1976, 1852.

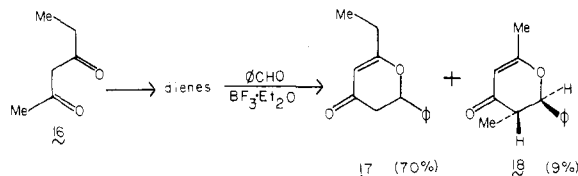
(5) Bednarski, M. D.; Danishefsky, S. *J. Am. Chem. Soc.* 1983, 105, 3716.

(6) All new compounds gave infrared, NMR, and mass spectral data which are consistent with the structures proposed. Spectral data are provided as supplementary material.

(7) (a) Emde, H.; Domsch, D.; Feger, H.; Frick, U.; Götz, A.; Hergott, H. H.; Hofmann, K.; Kober, W.; Krageloh, K.; Oesterle, T.; Steppan, W.; West, W.; Simchen, G. *Synthesis* 1982, 1. (b) A 2:1 molar excess of diene to aldehyde was typically employed. Dienes were approximately 90% pure.

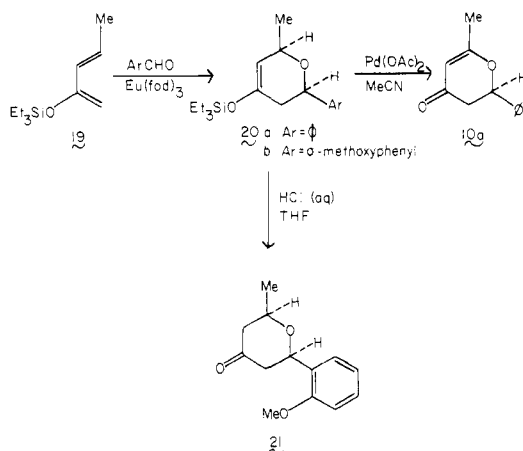
(8) 270-MHz <sup>1</sup>H NMR indicated this mixture to be composed of three isomers in a ratio of 80:13:7.

(9) (a) Campbell, W. C.; Fisher, M. H.; Stapley, E. O.; Albers-Schönberg, G.; Jacob, T. A. *Science (Washington, DC)* 1983, 221, 823. (b) Albers-Schönberg, G.; Arison, B. H.; Chabala, J. C.; Douglas, A. W.; Eskola, P.; Fisher, M. H.; Lusi, A.; Mrozik, H.; Smith, J. L.; Tolman, R. L. *J. Am. Chem. Soc.* 1981, 103, 4216. (c) Springer, J. P.; Arison, B. H.; Hirshfield, J. M.; Hoogsteen, K. *Ibid.* 1981, 103, 4221.



usual conditions (*vide supra*),<sup>7</sup> a mixture of dienes was produced.<sup>11</sup> Reaction of this mixture with benzaldehyde in the presence of  $\text{BF}_3 \cdot \text{Et}_2\text{O}$  provided a 70% yield of 17.<sup>6</sup> The trans-trisubstituted isomer 18<sup>6</sup> was also obtained in 9% yield. While we have no data on the efficacy of the participation of the individual dienes in the process, the product distribution suggests that the major product of bisilylation is the 1-ethyl-1,3-bis(silyloxy) system.<sup>10</sup> While the extendability of this preferential silylation to other systems remains to be determined, the ability to use nonsymmetrical  $\beta$ -diketones in an effective way is encouraging for future possibilities.

Finally, we record the feasibility of using 1-alkyl-3-oxygenated dienes in the cyclocondensation reaction.

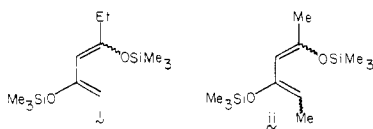


Through the use of  $\text{Eu}(\text{fod})_3$  catalysis,<sup>5</sup> the silyloxy diene 19<sup>12</sup> reacts with the appropriate aromatic aldehyde to give enol ethers 20a<sup>6</sup> and 20b<sup>6</sup> in nearly quantitative yield. Compound 20b was hydrolyzed to the 2,6-disubstituted tetrahydropyran 21<sup>6</sup> with aqueous  $\text{HCl}$ -THF. Thus, the endo selectivity of the europium-induced pericyclic reaction<sup>5</sup> provides a stereospecific entry to *cis*-2,6-disubstituted tetrahydropyranes.

Alternative possibilities for taking advantage of the intermediate silyl enol ether functionality have been realized. For instance, transformation of 20a  $\rightarrow$  10a<sup>13</sup> (previously obtained from 8) suggests some of the potentialities in this direction. Applications of these findings to the synthesis of aryl glycosides and other natural products are being examined in our laboratory.

(10) 2,4-Hexanedione was purchased from Pfaltz and Bauer, Inc.

(11) Analysis of the 270-MHz  $^1\text{H}$  NMR spectrum suggests this mixture to be composed of approximately 85% of a 1:1 mixture of dienes i and 15% of one of the isomeric dienes ii. The NMR portion of the spectrum attributable to i is very similar to that of isomers 8 while that portion assignable to ii is very similar to the spectrum previously seen for compounds 13.



(12) This diene was prepared by silylation (LDA/TESECl) of a mixture of 3-penten-2-one and 4-methyl-3-penten-2-one (from Aldrich) followed by distillation (87-93 °C (10 mmHg)).

(13) Ito, Y.; Hirao, T.; Saegusa, T. *J. Org. Chem.* 1978, 43, 1011.

These significant expansions in the scope of the cyclocondensation reaction are being applied to a variety of total synthesis undertakings. The results will be described in due course.

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**Registry No.** 5, 61539-61-5; 6a, 88083-77-6; 6b, 88083-78-7; 7a, 123-54-6; 7b, 815-57-6; (E)-8, 63446-76-4; (Z)-8, 63446-77-5; (E)-9, 81942-45-2; (Z)-9, 81942-37-2; 10a, 88083-79-8; 10b, 88083-80-1; 11a, 88083-81-2; 11b, 88083-82-3; 12, 7424-54-6; 13, 88083-83-4; 14a, 88083-84-5; 14b, 88083-85-6; 15a, 88083-86-7; 15b, 88083-87-8; 17, 88083-88-9; 18, 88083-89-0; 16, 3002-24-2; 19, 88083-96-9; 20a, 88083-97-0; 20b, 88083-98-1; 21, 88083-99-2; (E)-i, 88083-90-3; (Z)-i, 88083-91-4; (Z,Z)-ii, 88083-92-5; (Z,E)-ii, 88083-93-6; (E,E)-ii, 88083-94-7; (E,Z)-ii, 88083-95-8;  $\text{Me}_3\text{SiOTf}$ , 27607-77-8;  $\text{Et}_3\text{SiCl}$ , 994-30-9; benzaldehyde, 100-52-7; *n*-heptanal, 111-71-7; pent-3-en-2-one, 625-33-2.

**Supplementary Material Available:** Representative experimental procedures and spectral data for all compounds (6 pages). Ordering information is given on any current masthead page.

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## Upper Excited State Reactions of Thioketenes: Di-*tert*-butylthioketene

**Summary:** Di-*tert*-butylthioketene, while unreactive upon excitation to  $S_1$ , produces thiirenylidene carbene and zwitterionic intermediates upon excitation to  $S_2$ .

**Sir:** Photochemistry of ketenes, allenes, and related cumulenes is of contemporary interest.<sup>1</sup> Though the photobehavior of parent thioketene in an argon and nitrogen matrix at low temperatures ( $\sim 8$  K)<sup>2</sup> has received a great deal of attention, largely due to their involvement in the matrix isolation of thiirenes, no report has appeared on the photochemistry of thioketenes in solution. Photolysis ( $\lambda$  215-260 nm) of parent thioketene in the above matrix results in photodecomposition and conversion to ethynyl mercaptan.<sup>2</sup> Interestingly, it is stable to light of wavelength above 280 nm. It has been suggested that the interconversion of thioketene to ethynethiol takes place via thiirenylidene carbene and thiirene.<sup>3</sup> We describe the first account of the photochemical behavior of a stable thioketene—di-*tert*-butylthioketene (1)—in solution. Results presented in this report support some of the earlier sug-

(1) (a) Russel, R.; Rowland, F. S. *J. Am. Chem. Soc.* 1970, 92, 7508. (b) Kirmse, W.; Spaleck, W. *Angew. Chem., Int. Ed. Engl.* 1981, 20, 776. (c) Klett, M. W.; Johnson, R. P. *Tetrahedron Lett.* 1983, 24, 1107. (d) Klett, M. W.; Johnson, R. P. *Ibid.* 1983, 24, 2523. (e) Stierman, T. J.; Johnson, R. P. *J. Am. Chem. Soc.* 1983, 105, 2492. (f) Steinmetz, M. G.; Mayers, R. T.; Yang, J. C. *Ibid.* 1982, 104, 3518. (b) Fujita, K.; Matsui, K.; Shono, T. *Ibid.* 1975, 97, 6256. (h) Carlsen, L.; Schaumann, E. *J. Chem. Soc., Faraday Trans. 1* 1979, 75, 2624. (i) Zwanenburg, B. *Recl. Trav. Chim. Pays-Bas* 1982, 101, 1.

(2) Kranz, A.; Laureni, J. *J. Am. Chem. Soc.* 1981, 103, 486.

(3) Trorres, M.; Loran, E. M.; Gunning, H. E.; Stranz, O. P. *Pure Appl. Chem.* 1980, 52, 1263.