(Dimethylcopper(I))lithium smoothly converted **6** into **12a**, which was subsequently alkylated with methyl iodide/KO-*t*-Bu to afford the tetramethyl derivative **12b** in 85% yield. Removal of the methoxycarbonyl group was best accomplished by treatment with lithium iodide in hot γ-collidine,[22] which gave a 95% yield of a mixture of diastereomers, represented by **13**. The cuprate addition occurred with complete stereospecificity; for treatment of **13** with lithium diisopropylamide followed by diethoxyphosphoryl chloride[14] gave only one compound, **14**, in better than 80% yield. Attempts to convert the enolphosphonate into (±)-modhephene by the lithium–ammonia procedure of Ireland[23] met with only limited success; therefore, the ketone **13** was reduced to a mixture of epimeric alcohols, which was then dehydrated with bis(1,1,1,3,3,3-hexafluoro-2-phenyl-2-propoxy)diphenylsulfurane[24] to afford **1** as the sole product in greater than 60% yield from **13**. The spectra of synthetic modhephene **1** were identical in all respects with the spectra of **1** provided by Professors Smith,[3] Wender,[8] and Zalkow.[2]

We believe this route to modhephene illustrates the synthetic potential of bridgehead keto carbanions such as the one introduced here.

Acknowledgment. We thank Professors Wender, Smith, and Zalkow for providing copies of spectra **1** for comparison purposes. Special thanks are due to Dr. U. Weiss for his interest and encouragement and Professor W. von E. Doering for a stimulating discussion. Professor J. C. Martin kindly supplied the sulfurane used in the last step. We also thank the National Science Foundation (CHE-7910302) for generous financial support.

Supplementary Material Available: Experimental details are available (10 pages). Ordering information is given on any current masthead page.

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[22] Elsinger, F. *Org. Synth.* **1965**, *45*, 7.

[23] Ireland, R. E.; Pfister, G. *Tetrahedron Lett.* **1969**, 2145. Fetizon, M.; Jurion, M.; Anh, N. T. *J. Chem. Soc., Chem. Commun.* **1969**, 112.

[24] Martin, J. C.; Arhart, R. J. *J. Am. Chem. Soc.* **1972**, *94*, 5003.

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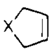
An Indirect Method for Engaging Unactivated Alkenes as Effective Dienophiles in Regioselective Diels–Alder Reactions

Summary: Terminal alkenes and cyclic olefins can be made to enter into efficient, regiocontrolled Diels–Alder cycloaddition by prior selenosulfonation and oxidation to the vinyl sulfone. Reductive desulfonation after condensation with an activated diene provides the formal adducts.

Sir: Although Diels–Alder cycloadditions are among the most versatile and preparatively useful reactions currently available, their scope would be profitably augmented if unactivated olefins could be made to serve as dienophiles.[1] Superpositioning of regioselective control, where appropriate, would enhance matters still further. As a simple solution to this problem, we have made use of a mild, position-selective method for replacing a vinyl proton by a phenylsulfonyl group. The resulting vinyl sulfones are sufficiently reactive[2,3] to enter into annulation reactions and to allow for site-specific attachment of appendages and/or functional groups to six-membered rings. Since subsequent removal of the activating group is readily accomplished, an entire domain of previously inaccessible synthetic methodology now becomes available. In this report, we draw particular attention to the rapid elaboration of 4,5-annulated and 5-substituted cyclohexenones, compounds otherwise accessible only indirectly.[4]

The process for cycloannulation is typified by the conversion of 2,5-dihydrofuran (**1a**) and cyclopentene (**1b**) to **4a** and **4b**, respectively. Irradiation of **1a** and phenylselenenyl benzenesulfonate[5] in CCl_4 solution with 2537 Å lamps[6] effected selenosulfonation and afforded, after direct hydrogen peroxide oxidation of the adduct, the crystalline vinyl sulfone **2a** (75%).[7] Heating of **2a** with (*E*)-1-methoxy-2-methyl-3-[(trimethylsilyl)oxy]-1,3-butadiene[8] in xylene for 28 h followed by mild acid hydrolysis produced **3a** (69%). The conversion to **4a** (83%) was achieved by reduction with zinc dust in acetic acid.[9] The same easily workable sequence led from **1b** to **4b** in 30% overall yield.



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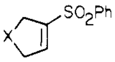

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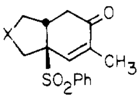

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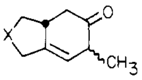

4

a, X = O ; b, X = CH_2

Since orientational dominance is exerted by the sulfonyl group, one can arrive cleanly at 5-substituted cyclohexenones by taking advantage of the anti-Markovnikov manner in which the selenolsulfonate adds to a terminal alkene under photochemical conditions. Thus, treatment of phenyl allyl ether as before delivers **5** cleanly and efficiently (89%). Diels–Alder reaction of **5** with the same unsymmetrical dienophile afforded adduct **6** (68%) from which **7** was obtained (78%). In similar fashion, 1-hexene was transformed via **8** (65%) and **9** (68%) to **10** (78%).

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[1] Norbornenes (Cava, M. P.; Scheel, F. M. *J. Org. Chem.* **1967**, *32*, 1304; Paquette, L. A.; Williams, R. V. *Tetrahedron Lett.* **1981**, 4643) and 1,5-cyclooctadiene (Eaton, P. E.; Chakraborty, U. R. *J. Am. Chem. Soc.* **1978**, *100*, 3634) are examples of cyclic alkenes that cycloadd to highly reactive dienes.

[2] (a) Carr, R. V. C.; Paquette, L. A. *J. Am. Chem. Soc.* **1980**, *102*, 853. (b) Paquette, L. A.; Kinney, W. A. *Tetrahedron Lett.* **1982**, 131. (c) Little, R. D.; Myong, S. O. *Ibid.* **1980**, 3339. (d) Paquette, L. A.; Charumilind, P. *J. Am. Chem. Soc.* **1982**, *104*, 3749. (e) Paquette, L. A.; Williams, R. V.; Carr, R. V. C.; Charumilind, P.; Blount, J. F. *J. Org. Chem.*, **1982**, *47*, 4566.

[3] For previous examples of sulfone activation of olefins, see: (a) Böll, W.; König, H. *Justus Liebigs Ann. Chem.* **1979**, 1657. (b) Trost, B. M.; Chan, D. M. T. *J. Am. Chem. Soc.* **1979**, *101*, 6429. (c) Danishefsky, S.; Marayama, T.; Singh, R. K. *Ibid.* **1979**, *101*, 7008.

[4] Consult, for example: (a) Vig, O. P.; Kapoor, J. C.; Puri, J.; Sharma, S. D. *Ind. J. Chem.* **1980**, *6*, 60. (b) Kelly, L. F.; Narula, A. S.; Birch, A. J. *Tetrahedron Lett.* **1980**, 2455. (c) Escalona, H.; Maldonado, L. A. *Synth. Commun.* **1980**, *10*, 857. (d) Kelly, L. F.; Dahler, P.; Narula, A. S.; Birch, A. J. *Tetrahedron Lett.* **1981**, 1433.

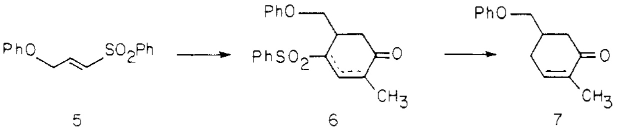
[5] Back, T. G.; Collins, S. *Tetrahedron Lett.* **1980**, 2213.

[6] Gancarz, R. A.; Kice, J. L. *Tetrahedron Lett.* **1980**, 4155; *J. Org. Chem.* **1981**, *46*, 4899. This photochemical procedure proved to be more efficient in our hands than the thermal alternative [Back, T. G.; Collins, S. *Tetrahedron Lett.* **1980**, 2215; *J. Org. Chem.* **1981**, *46*, 3249].

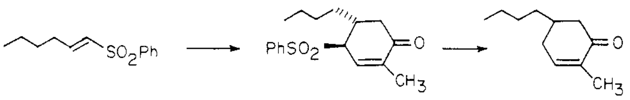
[7] The yields cited herein apply to purified products that were homogeneous by TLC analysis and gave elemental analyses and spectral data (^1H NMR, IR, *m/e*) in accord with their assigned structures.

[8] 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.

[9] Lansbury, P. T.; Erwin, R. W.; Jeffrey, D. A. *J. Am. Chem. Soc.* **1980**, *102*, 1602.



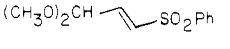
5 6 7



8 9 10

The selenosulfonation step is tolerant to a wide range of functional groups.[10] For example, with vinyltrimethylsilane and acrolein dimethyl acetal as substrates, **11** and **12** were made available in yields of 84% and 73%, respectively. With **12** in hand, it proved possible in turn to produce **13** (77%), then **14** and/or **15** (77%). As expected, the cyclohexenone moiety could be unmasked under hydrolytic conditions that did not affect the acetal group. The two incipient carbonyl functionalities were thereby easily distinguished.

11



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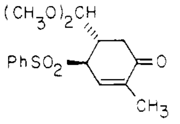

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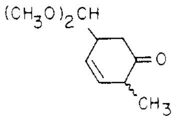

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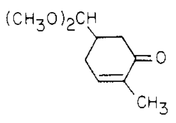
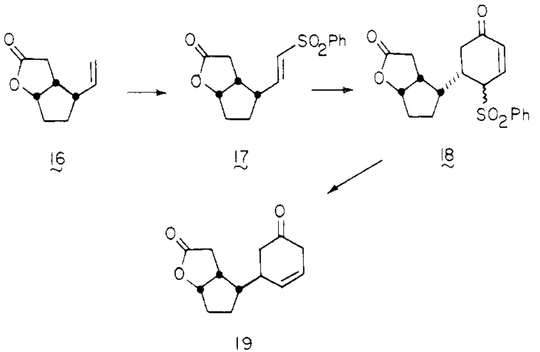


15

The dienophile **17** was similarly prepared (72%) from the previously described[11] prostaglandin intermediate **16**. Reaction of **17** with Danishefsky's diene gave **18** as a mixture of cis and trans isomers (68%). Reduction of **18** under normal conditions led to isolation of the keto lactone **19** (60%).



16 17 18

19

The methodology outlined above provides the groundwork and incentive for wide-ranging future experimentation. Not only is selenosulfonation shown to be applicable to the preparation of a wide variety of vinyl sulfones, but the hindered nature of these activated di- and trisubstituted olefins does not seriously hamper their ability to undergo [4 + 2] cycloaddition. Furthermore, the crystallinity imparted to molecules containing the phenylsulfonyl unit aids in the isolation and characterization of intermediates.

Noteworthily, the chemistry described herein involving **12** provides clear indication of a potentially powerful method for achieving regiochemical reversal in Diels–Alder reactions. Thus, whereas customary electronic factors would transform acrolein into 4-formylcyclohex-2(or 3)-enone, acrolein dimethyl acetal gives, following conversion to **12**, the 5-substituted isomer exclusively. Hence, vinyl sulfone cycloadditions will likely open up new routes to a number of specifically substituted alicyclic six-membered ring compounds (and their aromatic counterparts, if desired) which would be more difficult to prepare by alternative methods presently available.

Acknowledgment. This investigation was supported by the National Cancer Institute and the Eli Lilly Company.

Supplementary Material Available: Experimental details for the preparation of compounds **5**, **2b**, **6**, **3b**, **7**, and **4b** (3 pages). Ordering information is given on any current current masthead page.

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(10) For additional examples, see Paquette, L. A.; Kinney, W. A. *Tetrahedron Lett.* **1982**, 5127.

(11) (a) Paquette, L. A.; Crouse, G. D.; Sharma, A. K. *J. Am. Chem. Soc.* **1980**, *102*, 3972. (b) Crouse, G. D., Paquette, L. A. *Tetrahedron* **1981**, *37, Suppl. No. 9*, 281.

Additions and Corrections

Vol. 47, 1982

Michael Rosenberger,* Patrick G. McDougal, and Julie Bahr. Canthaxanthin. A New Total Synthesis.

Page 2130. Patric McDougal should read Patrick G. McDougal.

Michael Rosenberger* and Patrick G. McDougal. Synthesis of 2,2′-Dinorcanthaxanthin.

Page 2134. Patrick J. McDougal should read Patrick G. McDougal.

M. Ishiguro, N Ikeda, and H. Yamamoto.* Propargylic Titanium Reagents. Regio- and Stereocontrolled Synthesis of Allenic and Acetylenic Alcohols.

Page 2226. Entry 4 of Table II, the 8/9 ratio of the adduct should read 30:70. Other diastereoisomeric ratios reported are correctly stated. We thank Professor Yoshinori Yamamoto of Kyoto University for bringing the error to our attention.