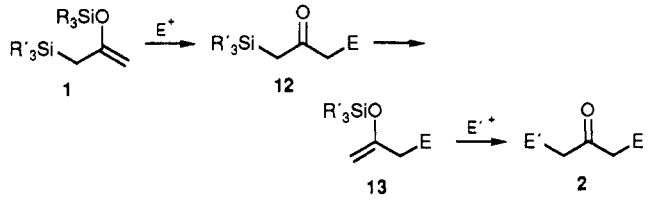
Scheme III. Double Alkylation Reactions of (2-Siloxyallyl)silane (1)



methane. Concerning the reaction temperature and time, the best yield was obtained at −78 °C → 0 °C and 5–7 h. For the aromatic acetals, boron trifluoride etherate is better than titanium tetrachloride as a Lewis acid. In latter case the alkoxy group of the products was replaced by a chlorine atom. With **1b**, the reaction was slow and the yield was rather low.[10]

Reactions of **1a** with carbonyl compounds **9** also gave consecutive double aldol products **10**, although the reactions were rather slow. The representative results are listed in Table II. Although reactions with ketones and aliphatic aldehydes did not always proceed satisfactorily, giving monoaldol products **11** in some cases, **10** was obtained with aromatic aldehydes in respectable yield. Benzyl (**9i**) afforded five-membered ring compounds (**10i**).

In these reactions, the temperature of about 0 °C was required for the occurrence of the second alkylation, presumably due to the slow 1,3 C→O Si shift in **12** under the present conditions.[11] Nevertheless it is well-known that silyl enol ethers react with **7** and **9** even at −78 °C.[12] In addition, since silyl enol ethers are more reactive toward electrophiles than allylsilanes,[2] these facts suggest strongly that the present double alkylation proceeds via a stepwise mechanism as shown in Scheme III, in which **1** works as a silyl enol ether, but not an allylsilane, with an α-silyl ketone (**12**)[13] being formed first. The resulting **12** without isolation undergoes 1,3 C→O Si shift under acidic conditions[6,8,14] to produce a monoalkylated silyl enol ether (**13**), which reacts with another electrophiles to afford a tandem double alkylation product (**2**).

Indeed the synthesis of the unsymmetric ketone **8k** could be realized by the addition of an equivalent of acetaldehyde dimethyl acetal (**7k**) at less than 0 °C followed by **7a**, although the yield was ca. 20%. Moreover, it has been found that the bis(silyl)acetone **5b** can be also viewed as the synthetic equivalent of acetone α,α′-dianion (**3**), although its reactivity is lower than that of **1**, probably due to slow conversion to the incipient **1a** at the stage of the first alkylation.[15]

The synthetic utility of the present reaction was mostly displayed by ready availability of starting materials, which are storable and easy to handle, and simple manipulation of the conversion. The methodology reported here, leading to compounds that are otherwise relatively inaccessible, provides a prototype for other ketone α,α′-dianion equivalents.

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Supplementary Material Available: Preparation of **1** and **5**, reaction procedures of **1** with **7** or **9**, and ^{1}H NMR, IR and MS spectral data for **1**, **4**, **5**, **8**, **10**, and **11** (8 pages). Ordering information is given on any current masthead page.

(10) This might be presumably due to the inefficiency of the nucleophilic assistance toward the silicon atom bearing the bulky *tert*-butyl group by the chlorine or alkoxy group.

(11) See the caption of entry 1 in Table I. Moreover, when the reaction of α-silyl ketone **5a** with **7a** was conducted at 0 °C for 7 h, it was found that 4-methyl-6-methyl-2-heptanone (**11a**) was obtained in 76% yield, although the reaction did not occur at −78 °C.

(12) (a) Mukaiyama, T.; Hayashi, M. *Chem. Lett.* **1974**, 15. (b) Mukaiyama, T.; Banno, K.; Narasaka, K. *J. Am. Chem. Soc.* **1974**, *96*, 7503.

(13) For the fluoride ion promoted and Lewis acid catalyzed reactions of α-silyl ketones, see the following. (a) Fiorenza, M.; Mordini, A.; Papaleo, S.; Pastorelli, Ricci, A. *Tetrahedron Lett.* **1985**, *26*, 787. (b) Johnson, W. S.; Edington, C.; Elliott, J. D.; Silverman, I. R. *J. Am. Chem. Soc.* **1984**, *106*, 7588.

(14) Although the direct conversion of **12** to **2** can not be necessarily excluded, it has been found that the ready 1,3 C→O Si shift occurs at room temperature under Lewis acidic conditions.

(15) Reactions of **5b** with 4 equiv of **7a** and **9b** afforded the corresponding double aldol products **8a** and **10b** in 32% and 38% yields, when reactions were conducted in the presence of $TiCl_4$ and $BF_3{\cdot}OEt_2$, respectively, at −78 °C → 0 °C for 6 h in dichloromethane.

Sulfonate Ester Radical Ion Chemistry

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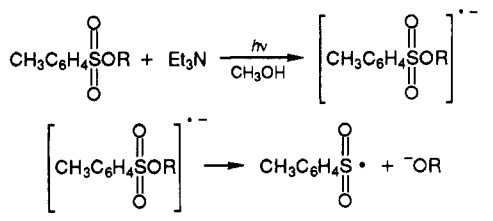
Summary: Tosylate ester radical anions in the gas phase cleave the sulfonate S–C bond, resulting in formation of a sulfite anion. This is in marked contrast to the solution-phase chemistry, where cleavage of the sulfonate S–O bond to produce a sulfonyl radical and alkoxide ion is observed. The difference in reaction pathways is attributable to solvation of the incipient alkoxide anion leaving group.

Sir: *p*-Toluenesulfonic acid esters, in the presence of an electron donor, undergo photochemical reaction yielding alcohols.[1,2] We have recently demonstrated that photolysis

Scheme I



of these esters initially produces a tosylate ester radical anion, which undergoes heterolytic cleavage to produce a

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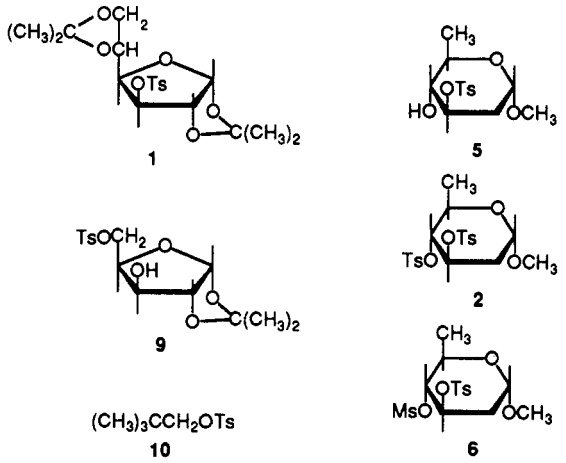
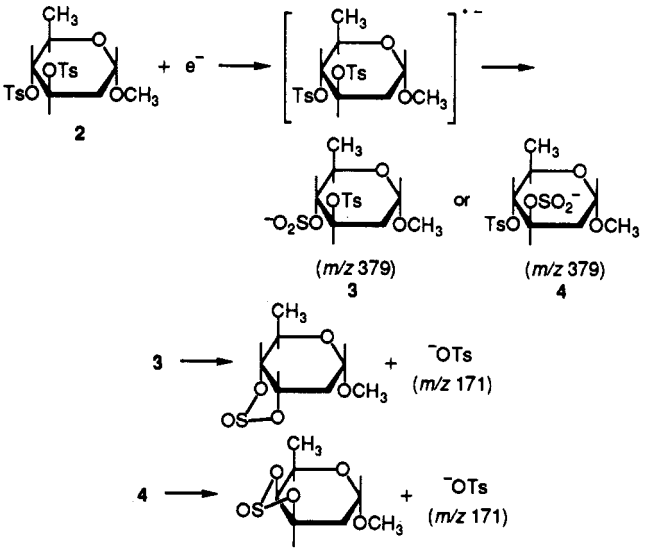
p-tolylsulfonyl radical and an alkoxide ion (Scheme I).[3,4] We now report that tosylate ester radical anions produced in the gas phase react by a route not observed in solution.

Gas-phase electron capture of thermalized electrons generated under chemical-ionization conditions is known to produce radical anions with little excess energy.[5-7] Negative-ion chemical ionization of 1,2:5,6-di-*O*-isopropylidene-3-*O*-(*p*-tolylsulfonyl)-α-D-glucofuranose (**1**)[8] employing methane, nitrous oxide, isobutane, or argon as the mediating gas at 1 Torr source pressure[9] gave a spectrum containing only a very small parent peak (<1% relative abundance, *m/z* 414) and a base peak at *m/z* 323 (M − 91). The collisionally activated decomposition (CAD) mass spectrum of the ion at *m/z* 323 led to a fragment ion at *m/z* 259 (a loss of 64 mass units). The presence of an extremely small parent-ion peak is consistent with the solution-phase lifetime of sulfonate ester radical anions of less than 10^{-7} s.[3] In light of the low energies involved in this ionization process,[5-7] the energy of activation for the radical anion decomposition must be quite small. Similar fragmentation has been observed for methyl 2,6-dideoxy-3-*O*-(*p*-tolylsulfonyl)-α-D-*arabino*-hexopyranoside (**5**),[10] 1,2-*O*-isopropylidene-5-*O*-(*p*-tolylsulfonyl)-α-D-xylofuranose (**9**),[11] and neopentyl tosylate (**10**).[12]

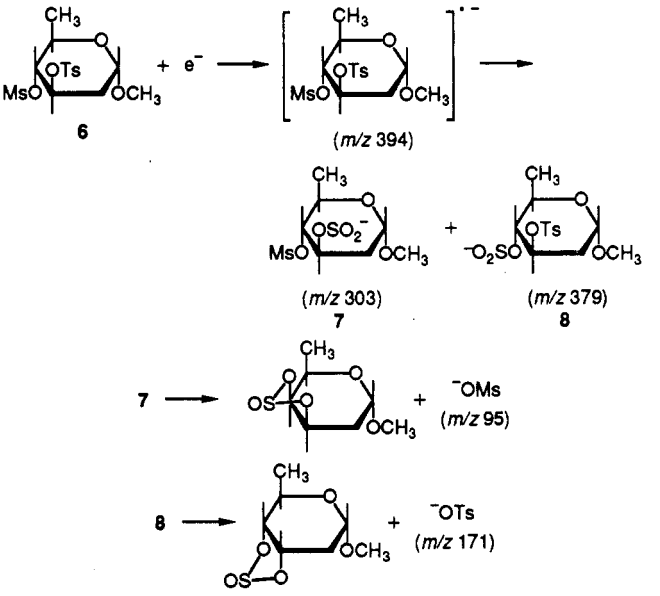


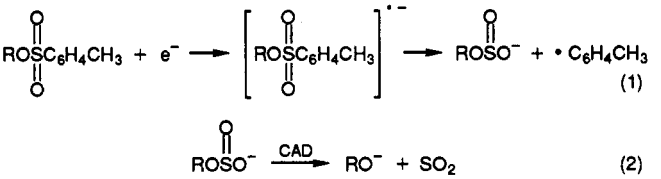
The base peaks in the monotosylate negative-ion mass spectra of **1**, **5**, **9**, and **10** arise from loss of a tolyl radical by a formal C–S homolytic cleavage resulting in formation of the corresponding sulfite anion (eq 1). CAD MS of the sulfite ion produces a large peak corresponding to loss of sulfur dioxide (a 64 mass unit loss) to form the corresponding alkoxide ion (eq 2).

Scheme II



Scheme III





To confirm the reaction pathways outlined in eq 1 and 2, negative ion MS analysis of some ditosylates was performed. Methyl 2,6-dideoxy-3,4-di-*O*-(*p*-tolylsulfonyl)-α-D-*arabino*-hexopyranoside (**2**)[12] afforded a peak at *m/z* 379 (M − 91, 85% relative abundance) and a base peak at *m/z* 171 (*p*-toluenesulfonate ion). These results can be explained by an initial C–S homolytic cleavage (as in the case of the monotosylates) to produce either of the sulfite ions **3** or **4** (*m/z* 379), which then undergo an internal nucleophilic substitution to produce a neutral cyclic sulfite or sulfonate with concomitant formation of *p*-toluenesulfonate ion (*m/z* 171). The ability of **3** or **4** to undergo internal displacement to produce *p*-toluenesulfonate ion

(1) Binkley, R. W. *Adv. Carbohydr. Chem. Biochem.* **1981**, *38*, 105.
(2) Binkley, R. W.; Flechtner, T. W. In *Synthetic Organic Photochemistry*; Horspool, W. M., Ed.; Plenum: New York, 1984; pp 377–382.
(3) Binkley, R. W.; Hehemann, D. G.; Koholic, D. J.; Masnovi, J. M. *J. Am. Chem. Soc.* Submitted for publication.
(4) Masnovi, J.; Koholic, D. J.; Berki, R. J.; Binkley, R. W. *J. Am. Chem. Soc.* **1987**, *109*, 2851.
(5) Hunt, D. F.; Sethi, S. K. In *High Performance Mass Spectrometry: Chemical Applications*; Gross, M. L., Ed.; ACS, Symposium Series 70; American Chemical Society: Washington, DC, 1978; pp 150–178.
(6) Harrison, A. G. *Chemical Ionization Mass Spectrometry*; CRC Press, Inc.: Boca Raton, FL 1983; pp 75–80.
(7) Friesen, M. D.; Hass, J. R. In *Mass Spectrometry Part B*; Merritt, C., Jr., Ed.; Marcel Dekker, Inc.: New York, 1980; pp 288–293.
(8) Nayak, U. G.; Whistler, R. L. *J. Org. Chem.* **1969**, *34*, 3819.
(9) Except for the difference in reagent gases, all other ionization conditions were kept constant. The data were collected on a Finnigan TSQ-45 triple quadrupole mass spectrometer operating with a source temperature held at 120 °C, and the electron energy was 70 eV with an emission current of 0.3 mA. All samples were introduced via the solids probe.
(10) Durette, P. L. *Carbohydr. Res.* **1982**, *100*, C27.
(11) Levene, P. A.; Rayond, A. L. *J. Biol. Chem.* **1933**, *102*, 317.
(12) Beringer, F. M.; Schultz, H. S. *J. Am. Chem. Soc.* **1955**, *77*, 5533.

(Scheme II) was confirmed through CAD analysis of the peak at m/z 379, which afforded p-toluenesulfonate ion (m/z 171) as the only negatively charged product.

In an effort to further elaborate on the nature of the substitution reaction occurring in the ditosylates, methyl 2,6-dideoxy-3-*O*-(*p*-tolylsulfonyl)-α-D-*arabino*-hexopyranoside (**5**) and methyl 2,6-dideoxy-3-*O*-(*p*-tolylsulfonyl)-4-*O*-(methylsulfonyl)-α-D-*arabino*-hexopyranoside (**6**) were analyzed. The monotosylate **5** led to the expected spectrum consisting of a very small parent peak at m/z 316 and a base peak at m/z 225 corresponding to the sulfite ion. No peak corresponding to formation of the p-toluenesulfonate ion was observed in the negative-ion MS of **5**. Thus it is the presence of a second sulfonate group, as in the case of the ditosylate **2**, that permits internal substitution.

The combined mesylate tosylate **6** produced peaks at m/z 394 (parent radical anion, relative abundance ≤1%), m/z 379 (M – CH_3 from the methylsulfonyl group, vide infra, 10% relative abundance), m/z 303 (M – tosyl, 100% relative abundance), m/z 171 (p-toluenesulfonate ion, 10% relative abundance), and m/z 95 (methanesulfonate ion, 5% relative abundance). From these data it can be seen that the initially formed radical anion cleaves to give either of two sulfite anions **7** or **8** (Scheme III). Internal nucleophilic displacement in **7** produces the p-toluenesulfonate ion while internal nucleophilic substitution in **8** produces the methanesulfonate ion. In order to prove these suppositions, CAD analysis was performed on both ions **7** and **8**. Ion **7** produced p-toluenesulfonate ion exclusively, and ion **8** produced methanesulfonate ion exclusively.

From these data it can be seen that formation of a p-toluenesulfonate ester radical anion in the gas phase leads to exclusive homolytic cleavage of the S–C bond as depicted in Scheme II.[14] In marked contrast to this is the solution-phase chemistry, where initial photochemical generation of the radical anion via an electron-transfer process in alcoholic solutions leads to cleavage of the p-toluenesulfonate esters at the S–O bond as outlined in Scheme I. To our knowledge this is the first example of a complete alteration in the course of a unimolecular fragmentation due solely to a solvent effect. The most reasonable explanation for this phenomenon is the difference in basicity of the alkoxide ion in the gas phase and in hydroxylic solvents. The extreme base strength (and resulting high energy of the corresponding ion) observed for an alkoxide ion in the gas phase[15] makes cleavage to form this ion directly a difficult process. In solution where this ion is well stabilized by its solvent cage, cleavage in this manner requires much less energy and therefore is more feasible.

Acknowledgment. We thank the Standard Oil Co. for support of this research and the Lewis Research Center (NASA) for donation of the Finnigan TSQ-45 mass spectrometer used in this work.

(13) Masakazu, M.; Kawamatsu, Y.; Kawashima, K.; Shinohara, M.; Tanaka, K.; Tatsuoka, S.; Nakanishi, K. *Tetrahedron* **1967**, *23*, 421.

(14) Bowie has examined the negative-ion mass spectrum of ethyl benzenesulfonate and observed ions resulting from cleavage between both the C–S and the S–O bond; however, this work was performed under high energy electron impact conditions, which are expected to produce much more extensive fragmentations. Nolde, C.; Madsen, J. O.; Lawesson, S.-O.; Bowie, J. H. *Ark. Kemi* **1969**, *31*, 481.

(15) Bartmess, J. E.; McIver, R. T. In *Gas Phase Ion Chemistry*; Bowers, M. T., Ed.; Academic Press: New York, 1979; Vol. 2, pp 87–121.

A Selective Method for the Direct Conversion of Aldehydes into β-Keto Esters with Ethyl Diazoacetate Catalyzed by Tin(II) Chloride

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Summary: Aldehydes are efficiently converted into β-keto esters by the addition of ethyl diazoacetate in the presence of tin(II) chloride.

Sir: β-Keto esters have been prepared by a variety of methods.[1] We have found that aldehydes can be converted into β-keto esters directly by the addition of ethyl diazoacetate in the presence of a catalytic amount of tin(II) chloride. Several early papers report this transformation under thermal conditions;[2] however, these conditions do not appear to be general as exemplified by the reaction of *n*-heptanal which leads to a dioxolane.[3] To the best of our knowledge there is no convenient method for the *direct conversion* of aldehydes into β-keto esters.[4] The analogous reaction for ketones has been described and extensively studied.[5]

Initially our aim was to generate an alkylidene-type reagent by reacting ethyl diazoacetate with a low-valent

(1) Schaefer, J.; Bloomfield, J. *Org. React.* **1967**, *15*, 1. Rathke, M. *Org. React.* **1975**, *22*, 423. Balasubrahmanyam, S. N.; Balasubramanian, M. *Organic Syntheses*; Wiley: New York, 1973; Vol. V, p 439. Claisen, L.; Lowman, O. *Ber.* **1887**, *20*, 651. Kocienski, P.; Stocks, M.; Donald, D.; Cooper, M.; Manners, A. *Tetrahedron Lett.* **1988**, *29*(35), 4481. Pellicciari, R.; Fringuelli, R.; Ceccherelli, P.; Sisani, E. *J. Chem. Soc., Chem. Commun.* **1979**, 959. Pellicciari, R.; Natalini, B.; Fringuelli, R.; Ceccherelli, P. *J. Chem. Soc., Perkin Trans. I* **1985**, 493. Wenkert, E.; McPherson, A. *J. Am. Chem. Soc.* **1972**, *94*, 8084. Ikota, N.; Takamura, N.; Young, S.; Ganem, B. *Tetrahedron Lett.* **1981**, *22*(42), 4163.

(2) Dieckmann, W. *Ber.* **1910**, *43*, 1024. Schlotterbeck, F. *Ber.* **1909**, *42*, 2565; **1907**, *40*, 479, 3000. Buchner, E.; Curtius, T. *Ber.* **1885**, *18*, 2371.

(3) For a review of the reaction of diazo derivatives with aldehydes and ketones, see: Gutsche, C. *Org. React.* **1954**, *8*, 364, (see p 375) and references therein.

(4) Wasfi, A. *J. Indian Chem. Soc.* **1970**, *47*, 341. Aparicio, F.; Herrera, F.; Fernandez, M. *Anal. Quimica* **1978**, *74*, 1561.

(5) Marchand, A.; Annapurna, P.; Reddy, S.; Watson, W.; Nagl. A. *J. Org. Chem.* **1989**, *54*, 187. Alonso, M.; Jano, P. *J. Heterocyl. Chem.* **1980**, 721. Greene, A.; Depres, J. *J. Am. Chem. Soc.* **1979**, *101*, 4003. Mock, W.; Hartman, M. *J. Org. Chem.* **1977**, *42*, 459, 466. Liu, H. *J. Org. Chem.* **1975**, *40*, 2252. Liu, H.; Majumdar, S. *Synth. Commum.* **1975**, *5*, 125. Mock, W.; Hartman, M. *J. Am. Chem. Soc.* **1970**, *92*, 5767. Tai, W.; Warnhoff, E. *Can. J. Chem.* **1964**, *42*, 1333. Muller, E.; Bauer, M. *Chem. Ber.* **1962**, *654*, 92. Johnson W.; Neeman, M.; Birkeland, S. *Tetrahedron Lett.* **1960**, *5*, 1. House, H.; Grubbs, E.; Gannon, W. *J. Am. Chem. Soc.* **1960**, *82*, 4099. Gutsche, C.; Hillman, M. *J. Am. Chem. Soc.* **1954**, *76*, 2236.

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