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[4+2]-Type polar cycloadditions of 2-benzothiopyrylium salt with alkenes

Hiroshi Shimizu,[a,*] Naoko Araki,[a] Osamu Muraoka [b] and Genzoh Tanabe [b]

[a] *Institute of Manufacturing Pharmacy, Gifu Pharmaceutical University, 6-1, Mitahora-higashi 5-chome, Gifu 502-8585, Japan*

[b] *Kinki University, Faculty of Pharmaceutical Sciences, 3-4-1, Kowakae, Higashi-osaka, Osaka 577-0818, Japan*

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Abstract

Treatment of 2-benzothiopyrylium salt with alkenes such as styrene, *p*-methylstyrene, *p*-methoxystyrene, α-methylstyrene, and *trans*-anethole afforded the corresponding [4+2]-type polar cycloaddition products, respectively. The structures of the cycloadducts were confirmed by X-ray crystal structure determination of the corresponding sulfone derivative.

Keywords: polar cycloaddition; 2-benzothiopyrylium salt; X-ray analysis.

We have developed thiopyrylium salt derivatives which acted as electron-deficient dienophiles towards several conjugated dienes to undergo [2+4]-type polar cycloaddition, affording benzo-fused bicyclic sulfonium adducts which were transformed to many novel sulfur-containing heterocyclic compounds.[1]

In the course of our continuing studies on the polar cycloaddition of 2-benzothiopyrylium salt **1** with a variety of conjugated dienes, we observed the possibility of the salt acting as an electron-deficient diene.[2] In this communication, we describe the first example of [4+2]-type polar cycloaddition of 2-benzothiopyrylium salt **1** with some electron-rich alkenes, such as various types of styrenes and vinyl ethers, giving benzo-fused bicyclo[2.2.2]thiaheterocycles.[3]

Treatment of 2-benzothiopyrylium tetrafluoroborate (**1**) with styrene (**2a**) in dry methanol at room temperature for 1 h afforded benzo-fused bicyclic compound **3a** as a pale yellow oil in 49% yield (Scheme 1). Treatment of the salt **1** with *p*-methylstyrene (**2b**) and *p*-methoxystyrene (**2c**) also afforded similar types of [4+2]-type polar cycloaddition products **3b** and **3c** in 32 and 47% yields, respectively. The structures of these thiaheterocycles **3** were assigned on the basis of spectral data.[4] The ^{1}H NMR spectra of compound **3** show higher chemical shifts of two *ortho*-hydrogens of the aryl groups (6.78 ppm for **3a**, 6.61 ppm for **3b**, 6.62 ppm for **3c**), suggesting that the aryl group of each compound is directed towards the benzene ring side and this is shielded owing to the ring current effect. These stereostructures were

* Corresponding author. Tel: +81 58 237 3931; fax: +81 58 237 5979; e-mail: shimizu@gifu-pu.ac.jp (H. Shimizu)

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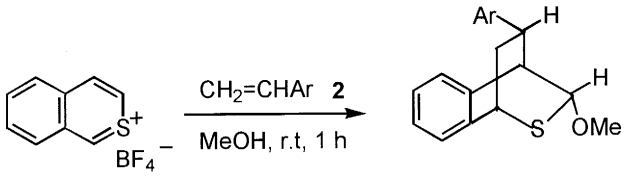
confirmed by X-ray crystal structure determination of the corresponding sulfone derivative of **3a** which was prepared by *m*-chloroperbenzoic acid oxidation (Fig. 1). Crystallographic data are summarized in Table 1. Selected bond distances and angles are provided with an ORTEP drawing in Fig. 1.



Scheme 1.

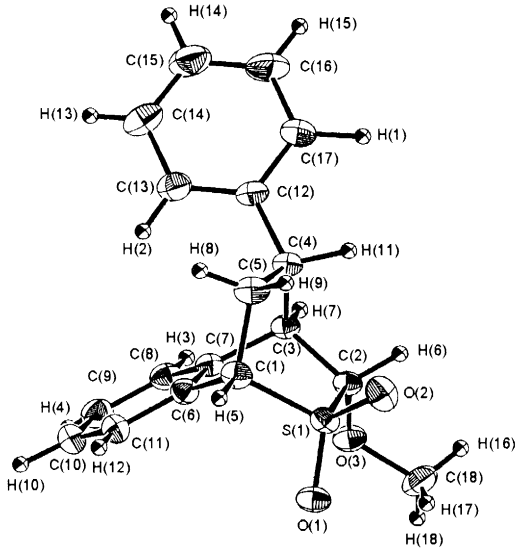
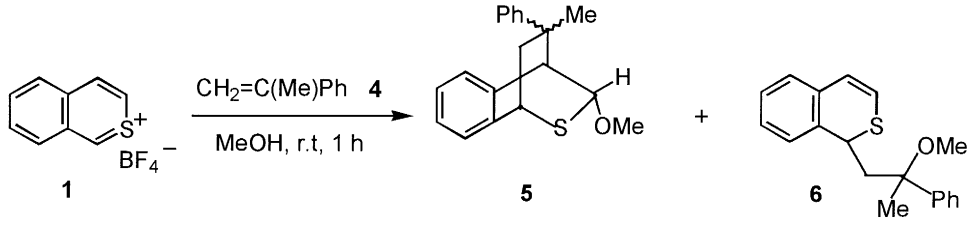


Fig. 1. Molecular structure of the sulfone derivative of compound **3a**. Selected bond distances (Å) and angles (°) are: S(1)–C(1)= 1.797(2), S(1)–C(2)=1.861(2), C(2)–C(3)=1.536(3), C(1)–C(5)=1.544(3), C(3)–C(4)=1.557(3), C(4)–C(5)=1.552(3), C(4)–C(12)=1.518(3), C(1)–S(1)–C(2)=100.3(1), S(1)–C(2)–C(3)=107.3(1), S(1)–C(1)–C(6)=107.3(2), S(1)–C(1)–C(5)=107.8(2), C(2)–C(3)–C(7)=109.2(2), C(1)–C(5)–C(4)=110.8(2), C(3)–C(4)–C(5)=110.6(2), C(3)–C(4)–C(12)=111.7(2), C(12)–C(4)–H(11)=106.96, C(3)–C(2)–O(3)=110.0(2)

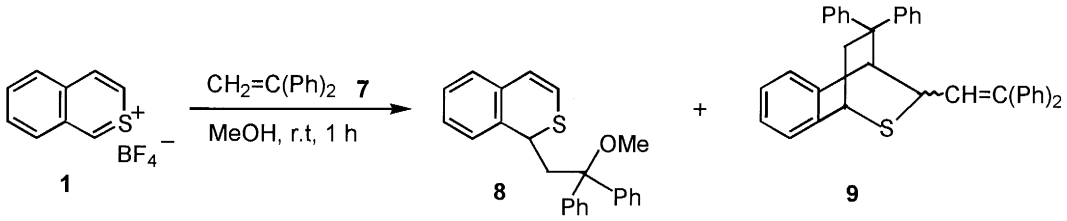
We next performed the cycloaddition reaction of the salt **1** with α-methylstyrene (**4**), affording the corresponding cycloadduct **5** in 46% yield and an addition product **6** as a by-product in 37% yield (Scheme 2). The cycloadduct **5** was obtained as a 1:1 mixture of two stereoisomers as regards the direction of the phenyl and methyl groups, and the product **6** was a mixture of diastereoisomers in a ratio of 1:3. On the contrary, the reaction with α-phenylstyrene (**7**) resulted in the formation of an addition compound **8** (64%) as a major product and an unexpected cycloadduct **9** (9%) as a minor one (Scheme 3). The latter compound does not contain any methoxyl group derived from methanol as a solvent. Therefore, we attempted the above reaction in dichloromethane to obtain **9** as the sole product, but in low yield (18%). We propose the following mechanism for the formation of the unexpected cycloadduct **9** (Scheme 4). The thienium ion intermediate **A** formed through cycloaddition of α-phenylstyrene to the salt **1** is attacked by another styrene molecule to give the subsequent intermediate **B**, which is deprotonated to lead to the final product **9** bearing a double bond.

Table 1
Crystallographic data for the sulfone derivative of compound **3a**

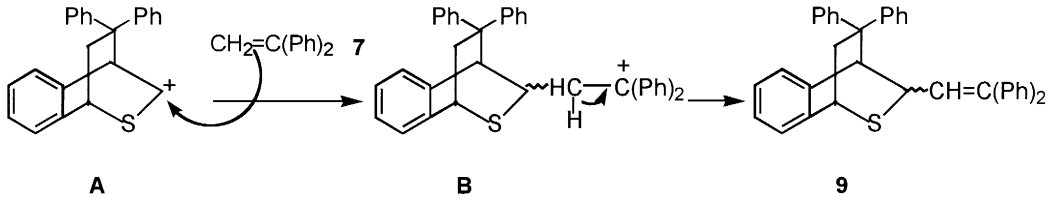
(a) Crystal parameters
Formula: $C_{18}H_{18}O_3S$ M=314.40 size(mm): 0.20 x 0.20 x 0.20 color: colorless
Crystal system: triclinic space group: P1(#2) T: 23 °C
a= 9.401(1)Å α= 103.03(1)° V= 804.4(2)Å^3
b= 10.888(2)Å β= 93.17(1)° Z= 2
c= 8.569(1)Å γ= 70.32(1)° Dc= 1.298 g/cm^3 F_{000}= 332 μ(MoKα)= 2.01 cm^{-1}
(b) Data collection
diffractometer: Rigaku AFC5R radiation: MoKα(λ= 0.71069 Å)
scan range: 36.51 < 2θ < 39.30°
number of reflections measured: Total:3909 Unique: 3683(R_{int}= 0.026)
(c) Refinement
R: 0.041 Rw= 0.049 GOF: 1.63



Scheme 2.



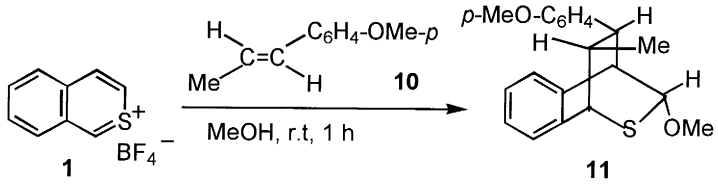
Scheme 3.



Scheme 4.

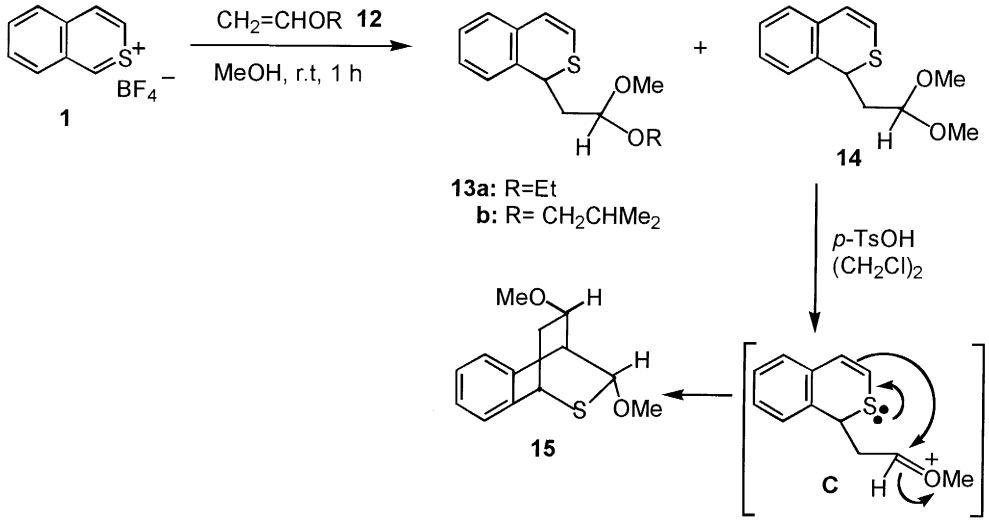
In order to investigate the regiochemical reactivity for the [4$^+$+2]-type cycloaddition of unsymmetrically substituted alkenes, we tried the reaction of **1** with *trans*-anethole (**10**). When treated with *trans*-anethole (**10**) in methanol at room temperature for 1 h, the salt **1** underwent regiospecific cycloaddition to afford the cycloadduct **11** as the sole isolable product in 46% yield (Scheme 5). The structure was elucidated based on ^{1}H and ^{13}C NMR spectral data including H–H and C–H COSY techniques.

We also examined the reaction of **1** with several vinyl ethers as alkenes. Treatment of the salt **1** with ethyl vinyl ether (**12a**) in methanol afforded only acetal compounds **13a** and **14**, but no corresponding



Scheme 5.

cycloaddition product (Scheme 6). Similarly, reaction with isopropyl vinyl ether (**12b**) gave only acetal compound **14**. In order to control the production of acetal compounds, we attempted the above reaction in dichloroethane instead of methanol as a solvent. However, this resulted in the formation of a complex mixture, but no formation of cycloaddition products. Upon treatment with *p*-toluenesulfonic acid, the acetal compound **14** obtained above underwent cleavage of the ether bond to generate the carbenium ion intermediate **C**, which was then cyclized to the 4-position of the 2-benzothiopyran skeleton to furnish the cycloadduct **15** in 45% yield.



Scheme 6.

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4. Satisfactory analytical data were obtained for all new compounds. Relevant spectral data for **3a** are as follows: ^{1}H NMR ($CDCl_3$, 400 Mz) δ: 1.76 (1H, ddd, J=2.4, 6.8, 13.2 Hz, C*H*H), 2.67 (1H, ddd, J=3.4, 9.8, 13.2 Hz, CH*H*), 3.18 (3H, s, OMe), 3.18 (1H, dd, J=6.8, 9.8 Hz, C*H*Ph), 3.59 (1H, d, J=3.4 Hz, 4-H), 4.18 (1H, dd, J=2.4, 3.4 Hz, 1-H), 5.33 (1H, d, J=3.4 Hz, 3-H), 6.73 (2H, dd, J=2.0, 7.3 Hz, *ortho*-2H of phenyl ring), 7.12 (4H, m, ArH), 7.30 (3H, m, ArH); ^{13}C NMR ($CDCl_3$) δ: 39.6, 39.9, 40.2, 47.8, 55.9, 90.0, 121.9, 126.3, 127.2, 127.4, 127.5, 128.3, 129.2, 134.2, 142.3, 145.2.