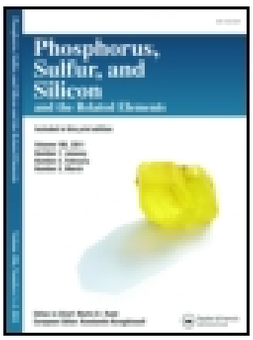


Taylor & Francis
Taylor & Francis Group

Phosphorus, Sulfur, and Silicon and the Related Elements

ISSN: 1042-6507 (Print) 1563-5325 (Online) Journal homepage: http://www.tandfonline.com/loi/gpss20

The Intramolecular S = O...H-O Hydrogen Bond In A Chiral Cyclic Sulfite Ester: How It Affects The Reaction Behavior And Spectral Properties

Xiaoyun Hu, Dongzhi Chen, Jirong Lan & Zixing Shan

To cite this article: Xiaoyun Hu, Dongzhi Chen, Jirong Lan & Zixing Shan (2016): The Intramolecular S = O...H-O Hydrogen Bond In A Chiral Cyclic Sulfite Ester: How It Affects The Reaction Behavior And Spectral Properties, Phosphorus, Sulfur, and Silicon and the Related Elements, DOI: 10.1080/10426507.2016.1192624

To link to this article: http://dx.doi.org/10.1080/10426507.2016.1192624

Accepted author version posted online: 25 May 2016.
Published online: 25 May 2016.

THE INTRAMOLECULAR S = O···H-O HYDROGEN BOND IN A CHIRAL CYCLIC SULFITE ESTER: HOW IT AFFECTS THE REACTION BEHAVIOR AND SPECTRAL PROPERTIES

Xiaoyun Hu[a,*], Dongzhi Chen[b], Jirong Lan[a] and Zixing Shan[c,*]

[a]College of Chemistry and Materials, South-Central University for Nationalities, Wuhan, China

[b]School of Materials Science and Engineering, Wuhan Textile University, Wuhan, China

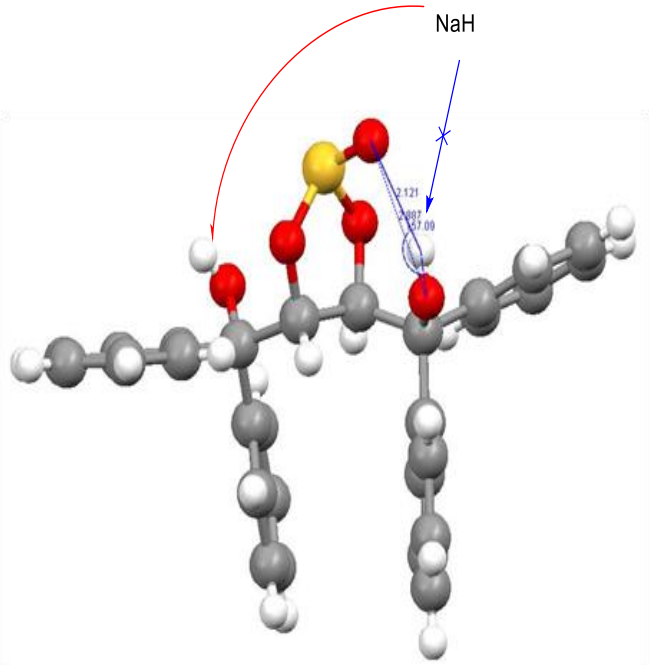
[c]College of Chemistry and Molecular Sciences, Wuhan University, Wuhan, China

zxshan@whu.edu.cn

[*]Corresponding author e mail:*xyhu@mail.scuec.edu.cn*

Abstract

The intramolecular S = O···H–O hydrogen bond in a chiral cyclic sulfite ester, which affects the reaction behavior and spectral properties considerably, was studied.



Keywords

intramolecular S = O···H–O H-bond, cyclic sulfite ester, cycloetherification

INTRODUCTION

The hydrogen bond is not a strong bond. In most cases, its bond energy lies in the 2 to 10 kcal/mol range. But it plays a very important role in biology, material science and chemistry.[1] It is generally regarded that hydrogen bonds have a significant influence in determining the structure and function for organic compounds. The hydrogen bond is usually presented in the form of X-H···Y, where X and Y are electronegative elements such as N, O and S. A relatively less electronegative carbon can also behave as an H-bond donor to form C-H···Y-type hydrogen bonds, which are regarded as weak hydrogen bonds.[2] Besides the electronegative atoms, C = O, N = O and S = O groups and π systems can also serve as H-bond acceptors.[3]

The S = O group is bonded via one σ bond and one (d-p)π coordinate bond.[4] As early as 1949, Barna et al.[5] described a hydrogen bond involving an S = O group in organic sulfur compounds. Several studies of the hydrogen bond between a donor molecule and the S = O group in sulfinyl and sulfonyl compounds also have also been performed.[6] However, compared with the systematical studies of compounds containing a C = O or P = O bond to participate as proton acceptors in hydrogen bonding, less attention has been paid to compounds which possess an S = O moiety as the proton acceptor.[7] Herein we report on the intramolecular S = O···H-O hydrogen bond in a chiral cyclic sulfite ester, which affects the reaction behavior and spectral properties considerably.

RESULTS AND DISCUSSION

During our ongoing research of the chemistry of chiral 1,1,4,4-tetrasubstituted butanetetraol,[8] we found that the cyclic sulfite ester (4*R*,5*R*)-4,5-bis(diphenyl-hydroxymethyl)-1,3,2-dioxathiolane 2-oxide **1** can be conveniently synthesized by a highly regio-selective 2,3-cyclosulfitation reaction of (2*R*,3*R*)-1,1,4,4-tetraphenylbutanetetraol **2** with thionyl chloride (Scheme 1). Therefore, we initially decided to synthesize a valuable C_2 chiral diol, (2*R*,3*R*)-1,4-dimethoxy-1,1,4,4-tetraphenyl-2,3-diol **3**, in the asymmetric synthesis of organoboronates[9] via cyclic sulfite ester (4*R*,5*R*)-**1**. As shown in Scheme 1, (4*R*,5*R*)-**1** was subjected to methylation with NaH/MeI[10] and then hydrolyzed with aqueous alkali to produce the desired product (2*R*,3*R*)-**3**. Surprisingly, under the traditional methylation conditions, the expected methylated product, (4*R*,5*R*)-4,5-bis(methoxydiphenylmethyl)-1,3,2-dioxathiolane 2-oxide **4** (Scheme 1), was not formed. Instead, a chiral tetrahydrofuranol (3*R*,4*R*)-4-methoxy-2,2,5,5-tetraphenyl-tetrahydrofuran-3-ol **5** was obtained. Obviously, the reaction did not occur toward the designed methylation route but an unexpected cycloetherification reaction took place. This unusual reaction behavior of (4*R*,5*R*)-**1** attracted our great interest, and an in-depth study of its structure- property relationship was carried out in this study.

As shown in Scheme 1, highly selective 2,3-cyclosulfitation of (2*R*,3*R*)-**2** with thionyl chloride took place in the presence of organic bases to yield (4*R*,5*R*)-**1** almost quantitatively. Then **1** was allowed to react with excess NaH in dry THF followed by MeI, and finally treated with water to afford (3*R*,4*R*)-**5** in excellent yield. To confirm the structure of this unexpected

product, a single crystal of (3*R*,4*R*)-**5** was grown, and its X-ray structure was determined. As seen in Fig. 1, the crystallographic data[11] reveal that there is one molecule in the unit cell, which belongs to the triclinic system, with space group P1.

How did this reaction take place? The formation of tetrahydrofuran derivatives from 1,4-diols by heating[12] or in strong acidic media[8f] has been observed. While cycloetherification rather than the traditional methylation reaction of chiral diols in the presence of NaH/MeI, has never been reported, as far as we know.

Considering the close relationship between the properties of an organic compound and its structure, (4*R*,5*R*)-**1** was used to find out more information about its structure and the relationship to its reaction behavior. It was dissolved in hot THF and then cooled slowly to room temperature. A colorless single crystal suitable for X-ray crystallographic analysis was obtained. The crystal structure of (4*R*,5*R*)-**1** bearing a molecule of THF is shown in Fig. 2. The crystallographic data reveal that there are two molecules of (4*R*,5*R*)-**1** in a unit cell which belongs to the monoclinic system, with space group P2(1).

The X-ray crystallographic analysis of **1** shows that both intramolecular S(1) = O(4)···H(3)–O(3) and intermolecular O(5)–H(5A)···O(6) hydrogen bonds exist in the crystal. As shown in Fig. 3, the O(4)–O(3) distance is 2.888 Å, and the O(4)–H(3)–O(3) bond angle is 160.22°. The O(5)–O(6) distance is 2.723 Å, and the O(5)–H(5a)–O(6) bond angle is 168.02°. It can be seen that under the interaction of the intramolecular S(1) = O(4)···H(3)–O(3) hydrogen bond, the five-membered cyclic sulfite ester skeleton, especially the S = O group, leans toward

the O(3)–H(3) hydroxy group. The hydroxy proton H(3) is besieged by four electronegative oxygen atoms O(1), O(2), O(3), O(4) and a bulky S(1) atom, which may intensively shield the hydroxy proton H(3) and should make it highly resistant to attack by NaH.

Based on the above analysis of the structure of **1**, a possible mechanism was proposed. As shown in Fig. 4, only the tertiary hydroxyl group engaged in an intermolecular hydrogen bond of **1** was attacked by hydride to generate an O^- center at room temperature, which then attacked the adjacent tertiary carbon to give a THF ring accompanied by liberation of a hydroxide ion. Subsequently, the sulfur atom was attacked by the freshly generated hydroxide anion, and one S-O bond was broken to form a poly-substituted THF sulfite ester with an oxygen anion. Therefore, only one secondary hydroxyl was etherified even if excess MeI was added. Finally the poly-substituted THF sulfite ester was hydrolyzed by the alkali resulting from excess NaH in water to give **5**. This proposed mechanism can satisfactorily explain the experimental results, and it is confirmed by the structural features of **1**.

In fact, the intramolecular S = O···H–O hydrogen bond also affects the spectral properties of **1** besides its reaction behavior. The ^{1}H NMR spectra data of **1** reveal that the tertiary hydroxyl proton H(3) is intensively shielded by the cyclic sulfite ester skeleton. Compared with the ^{1}H NMR spectra of **2**, there are two protons at 4.49 ppm and 2.37 ppm in the ^{1}H NMR spectra of **1**, which disappear after the addition of D_2O. They are thus assigned to the two tertiary hydroxyl groups of **1**. Among them, the hydroxy proton signal at 4.49 ppm, which is shifted slightly upfield (ca. 0.12 ppm), corresponds to the tertiary hydroxy proton H(5A) while the signal at 2.37 ppm, which shows a remarkable upfield shift (ca. 2.24 ppm), corresponds to the hydroxy proton

H(3). Obviously, the significant upfield shift of H(3) can be attributed to the intense shielding effect of the five-membered cyclic sulfite ester skeleton, which leans toward the H(3) proton by the interaction of an intramolecular S = O···H–O hydrogen bond.

CONCLUSION

In summary, an intramolecular S = O···H–O hydrogen bond is observed in the chiral cyclic sulfite ester **1**. Under the influence of this intramolecular hydrogen bond, the five-membered cyclic sulfite ester skeleton intensively shields the hydroxylic proton, and makes it highly resistant to attack by NaH. Thereby the reaction direction of cyclic sulfite ester **1** with NaH/MeI changes and an unusual cycloetherification reaction takes place under the traditional methylation conditions. Furthermore, the intramolecular S = O···H–O hydrogen bond also affects the spectral properties of **1**. These results reveal that the hydrogen bond is not a strong bond, but in certain cases it can affect the reaction behavior and spectral properties considerably.

EXPERIMENTAL

General

Diethyl (2*R*,3*R*)-tartrate was prepared from (2*R*,3*R*)-tartaric acid and ethanol. Pyridine was distilled after being dried over CaH_2. $SOCl_2$ was distilled prior to use. THF was dried with Na. Commercially available starting materials were used without further purification if not specified.

NMR spectra were recorded at 300 MHz for ^{1}H, and 75 MHz for ^{13}C on a Varian Mercury VS 300; □ (ppm) is given relative to TMS in $CDCl_3$ as solvent. Optical rotations were measured on a Perkin--Elmer 341 Mc polarimeter. Mp: VEB Wägetechnik Rapido PHMK 05; uncorrected.

The single crystal X-ray diffraction analysis was performed on a Bruker SMART 1 K CCD diffractometer using graphite-monochromated MoKα radiation (λ = 0.71073 Å). The structure was solved by direct methods (SHELXS-97) and refined on F_2 values by full matrix least squares for all unique data.

(2*R*,3*R*)-1,1,4,4-Tetraphenylbutanetetraol (2). Under dry Ar, a freshly dried three-necked round bottomed 500 mL flask equipped with a magnetic bar, 100 mL pressure-equalizing dropping funnel and reflux condenser with oil seal was charged with Mg turnings (5.28 g, 0.22 mol) and dry THF (100 mL). The pressure-equalizing dropping funnel was charged with a solution of bromobenzene (21 mL, 0.2 mol) in dry THF (76 mL). After the initiation of the Grignard reaction, the solution was added dropwise. The resulting mixture was refluxed for 1 h and cooled to room temp., followed by carefully dropwise adding a solution of (2*R*,3*R*)-diethyl tartrate (5.2 g, 25 mmol) in 50 mL dry THF. After addition, the mixture was allowed to reflux for 1.5 h. Saturated aqueous NH_4Cl was added with stirring, the organic layer was separated, and the aqueous layer was extracted with Et_2O (3 × 30 mL), the combined extracts were dried over Na_2SO_4, followed by removal of most of the solvent. Then steam distillation was carried out, and the residue was recrystallized from 80% EtOH to yield 6.2 g of (2*R*,3*R*)-**2**, yield, 58%, m.p. 149-150°C.[8(e)] $[\alpha]_D^{20}$ = +154.2 (c 0.5, $CHCl_3$). ^{1}H NMR: 7.37-7.13 (m, 20H), 4.61 (s, 2H,

disappeared after adding D_2O), 4.45 (d, *J* = 5.1 Hz, 2H), 3.74 (d, *J* = 4.5Hz, 2H, disappeared after adding D_2O).

(4*R*,5*R*)-4,5-Bis(diphenyl-hydroxymethyl)-1,3,2-dioxathiolane 2-oxide (1). A 25 mL dried round-bottom flask was charged with **2** (2.13 g, 5 mmol), pyridine (0.95 mL, 12 mmol) and dried THF (35 mL). The flask was sealed with a rubber septum and stirred in an ice-bath for 5 min. Then $SOCl_2$ (0.4 mL, 5.5 mmol) was added slowly with a syringe. After complete addition, the mixture was continued to stir for an additional 2h in ice-bath. The resultant was treated with water and the organic phase was separated, the aqueous phase was extracted with Et_2O. The combined extracts were dried over anhydrous Na_2SO_4, concentrated and cooled. A massy, colorless, transparent crystal was isolated, filtered, and dried in vacuum to give a solvate of (4*R*,5*R*)-**1**with THF (2.48 g, two batches of crystal quality), 92% yield, m.p. 165-167°C. $[\alpha]_D^{20}$ = +65.8 (c 0.19, $CHCl_3$). ^{1}H NMR: 7.50 (d, *J* = 8.1 Hz, 2H), 7.42 (d, *J* = 7.5 Hz, 2H), 7.34-7.19 (m, 8H), 7.03 (s, 8H), 5.97 (d, *J* = 2.1 Hz, 1H), 5.90 (d, *J* = 2.1 Hz, 1H), 4.49 (s, 1H, disappeared after adding D_2O), 3.70 (t, *J* = 6.0 Hz, 4H), 2.37 (s, 1H, disappeared after adding D_2O), 1.83 (t, *J* = 6.0 Hz, 4H). ^{13}C NMR: 145.1, 143.3, 141.5, 141.0, 128.7, 128.5, 128.4, 128.0, 127.4, 127.1, 126.9, 125.9, 89.7, 89.6, 87.2, 87.1, 78.8, 77.7, 68.1, 25.8. LC-MS (EI): 471 (40, [M^+-1]), 408 (100, [M^+-64 (SO_2)]). Calcd. for $C_{28}H_{24}O_5S$-C_4H_8O: C, 70.70; H, 4.45. Found: C, 70.52; H, 4.41.

Crystallographic date for 1

Empirical formula, $C_{32}H_{31}O_6S$; Formula weight, 544.64; Calculated density, 1.287 g/cm^3; Volume (V), 1405.2(2) Å^3; Crystal system, Monoclinic; Z = 2; space group, P2(1); Unit cell

dimensions (pm), a = 9.5599(19), b = 10.507(2), c = 13.995(3); μ, 0.159 mm^{-1}; −7≤h≤11, −12≤k≤12, −17≤l≤16; F(000), 576; *R*(reflections) = 0.0361(5358); *wR2* (reflections) = 0.0920 (8171); GOF, 1.028; T = 293(2) K; radiation type, MoKα. CCDC: 729972.

(*3R*,*4R*)-4-Methoxy-2,2,5,5-tetraphenyl-tetrahydrofuran-3-ol (5). A 25 mL dried round-bottom flask was charged with **1** (0.472 g, 1 mmol) and dried THF (10 mL). The flask was placed in an ice bath, 0.102 g NaH (70%, 3 mmol) was added and the solution was stirred for 0.5 h at room temperature, followed by adding 0.32 g MeI (2 mmol) and stirring at room temp. for 4 h. To the stirred reaction mixture was added distilled water (10 mL) to form a two phase solution and the organic phase was separated. The aqueous phase was extracted with Et_2O. The organic phase was combined and dried over anhydrous Na_2SO_4. The solution was concentrated to dryness and the solid residue was recrystallized in EtOH to afford a colorless crystal of **5** (0.342 g), 81% yield, m.p. 200-203°C. $[\alpha]_D^{20}$ = −91 (c 0.3, THF). ^{1}H NMR: 7.72-7.71 (m, 2H), 7.52-7.47 (m, 4H), 7.42-7.35 (m, 4H), 7.24-7.22 (m, 5H), 7.21-7.04 (m, 5H), 5.18 (d, *J* = 1.5 Hz, 1H), 4.53 (d, *J* = 1.8 Hz, 1H), 3.44 (s, 3H), 2.00 (d, *J* = 3.6 Hz, 1H, disappeared after adding D_2O). ^{13}C NMR: 145.8, 145.2, 142.9, 142.7, 127.8, 127.3, 127.2, 126.8, 126.5, 125.8, 125.4, 89.8, 87.4, 86.1, 75.9, 58.8, 58.7. Calcd. for $C_{29}H_{26}O_3$: C, 82.44; H, 6.20. Found: C, 82.20; H, 6.18.

Crystallographic data for 5

Empirical formula, $C_{29}H_{26}O_3$; Formula weight, 422.50; Calculated density, 1.277 g/cm^3; Volume (V), 549.51(9) $Å^3$; Crystal system, triclinic; Z = 1; space group, P1; Unit cell dimensions (pm), a = 8.6349(8), b = 8.6718(8), c = 8.9926(9); μ, 0.081 mm^{-1}; −10≤h≤10, −10≤k≤10,

−11≤l≤11; F(000), 224; *R*(reflections) = 0.0320(3402); *wR2* (reflections) = 0.0865 (4199); GOF, 1.084;T = 100(2) K; radiation type, MoKα. CCDC: 942645.

Acknowledgements

The Project was supported by the National Nature Science Foundation of China (No. 21302233 and No.51503161) and the Nature Science Foundation of Hubei Province of China (No. 2012FFB07410).

Supplementary data

^{1}H and ^{13}C NMR spectral data along with cif files associated with this article can be found in the online version.

REFERENCES AND NOTES

1. For recent important reviews and studies see: (a) Li, X. Z.; Walker, B.; Michaelides, A. *Proc. Natl. Acad. Sci. USA* **2011**, 108, 6369-6373. (b) Reedijk, J. *Chem. Soc. Rev.* **2013**, 42, 1776-1783. (c) Nishio, M. *Phys. Chem. Chem. Phys.* **2011**, 13, 13873-13900. (d) Ogretir, C. in *Advances in Quantum Chemical Bonding Structures*; Putz, M. V., Ed.; 2008; pp 271-285. (e) Custelcean, R. *Chem. Commun*. **2008**, 295-307. (f) Noujeim, N.; Leclercq, L.; Schmitzer, A. R. *Curr. Org. Chem.* **2010**, 14, 1500-1516.

2. (a) Taylor, R.; Kennard,O. *J. Am. Chem. Soc.* **1982**, 104, 5063-5070. (b) Wang, X. P.; Woo, H. K.; Kiran, B.; Wang, L. S. *Angew. Chem. Int. Ed.* **2005**, 44, 4968-4972. (c) Hu, X. Y.; Shan, Z. X.; Soloshonok, V. A. *Cryst. Growth Des.* **2012**, *12*, 33--36.

3. Steiner, T. *Angew. Chem. Int. Ed.* **2002.** 41, 48-76.

4. Gillespie, R. J; Robinson, E. A. *Can. J. Chem.* **1963**, 41, 2074-2085.

5. Barna, D.; Fabia, J. M.; Koch, H. P. *J. Chem. Soc*. **1949**, 2442-2454.

6. (a) Zhou, B.; Zheng, P. W. *Acta Crystallogr., Section E: Structure Reports Online* **2007**, 63, 04727-04727. (b) Steiner, T. *J. Chem. Soc., Chem. Commun.* **1994**, 2341-2342. (c) Ruostesuo, P.; Karjalainen, J. *Spectrochim. Acta, Part A: Mol. Biomol. Spectrosc.* **1981**, 37, 535-539.

7. Engberts, J. B. F. N.; Zuidema, G. *Rec. Trav. Chim. Pays-Bas.* **1970**, 89, 1202-1210.

8. For our studies on chiral 1,1,4,4-tetrasubstituted butanetetraol, see: (a) Xie, J. S.; Hu, X. Y.; Shan, Z. X.; Zhou, Z. Q. *Aust. J. Chem.* **2015**, 68, 995-998. (b) Hu, X. Y.; Shan, Z. X.; Song, Shaojun. *Tetrahedron: Asymmetry*, **2014**, 25, 503-506. (c) Hu, X. Y.; Shan, Z. X.; Soloshonok, V. A. *Cryst. Growth Des.* **2012**, 12, 33. (d) Hu, X. Y.; Shan, Z. X.; Chang, Q. *Lett. Org. Chem.* **2012**,

9, 493. (e) Shan, Z. X.; Hu, X. Y.; Zhou, Y.; Peng, X. T.; Li, Z. *Helv. Chim. Acta* **2010**, 93, 497. (f) Hu, X. Y.; Shan, Z. X.; Peng, X. T.; Li, Z. *Tetrahedron: Asymmetry* **2009**, 20, 2474. (g) Shan, Z. X.; Hu, X. Y.; Zhou, Y.; Peng, X. T.; Yi, J. *Tetrahedron: Asymmetry* **2009**, 20, 1445.

9. Berg, C. A.; Eichenauer, N. C.; Pietruszka, J. *Pure Appl. Chem.* **2012**, 84, 2339-2416.

10. (a) Nakayama, K.; Rainier, J. D. *Tetrahedron* **1990**, 46, 4165. (b) Bischop, M.; Cmrecki, V.; Ophoven, V.; Pietruszka, J. *Synthesis* **2008**, 2488.

11. Final atomic coordinates of the crystal for **1** and **5**, along with lists of anisotropic thermal parameters, hydrogen coordinates, bond lengths, and bond angles, have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. 729972 and 942645. Data can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K. (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.cn; web: http//www.ccdc.cam.ac.uk).

12. Gillis, B. T.; Beck, P. E. *J. Org. Chem*. **1963**, 28, 1388-190.

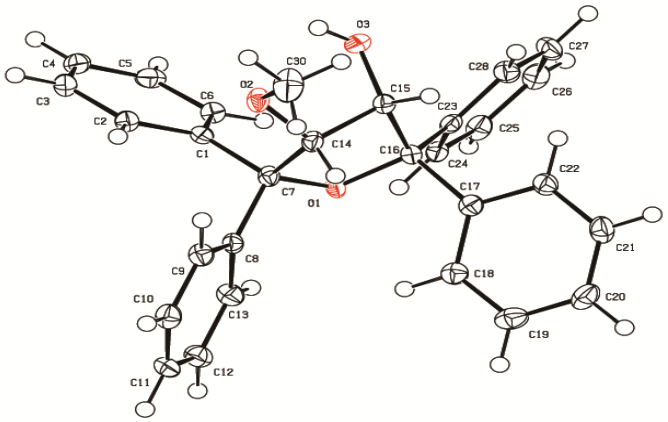


Figure 1. Crystal structure of **5**

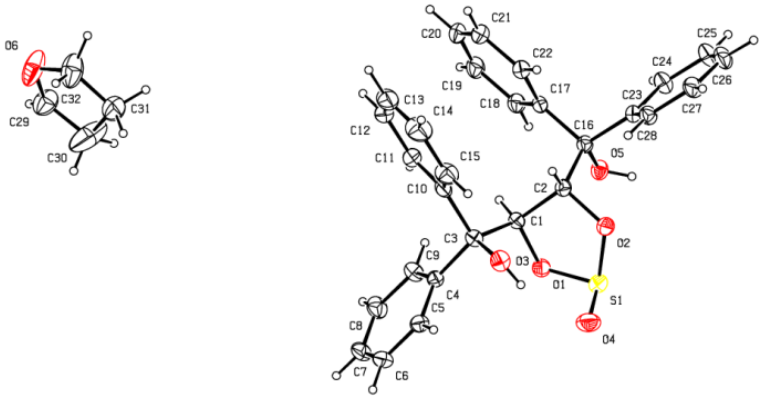


Figure 2. Crystal structure of **1**.

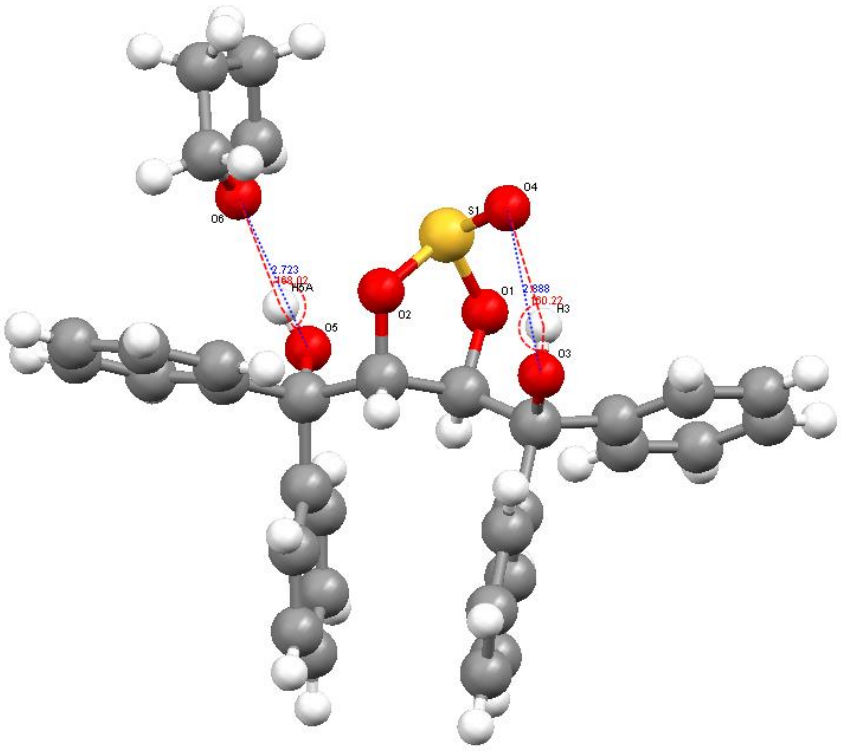


Figure 3. The intramolecular H-bond in a crystal of **1**.

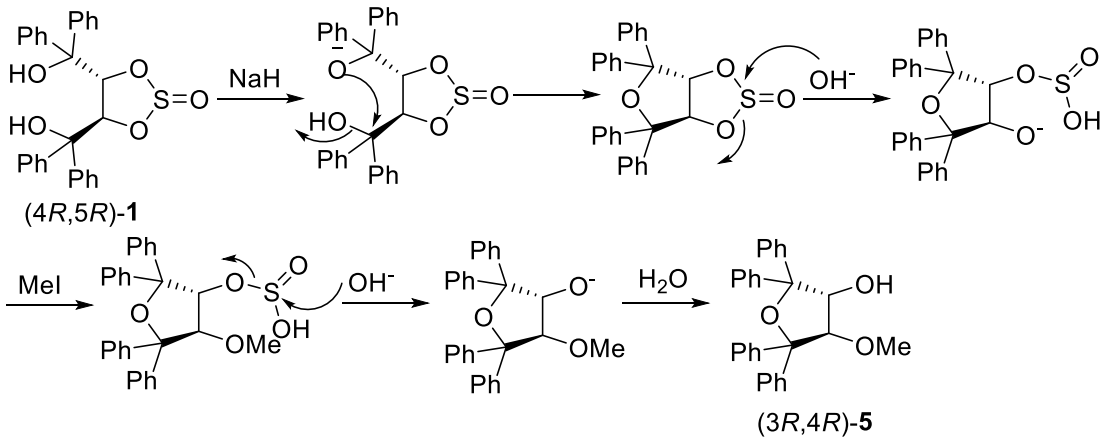
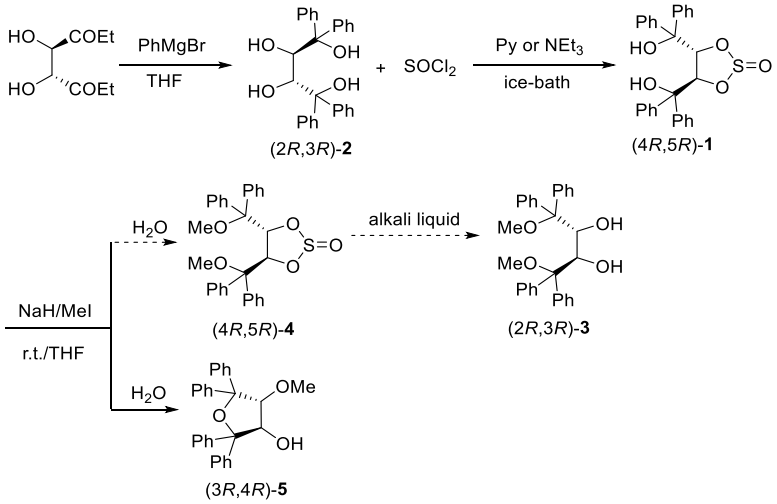


Figure 4. The proposed mechanism for forming of **5**.



Scheme 1. The designed synthetic route of (2*R*,3*R*)-**3** and the synthesis of the cycloetherification product (3*R*,4*R*)-**5**.