A Novel Synthesis of 2-Acyl Cyclic Ethers and 3-Keto Cyclic Ethers Including Spiro Cyclic Ethers via Intramolecular Ring-Opening of α,β-Epoxy Sulfoxides with Hydroxyl Group[1)]

Tsuyoshi SATOH, Ken-ichi IWAMOTO, Atsushi SUGIMOTO, and Koji YAMAKAWA*
Faculty of Pharmaceutical Sciences, Science University of Tokyo, Ichigaya-funagawara-machi, Shinjuku-ku, Tokyo 162
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The α,β-epoxy sulfoxides **1** and **2** bearing a ω-oxyalkyl group were synthesized from ω-oxyalkyl carbonyl compounds and 1-chloroalkyl phenyl sulfoxide. The intramolecular ring opening of the oxirane ring of these α,β-epoxy sulfoxides, through an attack of the terminal hydroxyl group, gave 2-acyl cyclic ethers or 3-keto cyclic ethers, including spiro-type cyclic ethers. This procedure is applicable to the preparation of five- and six-membered cyclic ethers.

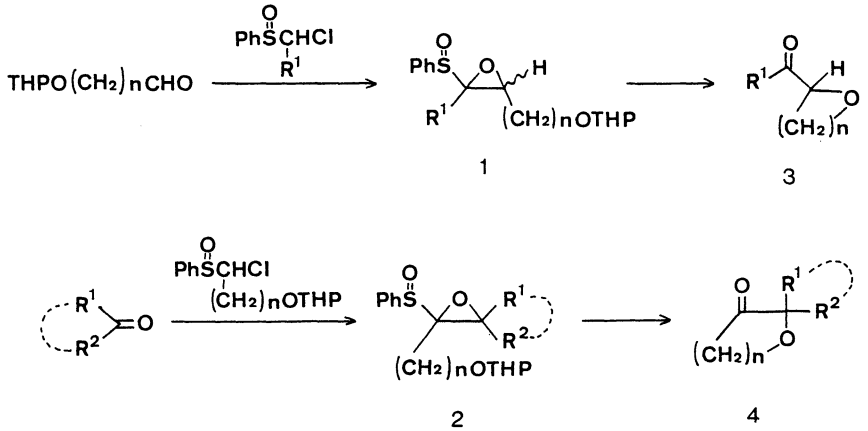
The intramolecular ring opening of an oxirane ring[2)] with a hydroxyl group is a quite useful method for constructing cyclic ether systems which are found in many natural products having remarkable biological activity, e.g., polyether antibiotics.[3)] However, the compounds containing an epoxy group is usually synthesized from olefins by an epoxidation with several oxidizing agents. In other words, in the step of constructing epoxy groups, carbon-carbon bond formation reactions were rarely used.

Recently, we have reported a new synthetic method for the preparation of α-substituted carbonyl compounds from carbonyl compounds with carbon homologation through α,β-epoxy sulfoxides.[4)] In our papers we reported that the β-position of α,β-epoxy sulfoxides was quite reactive toward many kinds of nucleophiles, such as selenolate,[4a)] thiolates[4b)] and amines,[4c)] giving α-substituted carbonyl compounds in very good yields. With these results in hand, it was anticipated that the intramolecular version of this reaction would be quite promising for constructing heterocyclic compounds having a carbonyl group. In this paper, as a continuation of our studies on the development of new synthetic methods using α,β-epoxy sulfoxides, we report a novel method for the synthesis of 2-acyl cyclic ethers **3** and 3-keto cyclic ethers including spirocyclic 3-keto ethers **4**, both from carbonyl compounds and 1-chloroalkyl phenyl sulfoxides via α,β-epoxy sulfoxides. The whole sequence is shown in Scheme 1.

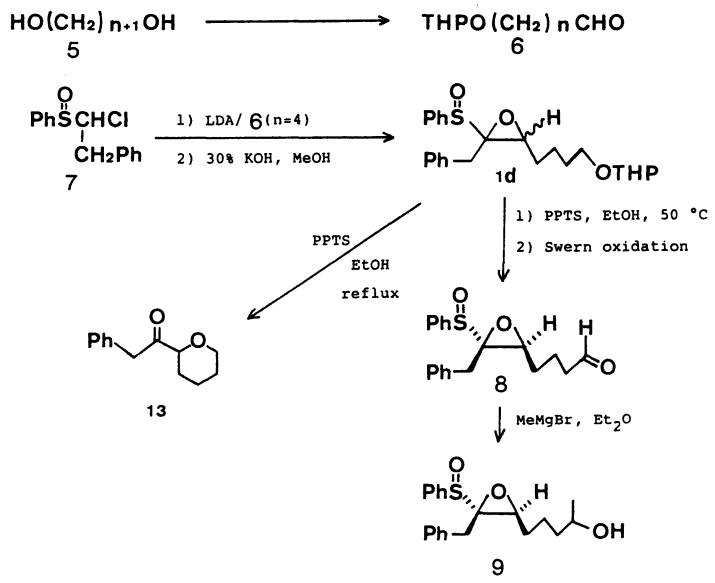
Results and Discussion

A Synthesis of 2-Acyl Cyclic Ethers. In a previous paper[4d)] we reported that the intermolecular reaction of the α,β-epoxy sulfoxides with alcohols did not work well; however, an intramolecular version of this reaction was thought to be possible since the rate of the intramolecular reaction was usually much faster than that of intermolecular reaction.

First, the α,β-epoxy sulfoxide **1d** was synthesized from 1-chloro-2-phenylethyl phenyl sulfoxide and aldehyde **6** (n=4)[6)] via chlorohydrins[4)] in over 85% yield. The treatment of **1d** with 0.2 equivalents of pyridinium p-toluenesulfonate (PPTS)[7)] in refluxing ethanol afforded deprotected alcohol within ten minutes; then an intramolecular ring opening of the epoxide group by the resulting alcohol took place slowly with a liberation of benzenesulfenic acid to give 2-acyltetrahydropyran **13** in 86% yield after heating for 6 h. The reaction time could be shortened to 2.5 h in refluxing 1-propanol. In this reaction PPTS was essential; upon heating the isolated intermediate alcohol in refluxing ethanol without PPTS, only a very

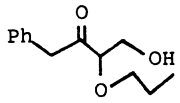
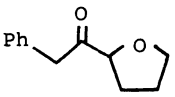
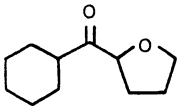
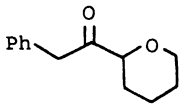
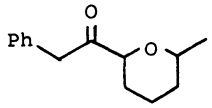
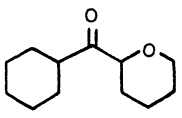
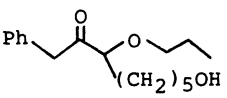
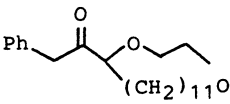


Scheme 1.



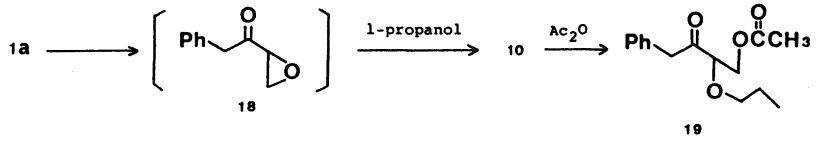
Scheme 2.

Table 1. Preparation of 2-Acyl Cyclic Ethers from α,β-Epoxy Sulfoxides

Entry	α,β-Epoxy sulfoxide			Condition[a]		Product		Yield[b]
	R^1	n		Solvent	Time			%
1	$PhCH_2$	1	**1a**	*n*-PrOH	5 h		**10**	70
2	$PhCH_2$	3	**1b**	EtOH (50 °C)	30 min		**11**	90
3		3	**1c**	EtOH	5 h		**12**	87
4	$PhCH_2$	4	**1d**	EtOH *n*-PrOH	6 h 2.5 h		**13**	86 85
5	$PhCH_2$	4	**9**	*n*-PrOH	4.5 h		**14**[c]	81
6		4	**1e**	*n*-PrOH	5 h		**15**	85
7	$PhCH_2$	5	**1f**	*n*-PrOH	2 d		**16**	46
8	$PhCH_2$	11	**1g**	*n*-PrOH	2 d		**17**[8]	77

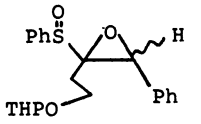
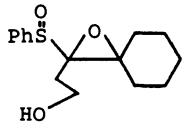
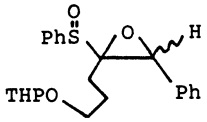
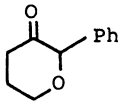
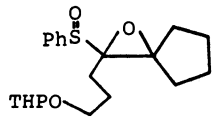
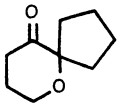
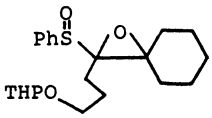
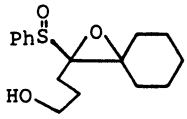
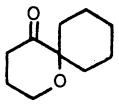
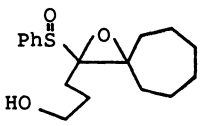
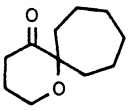
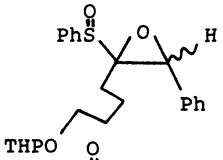
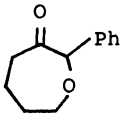
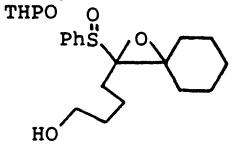
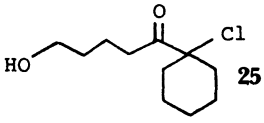
a) Unless otherwise noted the reaction was carried out in refluxing solvent. b) Isolated yield after silica-gel column chromatography. c) Single isomer.

slow reaction was observed. Encouraged by this result, some kinds of α,β-epoxy sulfoxides **1** were allowed to react under the conditions described above. The results are summarized in Table 1. These α,β-epoxy sulfoxides **1** were synthesized from **7** or 1-chloro-1-cyclohexylmethyl phenyl sulfoxide and the aldehyde **6**. The α,β-epoxy sulfoxide **9** was conveniently synthesized from **1d** through the aldehyde **8**, as shown in

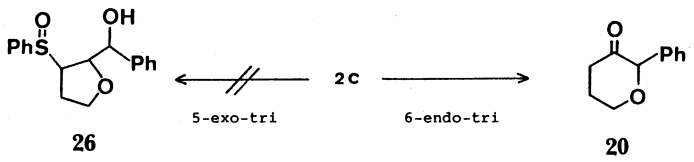


Scheme 3.

Table 2. Preparation of 3-Keto Cyclic Ethers from α,β-Epoxy Sulfoxides

Entry	α,β-Epoxy sulfoxide **2**	Additive (equiv)	Condition[a]		Product		Yield[b]
			Solvent	Time			%
1	 **2a**	PPTS (0.1)	EtOH	2 d	—[c]		—
			n-PrOH	11 h	—[c]		—
2	 **2b**	$MgCl_2$ (1)	*i*-PrOH	29 h	—[c]		—
3	 **2c**	PPTS (0.1)	EtOH	17 h		**20**	60
			n-PrOH	4 h			57
4	 **2d**	PPTS (0.1)	MeOH	1 h		**21**	77
5	 **2e**	PPTS (0.1)	*n*-PrOH	1 h	—[c]		—
6	 **2f**	$MgCl_2$ (1)	*i*-PrOH	13 h		**22**	74
7	 **2g**	$MgCl_2$ (1)	*i*-PrOH	4 h		**23**	73
8	 **2h**	PPTS (0.1)	*n*-PrOH	3 d		**24**	11
9	 **2i**	$MgCl_2$ (1)	*i*-PrOH	29 h		**25**	26

a) All reactions were carried out in refluxing solvent. b) Isolated yield after silica-gel column chromatography. c) A complex mixture.



26 20

Scheme 4.

Scheme 2.

The product **10** of the reaction in entry 1 was thought to be produced from the expected cyclic ether **18** with 1-propanol. The structure of **10** was determined by the NMR spectrum of the corresponding acetate **19**. Entries 2—6 show that this method is quite promising for constructing five- and six-membered cyclic ethers. Even secondary alcohol **9** reacted well to afford cyclic ether **14**. Entries 7 and 8 show that the limitation of this procedure lies between the formation of six- and seven-membered cyclic ether. The α,β-epoxy sulfoxides **1f** and **1g** upon heating in refluxing 1-propanol with PPTS gave the products quite slowly; however, the products were not the desired cyclic ethers but, rather, alcohols **16** and **17**.[8] In these cases, **1f** and **1g** gave only deprotected alcohols and no trace of cyclic ethers, even though 2-butanol (the secondary alcohol having higher boiling point than 2-propanol) was used as the solvent.

A Synthesis of 3-Keto Cyclic Ethers. Next, endo-type ring opening of the oxirane ring of the α,β-epoxy sulfoxides **2** was investigated. First of all the α,β-epoxy sulfoxides **2c** and **2e** (see Table 2) were synthesized from 1-chloro-4-(tetrahydropyranyloxy)butyl phenyl sulfoxide[9] and benzaldehyde or cyclohexanone according to the procedure shown in Scheme 1. Heating of this α,β-epoxy sulfoxide **2c** in refluxing ethanol in the presence of 0.1 equivalents of PPTS quickly gave the deprotected alcohol; however, the cyclization was quite sluggish, giving the desired 3-oxo-2-phenyltetrahydropyran in 60% yield after 17 h. It is interesting to note that this endo-type reaction was much slower than that of exo-type (compare with entry 4 in Table 1). Another important characteristic of this reaction was that **2c** only gave a 6-endo-trigonal[10] type product **20** and no trace of the 5-exo-trigonal[10] type product **26**. This result is inconsistent with our finding that the β-position of α,β-epoxy sulfoxides is much more reactive than the α-position.

In contrast to this result, heating the α,β-epoxy sulfoxide **2e** in ethanol or 1-propanol with PPTS gave a complex mixture very quickly. Recently, we reported[11] that magnesium in primary alcohol was quite effective in promoting the ring opening of α,β-epoxy sulfoxides giving α-alkoxy ketones. The result was applied to this intramolecular ring opening of the epoxy group of **2e**. The tetrahydropyranyl group of **2e** was deprotected to afford the alcohol **2f**. Heating of **2f** in refluxing 2-propanol in the presence of one equivalent of magnesium chloride for 13 h gave the desired spirocyclic β-keto ether **22** in 74% yield. The results of this reaction are summarized in Table 2.

Entries 1 and 2 indicate that the 5-endo-trigonal ring closure is quite difficult, as reported by Baldwin.[10] The result in entry 4 is notable. The α,β-epoxy sulfoxide **2d** gave spirocyclic ether **21** in 77% yield in refluxing methanol for 1 h. This remarkable reactivity of **2d** may be attributable to the highly strained nature of the spiro-cyclic structure of **2d**. Entries 8 and 9 indicate that the limitation of this procedure again lies between the formation of six- and seven-membered cyclic ethers.

In conclusion, because of the total simplicity of the reaction this procedure contributes to the synthesis of five- and six-membered cyclic ethers having ketone group.

Experimental

All melting points are uncorrected. The IR spectra were measured directly on a NaCl plate or KBr disks with a Hitachi 215 spectrometer. ^{1}H NMR spectra were measured in a $CDCl_3$ solution with a JEOL FX-100 spectrometer or Hitachi R-24B spectrometer using Me_4Si as an internal standard. Electron-impact mass spectra (MS) were obtained on a Hitachi M-80 double-focusing spectrometer at 70 eV by direct insertion. Silica gel BW-127 ZH (Fuji-Devison) containing a 2% fluoresence reagent (254) and a quartz column were used for column chromatography; products showing ultraviolet (UV) absorption were detected by UV irradiation.

α,β-Epoxy Sulfoxides. All α,β-epoxy sulfoxides, **1** and **2**, except **8** and **9** used in this study were prepared from carbonyl compounds and 1-chloroalkyl phenyl sulfoxides through chlorohydrins in nearly quantitative yields, which were reported previously.[4]

α,β-Epoxy Sulfoxide 1a: *Z*-Isomer, colorless oil, IR (neat) 1090, 1050, 1035, and 1025 (SO) cm^{-1}; ^{1}H NMR δ=1.3—1.8 (6H, m), 2.61, 3.51 (each 1H, d, *J*=16 Hz), 2.91 (1H, dd, *J*=4, 5 Hz), 3.4—4.3 (4H, m), 4.61 (1H, bs), and 6.8—7.8 (10H, m). *E*-Isomer, colorless oil, IR (neat) 1090, 1080, 1060, and 1035 (SO) cm^{-1}; ^{1}H NMR δ=1.3—1.8 (6H, m), 3.0—4.1 (7H, m), 4.55 (1H, bs), and 7.0—7.7 (10H, m).

α,β-Epoxy Sulfoxide 1b: *E*-Isomer, colorless oil, IR (neat) 1095, 1080, 1060, and 1040 (SO) cm^{-1}; ^{1}H NMR δ=1.1—2.0 (10H, m), 3.07 (2H, s), 3.1—4.0 (5H, m), 4.50 (1H, bs), 7.18, and 7.53 (each 5H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1055, 1040, and 1030 (SO) cm^{-1}; ^{1}H NMR δ=1.2—2.2 (10H, m), 2.54 (1H, d, *J*=15 Hz), 2.73 (1H, t, *J*=5 Hz), 3.1—4.1 (4H, m), 3.58 (1H, d, *J*=15 Hz), 4.56 (1H, bs), and 6.8—7.9 (10H, m).

α,β-Epoxy Sulfoxide 1c: Less polar isomer, colorless oil, IR (neat) 1090, 1055, 1040, and 1030 (SO) cm^{-1}; ^{1}H NMR δ=0.3—2.4 (21H, m), 3.2—4.0 (5H, m), 4.62 (1H, bs), and

7.3—7.8 (10H, m). More polar isomer, colorless oil, IR (neat) 1090, 1080, 1060, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.6—2.1 (21H, m), 3.2—4.0 (5H, m), 4.55 (1H, bs), and 7.4—7.8 (10H, m).

α,β-Epoxy Sulfoxide 1d: *E*-Isomer, colorless oil, IR (neat) 1095, 1080, 1060, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.1—2.0 (12H, m), 3.01, 3.05 (each 1H, d, J=16 Hz), 3.1—4.0 (5H, m), 4.52 (1H, bs), and 6.9—7.7 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1060, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.2—1.8 (10H, m), 2.01 (2H, m), 2.53, 3.54 (each 1H, d, J=15 Hz), 2.64 (1H, t, J=7 Hz), 3.2—4.0 (4H, m), 4.53 (1H, bs), and 6.8—7.8 (10H, m).

α,β-Epoxy Sulfoxide 9: A solution of 389 mg of **1d** (*E*-isomer) and PPTS (24 mg) in 20 ml of EtOH was heated at 50 °C for 4 h. The EtOH was evaporated to give a residue, which was dissolved in ether-benzene. The solution was washed once with half-saturated brine and dried over Na_2SO_4. The product was purified by silica-gel column chromatography to give 276 mg (90%) of deprotected alcohol as a colorless oil. IR (neat) 3430 (OH), 1095, and 1060 (SO) cm^{-1}; ^1H NMR δ=1.3—1.7 (6H, m), 3.01, 3.08 (each 1H, d, J=16 Hz), 3.4—3.8 (3H, m), and 6.9—7.7 (10H, m).

A solution of oxalyl dichloride (80 μl) in 3 ml of dry CH_2Cl_2 in a dry flask was cooled to −50 °C. DMSO (142 mg in 0.5 ml of CH_2Cl_2) was added to the solution dropwise with stirring and the mixture was stirred at −50 °C for 2 min. To this was added the alcohol (250 mg in 1 ml of CH_2Cl_2). The reaction mixture was stirred at −50 °C for 15 min; then, triethylamine (0.53 ml) was added. The reaction mixture was stirred and allowed to warm to 0 °C. The reaction was quenched by adding 10 ml of water and the whole was extracted with CH_2Cl_2. The product was purified by silica-gel column chromatography to afford 190 mg (77%) of the aldehyde **8** as a colorless oil. IR (neat) 2750 (CHO), 1730 (CO), 1095, and 1060 (SO) cm^{-1}; ^1H NMR δ=1.4—2.1 (4H, m), 2.2—2.6 (2H, m), 2.99, 3.08 (each 1H, d, J=16 Hz), 3.69 (1H, t, J=6 Hz), 7.0—7.8 (10H, m), and 9.66 (1H, t, J=1.5 Hz).

MeMgBr (1.1 equiv) was added dropwide to a solution of the aldehyde (**8**; 156 mg) in 7 ml of dry ether at −60 °C. The reaction mixture was stirred for 10 min; then, the reaction was quenched by satd. aq. NH_4Cl. The whole mixture was extracted with ether-benzene and the product was purified by silica-gel column chromatography to afford 142 mg (87%) of the alcohol **9** as a colorless oil. IR (neat) 3440 (OH), 1090, and 1060 (SO) cm^{-1}; ^1H NMR δ=1.14 (3H, d, J=6 Hz), 1.2—1.8 (6H, m), 2.97, 3.03 (each 1H, d, J=16 Hz), 3.4—3.9 (2H, m), and 6.9—7.7 (10H, m).

α,β-Epoxy Sulfoxide 1e: Less polar isomer, colorless oil, IR (neat) 1090, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.5—2.5 (23H, m), 3.26 (1H, t, J=6 Hz), 3.2—4.0 (4H, m), 4.57 (1H, bs), and 7.3—7.8 (5H, m). More polar isomer, colorless oil, IR (neat) 1090, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.6—2.0 (23H, m), 3.2—4.0 (5H, m), 4.54 (1H, bs), and 7.3—7.8 (5H, m).

α,β-Epoxy Sulfoxide 1f: *E*-Isomer, colorless oil, IR (neat) 1095, 1085, 1065, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.0—1.9 (14H, m), 3.00, 3.06 (each 1H, d, J=16 Hz), 3.1—4.0 (5H, m), 4.53 (1H, bs), and 7.0—7.7 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1060, 1045, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.1—2.1 (14H, m), 2.52 (1H, d, J=16 Hz), 2.63 (1H, t, J=6 Hz), 3.55 (1H, d, J=16 Hz), 3.2—4.0 (4H, m), 4.54 (1H, bs), and 6.8—7.8 (10H, m).

α,β-Epoxy Sulfoxide 1g: *E*-Isomer, colorless oil, IR (neat) 1090, 1080, 1055, 1045, and 1025 (SO) cm^{-1}; ^1H NMR δ=1.0—1.9 (26H, m), 3.00, 3.05 (each 1H, d, J=16 Hz), 3.1—4.0 (5H, m), 4.55 (1H, bs), and 6.9—7.7 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1085, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.0—2.1 (26H, m), 2.52 (1H, d, J=15 Hz), 2.61 (1H, t, J=6 Hz), 3.53 (1H, d, J=15 Hz), 3.2—4.0 (4H, m), 4.54 (1H, bs), and 6.8—7.8 (10H, m).

α,β-Epoxy Sulfoxide 2a: *E*-Isomer, colorless oil, IR (neat) 1090, 1060, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.2—2.1 (8H, m), 3.2—4.0 (4H, m), 4.54 (1H, bs), 4.97 (1H, s), and 7.0—7.9 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1080, 1055, and 1040 (SO) cm^{-1}; ^1H NMR δ=1.3—2.0 (7H, m), 2.4—2.9 (1H, m), 3.2—4.0 (4H, m), 4.64, 4.71 (each singlet), and 7.2—7.8 (10H, m).

α,β-Epoxy Sulfoxide 2b: Colorless crystals, mp 59—61 °C (AcOEt-hexane), IR (KBr) 3410 (OH), 1090, 1050, and 1035 (SO) cm^{-1}; ^1H NMR δ=1.3—2.4 (12H, m), 3.2—4.0 (3H, m), and 7.4—7.8 (5H, m); Found: C, 64.25; H, 7.29; S, 11.50%. Calcd for $C_{15}H_{20}O_3S$: C, 64.26; H, 7.19; S, 11.44%.

α,β-Epoxy Sulfoxide 2c: *E*-Isomer, colorless oil, IR (neat) 1095, 1085, 1065, 1045, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.1—1.9 (10H, m), 2.9—3.9 (5H, m), 4.39 (1H, bs), 4.81 (1H, s), and 7.0—7.9 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1095, 1080, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.1—2.0 (9H, m), 2.1—2.5 (1H, m), 3.0—3.9 (4H, m), 4.25 (1H, s), 4.28 (1H, bs), and 7.2—7.8 (10H, m).

α,β-Epoxy Sulfoxide 2d: Colorless oil, IR (neat) 1090, 1080, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.6—1.2 (1H, m), 1.2—2.2 (16H, m), 2.3—2.8 (1H, m), 2.9—3.24 (1H, m), 3.24—3.56 (2H, m), 3.56—3.90 (1H, m), 4.40 (1H, bs), and 7.3—7.8 (5H, m).

α,β-Epoxy Sulfoxide 2e: Colorless oil, IR (neat) 1095, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.5—1.1 (1H, m), 1.1—2.3 (19H, m), 2.8—4.0 (4H, m), 4.35 (1H, bs), and 7.3—7.9 (5H, m).

α,β-Epoxy Sulfoxide 2f: Colorless crystals, mp 90.5—92 °C (AcOEt-hexane), IR (KBr) 3460 (OH), 1090, 1050, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=0.7—1.2 (1H, m), 1.2—2.3 (13H, m), 3.37 (2H, t, J=6 Hz), and 7.3—7.8 (5H, m); Found: C, 65.20; H, 7.59; S, 11.08%. Calcd for $C_{16}H_{22}O_3S$: C, 65.27; H, 7.53; S, 10.89%.

α,β-Epoxy Sulfoxide 2g: Colorless crystals, mp 80.5—82.5 °C (AcOEt-hexane), IR (KBr) 3470 (OH), 1085, 1070, 1035, and 1025 (SO) cm^{-1}; ^1H NMR δ=1.0—2.1 (14H, m), 2.1—2.5 (2H, m), 3.35 (2H, t, J=6 Hz), and 7.3—7.8 (5H, m); Found: C, 66.11; H, 7.77; S, 10.48%. Calcd for $C_{17}H_{24}O_3S$: C, 66.20; H, 7.84; S, 10.40%.

α,β-Epoxy Sulfoxide 2h: *E*-Isomer, colorless oil, IR (neat) 1090, 1080, 1060, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.0—2.0 (11H, m), 2.1—2.7 (1H, m), 3.0—3.9 (4H, m), 4.44 (1H, bs), 4.78 (1H, s), and 7.0—7.8 (10H, m). *Z*-Isomer, colorless oil, IR (neat) 1090, 1080, 1055, 1040, and 1030 (SO) cm^{-1}; ^1H NMR δ=1.1—1.9 (11H, m), 2.0—2.5 (1H, m), 3.0—4.0 (4H, m), 4.44 (1H, s), 4.48 (1H, bs), and 7.2—7.8 (10H, m).

α,β-Epoxy Sulfoxide 2i: Colorless oil, IR (neat) 3450 (OH), 1085, and 1050 (SO) cm^{-1}; ^1H NMR δ=0.4—0.8 (1H, m), 1.0—2.3 (15H, m), 3.41 (2H, t, J=6 Hz), and 7.4—7.8 (5H, m).

General Procedure for the Preparation of 2-Acyl Cyclic Ethers and 3-Keto Cyclic Ethers from α,β-Epoxy Sulfoxides by PPTS-Induced Opening of the Oxiran Ring: The synthesis of 2-(1-oxo-2-phenylethyl)tetrahydrofuran (**11**) from

1b is described. To a solution of **1b** (96 mg) in 2 ml of EtOH was added PPTS (0.1 equiv) and the reaction mixture was stirred and heated at 50 °C for 30 min. The EtOH was evaporated under vacuum and the residue was dissolved in benzene. The solution was washed with satd. brine and dried over Na_2SO_4. The solvent was evaporated and the residue was purified by silica-gel column chromatography to afford 43 mg (90%) of **11** as a colorless oil. IR (neat) 1730 (CO) cm^{-1}; ^1H NMR δ=1.5—2.5 (4H, m), 3.83 (2H, s), 3.8—4.0 (2H, m), 4.20—4.45 (1H, m), and 7.0—7.4 (5H, m); MS *m/z* (%) 190 (M^+, 5), 136 ([M−C_4H_6]$^+$, 34), 91 ([M−$C_5H_7O_2$]$^+$, 100), and 71 ([M−C_8H_7O]$^+$, 42); Found: *m/z* 190.0985. Calcd for $C_{12}H_{14}O_2$: M, 190.0993.

4-Hydroxy-3-propoxy-1-phenyl-2-butanone (10) and Its Acetate (19). **10**: Colorless oil, IR (neat) 3450 (OH), 1730 (CO) cm^{-1}; ^1H NMR δ=0.93 (3H, t, *J*=6 Hz), 1.60 (2H, sextet, *J*=6 Hz), 2.12 (1H, t, *J*=6 Hz, OH), 3.38 (2H, t, *J*=6 Hz), 3.55—3.80 (2H, m), 3.80 (2H, s), and 7.12 (5H, bs). Acetate **19**: Colorless oil, IR (neat) 1740 (CO), 1250 (COC) cm^{-1}; ^1H NMR δ=0.95 (3H, t, *J*=7 Hz), 1.65 (2H, sextet, *J*=7 Hz), 2.02 (3H, s), 3.44 (2H, m), 3.91 (2H, s), 3.95 (1H, dd, *J*=5, 4 Hz), 4.32 (2H, dq, *J*=12, 4 Hz), and 7.24 (5H, m); MS *m/z* (%) 264 (M^+, 0.4), 204 ([M−$C_2H_4O_2$]$^+$, 0.3), 145 ([M−C_8H_7O]$^+$, 42), 103 (45), and 43 (100); Found: *m/z* 264.1374. Calcd for $C_{15}H_{20}O_4$: M, 264.1360.

2-(Cyclohexylcarbonyl)tetrahydrofuran (12). Colorless oil, IR (neat) 1720 (CO) cm^{-1}; ^1H NMR δ=0.6—2.4 (14H, m), 2.70 (1H, m), 3.90 (2H, m), and 4.41 (1H, m); MS *m/z* (%) 182 (M^+, 4), 111 ([M−C_4H_7O]$^+$, 7), and 71 (100).

2-(1-Oxo-2-phenylethyl)tetrahydropyran (13). Colorless oil, IR (neat) 1730 (CO) cm^{-1}; ^1H NMR δ=1.2—2.0 (6H, m), 3.28—3.60 (1H, m), 3.68—4.20 (2H, m), 3.86 (2H, s), and 7.21 (5H, m); MS *m/z* (%) 204 (M^+, 6), 136 ([M−C_5H_8]$^+$, 2), 91 ([M−$C_6H_9O_2$]$^+$, 25), and 85 ([M−C_8H_7O]$^+$, 100); Found: *m/z* 204.1128. Calcd for $C_{13}H_{16}O_2$: M, 204.1149.

2-Methyl-5-(1-oxo-2-phenylethyl)tetrahydropyran (14). Colorless oil, IR (neat) 1730 (CO) cm^{-1}; ^1H NMR δ=1.1—2.0 (6H, m), 1.26 (3H, d, *J*=6 Hz), 3.3—3.6 (1H, m), 3.76—3.95 (1H, m), 3.87, and 3.90 (each 1H, d, *J*=15 Hz); MS *m/z* (%) 218 (M^+, 9), and 99 ([M−C_8H_7O]$^+$, 100); Found: *m/z* 218.1320. Calcd for $C_{14}H_{18}O_2$: M, 218.1306.

2-(Cyclohexylcarbonyl)tetrahydropyran (15). Colorless oil, IR (neat) 1720 (CO) cm^{-1}; ^1H NMR δ=0.8—2.1 (16H, m), 2.80 (1H, m), 3.28—3.64 (1H, m), and 3.86—4.24 (2H, m); MS *m/z* (%) 196 (M^+, 2), and 85 ([M−$C_7H_{11}O$]$^+$, 100); Found: *m/z* 196.1463. Calcd for $C_{12}H_{20}O_2$: M, 196.1462.

8-Hydroxy-3-propoxy-1-phenyl-2-octanone (16). Colorlsss oil, IR (neat) 3400 (OH), 1730 (CO) cm^{-1}; ^1H NMR δ=0.93 (3H, t, *J*=7 Hz), 1.0—1.8 (10H, m), 3.32 (2H, m), 3.4—3.8 (3H, m), 3.82 (2H, s), and 7.23 (5H, m); MS *m/z* (%) 278 (M^+, 0.4), 218 ([M−C_3H_8O]$^+$, 1), 159 ([M−C_8H_7O]$^+$, 70), 99 (88), and 81 (100); Found: *m/z* 278.1876. Calcd for $C_{17}H_{26}O_3$: M, 278.1880.

14-Hydroxy-3-propoxy-1-phenyl-2-tetradecanone (17). Colorless oil, IR (neat) 3420 (OH), 1730 (CO) cm^{-1}; ^1H NMR δ=0.94 (3H, t, *J*=7 Hz), 1.0—1.9 (22H, m), 3.31 (2H, m), 3.5—3.8 (3H, m), 3.81 (2H, s), and 7.22 (5H, m); MS *m/z* (%) 362 (M^+, 0.3), 332 [M−CH_2O]$^+$, 0.3), 302 ([M−C_3H_8O]$^+$, 0.3), 243 ([M−C_8H_7O]$^+$, 88), and 43 (100); Found: *m/z* 362.2802. Calcd for $C_{23}H_{38}O_3$: M, 362.2818.

2-Phenyl-5,6-dihydro-2*H*-pyran-3(4*H*)-one (20). Colorless oil, IR (neat) 1730 (CO) cm^{-1}; ^1H NMR δ=1.96—2.32 (2H, m), 2.45—2.70 (2H, m), 3.68—4.22 (2H, m), 4.91 (1H, s), and 7.30 (5H, s); MS *m/z* (%) 176 (M^+, 25), 146 ([M−CO]$^+$, 84), 147 ([M−CHO]$^+$, 87), and 105 (100); Found: *m/z* 176.0823. Calcd for $C_{11}H_{12}O_2$: M, 176.0835.

6-Oxaspiro[4.5]decan-10-one (21). Colorless oil, IR (neat) 1710 (CO) cm^{-1}; ^1H NMR δ=1.4—2.2 (10H, m), 2.32 (2H, t, *J*=6 Hz), and 3.82 (2H, t, *J*=6 Hz).

2-Phenyl-3-oxepanone (24). Colorless oil, IR (neat) 1720 (CO) cm^{-1}; ^1H NMR δ=1.8—2.4 (4H, m), 2.4—2.6 (2H, m), 3.6—4.2 (2H, m), 4.87 (1H, s), and 7.35 (5H, s); MS *m/z* (%) 190 (M^+, 12), 162 ([M−CO]$^+$, 39), 161 ([M−CHO]$^+$, 45), and 105 ([M−C_5H_9O]$^+$, 100); Found: *m/z* 190.0994. Calcd for $C_{12}H_{14}O_2$: M, 190.0933.

General Procedure for the Preparation of Spirocyclic β-Keto Ethers from α,β-Epoxy Sulfoxides by $MgCl_2$-Induced Opening of the Oxirane Ring: The synthesis of 1-oxaspiro[5.5]undecan-5-one (**22**) from **2f** is described. $MgCl_2$ (33 mg; 0.34 mmol) was added to a solution of **2f** (100 mg; 0.34 mmol) in 7 ml of 2-propanol. The mixture was stirred and heated at reflux temperature under N_2 for 13 h. To the reaction mixture was added excess NH_4Cl and the 2-propanol was evaporated. The residue was extracted with benzene-ether and the organic layer was washed with satd. aq. NH_4Cl and dried over Na_2SO_4. The product was purified by silica-gel column chromatography to afford 45 mg (74%) of **22** as a colorless oil. IR (neat) 1720 (CO) cm^{-1}; ^1H NMR δ=0.8—2.0 (10H, m), 2.10 (2H, q, J=6 Hz), 2.49 (2H, t, *J*=6 Hz), and 3.84 (2H, t, *J*=6 Hz).

1-Oxaspiro[5.6]dodecan-5-one (23). Colorless oil, IR (neat) 1720 (CO) cm^{-1}; ^1H NMR δ=1.0—2.0 (12H, m), 2.10 (2H, q, *J*=6 Hz), 2.51 (2H, t, *J*=6 Hz), and 3.81 (2H, t, *J*=6 Hz); MS *m/z* (%) 182 (M^+, 16), 154 ([M−CO]$^+$, 28), and 112 (100); Found: *m/z* 182.1303. Calcd for $C_{11}H_{18}O_2$: M, 182.1305.

1-Chloro-1-(5-hydroxy-1-oxoheptyl)cyclohexane (25). Colorless oil, IR (neat) 3400 (OH), 1720 (CO) cm^{-1}; ^1H NMR δ=1.0—2.2 (14H, m), 2.77 (2H, t, *J*=6 Hz), and 3.64 (2H, t, *J*=6 Hz); MS *m/z* (%) 218 (M^+, 3), 157 (4), and 101 ([M−$C_6H_{10}Cl$]$^+$, 100).

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