γ-Chloromagnesio γ-Lactones and δ-Chloromagnesio δ-Lactones: Generation, Properties, and Synthetic Uses

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Abstract: Treatment of γ- and δ-lactones having a sulfinyl group at the γ- and δ-positions with isopropylmagnesium chloride in THF at –78 °C gave γ-chloromagnesio γ-lactones and δ-chloromagnesio δ-lactones, respectively, by the sulfoxide–magnesium exchange reaction in high yields. Comparing the stability of the γ-chloromagnesio γ-lactones with that of the δ-chloromagnesio δ-lactones, the former was found to be much more stable. The reaction of these γ-chloromagnesio γ-lactones and δ-chloromagnesio δ-lactones with electrophiles and the stereochemistry of the reactions are discussed.

Key words: γ-chloromagnesio γ-lactone, δ-chloromagnesio δ-lactone, sulfoxide–magnesium exchange reaction, organomagnesium compound, Grignard reagent

Organomagnesium compounds, generally called as Grignard reagents, were discovered by V. Grignard over 100 years ago.[1] Grignard reagents are easily prepared from alkyl- or aryl halides with magnesium metal in an ethereal solvent and are usually stable at room temperature and storable for a long period of time. In addition, Grignard reagent can act as a base and a nucleophile as well. These are the reasons why Grignard regents have been one of the most important reagents for the formation of a carbon–carbon bond on reaction with carbonyl compounds or alkyl halides.[2]

Although Grignard reagents are less basic and less nucleophilic than the corresponding organolithium reagents, the carbon–magnesium bond is still highly reactive and it has long been generally recognized that the presence of electrophilic functional groups, such as esters, nitriles, and ketones, cannot be compatible with the Grignard reagents. However, recently, the preparation of functionalized Grignard reagents and their properties have been studied and reported by Knochel[3] and others. The functionalized Grignard reagents are those of functionalized arylmagnesium reagents,[4] polyfunctional heteroarylmagnesium reagents,[5] and functionalized alkenylmagnesium reagents.[6] These functionalized magnesium reagents have ester, nitrile, halogen, and amide as the functional groups. However, these functional groups are usually present directly on the aromatic ring or on the sp^2-carbon, which means that there is no acidic α-hydrogen, although some exception is also reported.[7]

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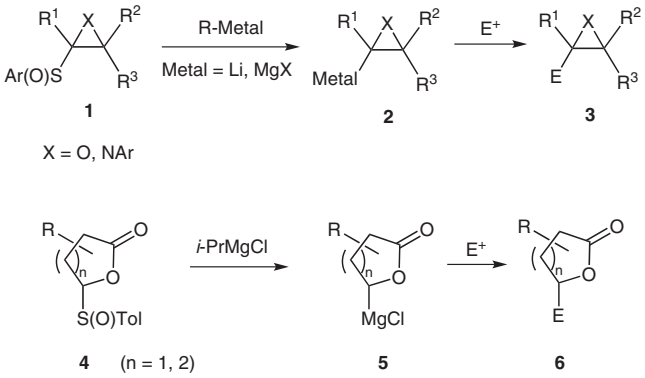
In our previous studies, it was found that the reaction of alkyl aryl sulfoxides having a heteroatom at the carbon bearing the sulfinyl group, such as sufinyloxiranes **1** (X = O) and sulfinylaziridines **1** (X = NAr), with alkylmetals (alkyllithiums and Grignard reagents) resulted in the formation of oxiranyl anions **2** (X = O)[8,9] and aziridinyl anions **2** (X = NAr) (Scheme 1).[8,10] Namely, the bond between the sulfur and the carbon bearing a heteroatom is cleaved by the reaction with alkylmetals through the sulfoxide–metal exchange reaction.[11] Furthermore, we found that the oxiranyl anions and aziridinyl anions **2** reacted with several electrophiles to give epoxides and aziridines **3** in good yields.

In continuation of this chemistry, we envisaged that if Grignard reagents react with the sulfinyl group in lactones **4**, γ-chloromagnesio γ-lactones **5** (n = 1) and δ-chloromagnesio δ-lactones **5** (n = 2) could be generated via sulfoxide–magnesium exchange reaction.[11] We also anticipated that the further reaction of **5** with various electrophiles would afford lactones **6** having a carbon–carbon bond at the γ- and δ-position, respectively. We report here, in detail, the first example for the generation of γ-chloromagnesio γ-lactones and δ-chloromagnesio δ-lactones and the investigation of their properties and the reaction with electrophiles (Scheme 1).[12]

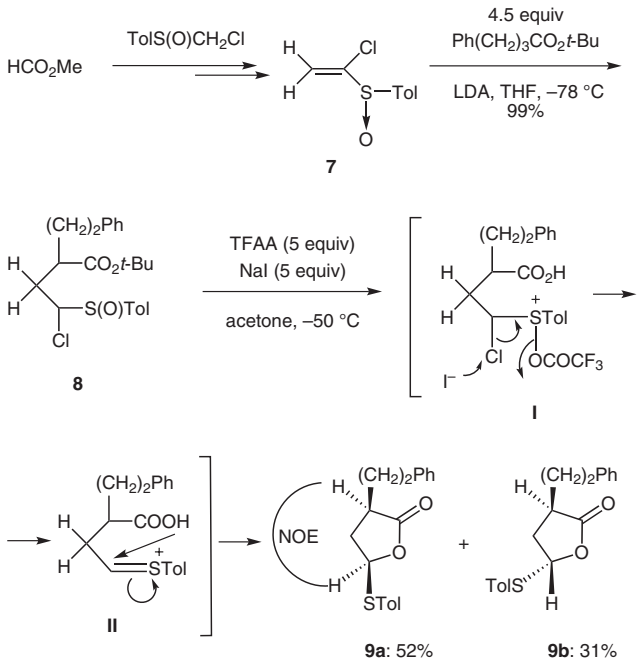


Scheme 1

Synthesis of γ-*p*-Tolylsulfanyl γ-Lactones and δ-*p*-Tolylsulfanyl δ-Lactones

At first, γ-(*p*-tolylsulfinyl) γ-lactones and δ-(*p*-tolylsulfinyl) δ-lactones **4** were synthesized as follows. Thus, 1-

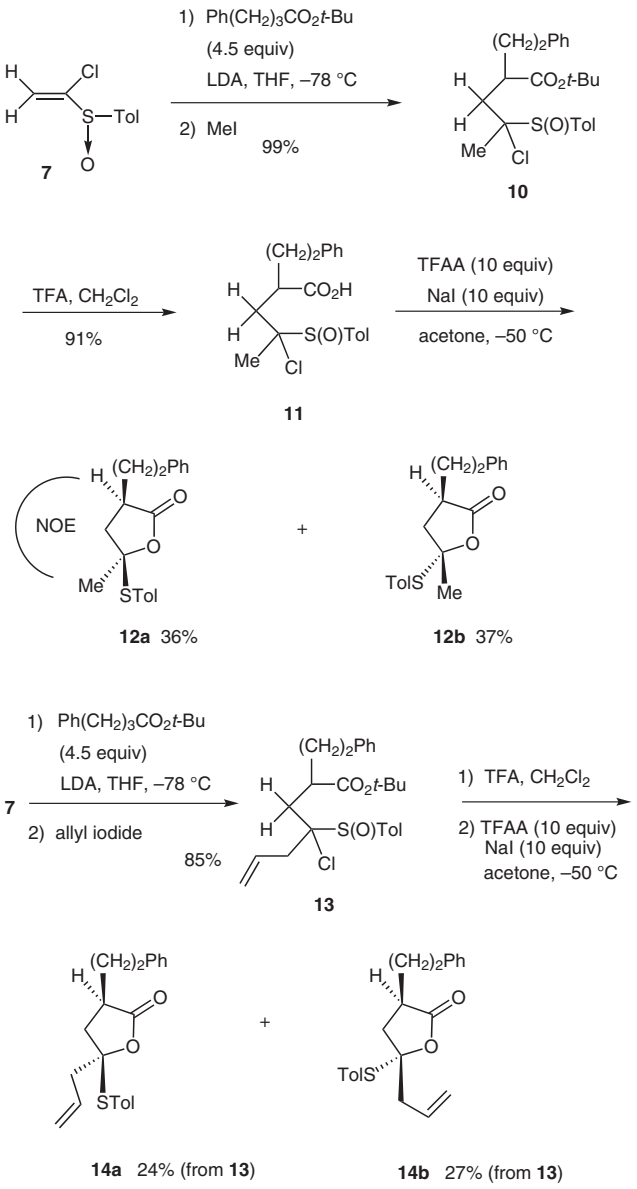
chlorovinyl *p*-tolyl sulfoxide (**7**) was synthesized starting from methyl formate and chloromethyl *p*-tolyl sulfoxide in three steps in 75% overall yield (Scheme 2).[13] Lithium enolate of *tert*-butyl 4-phenylbutyrate (4.5 equiv) was generated from *tert*-butyl 4-phenylbutyrate with LDA in THF at –78 °C and to this reaction mixture was added a solution of **7** in THF. The addition reaction was found to be instantaneous and the adduct **8** was obtained within one minute in 99% yield. When less amount of the lithium enolate of *tert*-butyl 4-phenylbutyrate was used, the reaction was not completed.



Scheme 2

Although adduct **8** has three chiral centers, only one isomer was obtained judging from its ^{1}H NMR spectrum. Next, the adduct **8** was treated with trifluoroacetic anhydride (TFAA) in the presence of NaI in acetone at –50 °C to give γ-lactone **9** having a tolylsulfanyl group at the γ-position.[14] The presumed mechanism of this reaction is shown in Scheme 2. First, the reaction of the sulfoxide **8** with TFAA gives an acyloxysulfonium ion. At the same time, the *tert*-butyl ester is eliminated by trifluoroacetic acid to carboxylic acid **I**. The iodine anion then attacks the chlorine atom to give thionium ion **II**. The oxygen of the carboxylic acid attacks intramolecularly the thionium ion to afford the γ-lactone **9**. Two diastereomers were observed on silica gel TLC and they could be separated by silica gel column chromatography. In order to determine the stereochemistry of these two products **9a** and **9b**, NOESY spectra of the lactones were measured. From detailed inspection of the spectra, we were able to determine that the main lactone **9a** has *cis*-stereochemistry as shown in Scheme 2.

In a similar way, the addition reaction of *tert*-butyl 4-phenylbutyrate with vinyl sulfoxide **7** was carried out and the intermediate of this addition reaction was trapped with iodomethane to give adduct **10** in 99% yield as a single isomer (Scheme 3).

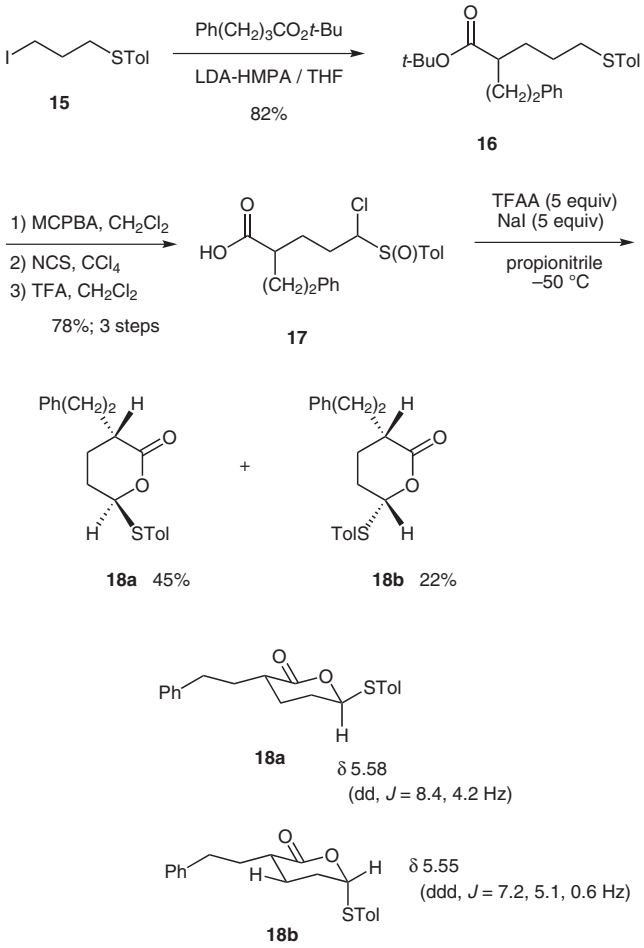


Scheme 3

As the treatment of **10** with TFAA and NaI did not give the desired γ-lactone but a complex mixture, *tert*-butyl ester group was converted to the carboxylic acid with trifluoroacetic acid (TFA) in dichloromethane to give **11** in 91% yield. Carboxylic acid **11** was treated with TFAA and NaI in the same way as described above to afford a mixture of γ-lactones **12a** (36%) and **12b** (37%). The stereochemistry of **12a** and **12b** was again determined by NOESY spectra of both lactones. In a similar way, the intermediate of the addition reaction of **7** with lithium enolate of *tert*-butyl 4-phenylbutyrate was trapped with allyl iodide to give **13** in 85% yield. Removal of the *tert*-butyl ester group of **13** with TFA followed by the treatment with

TFAA-NaI gave a mixture of γ-lactones **14a** and **14b** having an allyl group at the γ-carbon in moderate yield.

Next, the synthesis of δ-sulfanyl δ-lactones **18** was investigated (Scheme 4). Lithium enolate of *tert*-butyl 4-phenylbutyrate was generated from *tert*-butyl 4-phenylbutyrate with LDA in THF in the presence of HMPA and to this reaction mixture was added a solution of (3-iodo)propyl tolyl sulfide (**15**) in THF to afford the alkylated ester **16** in 82% yield. The sulfanyl group of **16** was oxidized with *m*-chloroperbenzoic acid (MCPBA) to a sulfinyl group, and the resulting sulfinyl ester was chlorinated with *N*-chlorosuccinimide (NCS). Finally, the *tert*-butyl ester was converted to the carboxylic acid **17** with TFA in 78% overall yield from **16**. Carboxylic acid **17** was treated with TFAA in the presence of NaI in propionitrile at –50 °C to afford the desired δ-sulfanyl δ-lactone **18** in moderate yield.



Scheme 4

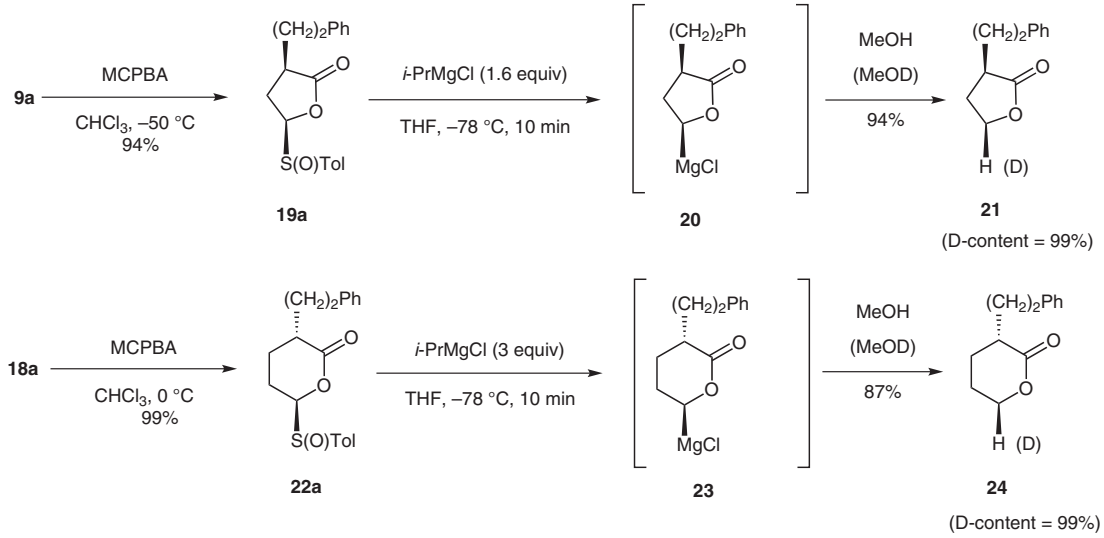
On a silica gel TLC, two products could be observed and they were separated by silica gel column chromatography as a less polar main product **18a** (45%) and a more polar minor product **18b** (22%). The stereochemistry of the two products was easily determined from the coupling pattern of the hydrogen at the carbon bearing the sulfanyl group as depicted in Scheme 4. Thus, the hydrogen of the minor product **18b** showed a double-double-doublet at δ = 5.55. The small coupling constant (J = 0.6 Hz) indicated that the hydrogen has long-range coupling (long-range W coupling)[15] between the equatorial hydrogen on the β-carbon (depicted in Scheme 4).

Generation of γ-Chloromagnesio γ-Lactones and δ-Chloromagnesio δ-Lactones from γ-*p*-Tolylsulfinyl γ-Lactones and δ-*p*-Tolylsulfinyl δ-Lactones, Respectively, with *i*-PrMgCl

Generation of γ-chloromagnesio γ-lactones and δ-chloromagnesio δ-lactones was investigated next. At first, **9a** and **18a** were used in the following studies. Sulfide **9a** was oxidized with *MC*PBA at –50 °C to afford sulfoxide **19a** as a mixture of two diastereomers in high yield. Next, the mixture of the sulfoxides **19a** was treated with 1.6 equivalents of *i*-PrMgCl at –78 °C for 10 minutes (a solution of **19a** in THF was added to a solution of *i*-PrMgCl in THF) to give the desulfinylated product **21** in 94% yield via sulfoxide–magnesium exchange reaction without a trace of the starting sulfoxide **19a**. Quenching this reaction with MeOD gave deuterated product (deuterated at γ-position) **21** with 99% deuterium incorporation. This result showed that the intermediate of this reaction was γ-chloromagnesio γ-lactone **20** (see Scheme 5).

In a similar way, sulfoxide–magnesium exchange reaction of δ-tolylsulfinyl δ-lactone **22a**, which was synthesized from δ-tolylsulfanyl δ-lactone **18a** with MCPBA in a quantitative yield, was carried out with three equivalents of *i*-PrMgCl and the reaction was quenched with MeOD to give δ-lactone **24** deuterated at δ-position in 87% yield (D-content 99%). When less than three equivalents of *i*-PrMgCl was used in this reaction, the sulfoxide-magnesium exchange reaction did not go to completion. Obviously, the intermediate of this reaction was the δ-chloromagnesio δ-lactone **23**. At this stage, we were worried about an intermolecular or an intramolecular proton abstraction of these magnesiated lactones; because, both **20** and **23** have relatively acidic hydrogen on the α-position. However, no deuterium incorporation at the α-position of **21** and **24** were observed as revealed by their ^{1}H NMR spectra.

Next, the stability of γ-chloromagnesio γ-lactone **20** and δ-chloromagnesio δ-lactone **23** was investigated. The stability of **20** and **23** was evaluated by the chemical yield and the rate of deuterium incorporation of the reaction of **19a** and **22a** with *i*-PrMgCl followed by MeOD and the results are summarized in Table 1. The result of the reaction of **19a** already mentioned in Scheme 5 is described in entry 1. The result of the reaction of **19a** with *i*-PrMgCl at –78 °C for 1 hour is shown in entry 2. Comparing the results shown in entries 1 and 2, it is expected that the generated γ-chloromagnesio γ-lactone **20** is stable at –78 °C for over one hour. Other reaction conditions for the reaction of **19a** with *i*-PrMgCl are shown in entries 3 to 6.



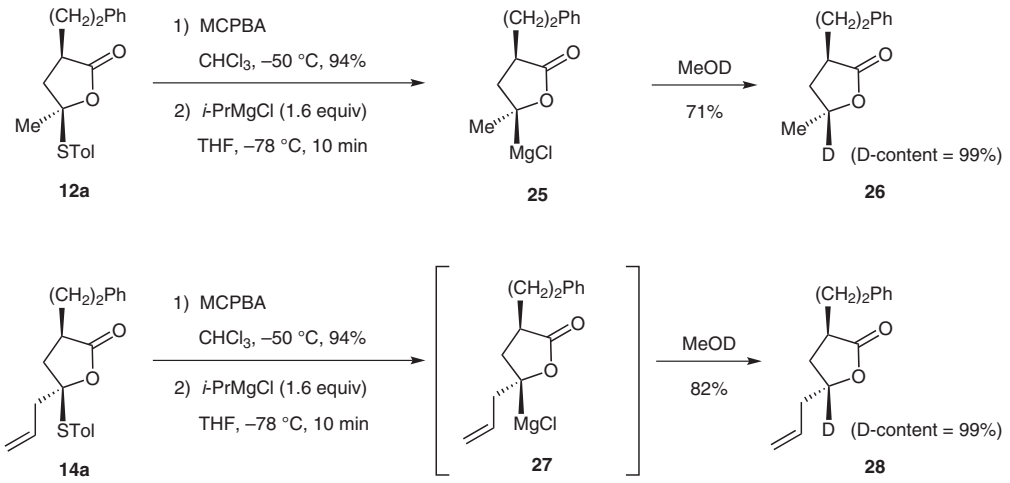
Scheme 5

These data indicate that γ-chloromagnesio γ-lactone **20** is rather stable even about –50 °C.

Contrary to the results described above, δ-chloromagnesio δ-lactone **23** generated from δ-*p*-tolylsulfanyl δ-lactone **22a** with *i*-PrMgCl was found to be fairly unstable. Thus, the reaction of **22a** carried out even at –78 °C for 10 minutes produced **24** in only 87% yield with several unknown by-products (entry 1). When the reaction mixture was stirred at –78 °C for one hour, the yield of **24** was markedly diminished (entry 2). When the temperature of the reaction mixture was allowed to warm to –50 °C, we obtained only a complex mixture (entry 4). We still find it difficult to propose a rational reason for the instability of δ-chloromagnesio δ-lactone **23** compared to **20** – the size of the ring is one possibility.

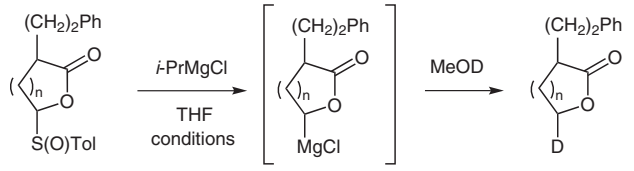
In a similar way, the sulfanyl group of **12a** was oxidized with MCPBA to a sulfinyl group, and the resultant sulfinyl lactone was treated with 1.6 equivalents of *i*-PrMgCl to give lactone **26** bearing a methyl group at the γ-position via γ-chloromagnesio γ-lactone **25** in 71% overall yield. When the reaction was quenched with MeOD, the rate of deuterium incorporation at the γ-position was 99%. Next, γ-sulfanyl γ-lactone **14a** was converted to γ-lactone bearing an allyl group **28** with 99% deuterium in corporation via γ-chloromagnesio γ-lactone **27** in 82% overall yield. Interestingly, although both γ-lactones **26** and **28** have two stereogenic centers, only a single product was obtained. No isomer was observed from detailed inspection of their ^{1}H NMR spectra. From these results, it was found that the stereochemistry of the carbon bearing the sulfinyl group of **12a** or **14a** at the γ-position was retained throughout the whole sequence (see Scheme 6).[10,16]

In order to extend this unprecedented Grignard reagent as a new synthetic method for γ-substituted γ-lactones, trapping of γ-chloromagnesio γ-lactones **20** and **31** with several electrophiles was investigated (Scheme 7). Thus, the reaction of **19a** and **19b** with *i*-PrMgCl followed by ethyl chloroformate at –78 °C for one hour gave good yields of esters **29** and **32**. Interestingly, both products, **29** and **32**, were obtained each as a single diastereomer.



Scheme 6

Table 1 Formation of Lactones **21** and **24** via Chloromagnesio Lactones **20** and **23** (Scheme 5)



19a (n = 1) **22a** (n = 2) **20** (n = 1) **23** (n = 2) **21** (n = 1) **24** (n = 2)

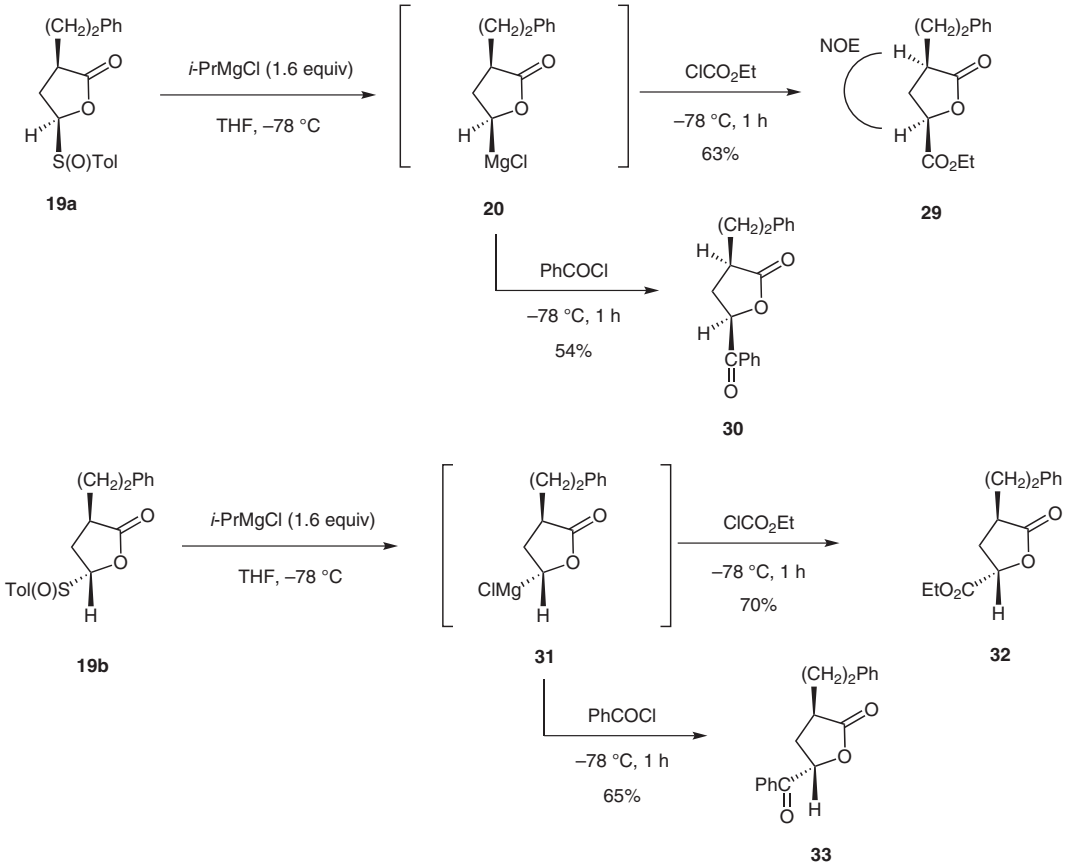
Entry	Conditions	**21** Yield (%)/ D-content (%)[a]	**24** Yield (%)/ D-content (%)[b]
1[c]	–78 °C, 10 min	94/99	87/99
2	–78 °C, 1 h	91/94	62/99
3	–78 °C, 2 h	85/91	55/99
4	–78 to –50 °C, 50 min, then –50 °C for 1 h	80/91	complex mixture
5	–78 to –50 °C, 50 min, then –50 °C for 2 h	80/88	–
6	–78 to –30 °C, 90 min, then –30 °C for 10 min	63/93	–

[a] Amount of *i*-PrMgCl used = 1.6 equiv.
[b] Amount of *i*-PrMgCl = 3.0 equiv.
[c] The results are described in Scheme 5.

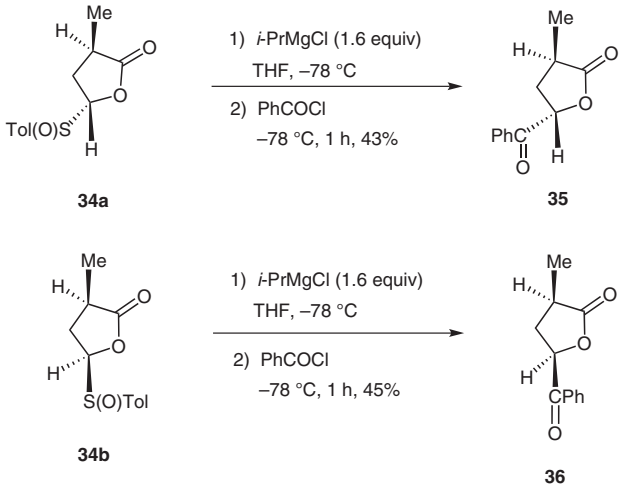
Configuration of the products was again confirmed by NOESY experiments and the reactions were found to be highly stereospecific as shown in Scheme 7. Namely, the stereochemistry of the anionic carbon was retained throughout the sequence. The reactions of **20** and **31** with benzoyl chloride at –78 °C for one hour gave products **30** and **33** in 54 and 65% yield, respectively, as a single product. When this reaction mixture was slowly allowed to warm to –50 °C and further stirred at –50 °C for one hour, the result was almost the same compared with the condition described above. No isomer was observed from detailed inspection of their ^{1}H NMR spectra.

In order to investigate the generality of these reactions, **34a** and **34b** were used in the following studies (Scheme 8). Treatment of γ-tolylsulfinyl γ-lactones **34a** and **34b** with *i*-PrMgCl followed by benzoyl chloride in the same way as described above resulted in the formation of γ-lactones **35** and **36**, respectively, via γ-chloromagnesio γ-lactones, again highly stereospecifically in moderate yields.

In order to compare the reactivity of δ-chloromagnesio δ-lactones with γ-chlolomagnesio γ-lactones, we tried to trap δ-chloromagnesio δ-lactones generated from **22a** and **22b** with ethyl chloroformate as an electrophile. In the same way described above, the reaction of **22a** and **22b** with *i*-PrMgCl followed by ethyl chloroformate at –78 °C for one hour gave the desired δ-lactones **37**and **38**, respectively, however, the yields were miserably low (Scheme

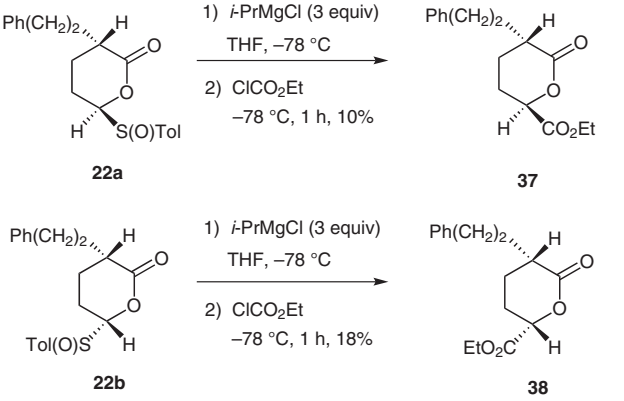


Scheme 7



Scheme 8

9) while, about 50% of protonated lactone at the δ-position was observed from ^{1}H NMR spectrum. From these results, γ-chloromagnesio γ-lactones were found to be more reactive at the low temperature. Instability of δ-chloromagnesio δ-lactones is one explanation for the low yields of the products **37** and **38**.



Scheme 9

β-Monosubstituted γ-Chloromagnesio γ-Lactones and β,β-Disubstituted γ-Chloromagnesio γ-Lactones

Finally, we investigated this reaction with β-monosubstituted γ-lactones **39a** and **39b**, and β,β-disubstituted γ-lactones, **39c** and **39d**, and the results are summarized in Table 2. γ-Sulfinylated γ-lactones **39** were treated with 1.6 equivalents of *i*-PrMgCl at –78 °C to give γ-chloromagnesio γ-lactones **40** in quantitative yields, which was confirmed by quenching the reaction with MeOD. The reaction gave γ-deuterated γ-lactones **41** in almost quantitative yields with 95–99% deuterium incorporation (entries 1, 6, and 10). These results indicates that γ-chloromagnesio γ-lactones **40a**, **40c**, and **40d** were generated from the corresponding sulfoxides by the sulfoxide–magnesium exchange reaction, and these are stable at –78 °C for at least 10 minutes. Entries 6 to 8 show that γ-chloromagnesio γ-lactone **40c** is fairly stable even at –50 °C for at least one hour.

The reaction of γ-chloromagnesio γ-lactones **40a** and **40b** with ethyl chloroformate at –78 °C for one hour gave the products **41b** and **41d** having an ethoxycarbonyl group in 36 and 46% yield, respectively (entries 2 and 4). In the same manner, the reaction of γ-chloromagnesio γ-lactones **40a** and **40b**, derived from **39a** and **39b**, with benzoyl chloride gave γ-lactones having a benzoyl group at the γ-position, **41c** and **41e**, in up to 61% yield (entries 3 and 5). The yields of both reactions were not satisfactory and steric hindrance was thought to be the reason for the low yield. Interestingly, the products were obtained as a single diastereomer, and again the reaction proceeded in a highly stereospecific manner.

Entries 6–11 show the results concerning the γ-chloromagnesio γ-lactones, **40c** and **40d**, generated from β,β-disubstituted γ-lactones **39c** and **39d**, respectively. As shown in the results in entries 6–8, and as already mentioned above, the γ-chloromagnesio γ-lactones **40c** generated from β,β-disubstituted γ-lactone **39c** were found to be stable at below –50 °C. The reactivity of the γ-chloromagnesio γ-lactone generated from **39c** and **39d** was investigated; however, both ethyl chloroformate and benzoyl chloride did not react at all with the generated γ-chloromagnesio γ-lactones **40c** and **40d**. Steric hindrance (neopentyl position) was thought to be the reason for the low reactivity with the electrophiles.

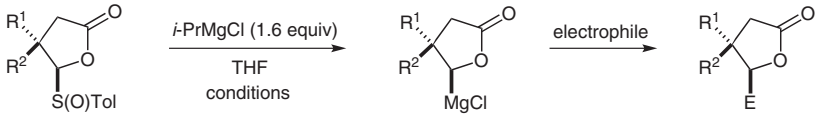
In conclusion, we were able to generate, for the first time, γ-chloromagnesio γ-lactones and δ-chloromagnesio δ-lactones from γ-lactones and δ-lactones having a tolylsulfinyl group at the γ- or δ-position by the sulfoxide–magnesium exchange reaction. Comparing the stability of γ-chlolomagnesio γ-lactones with δ-chloromagnesio δ-lactones, the former was found to be much more stable at low temperature and more reactive with some electrophiles. The presented procedure contributes to the synthesis of γ- or δ-lactones having multi-substituents.

All melting points were measured on Yanaco MP-S3 apparatus and are uncorrected. ^{1}H NMR spectra were measured in $CDCl_3$ using Jeol JNMLA 500 and Burker XWIN-600 spectrometers. Electron-impact mass spectra (MS) were obtained at 70 eV by direct insertion on a HITACHI M-80B mass spectrometer. IR spectra were recorded on a Perkin-Elmer Spectrum One FT-IR instrument. Silica gel 60N (Kanto Chemical) containing 0.5% fluorescence reagent 254 and a quartz column were used for column chromatography and the products having UV absorption were detected by UV irradiation. In experiments requiring an anhydrous reagent, CH_2Cl_2, DIPA, Et_3N, and pyridine were distilled from CaH_2. THF was distilled from diphenylketyl and acetone was dried over $CaSO_4$ and distilled before use. Benzoyl chloride and ethyl chloroformate were distilled prior to use.

tert-Butyl 4-Chloro-2-(2-phenylethyl)-4-(*p*-tolylsulfinyl)butyrate (8)

tert-Butyl 4-phenylbutyrate (440 mg, 2.0 mmol) was added to a solution of LDA [2.0 mmol, prepared from *i*-Pr_2NH (0.28 mL) and *n*-BuLi (1.25 mL, 1.6 M in hexane)] in anhyd THF (11.5 mL) at

Table 2 Generation of γ-Chloromagnesio γ-Lactone **40** from **39** and Quenching with Electrophiles



39 **40** **41**

Entry	**39**	R^1	R^2	Electrophile		Conditions	**41**	Yield (%)	
1	**39a**[a]	$Ph(CH_2)_2$	H	MeOD		–78 °C, 10 min	**41a**	95	(D-content, 98%)
2	**39a**[a]	$Ph(CH_2)_2$	H	$ClCO_2Et$		–78 °C, 1 h	**41b**	36[b]	
3	**39a**[a]	$Ph(CH_2)_2$	H	PhCOCl		–78 °C, 1 h	**41c**	36[b]	
4	**39b**[a]	$Me(CH_2)_5$	H	$ClCO_2Et$		–78 °C, 1 h	**41d**	46[b]	
5	**39b**[a]	$Me(CH_2)_5$	H	PhCOCl		–78 °C, 1 h	**41e**	61[b]	
6	**39c**	$-(CH_2)_{14}-$		MeOD		–78 °C, 10 min	**41f**	99	(D-content, 95%)
7	**39c**	$-(CH_2)_{14}-$		MeOD		–78 °C, 1 h	**41f**	90	(D-content, 91%)
8	**39c**	$-(CH_2)_{14}-$		MeOD		–78 to –50 °C, 1 h	**41f**	85	(D-content, 94%)
9	**39c**	$-(CH_2)_{14}-$		$ClCO_2Et$		–78 °C, 1 h		0	
10	**39d**[a]	4-$MeOC_6H_4(CH_2)_2$		Me	MeOD	–78 °C, 10 min	**41g**	99	(D-content, 99%)
11	**39d**[a]	4-$MeOC_6H_4(CH_2)_2$		Me	$ClCO_2Et$	–78 °C, 1 h		0	

[a] The main isomer of the γ-lactone having a *p*-tolylsulfinyl group at the γ-position was used.
[b] Some amount of lactone was contaminated and the yield was determined from its ^{1}H NMR spectrum.

–78 °C with stirring and the solution was stirred for 15 min. A solution of **7** (100 mg, 0.5 mmol) in THF (1 mL) was added to the solution dropwise with stirring. The reaction mixture was stirred for 5 min at –78 °C, and the reaction was quenched by adding sat. aq NH_4Cl (30 mL). The mixture was extracted with $CHCl_3$ (3 × 30 mL) and the combined organic layers were dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 5:1) to afford **8** (208 mg, 99%) as colorless crystals.

Mp 84–85 °C (EtOAc–hexane).

IR (KBr): 2975, 1723 (C=O), 1273, 1143, 1045 (S=O) cm^{-1}.

^{1}H NMR: δ = 1.42 (s, 9 H), 1.72–1.83 (m, 1 H), 1.85–2.01 (m, 2 H), 2.43 (s, 3 H), 2.41–2.45 (m, 1 H), 2.62 (t, *J* = 8.0 Hz, 2 H), 2.65–2.74 (m, 1 H), 4.54 (dd, *J* = 11.0, 2.7 Hz, 1 H), 7.13–7.22 (m, 3 H), 7.24–7.30 (m, 2 H), 7.34 (d, *J* = 8.0 Hz, 2 H), 7.59 (d, *J* = 8.0 Hz, 2 H).

Anal. Calcd for $C_{23}H_{29}ClO_3S$: C, 65.62; H, 6.94; Cl, 8.42; S, 7.62. Found: C, 65.32; H, 6.50; Cl, 8.54, S, 7.66.

γ-Sulfanyl γ-Lactones; 3-(2-Phenylethyl)-5-(*p*-tolylsulfanyl)dihydrofuran-2-ones (9a,b); Typical Procedure

A solution of NaI (356 mg, 2.4 mmol) in anhyd acetone (14 mL) was stirred for 15 min at –55 °C. TFAA (0.34 mL, 2.4 mmol) was added dropwise to the solution of NaI with stirring at –55 °C and the mixture was stirred for 15 min. A solution of the adduct **8** (200 mg, 0.48 mmol) in anhyd acetone (2 mL) was added dropwise to the solution of NaI and TFAA at –55 °C with stirring and the reaction mixture was stirred for 10 min. The reaction was quenched by adding sat. aq $NaHCO_3$ (20 mL) followed by sat. aq Na_2SO_3 (5 mL) and the mixture was extracted with $CHCl_3$ (3 × 30 mL). The organic layer was washed with sat. aq $NaHCO_3$ (30 mL) and dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 10:1) to give **9a** (78 mg, 52%) and **9b** (46.5 mg, 31%) as colorless crystals.

9a

Mp 70–71 °C (hexane).

IR (KBr): 2919, 1772 (C=O), 1758, 1492, 1455, 1170, 923 cm^{-1}.

^{1}H NMR: δ = 1.62–1.71 (m, 1 H), 1.84 (dt, *J* = 13.2, 9.3 Hz, 1 H), 2.14–2.23 (m, 1 H), 2.32 (s, 3 H), 2.51–2.75 (m, 4 H), 5.56 (dd,

J = 9.3, 6.6 Hz, 1 H), 7.12–7.20 (m, 5 H), 7.25–7.29 (m, 2 H), 7.40–7.43 (m, 2 H).

MS: m/z (%) = 312 (M^+, 28), 189 (63), 171 (23), 143 (13), 129 (21), 117 (36), 91 (100), 77 (9), 65 (12).

HRMS: m/z calcd for $C_{19}H_{20}O_2S$ (M^+): 312.1183; found: 312.1189.

Anal. Calcd for $C_{19}H_{20}O_2S$: C, 73.04; H, 6.45; S, 10.26. Found: C, 72.92; H, 6.28; S, 10.09.

9b

Mp 86–87 °C (hexane).

IR (KBr): 2920, 1781 (C=O), 1496, 1452, 1346, 1236, 1203, 1164, 1133, 1062 cm^{-1}.

^1H NMR: δ = 1.66–1.75 (m, 1 H), 2.12–2.21 (m, 1 H), 2.33 (s, 3 H), 2.28–2.49 (m, 3 H), 2.61–2.75 (m, 2 H), 5.72 (dd, J = 7.6, 3.4 Hz, 1 H), 7.10–7.21 (m, 5 H), 7.25–7.29 (m, 2 H), 7.37–7.41 (m, 2 H).

MS: m/z (%) = 312 (M^+, 29), 189 (67), 171 (24), 143 (14), 129 (22), 117 (37), 91 (100), 77 (9).

HRMS: m/z calcd for $C_{19}H_{20}O_2S$ (M^+): 312.1162; found: 312.1172.

Anal. Calcd for $C_{19}H_{20}O_2S$: C, 73.04; H, 6.45; S, 10.26. Found: C, 72.13; H, 6.36; S, 10.30.

Adduct of an Ester Having Functional Groups at the γ-Position; *tert*-Butyl 4-Chloro-2-(2-phenylethyl)-4-(*p*-tolylsulfinyl)pentanoate (10); Typical Procedure

tert-Butyl 4-phenylbutyrate (440 mg, 2 mmol) was added to a solution of LDA [2.0 mmol; prepared from *i*-Pr_2NH (0.28 mL) and *n*-BuLi (1.25 mL, 1.6 M in hexane)] in anhyd THF (12 mL) at –78 °C with stirring. The mixture was stirred for 15 min, then a solution of **7** (100 mg, 0.5 mmol) in anhyd THF (1 mL) was added. The mixture was stirred for 5 min at –78 °C, MeI (354 mg, 2.5 mmol) was added and the mixture was stirred for 5 min. The reaction was quenched by adding sat. aq NH_4Cl (30 mL) and the mixture was extracted with $CHCl_3$ (3 × 30 mL). The combined organic layers were dried ($MgSO_4$), filtered, and the filtrate was evaporated to give a residue which was purified by silica gel column chromatography (hexane–EtOAc, 10:1) to afford **10** (208 mg, 99%) as colorless crystals.

Mp 85–86 °C (hexane).

IR (KBr): 2973, 2927, 1722 (C=O), 1494, 1457, 1391, 1366, 1144, 1051 (S=O) cm^{-1}.

^1H NMR: δ = 1.45 (d, J = 9.0 Hz, 3 H), 1.48 (s, 9 H), 1.58 (m, 1 H), 1.79–2.18 (m, 4 H), 2.43 (s, 3 H), 2.55–2.68 (m, 3 H), 2.77–2.84 (m, 1 H), 7.15–7.33 (m, 7 H), 7.59–7.63 (m, 2 H).

Anal Calcd for $C_{24}H_{31}ClO_3S$: C, 66.26; H, 7.18; Cl, 8.15; S, 7.37. Found: C, 66.14; H, 7.09; Cl, 8.09; S, 7.42.

4-Chloro-2-(2-phenylethyl)-4-(*p*-tolylsulfinyl)pentanoic Acid (11)

Trifluoroacetic acid (TFA, 0.56 mL, 7.5 mmol) was added to a solution of **10** (208 mg, 0.5 mmol) in CH_2Cl_2 (10 mL) at r.t. The reaction mixture was stirred for 1 d and the reaction was quenched by adding sat. aq $NaHCO_3$ (20 mL). The mixture was extracted with CH_2Cl_2 (3 × 20 mL) and the aqueous separted. The aqueous layer was acidified with aq 10% HCl and extracted with CH_2Cl_2 (3 × 20 mL). The combined organic layers were evaporated to give **11** (172 mg, 91%) as colorless crystals.

Mp 93–94 °C (EtOAc–hexane).

IR (KBr): 2923, 1732 (C=O), 1454, 1032 (S=O), 811 cm^{-1}.

^1H NMR: δ = 1.45 (s, 3 H), 1.90–1.99 (m, 1 H), 2.02–2.12 (m, 1 H), 2.31 (dd, J = 15.0, 2.1 Hz, 1 H), 2.43 (s, 3 H), 2.93–2.99 (m, 1 H), 2.69–2.75 (m, 3 H), 7.17–7.29 (m, 5 H), 7.31 (d, J = 8.2 Hz, 2 H), 7.62 (d, J = 8.2 Hz, 2 H).

Anal. Calcd for $C_{20}H_{23}ClO_3S$: C, 63.40; H, 6.12; Cl, 9.36; S, 8.46. Found: C, 63.33; H, 6.08; Cl, 9.20; S, 8.32.

5-Methyl-3-(2-phenylethyl)-5-(*p*-tolylsulfanyl)dihydrofuran-2-ones (12a,b)

12a

Colorless crystals; mp 58–59 °C (hexane).

IR (KBr): 2939, 1774 (C=O), 1762 (C=O), 1232, 1143, 817 cm^{-1}.

^1H NMR: δ = 1.65–1.71 (m, 1 H), 1.67 (s, 3 H), 2.00 (dd, J = 13.2, 11.4 Hz, 1 H), 2.18–2.24 (m, 1 H), 2.42–2.48 (m, 1 H), 2.60–2.65 (m, 1 H), 2.61 (dd, J = 13.2, 9 Hz, 1 H), 2.68–2.74 (m, 1 H), 7.12 (d, J = 7.8 Hz, 2 H), 7.15 (d, J = 7.8 Hz, 2 H), 7.20–7.23 (m, 1 H), 7.28–7.30 (m, 2 H), 7.41 (d, J = 8.4 Hz, 2 H).

Anal. Calcd for $C_{20}H_{22}O_2S$: C, 73.58; H, 6.79; S, 9.82. Found: C, 73.53; H, 6.67; S, 9.85.

12b

Colorless crystals; mp 69–70 °C (hexane).

IR (KBr): 2942, 2927, 1760 (C=O), 1494, 1453, 1237, 1081, 920, 811 cm^{-1}.

^1H NMR: δ = 1.48–1.59 (m, 1 H), 1.61 (s, 3 H), 2.02–2.08 (m, 2 H), 2.33 (s, 3 H), 2.42 (dd, J = 13.2, 9.6 Hz, 1 H), 2.49–2.54 (m, 1 H), 2.58–2.71 (m, 2 H), 7.12, 7.16 (d, J = 7.8 Hz, 2 H each), 7.18–7.20 (m, 1 H), 7.27, 7.45 (d, J = 7.8 Hz, 2 H each).

Anal. Calcd for $C_{20}H_{22}ClO_2S$: C, 73.58; H, 6.79; S, 9.82. Found: C, 73.62, H, 6.70, S, 9.81.

***tert*-Butyl 4-Chloro-2-(2-phenylethyl)-4-(*p*-tolylsulfinyl)hept-6-enoate (13)**

Colorless crystals; mp 98–100 °C (hexane).

IR (KBr): 2977, 2931, 1727 (C=O), 1367, 1143, 1050 (S=O), 937, 811 cm^{-1}.

^1H NMR: δ = 1.49 (s, 9 H), 1.82–2.01 (m, 2 H), 2.11–2.19 (m, 2 H), 2.43 (s, 3 H), 2.66–2.78 (m, 4 H), 2.86–2.92 (m, 1 H), 5.14 (dd, J = 16.8, 1.2 Hz, 1 H), 5.22 (d, J = 10.0 Hz, 1 H), 5.73–5.81 (m, 1 H), 7.19–7.30 (m, 5 H), 7.32 (d, J = 8.2 Hz, 2 H), 7.64 (d, J = 8.2 Hz, 2 H).

Anal. Calcd for $C_{26}H_{33}ClO_3S$: C, 67.73; H, 7.21; Cl, 7.69; S, 6.95. Found: C, 67.63; H, 7.18; Cl, 7.61; S, 6.91.

5-Allyl-3-(2-phenylethyl)-5-(*p*-tolylsulfanyl)dihydrofuran-2-ones (14a,b)

14a

Colorless crystals; mp 111–112 °C (hexane).

IR (KBr): 2934, 1775 (C=O), 1495, 1452, 1257, 1216, 1139, 1022 cm^{-1}.

^1H NMR: δ = 1.63–1.72 (m, 1 H), 2.06–2.22 (m, 2 H), 2.34 (s, 3 H), 2.37–2.49 (m, 2 H), 2.55–2.74 (m, 4 H), 5.15 (dd, J = 10.1, 1.8 Hz, 1 H), 5.21 (dd, J = 10.1, 1.7 Hz, 1 H), 5.77 (m, 1 H), 7.12–7.22 (m, 5 H), 7.27–7.30 (m, 2 H), 7.42 (d, J = 8.1 Hz, 2 H).

Anal. Calcd for $C_{22}H_{24}O_2S$: C, 74.96; H, 6.86; S, 9.10. Found: C, 74.82; H, 6.76; S, 9.10.

14b

Colorless crystals; mp 105–106 °C (hexane).

IR (neat): 2926, 1772 (C=O), 1493, 1262, 1190, 936, 812 cm^{-1}.

^1H NMR: δ = 1.38–1.47 (m, 1 H), 1.92–2.04 (m, 2 H), 2.32 (s, 3 H), 2.45–2.61 (m, 6 H), 5.13–5.20 (m, 2 H), 5.71–5.81 (m, 1 H), 7.09–7.20 (m, 5 H), 7.25–7.29 (m, 2 H), 7.46 (d, J = 8.0 Hz, 2 H).

Anal. Calcd for $C_{22}H_{24}O_2S$: C, 74.96; H, 6.86; S, 9.10. Found: C, 74.85; H, 6.79; S, 9.08.

***tert*-Butyl 2-(2-Phenylethyl)-5-(*p*-tolylsulfanyl)pentanoate (16)**

tert-Butyl 4-phenylbutyrate (754 mg, 3.42 mmol) was added to a solution of LDA [3.42 mmol, prepared from *i*-Pr_2NH (0.48 mL and *n*-BuLi (2.14 mL), 1.6 M in hexane)] in the presence of HMPA (0.6 mL, 3.42 mmol) in anhyd THF (4.8 mL) at –78 °C with stirring. The mixture was stirred for 10 min, then a solution of 3-(*p*-tolylsulfanyl)propyl iodide (200 mg, 0.68 mmol) in THF (2 mL) was added The reaction mixture was stirred at –78 °C for 10 min. The reaction was quenched by adding sat. aq NH_4Cl (30 mL) and the mixture was extracted with $CHCl_3$ (3 × 30 mL). The combined organic layers were washed with sat. aq NH_4Cl (30 mL) and dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 10:1) to afford **16** (217 mg, 82%) as colorless oil.

IR (neat): 2930, 1724 (C=O), 1499, 1366, 1145 cm^{-1}.

^1H NMR: δ = 1.43 (s, 9 H), 1.57–1.63 (m, 3 H), 1.64–1.72 (m, 2 H), 1.85–1.93 (m, 1 H), 2.25 (sept. 1 H), 2.54–2.64 (m, 2 H), 2.84 (t, *J* = 6.7 Hz, 2 H), 7.08 (d, *J* = 7.9 Hz, 2 H), 7.14–7.19 (m, 3 H), 7.23 (d, *J* = 8.1 Hz, 2 H), 7.28 (d, *J* = 7.4 Hz, 2 H).

MS: *m*/*z* (%) = 218 (M^+, 65), 328 (100), 311 (15), 280 (14), 219 (7), 205 (23), 187 (15), 163 (25), 137 (28), 124 (44), 91 (60), 57 (28).

HRMS: *m*/*z* calcd for $C_{24}H_{32}O_2S$ (M^+): 384.2123; found: 384.2132.

5-Chloro-2-(2-phenylethyl)-5-(*p*-tolylsulfinyl)pentanoic Acid (17)

MCPBA (206 mg) was added to a solution of **16** (218 mg, 0.776 mmol) in CH_2Cl_2 (11 mL) at 0 °C with stirring. The solution was stirred for 10 min, and the reaction was quenched by adding sat. aq Na_2SO_3 (5 mL) followed by $NaHCO_3$ (30 mL). The mixture was extracted with CH_2Cl_2 (3 × 20 mL) and the combined organic layers were washed with sat. aq $NaHCO_3$ (30 mL) and dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue. The residue was purified by silica gel column chromatography to give the sulfoxide as a mixture of two diastereomers (colorless oil). *N*-Chlorosuccinimide (NCS, 112 mg, 0.833 mmol) was added to a solution of the sulfoxide (224 mg, 0.757 mmol) in CCl_4 (2.5 mL) and the suspension was stirred at r.t. for 12 h. The precipitate (succinimide) was filtered off and the solvent evaporated. The residue was purified by silica gel column chromatography to give 222 mg (89%) of *tert*-butyl 5-chloro-2-(2-phenylethyl)-5-(*p*-tolylsulfinyl)pentanoate (a mixture of two diastereomers) as a colorless oil. To a solution of the product (386 mg, 0.887mmol) in CH_2Cl_2 (12.6 mL) was added trifluoroacetic acid (1.36 mL, 17.7 mmol). The reaction mixture was stirred for 12 h and the reaction was quenched by adding sat. aq $NaHCO_3$ (20 mL). The mixture was extracted with CH_2Cl_2 (3 × 20 mL) and the organic layer was washed and dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 10:1) to afford carboxylic acid **17** (308 mg, 92%) as a colorless oil.

IR (neat): 3026, 2930, 1724 (C=O), 1495, 1454, 1216, 1085, 1040 (S=O), 811 cm^{-1}.

^1H NMR: δ = 1.69–1.81 (m, 2 H), 1.83–1.87 (m, 1 H), 1.96–2.02 (m, 2 H), 2.24–2.36 (m, 1 H), 2.42 (s, 3 H), 2.38–2.47 (m, 1 H), 2.57–2.63 (m, 2 H), 2.64–2.71 (m, 1 H) 4.51–4.55 (m, 1 H), 7.15–7.20 (m, 3 H), 7.27–7.29 (m, 2 H), 7.33 (d, *J* = 7.9 Hz, 2 H), 7.54 (d, *J* = 7.9 Hz, 2 H).

MS: *m*/*z* (%) = 378 (M^+, trace), 241 (3), 239 (10), 238 (10), 203 (15), 202 (13), 157 (19), 140 (62), 105 (30), 91 (100), 65 (20).

HRMS: *m*/*z* calcd for $C_{20}H_{23}ClO_3S$ (M^+): 378.1056; found: 378.1057.

3-(2-Phenylethyl)-6-(*p*-tolylsulfanyl)tetrahydropyran-2-ones (18a,b)

A solution of NaI (1.76 g, 11.7 mmol) in EtCN (55 mL) was stirred for 10 min at –50 °C. TFAA (1.62 mL, 11.7 mmol) was added dropwise with stirring at –50 °C and the reaction mixture was stirred for 15 min. A solution of carboxylic acid **17** (744 mg, 1.96 mmol) in EtCN (10 mL) was added dropwise –50 °C with stirring and the mixture was stirred for 10 min. The reaction was quenched by adding sat. aq $NaHCO_3$ (50 mL) followed by sat. aq Na_2SO_3 (10 mL). The mixture was extracted with $CHCl_3$ (3 × 50 mL) and the combined organic layers were washed with sat. aq $NaHCO_3$ (60 mL) and dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 20:1) to give **18a** (288 mg, 45%) and **18b** (144 mg, 22%) as colorless crystals.

18a

Mp 35–36 °C (EtOAc–hexane).

IR (KBr): 3027, 2954, 2926, 2869, 1713 (C=O), 1492, 1454, 1374, 1169, 1070, 1017, 814 cm^{-1}.

^1H NMR: δ = 1.59–1.66 (m, 1 H), 1.75–1.82 (m, 1 H), 1.85–1.92 (m, 1 H), 2.09–2.20 (m, 1 H), 2.23–2.38 (m, 3 H), 2.64–2.77 (m, 2 H), 5.58 (dd, *J* = 8.4, 4.2 Hz, 1 H), 7.13 (d, *J* = 7.8 Hz, 2 H), 7.18 (m, 3 H), 7.27 (t, *J* = 7.8 Hz, 2 H), 7.41 (d, *J* = 8.4 Hz, 2 H).

Anal. Calcd for $C_{20}H_{22}O_2S$: C, 73.58; H, 6.79; S, 9.82. Found: C, 73.54; H, 6.71; S, 9.73.

18b

Mp 75–76 °C (EtOAc–hexane).

IR (KBr): 2918, 1713 (C=O), 1493, 1454, 1192, 1170, 1143, 1074, 980, 858 cm^{-1}.

^1H NMR: δ = 1.75–1.82 (m, 2 H), 2.02–2.10 (m, 2 H), 2.19–2.25 (m, 2 H), 2.33 (s, 3 H), 2.41–2.46 (m, 1 H), 2.67–2.77 (m, 2 H), 5.55 (ddd, *J* = 7.2, 5.1, 0.6 Hz, 1 H), 7.13 (d, *J* = 7.8 Hz, 2 H), 7.19 (d, *J* = 7.2 Hz, 2 H), 7.27 (m, 3 H), 7.44 (d, *J* = 8.4 Hz, 2 H).

Anal. Calcd for $C_{20}H_{22}O_2S$: C, 73.58; H, 6.79; S, 9.82. Found: C, 73.76; H, 6.74; S, 9.73.

3-(2-Phenylethyl)-5-(*p*-tolylsulfinyl)dihydrofuran-2-ones (19a,b)

MCPBA (42.3 mg; 0.18 mmol) was added to a solution of **9a** (50 mg, 0.16 mmol) in $CHCl_3$ (5 mL) at 0 °C with stirring. The mixture was stirred for 30 min and the reaction was quenched by adding sat. aq Na_2SO_3 (5 mL) and $NaHCO_3$ (30 mL). The mixture was extracted with $CHCl_3$ (3 × 20 mL) and the combined organic layers were dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 10:1) to afford **19a** (49.4 mg, 94%) as a 9:1 mixture of two diastereomers.

19a

Colorless crystals; mp 117–120 °C (EtOAc).

IR (KBr): 2950, 2919, 1784 (C=O), 1770 (C=O), 1494, 1455, 1303, 1208, 1156, 1089, 1059 (S=O), 1034, 805 cm^{-1}.

^1H NMR: δ = 1.24–1.37 (m, 1 H), 1.94–2.01 (m, 1 H), 2.09–2.18 (m, 1 H), 2.39 (s, 3 H), 2.48–2.90 (m, 4 H), 4.92 (t, *J* = 9.5 Hz, 0.9 H), 5.18 (t, *J* = 10.0 Hz, 0.1 H), 7.11–7.36 (m, 5 H), 7.35, 7.40 (d, *J* = 8.0 Hz, 2 H each).

MS: *m*/*z* (%) = 329 ($[M + 1]^+$, trace), 312 (5), 189 (68), 171 (23), 140 (25), 117 (26), 91 (100), 84 (15).

HRMS: *m*/*z* calcd for $C_{19}H_{20}O_3S$ (M^+): 329.1201; found: 329.1209.

Anal. Calcd for $C_{19}H_{20}O_3S$: C, 69.48; H, 6.14; S, 9.76. Found: C, 69.26; H, 6.10; S, 9.74.

19b

Prepared from **9b**; colorless crystals; mp 79–80 °C (EtOAc–hexane).

IR (KBr): 2873, 1789 (C=O), 1493, 1129, 1045, 812 cm^{-1}.

^1H NMR: δ = 1.68–1.77 (m, 1 H), 1.92–1.99 (m, 1 H), 2.16–2.25 (m, 1 H), 2.44 (s, 3 H), 2.73 (t, *J* = 7.8 Hz, 2 H), 2.80–2.89 (m, 2 H), 5.18 (dd, *J* = 8.7, 1.5 Hz, 1 H), 7.16–7.31 (m, 5 H), 7.37 (d, *J* = 8.3 Hz, 2 H), 7.51 (d, *J* = 8.3 Hz, 2 H).

Anal. Calcd for $C_{19}H_{20}O_3S$: C, 69.48; H, 6.14; S, 9.76. Found: C, 69.39; H, 6.11; S, 9.71.

Generation of γ-Chloromagnesio γ-Lactones and δ-Chloromagnesio δ-Lactones; 5-Deuterio-3-(2-phenylethyl)dihydrofuran-2-one (21); Typical Procedure

A solution of *i*-PrMgCl (2.0 mol/L, 0.07 mL) in THF was added to a solution of **19a** (30 mg, 0.09 mmol) in THF (6 mL) in a flame-dried flask at –78 °C under argon. The reaction mixture was stirred for 10 min, quenched with MeOD (3 mL), and extracted with $CHCl_3$ (3 × 20 mL). The combined organic layers were dried ($MgSO_4$), filtered, and the solvent was evaporated to give a residue which was purified by silica gel column chromatography (hexane–EtOAc, 5:1) to afford **21** (16.1 mg, 94%) as a colorless oil.

IR (neat): 2927, 1766 (C=O), 1496, 1454, 1350, 1330, 1163, 1045 cm^{-1}.

^1H NMR: δ = 1.76–1.81 (m, 1 H), 1.91–2.01 (m, 2 H), 2.20–2.29 (m, 1 H), 2.37 (ddd, *J* = 12.4, 8.8, 6.7 Hz, 1 H), 2.46–2.54 (m, 1 H), 2.68–2.84 (m, 2 H), 4.13–4.20 (m, 1 H), 7.19–7.22 (m, 3 H), 7.28–7.32 (m, 2 H).

MS: *m*/*z* (%) = 191 (M^+, 19), 105 (17), 91 (38), 87 (100).

HRMS: *m*/*z* calcd for $C_{12}H_{13}DO_2$ (M^+): 191.1055; found: 191.1056.

3-(2-Phenylethyl)-6-(*p*-tolylsulfinyl)tetrahydropyran-2-ones (22a,b)

22a

Colorless crystals (mixture of two diastereomers).

Major product; mp 110–118 °C (EtOAc–hexane).

IR (KBr): 2960, 2922, 1736 (C=O), 1495, 1454, 1162, 1097, 1054 (S=O), 813 cm^{-1}.

^1H NMR: δ = 1.59–1.68 (m, 1 H), 1.75–1.87 (m, 1 H), 1.97–2.06 (m, 1 H), 2.16–2.33 (m, 3 H), 2.42 (s, 3 H), 2.49–2.59 (m, 1 H), 2.65–2.80 (m, 2 H), 4.88 (dd, *J* = 8.4, 5.5 Hz, 1 H), 7.20 (t, *J* = 6.8 Hz, 3 H), 7.29 (t, *J* = 6.8 Hz, 2 H), 7.35 (d, *J* = 8.0 Hz, 2 H), 7.54 (d, *J* = 8.0 Hz, 2 H).

Anal. Calcd for $C_{20}H_{22}O_3S$: C, 70.15; H, 6.48; S, 9.36. Found: C, 70.07; H, 6.42; S, 9.27.

22b

Colorless crystals (about 9:1 mixture of two diastereomers).

Major product; mp 108–113 °C (EtOAc–hexane).

IR (KBr): 2926, 1763 (C=O), 1496, 1453, 1093, 1047 (S=O), 939, 813 cm^{-1}.

^1H NMR: δ = 1.80–1.93 (m, 1 H), 1.99–2.14 (m, 3 H), 2.24–2.35 (m, 1 H), 2.42 (s, 3 H), 2.40–2.49 (m, 1 H), 2.53–2.62 (m, 1 H), 2.67–2.84 (m, 2 H), 4.82 (t, *J* = 4.9 Hz, 0.9 H), 5.02 (t, *J* = 5.1 Hz, 0.1 H), 7.18–7.23 (m, 3 H), 7.27–7.33 (m, 2 H), 7.36 (d, *J* = 8.2 Hz, 2 H), 7.58 (d, *J* = 8.2 Hz, 2 H).

Anal. Calcd for $C_{20}H_{22}O_3S$: C, 70.15; H, 6.48; S, 9.36. Found: C, 69.98; H, 6.50; S, 9.25.

5-Deuterio-3-(2-phenylethyl)dihydrofuran-2-one (24)

Colorless oil.

IR (neat): 2934, 1732 (C=O), 1454, 1375, 1250, 1144, 1094, 751 cm^{-1}.

^1H NMR: δ = 1.55–1.63 (m, 1 H), 1.74–1.81 (m, 1 H), 1.83–1.96 (m, 2 H), 2.13 (sext, *J* = 7.3 Hz, 1 H), 2.24–2.29 (m, 1 H), 2.43–2.47 (m, 1 H), 2.69–2.79 (m, 2 H), 4.26–4.30 (m, 1 H), 7.18–7.21 (m, 3 H), 7.26–7.30 (m, 2 H).

MS: *m*/*z* (%) = 205 (M^+, 4), 101 (100), 91 (42), 65 (11).

HRMS: *m*/*z* calcd for $C_{13}H_{15}DO_2$ (M^+): 205.1212; found: 205.1210.

5-Deuterio-5-methyl-3-(2-phenylethyl)dihydrofuran-2-one (26)

Colorless oil.

IR (neat): 2973, 2930, 1763 (C=O), 1496, 1454, 1244, 1143, 1108, 976 cm^{-1}.

^1H NMR: δ = 1.34 (s, 3 H), 1.71–1.83 (m, 1 H), 1.97–2.24 (m, 3 H), 2.57–2.83 (m, 3 H), 7.19–7.32 (m, 5 H).

MS: *m*/*z* (%) = 204 (M^+, 10), 100 (100), 91 (35), 65 (8), 41 (8).

HRMS: *m*/*z* calcd for $C_{15}H_{16}O_2$ (M^+): 204.1150; found: 204.1155.

5-Allyl-5-deuterio-3-(2-phenylethyl)dihydrofuran-2-one (28)

Colorless oil.

IR (neat): 2925, 1770 (C=O), 1643, 1454, 1206, 975 cm^{-1}.

^1H NMR: δ = 1.53–1.62 (m, 1 H), 1.68–1.80 (m, 1 H), 2.27 (dddd, *J* = 13.7, 9.2, 7.2, 4.9 Hz, 1 H), 2.36–2.83 (m, 6 H), 5.13–5.20 (m, 2 H), 5.71–5.85 (m, 1 H), 7.18–7.32 (m, 5 H).

MS: *m*/*z* (%) = 231 (M^+, 15), 190 (26), 172 (8), 144 (8), 127 (33), 109 (35), 91 (100), 77 (9).

HRMS: *m*/*z* calcd for $C_{15}H_{17}DO_2$ (M^+): 231.1369; found: 231.1370.

5-Ethoxycarbonyl-3-(2-phenylethyl)dihydrofuran-2-ones (29 and 32)

A solution of *i*-PrMgCl (2.0 mol/L, 0.11 mL) in THF was added to a solution of **19a** (45.4 mg, 0.14 mmol) in THF (5 mL) in a flame-dried flask at –78 °C under argon. After stirring the reaction mixture for 10 min, ethyl chloroformate (0.05 mL, 0.56 mmol) was added. The mixture was stirred for 1 h at –78 °C and the reaction was quenched by adding sat. aq NH_4Cl (20 mL). The mixture was extracted with $CHCl_3$ (3 × 20 mL) and the combined organic layers were dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 5:1) to afford **29** (23.1 mg, 63%) as a colorless oil.

IR (neat): 3029, 2939, 1782 (C=O), 1753 (C=O), 1497, 1454, 1378, 1217, 1155, 1070, 956 cm^{-1}.

^1H NMR: δ = 1.32 (t, *J* = 7.1 Hz, 3 H), 1.77–1.83 (m, 1 H), 2.00 (dt, *J* = 12.8, 9.2 Hz, 1 H), 2.24–2.31 (m, 1 H), 2.54–2.61 (m, 1 H), 2.67–2.73 (m, 2 H), 2.79–2.84 (m, 1 H), 4.27 (q, *J* = 7.3 Hz, 2 H), 4.77 (dd, *J* = 9.2, 7.3 Hz, 1 H), 7.18–7.23 (m, 3 H), 7.28–7.31 (m, 2 H).

MS: *m*/*z* (%) = 262 (M^+, 17), 189 (31), 171 (7), 158 (58), 140 (10), 129 (8), 112 (100), 105 (26), 91 (85), 77 (7).

HRMS: *m*/*z* calcd for $C_{15}H_{18}O_4$ (M^+): 262.1204; found: 262.1208.

32

Colorless oil.

IR (neat): 2983, 2939, 1779 (C=O), 1746 (C=O), 1497, 1455, 1377, 1195, 1164, 1136, 1061, 1025, 937 cm^{-1}.

^1H NMR: δ = 1.29 (t, *J* = 7.2 Hz, 3 H), 1.70–1.80 (m, 1 H), 2.19–2.29 (m, 2 H), 2.44–2.50 (m, 1 H), 2.62–2.77 (m, 3 H), 4.24 (q, *J* = 3.2 Hz, 2 H), 4.88 (dd, *J* = 9.2, 2.4 Hz, 1 H), 7.18–7.31 (m, 5 H).

MS: *m*/*z* (%) = 262 (M^+, 15), 190 (24), 189 (23), 158 (40), 112 (65), 91 (91), 86 (100), 84 (21). HRMS: *m*/*z* calcd for $C_{15}H_{18}O_4$ (M^+): 262.1205; found: 262.1203.

5-Benzoyl-3-(2-phenylethyl)dihydrofuran-2-ones (30 and 33)

A solution of *i*-PrMgCl (2.0 mol/L, 0.11 mL) in THF (5 mL) was added to a solution of **19a** (45.4 mg, 0.14 mmol) in THF (1 mL) in a flame-dried flask at –78 °C under argon. After stirring the reaction mixture for 10 min, benzoyl chloride (0.06 mL, 0.56 mmol) was added. The mixture was stirred for 1 h at –78 °C and the reaction was quenched by adding sat. aq NH_4Cl (20 mL). The mixture was extracted with $CHCl_3$ (3 × 20 mL) and the combined organic layers were dried ($MgSO_4$). Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc, 5:1) to afford **30** (22.3 mg, 54%) as colorless crystals.

30

Mp 87–88 °C (hexane).

IR (KBr): 2926, 1778 (C=O), 1694 (C=O), 1597, 1450, 1233, 1159 cm^{-1}.

^1H NMR: δ = 1.75–1.85 (m, 1 H), 2.16–2.31 (m, 2 H), 2.64–2.86 (m, 4 H), 5.56 (dd, *J* = 8.9, 7.0 Hz, 1 H), 7.16–7.32 (m, 5 H), 7.51 (t, *J* = 7.8 Hz, 2 H), 7.64 (t, *J* = 7.8 Hz, 1 H), 7.99 (d, *J* = 7.8 Hz, 2 H).

MS: *m*/*z* (%) = 294 (M^+, 9), 190 (25), 171 (12), 162 (9), 145 (24), 133 (15), 117 (22), 105 (100), 91 (66), 77 (41), 65 (11).

HRMS: *m*/*z* calcd for $C_{19}H_{18}O_3$ (M^+): 294.1255; found: 294.1257.

Anal. Calcd for $C_{19}H_{18}O_3$: C, 77.53; H, 6.16. Found: C, 77.45; H, 6.05.

33

Colorless crystals; mp 93–94 °C (hexane).

IR (KBr): 2943, 2924, 1768 (C=O), 1699, 1595, 1448, 1224, 1174, 1057, 1008 cm^{-1}.

^1H NMR: δ = 1.76–1.82 (m, 1 H), 2.22–2.35 (m, 2 H), 2.60–2.68 (m, 2 H), 2.74 (t, *J* = 8.2 Hz, 2 H), 5.77 (dd, *J* = 9.4, 2.1 Hz, 1 H), 7.17–7.30 (m, 5 H), 7.62–7.65 (m, 1 H), 7.97 (d, *J* = 8.3 Hz, 2 H).

Anal. Calcd for $C_{19}H_{18}O_3$: C, 77.53; H, 6.16. Found: C, 77.34; H, 6.07.

3-Methyl-5-(*p*-tolylsulfinyl)dihydrofuran-2-ones (34a and 34b)

34a

Colorless oil (ca. 7:3 mixture of two diastereomers).

IR (neat): 2976, 2937, 1788 (C=O), 1494, 1455, 1188, 1148, 1090 (S=O), 1018, 970, 813 cm^{-1}.

^1H NMR: δ = 1.19 (d, *J* = 7.2 Hz, 0.9 H), 1.28 (d, *J* = 6.8 Hz, 2.1 H), 1.88–1.98 (m, 0.7 H), 2.19–2.22 (m, 0.3 H), 2.43 (s, 0.9 H), 2.44 (s, 2.1 H), 2.87–2.99 (m, 2 H), 4.95 (dd, *J* = 8.3, 1.4 Hz, 0.7 H), 5.13 (dd, *J* = 8.3, 1.4 Hz, 0.3 H), 7.35–7.39 (m, 2 H), 7.53 (d, *J* = 8.2 Hz, 2 H).

MS: *m*/*z* (%) = 238 (M^+, trace), 222 (6), 140 (56), 139 (15), 123 (6), 99 (100), 92 (31), 91 (27), 71 (49).

HRMS: *m*/*z* calcd for $C_{12}H_{14}O_3S$ (M^+): 238.0664; found: 238.0665.

34b

Colorless oil (ca. 4:1 mixture of two diastereomers).

IR (neat): 2978, 2929, 1789 (C=O), 1494, 1455, 1308, 1187, 1145, 1088, 1054, 1022, 924 cm^{-1}.

^1H NMR: δ = 1.10 (d, *J* = 7.0 Hz, 0.6 H), 1.36 (d, *J* = 7.0 Hz, 2.4 H), 2.11 (dd, *J* = 8.0, 6.9 Hz, 0.2 H), 2.20 (dd, *J* = 8.0, 6.9 Hz, 0.8 H), 2.38–2.45 (m, 1 H), 2.43 (s, 3 H), 2.57–2.75 (m, 1 H), 4.93 (t, *J* = 7.7 Hz, 0.8 H), 5.16 (t, *J* = 7.7 Hz, 0.2 H), 7.36 (d, *J* = 8.3 Hz, 2 H), 7.51 (d, *J* = 8.3 Hz, 1.6 H), 7.55 (d, *J* = 8.3 Hz, 0.4 H).

MS: *m*/*z* (%) = 239 ($[M + H]^+$, 63), 221 (8), 154 (40), 123 (55), 123 (55), 99 (100).

HRMS: *m*/*z* calcd for $C_{12}H_{15}O_3S$ (M^+): 239.0742; found: 239.0738.

5-Benzoyl-3-methyldihydrofuran-2-ones (35 and 36)

35

Colorless crystals; mp 63–64 °C (hexane).

IR (KBr): 2976, 1785 (C=O), 1695 (C=O), 1595, 1451, 1222, 1167, 1007, 908 cm^{-1}.

^1H NMR: δ = 1.31 (d, *J* = 6.8 Hz, 3 H), 2.22–2.32 (m, 1 H), 2.61–2.77 (m, 2 H), 5.77 (dd, *J* = 9.5, 1.5 Hz, 1 H), 7.52 (dd, *J* = 9.3, 7.5 Hz, 1 H), 7.59–7.64 (m, 1 H), 7.98 (dd, *J* = 8.3, 1.2 Hz, 2 H).

MS: *m*/*z* (%) = 204 (M^+, trace), 105 (100), 99 (14), 77 (30), 71 (10).

HRMS: *m*/*z* calcd for $C_{12}H_{12}O_3$ (M^+): 204.0785; found: 204.0784.

Anal. Calcd for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92. Found: C, 70.65; H, 5.81.

36

Colorless crystals; mp 54–55 °C (hexane).

IR (KBr): 2990, 2941, 2888, 1775 (C=O), 1697 (C=O), 1597, 1449, 1231, 1198, 1186, 1013, 933 cm^{-1}.

^1H NMR: δ = 1.32 (d, *J* = 6.8 Hz, 3 H), 2.13–2.16 (m, 1 H), 2.75–2.83 (m, 2 H), 5.60 (dd, *J* = 9.2, 9.0 Hz, 1 H), 7.51 (t, *J* = 7.6 Hz, 2 H), 7.63 (tt, *J* = 7.4, 1.3 Hz, 1 H), 8.00 (dd, *J* = 8.5, 1.3 Hz, 2 H).

MS: *m*/*z* (%) = 204 (M^+, trace), 105 (100), 77 (27).

HRMS: *m*/*z* calcd for $C_{12}H_{12}O_3$: (M^+): 204.0786; found: 204.0788.

Anal. Calcd for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92. Found: C, 70.68; H, 5.79.

6-Ethoxycarbonyl-3-(2-phenylethyl)tetrahydropyran-2-ones (37 and 38)

37

Colorless oil.

IR (neat): 2932, 1740 (C=O), 1377, 1203, 1108, 1030, 752 cm^{-1}.

^1H NMR: δ = 1.28 (t, *J* = 7.2 Hz, 3 H), 1.60–1.72 (m, 1 H), 1.75–1.87 (m, 1 H), 1.94–2.15 (m, 2 H), 2.21–2.34 (m, 2 H), 2.42–2.52 (m, 1 H), 2.65–2.82 (m, 2 H), 4.24 (q, *J* = 7.2 Hz, 2 H), 4.87 (dd, *J* = 7.4, 5.4 Hz, 1 H), 7.17–7.22 (m, 3 H).

MS: *m*/*z* (%) = 276 (M^+, 2), 203 (20), 172 (69), 154 (30), 126 (40), 108 (54), 104 (21), 91 (100), 77 (8).

HRMS: *m*/*z* calcd for $C_{16}H_{20}O_4$ (M^+): 276.1360; found: 276.1366.

38

Colorless oil.

IR (neat): 2932, 1748 (C=O), 1379, 1196, 1114, 1029, 751 cm^{-1}.

^1H NMR: δ = 1.30 (t, *J* = 7.2 Hz, 3 H), 1.55–1.68 (m, 1 H), 1.84 (dddd, *J* = 13.5, 9.1, 7.4, 5.8 Hz, 1 H), 1.98–2.09 (m, 1 H), 2.10–2.23 (m, 2 H), 2.25–2.37 (m, 1 H), 2.40–2.50 (m, 1 H), 4.19–4.35 (m, 2 H), 4.90 (t, *J* = 4.9 Hz, 1 H), 7.17–7.23 (m, 3 H), 7.26–7.31 (m, 2 H).

MS: *m*/*z* (%) = 276 (M^+, 3), 203 (30), 172 (94), 154 (42), 126 (54), 108 (66), 104 (22), 91 (100), 77 (8), 65 (11).

HRMS: *m*/*z* calcd for $C_{16}H_{20}O_4$ (M^+): 276.1360; found: 276.1354.

4-Phenethyl-5-(toluene-4-sulfinyl)dihydrofuran-2-one (39a)

Colorless crystals (ca. 9:1 mixture of two diastereomers); mp 94–108 °C (EtOAc–hexane).

IR (KBr): 2924, 1792 (C=O), 1494, 1146, 1039, 813 cm^{-1}.

^1H NMR: δ = 1.40–1.69 (m, 1.8 H), 1.78–1.96 (m, 0.2 H), 2.09, 2.13 (d, *J* = 3.3 Hz, 0.05 H each), 2.25, 2.29 (d, *J* = 3.3 Hz, 0.45 H each), 2.32–2.40 (m, 2 H), 2.42 (s, 0.3 H), 2.44 (s, 2.7 H), 2.86–2.99 (m, 2 H), 4.72 (d, *J* = 2.5 Hz, 0.9 H), 4.82 (d, *J* = 2.3 Hz, 0.1 H), 6.94–7.27 (m, 5 H), 7.33 (d, *J* = 8.2 Hz, 2 H), 7.47 (d, *J* = 8.2 Hz, 2 H).

MS: *m*/*z* (%) = 329 ($[M + H]^+$, 21), 311 (39), 263 (20), 190 (10), 129 (100), 91 (25).

HRMS: *m*/*z* calcd for $C_{19}H_{21}O_3S$ (M^+): 329.1185; found: 329.1210.

4-Hexyl-5-(*p*-tolylsulfinyl)dihydrofuran-2-one (39b)
Colorless crystals (ca. 4:1 mixture of two diastereomers); mp 76–88 °C (EtOAc–hexane).

IR (KBr): 2927, 1800 (C=O), 1458, 1155, 1048 (S=O), 1022, 843, 812 cm^{-1}.

^1H NMR: δ = 0.84 (t, *J* = 7.5 Hz, 3 H), 0.87–1.36 (m, 10 H), 2.82–2.90 (m, 1 H), 2.22, 2.90 (d, *J* = 15.0 Hz, 0.8 H each), 2.08, 2.92 (*J* = 15.0 Hz, 0.4 H each), 4.69 (d, *J* = 2.1 Hz, 0.8 H), 4.84 (d, *J* = 2.5 Hz, 0.2 H), 7.38 (d, *J* = 8.0 Hz, 2 H), 7.52 (d, *J* = 8.0 Hz, 2 H).

Anal. Calcd for $C_{17}H_{24}O_3S$: C, 66.20; H, 7.84; S, 10.40. Found: C, 66.23; H, 7.88; S, 10.45.

1-(*p*-Tolylsulfinyl)-2-oxaspiro[4.14]nonadecan-3-one (39c)
Colorless oil (ca. 4:1 mixture of two diastereomers).

IR (neat): 2930, 1800 (C=O), 1459, 1140, 1055 (S=O), 1031, 811 cm^{-1}.

^1H NMR: δ = 1.23–1.54 (m, 28 H), 2.26, 2.89 (d, *J* = 17.4 Hz, 0.8 H each), 2.40, 2.64 (d, *J* = 17.7 Hz, 0.2 H each), 2.42 (s, 2.4 H), 2.43 (s, 0.6 H), 4.49 (s, 1 H), 7.34, 7.52 (d, *J* = 8.0 Hz, 1.6 H each), 7.35, 7.58 (d, *J* = 8.0 Hz, 0.4 H).

MS: *m*/*z* (%) = 418 (M^+, trace), 279 (100), 249 (12), 219 (8), 124 (25), 91 (33), 55 (27).

HRMS: *m*/*z* calcd for $C_{25}H_{38}O_3S$ (M^+): 418.2542; found: 418.2540.

4-[2-(4-Methoxyphenyl)ethyl]-4-methyl-5-(*p*-tolylsulfinyl)dihydrofuran-2-one (39d)
Colorless crystals; mp 160–161 °C (EtOAc–hexane).

IR (KBr): 2934, 1784 (C=O), 1610, 1513, 1246, 1051 (S=O), 811 cm^{-1}.

^1H NMR: δ = 1.33 (s, 3 H), 1.57 (d, *J* = 3.3 Hz, 1 H), 2.17 (d, *J* = 17.0 Hz, 1 H), 2.32–2.37 (m, 2 H), 2.42 (s, 3 H), 2.65–2.72 (m, 1 H), 2.81–2.88 (m, 1 H), 2.97 (d, *J* = 17.0 Hz, 1 H), 3.81 (s, 3 H), 4.46 (s, 1 H), 6.87 (d, *J* = 8.7 Hz, 2 H), 7.20 (d, *J* = 8.6 Hz, 2 H), 7.33 (d, *J* = 8.2 Hz, 2 H), 7.49 (d, *J* = 8.2 Hz, 2 H).

Anal. Calcd for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49; S, 8.61. Found: C, 67.55; H, 6.34; S, 8.63.

4-(2-Phenylethyl)dihydrofuran-2-one (41a, E = H)
Colorless oil.

IR (neat): 2924, 1770 (C=O), 1454, 1171, 1022, 840, 751 cm^{-1}.

^1H NMR: δ = 1.75–1.87 (m, 2 H), 2.19 (dd, *J* = 16.6, 7.7 Hz, 1 H), 2.48–2.70 (m, 4 H), 3.92 (dd, *J* = 9.1, 7.2 Hz, 1 H), 4.38 (dd, *J* = 9.1, 7.2 Hz, 1 H), 7.14–7.31 (m, 5 H).

MS: *m*/*z* (%) = 190 (M^+, 38), 159 (17), 130 (12), 104 (45), 91 (100), 77 (8).

HRMS: *m*/*z* calcd for $C_{12}H_{14}O_2$ (M^+): 190.0980; found: 190.0986.

5-Ethoxycarbonyl-4-(2-phenylethyl)dihydrofuran-2-one (41b)
Colorless oil.

IR (neat): 2929, 1788 (C=O), 1455, 1170, 1073, 1024, 840 cm^{-1}.

^1H NMR: δ = 1.30 (t, *J* = 7.3 Hz, 3 H), 1.78–1.84 (m, 2 H), 2.05 (sext, *J* = 6.8 Hz, 1 H), 2.51–2.79 (m, 4 H), 4.25 (q, *J* = 7.0 Hz, 2 H), 4.61 (d, *J* = 4.3 Hz, 1 H), 7.14–7.31 (m, 5 H).

MS: *m*/*z* (%) = 262 (M^+, 15), 244 (5), 189 (33), 158 (58), 171 (9), 158 (59), 140 (9), 117 (20), 112 (95), 91 (100), 86 (60).

HRMS: *m*/*z* calcd for $C_{15}H_{18}O_4$ (M^+): 262.1205; found: 262.1208.

5-Benzoyl-4-(2-phenylethyl)dihydrofuran-2-one (41c)
Colorless oil.

IR (neat): 2927, 1781 (C=O), 1693, 1452, 1170, 1022, 840 cm^{-1}.

^1H NMR: δ = 1.79–1.81 (m, 2 H), 2.00–2.02 (m, 1 H), 2.54–2.79 (m, 4 H), 5.43 (d, *J* = 3.4 Hz, 1 H), 7.14–7.32 (m, 5 H), 7.45–7.52 (m, 2 H), 7.59–7.66 (m, 1 H), 7.92–7.95 (m, 1 H), 8.09–8.12 (m, 1 H).

MS: *m*/*z* (%) = 294 (M^+, 10), 276 (6), 266 (3), 190 (30), 189 (20), 145 (25), 144 (22), 105 (100), 91 (70), 77 (35).

HRMS: *m*/*z* calcd for $C_{19}H_{18}O_3$ (M^+): 294.1256; found: 294.1261.

5-Ethoxycarbonyl-4-hexyldihydrofuran-2-one (41d)
Colorless oil.

IR (neat): 2928, 1790 (C=O), 1747 (C=O), 1466, 1378, 1169, 1022, 839 cm^{-1}.

^1H NMR: δ = 0.81–0.96 (m, 6 H), 1.21–1.40 (m, 8 H), 1.64–1.76 (m, 2 H), 2.22–2.36 (m, 1 H), 4.26 (q, *J* = 6.9 Hz, 2 H), 4.56 (d, *J* = 4.3 Hz, 1 H).

MS: *m*/*z* (%) = 242 (M^+, 2), 169 (51), 151 (10), 139 (6), 123 (10), 109 (100), 92 (17), 83 (26), 69 (35).

HRMS: *m*/*z* calcd for $C_{13}H_{22}O_4$ (M^+): 242.1518; found: 242.1520.

5-Benzoyl-4-hexyldihydrofuran-2-one (41e)
Colorless oil.

IR (neat): 2923, 1785 (C=O), 1459, 1380, 1144, 1089, 1021 cm^{-1}.

^1H NMR: δ = 0.86–0.89 (m, 6 H), 1.26–1.70 (m, 10 H), 1.84–1.90 (m, 1 H), 2.17–2.30 (m, 2 H), 5.44 (d, *J* = 3.2 Hz, 1 H), 7.50–7.54 (m, 2 H), 7.60–7.68 (m, 1 H), 7.96–7.98 (m, 2 H).

MS: *m*/*z* (%) = 274 (M^+, 2), 170 (2), 154 (4), 139 (9), 114 (32), 105 (61), 83 (47), 69 (54), 56 (100).

HRMS: *m*/*z* calcd for $C_{17}H_{22}O_3$ (M^+): 274.1569; found: 274.1573.

2-Oxaspiro[4.14]nonadecan-3-one (41f, E = H)
Colorless crystals; mp 53–54 °C ($EtOH–H_2O$).

IR (KBr): 2929, 1787 (C=O), 1459, 1170, 1025 cm^{-1}.

^1H NMR: δ = 1.31–1.52 (m, 28 H), 2.32 (s, 2 H), 4.01 (s, 2 H).

MS: *m*/*z* = 280 (M^+, 22), 249 (100), 222 (29), 55 (47), 41 (45).

HRMS: *m*/*z* calcd for $C_{18}H_{32}O_2$ (M^+): 280.2401; found: 280.2412.

Anal. Calcd C, 77.09; H, 11.50. Found: C, 77.32; H, 11.21.

4-[2-(4-Methoxyphenyl)ethyl]-4-methyltetrahydrofuran-2-one (41g, E = H)
Colorless oil.

IR (neat): 2933, 1722 (C=O), 1611, 1512, 1245, 1032, 822 cm^{-1}.

^1H NMR: δ = 1.25 (m, 3 H), 1.77 (t, *J* = 8.5 Hz, 2 H), 2.29 (d, *J* = 17.3 Hz, 1 H), 2.41 (d, *J* = 17.3 Hz, 1 H), 2.57 (t, *J* = 8.6 Hz, 2 H), 3.78 (s, 3 H), 3.97 (d, *J* = 8.7 Hz, 1 H), 4.05 (d, *J* = 8.7 Hz, 1 H), 6.83 (d, *J* = 8.9 Hz, 2 H), 7.08 (d, *J* = 8.9 Hz, 2 H).

MS: *m*/*z* = 234 (M^+, 28), 134 (13), 121 (100), 78 (7).

HRMS: *m*/*z* calcd for $C_{14}H_{18}O_3$ (M^+): 234.1254; found: 234.1255.

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