

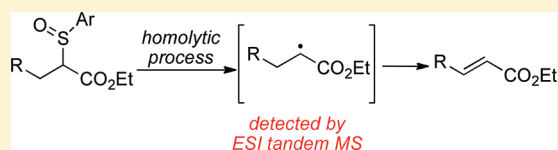
## Radical Mechanism in the Elimination of 2-Arylsulfinyl Esters

Antonio Latorre,<sup>†</sup> Irakusne López,<sup>†</sup> Victoria Ramírez,<sup>†</sup> Santiago Rodríguez,<sup>†</sup> Javier Izquierdo,<sup>†</sup> Florenci V. González,<sup>\*,†</sup> and Cristian Vicent<sup>\*,†,‡</sup>

<sup>†</sup>Departament de Química Inorgànica i Orgànica and <sup>‡</sup>Serveis Centrals d'Instrumentació Científica, Universitat Jaume I, 12080 Castelló, Spain

**S** Supporting Information

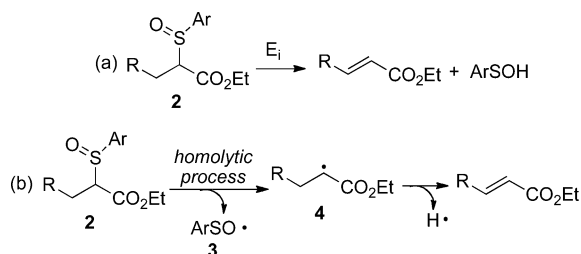
**ABSTRACT:** The mechanism of the dehydrosulfenylation of 2-arylsulfinyl esters was investigated. The reaction was found to follow a homolytic cleavage mechanism as verified by electrospray ionization tandem mass spectrometry and experimental work. Rearranged sulfoxides are obtained as byproduct during the elimination reaction.



Elimination reactions of sulfoxides and sulfones are well-known reactions in synthetic organic chemistry.<sup>1</sup> In particular, the transformation of 2-arylsulfinyl esters to afford unsaturated carbonyl compounds by elimination is a common synthetic transformation.<sup>2–5</sup> The elimination reaction of sulfoxides follows an Ei (elimination internal) mechanism, as demonstrated by the seminal work by Cram and Kingsbury,<sup>6</sup> who also suggested the existence of a competing homolytic mechanism for some sulfoxides having a group to stabilize a radical intermediate. Although extensive work has been reported for the elimination of sulfoxides through an Ei mechanism,<sup>7,8</sup> no convincing evidence has appeared for a radical mechanism involving any sulfinyl substrate.

In the context of our investigations with sulfoxides,<sup>9,10</sup> we became interested in determining the nature of the mechanism during the elimination reaction of 2-arylsulfinyl esters. We considered two plausible mechanistic routes for the elimination of a 2-arylsulfinyl ester to afford the corresponding enoate (Scheme 1): (a) the concerted elimination reaction (Ei) or (b) a radical process involving the homolytic scission of the C–S bond to furnish free radical **4** and aryl sulfinyl radical **3**.

### Scheme 1. Possible Mechanistic Routes



We undertook the study of the elimination reaction of 2-arylsulfinyl esters with a range of R alkyl groups and Ar aryl groups attached to the sulfur atom. 2-Arylsulfinyl esters **2a–f** were prepared from the corresponding 2-bromo esters by treatment with the corresponding sodium thiophenolates, which furnished the expected thioethers **1a–f**. Upon oxidation of the thioethers, sulfoxides **2a–f** were obtained as a mixture of

stereoisomers (Scheme 2).<sup>11</sup> Then compounds **2a–f** were submitted to elimination by heating to reflux in toluene for 5 h, affording the corresponding *E*-enoates.<sup>12</sup> 2-Arylsulfinyl esters **2a–c** gave rise to ethyl acrylate **5** and compounds **2d**, **2e**, and **2f** afforded enoates **6**, **7**, and **8**, respectively, as dominant products.<sup>13</sup>

Careful isolation of all the products obtained during the elimination reaction of compound **2a** gave the phenylthiosulfonate **9** (that partly converts to diphenyl disulfide and sulfonic acid, see below) and rearranged sulfoxide **10** as a minor product (15%) (Scheme 3).<sup>14</sup>

It is also noteworthy that the unprecedented rearrangement of 2-arylsulfinyl ester **2a** to yield **10** provided an alternative synthetic entry to 3-arylsulfinyl ester. To determine whether the formation of minor compound **10** was an inter- or an intramolecular process, we conducted a crossover experiment between **2b** and compound **2f** (see Scheme 4).

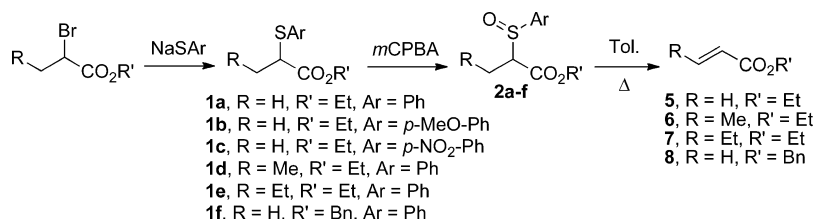
After heating of both sulfoxides **2b** and **2f**, the <sup>1</sup>H NMR or <sup>13</sup>C NMR spectra were highly crowded due to the presence of numerous species, making it difficult to identify the newly formed species. However, after removal of volatile acrylates and chromatographic separation of the fraction containing the 3-arylsulfinyl esters and the thiosulfonate esters, electrospray ionization mass spectrometry (ESI–MS) analysis, operated in positive ion mode (ESI(+)), unravelled a rapid and direct snapshot of the formed species in the reaction mixture (see Figures S1 and S2, Supporting Information) and demonstrated that the rearrangement was an intermolecular rather than an intramolecular process.<sup>15</sup> A similar result was observed when sulfoxides **2b** and **2e** were heated at 80 °C for 2 h as judged by ESI–MS analysis.

The corresponding 2-arylsulfonyl esters were also prepared. When 2-arylsulfonyl esters or 2-arythioethers (**1a–f**) underwent the same experimental conditions for elimination as the sulfoxides, only starting material was recovered, thus illustrating

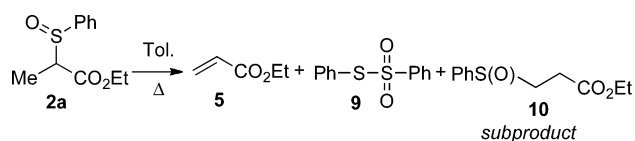
Received: April 10, 2012

Published: May 14, 2012

Scheme 2. Preparation and Elimination of 2-Arylsulfinyl Esters 2a–f



Scheme 3. Elimination Reaction of Compound 2a



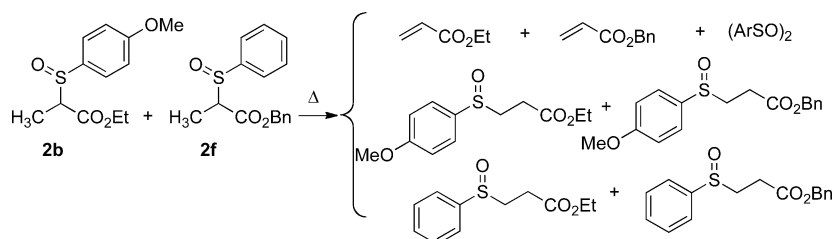
that eliminations are a characteristic feature of only the sulfoxides.

Since the photolytic homolysis of C–S bonds has been described,<sup>16</sup> the elimination reactions were also performed in the absence of light. When 2-arylsulfinyl esters 2a–f were submitted to elimination by heating in the absence of light the products were the same as in the presence of light, thus ruling out a photolytic homolysis.

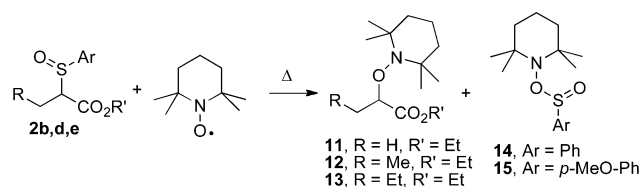
The interception of the radical intermediates would provide evidence for presence of a single-electron transfer mechanism in the elimination reaction. A nitroxyl radical (2,2,6,6-tetramethyl-1-piperidinyloxy) (Tempo) succeeded in intercepting the radical intermediates derived from 2-arylsulfinyl esters 2b, 2d, and 2e. The reactions were investigated by electrospray ionization mass spectrometry (ESI–MS).<sup>17</sup> Compounds 2b, 2d, and 2e afforded adducts 11 and 15, 12 and 14, and 13 and 14, respectively. In case of the reaction using 2e as starting material, both resulting reaction compounds 13 and 14 were isolated and fully characterized (see the Supporting Information) (Scheme 5).<sup>18</sup>

These results denote the occurrence of a radical process during the elimination of 2-arylsulfinyl esters into enoates. A possible mechanism is proposed in Scheme 6. Sulfoxide 2 would give rise to radical 4 and aryl sulfinyl radical 3. Sulfinyl radicals combine to give vicinal disulfoxides (*vic*-disulfoxides) which isomerize to give phenyl thiosulfonate 9. Thiosulfonate 9 partly converts into the corresponding diaryl sulfide 16 and sulfonic acid as it is known.<sup>19</sup> Radical 4 would furnish the enoate. The formation of the subproduct 10 can be explained by addition of in situ formed phenyl sulfenic acid to the enoate. The addition of sulfenic acids to unsaturated esters have been demonstrated previously.<sup>20–22</sup> Compound 10 would be formed in a low yield due to the high tendency of sulfinyl radicals (or sulfenic acids) to afford thiosulfonates, although final reaction

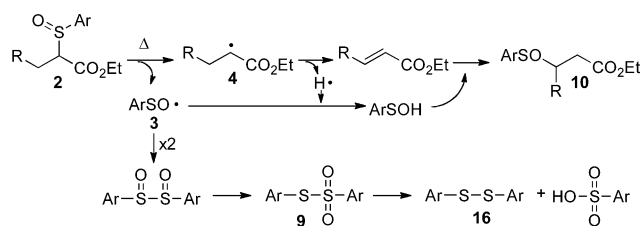
Scheme 4. Crossover Experiment between 2b and 2f



Scheme 5. Trapping of the Radical Intermediates Using Tempo



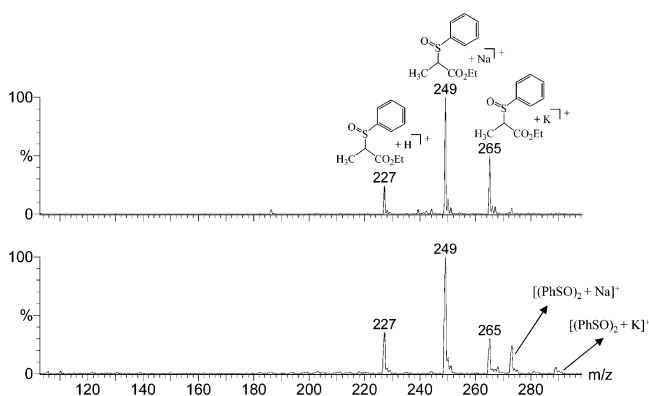
Scheme 6. Radical Mechanism in the Elimination of 2-Arylsulfinyl Esters



yields would depend on the subtle interplay between kinetics and thermodynamics of each elementary step depicted in Scheme 6.

In studies to determine the reaction mechanism of a multistep reaction, the identification of the intermediates is an essential process.<sup>23</sup> In this context, ESI–MS is a useful technique for analyzing chemical intermediates or products in diverse chemical and biochemical processes,<sup>24–26</sup> as illustrated above for the identification of the products formed in the crossover experiment. Although the detection of free radicals is sometimes difficult, ESI–MS has been recently employed for observing radical intermediates in some processes.<sup>27–32</sup> For a better understanding of the mechanism of the arylsulfinyl esters elimination depicted in Scheme 6, attempts to intercept and characterize the formed species were carried out on the basis of online ESI mass spectrometry and ESI tandem mass spectrometry. Closely related thermally driven homolytic reactions have been successfully investigated by Metzger's group by means of ESI mass spectrometry using modified ESI sources.<sup>28</sup> To investigate the elimination reaction, toluene

solutions of **2a** were heated to 100 °C and at different time intervals, aliquots were extracted, immediately diluted with hot acetonitrile, and analyzed by ESI(+) mass spectrometry. The obtained ESI mass spectra recorded at different intervals were nearly identical (Figure 1), with the most significant difference



**Figure 1.** ESI(+) mass spectra of toluene/acetonitrile solutions of compound **2a**. Samples of the initial solution of **2a** (upper panel) and of compound **2a** after heating for 60 min (lower panel). Note that species at  $m/z$  227, 249, and 265 in the lower panel correspond to **2a** and its rearranged isomer **10**.

being the appearance of new signals corresponding to the  $\text{PhSSO}_2\text{Ph}$  product as evidenced for the peaks assigned to  $[\text{PhSSO}_2\text{Ph} + \text{Na}]^+$  ( $m/z = 273$ ) and  $[\text{PhSSO}_2\text{Ph} + \text{K}]^+$  ( $m/z = 289$ ). Negative ESI mass spectrum revealed the presence of sulfonic acid as  $[\text{M} - \text{H}]^-$  adduct. Diphenyl disulfide was not observed in the ESI mass spectrum because it is not readily ionized upon ESI conditions.

The transient radical cations  $\text{PhSO}^\bullet$  and  $\text{CH}_3\text{CH}\cdot\text{CO}_2\text{CH}_2\text{CH}_3$  (not as  $\text{H}^+$ ,  $\text{Na}^+$ , or  $\text{K}^+$  adducts) could not be identified in the ESI mass spectrum directly. However, monitoring the advance of the **2a** conversion to methylacrylate and the rearranged product **10** was possible by ESI-MS, provided that both **2a** and **10** isomers at  $m/z = 249$  displayed distinctive unimolecular dissociation upon collision-induced dissociation (CID) conditions. CID spectra of the sodium adducts of **2a** and **10** are shown in Figure 2 which allowed us to monitor the temporal evolution of the species.

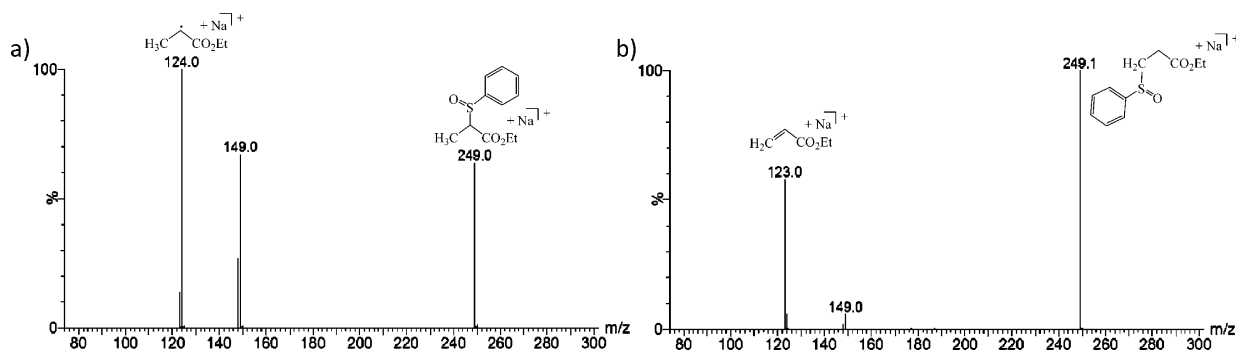
Also helpful is the use of the MS/MS technique, where the fragment spectrum gives direct information about structural aspects of the investigated ion and can provide efficient information about mechanistic properties. It is remarkable that species  $[\mathbf{2a} + \text{Na}]^+$  ( $m/z = 249$ ) dissociated predominantly via

homolytic C–S bond cleavage affording the radical species  $[\text{CH}_3\text{CH}\cdot\text{CO}_2\text{CH}_2\text{CH}_3 + \text{Na}]^+$  ( $m/z = 124$ ) whereas species  $[\mathbf{10} + \text{Na}]^+$  ( $m/z = 249$ ) dissociated via formation of the closed-shell  $[\text{CH}_2\text{CH}\cdot\text{CO}_2\text{CH}_2\text{CH}_3 + \text{Na}]^+$  ( $m/z = 123$ ) product ion. Moreover, at identical collision energies, it is clear that species  $[\mathbf{2a} + \text{Na}]^+$  is significantly easier to dissociate than  $[\mathbf{10} + \text{Na}]^+$  as evidenced by the relative intensity of the formed product ions. The gas-phase behavior of **2a** is reminiscent of that observed for heated solutions for which this compound is more prone to homolytically dissociate via S–C bond cleavage.

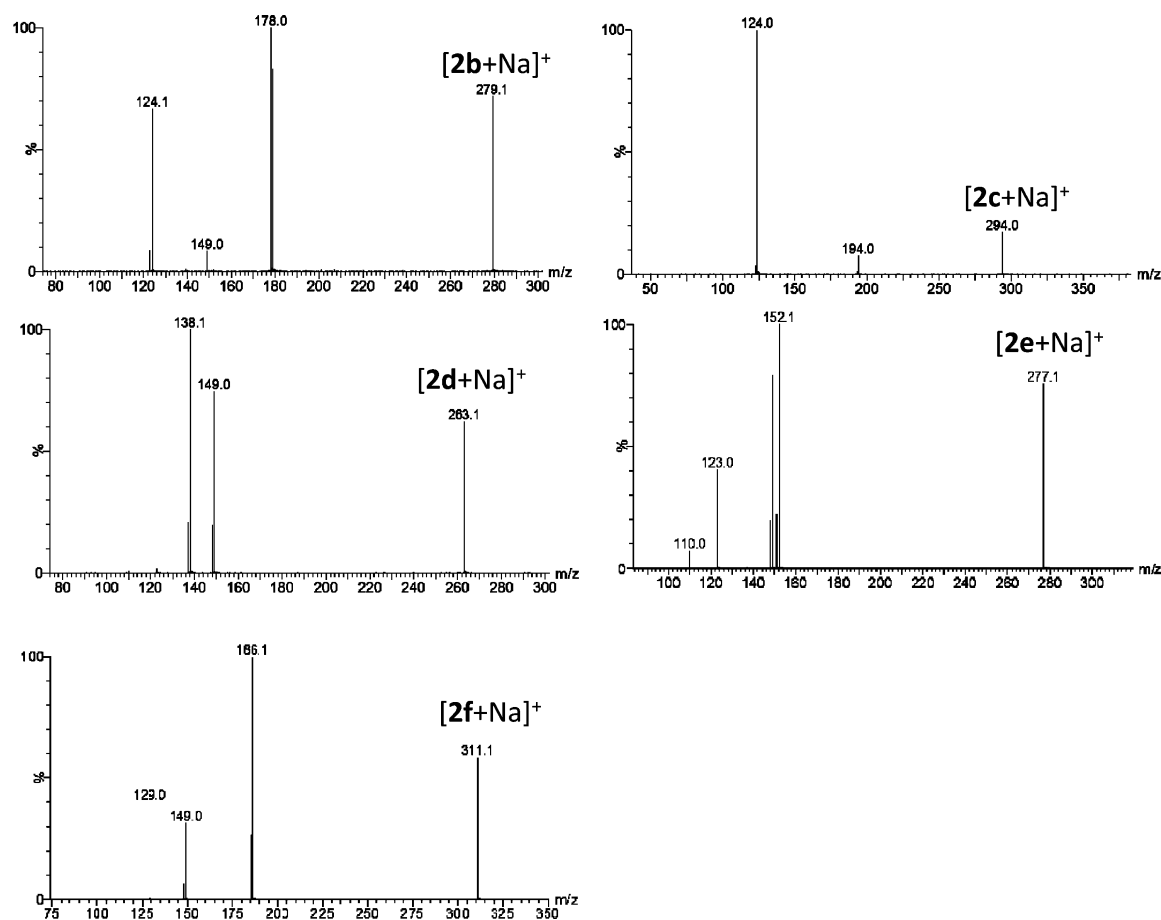
The same conditions were also used for monitoring the evolution of the reaction of 2-arylsulfinyl esters **2b–f**. It is remarkable that species  $[\mathbf{2a–f} + \text{Na}]^+$  invariably dissociated predominantly via homolytic C–S bond cleavage affording the respective radical species  $[\text{RCH}_2\text{CH}\cdot\text{CO}_2\text{X} + \text{Na}]^+$  respectively, as illustrated in Figure 3 for **2b–f**. Fragmentation studies were also performed for the 2-arylsulfide esters and 2-arylsulfonyl esters but no radical intermediates were detected in their respective CID spectra. It is known that sulfides and sulfones do not eliminate as easily as sulfoxides.<sup>33</sup>

The formation of rearrangement products during the elimination of a 2-arylsulfinyl ester was also observed during the synthesis of the natural product **18** starting from sulfoxide **17**.<sup>9</sup> In this case, 3-arylsulfonyl lactone **19** was obtained as a minor product along with the expected  $\alpha$ -methylene  $\gamma$ -butyrolactone **18** (Scheme 7) when the reaction was performed in open air. Sulfone **19** was formed in a highly stereoselective fashion as judged by single-crystal X-ray diffraction methods (see Figure S4, Supporting Information).<sup>34</sup> In this case, sulfone **19** was formed instead of the expected sulfoxide, following the well-known tendency of  $\gamma$ -hydroxy sulfides to be oxidized to sulfones instead of sulfoxides under photooxidation conditions.<sup>35</sup>

In summary, the mechanism of the dehydrosulfenylation of 2-arylsulfinyl esters for furnishing enoates has been determined to be a homolytic process. The interception of the radical intermediate using a nitroxyl radical and ESI-MS and ESI tandem MS techniques were useful for drawing a comprehensive picture of the intermediates involved in the dehydrosulfenylation of 2-arylsulfinyl esters and suggest that a radical-mediated process is operative. An unprecedented transformation of 2-arylsulfinyl esters to 3-arylsulfinyl esters is also observed as a side reaction whose intimate mechanism is proposed.

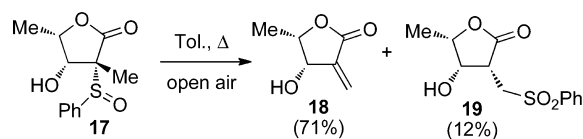


**Figure 2.** CID spectra of mass-selected species at (a)  $m/z = 249$   $[\mathbf{2a} + \text{Na}]^+$  and (b)  $m/z = 249$   $[\mathbf{10} + \text{Na}]^+$  ( $E_{\text{laboratory}} = 15$  eV).



**Figure 3.** CID spectra of mass-selected species  $[2b-f + Na]^+$  using a collision energy ( $E_{\text{laboratory}} = 15$  eV). Radical species detected are  $m/z = 124$  for **2b** and **2c**,  $m/z = 138$  for **2d**,  $m/z = 152$  for **2e** and  $m/z = 186$  for **2f**.

### Scheme 7. Synthesis of Compounds **18** and **19**



## EXPERIMENTAL SECTION

**General Experimental Methods.** All solvents used in reactions were freshly distilled from appropriate drying agents before use.  $^1\text{H}$  NMR spectra and  $^{13}\text{C}$  NMR spectra were measured in  $\text{CDCl}_3$  ( $^1\text{H}$ , 7.24 ppm;  $^{13}\text{C}$  77.0 ppm) solution at 30 °C on a 300 MHz or a 500 MHz NMR spectrometer. IR spectra were recorded as oil films or KBr discs or NaCl pellets on a FT-IR spectrometer. Silica gel 60 was used for column chromatography, while TLC was performed with precoated plates (Kieselgel 60,  $F_{254}$ , 0.25 mm). Unless otherwise specified, all reactions were carried out under argon atmosphere with magnetic stirring.

**Electrospray Ionization Mass Spectrometry (ESI-MS) and Electron Impact Mass Spectrometry (EI-MS).** For the online reaction monitoring, ESI mass spectra were recorded using an ESI tandem mass spectrometer (quadrupole-hexapole-quadrupole). The drying gas was nitrogen. The temperature of the source block was set to 120 °C and the desolvation temperature to 150 °C. A capillary voltage of 3.5 kV was used in the positive scan mode, and the cone voltage ( $U_c$ ) was set to 15 V to control the extent of fragmentation of the identified ions. Toluene solutions of **2a–f** were heated at 100 °C in an open vial, a drop of the solution was immediately extracted and diluted in hot  $\text{CH}_3\text{CN}$ , and a positive-ion mass spectrum was collected. For CID experiments, the cations of interest were mass-

selected using the first quadrupole (Q1) and interacted with argon in the hexapole collision cell at variable collision energies (typically in the  $E_{\text{laboratory}} = 3–10$  eV range) while mass analyzing the products with the second analyzer. The isolation width was ca. 1 Da and argon was used as a collision gas to produce a pressure of  $8 \times 10^{-4}$  mbar.

For accurate  $m/z$  determinations (for all the compounds except for **16**) and CID experiments, an ESI tandem mass spectrometer (quadrupole-Twave-time-of-flight) was used. The drying gas was nitrogen. The temperature of the source block was set to 120 °C and the desolvation temperature to 150 °C. A capillary voltage of 3.5 kV was used in the positive scan mode, and the cone voltage was set to a low value to control the extent of fragmentation (typically 15 V). Methanol sample solutions were infused via syringe pump directly connected to the ESI source at a flow rate of 10  $\mu\text{L}/\text{min}$ . Mass calibration was performed using a mixture of NaOH 0.05 M/formic acid 10% (50:50) from  $m/z$  50 to 900. For accurate mass measurements, a solution of leucine enkephalin ( $m/z = 556.2771$ ) was introduced via the lock spray needle at a flow rate of 30  $\mu\text{L}/\text{min}$ .

For an accurate  $m/z$  determination of compound **16**, a GC-EIMS was used. The GC instrumentation used was equipped with an autosampler coupled to a TOF mass spectrometer operating in electron ionization (EI) mode. The GC separation was performed using a fused silica column (30 m  $\times$  0.25 mm i.d., 0.25 mm film thickness). The oven temperature was programmed as follows: 90 °C (hold 1 min); 10 °C/min to 300 °C (hold 2 min). The total running time was 24 min. Splitless injections of 1 mL of sample extracts were carried out with an injector temperature of 300 °C and with a splitless time of 1 min. Helium 99.999% was used as carrier gas at a constant flow of 1 mL/min. The interface and ion source temperatures were set to 260 and 250 °C, respectively. A solvent delay of 3 min was used to prevent damage in the ion source filament. TOF MS was operated at



an scan time of 0.95 s in the mass range  $m/z$  60–300 and using a multichannel plate voltage of 2700 V. TOF MS resolution was about 8500 (fwhm) at  $m/z$  614. Pure PFTBA (Perfluorotri-*n*-butylamine), used for the daily mass calibration/verification as well as for lock mass, was injected via syringe ( $\sim 1$  mL) in the reference reservoir at 30 °C. The  $m/z$  monitored was 218.9856.

**X-ray Crystallography.** Crystals of compound **19** are air stable and were mounted on the tip of a glass fiber with the use of epoxy cement. X-ray diffraction experiments were carried out on a diffractometer using Mo K $\alpha$  radiation ( $\lambda = 0.71073$  Å) at room temperature. The data were collected with a frame width of 0.3° in  $\omega$  and a counting time of 60 s per frame at a crystal to detector distance of 4 cm. The diffraction frames were integrated using the SAINT package and corrected for absorption with SADABS. The structures were solved by direct methods and refined by the full-matrix method based on  $F^2$  using the SHELXTL software package. All non-hydrogen atoms were refined anisotropically. Hydrogen atoms were generated geometrically, assigned isotropic thermal parameters and allowed to ride on their respective parent carbon atoms. Crystal data and structure refinement for **19**: empirical formula C<sub>12</sub>H<sub>14</sub>O<sub>3</sub>S; crystal system monoclinic; space group  $P2(1)$ ; unit cell dimensions  $a = 4.8321(7)$  Å,  $b = 21.157(3)$  Å,  $c = 6.4661(9)$  Å,  $\beta = 95.816(3)^\circ$ ;  $Z = 2$ ;  $\theta$  range for data collection 1.93–30.49°; reflections collected 5373; independent reflections 3114 [ $R(\text{int}) = 0.0247$ ]; goodness-of-fit on  $F^2 = 1.030$ ; final  $R$  indices [ $I > 2\sigma(I)$ ]  $R1 = 0.0424$ ,  $wR2 = 0.0928$ ;  $R$  indices (all data)  $R1 = 0.0685$ ,  $wR2 = 0.1034$ ; absolute structure parameter  $-0.03(8)$ ; largest diff peak and hole 0.268 and  $-0.180$  e $\cdot$ Å $^{-3}$ .

**General Experimental Procedure for the Preparation of Thioethers 1a–f.** To an ice-bath solution of sodium hydride (1.85 g, 46.2 mmol) (60% in mineral oil) in tetrahydrofuran (110 mL) was added dropwise the corresponding thiophenol (92.4 mmol). The resulting mixture was stirred in an ice bath for 30 min. The bromoester (92.4 mmol) was added, and the resulting mixture was stirred at room temperature for 72 h. The mixture was quenched with brine and extracted with ethyl ether (3  $\times$  15 mL), and then the organic layers were washed with a saturated aqueous solution of sodium bicarbonate and water, dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated. The crude was purified through chromatography (silica gel, hexanes/ethyl acetate (95:5)) to afford the desired compound.

**Ethyl 2-(phenylthio)propanoate (1a):** yield = 12.61 g, 65%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.46–7.48 (2H, m), 7.26–7.32 (3H, m), 4.11 (2H, q,  $J = 7.2$  Hz), 3.78 (1H, q,  $J = 6.9$  Hz), 1.48 (3H, d,  $J = 6.9$  Hz), 1.17 (3H, t,  $J = 7.2$  Hz); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  173.0, 133.4, 129.2, 128.3, 61.5, 45.6, 17.7, 14.3 ppm; IR (NaCl)  $\delta$  3060, 2981, 2933, 2872, 1955, 1883, 1732, 1583, 1476, 1440, 1375, 1323, 1256, 1225, 1159, 1068, 1025, 897, 859, 776, 748, 691, 596 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>11</sub>H<sub>14</sub>O<sub>2</sub>SNa [M + Na<sup>+</sup>] 233.0612, found 233.0611.

**Ethyl 2-((4-methoxyphenyl)thio)propanoate (1b):** yield = 13.3 g, 60%; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  7.36 (2H, d,  $J = 8.0$  Hz), 6.79 (2H, d,  $J = 8.5$  Hz), 4.06 (2H, q,  $J = 7.0$  Hz), 3.75 (3H, s), 3.57 (1H, q,  $J = 7.0$  Hz), 1.37 (3H, d,  $J = 7.0$  Hz), 1.14 (3H, t,  $J = 7.5$  Hz); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  172.9, 160.5, 136.7, 123.4, 114.7, 61.2, 55.5, 46.2, 17.4, 14.3 ppm; IR (NaCl)  $\delta$  2927, 1727, 1591, 1493, 1461, 1286, 1247, 1172, 1029, 827 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>12</sub>H<sub>16</sub>O<sub>3</sub>SNa [M + Na<sup>+</sup>] 263.0718, found 263.0712.

**Ethyl 2-((4-nitrophenyl)thio)propanoate (1c):** yield = 12.25 g, 52%; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  8.11 (2H, d,  $J = 8.5$  Hz), 7.46 (2H, d,  $J = 9.0$  Hz), 4.15 (2H, m), 4.00 (2H, q,  $J = 7.0$  Hz), 1.56 (3H, d,  $J = 7.5$  Hz), 1.19 (3H, t,  $J = 7.0$  Hz); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  172.2, 144.9, 131.5, 129.3, 124.3, 62.1, 44.1, 17.6, 14.4 ppm; IR (NaCl)  $\delta$  2925, 1732, 1596, 1578, 1515, 1477, 1341, 1259, 1174, 1076, 1013, 853, 742, 683 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>11</sub>H<sub>13</sub>NO<sub>4</sub>S [M + H<sup>+</sup>] 256.0644, found 256.0647; calcd for C<sub>11</sub>H<sub>13</sub>NO<sub>4</sub>SNa [M + Na<sup>+</sup>] 278.0463, found 278.0464.

**Ethyl 2-(phenylthio)butanoate (1d):** yield = 19.25 g, 93%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.44 (2H, m), 7.25 (3H, m), 4.09 (2H, dq,  $J = 1.2, 7.2$  Hz), 3.56 (1H, dd,  $J = 6.6, 8.4$  Hz), 1.70–1.95 (m, 2H), 1.15 (3H, t,  $J = 6.9$  Hz), 1.09 (3H, t,  $J = 7.2$  Hz); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  172.0, 133.7, 132.7, 128.8, 127.7, 60.9, 52.4, 25.1, 14.0, 11.7

ppm; IR (oil)  $\delta$  3079, 2970, 2936, 2877, 1959, 1884, 1735, 1583, 1480, 1443, 1368, 1343, 1300, 1234, 1209, 1160, 1091, 1026, 941, 864, 811 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>12</sub>H<sub>17</sub>O<sub>2</sub>S [M + H<sup>+</sup>] 225.0949, found 225.0953; calcd for C<sub>12</sub>H<sub>16</sub>O<sub>2</sub>SNa [M + Na<sup>+</sup>] 247.0769, found 247.0772.

**Ethyl 2-(phenylthio)pentanoate (1e):** yield = 19.35 g, 88%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.43–7.47 (2H, m), 7.24–7.31 (3H, m), 4.10 (2H, q,  $J = 7.2$  Hz), 3.65 (1H, dd,  $J = 6.6, 8.1$  Hz), 1.67–1.94 (m, 2H), 1.38–1.52 (m, 2H), 1.15 (3H, t,  $J = 6.6$  Hz), 0.92 (3H, t,  $J = 7.2$  Hz); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  172.0, 133.7, 132.7, 128.7, 127.6, 60.7, 50.5, 33.7, 20.5, 14.0, 13.6 ppm; IR (oil)  $\delta$  3066, 2968, 2936, 2876, 1958, 1884, 1733, 1585, 1483, 1444, 1374, 1335, 1303, 1279, 1243, 1163, 1106, 1033, 934, 860, 808 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>13</sub>H<sub>19</sub>O<sub>2</sub>S [M + H<sup>+</sup>] 239.1106, found 239.1115; calcd for C<sub>13</sub>H<sub>18</sub>O<sub>2</sub>SNa [M + Na<sup>+</sup>] 261.0925, found 261.0923.

**Benzyl 2-(phenylthio)propanoate (1f):** yield = 17.59 g, 70%; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.24–7.44 (10H, m), 5.11 (2H, s), 3.85 (1H, d,  $J = 7.2$  Hz), 1.52 (3H, d,  $J = 7.2$  Hz); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  172.5, 135.5, 133.2, 133.0, 128.9, 128.5, 128.2, 128.0, 66.7, 45.3, 17.3 ppm; IR (oil)  $\delta$  3061, 2986, 2936, 1959, 1888, 1735, 1586, 1480, 1443, 1380, 1324, 1268, 1162, 1063, 1029, 1004, 954, 898, 780 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>16</sub>H<sub>17</sub>O<sub>2</sub>S [M + H<sup>+</sup>] 273.0949, found 273.0946; calcd for C<sub>16</sub>H<sub>16</sub>O<sub>2</sub>SNa [M + Na<sup>+</sup>] 295.0769, found 295.0770.

**General Experimental Procedure for the Preparation of Sulfoxides 2a–f.** To a  $-10$  °C cold solution of thioether (0.95 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (5 mL) was added a solution of *m*-CPBA (77% pure) (177 mg, 0.79 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (4 mL). The resulting mixture was stirred at  $-10$  °C for 30 min, quenched with saturated aqueous solution of sodium bicarbonate, and extracted with CH<sub>2</sub>Cl<sub>2</sub> (3  $\times$  15 mL), and then the organic layers were sequentially washed with brine and saturated aqueous solution of sodium bicarbonate and water, dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated. The crude was purified through chromatography (silica gel, hexanes/ethyl acetate (7:3)) to afford the desired sulfoxide.

**Ethyl 2-(phenylsulfinyl)propanoate (2a):** yield = 178 mg, 83%; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  7.25–7.45 (5H, m) (major and minor), 4.12 (2H, m) (major and minor), 3.81 (1H, q,  $J = 6.5$  Hz) (major), 3.49 (1H, q,  $J = 7.0$  Hz) (minor), 1.49 (3H, d,  $J = 7.0$  Hz) (major), 1.32 (3H, d,  $J = 7.5$  Hz) (minor), 1.21 (3H, t,  $J = 6.5$  Hz) (minor), 1.18 (3H, t,  $J = 7.0$  Hz) (major); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  168.9, 168.1, 142.6, 140.9, 134.5, 132.1, 131.9, 129.7, 129.5, 129.3, 125.5, 125.1, 66.2, 64.1, 62.1, 62.0, 14.3, 14.2, 10.0, 9.1 ppm; IR (NaCl)  $\delta$  3051, 2988, 2926, 1968, 1895, 1724, 1577, 1472, 1445, 1371, 1316, 1254, 1215, 1165, 1083, 1045, 1017, 920, 889, 858, 749, 691 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>11</sub>H<sub>14</sub>O<sub>3</sub>SNa [M + Na<sup>+</sup>] 249.0556, found 249.0557.

**Ethyl 2-((4-methoxyphenyl)sulfinyl)propanoate (2b):** yield = 124 mg, 51%; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  7.56 (2H, d,  $J = 8.5$  Hz) (major), 7.52 (2H, d,  $J = 8.5$  Hz) (minor), 7.00 (2H, d,  $J = 8.5$  Hz) (major and minor), 4.04–4.20 (2H, m) (major and minor), 3.85 (3H, s) (major and minor), 3.78 (1H, q,  $J = 7.0$  Hz) (major), 3.47 (1H, q,  $J = 8.0$  Hz) (minor), 1.50 (3H, d,  $J = 7.0$  Hz) (major), 1.27 (3H, d,  $J = 7.0$  Hz) (minor), 1.23 (3H, t,  $J = 7.0$  Hz) (minor), 1.15 (3H, t,  $J = 7.0$  Hz) (major); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  169.1, 168.3, 162.7, 133.2, 131.5, 127.3, 126.9, 114.9, 114.8, 66.3, 64.3, 61.9, 55.8, 14.3, 14.3, 10.4, 8.9 ppm; IR (KBr)  $\delta$  3096, 3069, 2981, 2940, 2842, 1727, 1598, 1500, 1459, 1306, 1258, 1173, 1092, 1024, 834, 793, 626 cm $^{-1}$ ; HRMS  $m/z$  calcd for C<sub>12</sub>H<sub>17</sub>O<sub>4</sub>S [M + H<sup>+</sup>] 257.0848; found 257.0849; calcd for C<sub>12</sub>H<sub>16</sub>O<sub>4</sub>SNa [M + Na<sup>+</sup>] 279.0667, found 279.0656.

**Ethyl 2-((4-nitrophenyl)sulfinyl)propanoate (2c):** yield = 160 mg, 62%; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  8.31 (2H, d,  $J = 8.5$  Hz) (major), 8.30 (2H, d,  $J = 9.0$  Hz) (minor), 7.82 (2H, d,  $J = 9.0$  Hz) (major), 7.77 (2H, d,  $J = 9.0$  Hz) (minor), 4.04–4.15 (2H, m) (major and minor), 3.84 (1H, q,  $J = 7.0$  Hz) (major), 3.48 (1H, q,  $J = 7.0$  Hz) (minor), 1.41 (3H, d,  $J = 7.5$  Hz) (major), 1.30 (3H, d,  $J = 7.0$  Hz) (minor), 1.17 (3H, t,  $J = 7.5$  Hz) (minor), 1.15 (3H, t,  $J = 7.5$  Hz) (major); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  169.6, 168.3, 149.7, 147.9, 126.6, 126.2, 127.3, 125.6, 125.0, 65.6, 63.7, 62.5, 62.3, 14.2, 9.4, 9.0 ppm; IR (NaCl)  $\delta$  3101, 2985, 1732, 1603, 1579, 1527, 1475, 1450,

1398, 1347, 1150, 1089, 1054, 1011, 1017, 853, 743, 723, 684  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{11}\text{H}_{14}\text{NO}_3\text{S}$  [ $\text{M} + \text{H}^+$ ] 272.0593, found 272.0580; calcd for  $\text{C}_{11}\text{H}_{13}\text{NO}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 294.0412, found 294.0405.

**Ethyl 2-(phenylsulfinyl)butanoate (2d):** yield = 187 mg, 82%;  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.49–7.66 (5H, m) (major and minor), 3.95–4.10 (2H, m) (major and minor), 3.48 (1H, dd,  $J = 5.0, 10.0$  Hz) (major), 3.39 (1H, dd,  $J = 5.0, 9.5$  Hz) (minor), 2.06–2.16 (1H, m) (major and minor), 1.76–1.90 (1H, m) (major and minor), 1.12 (3H, t,  $J = 7.5$  Hz) (major), 1.06 (3H, t,  $J = 7.5$  Hz) (minor), 1.03 (3H, t,  $J = 7.0$  Hz) (major), 1.00 (3H, t,  $J = 7.5$  Hz) (minor);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  167.6, 166.7, 142.2, 141.1, 131.7, 131.4, 129.9, 128.9, 124.8, 124.7, 73.5, 70.6, 61.3, 20.3, 18.7, 13.8, 11.5, 11.3 ppm; IR (oil)  $\delta$  3066, 2975, 2940, 2880, 2088, 1972, 1894, 1726, 1638, 1581, 1476, 1448, 1374, 1335, 1258, 1202, 1163, 1089, 1039, 952, 860, 815  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{12}\text{H}_{17}\text{O}_3\text{S}$  [ $\text{M} + \text{H}^+$ ] 241.0898, found 241.0900; calcd for  $\text{C}_{12}\text{H}_{16}\text{O}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 263.0718, found 263.0722.

**Ethyl 2-(phenylsulfinyl)pentanoate (2e):** yield = 222 mg, 92%;  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.46–7.65 (5H, m) (major and minor), 3.88–4.10 (2H, m) (major and minor), 3.53 (1H, dd,  $J = 5.5, 10.0$  Hz) (major), 3.43 (1H, dd,  $J = 5.0, 9.0$  Hz) (minor), 2.02–2.10 (1H, m) (major and minor), 1.73–1.84 (1H, m) (major and minor), 1.28–1.48 (2H, m) (major and minor), 1.09 (3H, t,  $J = 7.0$  Hz) (major), 1.03 (3H, t,  $J = 7.5$  Hz) (minor), 0.91 (3H, t,  $J = 7.0$  Hz) (major), 0.88 (3H, t,  $J = 7.5$  Hz) (minor);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  167.9, 166.8, 142.3, 141.7, 131.7, 131.5, 129.0, 128.8, 124.8, 124.7, 72.1, 68.8, 61.2, 28.7, 27.0, 20.3, 13.8, 13.5 ppm; IR (oil)  $\delta$  3062, 2968, 2940, 2879, 2095, 1972, 1891, 1729, 1585, 1469, 1447, 1377, 1335, 1275, 1247, 1191, 1156, 1089, 1057, 941, 860, 825  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{13}\text{H}_{19}\text{O}_3\text{S}$  [ $\text{M} + \text{H}^+$ ] 255.1055, found 255.1053; calcd for  $\text{C}_{13}\text{H}_{18}\text{O}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 277.0874, found 277.0876.

**Benzyl 2-(phenylsulfinyl)propanoate (2f):** yield = 192 mg, 70%;  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.17–7.55 (10H, m) (major and minor), 5.10 (1H, d,  $J = 12.0$  Hz) (major), 5.10 (1H, d,  $J = 12.0$  Hz) (minor), 5.00 (1H, d,  $J = 12.0$  Hz) (major), 4.99 (1H, d,  $J = 12.0$  Hz) (minor), 3.82 (1H, q,  $J = 7.2$  Hz) (major), 3.50 (1H, q,  $J = 7.2$  Hz) (minor), 1.41 (3H, d,  $J = 6.9$  Hz) (major), 1.26 (3H, d,  $J = 7.2$  Hz) (minor);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  168.4, 167.5, 142.0, 140.2, 134.9, 131.7, 131.5, 129.1, 128.9, 128.6, 128.5, 128.4, 128.3, 125.0, 124.6, 67.4, 67.3, 65.4, 63.5, 9.4, 8.6 ppm; IR (oil)  $\delta$  3067, 3036, 2939, 1965, 1894, 1732, 1583, 1499, 1477, 1449, 1380, 1318, 1222, 1163, 1050, 998, 957, 920, 848, 820, 777  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{16}\text{H}_{17}\text{O}_3\text{S}$  [ $\text{M} + \text{H}^+$ ] 289.0898, found 289.0894; calcd for  $\text{C}_{16}\text{H}_{16}\text{O}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 311.0718, found 311.0713.

**Experimental Procedure for Elimination.** A mixture of compound 2 (1 mmol) in toluene (6 mL) was heated at 110 °C for 5 h (in the case of compounds 2a, 2b, 2c and 2f, the reaction was performed in a sealed flask to avoid acrylate loss). Then the resulting crude mixture was purified through chromatography (silica gel, hexanes/ethyl acetate (1:1), (1:2) and ethyl acetate) to afford the corresponding enoate.

**S-phenyl benzenesulfonothioate (9):**  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.13–7.51 (10H, m);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  143.0, 136.6, 133.6, 131.4, 129.4, 129.0, 128.8, 127.9, 127.6, 127.2 ppm; IR (NaCl)  $\delta$  3064, 1580, 1445, 1323, 1144, 1076, 1021, 748, 688  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{12}\text{H}_{10}\text{O}_2\text{S}_2\text{Na}$  [ $\text{M} + \text{Na}^+$ ] 273.0020, found 273.0026.

**Diphenyl disulfide (16):**  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.13–7.17 (2H, m), 7.21–7.24 (4H, t,  $J = 8.5$  Hz), 7.42 (4H, d,  $J = 8.5$  Hz);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  137.1, 129.0, 127.6, 127.2 ppm; IR (NaCl)  $\delta$  3064, 1946, 1864, 1800, 1735, 1574, 1470, 1432, 1379, 1298, 1068, 1017, 896, 787, 735, 686, 605  $\text{cm}^{-1}$ ; HRMS (EI)  $m/z$  calcd for  $\text{C}_{12}\text{H}_{10}\text{S}_2$  [ $\text{M}$ ] 218.0224, found 218.0210.

**2-(Ethoxycarbonyl)ethyl benzenesulfenate (10):**  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.61–7.62 (2H, m), 7.49–7.54 (3H, m), 4.11 (2H, q,  $J = 7.5$  Hz), 3.22 (1H, m), 2.97 (1H, m), 2.84 (1H, m), 2.54 (1H, m), 1.22 (3H, d,  $J = 7.5$  Hz);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  171.5, 143.4, 131.5, 129.6, 124.4, 61.4, 51.5, 26.5, 14.4 ppm; IR (NaCl)  $\delta$  2963, 1733, 1445, 1373, 1260, 1087, 1045, 799, 750, 691  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{11}\text{H}_{14}\text{O}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 249.0561, found 249.0561.

**Experimental Procedure for Trapping the Radical.** A mixture of compound 2e (500 mg, 1.96 mmol) and 2,2,6,6-Tetramethyl-1-piperidinyloxy (Tempo) (614 mg, 3.93 mmol) in toluene (10 mL) was heated at 80 °C for 2 h. The resulting crude mixture was carefully concentrated under vacuum and then purified through chromatography (silica gel, hexanes/ethyl acetate (95:5)) to afford compound 13 (17 mg, 3%) as an oil and compound 14 (60 mg, 11%) as a white solid. Recrystallization of 14 from  $\text{CH}_2\text{Cl}_2$ /hexanes gave white prismatic crystals (mp = 128–130 °C).

**Ethyl 2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)pentanoate (13):**  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  4.21 (1H, dd,  $J = 6.6, 7.5$  Hz), 4.15 (2H, q,  $J = 7.2$  Hz), 1.74–1.85 (2H, m), 1.01–1.48 (23H, m), 0.91 (3H, t,  $J = 7.2$  Hz);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  173.6, 85.5, 60.1, 40.3, 34.2, 33.6, 33.0, 20.2, 17.9, 17.1, 14.2, 13.9 ppm; IR (KBr)  $\delta$  2974, 2933, 2876, 1748, 1466, 1381, 1366, 1269, 1245, 1184, 1133, 1105, 1058, 1031, 993, 976, 963, 929, 881, 857, 793, 752, 722, 681, 650  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{16}\text{H}_{32}\text{NO}_3$  [ $\text{M} + \text{H}^+$ ] 286.2382, found 286.2377.

**2,2,6,6-Tetramethylpiperidin-1-yl benzenesulfinate (14):**  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.82–7.89 (2H, m), 7.39–7.47 (3H, m), 1.66 (6H, s), 1.57 (12H, s);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  147.2, 131.2, 128.5, 126.0, 60.8, 43.8, 31.1, 16.7 ppm; IR (KBr)  $\delta$  3069, 3035, 2984, 2944, 2916, 2879, 1404, 1394, 1245, 1204, 1184, 1139, 1095, 1071, 980, 922, 786, 766, 715, 701, 626, 613  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{15}\text{H}_{23}\text{NO}_2\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 304.1347, found 304.1348.

**(4S,5S)-Dihydro-4-hydroxy-5-methyl-3-methylenefuran-2(3H)-one (18) and (3R,4S,5S)-Dihydro-4-hydroxy-5-methyl-3-((phenylsulfonyl)methyl)furan-2(3H)-one (19).** An oxygen-flushed mixture of compound 17 (124 mg, 0.48 mmol) in toluene (8 mL) was heated at 110 °C for 5 h. Then the solvent was removed under vacuum and the resulting mixture was purified through chromatography (silica gel, hexanes/ethyl acetate (1:1), (1:2) and ethyl acetate) to afford 44 mg (71%) of compound 18 as a colorless oil and 16 mg (12%) of compound 19 as a white solid. Recrystallization from  $\text{CHCl}_3$ /hexanes gave white needles (mp = 117–120 °C).

Spectroscopic data of 18:  $[\alpha]_{\text{D}}^{20} = -97.26$  ( $c = 1.3$ ,  $\text{CHCl}_3$ );  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  6.41 (1H, d,  $J = 2.1$  Hz), 5.97 (1H, d,  $J = 1.5$  Hz), 4.83 (1H, d,  $J = 5.7$  Hz), 4.65 (1H, dq,  $J = 6.0, 6.6$  Hz), 1.34 (3H, d,  $J = 6.6$  Hz);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  168.9, 138.8, 126.3, 78.4, 69.7, 14.3; IR (NaCl)  $\delta$  3439, 3015, 2930, 1756, 1672, 1387, 1263, 1186, 1103, 1045, 958, 910, 861, 821, 784  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_6\text{H}_8\text{O}_3\text{Na}$  [ $\text{M} + \text{Na}^+$ ] 151.0371, found 151.0354.

Spectroscopic data of 19:  $[\alpha]_{\text{D}}^{26} = -33.94$  ( $c = 1$ ,  $\text{CHCl}_3$ );  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.95 (2H, d,  $J = 7.2$  Hz), 7.72 (t, 1H,  $J = 7.5$  Hz), 7.61 (t, 2H,  $J = 7.8$  Hz), 4.72 (m, 1H), 4.63 (m, 1H), 3.56 (m, 2H), 3.26 (m, 1H), 2.93 (d, 1H,  $J = 4.2$  Hz), 1.49 (3H, d,  $J = 6.6$  Hz);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  174.6, 138.4, 134.5, 129.7, 127.8, 79.6, 70.1, 51.2, 42.7, 13.6 ppm; IR (NaCl)  $\delta$  3350, 2949, 2836, 1764, 1656, 1449, 1412, 1117, 1033  $\text{cm}^{-1}$ ; HRMS  $m/z$  calcd for  $\text{C}_{12}\text{H}_{14}\text{O}_3\text{SNa}$  [ $\text{M} + \text{Na}^+$ ] 293.0460, found 293.0429.

## ■ ASSOCIATED CONTENT

### ● Supporting Information

Crystallographic data (CIF), graphical NMR spectra of all compounds, and ORTEP representations. This material is available free of charge via the Internet at <http://pubs.acs.org>.

## ■ AUTHOR INFORMATION

### Corresponding Author

\*E-mail: [fgonzale@qio.uji.es](mailto:fgonzale@qio.uji.es), [barrera@sg.uji.es](mailto:barrera@sg.uji.es).

### Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

This work was financed by Bancaixa-UJI Foundation (P1 1B2011-59 and P1 1B2011-28). We are grateful to the Serveis

Centrals d'Instrumentació Científica (SCIC) of the Universitat Jaume I for providing us with mass spectrometry and NMR.

## DEDICATION

We dedicate this work to the memory of Prof. Purificación Escribano.

## REFERENCES

- (1) Carreño, C. *Chem. Rev.* **1995**, *95*, 1717–1760.
- (2) Trost, B. M.; Salzmann, T. N.; Hiroi, K. *J. Am. Chem. Soc.* **1975**, *97*, 4887–4902.
- (3) Trost, B. M.; Leung, K. K. *Tetrahedron Lett.* **1975**, *48*, 4197–4200.
- (4) Trost, B. M.; Mao, M. K. T.; Balkovec, J. M.; Buhlmyer, P. *J. Am. Chem. Soc.* **1986**, *108*, 4965–4973.
- (5) Bänziger, M.; Kleina, S.; Rihs, G. *Helv. Chim. Acta* **2002**, *85*, 1399–1406.
- (6) Kingsbury, C. A.; Cram, D. J. *J. Am. Chem. Soc.* **1960**, *82*, 1810–1819.
- (7) Cubagge, J. W.; Guo, Y.; McCulla, R. D.; Jenks, W. S. *J. Org. Chem.* **2001**, *66*, 8722–8736.
- (8) McCulla, R. D.; Jenks, W. S. *J. Org. Chem.* **2003**, *68*, 7871–7879.
- (9) López, I.; Izquierdo, J.; Rodríguez, S.; González, F. V. *J. Org. Chem.* **2007**, *72*, 6614–6617.
- (10) González, F. V.; Jain, A.; Rodríguez, S.; Sáez, J.; Vicent, C.; Peris, G. *J. Org. Chem.* **2010**, *75*, 5888–5894.
- (11) An approximately 3:2 mixture of stereomeric sulfoxides was obtained in all cases (see the Supporting Information).
- (12) The elimination reactions afforded *trans* isomers as the reaction product, and the corresponding *cis* isomers were never observed (NMR spectra) even in trace amounts. The elimination reactions were also performed at 80 °C, and the result was similar to that for the reaction carried out at 110 °C: only *trans* enoates were obtained.
- (13) Compounds **5–8** were identified on the basis of NMR (see the Supporting Information) comparing with prior literature. For compound **5**: *Aldrich Library of <sup>13</sup>C and <sup>1</sup>H FT NMR spectra*; Aldrich: Milwaukee; 1993, p 973C. For compound **6**: Nishizawa, M.; Hirakawa, H.; Nakagawa, Y.; Yamamoto, H.; Namba, K.; Imagawa, H. *Org. Lett.* **2007**, *9*, 5577–5580. For compound **7**: Kandula, S. R. V.; Kumar, P. *Tetrahedron:Asymmetry* **2005**, *16*, 3268–3274. For compound **8**: Pittelkow, M.; Christensen, J. B. *Org. Lett.* **2005**, *7*, 1295–1298.
- (14) Rearranged sulfoxides similar to **10** from the elimination reactions of compounds **2b–2f** have been detected as traces by NMR and MS of the crude.
- (15) Compound **10** was isolated from the crossover experiment reaction mixture depicted in scheme 4, and compared with authentic sample already isolated and characterized.
- (16) Guo, Y.; Jenks, W. S. *J. Org. Chem.* **1997**, *62*, 857–864.
- (17) ESI-MS has shown to be a good technique for the detection of radicals by Tempo combination: Zhang, X.; Wang, H.; Guo, Y. *Rapid Commun. Mass Spectrom.* **2006**, *20*, 1877–1882.
- (18) Nitroxides as **11** are radical initiators (*Macromolecules* **1997**, *30*, 6445–6450). When the elimination reaction to trap the radical intermediate was performed at 110 °C, compounds **14** and **15** were detected but **11–13** were not. Finally, compounds **11–13** could be detected when the reaction was carried out at 80 °C.
- (19) Phenyl disulfide was isolated and characterized (see the Supporting Information), and phenylsulfonic acid was detected by ESI-MS. For references related to the conversion of thiosulfonates into disulfides, see: Pinnick, H. W.; Reynolds, M. A.; McDonald, R. T.; Brewster, W. D. *J. Org. Chem.* **1980**, *45*, 930–932 and cites herein.
- (20) Shelton, J. R.; Davis, K. E. *J. Am. Chem. Soc.* **1967**, *89*, 718–719.
- (21) Barton, D. H. R.; Comer, F.; Greig, D. G. T.; Lucente, G.; Sannes, P. G.; Underwood, W. G. *J. Chem. Soc., Chem. Commun.* **1970**, *17*, 1059.
- (22) Barton, D. H. R.; Sannes, P. G.; Taylor, M. V.; Cooper, C. M.; Hewitt, G.; Looker, B. F.; Underwood, W. G. *J. Chem. Soc., Chem. Commun.* **1971**, *18*, 1137.
- (23) Carey, F. A.; Sundberg, R. J. *Advanced Organic Chemistry*; Kluwer Academic/Plenum Publishers: New York, 2000; Part A, pp226.
- (24) Santos, L. S.; Knaack, L.; Metzger, J. O. *Int. J. Mass Spectrom.* **2005**, *246*, 84–104.
- (25) Eberlin, M. N. *Eur. J. Mass Spectrom.* **2007**, *13*, 19–28.
- (26) Santos, L. S. *Eur. J. Org. Chem.* **2008**, 235–253.
- (27) Meyer, S.; Koch, R.; Metzger, J. O. *Angew. Chem., Int. Ed.* **2003**, *42*, 4700–4703.
- (28) Griep; Raming, J.; Metzger, J. O. *Anal. Chem.* **2000**, *72*, 5665–5668.
- (29) Meyer, S.; Metzger, J. O. *Anal. Bioanal. Chem.* **2003**, *377*, 1108–1114.
- (30) Fürmeier, S.; Metzger, J. O. *J. Am. Chem. Soc.* **2004**, *126*, 14485–14492.
- (31) Zhang, X.; Liao, Y.; Qian, R.; Wang, H.; Guo, Y. *Org. Lett.* **2005**, *7*, 3877–3880.
- (32) Schäfer, M.; Drayb, M.; Springer, A.; Zacharias, P.; Meerholz, K. *Eur. J. Org. Chem.* **2007**, 5162–5174.
- (33) Cubagge, J. W.; Vos, B. W.; Jenks, W. S. *J. Am. Chem. Soc.* **2000**, *122*, 4968–4971.
- (34) The X-ray structure of compound **19** confirmed the stereochemistry (see the Supporting Information).
- (35) Clennan, E. L.; Kang, Y. *J. Org. Chem.* **1992**, *57*, 4477–4487.