Base-Mediated Synthesis of 1-Aryl-4-(phenylsulfonyl)butan-1-ones from 1,2-Bis(phenylsulfonyl)ethane and Ketones

Ye-Xiang Xie, Ren-Jie Song,* Yu Liu, Zhi-Qiang Wang, Jian-Nan Xiang,* Jin-Heng Li*

State Key Laboratory of Chemo/Biosensing and Chemometrics, College of Chemistry and Chemical Engineering, Hunan University, Changsha 410082, P. R. of China
Fax +86(731)88713642; E-mail: jhli@hnu.edu.cn; E-mail: srj0731@hnu.edu.cn; E-mail: jnxiang@hnu.edu.cn

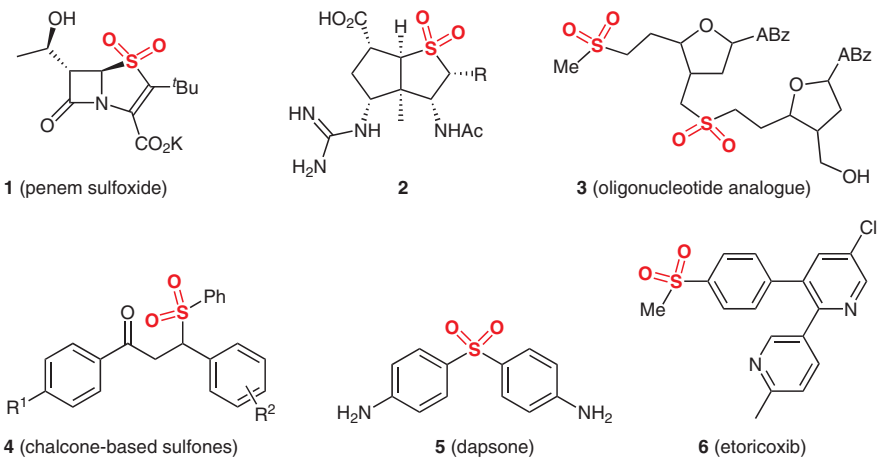
Received: 20.08.2013; Accepted after revision: 23.10.2013

Abstract: A new, simple, base-mediated addition reaction of 1,2-bis(phenylsulfonyl)ethane to ketones has been developed for the synthesis of 1-aryl-4-(phenylsulfonyl)butan-1-ones. This method represents the first example of preparing sulfones using 1,2-bis(phenylsulfonyl)ethane as the sulfone resource.

Key words: base, addition, 1,2-bis(phenylsulfonyl)ethane, ketones, sulfones

Sulfones are important units found in organic materials, bioactive molecules, and pharmaceuticals (Figure 1),[1] they also serve widely as valuable intermediates in synthetic chemistry.[1–3] As a result, considerable effort has been paid to the development of new and efficient methods for sulfone synthesis. Generally, conjugate addition of carbon nucleophiles to vinyl sulfones is one of the most important accesses to various sulfones by a carbon–carbon bond-forming process.[4–7] In this context, the Brønsted base-catalyzed Michael addition of α-carbon nucleophiles in carbonyl compounds with vinyl sulfones is particularly popular [Scheme 1 (a)].[6,7] Despite impressive progress in this field, the methods are limited to aldehydes, imines, and other activated α-C–H bond-containing reagents (often 1,3-dicarbonyl compounds); moreover, examples of using common ketones as the carbon nucleophiles have not been reported. Herein, we wish to report a new approach to sulfones via base-mediated addition of 1,2-bis(phenylsulfonyl)ethane with ketones; this simple and selective approach expands the scope to common ketones and involves the use of the commercial available 1,2-bis(phenylsulfonyl)ethane instead of vinyl sulfones for the preparation of new functionalized sulfones [Scheme 1 (b)].[8]

The reaction between 1,2-bis(phenylsulfonyl)ethane (**1a**) and 2-phenoxy-1-phenylethanone (**2a**) was initially investigated to optimize the reaction conditions, and the results are summarized in Table 1. To our delight, treatment of substrate **1a** with ketone **2a** and potassium *tert*-butoxide successfully afforded the desired product **3** in 65% yield (entry 1). Screening revealed that the amount of potassium *tert*-butoxide affected the reaction, and the reaction using two equivalents of potassium *tert*-butoxide gave the best results (entries 1–4): while moderate yields of **3** were obtained using two or three equivalents of potassium *tert*-butoxide, the yield was lowered to 37% using one equivalent of potassium *tert*-butoxide and to 12% yield using 0.2 equivalents of potassium *tert*-butoxide. Among the reaction temperatures examined, the viable temperature was 120 °C (entry 1 vs. 5 and 6). A series of bases, such as cesium carbonate, potassium carbonate, cesium fluoride,

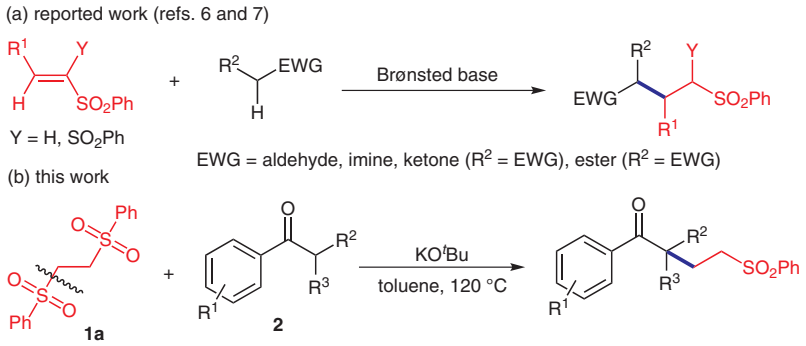


1 (penem sulfoxide) **2** **3** (oligonucleotide analogue)

4 (chalcone-based sulfones) **5** (dapsone) **6** (etoricoxib)

Figure 1 Examples of important sulfones

SYNTHESIS 2014, 46, 0203–0211
Advanced online publication: 14.11.2013
DOI: 10.1055/s-0033-1338557; Art ID: SS-2013-H0578-OP

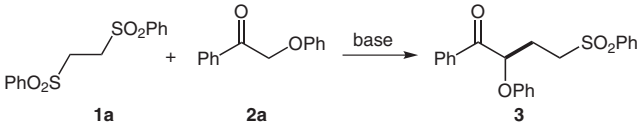


Scheme 1 Synthesis of sulfones

and lithium hexamethyldisilazanide, were also evaluated, and they were all less effective than potassium *tert*-butoxide (entry 1 vs. 6–10). Notably, the effect of the solvent played an important role in the reaction (entry 1 vs. 11–13): a series of solvents, including acetonitrile, 1,2-dichloroethane, and *N*,*N*-dimethylformamide, were examined, and they were less effective.

With the optimal conditions in hand, we next set out to explore the scope of the ketone **2** with respect to 1,2-bis(phenylsulfonyl)ethane (**1a**) (Table 2). Initially, a variety of 1-aryl-2-aryloxyethanones **2b**–**n** were investigated, and they were compatible with the optimal conditions (entries 1–13). The results demonstrated that substituents, such as methyl, methoxy, chloro, or iodo groups, on the aromatic ring of the aryloxy moiety were well tolerated (entries 1–6). For example, substrate **2f** with a chloro group reacted with 1,2-bis(phenylsulfonyl)ethane (**1a**) smoothly, providing the target product **8** in 67% yield (entry 5). To our delight, 2-(naphthalen-1-yloxy)-1-phenylethanone (**2h**) reacted with **1a** to give **10** in 64% yield (entry 7). Extensive screening revealed that substituents, either electron-donating or electron-withdrawing groups, on the aromatic ring of the arylethanone moiety were also tolerated (entries 8–12). Using substrate **2l** bearing a bulky 2-methoxy group in the presence of **1a** and potassium *tert*-butoxide, for instance, gave a good yield of product **14** (entry 11). Interestingly, 2-phenoxy-1-phenylpropan-1-one (**2n**) was also viable in the reaction (entry 13). Notably, two other acetophenones **2o** and **2p**, with a CO_2Et or CN group at the α-position, reacted successfully with **1a** and potassium *tert*-butoxide, furnishing the corresponding products **17** and **18** in 73% and 27% yields, respectively (entries 14 and 15). We were happy to find that reaction of acetophenone (**2q**), a common ketone, with **1a** was successful under the optimal conditions (entry 16). It is noteworthy that scope of this current protocol can be expanded to benzofuran-3(2*H*)-one (**2r**), a heterocyclic compounds, which makes the application of this methodology more attractive in organic synthesis (entry 17).

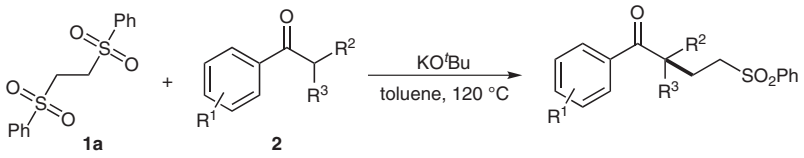
Table 1 Screening Optimal Conditions[a]



Entry	Base (equiv)	Solvent	T (°C)	Isolated yield (%)
1	KO*t*-Bu (2.0)	toluene	120	65
2	KO*t*-Bu (3.0)	toluene	120	63
3	KO*t*-Bu (1.0)	toluene	120	37
4	KO*t*-Bu (0.2)	toluene	120	12
5	KO*t*-Bu (2.0)	toluene	100	46
6	KO*t*-Bu (2.0)	toluene	80	29
7	Cs_2CO_3 (2.0)	toluene	120	61
8	K_2CO_3 (2.0)	toluene	120	52
9	CsF (2.0)	toluene	120	24
10	LiHMDS (2.0)	toluene	120	59
11	KO*t*-Bu (2.0)	MeCN	120	48
12	KO*t*-Bu (2.0)	DCE	120	22
13	KO*t*-Bu (2.0)	DMF	120	trace

[a] Reaction conditions: **1a** (0.2 mmol), **2a** (0.3 mmol), solvent (2 mL), 36 h.

Table 2 Addition of 1,2-Bis(phenylsulfonyl)ethane (**1a**) to Ketones **2**[a]



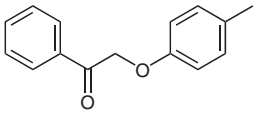
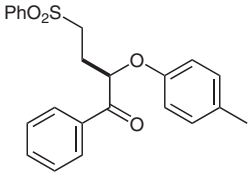
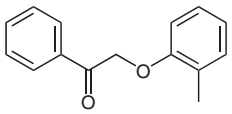
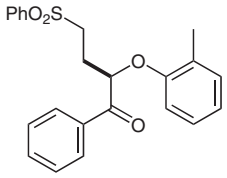
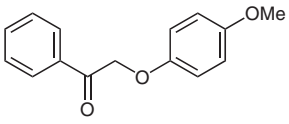
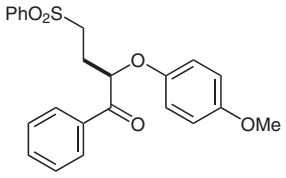
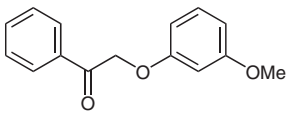
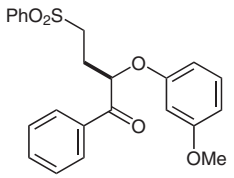
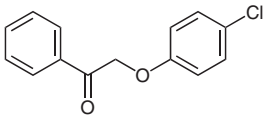
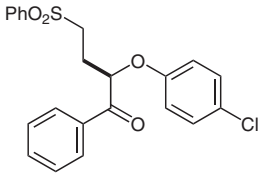
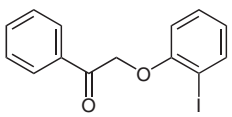
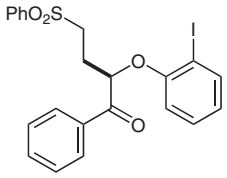
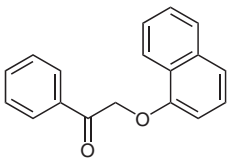
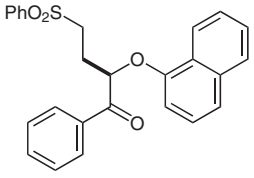
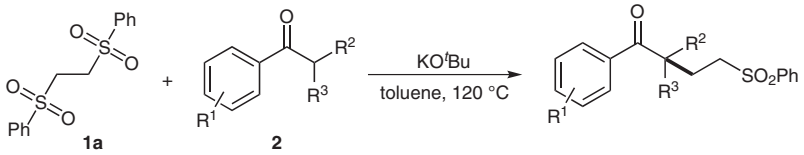
Entry	Substrate **2**	Product	Isolated yield (%)
1	 **2b**	 **4**	45
2	 **2c**	 **5**	56
3	 **2d**	 **6**	59
4	 **2e**	 **7**	54
5	 **2f**	 **8**	67
6	 **2g**	 **9**	67
7	 **2h**	 **10**	64

Table 2 Addition of 1,2-Bis(phenylsulfonyl)ethane (**1a**) to Ketones **2**[a] (continued)



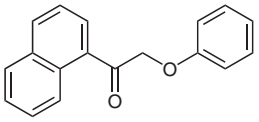
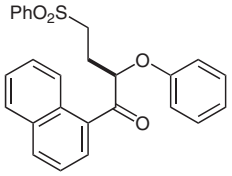
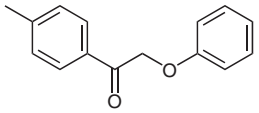
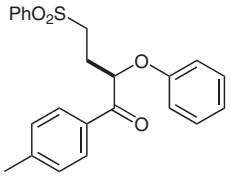
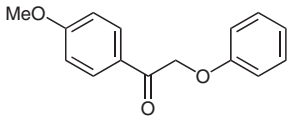
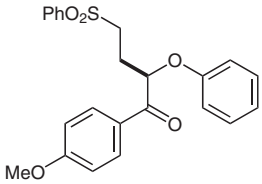
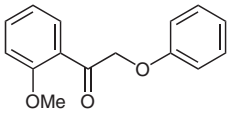
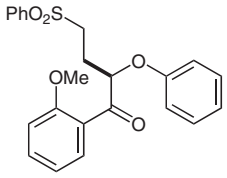
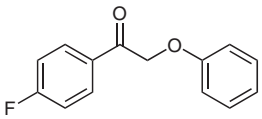
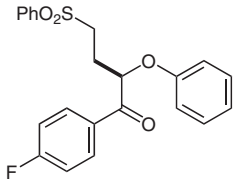
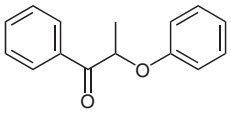
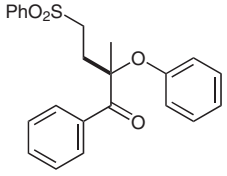
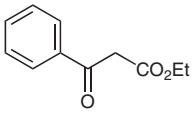
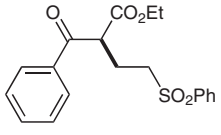
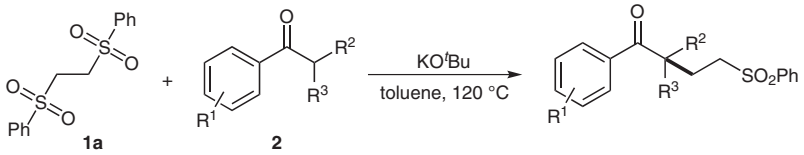
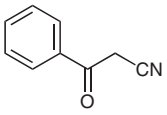
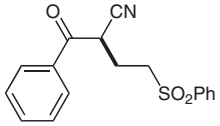
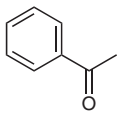
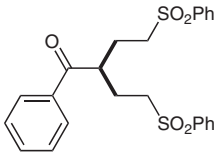
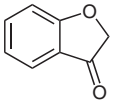
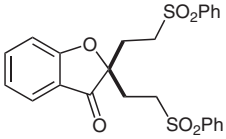
Entry	Substrate **2**	Product	Isolated yield (%)
8	 **2i**	 **11**	74
9	 **2j**	 **12**	71
10	 **2k**	 **13**	69
11	 **2l**	 **14**	89
12	 **2m**	 **15**	76
13	 **2n**	 **16**	81
14	 **2o**	 **17**	73

Table 2 Addition of 1,2-Bis(phenylsulfonyl)ethane (**1a**) to Ketones **2**[a] (continued)

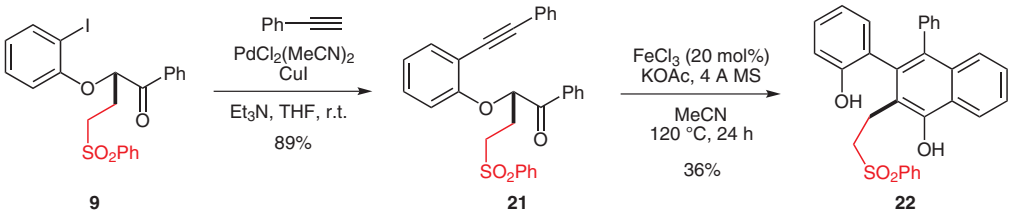


Entry	Substrate **2**	Product	Isolated yield (%)
15	 **2p**	 **18**	27
16	 **2q**	 **19**	46
17	 **2r**	 **20**	46

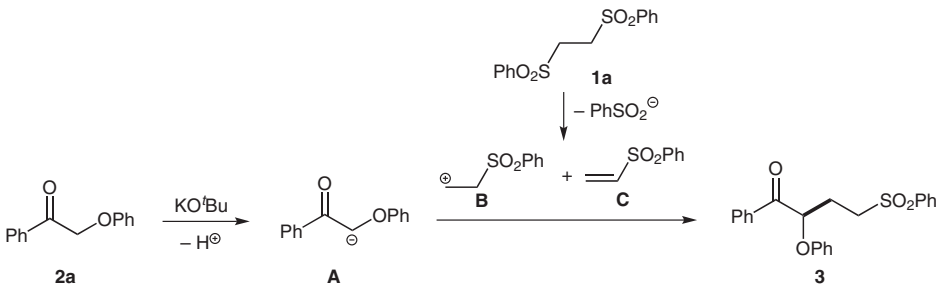
[a] Reaction conditions: **1a** (0.2 mmol), **2** (0.3 mmol), KO*t*-Bu (2.0 equiv), toluene (2 mL), 120 °C, 36 h.

With 2-(2-iodophenoxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (**9**) in hand, we turned our attention to the application of this product in the synthesis of naphthalene derivatives (Scheme 2). Treatment of **9** with phenylacetylene, $PdCl_2(MeCN)_2$, and copper(I) iodide afforded the corresponding Sonogashira product **21** in 89% yield, followed by intramolecular cyclization of compound **21** in the presence of iron(III) chloride[9] resulted in naphthalen-1-ol **22** in 36% yield.

A possible mechanism for the reaction of **1a** with ketones **2** is presented in Scheme 3.[7,8] In the presence of a base, anion intermediate **A** can be readily obtained from a ketone.



Scheme 2 Application of product **9**



Scheme 3 Possible mechanism

Intermediate **A** then undergoes addition to sulfone cation **B** and vinyl sulfone **C**, generated in situ from 1,2-bis(phenylsulfonyl)ethane (**1a**) with the aid of a base, to afford the desired product **3**. Notably, vinyl sulfone **C** was observed by in situ GC-MS analysis of the reaction between 1,2-bis(phenylsulfonyl)ethane (**1a**) and 2-phenoxy-1-phenylethanone (**2a**).

In summary, we have illustrated the first example of the preparation of sulfones using 1,2-bis(phenylsulfonyl)ethane as the sulfone source. In presence of potassium *tert*-butoxide, a variety of ketones were treated with 1,2-bis(phenylsulfonyl)ethane to afford the corresponding 1-aryl-4-(phenylsulfonyl)butan-1-one in moderate to good yields. Notably, this method is simple and general with a wide range of compatible ketones, which opens a new route for the synthesis of important sulfones.

NMR spectroscopy was performed on a Bruker Avance spectrometer operating at 500 MHz (^{1}H NMR) and 125 MHz (^{13}C NMR) or 400 MHz (^{1}H NMR) and 100 MHz (^{13}C NMR). Mass spectrometric analysis was performed on GC-MS analysis (Shimadzu GCMS-QP2010) and ESI-Q-TOF (Bruker MicroQTOF-II. Meltingn points are uncorrected.

1-Aryl-4-(phenylsulfonyl)butan-1-ones 3–20; General Procedure

To a Schlenk tube were added 1,2-bis(phenylsulfonyl)ethane (**1a**, 0.2 mmol), ketone **2** (0.3 mmol), KO*t*-Bu (2.0 equiv), and toluene (2 mL). Then the tube was stirred at 120 °C (oil bath temperature) in air for the indicated time until complete consumption of starting material (TLC and GC-MS monitoring). When the reaction was complete, the mixture was diluted with Et_2O (5 mL), and washed with brine (3 × 1 mL). The aqueous phase was re-extracted with Et_2O (3 × 2 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated in vacuo, and the resulting residue was purified by column chromatography (silica gel, *n*-hexane–EtOAc, 10:1) to afford the product.

2-Phenoxy-1-phenyl-4-(phenylsulfonyl)butan-1-one (3)

Colorless oil; yield: 49.4 mg (65%).

IR (KBr): 1698, 1653, 1558 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06 (d, *J* = 8.0 Hz, 2 H), 7.90 (d, *J* = 7.6 Hz, 2 H), 7.65–7.61 (m, 2 H), 7.57–7.48 (m, 4 H), 7.22 (t, *J* = 8.0 Hz, 2 H), 6.95 (t, *J* = 7.6 Hz, 1 H), 6.81 (d, *J* = 8.0 Hz, 2 H), 5.63–5.60 (m, 1 H), 3.49–3.34 (m, 2 H), 2.58–2.49 (m, 1 H), 2.44–2.35 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.0, 157.0, 138.8, 134.2, 133.9, 133.8, 129.7, 129.4, 129.0, 128.7, 127.9, 122.0, 115.2, 77.4, 52.0, 26.0.

LRMS (EI, 70 eV): *m*/*z* (%) = 380 (M$^+$, 3), 275 (27), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{22}H_{20}O_4SNa$: 403.0975; found: 403.0968.

1-Phenyl-4-(phenylsulfonyl)-2-(*p*-tolyloxy)butan-1-one (4)

Colorless oil; yield: 35.5 mg (45%).

IR (KBr): 1687, 1643, 1507 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.05 (d, *J* = 7.5 Hz, 2 H), 7.90 (d, *J* = 7.0 Hz, 2 H), 7.66–7.60 (m, 2 H), 7.55 (t, *J* = 8.0 Hz, 2 H), 7.50–7.47 (m, 2 H), 7.00 (d, *J* = 8.0 Hz, 2 H), 6.72–6.70 (m, 2 H), 5.57–5.55 (m, 1 H), 3.44–3.36 (m, 2 H), 2.52–2.49 (m, 1 H), 2.40–2.35 (m, 1 H), 2.23 (s, 3 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 197.3, 154.9, 138.8, 134.2, 133.9 (2 C), 131.4, 130.1, 129.4, 129.0, 128.8, 127.9, 115.1, 77.7, 52.0, 26.0, 20.4.

LRMS (EI, 70 eV): *m*/*z* (%) = 396 (1), 394 (M$^+$, 5), 289 (14), 147 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_4SNa$: 417.1131; found: 417.1115.

1-Phenyl-4-(phenylsulfonyl)-2-(*o*-tolyloxy)butan-1-one (5)

Colorless oil; yield: 44.1 mg (56%).

IR (KBr): 1716, 1652, 1558 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.03 (d, *J* = 7.5 Hz, 2 H), 7.90 (d, *J* = 7.0 Hz, 2 H), 7.65–7.61 (m, 2 H), 7.60–7.53 (m, 2 H), 7.48 (t, *J* = 7.5 Hz, 2 H), 7.12–7.02 (m, 1 H), 6.99 (t, *J* = 7.5 Hz, 1 H), 6.84 (t, *J* = 7.5 Hz, 1 H), 6.55 (d, *J* = 7.0 Hz, 1 H), 5.61–5.58 (m, 1 H), 3.48–3.36 (m, 2 H), 2.54–2.51 (m, 1 H), 2.46–2.42 (m, 1 H), 2.22 (s, 3 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 197.0, 154.8, 138.6, 134.0, 133.8, 131.0, 129.3, 128.9, 128.5, 127.8, 126.8, 126.7, 121.4, 111.4, 77.2, 51.9, 26.0, 16.3.

LRMS (EI, 70 eV): *m*/*z* (%) = 396 (1), 394 (M$^+$, 8), 289 (13), 147 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_4SNa$: 417.1131; found: 417.1118.

2-(4-Methoxyphenoxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (6)

Red oil; yield: 48.4 mg (59%).

IR (KBr): 1688, 1508, 1461 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.04 (d, *J* = 8.0 Hz, 2 H), 7.90 (d, *J* = 8.0 Hz, 2 H), 7.64–7.61 (m, 2 H), 7.55 (t, *J* = 7.6 Hz, 2 H), 7.49 (t, *J* = 7.6 Hz, 2 H), 6.79–6.73 (m, 4 H), 5.55–5.52 (m, 1 H), 3.71 (s, 3 H), 3.50–3.34 (m, 2 H), 2.54–2.45 (m, 1 H), 2.40–2.31 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.3, 154.6, 151.1, 138.8, 134.1, 133.9, 129.4, 128.9, 128.7, 127.9, 116.5, 114.7, 78.3, 55.5, 51.9, 26.0.

LRMS (EI, 70 eV): *m*/*z* (%) = 412 (1), 410 (M$^+$, 14), 287 (64), 163 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_5SNa$: 433.1080; found: 433.1063.

2-(3-Methoxyphenoxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (7)

Red oil; yield: 44.3 mg (54%).

IR (KBr): 1683, 1596 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.04 (d, *J* = 7.6 Hz, 2 H), 7.90 (d, *J* = 7.6 Hz, 2 H), 7.64–7.61 (m, 2 H), 7.56–7.47 (m, 4 H), 7.09 (t, *J* = 8.0 Hz, 1 H), 6.50 (d, *J* = 8.4 Hz, 1 H), 6.41 (s, 1 H), 6.37 (t, *J* = 8.4 Hz, 1 H), 5.64–5.61 (m, 1 H), 3.72 (s, 3 H), 3.45–3.37 (m, 2 H), 2.56–2.48 (m, 1 H), 2.42–2.33 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 196.8, 160.8, 158.1, 138.8, 134.2, 133.9, 133.8, 130.1, 129.4, 129.0, 128.7, 127.9, 107.6, 106.8, 101.7, 55.2, 51.9, 25.9.

LRMS (EI, 70 eV): *m*/*z* (%) = 412 (1), 410 (M$^+$, 14), 287 (64), 163 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_5SNa$: 433.1086; found: 433.1063.

2-(4-Chlorophenoxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (8)

Yellow oil; yield: 55.5 mg (67%).

IR (KBr): 1680, 1491 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.04 (d, *J* = 7.0 Hz, 2 H), 7.91–7.89 (m, 2 H), 7.66–7.62 (m, 2 H), 7.56–7.49 (m, 4 H), 7.17–7.15 (m, 2 H), 6.75–6.74 (m, 2 H), 5.65–5.63 (m, 1 H), 3.47–3.43 (m, 1 H), 3.37–3.31 (m, 1 H), 2.55–2.53 (m, 1 H), 2.40–2.35 (m, 1 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 196.5, 155.5, 138.7, 134.3, 133.9, 133.5, 129.4, 129.3, 129.0, 128.6, 127.8, 126.8, 116.4, 77.5, 51.7, 25.9.

LRMS (EI, 70 eV): *m*/*z* (%) = 416 (1), 414 (M^+, 3), 275 (26), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{22}H_{19}ClO_4SNa$: 437.0590; found: 437.0578.

2-(2-Iodophenoxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (9)
Yellow oil; yield: 67.8 mg (67%).

IR (KBr): 1696, 1580, 1470 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.07 (d, *J* = 7.6 Hz, 2 H), 7.93 (d, *J* = 8.0 Hz, 2 H), 7.74 (d, *J* = 8.0 Hz, 1 H), 7.65–7.60 (m, 2 H), 7.55–7.49 (m, 4 H), 7.13 (t, *J* = 8.0 Hz, 1 H), 6.69 (t, *J* = 7.6 Hz, 1 H), 6.47 (d, *J* = 8.0 Hz, 1 H), 5.58–5.55 (m, 1 H), 3.68–3.61 (m, 1 H), 3.51–3.44 (m, 1 H), 2.63–2.55 (m, 1 H), 2.52–2.42 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 196.3, 155.4, 139.7, 138.9, 134.4, 133.9, 133.5, 129.4, 129.1, 128.8, 127.9, 123.6, 112.6, 86.5, 78.7, 52.0, 26.4.

LRMS (EI, 70 eV): *m*/*z* (%) = 506 (M^+, 7), 401 (32), 259 (84), 105 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{22}H_{19}IO_4SNa$: 528.9941; found: 528.9927.

2-(Naphthalen-1-yloxy)-1-phenyl-4-(phenylsulfonyl)butan-1-one (10)
Yellow solid; yield: 55.0 mg (64%); mp 142.4–143.2 °C.

IR (KBr): 1696, 1596, 1578 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.21 (d, *J* = 7.5 Hz, 1 H), 8.08 (d, *J* = 7.0 Hz, 2 H), 7.90–7.88 (m, 2 H), 7.78–7.76 (m, 1 H), 7.61–7.57 (m, 2 H), 7.51–7.40 (m, 7 H), 7.21 (t, *J* = 8.0 Hz, 1 H), 6.59 (d, *J* = 8.0 Hz, 1 H), 5.77–5.74 (m, 1 H), 3.54–3.43 (m, 2 H), 2.65–2.56 (m, 2 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 197.8, 152.6, 138.8, 134.6, 134.2, 133.9, 129.4, 129.0, 128.7, 127.9, 127.5, 126.6, 125.6, 125.4 (2 C), 121.7, 121.6, 105.7, 77.7, 52.1, 26.1.

LRMS (EI, 70 eV): *m*/*z* (%) = 432 (2), 430 (M^+, 15), 287 (88), 183 (76), 195 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{26}H_{22}O_4SNa$: 453.1131; found: 453.1126.

1-(Naphthalen-1-yl)-2-phenoxy-4-(phenylsulfonyl)butan-1-one (11)
Yellow solid; yield: 63.6 mg (74%); mp 75.4–76.2 °C.

IR (KBr): 1684, 1653, 1559 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.69 (s, 1 H), 8.06 (d, *J* = 2.0 Hz, 1 H), 8.00 (d, *J* = 2.0 Hz, 1 H), 7.91–7.87 (m, 4 H), 7.64–7.60 (m, 3 H), 7.53–7.51 (m, 2 H), 7.21–7.19 (m, 2 H), 6.93 (t, *J* = 7.6 Hz, 1 H), 6.85 (d, *J* = 8.0 Hz, 2 H), 5.80–5.77 (m, 1 H), 3.55–3.38 (m, 2 H), 2.65–2.42 (m, 2 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 197.0, 157.0, 138.8, 136.0, 133.9, 132.4, 131.0, 130.9, 129.9, 129.7, 129.4, 129.2, 128.9, 127.9, 127.9, 127.8, 127.1, 123.9, 122.0, 115.2, 77.5, 52.0, 26.4.

LRMS (EI, 70 eV): *m*/*z* (%) = 432 (1), 430 (M^+, 7), 275 (32), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{26}H_{22}O_4SNa$: 453.1131; found: 453.1119.

2-Phenoxy-4-(phenylsulfonyl)-1-*p*-tolylbutan-1-one (12)
Colorless oil; yield: 55.9 mg (71%).

IR (KBr): 1683, 1558, 1457 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.96 (d, *J* = 8.4 Hz, 2 H), 7.89 (d, *J* = 7.6 Hz, 2 H), 7.64 (t, *J* = 7.6 Hz, 1 H), 7.54 (t, *J* = 7.6 Hz, 2 H), 7.28 (d, *J* = 8.0 Hz, 2 H), 7.22–7.19 (m, 2 H), 6.92 (t, *J* = 7.2 Hz, 1 H), 6.80 (d, *J* = 8.0 Hz, 2 H), 5.60–5.57 (m, 1 H), 3.49–3.33 (m, 2 H), 2.55–2.47 (m, 1 H), 2.41 (s, 3 H), 2.39–2.33 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 196.5, 157.0, 145.3, 138.8, 133.8, 131.3, 129.7, 129.6, 129.4, 128.8, 127.9, 121.8, 115.1, 77.2, 52.0, 26.1, 21.7.

LRMS (EI, 70 eV): *m*/*z* (%) = 394 (M^+, 5), 275 (32), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_4SNa$: 417.1131; found: 417.1118.

1-(4-Methoxyphenyl)-2-phenoxy-4-(phenylsulfonyl)butan-1-one (13)
Red oil; yield: 56.6 mg (69%).

IR (KBr): 1683, 1598, 1492 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06 (d, *J* = 8.4 Hz, 2 H), 7.90 (d, *J* = 8.0 Hz, 2 H), 7.64 (t, *J* = 7.5 Hz, 1 H), 7.54 (t, *J* = 7.5 Hz, 2 H), 7.22–7.19 (m, 2 H), 6.96–6.91 (m, 3 H), 6.80 (d, *J* = 8.4 Hz, 2 H), 5.54–5.51 (m, 1 H), 3.87 (s, 3 H), 3.46–3.36 (m, 2 H), 2.55–2.47 (m, 1 H), 2.44–2.35 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 195.4, 164.3, 157.0, 138.8, 133.9, 131.2, 129.6, 129.4, 127.9, 126.7, 121.8, 115.1, 114.2, 77.4, 55.5, 52.1, 26.3.

LRMS (EI, 70 eV): *m*/*z* (%) = 410 (M^+, 7), 275 (22), 135 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_5SNa$: 433.1080; found: 433.1062.

1-(2-Methoxyphenyl)-2-phenoxy-4-(phenylsulfonyl)butan-1-one (14)
Red solid; yield: 73.0 mg (89%); mp 110.1–111.2 °C.

IR (KBr): 1683, 1598, 1492 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.87 (d, *J* = 7.6 Hz, 2 H), 7.75 (d, *J* = 7.6 Hz, 1 H), 7.64 (t, *J* = 7.6 Hz, 1 H), 7.56–7.52 (m, 3 H), 7.21 (t, *J* = 7.6 Hz, 2 H), 7.06–7.00 (m, 2 H), 6.92 (t, *J* = 7.2 Hz, 1 H), 6.78 (t, *J* = 8.0 Hz, 2 H), 5.80–5.77 (m, 1 H), 3.91 (s, 3 H), 3.40–3.34 (m, 2 H), 2.57–2.53 (m, 1 H), 2.23–2.14 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.0, 158.6, 157.5, 138.9, 134.9, 133.8, 131.4, 129.5, 129.3, 127.9, 125.0, 121.5, 121.3, 115.2, 111.6, 79.7, 55.7, 52.5, 25.0.

LRMS (EI, 70 eV): *m*/*z* (%) = 410 (M^+, 7), 275 (22), 135 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_5SNa$: 433.1080; found: 433.1064.

1-(4-Fluorophenyl)-2-phenoxy-4-(phenylsulfonyl)butan-1-one (15)
Red solid; yield: 60.5 mg (76%); mp 92.9–93.8 °C.

IR (KBr): 1716, 1683, 1558 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.13–8.09 (m, 2 H), 7.90 (d, *J* = 8.0 Hz, 2 H), 7.65 (t, *J* = 7.0 Hz, 1 H), 7.56 (t, *J* = 7.5 Hz, 2 H), 7.21 (t, *J* = 8.0 Hz, 2 H), 7.14 (t, *J* = 7.6 Hz, 2 H), 6.94 (t, *J* = 7.2 Hz, 1 H), 6.81 (d, *J* = 8.4 Hz, 2 H), 5.57–5.54 (m, 1 H), 3.48–3.35 (m, 2 H), 2.55–2.35 (m, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 195.6, 167.5, 164.9, 156.8, 138.7, 133.9, 131.6 (2 C), 129.7, 129.4, 127.8, 122.0, 116.3, 116.0, 115.0. 77.6, 51.9, 25.9.

LRMS (EI, 70 eV): *m*/*z* (%) = 398 (M^+, 2), 275 (18), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{22}H_{19}FO_4SNa$: 421.0880; found: 421.0866.

2-Methyl-2-phenoxy-1-phenyl-4-(phenylsulfonyl)butan-1-one (16)
Colorless oil; yield: 63.8 mg (81%).

IR (KBr): 1683, 1558, 1457 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 8.18 (d, *J* = 7.0 Hz, 2 H), 7.80 (d, *J* = 7.5 Hz, 2 H), 7.61 (t, *J* = 7.5 Hz, 1 H), 7.51–7.47 (m, 3 H), 7.35 (t, *J* = 7.5 Hz, 2 H), 7.08 (t, *J* = 7.5 Hz, 2 H), 6.89 (t, *J* = 7.5 Hz, 1 H), 6.60 (d, *J* = 7.5 Hz, 2 H), 3.34–3.22 (m, 2 H), 2.64–2.58 (m, 1 H), 2.35–2.29 (m, 1 H), 1.56 (s, 3 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 201.1, 154.2, 138.3, 133.9, 133.7, 133.4, 129.8, 129.5, 129.3, 128.5, 127.9, 122.5, 118.3, 85.1, 50.9, 30.8, 22.7.

LRMS (EI, 70 eV): *m*/*z* (%) = 394 (M^+, 4), 380 (23), 275 (32), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{22}O_4SNa$: 417.1137; found: 417.1130.

Ethyl 2-Benzoyl-4-(phenylsulfonyl)butanoate (17)
Colorless oil; yield: 52.6 mg (73%).

IR (KBr): 1733, 1683, 1457 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 8.00–7.98 (m, 2 H), 7.93–7.90 (m, 2 H), 7.68–7.65 (m, 1 H), 7.63–7.56 (m, 3 H), 7.51–7.48 (m, 2 H), 4.67 (d, *J* = 7.0 Hz, 1 H), 4.14–4.10 (m, 2 H), 3.28–3.19 (m, 2 H), 2.45–2.37 (m, 2 H), 1.14 (t, *J* = 7.0 Hz, 3 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 194.1, 168.8, 138.7, 135.6, 133.9 (2 C), 133.7 (2 C), 129.4, 129.3, 128.8, 128.7, 128.4, 128.0 (2 C), 61.8, 53.4, 51.5, 21.9, 13.8.

LRMS (EI, 70 eV): *m*/*z* (%) = 360 (M^+, 1), 315 (2), 219 (30), 105 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{19}H_{20}O_5SNa$: 383.0924; found: 383.0909.

1-Benzoyl-4-(phenylsulfonyl)butanenitrile (18)
Colorless oil; yield: 16.9 mg (27%).

IR (KBr): 1699, 1653, 1558 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 8.01 (d, *J* = 1.5 Hz, 2 H), 7.94 (d, *J* = 7.0 Hz, 2 H), 7.73–7.68 (m, 2 H), 7.61 (t, *J* = 7.5 Hz, 2 H), 7.56 (t, *J* = 8.0 Hz, 2 H), 4.89–4.87 (m, 1 H), 3.41–3.29 (m, 2 H), 2.63–2.56 (m, 1 H), 2.46–2.38 (m, 1 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 189.2, 138.5, 138.0, 135.0, 134.6, 134.3, 133.5, 129.7, 129.6, 129.3, 129.2, 129.0, 128.1, 128.0, 116.2, 52.6, 49.5, 37.4, 22.4.

LRMS (EI, 70 eV): *m*/*z* (%) = 313 (M^+, 5), 285 (5), 208 (5), 105 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{17}H_{15}NO_3SNa$: 336.0665; found: 336.0663.

1-Phenyl-4-(phenylsulfonyl)-2-[2-(phenylsulfonyl)ethyl]butan-1-one (19)
Yellow solid; yield: 21.0 mg (46%); mp 78.1–79.2 °C.

IR (KBr): 1732, 1685, 1655 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.89 (d, *J* = 7.6 Hz, 2 H), 7.83 (d, *J* = 7.6 Hz, 4 H), 7.64 (t, *J* = 7.6 Hz, 2 H), 7.59–7.51 (m, 5 H), 7.46 (t, *J* = 7.2 Hz, 2 H), 3.96–3.92 (m, 1 H), 3.10–2.97 (m, 4 H), 2.22–2.13 (m, 2 H), 1.98–1.89 (m, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.0, 138.6, 135.7, 133.9, 133.8, 129.3, 128.9, 128.3, 127.8, 53.0, 42.1, 24.2.

LRMS (EI, 70 eV): *m*/*z* (%) = 456 (M^+, 1), 315 (6), 172 (4), 105 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{24}H_{24}O_5S_2Na$: 479.0963; found: 479.0952.

2,2-Bis[2-(phenylsulfonyl)ethyl]benzofuran-3(2*H*)-one (20)
Yellow solid; yield: 21.6 mg (46%); mp 115.1–116.2 °C.

IR (KBr): 1728, 1688 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.84 (d, *J* = 7.0 Hz, 4 H), 7.69–7.65 (m, 3 H), 7.60–7.56 (m, 5 H), 7.13–7.08 (m, 2 H), 3.07–3.01 (m, 2 H), 2.91–2.85 (m, 2 H), 2.26–2.14 (m, 4 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 200.5, 171.3, 139.3, 138.3, 134.1, 129.5, 128.0, 124.7, 123.0, 120.1, 113.6, 87.7, 50.1, 28.5.

LRMS (EI, 70 eV): *m*/*z* (%) = 470 (M^+, 1), 133 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{24}H_{22}O_6S_2Na$: 493.0756; found: 493.0743.

1-Phenyl-2-[2-(2-phenylethynyl)phenoxy]-4-(phenylsulfonyl)butan-1-one (21)
Brown oil; yield: 85.4 mg (89%).

^1H NMR (500 MHz, $CDCl_3$): δ = 8.07–8.09 (m, 2 H), 7.76–7.78 (m, 2 H), 7.57–7.60 (m, 1 H), 7.42–7.55 (m, 6 H), 7.33–7.39 (m, 5 H), 7.11 (t, *J* = 7.5 Hz, 1 H), 6.92 (t, *J* = 7.5 Hz, 1 H), 6.60 (d, *J* = 8.5 Hz, 1 H), 5.61–5.63 (m, 1 H), 3.58–3.64 (m, 1 H), 3.45–3.51 (m, 1 H), 2.57–2.63 (m, 1 H), 2.44–2.51 (m, 1 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 196.5, 171.0, 157.3, 138.7, 134.2, 133.6, 133.6, 133.4, 131.4, 129.5, 129.2, 128.9, 128.7, 128.3, 128.2, 127.7, 123.2, 121.9, 113.6, 113.5, 93.9, 85.3, 78.6, 60.2, 51.8, 26.2, 20.9, 14.1.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{30}H_{24}O_4SNa$: 503.1293; found: 503.1280.

3-(2-Hydroxyphenyl)-4-phenyl-2-[2-(phenylsulfonyl)ethyl]naphthalen-1-ol (22)
Yellow solid; yield: 30.8 mg (36%); mp >240 °C.

IR (KBr): 3459, 3422, 2920, 2851 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 9.45 (s, 1 H), 9.22 (s, 1 H), 8.27 (d, *J* = 8.5 Hz, 1 H), 7.65–7.69 (m, 3 H), 7.55–7.58 (m, 2 H), 7.45–7.46 (m, 1 H), 7.31–7.33 (m, 1 H), 7.20–7.24 (m, 2 H), 7.08–7.13 (m, 3 H), 7.02–7.03 (m, 1 H), 6.83–6.85 (m, 1 H), 6.63–6.64 (m, 1 H), 6.55–6.57 (m, 1 H), 6.43–6.36 (m, 1 H), 3.38–3.44 (m, 1 H), 3.20–3.27 (m, 1 H), 2.68–2.78 (m, 2 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 154.4, 149.6, 139.8, 138.6, 137.3, 133.9, 132.4, 131.8, 131.7, 131.4, 131.2, 131.1, 129.9, 129.7, 129.1, 129.0, 128.5, 127.9, 127.6, 127.4, 126.7, 126.6, 126.3, 126.0, 125.0, 124.9, 122.0, 119.5, 118.5, 115.1, 54.1, 31.0, 22.4.

LRMS (EI, 70 eV): *m*/*z* (%) = 480 (M^+, 1), 298 (31), 168 (100).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{30}H_{24}O_4SNa$: 503.1293; found: 503.1274.

Acknowledgment

We thank the Natural Science Foundation of China (No. 21172060), Specialized Research Fund for the Doctoral Program of Higher Education (No. 20120161110041), and Hunan Provincial Natural Science Foundation of China (No. 13JJ2018) for financial support. Dr. R.-J. Song also thanks the China Postdoctoral Science Foundation (No. 2012M511716) and Hunan Province Science and Technology Project (No. 2013RS4026)

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synthesis.

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