PERKIN 1 COMMUNICATION

The first isolation and characterization of sulfonylbuta-1,3-diynes

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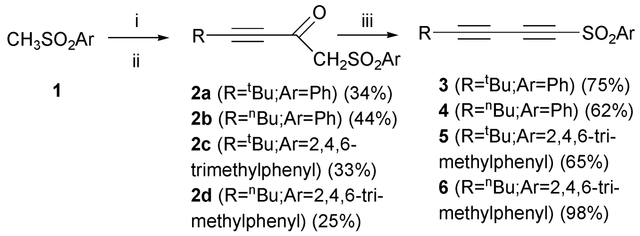
We have isolated the sulfonylbuta-1,3-diynes 3 and 5 as colorless prisms, which demonstrate unprecedented dimerization. Furthermore, the reactions of 3 and 5 with alkoxides or buta-1,3-dienes were examined and the products obtained were either sulfonyl-β-alkoxybut-1-en-3-ynes 16a–e, β-alkoxybut-3-en-1-ynes 17a–d or the cycloadducts 23 and 24a,b.

Acetylenic sulfones are extremely useful as Michael acceptors with suitable heteroatom nucleophiles such as alcohols, amines and thiols. Their reactions provide β-heteroatom-substituted vinylic sulfones, some of which are easily transformed into a wide variety of heterocycles, natural products and bioactive compounds.[1] Furthermore, acetylenic sulfones can undergo cycloaddition reactions, including [4+2], [2+2] and [3+2] processes to give many types of cyclic compounds. On the other hand, sulfonylbuta-1,3-diynes, which have a longer conjugated system, have received little attention in synthetic organic chemistry. Several reports concerning the preparation and reactions of sulfonylbuta-1,3-diynes have been published: one reports that buta-1,3-diynyl phenyl sulfone reacts to form a polyacetylene,[2] while another describes the 1,4-bis(perfluoroalkylsulfonyl)buta-1,3-diynes, formed *in situ*, reacting with cyclopentadiene to afford the 4 + 2 cycloadducts.[3] To our knowledge sulfonylbuta-1,3-diynes have not been previously isolated. However, if they could be isolated, the sulfonylbuta-1,3-diynes would be expected to undergo transformations into other useful compounds *via* regioselective Michael addition reactions with nucleophiles, or cycloaddition reactions with buta-1,3-dienes. We have succeeded in isolating and characterising the sulfonylbuta-1,3-diynes **3** and **5** and observed an unprecedented dimerization of these sulfonylbuta-1,3-diynes. We report herein these results.

First, we prepared the buta-1,3-diynes as shown in Scheme 1.



Scheme 1 *Reagents and conditions*: i, EtMgBr, 0 °C, RCCCHO; ii, PCC, CH_2Cl_2: iii, $EtN(^iPr)_2$, $(CF_3SO_2)_2O$, −78 °C.

Aryl methyl sulfone was treated with EtMgBr and prop-2-ynals, and the following oxidation with PCC afforded the ynones **2a**–**d** in moderate yields. Treatment of **2a** with Tf_2O–Hunig's base[4] gave the corresponding sulfonylbuta-1,3-diyne **3** in 75% yield.[5] However, this sulfone is labile at room temperature and gradually changes to the dimer **7a**. The proposed structure of **7a** was based upon its spectral data and the molecular formula $C_{28}H_{28}O_2S$.[6] The ^1H NMR spectrum shows two *tert*-butyl groups at δ 1.23 and 1.33 ppm. The ^{13}C NMR spectrum exhibits six singlets at δ 64.25, 69.97, 78.34, 89.02, 94.60 and 98.82 ppm which are due to the acetylenic carbons. However, we could not find any evidence of the conjugated system. The structure of **7a** was elucidated by single crystal X-ray analysis as shown in Fig. 1.[7,8] The sulfone **3** was heated at 50 °C without a solvent to

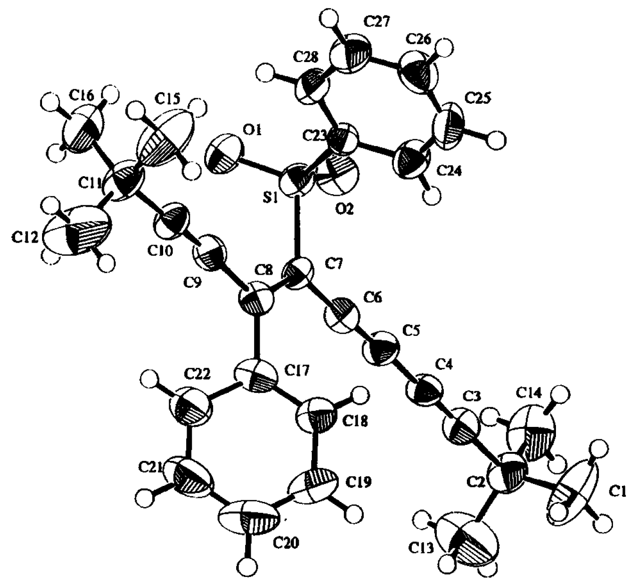
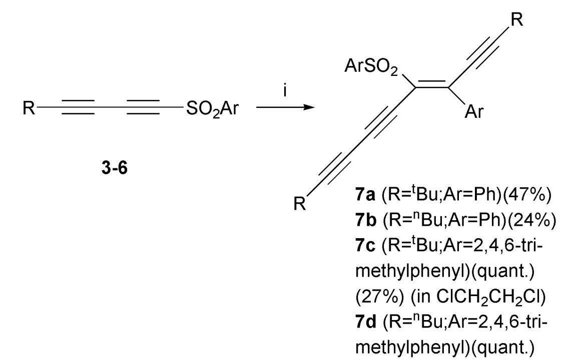


Fig. 1 ORTEP drawing of **7a**.



Scheme 2 *Conditions*: i, neat, rt–50 °C.

give the dimer **7a** in 47% yield (Scheme 2). The rate of transformation of the sulfonylocta-1,3-diyne **4** to the corresponding dimer **7b** was fast and the yield was high. In order to isolate the sulfonylbuta-1,3-diynes as stable crystals, we prepared 2,4,6-trimethylphenyl-5,5-dimethylhexa-1,3-diynyl sulfone **5** by the same method. Sulfonylbuta-1,3-diyne **5** was isolated in the form of stable crystalline prisms (mp 70–72 °C).[9] Furthermore, we attempted the preparation of the *n*-butyl derivative **6**. The rate of dimerization of the sulfonylbuta-1,3-diyne **6** is slower than that of **4**; however, **6** transformed into the dimer **7d** at room temperature. In order to clarify the mechanism of this unique dimerization of the sulfonylbuta-1,3-diynes, we carried out the dimerization reaction of **3** with a galvinoxyl radical.† The dimer **7a** was formed in low yield and the other products **8** and

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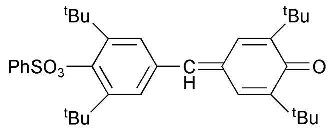

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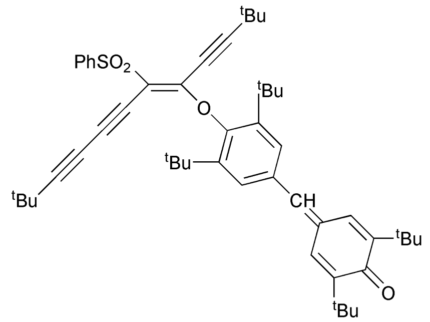
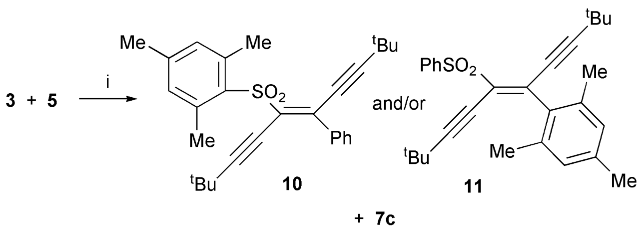


9

Fig. 2

9 were trapped by the galvinoxyl radical (Fig. 2).[10] Sulfone **3** was found to be more stable in $CHCl_3$, rather than in the pure form and the rate of the dimerization was distinctly repressed. We performed a crossover experiment as shown in Scheme 3. A



Scheme 3 *Conditions*: i, neat, 50 °C, 30 min.

mixture of diynes **3** and **5** were heated at 50 °C and mainly formed the dimers **10** or **11** (which have a molecular ion peak at *m*/*z* 470) and **7c**.[11] These results show that the dimerization proceeds *via* a bimolecular mechanism. Thus, we propose a possible mechanism for the dimerization of the sulfonylbuta-1,3-diynes as shown in Scheme 4.[12] First, the initiator adds to **12** at the β-position to the sulfonyl group to provide the vinyl radical **13a**,**b**, which subsequently adds to **12** to afford the dienyl radical **14**. Tandem reactions with **12** provides the polyacetylene. Two possible routes to the dimer **17** exist. One is *via* a direct 1,2-migration of the ethynyl group of **14** and successive dearylsulfonylation. Next, the aryl radical forms by the direct loss of sulfur dioxide from the arylsulfonyl radical. However, it is unusual for the arylsulfonyl radical to afford an aryl radical under the mild reaction conditions used here. Therefore an alternative path is predicted in which the alkylidene carbene **16** is formed from **14** with the formation of the aryl radical and then loss of sulfur dioxide. The final 1,2-migation provides the product **17** and the aryl radical thus formed further reacts with **12**.

In order to characterize the new sulfonylbuta-1,3-diynes we conducted reactions between the sulfones and various nucleophiles. The reaction of **3** with NaOMe at 0 °C gave 2-methoxy-5,5-dimethyl-1-(phenylsulfonyl)hex-1-en-3-yne (**18a**)[13] (32%) and 4-methoxy-5,5-dimethyl-1-(phenylsulfonyl)hex-3-en-1-yne (**19a**)[14] (13%), respectively. The regioselectivities of the products were elucidated by NOE enhancements (Fig. 3). Irradiation

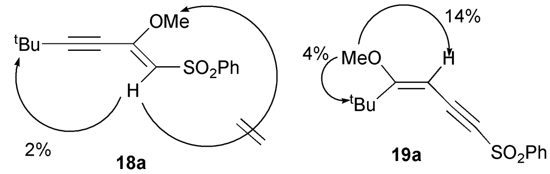
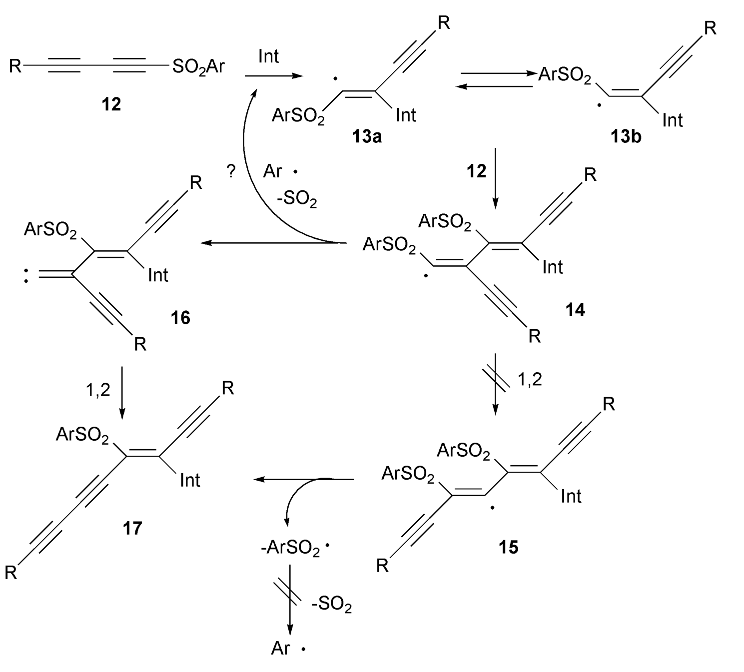
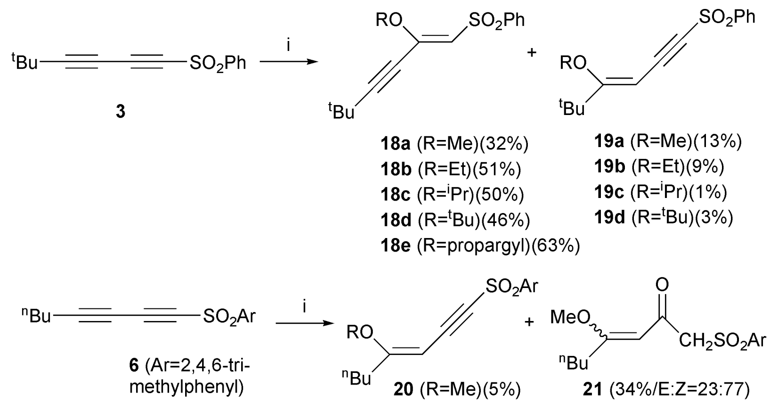


Fig. 3 NOE enhancement of **11a** and **12a**.

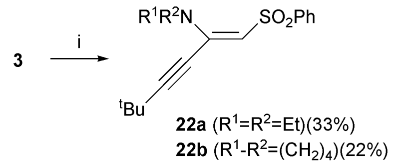
of the olefinic protons of **18a** at δ 6.30 ppm increased the intensity of the *tert*-butyl protons (2%) but not that of the methoxy protons. NOE enhancements of the product **19a** were observed between the methoxy protons and the *tert*-butyl protons (4%); between the methoxy protons and the olefinic protons (14%). These results show that the addition of alkoxides to sulfonyl-4-*tert*-butylbuta-1,3-diynes mainly occurs at the β-position to the sulfonyl group. Reactions of **3** with other alkoxides also provided two kinds of adducts **18b**–**e** and **19b**–**d** (Scheme 5). However, the regioselectivities were found to be higher than that for the reaction with NaOMe. On the other hand, the reaction of the *n*-butyl derivative **6** with NaOMe gave two kinds of products: one is the δ-adduct **20** and another is β-methoxy-α,β-unsaturated ketone **21**, which results from the hydration of the β,δ-dimethoxybuta-1,3-diene. These results show that the reactions of buta-1,3-diyne with nucleophiles first occur at the β-position to the sulfonyl group. The reactions of **3** with amides also afforded the β-adducts **22a**,**b** (Scheme 6).



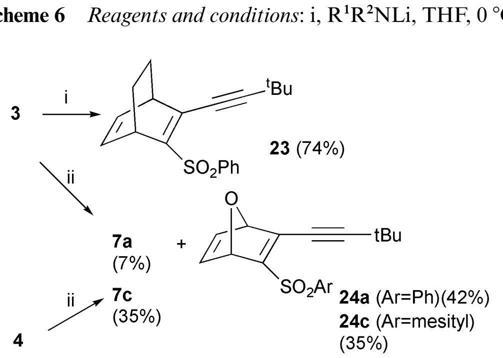
Scheme 4



Scheme 5 *Reagents and conditions*: i, RONa, ROH, 0 °C.



Scheme 6 *Reagents and conditions*: i, R^1R^2NLi, THF, 0 °C.



Scheme 7 *Reagents and conditions*: i, cyclohexa-1,3-diene, sealed tube, 100 °C, 1 h; ii, furan, sealed tube, 100 °C, 30 min.

We further investigated the cycloadditions of **3** or **4** with various dienes as shown in Scheme 7. First we examined the reaction of **3** with hexa-1,3-diene in a sealed tube at 100 °C. The cycloadduct **23** was exclusively obtained in good yield.[15] The reaction with furan gave the bicyclic compound **24a**, accompanied by the dimer **7a**. The mesityl sulfone **4** also afforded the adduct **24c**.

Acknowledgements

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† The IUPAC name for galvinoxyl is 2,6-di-*tert*-butyl-α-(3,5-di-*tert*-butyl-4-oxocyclohexa-2,5-dien-1-ylidene)-*p*-tolyloxyl.

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5 Data for **3**: colorless oil, IR ν_{max}/cm^{-1} 2210 (acetylene), 1330, 1160 (SO_2); ^{1}H NMR δ 1.23 (9H, s, Me × 3), 7.31–7.74 (3H, m, ArH), 7.96–8.02 (2H, m, ArH); ^{13}C NMR δ 28.51 (s), 29.77 (q × 3), 61.44 (s), 70.67 (s), 100.26 (s), 111.08 (s), 127.53 (d × 2), 129.59 (d × 2), 133.71 (s), 134.61 (d), 141.37 (s); MS *m*/*z* 246 (M$^+$). Anal. calcd for $C_{14}H_{14}O_2S$: C, 68.27; H, 5.73. Found: C, 68.12; H, 5.78%.

6 Data for **7a**: colorless needles, mp 168–171 °C; IR ν_{max}/cm^{-1} 2210 (acetylene), 1330, 1160 (SO_2); ^{1}H NMR δ 1.23 (9H, s, Me × 3), 1.33 (9H, s, Me × 3), 7.26–7.37 (3H, m, ArH), 7.52–7.56 (2H, m, ArH), 7.61–7.65 (1H, m, ArH), 7.72–7.75 (2H, m, ArH), 8.06–8.09 (2H, m, ArH); ^{13}C NMR δ 28.75 (s), 29.38 (s), 30.29 (q × 3), 30.49 (q × 3), 64.25 (s), 69.97 (s), 78.34 (s), 89.02 (s), 94.60 (s), 98.82 (s), 122.36 (s), 128.25 (d × 2), 128.37 (d × 2), 128.95 (d × 2), 129.08 (d × 2), 130.39 (d), 133.66 (d), 137.58 (s), 140.73 (s), 140.87 (s); MS *m*/*z* 428 (M$^+$). Anal. calcd for $C_{28}H_{28}O_2S$: C, 78.47; H, 6.59. Found: C, 78.14; H, 6.51%.

7 Crystal data for **7a**: $C_{28}H_{28}O_2S$, M = 428.59, monoclinic, a = 15.837(3) Å, b = 10.389(2) Å, c = 15.924(3) Å, β = 104.02(1)°, V = 2541.9(8) Å^3, T = 296 K, space group $P2_1/a$, Z = 4, μ(Mo-Kα) = 1.47 cm^{-1}, D_C = 1.120 mg m^{-3}, 6395 reflections collected (Rigaku AFC5R diffractometer) of which 6180 were unique (R_{int} = 0.031) and 2219 were observed [$I > 3.00\sigma(I)$]. Solved by direct methods (ORIENT) (see ref. 3) and refined by full-matrix least squares (teXsan) on F of all unique data to give R = 0.054, Rw = 0.064. CCDC reference number 179796. See http://www.rsc.org/suppdata/p1/b2/b203913n/ for crystallographic files in .cif or other electronic format.

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9 Data for **5**: colorless prisms, mp 70–72 °C (dec.); IR ν_{max}/cm^{-1} 2210 (acetylene), 1330, 1160 (SO_2); ^{1}H NMR δ 1.17 (9H, s, Me × 3), 2.31 (3H, s, Me), 2.70 (6H, s, Me × 2), 6.97 (2H, s, ArH); ^{13}C NMR δ 21.21 (q), 22.54 (q × 2), 28.44 (s), 28.55 (q × 3), 61.66 (s), 71.88 (s), 75.98 (s), 99.23 (s), 132.30 (d × 2), 135.33 (s), 140.11 (s × 2), 144.36 (s); MS *m*/*z* 288 (M$^+$). Anal. calcd for $C_{17}H_{20}O_2S$: C, 70.80; H, 6.99. Found: C, 71.00; H, 7.19%.

10 Data for **8**: a brown oil, IR ν_{max}/cm^{-1} 1360, 1160 (SO_2); ^{1}H NMR δ 1.32 (9H, s, Me × 3), 1.34 (9H, s, Me × 3), 1.38 (18H, s, Me × 6), 7.03–7.05 (1H, m, ArH), 7.18 (1H, s, olefinic H), 7.41 (2H, s, ArH), 7.49–7.50 (1H, m, ArH), 7.55–7.59 (2H, m, ArH), 7.66–7.71 (1H, m, ArH), 7.88–7.91 (2H, m, ArH); ^{13}C NMR δ 29.74 (q × 3), 29.88 (q × 3), 32.94 (q × 6), 35.75 (s), 37.33 (s × 2), 127.89 (d), 128.67 (d × 2), 129.34 (d × 2), 130.40 (d × 2), 132.08 (s), 133.39 (s), 134.28 (d), 135.43 (d), 136.83 (s), 142.44 (d), 145.96 (s), 147.98 (s), 149.76 (s), 186.75 (s); high-resolution mass calcd for $C_{35}H_{42}O_4S$: 558.2803, found *m*/*z* 558.2825. Data for **9**: a brown oil, IR ν_{max}/cm^{-1} 2200 (acetylene), 1320, 1140 (SO_2); ^{1}H NMR δ 1.16 (18H, s, Me × 6), 1.24 (9H, s, Me × 3), 1.30 (9H, s, Me × 3), 1.47 (9H, s, Me × 3), 5.87 (2H, s, ArH), 5.91 (1H, s, olefinic H), 6.60–6.67 (1H, m, ArH), 7.04–7.05 (1H, m, ArH), 7.51–7.55 (2H, m, ArH), 7.62–7.66 (1H, m, ArH), 7.99–8.02 (2H, m, ArH); MS *m*/*z* 772 (M$^+$).

11 Data for **10** or **11**: a colorless oil, IR ν_{max}/cm^{-1} 2220 (acetylene), 1340, 1160 (SO_2); ^{1}H NMR δ 1.18 (9H, s, Me × 3), 1.26 (9H, s, Me × 3), 2.03 (6H, s, Me × 2), 2.25 (3H, s, Me), 6.80 (2H, s, ArH), 7.53–7.57 (2H, m, ArH), 7.62–7.66 (1H, m, ArH), 8.07–8.11 (2H, m, ArH); MS *m*/*z* 470 (M$^+$).

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13 Data for **18a**: mp 58–63 °C, colorless prisms; IR ν_{max}/cm^{-1} 2200 (acetylene), 1330, 1160 (SO_2); ^{1}H NMR δ 1.24 (9H, s, Me × 3), 4.00 (3H, s, OMe), 6.30 (1H, s, olefinic H), 7.52–7.56 (2H, m, ArH), 7.61–7.65 (1H, m, ArH), 7.90–7.92 (2H, m, ArH); ^{13}C NMR δ 28.66 (s), 30.51 (q × 3), 61.95 (q), 71.59 (s), 99.40 (d), 111.08 (s), 128.72 (d × 2), 129.25 (d × 2), 133.98 (d), 138.23 (s), 160.68 (s); HRMS calcd for $C_{15}H_{18}O_3S$: 278.0977; found *m*/*z* 278.0948.

14 Data for **19a**: mp 66–69 °C, E : Z = 83 : 17, colorless prisms; IR ν_{max}/cm^{-1} 2200 (acetylene), 1300, 1140 (SO_2); ^{1}H NMR δ 1.25 (s, (Z)-Me), 1.31 (s, (E)-Me), 3.67 (s, (E)-OMe), 3.76 (s, (Z)-OMe), 5.82 (s, (Z)-olefinic H), 5.98 (s, (E)-olefinic H), 7.49–7.52 (m, ArH), 7.56–7.59 (m, ArH), 7.96–7.99 (m, ArH); ^{13}C NMR of (E)-**19a** δ 28.49 (s), 30.06 (q × 3), 56.97 (q), 70.76 (s), 110.83 (d), 111.23 (s),

127.28 (d × 2), 128.96 (d × 2), 132.92 (d), 143.34 (s), 152.15 (s); MS m/z 278 (M^+). Anal. calcd for $C_{15}H_{18}O_3S$: C, 64.72; H, 6.51. Found: C, 64.52; H, 6.51%.

15 Data for **23**: colorless prisms, mp 82–84 °C, IR ν_{max}/cm^{-1} 2220 (acetylene), 1310, 1140 (SO_2); ^{1}H NMR δ 1.30 (9H, s, Me × 3), 1.31–1.47 (4H, m, CH_2), 3.73 (1H, br s, CH), 4.23 (1H, br s, CH), 6.23–6.27 (2H, m, olefinic H), 7.47–7.51 (2H, m, ArH), 7.55–7.60 (1H, m, ArH), 7.89–7.93 (2H, m, ArH); ^{13}C NMR δ 23.91 (t), 25.80 (t), 28.61 (s), 30.54 (q × 3), 38.18 (d), 46.69 (d), 75.03 (s), 112.75 (s), 127.19 (d × 2), 128.92 (d × 2), 132.95 (d), 133.08 (d), 133.54 (d), 139.04 (s), 141.68 (s), 144.95 (s); MS m/z 326 (M^+). Anal. calcd for $C_{20}H_{22}O_2S$: C, 73.58; H, 6.79. Found: C, 73.26; H, 6.75%.