PREPARATION AND STRUCTURE OF SOME SULFANYLPROPENYLIDENE DERIVATIVES OF MELDRUM'S ACID

Lynne A. CRAWFORD[1] and Hamish McNAB[2,*]

School of Chemistry, The University of Edinburgh, West Mains Road, Edinburgh EH9 3JJ, UK; e-mail: [1] crawford_lynne@hotmail.com, [2] hmcn01@staffmail.ed.ac.uk

Received February 25, 2009
Accepted April 20, 2009
Published online June 23, 2009

Dedicated, with greatest respect, to Dr. Alfred Bader – chemist, entrepreneur, art collector, philanthropist – on the occasion of his 85th birthday.

Condensation of Meldrum's acid with the 3-sulfanylpropenal derivatives **7a** and **7b** gives the 3-sulfanylpropenylidene derivatives **2a** and **2b**, respectively. NMR and X-ray analysis of **2a** and **2b** show that the electron-donating group conjugates with the electron-withdrawing dioxanedione moiety but the effect is much less pronounced than in analogous dialkylamino derivatives **1**. There is little or no conjugation of the *ortho*-alkylsulfanyl group to the dioxanedione moiety in the benzylidene derivatives **4a** and **4b**.

Keywords: Meldrum's acid; Sulfanylpropenals; Push-pull conjugation; X-ray diffraction; Dioxanes; Aldehydes; Knoevenagel condensations.

We have previously reported the synthesis of a series of aminopropenylidene derivatives of Meldrum's acid (2,2-dimethyl-1,3-dioxane-4,6-dione) by condensation of enaminals with Meldrum's acid in pyridine solution[1]. The structural and spectroscopic properties of these 'push-pull' compounds **1** (Fig. 1) are of interest because the strongly electron donating amino group is directly conjugated to the strongly electron withdrawing dione function of the Meldrum's acid. Indeed X-ray analysis shows that the formal C–C single bond in the propenylidene chain is shorter than the adjacent C=C double bonds[2]. In this paper, we describe the synthesis of thio analogues **2** of these compounds and the effect on the spectroscopic and structural properties caused by replacing the nitrogen atom with a sulfur atom. The bis(trifluoroacetyl) compound **3** is the closest analogue of this series to have been previously reported[3]. In addition, we probe the effect on the conjugated system of the sulfur series by a fused benzene ring on the propenylidene chain, as in compound **4**; the dialkylamino analogues of the latter

Collect. Czech. Chem. Commun. 2009, Vol. 74, No. 6, pp. 995–1009

doi:10.1135/cccc2009020

products cannot be made because a low-energy 'tertiary amino' rearrangement[4] takes place under the conditions of the Knoevenagel condensation[5].

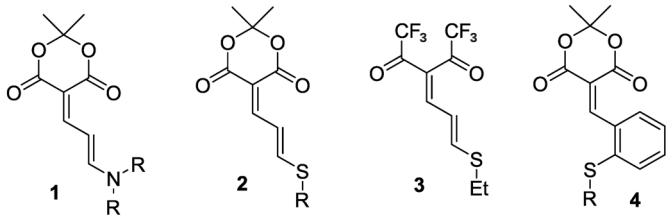


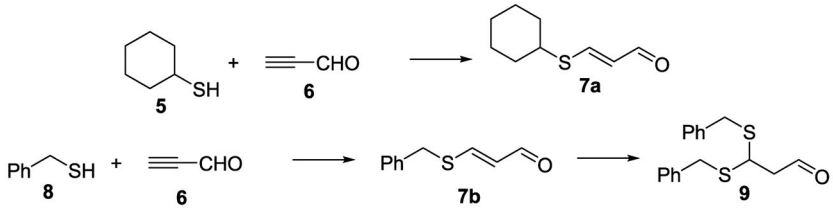
FIG. 1
Some 'push-pull' propenylidenes

RESULTS AND DISCUSSION

Preparation and Properties of the Aldehyde Starting Materials

3-(Alkylsulfanyl)propenals **7** are the key starting materials for the synthesis of **2**. Such compounds have been made but are much less well known than their 3-(dialkylamino)propenal analogues. A literature route[6] to 3-(cyclohexylsulfanyl)propenal **7a** was used which involved reacting cyclohexanethiol (**5**) with propynal (**6**) in chloroform at 40 °C (Scheme 1). Propynal (**6**) was synthesised by flash vacuum pyrolysis (FVP) of diprop-2-ynyl ether[7].

Although the benzyl compound **7b** is known[8] there appears to be no convenient synthetic method. Only unreacted thiol was obtained when the chloroform route[6] was applied, as above, but reaction of phenylmethanethiol (**8**) with propynal (**6**) in methanol in the presence of triethylamine gave two products. The first was 3-(benzylsulfanyl)propenal (**7b**) and the second product was identified as compound **9**, formed by a subsequent conjugate addition process (Scheme 1). Attempts to prevent this reaction by adding a dilute solution of base and thiol to excess propynal had no effect



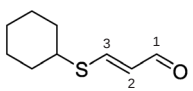
SCHEME 1

on the product ratio. It was also found that the base was necessary for the reaction to take place. However, the two products **7b** and **9** could be separated by dry flash chromatography in yields of 23 and 20%, respectively.

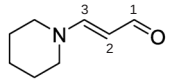
The spectroscopic properties of 3-(alkylsulfanyl)propenal derivatives such as **7** have not been studied systematically. The NMR chemical shifts of the conjugated system of **7** are easily assigned by inspection, with the aldehyde signals (position 1) resonating around δ_H 9.3 (δ_C 190), position 2 at around δ_H 6.1 (δ_C 125) and position 3 at around δ_H 7.5 (δ_C 156). These shifts can be rationalised by the resonance structures shown in Fig. 2 (X = S) which demonstrate that positions 1 and 3 are electron-deficient (conjugating to the carbonyl group) whereas position 2 is electron-rich (conjugating to the sulfur atom). However, the electron-donating effect of the sulfur atom is dramatically less than that of nitrogen in the corresponding enaminals (e.g. **10**); representative data (Table I) show that position 2 is shielded by $\delta_H > 1$ ppm ($\delta_C > 25$ ppm) in the case of **10** [9].

As a consequence, the C(2)=C(3) bond has much more double bond character in the sulfanylpropenals **7** than in the aminopropenals (e.g. **10**), as reflected in the coupling constants (**7a**, $^3J_{2,3}$ = 15.2 Hz; **10**, $^3J_{2,3}$ = 12.6 Hz).

TABLE I
Comparison of selected NMR parameters of the thiopropenal **7a** and the enaminal **10**



7a



10

Position	δ_H, ppm (*J*, Hz)		δ_C, ppm	
	7a	**10**	**7a**	**10**
1	9.32, d (7.6)	8.92, d (8.3)	189.9	189.2
2	6.12, dd (15.2, 7.6)	5.06, dd (12.6, 8.3)	125.9	100.2
3	7.57, d (15.2)	6.87, d (12.6)	156.2	159.0

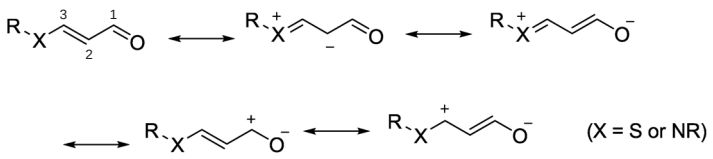


FIG. 2
Resonance structures of **7** and the corresponding enaminals

The aldehydes **11a** and **11b**, precursors of the Meldrum's acid derivatives **4**, were synthesised from 2-fluorobenzaldehyde and the appropriate thiol, in propan-2-ol, in 67 and 49% yields, respectively (Fig. 3)[10].

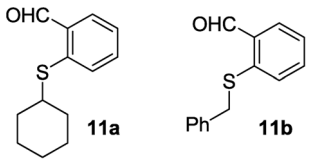


FIG. 3
The substituted benzaldehydes **11**

Synthesis and Properties of the Meldrum's Acid Derivatives

Condensation of 3-(cyclohexylsulfanyl)propenal **7a** with Meldrum's acid in toluene in the presence of a little piperidinium acetate, a common method for aldehyde substrates[11], gave no **2a**, but the piperidino derivative **1a** was isolated by dry flash chromatography in 7% yield (Fig. 4). This suggests that the catalytic amount of piperidine can displace the thiol group from the

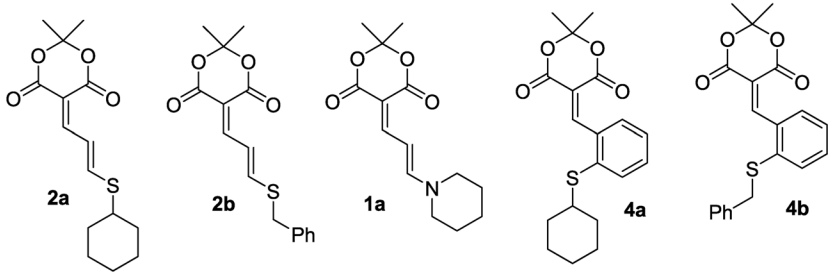
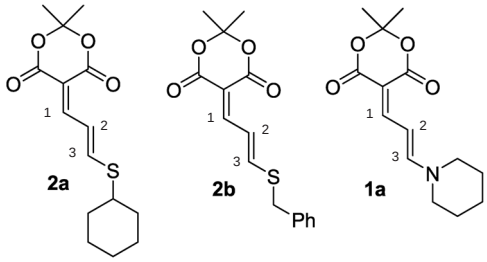


FIG. 4
The Meldrum's acid derivatives synthesised

sulfanylpropenal **7a**, and the resulting enaminal **10** then reacts with Meldrum's acid. However, condensation of **7a** and **7b** with Meldrum's acid in the presence of titanium tetrachloride (the recipe more usually used for ketones[11]) resulted in compounds **2a** and **2b** in 36 and 32% yields, respectively (Fig. 4).

The extent of delocalisation of the sulfanylpropenylidene derivatives (e.g. **2a**) was probed by NMR spectroscopy and X-ray crystallography. The NMR spectra show similar features to those of the (alkylsulfanyl)propenals (above), when compared with their dialkylamino analogues (Table II). Once again, a deshielding effect of ca. 20 ppm is observed at C(2) in **2a**, when compared with **1a**, though the heteroatom has little effect on the chemical shifts of C(1) and C(3) (Table II). The shift of the quaternary carbon C(5) of the Meldrum's acid ring occurs in the range δ_C 104–106 ppm in the thio compounds **2a** and **2b** whereas the corresponding carbon atom in the

TABLE II
Comparison of selected NMR parameters of the Meldrum's acid derivatives **2a**, **2b** and **1a**



Position	δ_H, ppm (*J*, Hz)		δ_C, ppm	
	2b[a]	**1a**	**2a**	**1a**
1	7.90, d (11.8)	7.95, d (13.2)	160.1[b]	161.2[c]
2	7.78, dd (14.0, 11.8)	6.98, dd (13.2, 12.1)	122.4	101.8
3	7.59, d (14.0)	7.25, d (12.1)	156.0[b]	158.7[c]

[a] Data for **2b** quoted because protons H(1)–H(3) are not first order in the spectrum of **2a** at 250 MHz. [b] Assignment may be interchanged. [c] Assignment may be interchanged.

dialkylamino compound **1a** is shielded by >10 ppm at δ_C 93.7. In the ^{1}H NMR spectrum of compound **2b**, significant deshielding of proton H(2) is observed, by comparison with the corresponding proton of the dialkylamino analogue **1a**.

The structures of the sulfanylpropenylidene derivatives **2a** and **2b** were confirmed by X-ray crystallography as shown in Fig. 5. The propenylidene chain is all-*trans* and approximately coplanar with the dione system of the Meldrum's acid unit in both cases (mean deviation from the O(61)–C(6)–C(5)–C(4)–O(41)–C(1′)–C(2′)–C(3′)–S(1) plane in compound **2a**: 0.101 Å; in compound **2b**: 0.096 Å; maximum deviation from this plane in compound **2a**: 0.195 Å at O(61); in compound **2b**: 0.188 Å at O(41)). In compound **2b** the configuration of the benzyl group is unexpectedly twisted towards the Meldrum's acid moiety, possibly to optimise π–π stacking interactions between the benzene rings in the crystal (symmetry element $-x$, $-y$, $1 - z$; centroid to centroid distance 4.6398(12) Å; dihedral angle between benzene planes 0°; slippage 2.625 Å).

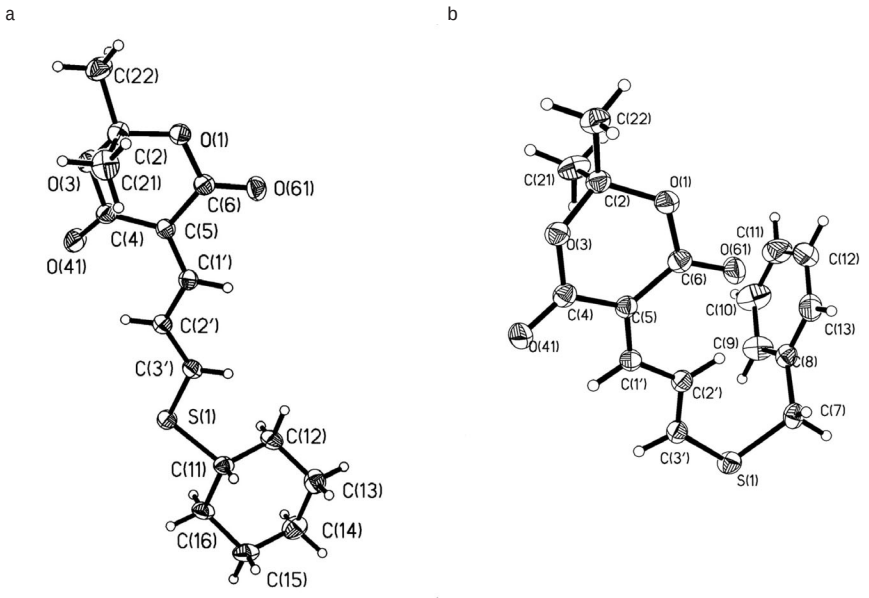


FIG. 5

Plot of the Meldrum's acid derivative **2a** (a) and plot of **2b** (b), both showing the crystallographic numbering scheme. Displacement ellipsoids are drawn at the 30% probability level

Bond lengths of the conjugated systems of **2a**, **2b**, **1b** and the arylpropenylidene derivative[12] **12** are shown in Fig. 6. These parameters of **2a** and **2b** show a high level of consistency and no significant differences are observed despite the different configurations of the sulfur substituent. There are large differences between the lengths of the formal C=C double bonds (1.348–1.366 Å) and the formal single bonds (both 1.418 Å) in the propenylidene chain. The parameters of the Meldrum's acid ring are highly symmetrical; the carbonyl groups all have bond lengths in the range 1.203–1.209 Å and the corresponding C(4)–C(5) and C(5)–C(6) bonds (Fig. 6) lie between 1.462–1.471 Å (all standard deviations 0.002 Å). All of these parameters are very close in magnitude to those of the arylpropenylidene derivative[12] **12**. On the other hand, the differences between the data for compounds **2** and those for the dimethylamino compound **1b** are striking[2]. Thus, the shortest bond in the propenylidene chain of **1b** is the formal single bond (1.385 Å) and all the bonds of the chain are within 0.024 Å of one another. The bond lengths of the carbonyl groups and correspond-

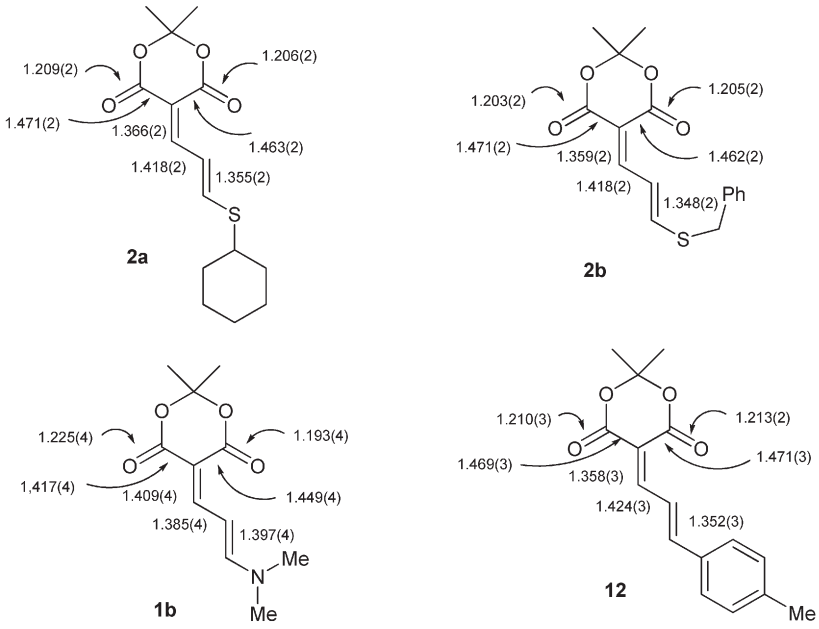


FIG. 6
Selected bond lengths of compounds **2a**, **2b**, **1b** [2] and **12** [12]

ing C–C bonds of **1b** are distorted. One C=O bond of **1b** is significantly longer, at 1.225 Å, than in **2b** and the other is shorter (1.193 Å), whereas the corresponding C–C bonds are 1.417 and 1.449 Å, respectively[2].

These results confirm that the electron-donating ability of the sulfur atom in **2a** and **2b** is insufficient to distort the geometry of the propenylidene chain; hence the formal double and single bonds have significantly different lengths. Similarly the carbonyl groups and the associated C–C bonds show only minimal evidence of 'push-pull' delocalisation summarised by the resonance structures shown in Fig. 7. In contrast, the amino compound **1b** shows evidence of extensive delocalisation, particularly to the *trans*-carbonyl group[2].

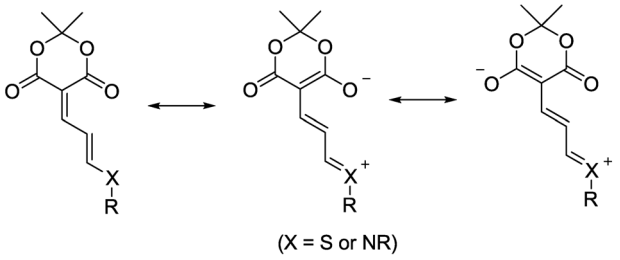


FIG. 7
Resonance structures of propenylidene derivatives of Meldrum's acid

In order to discover the effect of a fused benzene ring on the delocalisation, the condensation products **4a** and **4b** were first made (45 and 56% yields, respectively) by treatment of the aldehydes **11a** and **11b** with Meldrum's acid overnight in pyridine (Fig. 4). The quaternary carbon C(5) of the Meldrum's acid ring in **4a** and **4b** occurs in the range δ_C 115–116 ppm, i.e. >10 ppm deshielded by comparison with the non-annelated analogues **2a** and **2b**. The corresponding parameter of 5-benzylidene Meldrum's acid itself[13] is δ_C 114.75 which suggests that the sulfur atom has little role in conjugation to the Meldrum's acid ring in compounds **4**.

The crystal structure of **4b** is shown in Fig. 8. Unlike the structure of **2b**, the *S*-benzyl group is twisted away from the Meldrum's acid ring. Various components of the potential conjugated systems are significantly non-planar relative to one another (Fig 8b). Key bond length data are summarised in Fig. 9.

All of the structural parameters are consistent with even less delocalisation in the annelated derivative **4b** compared with its propenylidene analogue **2b**. Thus, all the formal single bonds (C(4)–C(5), C(5)–C(6),

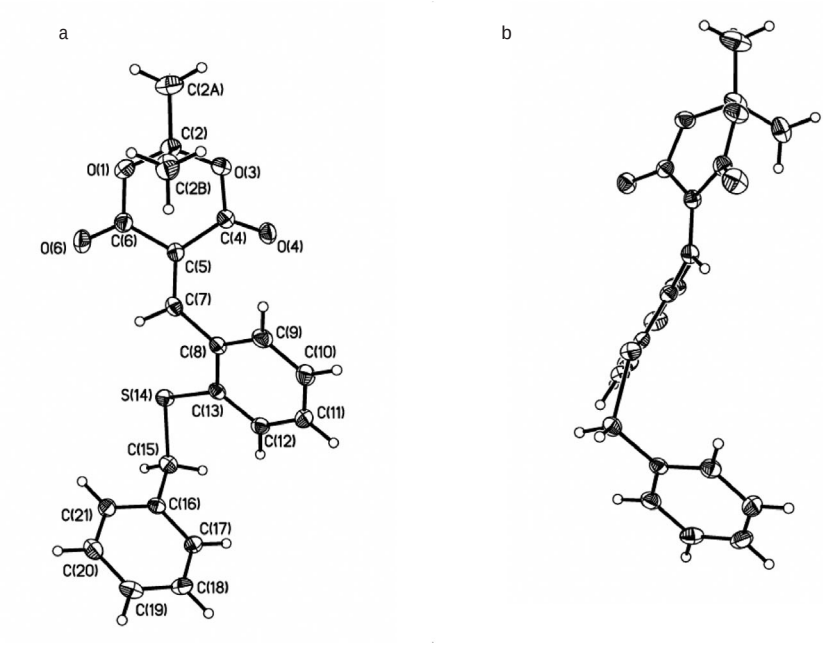


FIG. 8
Plots of the Meldrum's acid derivative **4b** showing the crystallographic numbering scheme (a). Alternative view of **4b** showing non-planarity of the molecule as a whole (b). Displacement ellipsoids are drawn at the 30% probability level

C(7)–C(8)) are longer and the formal double bonds (C(4)–O(4), C(6)–O(6), C(5)–C(7)) are shorter in **4b** compared with **2b** (Fig. 9). This suggests that the presence of the benzene ring in compound **4b** blocks the delocalisation of the sulfur lone pair and implies that some delocalisation occurs in compounds **2a** and **2b** though clearly not as much as in the nitrogen analogues **1**. Comparison of these parameters of **4b** with those of the arylidene derivatives **13a** and **13b** previously reported[14] (Fig. 9) shows that there is very close structural correspondence with the 4-nitro derivative **13a**.

Flash vacuum pyrolysis (FVP) of the aminopropenylidene derivatives **1** provides a useful synthetic route to azepin-3(2*H*)-ones by generation of a methyleneketene followed by hydrogen atom transfer and electrocyclisation[1,15]. In the mechanistically related formation of pyrrol-3(2*H*)-ones[15,16] and thiophen-3(2*H*)-ones[15,17], from methylene Meldrum's acid derivatives, the hydrogen atom transfer is particularly efficient when it takes place from a benzyl substituent. FVP reactions of compounds **2a**, **2b**, **4a** and **4b** were carried out, but no thiepinones could be detected. FVP of **2a** and **4a** at

600 °C gave no identifiable products and starting material was recovered at lower temperatures. FVP of **2b** and **4b** at 525–600 °C produced significant quantities of bibenzyl, a common product of radical cleavage and coupling under FVP conditions.

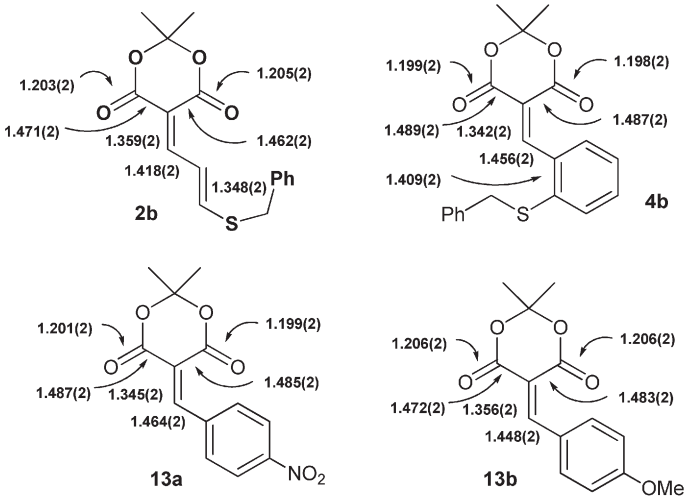


FIG. 9
Selected bond lengths of compounds **2b**, **4b**, **13a** [14] and **13b** [14]

In conclusion, we have reported the successful syntheses of **2a** and **2b**, representative examples of 3-(alkylsulfanyl)propenylidene derivatives of Meldrum's acid and rare examples of sulfur-containing push-pull conjugated systems. The degree of conjugation is limited, as assessed by comparison of NMR chemical shift and bond length data with appropriate model compounds. Unlike the related 3-(dialkylamino)propenylidene derivatives **1**, FVP of **2** did not give rise to cyclised products; reasons for this behaviour will be addressed in a future publication.

EXPERIMENTAL

^{1}H and ^{13}C NMR spectra were recorded at 250 and 63 MHz, respectively, in $CDCl_3$ solutions unless otherwise stated. ^{13}C NMR signals refer to one CH resonance unless otherwise stated; the term 'quat' refers to a quaternary carbon atom. Chemical shifts (δ) are given in ppm relative to TMS; coupling constants (*J*) are quoted in Hz. Mass spectra were recorded under electron impact conditions. Where hexane–ethyl acetate mixtures are used for dry-flash chromatography, a gradient elution method was used involving a 10% increase in the more polar component every second fraction.

3-(Cyclohexylsulfanyl)propenal (**7a**)

Cyclohexanethiol (**5**; 0.35 g, 3 mmol) and propynal (**6**; 0.22 g, 4 mmol) were added to chloroform (0.5 ml) with stirring at 20 °C. The temperature was increased to 40 °C for 2 h, the solvent was removed under reduced pressure and the resulting 3-(cyclohexylsulfanyl)propenal (**7a**; 64%) was purified by Kugelrohr distillation. ^{1}H NMR (250 MHz): 9.32 d, 1 H, ^3J = 7.6; 7.57 d, 1 H, ^3J = 15.2; 6.12 dd, 1 H, ^3J = 15.2, 7.6; 3.09 m, 1 H; 1.17–2.04 m, 10 H (compatible with published data[6]). ^{13}C NMR (63 MHz): 189.9, 156.2, 125.9, 45.3, 32.6 (2 CH_2), 25.5 (2 CH_2), 25.2 (CH_2). EI-MS: 170 (31) [M^+], 137 (8), 83 (57), 67 (30), 55 (100). HRMS: for $C_9H_{14}OS$ (M^+) calculated 170.0762, found 170.0764. B.p. 140–142 °C/130 Pa.

3-(Benzylsulfanyl)propenal (**7b**)

Triethylamine (3 drops) was added to an ice-cooled solution of phenylmethanethiol (**8**; 0.25 g, 2 mmol) and propynal (**6**; 0.12 g, 2.2 mmol) in methanol (10 ml) with stirring. The solution was allowed to stir for 1 h and the solvent was removed under reduced pressure. The resulting oil was subjected to dry flash chromatography on silica using hexane–ethyl acetate as eluent to give 3-(benzylsulfanyl)propenal (**7b**; 23%). ^{1}H NMR (250 MHz): 9.35 d, 1 H, ^3J = 7.6; 7.54 d, 1 H, ^3J = 15.2; 7.25–7.36 m, 5 H; 6.17 dd, 1 H, ^3J = 15.2, 7.6; 4.06 s, 2 H. ^{13}C NMR (63 MHz): 189.7, 155.4, 134.6 (quat), 128.8 (2 CH), 128.6 (2 CH), 127.8, 126.2, 36.6 (CH_2). EI-MS: 178 (11) [M^+], 145 (2), 124 (9), 91 (100), 77 (6). HRMS: for $C_{10}H_{10}OS$ (M^+) calculated 178.0452, found 178.0452. B.p. 107–109 °C/130 Pa (lit.[8] 107–112 °C/170 Pa).

The second fraction was 3,3-bis(benzylsulfanyl)propanal (**9**; 20%). ^{1}H NMR (250 MHz): 9.49 t, 1 H, ^3J = 2.0; 7.24–7.36 m, 10 H; 4.02 t, 1 H, ^3J = 7.2; 3.76–3.91 m, 4 H; 2.73 dd, 2 H, ^3J = 7.2, 2.0. ^{13}C NMR (63 MHz): 198.5, 137.2 (2 quat), 128.8 (4 CH), 128.5 (4 CH), 127.1 (2 CH), 48.4 (CH_2), 43.5, 34.6 (2 CH_2). EI-MS: 302 (1) [M^+], 246 (11), 178 (15), 124 (11), 91 (100), 77 (12). HRMS: for $C_{17}H_{18}OS_2$ (M^+) calculated 302.0799, found 302.0799. M.p. 44–45 °C.

2-(Alkylsulfanyl)benzaldehyde Derivatives **11**

2-Fluorobenzaldehyde (2.5 g, 20 mmol), the appropriate thiol (20 mmol) and potassium carbonate (3 g, 20 mmol) were stirred under reflux in propan-2-ol (35 ml) for 20 h [10]. The solution was cooled and poured into water (100 ml), extracted with dichloromethane (3 × 50 ml), dried (anhydrous $MgSO_4$) and the solvent removed under reduced pressure. The following products were made by this method:

2-(Cyclohexylsulfanyl)benzaldehyde (**11a**). Compound **11a** (49%) was made from cyclohexanethiol following the general procedure. ^{1}H NMR (250 MHz): 10.55 s, 1 H; 7.25–7.88 m, 4 H; 3.11 m, 1 H; 1.23–1.99 m, 10 H. ^{13}C NMR (63 MHz): 192.1, 139.9 (quat), 135.8 (quat), 133.7, 132.5, 129.9, 126.6, 47.1, 33.0 (2 CH_2), 25.8 (2 CH_2), 25.5 (CH_2) (NMR spectra consistent with reported data[18]). EI-MS: 220 (46) [M^+], 138 (100), 83 (29), 77 (12). HRMS: for $C_{13}H_{16}OS$ (M^+) calculated 220.0922, found 220.0922. B.p. 120–124 °C/110 Pa.

2-(Benzylsulfanyl)benzaldehyde (**11b**). Compound **11b** (67%) was made from phenylmethanethiol following the general procedure. ^{1}H NMR (250 MHz): 10.24 s, 1 H; 7.22–7.82 m, 9 H; 4.12 s, 2 H. ^{13}C NMR (63 MHz): 191.3, 140.8 (quat), 136.0 (quat), 134.4 (quat), 133.8, 131.5, 129.7, 128.7, 128.5, 127.3, 125.9, 38.7 (CH_2). M.p. 71–73 °C (lit.[19] 72–74 °C).

Synthesis of Meldrum's Acid Derivatives **2**

A solution of titanium tetrachloride (4 mmol) in tetrachloromethane (1 ml) was added dropwise to ice-cold tetrahydrofuran (8 ml). Appropriate precautions were taken when handling the toxic tetrachloromethane. This was followed by slow addition of a solution of 2,2-dimethyl-1,3-dioxane-4,6-dione (2 mmol) and 3-(alkylsulfanyl)propenal (2 mmol) in tetrahydrofuran (2 ml), then of a solution of pyridine (0.8 ml) in tetrahydrofuran (1 ml). The stirring was continued at 0 °C for 1 h and at room temperature overnight, after which water (10 ml) and ether (20 ml) were added. The organic layer was separated, washed with brine (2 × 20 ml), saturated aqueous sodium hydrogen carbonate (2 × 20 ml), dried (anhydrous $MgSO_4$) and the solvent was removed under reduced pressure. The residue was subjected to dry flash chromatography on silica using hexane–ethyl acetate as eluent. The following products were made by this method:

5-[3-(Cyclohexylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2a**). Reaction of **7a** with Meldrum's acid using the general method gave 5-[3-(cyclohexylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2a**; 36%). ^{1}H NMR (250 MHz): 7.92 m, 1 H; 7.72 m, 2 H; 3.27 m, 1 H; 1.29–2.15 m, 10 H; 1.71 s, 6 H. ^{13}C NMR (63 MHz): 163.5 (quat), 161.1 (quat), 160.1, 156.0, 122.4, 105.1 (quat), 104.3 (quat), 46.4, 32.8 (2 CH_2), 27.4 (2 CH_3), 25.5 (2 CH_2), 25.2 (CH_2). EI-MS: 296 (8) [M^+], 269 (3), 238 (3), 181 (30), 123 (100), 115 (58), 83 (45). HRMS: for $C_{15}H_{20}O_4S$ (M^+) calculated 296.1087, found 296.1085. M.p. 167–169 °C (acetonitrile).

A suspension of Meldrum's acid (2 mmol) and 3-(cyclohexylsulfanyl)propenal (**7a**; 2 mmol) in toluene (3 ml) was treated with acetic acid (4 drops) and piperidine (4 drops) and the mixture was stirred at room temperature for 1 h. After removal of the solvent under reduced pressure and dry flash chromatography of the residue on silica (using hexane–ethyl acetate as eluent), the only isolated product was 5-[3-(piperidin-1-yl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**1a**; 7%). ^{1}H NMR (250 MHz): 7.95 d, 1 H, ^3J = 13.2; 7.25 d, 1 H, ^3J = 12.1; 6.98 dd, 1 H, ^3J = 13.2, 12.1; 3.56–3.58 m, 4 H; 1.73 s, 6 H; 1.67 s, 6 H. ^{13}C NMR (63 MHz): 165.4 (quat), 163.5 (quat), 161.2, 158.7, 103.0 (quat), 101.8, 93.7 (quat), 56.5 (CH_2), 47.6 (CH_2), 26.9 (2 CH_3), 26.6 (CH_2), 25.2 (CH_2), 23.5 (CH_2). For $C_{14}H_{19}NO_4$ calculated: 62.55% C, 7.25% H, 5.2% N; found: 62.7% C, 7.2% H, 5.1% N. M.p. 166–167 °C.

5-[3-(Benzylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2b**). Reaction of **7b** with Meldrum's acid using the general method gave 5-[3-(benzylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2b**; 32%). ^{1}H NMR (250 MHz): 7.90 d, 1 H, ^3J = 11.8; 7.78 dd, 1 H, ^3J = 14.0, 11.8; 7.59 d, 1 H, ^3J = 14.0; 7.35–7.38 m, 5 H; 4.18 s, 2 H; 1.70 s, 6 H. ^{13}C NMR (63 MHz): 163.3 (quat), 161.0 (quat), 158.4, 155.5, 134.5 (quat), 128.9 (2 CH), 128.9 (2 CH), 128.0, 122.2, 106.0 (quat), 104.3 (quat), 37.4 (CH_2), 27.4 (2 CH_3). EI-MS: 304 (14) [M^+], 246 (34), 228 (5), 181 (91), 123 (81), 84 (100). For $C_{16}H_{16}O_4S$ calculated: 63.15% C, 5.25% H; found: 62.75% C, 5.0% H. HRMS: for $C_{16}H_{16}O_4S$ (M^+) calculated 304.0775, found 304.0775. M.p. 101–102 °C (ethanol).

5-[2-(Alkylsulfanyl)benzylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione Derivatives **4**

The appropriate aldehyde (5 mmol) was dissolved in pyridine (10 ml). Meldrum's acid (0.72 g, 5 mmol) was added and the solution was stirred at room temperature overnight. The mixture was added to ether (30 ml) and was washed with a copper(II) sulfate solution (3 × 30 ml), then with water (2 × 30 ml). The aqueous layers were then combined and washed with ether

(2 × 30 ml). The combined organic layers were dried (anhydrous $MgSO_4$) and the solvent removed under reduced pressure. The following products were made by this method:

5-[2-(Cyclohexylsulfanyl)benzylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**4a**). Reaction of **11a** with Meldrum's acid gave compound **4a** (45%). ^{1}H NMR (250 MHz): 8.89 s, 1 H; 7.18–7.89 m, 4 H; 3.10 m, 1 H; 1.22–2.16 m, 16 H. ^{13}C NMR (63 MHz): 162.5 (quat), 159.5 (quat), 156.8, 138.4 (quat), 134.5 (quat), 132.0, 131.9, 131.1, 126.2, 115.9 (quat), 104.6 (quat), 48.2, 33.1 (2 CH_2), 27.6 (2 CH_3), 25.8 (2 CH_2), 25.4 (CH_2). EI-MS: 346 (4) [M^+], 288 (3), 220 (61), 138 (100), 83 (78). HRMS: for $C_{19}H_{22}O_4S$ (M^+) calculated 346.1239, found 346.1232. B.p. 140–144 °C/130 Pa.

5-[2-(Benzylsulfanyl)benzylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**4b**). Reaction of **11b** with Meldrum's acid gave compound **4b** (56%). ^{1}H NMR (250 MHz): 8.70 s, 1 H; 7.18–7.68 m, 9 H; 4.06 s, 2 H; 1.79 s, 6 H. ^{13}C NMR (63 MHz): 162.3 (quat), 159.3 (quat), 156.3, 138.3 (quat), 136.5 (quat), 134.1 (quat), 132.0, 131.5, 130.9, 128.8 (2 CH), 128.5 (2 CH), 127.3, 126.5, 116.3 (quat), 104.6 (quat), 40.3 (CH_2), 27.7 (2 CH_3). EI-MS: 354 (0.4) [M^+], 296 (7), 278 (1), 228 (68), 137 (87), 109 (56), 91 (100). For $C_{20}H_{18}O_4S$ calculated: 67.8% C, 5.05% H; found: 67.75% C, 5.5% H. HRMS: for $C_{20}H_{18}O_4S$ (M^+) calculated 354.0926, found 354.0929. M.p. 85–86 °C (hexane–ethyl acetate).

FVP Reactions

The appropriate derivative was sublimed under vacuum through a silica furnace tube (35 × 2.5 cm) and the product(s) were collected in a trap cooled by liquid nitrogen situated at the exit point of the furnace. Upon completion of the pyrolysis, the trap was allowed to warm to room temperature under nitrogen atmosphere. The entire pyrolysate was dissolved in solvent and removed from the trap. Pyrolysis conditions are quoted as follows: substrate, quantity, furnace temperature (T_f), inlet temperature (T_i), pressure (P), pyrolysis time (t) and product(s). The following derivatives were pyrolysed:

Pyrolysis of 5-[3-(cyclohexylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2a**). FVP of **2a** (0.30 g, T_f = 600 °C, T_i = 150 °C, P = 0.5 Pa, t = 30 min) gave no products identifiable by ^{1}H NMR spectroscopic analysis of the pyrolysate. Pyrolysis at higher and lower temperatures gave the same result.

Pyrolysis of 5-[3-(benzylsulfanyl)propenylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**2b**). The ^{1}H NMR spectrum of the products obtained by FVP of **2b** (0.03 g, T_f = 600 °C, T_i = 150 °C, P = 0.5 Pa, t = 30 min) showed the presence of bibenzyl (32%). ^{1}H NMR (200 MHz): 7.16–7.87 m, 10 H; 2.92 s, 4 H. ^{13}C NMR (63 MHz): 129.3 (2 quat), 128.3 (4 CH), 128.2 (4 CH), 125.8 (2 CH), 37.8 (CH_2) (NMR data consistent with published values[20]) and no other identifiable products.

Pyrolysis of 5-[2-(cyclohexylsulfanyl)benzylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**4a**). FVP of **4a** (0.3 g, T_f = 600 °C, T_i = 150 °C, P = 0.5 Pa, t = 30 min) gave no identifiable products. Pyrolysis at higher and lower temperatures gave the same result.

Pyrolysis of 5-[(2-benzylsulfanyl)benzylidene]-2,2-dimethyl-1,3-dioxane-4,6-dione (**4b**). The ^{1}H NMR spectrum of the products obtained by FVP of **4b** (0.03 g, T_f = 525 °C, T_i = 150 °C, P = 0.5 Pa, t = 30 min) showed the presence of bibenzyl[20] (46%). ^{1}H NMR (200 MHz): 7.10–7.85 m, 10 H; 2.96 s, 4 H; and no other identifiable products. Pyrolysis at lower temperatures gave only recovered starting material.

Crystallography

Diffraction data were collected using a Stoe Stadi-4 four-circle diffractometer (**2a** and **4b**) or a Bruker Smart Apex CCD instrument (**2b**). The structures were solved by direct methods (SHELXS) and refined by full matrix least squares against F^2 (SHELXL). H-atoms attached to methyl groups were located in difference maps and the groups thereafter treated as rotating rigid groups; other H atoms were placed in idealised positions. All non-H atoms were refined with anisotropic displacement parameters. Crystal and refinement data are summarised in Table III. CCDC 275015 (**2a**), 610398 (**2b**) and 276770 (**4b**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/ conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; fax: +44 1223 336033; or deposit@ccdc.cam.ac.uk).

TABLE III
Crystallographic data for **2a**, **2b** and **4b**

Crystal data	**2a**	**2b**	**4b**
Chemical formula	$C_{15}H_{20}O_4S$	$C_{16}H_{16}O_4S$	$C_{20}H_{18}O_4S$
M_r	296.37	304.35	354.40
Cell settings	monoclinic	triclinic	monoclinic
Space group	$P2_1/c$	P-1	$P2_1/n$
Temperature, K	150(2)	150(2)	220(2)
a, Å	6.9480(9)	6.6366(7)	9.5242(9)
b, Å	10.322(2)	10.6039(10)	16.2889(15)
c, Å	21.304(4)	11.7281(12)	11.4371(9)
α, °	90.00	111.9440(10)	90.00
β, °	96.417(14)	103.301(2)	92.987(6)
γ, °	90.00	90.298(2)	90.00
V, Å^3	1518.3(5)	741.21(13)	1771.9(3)
Z	4	2	4
Radiation type	CuKα	MoKα	MoKα
Crystal form	needle	tablet	block
Colour	red	orange	yellow
Crystal size, mm	0.51 × 0.35 × 0.27	0.62 × 0.40 × 0.22	0.58 × 0.39 × 0.39
$R[F^2 > 2\sigma(F^2)]$	0.042	0.036	0.031
$wR(F^2)$, S	0.113, 1.05	0.093, 1.05	0.078, 1.02

We are grateful to the Engineering and Physical Sciences Research Council (EPSRC) UK for a research studentship to L. A. Crawford, to Dr. E. Stevenson for some preliminary experiments and to Dr. A. Dawson and Prof. S. Parsons for the X-ray crystal structures.

REFERENCES

1. Blake A. J., McNab H., Monahan L. C.: *J. Chem. Soc., Perkin Trans. 1* **1989**, 425.
2. Blake A. J., McNab H., Monahan L. C.: *J. Chem. Soc., Perkin Trans. 2* **1991**, 2003.
3. a) Hojo M., Masuda R., Okada E.: *Chem. Lett.* **1990**, 2095; b) Hojo M., Masuda R., Okada E.: *Synthesis* **1991**, 46.
4. Meth-Cohn O., Suschitzky H.: *Adv. Heterocycl. Chem.* **1972**, *14*, 211.
5. a) Dyachenko E. V., Glukhareva T. V., Nikolaenko E. F., Tkachev A. V., Morzherin Y. Y.: *Russ. Chem. Bull.* **2004**, *53*, 1240; b) Rabong C., Hametner C., Mereiter K., Kartsev V. G., Jordis U.: *Heterocycles* **2008**, *75*, 799; c) Ryabukhin S. V., Plaskon A. S., Volochnyuk D. M., Pipko S. E., Tolmachev A. A.: *Synth. Commun.* **2008**, *38*, 3032.
6. Neuenschwander M., Neuenschwander A., Steinegger E., Engel P.: *Helv. Chim. Acta* **1979**, *62*, 609.
7. McNab H., Morel G., Stevenson E.: *J. Chem. Res., Synop.* **1997**, 207.
8. Sauer J. C.: *J. Am. Chem. Soc.* **1957**, *79*, 5314.
9. Stevenson E.: *Ph.D. Thesis*. The University of Edinburgh, Edinburgh 1998.
10. Niewiadomski K. B., Suschitzky H.: *J. Chem. Soc., Perkin Trans. 1* **1975**, 1679.
11. Typical recipes are quoted in: McNab H., Stobie I.: *J. Chem. Soc., Perkin Trans. 1* **1982**, 1845.
12. Low J. N., Cobo J., Nogueras M., Sanchez A., Insuasty B., Torres H.: *Acta Crystallogr., Sect. C: Cryst. Struct. Commun.* **2002**, *58*, o39.
13. Andreev G. N., Shults E. E., Volkov A. A., Shakirov M. M., Bagryanskaya I. Yu., Gatilov Yu. V., Tolstikov G. A.: *Russ. J. Org. Chem.* **2004**, *40*, 854.
14. Novoa de Armas H., Blaton N. M., Peeters O. M., De Ranter C. J., Suárez M., Ochoa E., Verdecia Y., Salfrán E.: *J. Chem. Crystallogr.* **2000**, *30*, 189.
15. Reviews: a) Gaber A. M., McNab H.: *Synthesis* **2001**, 2059; b) McNab H.: *Aldrichimica Acta* **2004**, *37*, 19.
16. McNab H., Monahan L. C.: *J. Chem. Soc., Perkin Trans. 1* **1988**, 863.
17. Hunter G. A., McNab H.: *J. Chem. Soc., Perkin Trans. 1* **1995**, 1209.
18. Lin W., Sapountzis I., Knochel P.: *Angew. Chem. Int. Ed.* **2005**, *44*, 4258.
19. Creed T., Leardini R., McNab H., Nanni D., Nicolson I. S., Reed D.: *J. Chem. Soc., Perkin Trans. 1* **2001**, 1079.
20. Pouchert J., Behnke J.: *The Aldrich Library of ^{13}C and ^{1}H FT NMR Spectra*. Aldrich Chemical Company Inc., Milwaukee 1993.