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# Lewis Acid Mediated Addition of 2-Acyl-1,3-dithianes to α,β-Unsaturated Ketones: Synthesis of Cyclohexenedione Mono-dithioacetals.

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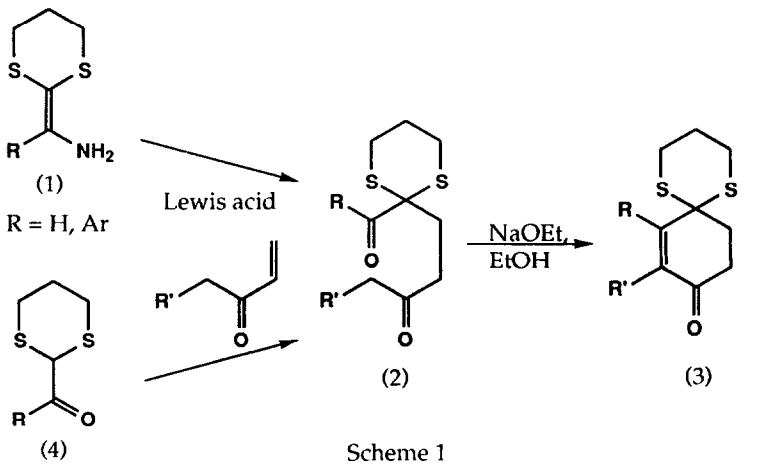
2-Acyl-1,3-dithianes undergo Lewis acid-mediated conjugate addition to α,β-unsaturated ketones to provide 1,5-diketones which suffer base-catalyzed intramolecular aldol reaction to produce mono-dithioacetals of cyclohex-2-en-1,4-diones and cyclohex-3-en-1,2 diones

## Introduction

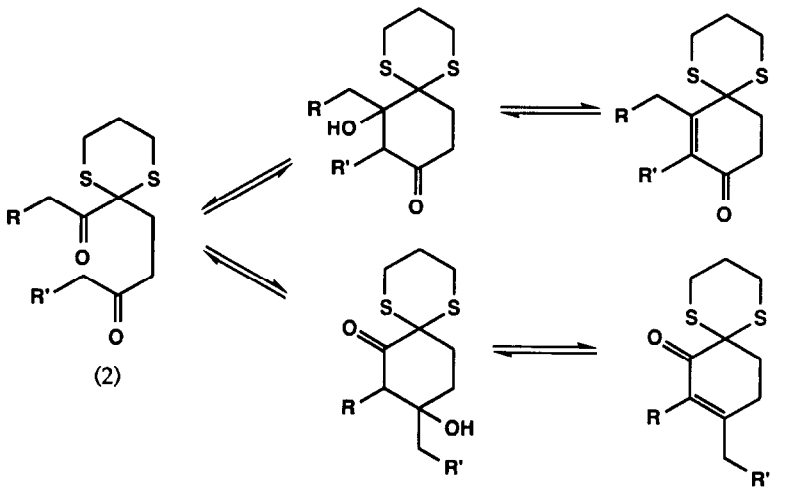
We have recently reported that Lewis acid mediated addition of aminoketene dithioacetals (1) to α,β-unsaturated ketones gives 1,5-diketones (2) after hydrolytic work up.[1] These diketones readily undergo aldol cyclization to give the interesting cyclohex-2-en-1,4-dione mono-dithioacetals (3).[2] Cyclohexenedione mono-dithioacetals have some potential as synthetic building blocks – they undergo enolate, conjugate addition, and cycloaddition chemistry – but their synthesis using our original route is limited to proton or aryl substituents. We were therefore pleased to discover that 2-acyl-1,3-dithianes (4) may be used to prepare cyclohexenedione mono-dithioacetals with much greater generality (scheme 1).[3]




Scheme 1

Little use has yet been made of acyl dithianes as synthetic intermediates.[4] We have found them to be stable materials, often crystalline, which exist in the keto form. They are readily prepared by acylation of dithiane 2-anions or, in improved yields, by reaction of dithiane anions with aldehydes followed by oxidation.[5] They undergo normal enolate chemistry,[6] nucleophilic addition,[7] conjugate addition,[8] carbonyl group reduction [9] and sulphoxidation reactions – in our laboratories high enantiomeric excesses have been achieved in sulphoxidation reactions using 2-acyl-1,3-dithianes as substrates.[10]

2-Acyl-1,3-dithianes lacking a second substituent at C-2 display a similar pattern of reactivity to aminoketene dithioacetals, providing 1,5-diketones upon Lewis acid mediated reaction with enones. However, unlike our previous investigation, the greater available range of substituents allows two possible modes of cyclization for the subsequent intramolecular aldol reaction leading to two possible types of regioisomeric products (Scheme 2).



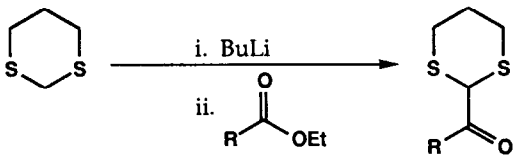
(2)

Scheme 2

**Preparation of 2-acyl-1,3-dithianes**

Several methods are currently available for the acylation of 1,3-dithiane anions.[11,15] As reported by Corey,[12] acid chlorides give poor results; however, we have found that addition of 2-lithio-1,3-dithiane to a large excess of suitable ester at −78 °C using a cannula provides reasonable yields of 2-acyl-1,3-dithianes (Table I). It is necessary to use this protocol to prevent the usual side reactions of product deprotonation and double addition of 2-lithio-1,3-dithiane. This process is rapid and successful on a multigram scale, but as a large excess is necessary it is not suitable for precious esters. In the case of acylation using ethyl nitroacetate the α-proton proved to be too acidic, and only deprotonation occurred. Trimethylsilylacetate and laevulinate were also unsuccessful substrates, although methoxyacetate (Table I, entry g) gave the highest yield of all. Curiously, diethyl oxalate gave only (5), the product of a double addition of the electrophile. An alternative two-step procedure, very general but most suitable for smaller quantities and precious esters, is available by addition of 2-lithio-1,3-dithiane to aldehydes followed by subsequent alcohol oxidation, preferably using the Swern procedure. This is also a general method for acylation of 2-monosubstituted 1,3-dithianes. [13]

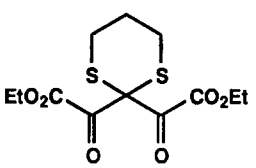
**Table I. Preparation of Acyl Dithianes**




| Entry | R | Yield/% |
|---|---|---|
| a. | H | 72 |
| b. | $CH_3$ | 65 |
| c. | $CH_3CH_2$ | 42 |
| d. | $CH_3CH_2CH_2$ | 38 |
| e. | Ph | 29 |
| f. | $CH_2$=$CHCH_2CH(CH_3)$ | 59 |
| g. | $CH_3OCH_2$ | 100 |
| h. | 2-(1,3-Dithianyl) | 18 |

**Reaction of 2-acyl-1,3-dithianes with enones to give 1,5-diketones**

Deprotonation of 2-acyl-1,3-dithianes using butyl lithium followed by addition of the anion to α,β-unsaturated ketones gave poor yields of 1,5-diketones, as did subjecting mixtures of acyl dithianes and enones to the action of toluene 4-sulphonic acid. We next examined the effect of Lewis acids upon the reaction, and were pleased to find that the use of zinc chloride etherate in dichloromethane or ether solution provided the corresponding 1,5-diketones in excellent yields (Table II). For example, a particularly successful reaction was observed between 2-(2-methoxyacetyl)-1,3-dithiane and methyl vinyl ketone in the presence of zinc chloride etherate, from which a quantitative yield of the diketone was obtained (Table II, entry n). It is interesting that zinc chloride should have proved so much more successful than other Lewis acids; while we have no satisfactory explanation for this behaviour, similar observations have been made by other investigators.[13] Exceptionally, methyl acrylate was poorly successful as an electrophile, perhaps due to competing 1,2-addition, providing only a 24% yield of (6) from acetyl dithiane after seven days. Reactions of 2-formyl-1,3-dithiane (entries a, b, c) generally proceeded in low yield, primarily because of its instability.

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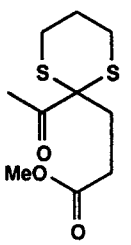
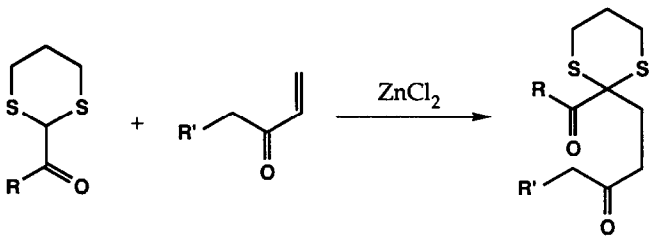



(6)

As the reactions proceed a colourless suspension is formed in the reaction mixture. Evaporation to dryness of the mixture upon completion of the reaction between 2-acetyl-1,3-dithiane and methyl vinyl ketone, but without work-up, gave a solid intermediate from which on standing in the air for a matter of seconds collapsed to an oil consisting largely of the crude 1,5-diketone product. We suspect that the solid initially formed is a zinc

complex of the product, but further speculation is of little value since spectroscopic data was not obtainable. Addition of the zinc chloride to 2-acetyl-1,3-dithiane induces in the $^1H$ nmr spectrum a small downfield shift (*ca.* 0.1 ppm) in the chemical shift of the proton at C-2 of the 1,3-dithiane unit. This effect might be attributable to a co-ordination of zinc chloride to the acyl dithiane, presumably at the sulphur or oxygen atoms, but further speculation again seems fruitless.

**Table II. Formation of 1,5-Diketones**



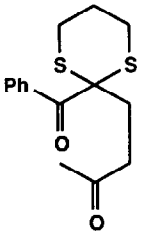

| Entry | R | R' | Time/days | Yield/% |
|---|---|---|---|---|
| a. | H | H | 3 | 76 |
| b. | H | $CH_3$ | 3 | 34 |
| c. | H | $CH_3CH_2$ | 3 | 34 |
| d. | $CH_3$ | H | 1 | 75 |
| e. | $CH_3$ | $CH_3$ | 2 | 74 |
| f. | $CH_3$ | $CH_3CH_2$ | 1 | 75 |
| g. | $CH_3CH_2$ | H | 3 | 65 |
| h. | $CH_3CH_2$ | $CH_3$ | 4 | 70 |
| i. | $CH_3CH_2$ | $CH_3CH_2$ | 4 | 75 |
| j. | $CH_3CH_2CH_2$ | H | 3 | 59 |
| k. | $CH_3CH_2CH_2$ | $CH_3$ | 4 | 79 |
| l. | $CH_3CH_2CH_2$ | $CH_3CH_2$ | 4 | 79 |
| m. | $CH_2$=$CHCH_2CH(CH_3)$ | H | 3 | 70 |
| n. | $CH_3OCH_2$ | H | 1 | 100 |
| o. | 2-(1,3-Dithianyl) | $CH_3$ | 3 | 100 |

2-Benzoyl-1,3-dithiane did not undergo any reaction over a period of one week with any of the enones examined. This result is complementary to our previous results using aminoketene thioacetals, where the phenyl derivative (1, R = Ph) is a particularly successful substrate, providing the 1,5-diketone (7) in 98% yield upon reaction with methyl vinyl ketone.[1] 2-Carboxyethyl-1,3-dithiane (8) also does not undergo addition to methyl vinyl ketone in the presence of zinc chloride etherate. In these cases the addition reaction may be prevented due to a disfavouring of the necessary enolization process. Furthermore, introduction of substituents at the β-terminus of the enone prevents the reaction from taking place; for example, 1,5-diketones could not be prepared from reactions of 2-acetyl-1,3-dithiane with enones (9) or (10). α,β-Unsaturated aldehydes and alkynones were also unsuccessful substrates.

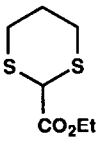
**Cyclization of diketones to give cyclohexenedione mono-dithioacetals.**

Cyclization of the 1,5-diketones was carried out by treatment with sodium ethoxide in ethanolic solution and generally took place in about 5 minutes at room temperature

(Table III). Unlike our previous investigation, the greater range of substituents which may be introduced using this route provides two cyclization modes, leading to two possible regioisomeric product types (Scheme 2).




(7)

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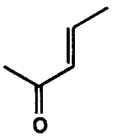


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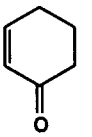



(10)

In most cases the major product observed was the cyclohex-3-en-1,2-dione mono-dithioacetal (11), formed exclusively and quantitatively in the case of the methoxyacetyl derivative (Table III, entry n), although in two cases (entries k and l) the regioselectivity was reversed to favour the cyclohex-2-en-1,4-dione mono-dithioacetal (12). In these cases the reversal of selectivity is clearly consequent upon a very minor structural change; however, it is clear from Table III that as the group R, originally the acyl dithiane side chain, is increased in size there is a tendency for production of a higher proportion of isomer (12). The data also demonstrate that increasing the size of group R', originally the enone side chain, appears to have little effect upon the ratio of product isomers.

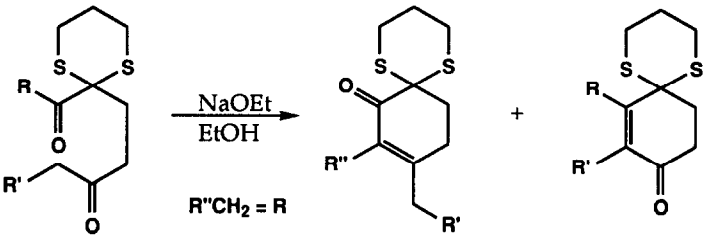
Regioisomers (11) and (12) each show characteristic patterns in their $^1$H NMR spectra. Nonetheless, initially we found it extremely difficult to assign the correct structure to each isomer, and accordingly an X-ray structure determination was carried out on compound (11, R' = R" = H) (entry d). [14]

These cyclization reactions also occur under Dean-Stark conditions in the presence of toluene 4-sulphonic acid in refluxing toluene solution; while the ratios of product isomers (11) and (12) are the same as those observed from the base mediated method, the overall yields are considerably lower. For example, under basic conditions the reaction shown in entry i proceeds in 82% total yield, but 51% under the acid-catalyzed conditions.

Presumably the cyclization reaction proceeds through an aldol reaction under thermodynamic control. Indeed, subjection of cyclized compound (11, R" = Et, R' = H) (entry j) to the reaction conditions used for cyclization gives a regioisomeric mixture of (11) and (12) in the same ratio as observed in the initial cyclization. However, this process requires about two days to reach equilibrium, in contrast to the initial cyclization which is complete in less than one hour. This behaviour perhaps suggests that the reaction proceeds through a rapid equilibration of cyclized aldolates followed by a rate-determining reversible elimination with a slow back reaction.

It is therefore not surprising that should a substituent be placed $\alpha$ to the ketone in the acyl dithiane starting material then cyclization proceeds so as to enable conjugation of the double bond formed during the elimination with the carbonyl group of the final product. For example 1,5-diketone (13) cyclizes to give product (14) only in 70% yield (entry m).

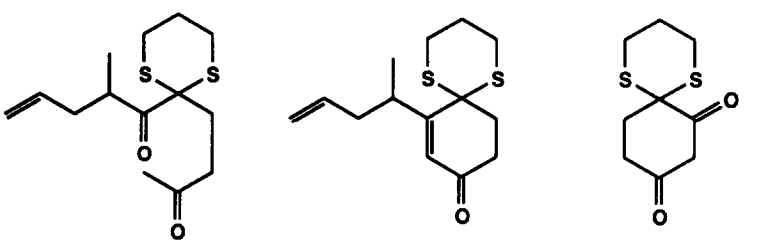
**Table III. Cyclization of 1,5-Diketones**




(11) (12)

| Entry | R | R' | Yield(11)/% | Yield(12)/% | Ratio 11:12 |
|---|---|---|---|---|---|
| a. | H | H | — | 98 | — |
| b. | H | $CH_3$ | — | 100 | — |
| c. | H | $CH_3CH_2$ | — | 100 | — |
| d. | $CH_3$ | H | 60 | 0 | exclusive |
| e. | $CH_3$ | $CH_3$ | 74 | 6 | 12.3:1 |
| f. | $CH_3$ | $CH_3CH_2$ | 78 | 4 | 19.5:1 |
| g. | $CH_3CH_2$ | H | 51 | 23 | 2.2:1 |
| h. | $CH_3CH_2$ | $CH_3$ | 75 | 13 | 5.8:1 |
| i. | $CH_3CH_2$ | $CH_3CH_2$ | 70 | 13 | 5.4:1 |
| j. | $CH_3CH_2CH_2$ | H | 57 | 25 | 2.3:1 |
| k. | $CH_3CH_2CH_2$ | $CH_3$ | 13 | 76 | 1:5.8 |
| l. | $CH_3CH_2CH_2$ | $CH_3CH_2$ | 11 | 85 | 1:7.7 |
| m. | $CH_2$=$CHCH_2CH(CH_3)$ | H | — | 70 | — |
| n. | $CH_3OCH_2$ | H | 87 | 0 | exclusive |
| o. | Ph | H | — | 100 | — |
| p. | Ph | $CH_3$ | — | 100 | — |
| q. | Ph | $CH_3CH_2$ | — | 91 | — |

This methodology may also be applied to produce singly protected 1,3,4-triketones. Cyclization of ketoester (6) using ethanolic sodium ethoxide gives spiro-1,2'-(cyclohexane-2,4-dione)(1',3'-dithiane) (15) in 16% yield.

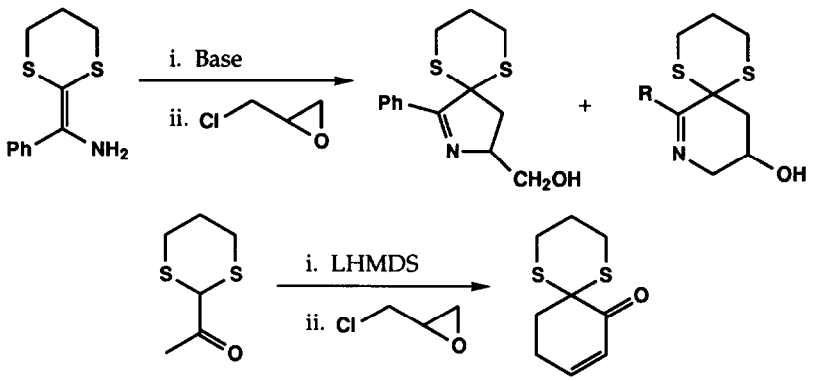


(13) (14) (15)

**Cyclization of 2-acetyl-1,3-dithiane using epichlorohydrin**

Previously we have reported that anions derived from aminoketene dithioacetals react with epichlorohydrin to give mixtures of five- and six- membered ring

heterocycles.[15] Interestingly the corresponding reaction of 2-acetyl-1,3-dithiane with epichlorohydrin using lithium hexamethyl disilazide (2 equiv.) as a base gave only the six-membered conjugated carbocyclic system cyclohex-3-ene-2-one 1,3-dithiane (16) in 79% yield (Scheme 3), a compound which *cannot* be prepared using the 1,5-diketone cyclization methodology described above. No uncyclized addition product was observed and no starting material was recovered. Curiously, increasing the acyl chain length to propionyl or butyryl gave no reaction. Other bases such as lithium diisopropylamide, butyl lithium and sodium hydride were tested, but no reaction occurred.




Scheme 3 (16)

**Acknowledgment**

This investigation has enjoyed the support of SERC and Shell Research Ltd. (studentships to APM & LJG). We are indebted to the SERC Very High Field NMR Service at the University of Warwick for their help and patience.

## EXPERIMENTAL SECTION

### General experimental details

*Purification of Reagents*

Commercially available reagents were used as supplied unless otherwise stated. Butyllithium was either purchased from the Lithium Corporation of Europe in one gallon quantities and decanted into 500 ml oven baked bottles stoppered with septa, or purchased from Aldrich Chemical Company. The molarity was determined by titration against a solution of diphenyl acetic acid. 1,3-Dithiane was stored in a desiccator over self-indicating silica gel. It was occasionally necessary to recrystallise the reagent from petroleum ether (bp 40-60 °C). Zinc chloride was purchased from either BDH Chemical Company, or purchased in 1 litre bottles as its etherate (1M solutions) from Aldrich Chemical Company. Triethylamine was distilled from potassium hydroxide pellets under nitrogen, and stored over activated type 4Å molecular sieve.

*Purification of Solvents*

Tetrahydrofuran and diethyl ether were freshly distilled under nitrogen from the sodium/benzophenone ketyl radical immediately prior to use. Toluene and dichloromethane were allowed to stand over calcium hydride overnight prior to distillation under nitrogen. Dimethylformamide was distilled from calcium hydride and the distillate flash distilled from alumina activated by heating to 150 °C overnight. Dry solvent

was stored over activated type 4Å molecular sieve under an atmosphere of nitrogen. Ethanol was distilled under nitrogen from activated magnesium. Petroleum ether (b.p. 40-60 °C and b.p. 60-80 °C) was distilled prior to use.

*Preparation of glassware*

Reactions requiring rigorously anhydrous conditions were carried out in glassware which had been baked at 150 °C for a minimum of four hours. The flasks were allowed to cool in a desiccator over self-indicating silica gel, and were purged with either nitrogen or argon prior to being stoppered with septum caps. Syringes, needles, cannulas, and magnetic stirring bars used in organometallic reactions were also baked and allowed to cool in a desiccator. Reactions were maintained in under a slight static positive pressure of nitrogen or argon and reagents and solvents introduced *via* syringe or using cannula techniques, through a septum cap.

*Normal work-up procedures*

Reactions were usually worked-up by addition of a saturated aqueous solution of ammonium chloride, followed by extraction of the aqueous phase using several portions of chloroform or dichloromethane. The combined organic extracts were dried over anhydrous magnesium sulphate which was later removed by filtration. The filtrate was reduced in volume on a rotary evaporator to give the crude reaction mixture.

*Purification of Products*

Flash column chromatography was carried out using Merck 9385 Kieselgel 60 (230-400 mesh), using hand-bellows or an air line to apply pressure to the column. Mixtures of ethyl acetate and petroleum ether (bp 40-60 °C) in proportions ranging from 1:1 to 1:10 were used as eluant, unless otherwise stated. Dry flash column chromatography was carried out using Merck 15111 silica gel using petroleum ether (bp 40-60 °C) containing an increasing proportion of ethyl acetate as eluant. High pressure liquid chromatography was carried out using a Waters Prep LC3000 pumping system, Waters R401 and R404 differential refractometers, Rainin normal phase columns, a Waters 745 integrator, an ISCO 2150 peak separator, and an ISCO Foxy fraction collector. A Büchi Kugelrohr oven was used as the heat source for bulb to bulb distillations; boiling points quoted refer to the oven temperature. Thin layer chromatography was carried out on glass or aluminium backed plates coated with a 0.25 mm layer of silica gel 60H containing fluorescer, using mixtures of ethyl acetate and petroleum ether (bp 40-60 °C) as eluant unless otherwise stated. UV inactive compounds were visualised by spraying with either *dodeca*-molybdophosphoric acid (15% w/v in ethanol), or an alkaline solution of potassium permanganate (1% w/v in water) followed in both cases by charring where appropriate.

*Spectroscopy and other data*

Infrared spectra were recorded in the range 4000-600 $cm^{-1}$ using Perkin Elmer 298 or 1320 spectrophotometers, and were calibrated against the 1602 $cm^{-1}$ absorption of polystyrene. Solid samples were run as nujol mulls or in solution, and liquids as thin films. $^{1}H$ NMR spectra were recorded using Perkin Elmer R34, Bruker WM250, Bruker AC200, Jeol PMX60 or Nicolet QE300 instruments using deuteriochloroform solutions and tetramethylsilane as internal reference. $^{13}C$ NMR spectra were recorded on Bruker WM250, Bruker AC200, or Nicolet QE300 instruments using deuteriochloroform solutions and tetramethylsilane as internal reference. Mass spectra were obtained on VG Micromass 7070E, AEI MS 902, Finnigan MAT 90, or Finnigan MAT 4500 mass spectrometers. Microanalyses were performed either at the University of Liverpool, Department of

Chemistry microanalytical laboratory or at Shell Research Limited, Sittingbourne. Melting points were determined on a Reichert hot stage apparatus and are uncorrected. Solvents used for recrystallization are indicated in brackets after the melting point.

**Preparation of 2-Acyl-1,3-dithianes (4)**

*General method*

1,3-Dithiane (4 g, 33 mmol) is dissolved in THF and the solution cooled to –78 °C. and the reaction was allowed to stir for two hours at –78 °C. A solution of butyl lithium (*ca.* 1 equiv.) is added and the mixture stirred for two hours at –78 °C, then transferred using a cannula to ethyl ester at –78 °C, and the reaction mixture allowed to reach room temperature overnight. Saturated aqueous ammonium chloride is added and the mixture extracted into dichloromethane, dried over magnesium sulphate, and the solvent removed *in vacuo*.

*2-Formyl-1,3-dithiane (Table I, entry a)*

Treatment of a solution of 1,3-dithiane (5.0 g, 41.7 mmol) in THF (250 ml) as described above with butyl lithium (16.6 ml, 2.5 M, 41.7 mmol) and ethyl formate (33.7 ml 417 mmol) gave 2-formyl-1,3-dithiane as an unstable clear oil (5.8 g, 94%), purified by flash column chromatography; $\nu_{max}$ 2930 and 1735 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 9.42 (1H, s), 4.15 (1H, s), 3.05-2.80 (2H, m), 2.58-2.36 (2H, m) and 2.05-1.80 (2H, m); *m/z* 148.0010 ($M^+$), 119, 75, 73 and 45; $C_5H_8OS_2$ requires148.0017.

*2-Acetyl-1,3-dithiane (Table I, entry b)*

Treatment of a solution of 1,3-dithiane (20.3 g, 169 mmol) in THF (500 ml) as described above with butyl lithium (75 ml, 2.5 M, 186 mmol) and ethyl acetate (148 ml, 169 mmol) gave 2-acetyl-1,3-dithiane, purified by distillation to give a colourless oil (17.8 g, 65%), b.p. 101 °C at 2 mmHg; $\nu_{max}$ 2900 and 1710 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.25 (1H, s), 3.25-3.10 (2H, m), 2.65-2.55 (2H, m), 2.35 (3H, s), and 2.10-1.90 (2H, m); *m/z* (CI) 163 ($(M+H)^+$) and 133. Found: C, 44.54; H, 6.33; $C_6H_{10}OS_2$ requires C, 44.40; H, 6.21%.

*2-Propionyl-1,3-dithiane (Table I, entry c)*

Treatment of a solution of 1,3-dithiane (2.0 g, 16.7 mmol) in THF (100 ml) as described above with butyl lithium (6.7 ml, 2.5 M, 16.7 mmol) and ethyl propionate (17.0 ml, 16.7 mmol) gave 2-propionyl-1,3-dithiane, purified by flash column chromatography to give the product as a colourless oil (1.23 g, 42%); $\nu_{max}$ 2900 and 1710 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.25 (1H, s), 3.25-3.10 (2H, m), 2.80-2.55 (4H, m), 2.35 (3H, s) and 2.1-1.9 (2H, m); *m/z* (CI) 177 ($(M+H)^+$) and 133. Found: C,47.5; H, 6.90; $C_7H_{12}OS_2$ requires C, 47.69; H, 6.86%.

*2-Butyryl-1,3-dithiane (Table I, entry d)*

Treatment of a solution of 1,3-dithiane (5.0 g, 41.7 mmol) in THF (100 ml) as described above with butyl lithium (16.7 ml, 2.5 M, 41.7 mmol) and ethyl butyrate (24.2 g, 27.6 ml, 208.5 mmol) gave 2-propionyl-1,3-dithiane, purified by flash column chromatography to give a colourless oil (3.2 g, 38%); $\nu_{max}$ 2920 and 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.20 (1H, s), 3.30-3.25 (2H, m), 2.70-2.50 (4H, m), 2.15-1.95 (2H, m), 1.70-1.55 (2H, m) and 0.95-0.70 (3H, m); *m/z* (CI) 191 ($(M+H)^+$) and 133. Found: C, 50.8; H, 7.4, $C_8H_{14}OS_2$ requires C,50.49; H, 7.41%.

*2-Benzoyl-1,3-dithiane (Table I, entry e)*

Treatment of a solution of 1,3-dithiane (4.0 g, 33 mmol) in THF (200 ml) as described above with butyl lithium (13.3 ml, 2.5 M, 33 mmol) and ethyl benzoate (47 ml,

33 mmol) gave 2-benzoyl-1,3-dithiane, purified by flash column chromatography to give a colourless crystalline solid (29%), m.p. 91-92 °C; $\nu_{max}$ 2920 and 1670 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 8.05-7.95(2H, m), 7.65-7.40 (3H, m), 5.19 (1H, s) 3.50-3.30 (2H, m) 2.79-2.60 (2H, m) and 2.2-2.01 (2H, m); *m/z* (CI) 224 [$(M+H)^+$] and 119. Found: C, 60.2; H, 5.6; $C_{11}H_{12}OS_2$ requires C, 58.89; H, 5.39%.

*2-(1-(2-Methylpent-4-enoyl))-1,3-dithiane (Table I, entry f)*

Treatment of a solution of 1,3-dithiane (2.0 g, 16.7 mmol) in THF (100 ml) as described above with butyl lithium (6.7 ml, 2.5 M, 16.7 mmol) and ethyl 2-methyl-4-pentenoate (8.14 ml, 50 mmol) gave 2-benzoyl-1,3-dithiane, purified by flash column chromatography to give a colourless oil (2.12 g, 59%); $\nu_{max}$ 2900, 1705 and 1640 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.80-5.65 (1H, m), 5.15-5.00 (2H, m), 4.25 (1H, s), 3.32-3.17 (2H, m), 3.03-2.88 (1H, m), 2.65-2.50 (2H, m),2.48-2.35 (1H, m), 2.20-1.98 (3H, m) and 1.20-1.10 (3H, d, *J* 8.5 Hz); *m/z* (CI) 217 [$(M+H)^+$] and 133. Found: C, 55.44; H, 6.97; $C_{10}H_{16}OS_2$ requires C, 55.52; H, 7.45%.

*2-Methoxyacetyl-1,3-dithiane (Table I, entry g)*

Treatment of a solution of 1,3-dithiane (4.0 g, 33 mmol) in THF (250 ml) as described above with butyl lithium (14.7 ml, 2.5 M, 36.3 mmol) and ethyl methoxyacetate (11.8 g, 11.7 ml, 100 mmol) gave 2-methoxyacetyl-1,3-dithiane, purified by flash column chromatography to give a colourless crystalline solid (6.4 g, 100%), m.p. 37-38 °C; $\nu_{max}$ 2900 and 1730 $cm^{-1}$; δH ($CDCl_3$) 4.75-4.65 (1H, m), 4.52-4.40 (2H, m), 3.85-3.45 (5H, m), 2.90-2.70 (2H, m), and 2.50-2.15 (2H, m); *m/z* (CI) 193 [$(M+H)^+$], 161 and 133. Found: C, 43.90; H, 6.30; $C_7H_{12}O_2S_2$ requires C, 43.72; H, 6.29%.

*bis-2-(1,3-Dithianyl) ketone (Table I, entry h)*

Treatment of a solution of 1,3-dithiane (2.0 g, 16.7 mmol) in THF (200 ml) as described above with butyl lithium (7.3 ml, 16.7 mmol) and ethyl 1,3-dithiane-2-carboxylate (3.2 g, 2.6 ml, 16.6 mmol) gave bis-2-(1,3-dithianyl) ketone, purified by flash column chromatography to give a colourless crystalline solid (0.78 g, 18%), m.p. 159-160 °C; $\nu_{max}$ 2910 and 1710 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.61 (2H, s), 3.40-3.18 (4H, m), 2.65-2.44 (4H, m) and 2.22-1.85 (4H, m); *m/z* (EI) 265.9926 ($M^+$) and 119; $C_9H_{14}OS_4$ requires 265.9928. Found: C, 40.58; H, 5.26; $C_9H_{14}OS_4$ requires C, 40.57; H, 5.30%.

**Preparation of 1,5-Diketones (2)**

*General method*

To a solution of 2-acyl-1,3-dithiane in dry dichloromethane is added ethereal zinc chloride (1 equiv.) followed by enone (3 equiv.). The mixture is stirred for three days before normal work-up and purification.

*2-Formyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry a)*

Treatment of 2-formyl-1,3-dithiane (0.7 g, 4.73 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 4.73 mmol) followed by methyl vinyl ketone (0.1 g, 14.19 mmol) gave 2-formyl-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.79 g, 76%), b.p. 200 °C at 0.1 mmHg; $\nu_{max}$ 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 9.0 (1H, s), 3.1-2.9 (2H, m), 2.8-2.6 (4H, m), 2.2-2.0 (6H, m) and 1.9-1.6 (1H, m); *m/z* (EI) 218 ($M^+$), 189, 119 and 106. Found: C, 49.76; H, 6.63; $C_9H_{14}O_2S_2$ requires C, 49.51; H, 6.46%.

*2-Formyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table II, entry b)*

Treatment of 2-formyl-1,3-dithiane (1.0 g, 6.7 mmol) as described above in dry

dichloromethane (50 ml) with ethereal zinc chloride (1 M, 6.7 mmol) followed by ethyl vinyl ketone (1.7 g, 20 mmol) gave 2-formyl-2-(1-(pentan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.53 g, 34%); $\nu_{max}$ 1730 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 9.0 (1H, s), 3.6-3.5 (2H, m), 2.7-2.6 (4H, m), 2.5 (2H, q, *J* 7.2 Hz), 2.2 (2H, t, *J* 7.2 Hz), 1.95-1.85 (1H, m), 1.4 (3H, t, *J* 7 Hz) and 1.35-1.25 (1H, m); *m/z* (EI) 232 ($M^+$), 217 and 119. Found: C, 51.76; H, 6.73; $C_{10}H_{16}O_2S_2$ requires C, 51.69; H, 6.94%.

*2-Formyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table II, entry c)*

Treatment of 2-formyl-1,3-dithiane (1.0 g, 6.7 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 6.7 mmol) followed by propyl vinyl ketone (2.0 ml, 20 mmol) gave 2-formyl-2-(1-(hexan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.56 g, 34%); $\nu_{max}$ 1730 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 9.0 (1H, s), 3.2-2.9 (2H, m), 2.8-2.6 (4H, m), 2.5 (2H, t, *J* 7 Hz), 2.15 (2H, t, *J* 8 Hz), 1.95-1.85 (1H, m), 1.65 (2H, q, *J* 7 Hz), 1.45-1.35 (1H, m) and 1.05-0.95 (3H, m); *m/z* 246 ($M^+$) and 217. Found: C, 53.56; H, 7.39; $C_{11}H_{18}O_2S_2$ requires C, 53.62; H, 7.36%.

*2-Ethanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry d)*

Treatment of 2-acetyl-1,3-dithiane (1.0 g, 6.17 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 12.4 mmol) followed by methyl vinyl ketone (0.865 g, 12.4 mmol) gave 2-ethanoyl-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (1.2 g, 75%); $\nu_{max}$ 2900, 1710 and 1420 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.15-3.05 (2H, m), 2.90-2.65 (4H, m), 2.60-2.00 (9H, m) and 2.00-1.80 (1H, m); *m/z* (EI) 232 ($M^+$), 205 and 189. Found: C, 51.73; H, 6.94; $C_{10}H_{16}O_2S_2$ requires C, 51.69; H, 6.94%.

*2-Ethanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table II, entry e)*

Treatment of 2-acetyl-1,3-dithiane (1.0 g, 6.17 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 6.2 mmol) followed by ethyl vinyl ketone (1.04 g, 12.4 mmol) gave 2-ethanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless crystalline solid (1.14 g, 74%), m.p. 39-40 °C; $\nu_{max}$ 2900 and 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$)3.02-2.90 (2H, m), 2.70-2.65 (4H, m), 2.47-2.35 (2H, q, *J* 7 Hz), 2.34-2.25 (5H, m), 2.10-1.98 (1H, m), 1.87-1.75 (1H, m) and 1.05 (3H, t, *J* 7 Hz); *m/z* (EI) 246 ($M^+$), 217 and 203. Found: C, 53.60; H, 7.41; $C_{11}H_{18}O_2S_2$ requires C, 53.62; H, 7.36%.

*2-Ethanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table II, entry f)*

Treatment of 2-acetyl-1,3-dithiane (1.0 g, 6.17 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 6.2 mmol) followed by propyl vinyl ketone (1.81 g, 18.5 mmol) gave 2-ethanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless crystalline solid (1.2 g, 75%), m.p. 49-50 °C; $\nu_{max}$ 2900 and 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.00-2.90 (2H, m), 2.70-2.55 (4H, m), 2.40-2.23 (7H, m), 2.10-1.95 (1H, m), 1.90-1.70 (1H, m), 1.65-1,50 (2H, m) and 0.93-0.85 (3H, t, *J* 8 Hz); *m/z* (EI) 217, 143 and 107. Found: C, 55.30; H, 7.7; $C_{12}H_{20}O_2S_2$ requires C, 55.35; H, 7.74%.

*2-Propanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry g)*

Treatment of 2-propanoyl-1,3-dithiane (0.5 g, 2.84 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 2.84 mmol) followed by methyl vinyl ketone (0.4 g, 5.68 mmol) gave 2-propanoyl-2-(1-(butan-3-onyl))-1,3-dithiane,

purified by flash column chromatography to give a colourless oil (0.46 g, 65%); $\nu_{max}$ 2900 and 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.05-2.90 (2H, m), 2.75-2.50 (7H, m),2.35-2.25 (2H, m), 2.15 (3H, s), 2.10-2.00 (1H, m) and 1.10 (3H, t, *J* 8 Hz); *m/z* (CI) 247 [(M+H)+], 229, 189 and 141. Found: C, 53.60; H, 7.30; $C_{11}H_{18}O_2S_2$ requires C, 53.62; H, 7.36%.

*2-Propanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table II, entry h)*

Treatment of 2-propanoyl-1,3-dithiane (3.0 g, 17.0 mmol) as described above in dry dichloromethane (150 ml) with ethereal zinc chloride (1 M, 17.0 mmol) followed by ethyl vinyl ketone (2.86 g, 34.0 mmol) gave 2-propanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (3.12 g, 70%); $\nu_{max}$ 2900, 1740 and 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.15-2.88 (2H, m), 2.85-2.62 (6H, m), 2.60-2.25 (4H, m), 2.20-1.78 (2H, m) and 1.50-0.95 (6H, m); *m/z* (EI) 260.0879 ($M^+$), 203, 149 and 129; $C_{12}H_{20}O_2S_2$ requires 260.0905.

*2-Propanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table II, entry i)*

Treatment of 2-propanoyl-1,3-dithiane (3.0 g, 17.0 mmol) as described above in dry dichloromethane (150 ml) with ethereal zinc chloride (1 M, 17.0 mmol) followed by propyl vinyl ketone (3.4 g, 34.0 mmol) gave 2-propanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (3.51 g, 75%); $\nu_{max}$ 2900 and 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.05-2.90 (2H, m), 2.77-2.15 (10H, m), 2.13-1.97 (1H, m), 1.95-1.55 (3H, m), 1.05 (3H, t, *J* 7 Hz) and 0.95 (3H, t, *J* 8 Hz); *m/z* (EI) 274 ($M^+$), 217, 143,107, 73, 57 and 43. Found: C, 57.08; H, 8.06; $C_{13}H_{22}O_2S_2$ requires C, 56.90; H, 8.08%.

*2-Butanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry j)*

Treatment of 2-butanoyl-1,3-dithiane (1.0 g, 5.3 mmol) as described above in dry dichloromethane (150 ml) with ethereal zinc chloride (1 M, 5.3 mmol) followed by methyl vinyl ketone (0.74 g, 10.6 mmol) gave 2-butanoyl-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.81 g, 59%); $\nu_{max}$ 2900, 1700 and 1420 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.05-2.90 (2H, m), 2.75-2.60 (5H, m), 2.35-2.25 (2H, m), 2.15 (3H, s), 2.1-1.95 (1H, m), 1.90-1.75 (1H, m), 1.70-1.55 (3H, m) and 0.90 (3H, t, *J* 7 Hz); *m/z* (CI) 261 [(M+H)+], 243, 191 and 165. Found: C, 55.70; H, 8.00; $C_{12}H_{20}O_2S_2$ requires C, 55.35; H, 7.74%.

*2-Butanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table II, entry k)*

Treatment of 2-butanoyl-1,3-dithiane (3.0 g, 15.8 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 15.8 mmol) followed by ethyl vinyl ketone (2.65 g, 31.6 mmol) gave 2-butanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (3.4 g, 79%); $\nu_{max}$ 2900 and 1710 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.04-2.87 (2H, m), 2.70-2.50 (6H, m), 2.46 (2H, q, *J* 9 Hz), 2.31-2.24 (2H, m), 2.10-1.95 (1H, m), 1.90-1.70 (1H, m), 1.69-1.50 (2H, m) 1.05 (3H, t, *J* 9 Hz) and 0.9 (3H, t, *J* 9 Hz); *m/z* (EI) 274.1057 ($M^+$), 203, 149 and 129; $C_{13}H_{22}O_2S_2$ requires 274.1061. Found: C, 56.80; H, 8.40; $C_{13}H_{22}O_2S_2$ requires C, 56.90; H, 8.08%.

*2-Butanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table II, entry l)*

Treatment of 2-butanoyl-1,3-dithiane (3.0 g, 15.8 mmol) as described above in dry dichloromethane (150 ml) with ethereal zinc chloride (1 M, 15.8 mmol) followed by propyl vinyl ketone (3.09 g, 31.6 mmol) gave 2-butanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (3.6 g, 79%); $\nu_{max}$ 2900 and 1710 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.05-2.87 (2H, m), 2.70-2.50 (6H, m), 2.50-2.22 (4H, m),

2.15-1.97 (1H, m), 1.96-1.56 (5H, m) and 1.05-0.88 (6H, m); *m/z* (EI) 288.1221 ($M^+$), 217, 143, 107 and 71; $C_{14}H_{24}O_2S_2$ requires 288.1218. Found: C, 58.25; H, 8.53; $C_{14}H_{24}O_2S_2$ requires C, 58.29; H, 8.39%.

*2-(2-Methylpent-4-enoyl)-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry m)*

Treatment of 2-(2-methylpent-4-enoyl)-1,3-dithiane (1.0 g, 4.6 mmol) as described above in dry dichloromethane (100 ml) with ethereal zinc chloride (1 M, 4.6 mmol) followed by methyl vinyl ketone (0.65 g, 9.3 mmol) gave 2-(2-methylpent-4-enoyl)-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.92 g, 70%); $\nu_{max}$ 2900, 1705 and 1640 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.80-5.65 (1H, m), 5.10-4.95 (2H, m), 3.36-3.25 (1H, m), 3.00-2.85 (2H, m), 2.75-2.60 (4H, m), 2.40-1.90 (8H, m), 1.88-1.70 (1H, m) and 1.10 (3H, d, *J* 6 Hz); *m/z* (CI) 287 [(M+H)+], 269, 189 and 181. Found: C, 58.81; H, 7.84; $C_{14}H_{22}O_2S_2$ requires C, 58.70; H, 7.74%.

*2-Methoxyacetyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table II, entry n)*

Treatment of 2-methoxyacetyl-1,3-dithiane (4.0 g, 20.8 mmol) as described above in dry dichloromethane (100 ml) with ethereal zinc chloride (1 M, 12.4 mmol) followed by methyl vinyl ketone (4.4 g, 62.5 mmol) gave 2-methoxyacetyl-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless solid (5.45 g, 100%), m.p. 30-31 °C; $\nu_{max}$ 2900 and 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.50 (2H, s), 3.42 (3H, s), 3.03-2.92 (2H, m), 2.71-2.60 (4H, m), 2.30-2.20 (2H, m), 2.15 (3H, s), 2.10-2.00 (1H, m) and 1.90-1.70 (1H, m); *m/z* (EI) 262 ($M^+$), 234, 189, 115 and 107. Found: C, 50.60; H, 6.90; $C_{11}H_{18}O_3S_2$ requires C, 50.35; H, 6.91%.

*2-(2-(1,3-Dithianyl))-2-(1-(pentan-3-onyl))-1,3-dithiane (Table II, entry o)*

Treatment of bis-2-(1,3-dithianyl) ketone (0.3 g, 1.13 mmol) as described above in dry dichloromethane (50 ml) with ethereal zinc chloride (1 M, 1.13 mmol) followed by ethyl vinyl ketone (0.2 g, 2.26 mmol) gave 2-(2-(1,3-dithianyl))-2-(1-(butan-3-onyl))-1,3-dithiane, purified by flash column chromatography to give a colourless solid (0.4 g, 100%); $\nu_{max}$ 2900 and 1715 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 4.90 (1H, s), 3.65-3.45 (2H, m), 3.20-3.05 (2H, m), 2.80-1.85 (14H, m) and 1.05 (3H, t, *J* 7 Hz); *m/z* (EI) 262, 203 and 119. Found: C, 48.12; H, 6.44; $C_{14}H_{22}O_2S_4$ requires C, 47.96; H, 6.33%.

*2-Ethanoyl-2-(1-(2-carboxymethyl)ethyl)-1,3-dithiane (6)*

Treatment of 2-acetyl-1,3-dithiane (2.0 g, 12.4 mmol) as described above in dry dichloromethane (100 ml) with ethereal zinc chloride (1 M, 12.4 mmol) followed by methyl acrylate (3.2 g, 37.2 mmol) gave 2-ethanoyl-2-(1-(2-carboxymethyl))-1,3-dithiane, purified by flash column chromatography to give a colourless oil (0.74 g, 24%); $\nu_{max}$ 2900, 1735 and 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.68 (3H, s), 3.05-2.90 (2H, m), 2.70-2.60 (2H, m), 2.55-2.45 (2H, m), 2.40-2.30 (2H, m), 2.35 (3H, s), 2.10-2.00 (1H, m) and 1.90-1.70 (1H, m); *m/z* (EI) 248 ($M^+$), 232, 223, 205 and 145. Found: C, 48.50; H, 6.30; $C_{10}H_{16}O_3S_2$ requires C, 48.36; H, 6.49%.

**Preparation of cyclohexendione mono-dithioacetals (11) & (12)**

*General method*

To a solution of 1,3-diketone in ethanol at room temperature or under reflux was added slowly sodium ethoxide (1 equiv.) in ethanolic solution. Upon consumption of all the starting material by TLC analysis the reaction was treated with saturated aqueous ammonium chloride, extracted into dichloromethane, dried over magnesium sulphate, and the solvent removed *in vacuo*. The residue was purified using column

chromatography.

*Cyclization of 2-formyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry a)*

Treatment of 2-formyl-2-(1-(butan-3-onyl))-1,3-dithiane (2.0 g, 9.2 mmol) in ethanol (50 ml) at reflux as described above gave cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane), purified by flash column chromatography to give a colourless crystalline solid (1.83 g, 98%), m.p. 75-77 °C; $\nu_{max}$ 1670 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 7.10 (1H, d, *J* 10 Hz), 5.9 (1H, d, *J* 10 Hz), 3.0-2.7 (4H, m), 2.7-2.6 (2H, m), 2.6-2.5 (2H, m) and 2.15-2.0 (2H, m); *m/z* (EI) 200.0327 ($M^+$) and 126; $C_9H_{12}OS_2$ requires 200.0330. Found: C, 53.97; H, 6.04; $C_9H_{12}OS_2$ requires C, 53.97; H, 6.04%.

*Cyclization of 2-formyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table III, entry b)*

Treatment of 2-formyl-2-(1-(pentan-3-onyl))-1,3-dithiane (1.0 g, 4.3 mmol) in ethanol (50 ml) at reflux as described above gave 3-methylcyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane), purified by flash column chromatography to give a yellow oil (0.92 g, 100%); $\nu_{max}$ 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 6.80 (1H, s), 3.10-2.90 (4H, m), 2.75-2.65 (2H, m), 2.65-2.55 (2H, m), 2.15-2.05 (2H, m) and 1.90 (3H, s); *m/z* (EI) 214.04871 ($M^+$) and 140; $C_{10}H_{14}OS_2$ requires 214.04860.

*Cyclization of 2-formyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table III, entry c)*

Treatment of 2-formyl-2-(1-(hexan-3-onyl))-1,3-dithiane (1.0 g, 4.0 mmol) in ethanol (50 ml) at reflux as described above gave 3-ethylcyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane), purified by flash column chromatography to give a colourless crystalline solid (0.91 g, 100%); $\nu_{max}$ 1700 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 6.50 (1H, s), 3.10-2.90 (4H, m), 2.70-2.50 (4H, m), 2.25-2.15 (2H, m), 2.05-1.95 (2H, m) and 1.00 (3H, t, *J* 7 Hz); *m/z* (EI) 228.06423 ($M^+$), 154 and 136; $C_{11}H_{16}OS_2$ requires 214.06425.

*Cyclization of 2-ethanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry d)*

Treatment of 2-ethanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (0.35 g, 1.5 mmol) in ethanol (50 ml) at room temperature as described above gave 4-methyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane), purified by flash column chromatography to give a colourless crystalline solid (0.195 g, 60%), m.p. 114-115 °C; $\nu_{max}$ 2900, 1650 and 1460 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.85 (1H, s), 3.60-3.40 (2H, m), 2.72-2.60 (2H, m), 2.55-2.40 (2H, m), 2.40-2.15 (4H, m) and 2.00 (3H, m); *m/z* (CI) 215 ($(M+H)^+$) and 181. Found: C, 56.10; H, 7.40; $C_{10}H_{14}OS_2$ requires C, 56.07; H, 6.58%.

*Cyclization of 2-ethanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table III, entry e)*

Treatment of 2-ethanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (1.12 g, 1.55 mmol) in ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 4-ethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (0.77 g, 74%) together with 2,3-dimethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) (0.06 g, 6%) as colourless crystalline solids.

For 4-ethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 60-61 °C; $\nu_{max}$ 1655 and 1645 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.75 (1H, s), 3.55-3.45 (2H, m), 2.70-2.55 (2H, m), 2.45-2.35 (2H, m), 2.30-2.15 (5H, m), 1.95-1.70 (1H, m), and 1.05 (3H, t, *J* 7.5Hz.); *m/z* (EI) 228 ($M^+$), 195 and 132. Found: C, 57.59; H, 7.15; $C_{11}H_{16}OS_2$ requires C, 57.85; H, 7.06%.

For 2,3-dimethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): m.p. 55-56 °C; $\nu_{max}$ 2900 and 1670 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.18-3.00 (2H, m), 2.80-2.50 (6H, m), 2.25 (3H, s), 2.20-2.05 (1H, m), 1.95-1.80 (1H, m), and 1.80 (3H, s); *m/z* (EI) 228 ($M^+$), 154 and 126. Found: C, 58.01; H, 7.12. $C_{11}H_{16}OS_2$ requires C, 57.85; H, 7.06%.

*Cyclization of 2-ethanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table III, entry f)*

Treatment of 2-ethanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (0.97 g, 3.7 mmol) in ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 4-propyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (0.7 g, 78%) together with 2-methyl-3-ethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) (0.04 g, 4%) as colourless crystalline solids.

For 4-propyl-cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 35-36 °C; $\nu_{max}$ 1660 and 1630 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.73 (1H, s), 3.55-3.27 (2H, m), 2.62-2.45 (2H, m), 2.42-2.27 (2H, m), 2.25-2.10 (4H, m), 2.00-1.76.(1H, m), 1.60-1.42 (2H, m),1.27-1.16 (1H, m) and 1.02-0.82 (3H, m); *m/z* (EI) 242.0796 ($M^+$), 209 and 132; $C_{12}H_{18}OS_2$ requires 242.0799. Found: C, 59.91; H, 6.87; $C_{12}H_{18}OS_2$ requires C, 59.46; H, 7.48%.

For 2-methyl-3-ethyl-cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): m.p. 31-32 °C; $\nu_{max}$ 2900, 1700 and 1650 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.40-3.37 (4H, m), 2.78-2.10 (6H, m), 1.38-1.08 (2H, m), 1.22 (3H, s) and 1.00 (3H, t, *J* 7 Hz); *m/z* (EI), 242.0794 ($M^+$) and 132; $C_{12}H_{18}OS_2$ requires 242.0799. Found: C, 59.23; H, 6.97; $C_{12}H_{18}OS_2$ requires C, 59.46; H, 7.48%.

*Cyclization of 2-propanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry g)*

Treatment of 2-propanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (0.19 g, 0.77 mmol) in ethanol (50 ml) at room temperature as described above gave after purification by flash column chromatography 3,4-dimethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (0.09 g, 51%) together with 2-ethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) (0.04 g, 23%) as colourless crystalline solids.

For 3,4-dimethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 79-80 °C; $\nu_{max}$ 2900, 1650 and 1460 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.55-3.40 (2H, m), 2.65-2.40 (4H, m), 2.30-2.15 (4H, m), 1.90 (3H, s) and 1.80 (3H, s); *m/z* (CI) 229 [$(M+H)^+$], 135 and 123. Found: C, 58.20; H, 7.10; $C_{11}H_{16}OS_2$ requires C, 57.85; H, 7.06%.

For 2-ethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): m.p. 76-77 °C; $\nu_{max}$ 2900, 1670 and 1455 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.90 (1H, s), 3.20-3.00 (2H, m), 2.80-2.55 (8H, m), 2.20-1.75 (2H, m) and 1.12 (3H, t, *J* 7 Hz); *m/z* (CI) 229 [$(M+H)^+$] and 123. Found: C, 57.7; H, 7.06; $C_{11}H_{16}OS_2$ requires C, 57.85; H, 7.06%.

*Cyclization of 2-propanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table III, entry h)*

Treatment of 2-propanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (1.0 g, 3.85 mmol) in ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 3-methyl-4-ethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) as a colourless crystalline solid (0.7 g, 75%) together with 2-ethyl-3-methyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) as a colourless oil (0.12 g, 13%) .

For 3-methyl-4-ethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 25-26 °C; $\nu_{max}$ 1655 and 1635 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.59-3.40 (2H, m), 2.72-2.41 (4H, m), 2.39-2.15 (4H, m), 1.94 (3H, s), 1.60-1.45 (2H, m) and 1.00 (3H, t, *J* 7 Hz); *m/z* (EI ) 242.0796 ($M^+$), 209, 168 and 140; $C_{12}H_{18}OS_2$ requires.242.0799).

For 2-ethyl-3-methyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): $\nu_{max}$ 1700 and 1655 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.75-3.45 (4H, m), 2.70-2.50 (4H, m), 2.35-2.05 (2H, m), 1.95-1.10 (2H, m), 1.00 (3H, s) and 1.05-0.90 (3H, m); *m/z* (CI), 242.0794 ($M^+$) and 185; $C_{12}H_{18}OS_2$ requires.242.0799.

*Cyclization of 2-propanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table III, entry i)*

Treatment of 2-propanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (1.0 g, 3.9 mmol) in

ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 3-methyl-4-propyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) as a waxy solid (0.65 g, 70%) together with 2,3-diethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) as a yellow oil (0.12 g, 13%).

For 3-methyl-4-propyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 40-41 °C; $\nu_{max}$ 1655 and 1635 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.52-3.32 (2H, m), 2.63-2.40 (4H, m), 2.35-2.10 (6H, m), 1.98-1.70 (5H, m) and 1.10 (3H, t, *J* 8 Hz); *m/z* (EI) 256. ($M^+$) 256.0957, 223, 132 and 96; $C_{13}H_{20}OS_2$ requires 256.0956.

For 2,3-diethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): $\nu_{max}$ 1710 and 1655 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.80-3.50 (2H, m), 2.85-2.55 (4H, m), 2.54-2.05 (5H, m), 1.98-1.80 (1H, m), 1.79-1.50 (2H, m) and 1.25-0.90 (6H, m); *m/z* (EI) 256.0937 ($M^+$), 146 and 71; $C_{13}H_{20}OS_2$ requires.256.0956.

*Cyclization of 2-butanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry j)*

Treatment of 2-butanoyl-2-(1-(butan-3-onyl))-1,3-dithiane (0.3 g, 1.15 mmol) in ethanol (50 ml) at room temperature as described above gave after purification by flash column chromatography 3-ethyl-4-methyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (0.16 g, 57%) together with 2-propyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) (0.07 g, 25%) as colourless crystalline solids.

For 3-ethyl-4-methyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 63-64 °C; $\nu_{max}$ 2900 and 1640 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.50-3.35 (2H, m), 2.65-2.10 (10H, m), 1.90 (3H, s) and 0.95 (3H, t, *J* 7 Hz); *m/z* (CI) 243 ($(M + H)^+$) and 137. Found: C, 59.70; H, 7.70; $C_{12}H_{18}OS_2$ requires C, 59.46; H, 7.48%.

For 2-propyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): m.p. 76-77 °C; $\nu_{max}$ 2900 and 1660 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.90 (1H, s), 3.15-3.00 (2H, m), 2.80-2.50 (6H, m), 2.35-1.70 (2H, m), 1.65-1.40 (2H, m), 1.30-1.20 (2H, m) and 1.05-0.90 (3H, m); *m/z* (CI) 243 ($(M+H)^+$) and 137. Found: C, 59.0; H, 7.60; $C_{12}H_{18}OS_2$ requires C, 59.46; H, 7.48%.

*Cyclization of 2-butanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (Table III, entry k)*

Treatment of 2-butanoyl-2-(1-(pentan-3-onyl))-1,3-dithiane (1.0 g, 3.65 mmol) in ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 3,4-diethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) as a colourless crystalline solid (0.14 g, 13%) together with 2-propyl-3-methyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) as colourless oil (0.71 g, 76%).

For 3,4-diethyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 38-39 °C; $\nu_{max}$ 2900, 1655 and 1625 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.55-3.35 (2H, m), 2.71-2.55 (4H, m), 2.50-2.05 (6H, m), 1.95-1.70 (2H, m) and 1.40-0.80 (6H, m); *m/z* (EI) 256.0952 ($M^+$), 223, 132 and 124; $C_{13}H_{20}OS_2$ requires 256.0956.

For 2-propyl-3-methyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): $\nu_{max}$ 2900, 1710 and 1640 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.70-3.50 (1H, m), 3.40-3.25 (1H, m), 2.77-2.45 (3H, m), 2.37-1.10 (10H, m) and 1.00-0.75 (5H, m); *m/z* (EI) 256.0954 ($M^+$), 203 and 146; $C_{13}H_{20}OS_2$ requires 256.0956.

*Cyclization of 2-butanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (Table III, entry l)*

Treatment of 2-butanoyl-2-(1-(hexan-3-onyl))-1,3-dithiane (1.0 g, 3.47 mmol) in ethanol (100 ml) at room temperature as described above gave after purification by flash column chromatography 3-ethyl-4-propyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (0.12 g, 11%) together with 2-propyl-3-ethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) (0.80 g, 85%) as colourless crystalline solids.

For 3-ethyl-4-propyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane): m.p. 50-52 °C;

$\nu_{max}$ 2910, 1655 and 1635 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.50-3.30 (2H, m), 2.70-2.45 (2H, m), 2.43-2.05 (9H, m), 1.95-1.70 (1H, m), 1.60-1.35 (2H, m) and 1.02-0.75 (6H, m); *m/z* (EI) 270.1108 ($M^+$), 237, 138, 132 and 110; $C_{14}H_{22}OS_2$ requires 270.1112.

For 2-propyl-3-ethyl cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane): m.p. 65-67 °C; $\nu_{max}$ 2900, 1710 and 1635 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.70-3.50 (1H, m), 3.45-3.25 (1H, m), 2.82-2.50 (3H, m), 2.42-1.15 (11H, m) and 1.10-0.80 (6H, m); *m/z* (EI) 270.1108 ($M^+$), 217 and 146; $C_{14}H_{22}OS_2$ requires 270.1112.

*Cyclization of 2-(2-methylpent-4-enoyl)-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry m)*

Treatment of 2-(2-methylpent-4-enoyl)-2-(1-(butan-3-onyl))-1,3-dithiane (13) (0.50 g, 1.75 mmol) in ethanol (50 ml) at room temperature as described above gave after purification by flash column chromatography 2-(1-(1-methylbut-3-enyl)) cyclohex-2-en-4-one spiro-1,2'-(1',3'-dithiane) as a colourless crystalline solid (0.34 g, 70%), m.p. 73-74 °C; $\nu_{max}$ 2910, 1670 and 1610 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 5.93 (1H, s), 5.85-5.70 (1H, m), 5.10-5.00 (2H, m), 3.20-3.00 (3H, m), 2.80-2.65 (4H, m), 2.60-2.50 (2H, m), 1.40-1.25 (1H, m), 2.20-2.00 (2H, m), 1.98-1.70 (1H, m) and 1.10 (3H, d, *J* 7 Hz); *m/z* (CI) 269 [$(M+H)^+$], 227 and 163. Found: C, 62.70; H, 7.50; $C_{14}H_{20}OS_2$ requires C, 62.64; H, 7.51%.

*Cyclization of 2-methoxyacetyl-2-(1-(butan-3-onyl))-1,3-dithiane (Table III, entry n)*

Treatment of 2-methoxyacetyl-2-(1-(butan-3-onyl))-1,3-dithiane (3.0 g, 12.3 mmol) in ethanol (150 ml) at room temperature as described above gave after purification by flash column chromatography 3-methoxy-4-methyl cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (2.4 g, 87%) as a colourless crystalline solid, m.p. 77-78 °C; $\nu_{max}$ 2920, 1665, 1425 and 1135 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.65 (3H, s), 3.52-3.40 (2H, m), 2.65-2.43 (4H, m), 2.25-2.14 (4H, m) and 1.92-1.85 (3H, s); *m/z* (EI) 244.0587 ($M^+$), 227, 170, 142 and 69; $C_{11}H_{16}O_2S_2$ requires 244.0591. Found: C, 53.73; H, 6.56; $C_{11}H_{16}O_2S_2$ requires C, 54.07; H, 6.60%.

*Cyclization of 2-ethanoyl-2-(1-(2-carboxymethyl)ethyl)-1,3-dithiane (6)*

Treatment of 2-ethanoyl-2-(1-(2-carboxymethyl)ethyl)-1,3-dithiane (6) (0.33 g, 1.5 mmol) in ethanol (50 ml) at room temperature as described above gave after purification by flash column chromatography cyclohexan-2,4-dione spiro-1,2'-(1',3'-dithiane) as a colourless crystalline solid (0.047 g, 16%), m.p. 139-140 °C; $\nu_{max}$ 2900 and 1600 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 3.65 (2H, s), 3.45-3.22 (2H, m), 2.80-2.60 (4H, m), 2.40-2.18 (3H, m) and 2.10-1.85 (1H, s); *m/z* (EI) 216 ($M^+$), 188 and 159. Found: C, 50.01; H, 5.62; $C_9H_{12}O_2S_2$ requires C, 49.97; H, 5.59%.

*Cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (16)*

A solution of lithium hexamethyl disilazide (1.0 M, 24.6 ml, 24.6 mmol) was added to a solution of 2-acetyl-1,3-dithiane (2.0 g, 12.3 mmol) in THF at –78 °C and the reaction was allowed to stir for two hours at –78 °C. A solution of epichlorohydrin (2.0 g, 24.6 mmol) in THF was added, the mixture stirred at –78 °C, and the reaction allowed to reach room temperature overnight. Saturated aqueous ammonium chloride was added and the mixture extracted into dichloromethane, dried over magnesium sulphate, and the solvent removed *in vacuo*. The residue was purified by column chromatography using 10% ethyl acetate/petroleum ether as eluent to give cyclohex-3-en-2-one spiro-1,2'-(1',3'-dithiane) (16) (1.94 g, 79%) as a colourless oil; $\nu_{max}$ 1690 and 1600 $cm^{-1}$; $\delta_H$ ($CDCl_3$) 7.05 (1H, d, *J* 10Hz), 5.85 (1H, d, *J* 10Hz), 3.25-3.15 (2H, m), 2.95-2.85 (4H, m), 2.70-2.60 (2H, m) and 2.20-2.10 (2H, m); *m/z* (EI) 200.0327 ($M^+$), 163 and 145; $C_9H_{12}OS_2$ requires 200.0330.

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