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Synthesis of Spirocyclic Acetals by Manganic Acetate Promoted Additions to Exocyclic Enol Ethers

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Abstract: Reaction of β-ketoesters and β-dicarbonyl compounds with manganic acetate in acetic acid gives intermediates, which add to exocyclic enol ethers to afford a variety of interesting spirocyclic acetals. As the exocyclic enol ethers are shown to be readily accessible, the results constitute a useful route based on radical chemistry to the synthesis of unsaturated spiroacetals.

The synthesis of spiroacetals has received much attention because of their pheromonal and antibiotic activity. In recent reviews[1] of the area it is interesting to recognise the paucity of routes which afford unsaturated spiroacetals. Methods for introduction of unsaturation into spiroacetal skeletons have recently been discussed[2]. In addition to the interest in antibiotic unsaturated spiroacetals such as narasin A and okadaic acid, the need for methods of synthesis, which will directly afford unsaturated spiroacetals, is further reinforced, by the isolation and characterisation of simpler unsaturated spiroketals. For example a 1,6-dioxaspiro[4,4]nona-3,8-diene[3], and a 1,6-dioxaspiro[4,5]decene[4] have been reported in *Artemisia* species. Related unsaturated spiroacetals[5] have been found in a culture broth. Earlier we have published two preliminary publications[6,7] describing the manganic acetate promoted addition of β–dicarbonyl compounds to electron rich exocyclic- and endocyclic- alkenes. In the former case spirocyclic systems were generated, and in the latter case fused heterocycles were obtained. Three types of spirocycle were prepared, oxaspirolactones[6] from exocyclic unsaturated lactones, unsaturated spiroacetals[6] from exocyclic enol ethers, and a variety of spirocyclic hemithioacetals and other thiaspirocycles from exocyclic vinyl sulphides[7]. We have subsequently generalised these routes to diverse heterocyclic systems. In the preceeding papers we describe in detail the preparation of oxaspirolactones[8], and fused acetals and ketals[9]. In this paper we report a general procedure based on radical chemistry, which readily affords a series of unsaturated spiroacetals. It has recently been noted[10] that none of the general strategies for synthesis of spiroacetals relied upon radical mediated cyclizations. Aside from our earlier preliminary papers, this recent study[10] provides a new radical route to spiroacetals.

Recently methods have been described for the preparation of the exocyclic enol ethers (7) and (9) by iodocyclisations. In the former case the ester (1) has been shown in a preliminary communication[11] to afford the

Table 1

Synthesis of Spirocyclic Acetals

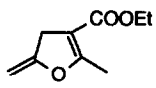
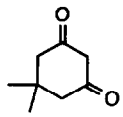
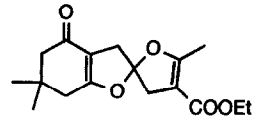
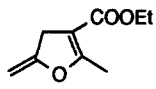
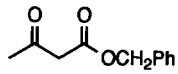
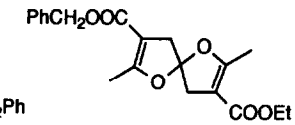
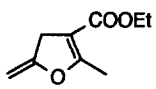
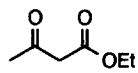
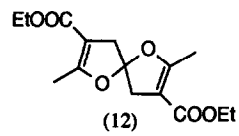
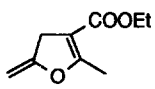
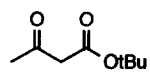
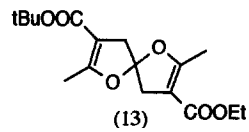
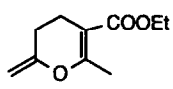
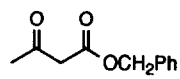
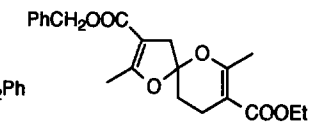
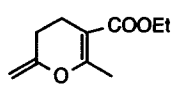
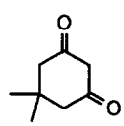
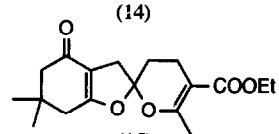
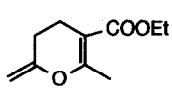
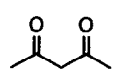
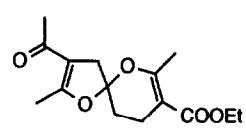
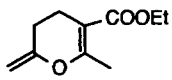
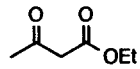
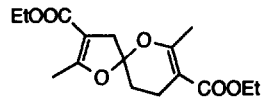
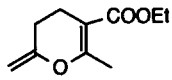
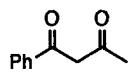
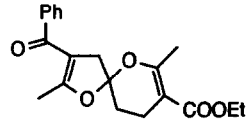
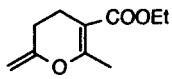
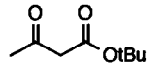
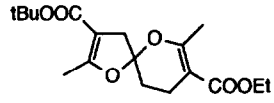
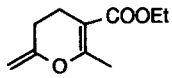
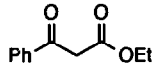
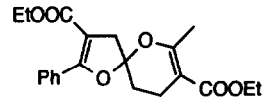
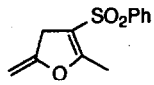
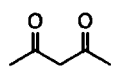
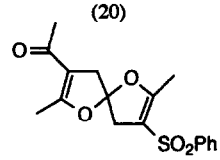
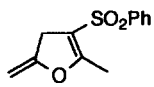
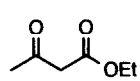
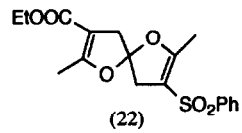
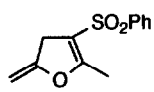
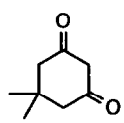
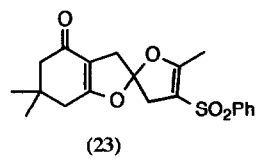
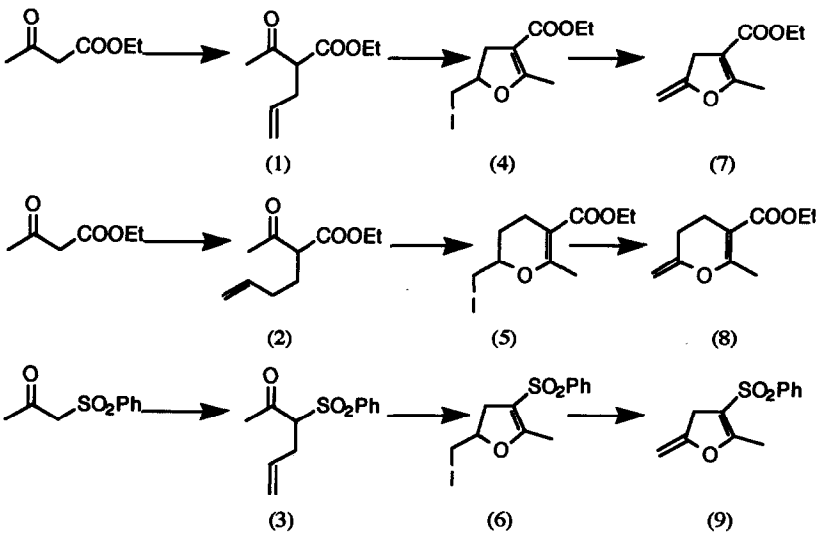
Reactants		Product	Yield (%)
 (7)		 (10)	43
 (7)		 (11)	40
 (7)		 (12)	37
 (7)		 (13)	11
 (8)		 (14)	61
 (8)		 (15)	69
 (8)		 (16)	66

Table 1 (continued)

Reactants		Product	Yield (%)
 (8)		 (17)	58
 (8)		 (18)	33
 (8)		 (19)	44
 (8)		 (20)	41
 (9)		 (21)	36
 (9)		 (22)	28
 (9)		 (23)	30



iodide (4) in good yield. Elimination was shown to give the exocyclic enol ether (7). In a very similar procedure[12] cyclisation of the sulfone (3), and subsequent elimination of the intermediate iodide (6) was reported to afford the second enol ether (9). In both studies the isomerisation of the exocyclic compounds afforded furans readily. Although it was considered likely that the two enol ethers might be sufficiently stable in acetic acid, the normal medium for manganese acetate promoted additions, it was considered to be prudent to study a third enol ether (8). In this third case isomerisation would not afford an aromatic system, and hence a comparison with the other two ethers (7) and (9) might be informative. The three ethers (7-9) were obtained without difficulty. Recent improvements in the methodology[13] for alkylation of β-dicarbonyl compounds, coupled with the efficient iodocyclisations and eliminations, described fully below, permit the easy preparation of the ethers (4-6). Thus iodocyclisation of the ester (1) gives the iodide (4) in 89% yield. Subsequent elimination using DBU gives the unsaturated ester (7) in 73% yield. In a similar manner the ester (2) is converted via the iodide (5) to the unsaturated ester (8). The sulfone (9) was prepared via successive alkylation (85% yield) to give the unsaturated sulfone (3), iodocyclisation (71% yield) to give the iodide (6), and finally elimination (61% yield) with DBU.

The unsaturated esters (7) and (8), and the sulfone (9) were found to be moderately acid sensitive. They may be purified by chromatography over silica gel without difficulty. They are stable to acetic acid at room temperature.

The result of reaction of the three exocyclic alkenes (7-9) with a variety of β-dicarbonyl compounds is shown in the Table. When reaction with manganic acetate is carried out in acetic acid at 60°C, products are typically isolated following work up and chromatography in 35-60% yield. The tricyclic product (10) obtained by reaction of the alkene (7) with dimedone shows a characteristic resonance associated with the spiro centre at 102.67ppm. Related spiroacetals[14], for example have a resonance associated with the spiro centre at a similar position (101.7-105.25ppm). The observation of a long range coupling (J 1.7Hz) between the protons of the methylene group and the allylic protons of the methyl group is a characteristic of most of the spirocycles. In each of the products (10-23) shown in the Table similar spectroscopic features permit ready structural identification. In the

case of the addition of benzoylacetone two products might be envisaged depending upon the course of the final cyclisation. Observation of the long range coupling to both methyl groups in the product (18) enables the alternative product carrying a pendant acetyl group to be excluded. Therefore in each of the 14 examples shown in the Table elaboration of the exocyclic double bond by the manganic acetate oxidation of a β-dicarbonyl substrate permits the generation of interestingly substituted spirocyclic acetals. We have established that these acetals are sufficiently stable to enable subsequent transformations without skeletal changes, for example bromination. Hence these readily available acetals have a promise both in terms of the synthesis of compounds exhibiting spirocyclic conjugation and in the synthesis of unsaturated naturally occurring spiroacetals. The methodology is valuable in affording spirocycles with unsaturation in both rings. Other methods permit spirocycle formation with one ring unsaturated. The combination of the incorporation of unsaturation in two rings, and the diversity of side chain functionality, gives this synthetic methodology a unique advantage relative to earlier spiroacetal syntheses.

Experimental

General procedures have been described elsewhere[8].

Preparation of 3-Ethoxycarbonylhex-5-en-2-one (1).

Allyl bromide (16.72g) and potassium carbonate (11.34g) were added to a stirred solution of ethyl acetoacetate (15.0g) in acetonitrile (100ml). The resulting heterogeneous mixture was stirred at room temperature for 24h. Water (50ml) and ether (30ml) were added and the organic phase was separated. The aqueous layer was further extracted with ether (3x30ml). The combined organic extracts were washed with water (50ml) and brine (2x20ml), dried ($MgSO_4$), filtered and evaporated under reduced pressure to afford an oil. Distillation of this oil afforded the title compound[11] (1) (14.8g, 75.4% yield) b.p. 65-68°C at 0.8mm Hg, ν_{max} ($CHCl_3$) 3010, 1750, 1725 and 1655cm $^{-1}$; δ_H 1.25 (3H, t, J7, CH_2CH_3), 2.24 (3H, s, $COCH_3$), 2.60 (2H, t, J7 $CHCH_2$), 3.56 (1H, t, J7, CH), 4.22 (2H, q J7, OCH_2), 5.00-5.14 (2H, m, CH_2), 5.75 (1H, m, =CH); δ_C 14.24 (CH_3), 29.25 ($COCH_3$), 32.29 (CH_2), 59.35 (CH), 61.56 (OCH_2), 117.59 (=CH_2), 134.35 (C=CH), 169.36 (CO), 202.65 ($COCH_3$)

Preparation of 3-Ethoxycarbonylhept-6-en-2-one (2).

Reaction of 1-bromobut-3-ene with ethyl acetoacetate as described above afforded the crude ester (2). Purification by flash chromatography [silica gel: eluant ethyl acetate: petrol (1:9)] afforded as a colourless oil the title compound (2) (5.2g, 45% yield), ν_{max}. ($CHCl_3$) 3010, 1750, 1725 and 1660cm.$^{-1}$; δ_H 1.22 (3H, t J7, CH_2CH_3), 1.84-2.18 (4H, m, CH_2CH_2), 2.22 (3H, s, CH_3), 3.48 (1H, t, J7, CH), 4.18 (2H, q J7, CH_2CH_3), 5.14 (2H, m, C=CH_2), and 5.78 (1H, m, CH=C); δ_C 14.27 (CH_3), 27.28 (CH_2), 29.18 (CH_3), 31.53 (CH_2), 59.03 (CH), 61.53 (OCH_2), 116.16 (=CH_2), 137.18 (=CH), 169.91(CO) and 203.30 ($COCH_3$).

Preparation of 3-Phenylsulfonylhex-5-en-2-one (3).

Allyl bromide (2.68g) and potassium carbonate (1.98g) were added to a stirred solution of 1-phenylsulphonylpropan-2-one (4.0g) in acetonitrile (100ml). The resulting heterogeneous mixture was stirred at room temperature for 24h. Water (50ml) and ether (30ml) were added and the organic phase was separated. The

aqueous layer was further extracted with ether (3x30ml). The combined organic extracts were washed with water (50ml) and brine (2x20ml), dried ($MgSO_4$) filtered, and evaporated under reduced pressure to afford a yellow oil. Flash chromatography [silica gel: eluant ethyl acetate: petrol (1:9)] gave as an oil the title compound[12] (3) (4.0g, 85% yield), ν_{max} ($CHCl_3$) 3010, 1735, 1670, 1630 and 1600cm.$^{-1}$; δ_H 2.38 (3H, s, CH_3), 2.64 (2H, m, CH_2), 4.20 (1H, dd J 5.5 and 3.7, COCH), 5.01-5.08 (2H, m, C=CH_2). 5.58 (1H, m, C=CH), 7.6-7.8 (5H, complex, Ar); δ_C 31.00 (CH_2), 31.90 (CH_3), 74.77 (CH), 119.13 (C=CH_2), 129.26, 131.70, 134.52, and 136.43 (CH and Ar), 199.56 (CO); m/z 238 (M^+) (100%) (Found: M^+, 238.0653. $C_{12}H_{14}O_3S$ requires M^+, 238.0663).

Preparation of 3-Ethoxycarbonyl-5-iodomethyl-2-methyl-4,5-dihydrofuran (4).

Iodine (46.0g) and sodium hydrogen carbonate (8.3g) were added in one portion to a stirred solution of 3-ethoxycarbonylhex-5-en-2-one (1) (14.0g) in acetonitrile (50ml). The resulting heterogeneous mixture was efficiently stirred at room temperature for 18h. Ether (100ml) and saturated aqueous sodium thiosulfate solution (60ml) were added, the solution well shaken to remove iodine and the phases were separated. The aqueous phase was further extracted with ether (2x25ml). The combined organic extracts were washed with water (50ml) and brine (50ml), dried ($MgSO_4$) filtered, and evaporated under reduced pressure to afford an oil, which slowly crystallised. Recrystallisation (ether-pentane) afforded the title compound[11] (4) (21.8g, 89.4% yield) m.p. 62-64°C, ν_{max} ($CHCl_3$) 3010, 1699 and 1655 cm.$^{-1}$; δ_H 1.33 (3H, t J7, CH_2CH_3), 2.18 (3H, s, =CCH_3), 2.65 (1H, m) and 3.05 (1H, m) (CH_2), 3.32 (2H, m, CH_2I), 4.18 (2H q J 5, OCH_2) and 4.70 (1H, m, CHO); δ_C 8.84 (CH_2I), 14.24 (CH_2CH_3), 14.60 (=CCH_3), 36.19 (C=CH_2), 59.78 (OCH_2), 80.64 (CH), 101.96 (CCOOEt), 165.99 (C) and 167.35 (CO) m/z 296 (M^+) (100%) (Found: M^+ 295.9902. $C_9H_{13}IO_3$ requires 295.9909).

Preparation of 3-Ethoxycarbonyl-6-iodomethyl-2-methyl-5,6-dihydro-4H-pyran (5).

Reaction of 3-ethoxycarbonylhept-6-en-2-one (2) with iodine, as described above, afforded after purification by flash chromatography [silica gel: eluant ether: petrol (1:6)] as an oil the title compound (5) δ_H 1.26 (3H, t, J 7, CH_2CH_3), 1.68 (2H, m, CH_2), 2.08 (1H, m) and 2.39 (1H, m) (CH_2), 2.24 (3H, s, CCH_3), 3.32 (2H, m, CH_2I), 3.95 (1H, m, CH), 4.18 (2H, q, J 7, OCH_2); δ_C 7.31 (CH_2I), 14.55 (CH_3), 20.24 ($COCH_3$), 20.96 (CH_2), 26.78 (CH_2), 59.88 (CH_2O), 75.21 (CH), 101.57 (*C*COOEt), 164.65 (C=*C*O) and 168.35 (CO); m/z 310 (M^+) (50%) (Found: M^+ 310.0059 $C_{10}H_{15}IO_3$ requires 310.0065).

Preparation of 5-Iodomethyl-2-methyl-3-phenylsulfonyl-4,5-dihydrofuran (6).

Iodine (8.45g) and sodium hydrogen carbonate (1.52g) were added in one portion to a stirred solution of the sulfone (3) (3.6g) in acetonitrile (20ml). The resulting heterogeneous mixture was efficiently stirred at room temperature for 18h in the dark. Ether (100ml) and saturated aqueous sodium thiosulfate solution (60ml) were added, the solution well shaken to remove iodine and the phases were separated. The aqueous phase was further extracted with ether (2x50ml). The combined organic extracts were washed with water (50ml) and brine (50ml), dried ($MgSO_4$) filtered, and evaporated under reduced pressure to afford an oil. Flash chromatography [silica gel: eluant ethyl acetate: petrol (1:6) gave as an oil the title compound[12] (6) (3.94g, 71% yield), ν_{max} ($CHCl_3$) 3015

and 1650 cm.$^{-1}$; δ_H 2.23 (3H, s, CH_3), 2.62 (1H, m) and 3.02 (1H, m) (CH_2), 3.22 (2H, m, CH_2I), 4.54 (1H, m, CH) and 7.6-7-85 (5H, m, Ar); δ_C 8.33 (CH_2I), 13.30 (CCH_3), 36.53 (CH_2), 79.99 (CH), 108.57 (C=CSO_2), 126.86, 129.22 and 132.99 (CHAr), 141.60 (CSO_2) and 165.39 (C=CO); m/z 364 (M^+) (100%) (Found: M^+ 363.9630. $C_{12}H_{13}IO_3S$ requires M^+ 363.9630).

Preparation of 3-Ethoxycarbonyl-2-methyl-5-methylene-4,5-dihydrofuran (7).

DBU (12.36g) was added to a stirred solution of the iodide (4) (20.0g) in benzene (150ml). The resulting solution was stirred at room temperature for 24h., filtered and the filtrate evaporated under reduced pressure. The residue was partitioned between water (30ml) and ether (50ml), and the aqueous phase was further extracted with ether (2x20ml). The combined organic extracts were washed with water (20ml) and brine (2x20ml), dried ($MgSO_4$) filtered, and evaporated under reduced pressure to afford an oil. Flash chromatography [silica gel: eluant ethyl acetate: petrol (2:25) gave as an oil the title compound[11] (7) (8.3g, 73% yield), ν_{max} ($CHCl_3$) 3000-2990, 1700 and 1670 cm.$^{-1}$; δ_H 1.29 (3H, t, J 7, OCH_2CH_3), 2.24 (3H, t, J 1.9 CCH_3), 3.58 (2H, m CCH_2), 4.18 (2H, q J 7, OCH_2), 4.25 (1H, m) and 4.60 (1H, m) C=CH_2); δ_C 13.73 (CH_3), 14.47 (CH_3), 33.47 (CH_2), 60.31 (OCH_2), 85.95 (C=CH_2), 112.07 (C=CCOOEt), 159.95 (C=CO), 164.91 (C=CCH_3) and 165.87 (CO).

Preparation of 3-Ethoxycarbonyl-2-methyl-6-methylene-5,6-dihydro-4H-pyran (8). Reaction of the iodide (5) with DBU, as described above, with the modification of heating under reflux for 2h., and subsequent purification by flash chromatography [silica gel: eluant ether: petrol (1:4)] afforded as a colourless oil in 46% yield the title compound (8), ν_{max} ($CHCl_3$) 3010-3000, 1695, 1675 and 1650 cm.$^{-1}$; δ_H 1.31 (3H, t, J 7, CH_2CH_3), 2.24 (3H, s, CCH_3), 2.42 (4H, s, CH_2), 4.18-4.21(3H, complex, OCH_2 and C=CH_2), 4.58 (1H, d, J 1, C=CH_2); δ_C 14.48 (CH_3), 19.59 (CH_3), 21.61 (CH_2), 25.50 (CH_2), 60.02 (OCH_2), 91.17 (=CH_2), 103.00 (C=CCOOEt), 155.41 (H_2C=CO), 161.88 (CH_3CO) and 167.88 (CO); m/z 182 (M^+) (100%) (Found: M^+ 182.0955. $C_{10}H_{14}O_3$ requires M^+ 182.0942).

Preparation of 2-Methyl-5-methylene-3-phenylsulfonyl-4,5-dihydrofuran (9).

DBU (1.60g) was added to a stirred solution of the iodide (6) (3.2g) in benzene (35ml). The resulting solution was stirred at room temperature for 24h., and then evaporated under reduced pressure. The residue was partitioned between water (30ml) and ether (50ml), and the aqueous phase was further extracted with ether (2x20ml). The combined organic extracts were washed with water (20ml) and brine (2x20ml), dried ($MgSO_4$) filtered, and evaporated under reduced pressure to afford an oil. Flash chromatography [silica gel: eluant ethyl acetate: petrol (1:6) gave as an oil the title compound[12] (9) (0.8g, 61% yield), ν_{max} ($CHCl_3$) 3020-2930, 1650, 1620 and 1585 cm.$^{-1}$; δ_H 2.32 (3H, t J 1.7, CH_3), 3.56 (2H, m, (CH_2), 4.26 (1H, m) and 4.64 (1H, m) (C=CH_2), 7.55-7.65(3H, m, Ar) and 7.85-7.95(2H, m, Ar); δ_C 12.88 (CH_3), 33.83 (CH_2), 87.47 (CH_2), 110.98 (C=CSO_2), 126.92, 129.34 and 133.25 (CH Ar), 141.26 (CSO_2), 157.62 (C=CO), 163.89 (C=CCH_3); m/z 236 (M^+) (100%) (Found: M^+ 236.0511. $C_{12}H_{12}O_3S$ requires M^+ 236.0507).

General Procedure for Synthesis of the Spiroheterocycles.

Manganese (3) acetate dihydrate (2.0-3.0mmol) was heated in acetic acid (20ml) under nitrogen at 60-70°C until a black homogeneous solution was obtained. The β-dicarbonyl compound (0.8-1.5mmol) and the alkene (1.0mmol) were added and the reaction mixture was kept at 60°C until the colour had disappeared (10-120 min). To the cold mixture water (50ml) was added and the solution was extracted with dichloromethane (3x25ml). The combined organic extracts were washed with saturated sodium bicarbonate solution and evaporated under reduced pressure to give an oil. Products were purified by flash chromatography on either silica gel or deactivated basic alumina. The following compounds were obtained in the above manner.

4'-Ethoxycarbonyl-6,6,5'-trimethyl-4,5,6,7-tetrahydrospiro[benzofuran-2(3H),2'(3'H)-furan-4-one] (10)

Dimedone (0.49g), the alkene (7) (0.5g), manganese acetate (1.97g) and potassium acetate (0.72g) in acetic acid (15ml) afforded after chromatography on silica gel as an oil the title compound (10) (0.39g, 43% yield), ν_{max} ($CHCl_3$) 2950, 1700 and 1650 $cm.^{-1}$; δ_H 1.04 (3H, s, CH_3), 1.08 (3H, s, CH_3), 1.30 (3H, t, J 7, CH_2CH_3), 2.21 (3H, t, J 1.7, CH_3), 2.21-2.41 (4H, m, 2xCH_2), 2.96-3.31 (4H, m, 2xCH_2) and 4.18 (2H, J 7, CH_2CH_3); δ_C 14.08 (CH_3), 14.55 (CH_3), 28.53 (CH_3), 29.23 (CH_3), 34.32 (CMe_2), 36.97 (CH_2), 37.59 (CH_2), 41.29 (CH_2), 51.10 (CH_2), 60.04 (CH_2), 102.67 (OCO), 111.18 (*C*CO), 119.23 (*C*CO), 165.03 (C=*C*O), 165.25 (CO), 173.57(C=*C*O) and 194.49 (CO); m/z: M^+ 306 (99%) (Found: M^+ 306.1464. $C_{17}H_{22}O_5$ requires M^+ 306.1464)

3-Benzyloxycarbonyl-2,7-dimethyl-8-ethoxycarbonyl-1,6-dioxaspiro[4,4]nona-2,7-diene (11)

Benzyl acetoacetate (0.2g), the alkene (7) (0.88g) and manganese acetate (0.83g) in acetic acid (15ml) afforded after chromatography on silica gel as an oil the title compound (11) (0.14g, 40% yield), ν_{max} ($CHCl_3$) 3005-2995, 1695 and 1660 $cm.^{-1}$; δ_H 1.31 (3H, t, J 7, CH_3), 2.23 (6H, m, 2xCH_3), 3.01-3.30 (4H, m, 2xCH_2), 4.18 (2H, q, J 7, OCH_2) 5.19 (2H, s, OCH_2Ph) and 7.3-7.4 (5H, m, Ar); δ_C 14.15 (CH_3), 14.28 (CH_3), 14.58 (CH_3), 40.74 (CH_2), 40.84 (CH_2), 59.97 (OCH_2), 65.75 (OCH_2Ph), 102.25 (OCO), 111.77 (C=*C*CO), 116.23 (C=*C*CO), 128.18, 128.24 and 128.70 (CHAr), 136.52 (CAr), 164.90 (C=*C*O), 165.20 (C=*C*O), 165.29 (CO) and 165.99 (CO); m/z: M^+ 358 (23%) (Found: M^+ 358.1405. $C_{20}H_{22}O_6$ requires M^+ 358.1416)

3,8-Diethoxycarbonyl-2,7-dimethyl-1,6-dioxaspiro[4,4]nona-2,7-diene (12)

Ethyl acetoacetate (0.46g), the alkene (7) (0.5g) and manganese acetate (2.3g) in acetic acid (15ml) afforded after chromatography on silica gel as an oil the title compound (12) (0.18g, 37% yield) ν_{max} ($CHCl_3$) 2990, 1699 and 1660 $cm.^{-1}$; δ_H 1.26 (6H, t, J 7, 2xCH_3), 2.23 (6H, t, J 1.9, 2xCH_3), 3.05 (2H, dq, J 16.4, 1.7) and 3.20 (2H, dq, J 16.4 and 1.7 2xCH_2) and 4.19 (4H, q, J 7, 2xOCH_2); δ_C 14.14 (CH_3), 14.62 (CH_3), 40.87 (CH_2), 60.01 (CH_2), 102.27 (OCO), 116.19 (C=*C*CO), 165.30 (C=*C*O) and 165.39 (CO) ; m/z: M^+ 296 (25%) (Found: M^+ 296.1248. $C_{15}H_{20}O_6$ requires M^+ 296.1259)

3-t-Butoxycarbonyl-2,7-dimethyl-1,6-dioxaspiro[4,4]nona-2,7-diene (13)

t-Butylacetoacetate (0.34g), the alkene (7) (0.5g) and manganese acetate (2.36g) in acetic acid (15ml) afforded after chromatography on silica gel as an oil the title compound (13) (0.09g), 11% yield), ν_{max} ($CHCl_3$) 3010-2990, 1710-1705 and 1670-1660 $cm.^{-1}$; δ_H 1.28 (3H, t, J 7, CH_3), 1.52 (9H, s, 3xCH_3), 2.19 (3H, s, CH_3), 2.32 (3H, s, CH_3), 2.98-3.22 (4H, m, 2xCH_2) and 4.18 (2H, q, J 7, OCH_2); δ_C 14.15 (CH_3), 14.21 (CH_3), 14.61 (CH_3), 28.53(3xCH_3), 40.81 (CH_2), 41.19 (CH_2), 59.94 (OCH_2), 80.27 (CMe_3), 102.19 (OCO), 103.69 (C=*C*CO), 115.90 (C=*C*CO), 164.10 (C=*C*O), 164.71 (C=*C*O),165.30 (CO) and 165.36 (CO) ; m/z: M^+338 (5%) (Found: M^+ 338.1715. $C_{18}H_{26}O_6$ requires M^+ 338.1729)

3-Benzyloxycarbonyl-2,7-dimethyl-8-ethoxycarbonyl-1,6-dioxaspiro[4.5]deca-2,7-diene (14)

Benzyl acetoacetate (0.4g), the alkene (8) (0.5g) and manganese acetate (1.76g) in acetic acid (15ml) afforded after chromatography on basic alumina as an oil the title compound (14) (0.48g, 61% yield), ν_{max} ($CHCl_3$) 3010-2995, 1720-1715 and 1660 $cm.^{-1}$; δ_H 1.31 (3H, t, J 7, CH_3), 1.88 (1H, m) and 2.21 (1H, m) (CH_2), 2.21 (6H, s, 2xCH_3), 2.45 (2H, m, CH_2), 2.90 (1H, dq, J 16.1, 1.7) and 3.04 (1H, dq, J 16.1and 1.7) (CH_2), 4.18 (2H, q, J 7, OCH_2) 5.20 (2H, s, CH_2OPh) and 7.35-7.45 (5H, m, Ar); δ_C 14.35 (CH_3), 14.51 (CH_3), 18.66 (CH_2), 20.02 (CH_3), 29.84 (CH_2), 41.36 (CH_2), 60.07 (OCH_2), 65.67 (OCH_2Ph), 101.61 (C=*C*CO),102.44 (OCO), 107.61 (C=*C*CO), 128.18 and 128.66 (CHAr), 136.56 (CAr), 161.13 (C=*C*O), 165.30 (C=*C*O), 166.08 (CO) and 168.04 (CO) ; m/z: M^+372 (5%) (Found: M^+ 372.1562. $C_{21}H_{24}O_6$ requires M^+ 372.1572)

5'-Ethoxycarbonyl-6,6,6'-trimethyl-4,5,6,7-hexahydrospiro[benzofuran-2(3H),2'(3'H)-pyran-4-one] (15)

Dimedone (0.17g), the alkene (8) (0.3g) and manganese acetate (1.32g) in acetic acid (15ml) afforded after chromatography on basic alumina as an oil the title compound (15) (0.36g, 69% yield), ν_{max} ($CHCl_3$) 3010-2990, 1715 and 1655 $cm.^{-1}$; δ_H 1.10 (3H, s, CH_3), 1.15 (3H, s, CH_3), 1.32 (3H, t, J 7, CH_2CH_3), 1.90 (1H, m) and 2.15 (1H, m) (CH_2), 2.2-2.4 (4H, m, 2xCH_2) 2.22 (3H, t, J 1.7, CH_3), 2.52 (2H, m, CH_2) 2,83 (1H, dq, J 14.7 and 1.7) and 2.98 (1H, dq, J 14.7 and 1.7) (CH_2) and 4.18 (2H, q, J 7, OCH_2); δ_C 14.52 (CH_3), 18.57 (CH_2), 19.94 (CH_3), 28.58 (CH_3), 29.15 (CH_3), 29.90 (CH_2), 34.32 (CMe_2), 37.75 (CH_2), 51.07 (CH_2), 60.17 (OCH_2), 102.82 (OCO), 110.93 (C=*C*CO), 111.11 (C=*C*CO), 160.85 (C=*C*O), 167.92 (C=*C*O), 173.68 (CO) and 194.81 (CO) ; m/z: M^+320 (6%) (Found: M^+ 320.1628. $C_{18}H_{24}O_5$ requires M^+ 320.1624)

3-Acetyl-2,7-dimethyl-8-ethoxycarbonyl-1,6-dioxaspiro[4,5]deca-2,7-diene (16)

Acetylacetone (0.12g), the alkene (8) (0.3g) and manganese acetate (1.32g) in acetic acid (15ml) afforded after chromatography on basic alumina a white solid. Recrystallisation (dichloromethane-pentane) gave as needles the title compound (16) (0.22g, 66% yield) m.p. 95-96°C (Found: C, 64.0; H, 7.15. $C_{15}H_{20}O_5$ requires C, 64.3; H, 7.2%), ν_{max} ($CHCl_3$) 3010-2990, 1720-1700 and 1650 $cm.^{-1}$; δ_H 1.28 (3H, t, J 7, CH_3), 1.88 (1H, m) and 2.10 (1H, m) (CH_2), 2.22 (6H, s, 2xCH_2), 2.24 (3H, t, J 1.7, CH_3), 2.50 (2H, m CH_2), 2.95 (1H, dq,J 15.6 and 1.7) and 3.09 (1H, dq, J 15.6 and 1.7) (CH_2) and 4.18 (2H, q, J 7, OCH_2); δ_C 14.49 (CH_3), 15.11

(CH_3), 18.64 (CH_2), 20.00 (CH_3), 29.61 (CH_3), 29.83 (CH_2), 42.03 (CH_2), 60.08 (OCH_2), 102.50 (OCO), 107.35 (C=*C*CO), 111.81 (C=*C*CO), 161.04 (C=*C*O), 164.91 (C=*C*O), 168.00 (CO) and 194.26 (CO); m/z: M^+ 280 (6%) (Found: M^+ 280.1311. $C_{15}H_{20}O_5$ requires M^+ 280.1310)

3,8-Diethoxycarbonyl-2,7-dimethyl-1,6-dioxaspiro[4,5]deca-2,7-diene (17)

Ethyl acetoacetate (0.16g), the alkene (8) (0.3g) and manganese acetate (1.32g) in acetic acid (15ml) afforded after chromatography on basic alumina a white solid. Recrystallisation (dichloromethane-pentane) gave as white prisms the title compound (17) (0.21g, 58% yield) m.p. 138-139°C (Found: C, 61.7; H, 7.4. $C_{16}H_{22}O_6$ requires C, 61.9; H, 7.2%), ν_{max} ($CHCl_3$) 3010-2995, 1715 and 1655 cm. $^{-1}$; δ_H 1.25 (3H, t, J 7, CH_2CH_3), 1.26 (3H, t, J 7, CH_2CH_3), 1.86 (1H, m) and 2.10 (1H, m) (CH_2), 2.23 (6H, s, 2xCH_3), 2.52 (2H, m, CH_2), 2.90 (1H, dq, J 16.0 and 1.7) and 3.00 (1H, dq, J 16.0, 1.7) (CH_2) and 4.19 (4H, q, J 7, 2xOCH_2); δ_C 14.24 (CH_3), 14.51 (CH_3), 14.57 (CH_3), 18.70 (CH_2), 20.04 (CH_3), 29.86 (CH_2), 41.44 (CH_2), 59.84 (OCH_2), 60.05 (OCH_2), 101.91 (C=*C*CO), 102.41 (OCO), 107.51 (C=*C*CO), 161.17 (C=*C*O), 165.40 (C=*C*O), 165.61 (CO) and 168.07 (CO); m/z: M^+ 310 (9%) (Found: M^+ 310.1427. $C_{16}H_{22}O_6$ requires M^+ 310.1416)

3-Benzoyl-8-ethoxycarbonyl-2,7-dimethyl-1,6-dioxaspiro[4,5]deca-2,7-diene (18)

Benzoylacetone (0.2g), the alkene (8) (0.3g) and manganese acetate (1.32g) in acetic acid (15ml) afforded as an oil the title compound (18) (0.14g, 33% yield), ν_{max} ($CHCl_3$) 3010-2995, 1715 and 1655 cm. $^{-1}$; δ_H 1.28 (3H, t, J 7, CH_2CH_3), 1.95 (1H, m) and 2.22 (1H, m) (CH_2), 2.03 (3H, s, CH_3), 2.30 (3H, s, CH_3), 2.52 (2H, m, CH_2), 3.14 (1H, dq, J 16.5, 1.7) and 3.24 (1H, dq, J 16.5 and 1.7) (CH_2), 4.18 (2H, q, J 7, OCH_2) and 7.4-7.6 (5H, m, Ar); δ_C 14.52 (CH_3), 18.71 (CH_2), 20.04 (CH_3), 29.18 (CH_3), 29.79 (CH_2), 42.86 (CH_2), 60.11 (OCH_2), 102.61 (OCO), 107.16 (C=*C*CO), 114.12 (C=*C*CO), 128.49, 129.52 and 130.96 (CHAr), 130.56 (CAr), 161.14 (C=*C*CO), 163.40 (C=*C*CO), 168.07 (CO) and 194.56 (CO); m/z: M^+ 342 (9%) (Found: M^+ 342.1467. $C_{20}H_{22}O_5$ requires M^+ 342.1467)

3-t-Butoxycarbonyl-2,7-dimethyl-8-ethoxycarbonyl-1,6-dioxaspiro[4,5]deca-2,7-diene (19)

t-Butyl acetoacetate (0.13g), the alkene (8) (0.2g) and manganese acetate (1.32g) in acetic acid (15ml) afforded as an oil the title compound (19) (0.12g, 44% yield) ν_{max} ($CHCl_3$) 3010-2995, 1710, 1680 and 1655 cm.$^{-1}$; δ_H 1.22 (3H, t, J 7, CH_3), 1.48 (9H, s, 3xCH_3), 1.84 (1H, m) and 2.08 (1H, m) (CH_2), 2.18 (3H, t, J 1.9, CH_3), 2.23 (3H, t, J 1.9, CH_3), 2.52 (2H, m, CH_2), 2.86 (1H, dq, J 16.5 and 1.7) and 2.97 (1H, dq, J 16.5 and 1.7) (CH_2), and 4.18 (2H, q, J 7, OCH_2); δ_C 14.24 (CH_3), 14.55 (CH_3), 18.73 (CH_2), 20.11 (CH_3), 28.53 (3xCH_3), 29.93 (CH_2), 41.77 (CH_2), 60.07 (OCH_2), 80.11 (*C*Me_3), 102.37 (OCO), 103.30 (C=*C*CO), 107.21 (C=*C*CO), 161.30 (C=*C*CO), 164.21 (C=*C*CO), 165.21 (CO) and 168.17 (CO) ; m/z: M^+ 338 (5%) (Found: M^+ 338.1715. $C_{18}H_{26}O_6$ requires M^+ 338.1729)

3,8-Diethoxycarbonyl-7-methyl-2-phenyl-1,6-dioxaspiro[4,5]deca-2,7-diene (20)

Ethyl benzoylacetate (0.2g), the alkene (8) (0.23g) and manganese acetate (1.32g) in acetic acid (15ml) afforded as an oil the title compound (20) (0.16g, 41% yield), ν_{max} ($CHCl_3$) 3010-2995, 1710 and 1655 cm.$^{-1}$; δ_H 1.22

(3H, t, J 7, CH_3), 1.30 (3H, t, J 7, CH_3), 1.93 (1H, m) and 2.18 (1H, m) (CH_2), 2.22 (3H, s, CH_3), 2.52 (2H, m, CH_2), 3.11 (1H, d, J 16.8) and 3.28 (1H, d, J 16.8) (CH_2), 4.18 (4H, q, J 7, 2xCH_2), 7.35-7.45 (3H, m, Ar) and 7.8 (2H, m, Ar); δ_C 14.38 (CH_3), 14.52 (CH_3), 18.79 (CH_2), 20.07 (CH_3), 29.82 (CH_2), 43.10 (CH_2), 60.10 (OCH_2), 60.17 (OCH_2), 102.24 (C=*C*CO), 102.47 (OCO), 106.67 (C=*C*CO), 127.80, 129.11 and 130.70 (CHAr), 129.51 (CAr), 161.27 (C=*C*CO), 162.42 (C=*C*CO), 164.79 (CO) and 168.14 (CO); m/z: M^+ 324 (34%) (Found: M^+ 324.1576. $C_{17}H_{24}O_6$ requires M^+ 324.1573)

8-Acetyl-2,7-dimethyl-3-phenylsulfonyl-1,6-dioxaspiro[4,4]nona-2,7-diene (21)

Acetylacetone (0.24g), the alkene (9) (0.2g) and manganese acetate (0.65g) in acetic acid (15ml) afforded as an oil the title compound (21) (0.13g), 36% yield), ν_{max} ($CHCl_3$) 3000-2990, 1690 and 1655-1630 $cm.^{-1}$; δ_H 2.20 (6H, s, 2xCH_3), 2.32 (3H, t, J 1.9, CH_3), 3.05-3.30(4H, m, 2xCH_2), 7.45-7.65 (3H, m, Ar) and 7.85-7.90 (2H, m, Ar); δ_C 13.37 (CH_3), 14.91 (CH_3), 29.64 ($COCH_3$), 40.96 (CH_2), 41.49 (CH_2), 109.15 (OCO), 112.17 (*C*=CO), 115.47 (CSO_2Ph), 127.00, 129.48 and 133.34 (CHAr), 141.65 (CSO_2), 163.50 (C=*C*O), 164.48 (C=*C*O) and 193.76 (CO); m/z: M^+ 334 (38%) (Found: M^+ 334.0861 $C_{17}H_{18}O_5S$ requires M^+ 334.0908)

2,7-Dimethyl-3-ethoxycarbonyl-8-phenylsulfonyl-1,6-dioxaspiro[4,4]nona-2,7-diene (22)

Ethyl acetoacetate (0.08g), the alkene (9) (0.08g) and manganese acetate (0.27g) in acetic acid (8ml) afforded as an oil the title compound (22) (0.015g, 28% yield); ν_{max} ($CHCl_3$) 3020, 1710 and 1655 $cm.^{-1}$; δ_H 1.28 (3H, t, J 7, CH_3), 2.19 (3H, t, J 1.9, CH_3), 2.30 (3H, t, J 1.9, CH_3), 2.98-3.20 (4H, m, 2x CH_2), 4.18 (2H, q, J 7, OCH_2), and 7.51-7.90 (5H, Ar); δ_C 13.38 (CH_3), 14.03 (CH_3), 14.54 (CH_3), 41.00 (CH_2), 41.06 (CH_2), 40.96 (CH_2), 60.08 (CH_2O), 102.38 (*C*=CO), 109.04 (OCO), 115.73 (CSO_2Ph), 127.00, 129.34 and 133.12 (CHAr), 141.75 (CSO_2), 163.59 (C=*C*O), 164.96 (C=*C*O) and 165.09 (CO); m/z: M^+ 364 (30%) (Found: M^+ 364.0967 $C_{18}H_{20}O_6S$ requires M^+ 364.0980)

4'-Phenylsulfonyl-5',6,6-trimethyl-4,5,6,7-tetrahydrospiro[benzofuran-2(3H),2'(3'H)furan-4-one (23)

Dimedone (0.09g), the alkene (9) (0.15g) and manganese acetate (0.42g) in acetic acid (15ml) afforded as an oil the title compound (23) (0.07g, 30% yield); ν_{max} ($CHCl_3$) 3000-2960, 1720 and 1642 $cm.^{-1}$; δ_H 1.03 (3H, s, CH_3), 1.08 (3H, s, CH_3), 2.20-2.23 (4H, m, 2xCH_2), 2.24 (3H, s, CH_3), 2.22 and 2.96 (2H, m, CH_2), 3.05 (1H, dd, J 16, 2) and 3.20 (1H, dd, J 16, 2), 7.60-7.88 (5H, Ar); δ_C 13.34 (CH_3), 28.49 (CH_3), 29.17 ($COCH_3$), 34.37 (*C*Me_2), 37.07 (CH_2), 37.47 (CH_2), 41.41 (CH_2), 51.07 (CH_2), 109.73 (OCO), 111.15 (C=*C*SO_2), 118.61 (CSO_2Ph), 127.08, 129.52 and 133.40 (CHAr), 141.63 (CSO_2), 163.55 (C=*C*O), 173.35 (C=*C*O) and 194.36 (CO); m/z: M^+ 374 (74%) (Found: M^+ 374.1179 $C_{20}H_{22}O_5S$ requires M^+ 374.1187)

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