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Synthesis of Oxaspirolactones by Manganic Acetate Promoted Additions to Exocyclic Enol Lactones

John M. Mellor* and Shahid Mohammed
Department of Chemistry, Southampton University, Southampton SO9 5NH, England.

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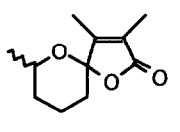
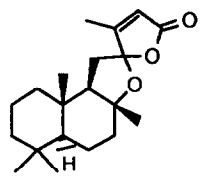
Abstract: Oxidation of diverse β-diketones and β-ketoesters with manganic acetate generates intermediates which add to exocyclic enol lactones to afford spirocyclic lactone products. In the presence of added copper acetate the reaction pathway can be diverted to give unsaturated ketoesters.

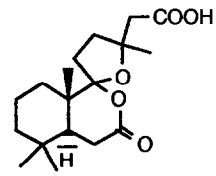
The important pheromonal and antibiotic activity of spirocyclic acetals has stimulated extensive study of synthetic methods for the construction of the spirocycles. Earlier methods[1] have been reviewed. A recent method[2] proceeds by initial construction of an oxaspirolactone and subsequent reduction of the lactone to afford a spiroacetal. Oxaspirolactones have become an important sub-group of the spiroacetals. Many including spirooxabovolide, α-levantenolide and grindelistrictic acid occur naturally[3] and polycyclic lactones such as bilobalide[4] are found in the ginkgo tree.



Spiroxabovolide



α-Levantenolide



Grindelistrictoic acid

In contrast to the synthesis of spiroacetals, the synthesis of oxaspirolactones has received much less attention. In this paper we describe a general method of synthesis of oxaspirolactones. Earlier[5,6] we have presented in preliminary publications a methodology based on the manganic acetate promoted addition of β-dicarbonyl compounds to nucleophilic alkenes. This radical addition permitted the development of exocyclic alkenes and endocyclic alkenes to afford respectively spiroheterocycles and fused heterocycles. The common feature of the manganese acetate promoted additions of β-dicarbonyl- and related compounds to diverse alkene substrates is the oxidation of the β-dicarbonyl compound generating an electrophilic intermediate which then adds to the alkene. The major emphasis in the studies of this oxidative approach to carbon-carbon bond formation has been addition of the intermediate radical to alkenes. These studies, which have been reviewed[7], have led to useful

Table 1

Synthesis of Spirolactones

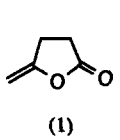
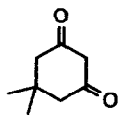
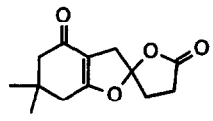
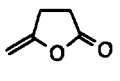
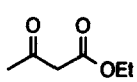
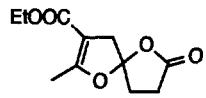
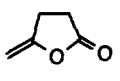
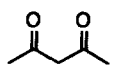
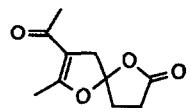
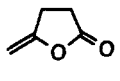
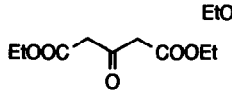
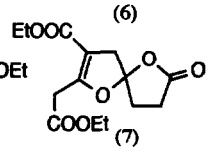
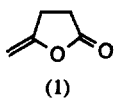
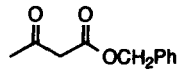
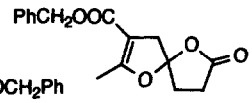
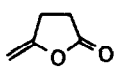
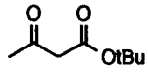
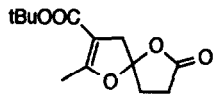
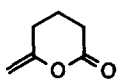
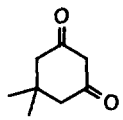
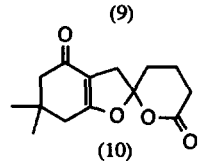
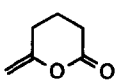
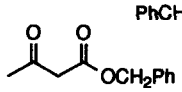
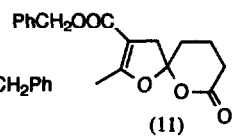
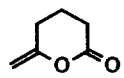
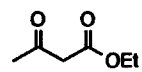
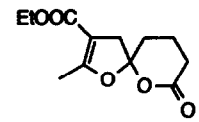
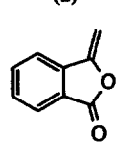
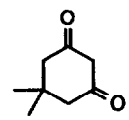
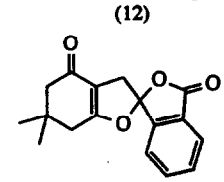
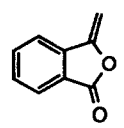
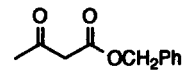
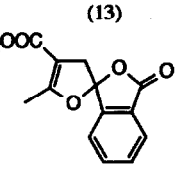
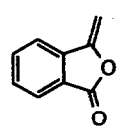
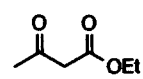
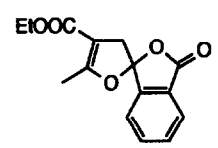
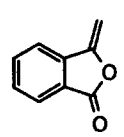
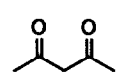
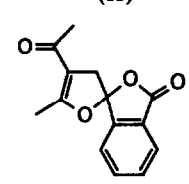
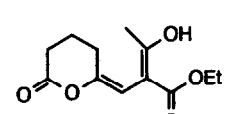
Reactants[a]		Product	Yield (%)
 (1)		 (4)	64
 (1)		 (5)	47
 (1)		 (6)	51
 (1)		 (7)	37
 (1)		 (8)	52
 (1)		 (9)	31
 (2)		 (10)	36[b]
 (2)		 (11)	19[b]

Table 1 (continued)

Reactants[a]		Product	Yield (%)
 (2)		 (12)	30[b]
 (3)		 (13)	87
 (3)		 (14)	78
 (3)		 (15)	85
 (3)		 (16)	91

a) Reactions in acetic acid at 65°C
b) Reaction at room temperature


(17)

intermolecular additions, and more recently, to intramolecular additions[8]. Although β-dicarbonyl substrates have been particularly well studied, others, for example β-ketosulfoxides, have been investigated[9]. Promotion of related additions by other inorganic oxidants has been assessed. Thus cerium ammonium nitrate efficiently promotes[10] intramolecular additions to an alkene. An increase in the nucleophilicity of the alkene might be expected to facilitate such additions. Hence the additions of these radicals to substituted alkenes carrying donor substituents are of synthetic interest. Recently it has been shown[11] that a methyl substituent feebly accelerates addition, but a bromine substituent slightly retards addition to vinyl bromides. In related additions[11] the effect of a chlorine substituent was also studied. The consequences of substitution by other heteroatom substituents, in particular oxygen, sulfur and nitrogen would be of great interest. The synthetic potential is easily recognised of the addition of radicals, generated by manganese acetate oxidation of β-dicarbonyl compounds, to enol ethers, enol esters, vinyl sulfides, and enamines and related compounds. Little attention has been paid to such additions. A successful addition to acyclic enol ethers and related compounds such as 1-methoxycyclohexene was described[12], and more recently reaction was reported of potassium methyl malonate to dihydropyrans to give[13] fused oxaspirolactones of unspecified stereochemistry. No additions to exocyclic enol ethers or enol lactones have been reported prior to our preliminary communication[5] describing the successful addition to both exo- and endocyclic enol ethers and lactones. In a second communication[6] we have reported the first manganese acetate promoted additions of radicals to vinyl sulfides. In this paper we describe the successful synthesis of oxaspirolactones by manganese acetate promoted additions to exocyclic enol lactones. In the two following publications we use the methodology for the effective synthesis of fused acetals, and unsaturated spiroacetals using endo-[14] and exo-cyclic[15] enol ethers as substrates.

Using the procedure of Jager and Gunther[16] the lactone (1) was efficiently prepared by iodocyclisation of 4-pentenoic acid to give an intermediate iodolactone, which underwent elimination in the presence of DBU to give the lactone (1). The lactone (2) was better prepared via the literature procedure[17] of Krafft and Katzenellenbogen involving mercury catalysed cyclisation of 5-hexynoic acid. The third lactone (3) was prepared by the method of Liu and Howe[18].

Manganic acetate promoted additions are typically carried out in acetic acid. A major question in our proposed reactions was the stability of substrates and products to the reaction conditions. However addition of ethyl acetoacetate to the lactone (1) affords in 47% yield the spirocyclic lactone (5). Neither the enol lactone nor the spirocyclic product are readily solvolysed under the reaction conditions. The structure of the product is easily established spectroscopically. In particular the formation of the spirocycle is indicated by observation of resonances at δ 3.08 and 3.22, associated with a ring methylene group. The two protons show a geminal coupling (J 15Hz.) A second useful observation is the resonance at 111.67 ppm in the ^{13}C nmr spectrum. The result of this, and five further additions to the lactone (1) are reported in Table 1. In all cases products are easily isolated by conventional work up and chromatographic purification. Although the lactone products show some instability on exposure to stronger acids, they are both stable to acetic acid at room temperature and to the conditions of chromatography.

In a similar manner additions can be made to the six-membered lactone (2) with dimedone, benzyl acetoacetate

and ethyl acetoacetate. It was noted that the products in this series were more sensitive to acid than those derived from the five-membered lactone (1). Manifestations of this extra sensitivity were the reduced yields of crude products from the lactone (2) isolated from acetic acid, and the tendency for this series of products to decompose during chromatographic purification on silica gel.

Additions to the lactone (3) proceeded very efficiently. Products showed little acid sensitivity and were readily isolated. In Table 1 the generality of the reaction is illustrated with six different β-dicarbonyl partners. Therefore the 13 examples in Table 1 establish that the manganese acetate promoted addition of β-dicarbonyl compounds to enol lactones provides a general and efficient route to spirolactones. The acid sensitivity of the lactone substrates and products is a constraint on the success of the procedure. With the more robust compounds derived from the lactone (3) excellent yields are obtained. The lower yields in reactions based on the lactone (2) are clearly attributable to acid sensitivity of the materials. Better yields of oxaspirolactones are obtained from the lactone (2) when reactions are carried out at room temperature. In the presence of added copper acetate the reaction of the lactone (2) with ethyl acetoacetate is diverted to give the unsaturated lactone (17) in 61% yield. This unsaturated lactone is a minor product in the absence of added copper acetate and is probably formed by oxidative trapping of the radical stemming from addition of an electrophilic radical to the lactone (2). In all these cases, because of the paucity of procedures affording oxaspirolactones, the simple protocol that we describe is of synthetic interest. Combined with the ready availability of the enol lactones via electrophilic cyclisations of unsaturated acids, these manganic acetate promoted additions provide a rapid access to a previously rather neglected series of spirocycles.

Experimental

Melting points were determined in a capillary tube using an Electrothermal melting point apparatus, and are uncorrected. Microanalyses were performed at University College London. Mass spectra were recorded using a VG Analytical 70-250-SE instrument. Infra-red spectra were recorded on a Perkin-Elmer 298 spectrometer, as thin films or as solutions in chloroform. ^1H Nuclear magnetic resonance spectra were recorded in $CDCl_3$ unless otherwise stated, using a Jeol JNM-GX 270 spectrometer, using residual protic solvent $CHCl_3$ ($\delta H = 7.26$ppm) or $CDCl_3$ ($\delta C = 77.2$ ppm) as internal reference or tetramethylsilane as internal reference. Coupling constants are measured in Hertz. ^{13}C Spectra were recorded at 68MHz using the Jeol spectrometer, and are reported as position (δC) using tetramethylsilane as reference. All experiments were carried out in oven dried glassware under a nitrogen atmosphere unless otherwise stated. Petrol refers to petroleum ether b.p. 40-60°C, which was distilled prior to use. Thin layer chromatography was performed on precoated glass-backed basic aluminium oxide plates (ALOX-25UV_{254}; 0.25mm; Macherey-Nagel) and visualised by uv fluorescence and aqueous potassium permanganate solution.. Preparative column chromatography was performed at low positive pressure on silica gel (C60 Sorbsil; May and Baker) and on deactivated (3% water by weight) basic aluminium oxide (pH 9.3-9.7; type 5016A; Fluka). The lactones (1)[16], (2)[17] and (3)[18] were prepared by literature procedures.

General Procedure for Synthesis of Spirolactones. Manganese (3) acetate dihydrate (2.0 mmol) was heated in acetic acid (20 ml) under nitrogen at 60-70°C until a black homogeneous solution was obtained. The β–dicarbonyl compound (1.5 mmol) and the alkene (1.0 mmol) were added and the reaction mixture was kept at 60°C until the colour had disappeared (10-120 min). To the cold mixture water (50 ml) was added and the solution was extracted with dichloromethane (3x25 ml). 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, either on silica gel or alumina. The following compounds were obtained.

6,6-Dimethyl-4,5,6,7,4'5'-hexahydrospiro[benzofuran-2(3H),2'(3'H)-furan-4,5'-dione] (4)
Dimedone (0.38g), the lactone (1) (0.24g) and manganese acetate (1.0g) in acetic acid (8 ml) afforded an oil, which slowly crystallised. Recrystallisation (ethyl acetate) afforded as white flakes the title compound (4) (0.38g, 64% yield), m.p. 116-117°C, ν_{max} ($CHCl_3$) 2990, 1815 and 1650 $cm.^{-1}$; δ_H 1.11 (3H, s, CH_3), 2.25 (2H, m, CH_2), 2.36 (2H, m, CH_2), 2.40-2.90 (4H, complex, 2xCH_2), 2.98 (1H, d, J 15) and 3.20 (1H, d, J15) (CH_2); δ_C 28.26 (CH_2), 28.62 (CH_3), 29.00 (CH_3), 33.24 (CH_2), 34.36 ($C(CH_3)_2$), 36.16 (CH_2), 37.44 (CH_2), 51.02 (CH_2), 111.46 (OC=*C*), 117.35 (OCO), 173.35 (O*C*=C), 174.76 (CO) and 194.41 (CO); m/z: M^+ 236 (37%) (Found M^+ 236.1044. $C_{13}H_{16}O_4$ requires M^+ 236.1048). (Found: C, 66.0; H, 6.74. $C_{13}H_{16}O_4$ requires C, 65.7; H, 6.76%)

3-Ethoxycarbonyl-2-methyl-1,6-dioxaspiro[4,4]non-2-ene-7-one (5)
Ethyl acetoacetate (0.146g), the lactone (1) (0.10g) and manganese acetate (0.46g) in acetic acid (8ml) afforded as an oil the title compound (5) (0.11g, 47% yield), ν_{max} ($CHCl_3$) 3010, 1810, 1715 and 1675 $cm.^{-1}$; δ_H 1.24 (3H, t, J 7, CH_3), 2.23 (3H, s, CH_3), 2.28-2.98 (4H, complex, 2xCH_2), 3.08 (1H, d, J 15) and 3.22 (1H, d, J15) (CH_2) and 4.20 (2H, q, J 7, OCH_2); δ_C 13.94 (CH_3), 14.13 (CH_3), 28.36 (CH_2), 32.99 (CH_2), 39.86 (CH_2), 60.02 (OCH_2), 102.61 (*C*=CO), 114.46 (OCO), 164.87 and 164.98 (C=*C*O), and 175.01 (CO); m/z: M^+ 226(36%) (Found M^+ 226.0830. $C_{11}H_{14}O_5$ requires M^+ 226.0841).

3-Acetyl-2-methyl-1,6-dioxaspiro[4,4]non-2-ene-7-one (6)
Acetylacetone (0.76g), the lactone (1) (0.5g) and manganese acetate (2.3g) in acetic acid (10ml) afforded as an oil the title compound (6) (0.56g, 51% yield, ν_{max} ($CHCl_3$) 2990, 1810, and 1645 $cm.^{-1}$; δ_H 2.25 (3H, s, CH_3), 2.26 (3H, s, CH_3), 2.33-2.98 (4H, complex, 2xCH_2), and 3.05 (1H, m) and 3.24 (1H, d, J 15) (CH_2); δ_C 14.87 (CH_3), 28.36 (CH_2), 29.62 (CH_3), 32.96 (CH_2), 40.45 (CH_2), 112.52 (*C*=CO), 114.23 (OCO), 164.38 (C=*C*O), 174.89 (CO) and 193.71 (CO); m/z: M^+ 196 (47%) (Found M^+ 196.0734. $C_{10}H_{12}O_4$ requires M^+ 196.0735).

3-Ethoxycarbonyl-2-ethoxycarbonylmethyl-1,6-dioxaspiro[4,4]non-2-ene-7-one (7)
Diethyl acetonedicarboxylate (0.5g), the lactone (1) (0.20g) and manganese acetate (0.93g) in acetic acid (10ml) afforded as an oil the title compound (7) (0.22g, 37% yield) ν_{max} ($CHCl_3$) 3000, 1810, and 1745 $cm.^{-1}$; δ_H 1.25 (3H, t, J 7, CH_3), 1.26 (3H, t, J 7, CH_3), 2.05 (2H, m, CH_2), 2.30-2.80 (4H, complex, 2xCH_2), 3.16 (1H, dt, J 16.8, 1.35 and 1.35) and 3.28 (1H, dd, J 16.8 and 0.8) (CH_2), 3.58 (1H, dt, J 16.6, 1.35 and 1.35) and 3.90 (1H, dd, J 16.6 and 0.8) (CH_2) and 4.17-4.22 (4H, m, 2x OCH_2); δ_C 14.19 (CH_3), 14.41 (CH_3),

28.27 (CH_3), 33.13 (CH_2), 33.90 (CH_2), 39.69 (CH_2), 60.38 (OCH_2), 61.53 (OCH_2), 105.36 (C=CCO_2Et), 114.91 (OCO), 159.90 (C=*C*O), 164.20, 167.81 and 174.81 (CO); m/z: M^+298 (32%) (Found M^+ 298.1049. $C_{14}H_{18}O_7$ requires M^+ 298.1052).

3-Benzyloxycarbonyl-2-methyl-1,6-dioxaspiro[4,4]non-2-ene-7-one (8)

Benzyl acetoacetate (1.07g), the lactone (1) (0.50g) and manganese acetate (1.32g) in acetic acid (15ml) afforded as an oil the title compound (8) (0.75g, 52% yield) ν_{max} ($CHCl_3$) 3000, 1800, 1705 and 1665 $cm.^{-1}$; δ_H 2.22 (3H, t, J 1.7 CH_3), 2.35-2.98 (4H, complex, 2xCH_2), 3.05 (1H, dq, J 15 and 1.7) and 3.24 (1H, dq, J 15 and 1.7) (CH_2), 5.21 (2H, s, CH_2) and 7.38 (5H, m, Ar); δ_C 14.08 (CH_3), 28.36 (CH_2), 32.98 (CH_2), 39.85 (CH_2), 65.82 ($PhCH_2$), 102.37 (*C*=CO), 114.55 (OCO), 128.13, 128.26 and 128.69 (CHAr), 136.36 (CAr), 164.63 (C=*C*O), 165.68 (CO) and 174.94 (CO); m/z: M^+ 288 (14%) (Found M^+ 288.1001. $C_{16}H_{16}O_5$ requires M^+ 288.0998).

3-t-Butoxycarbonyl-2-methyl-1,6-dioxaspiro[4,4]non-2-ene-7-one (9)

t-Butyl acetoacetate (1.07g), the lactone (1) (0.50g) and manganese acetate (1.32g) in acetic acid (15 ml) afforded as an oil the title compound (9) (0.4g, 31% yield) ν_{max} ($CHCl_3$) 3000, 1800, 1695 and 1660 $cm.^{-1}$; δ_H 1.46 (9H, s, 3xCH_3), 2.18 (3H, t, J 1.9, CH_3), 2.32-2.91 (4H, complex, 2xCH_2), and 3.03 (1H, dq, J 15 and 1.9) and 3.22 (1H, dq, J 15 and 1.9) (CH_2); δ_C 13.96 (CH_3), 28.46 (3xCH_3 and CH_2), 33.04 (CH_2), 40.24 (CH_2), 80.47 ($C(CH_3)_3$), 104.11(*C*=CO), 114.31 (OCO), 163.86 (C=*C*O), 164.37 (CO) and 175.12 (CO); m/z: M^+ 254 (11%) (Found M^+ 254.1172. $C_{13}H_{18}O_5$ requires M^+ 254.1154).

6,6-Dimethyl-4,5,6,7,5'6'-dihydrospiro[benzofuran-2(3H),2'(3H')-4H-pyran-4,6'-dione] (10)

Dimedone (1.25g), the lactone (2) (0.50g) and manganic acetate (2.4g) in acetic acid (10ml) by reaction at room temperature for 18h. afforded an oil which slowly crystallised. Recrystallisation (ethyl acetate) gave as white flakes the rather unstable title compound (10) (0.40g, 36% yield), m.p. 124-125^{0}C ν_{max} ($CHCl_3$) 2995, 1750, 1725 and 1655 $cm.^{-1}$; δ_H 1.10 (3H, s, CH_3), 1.18 (3H, s, CH_3), 1.85-2.45 (6H, complex, 3xCH_2), 2.50-2.62 (1H, m,) and 2.70-2.82 (1H, m) (CH_2) and 2.90 (1H, dt, J 16.2, 2.3and 2.3) and 3.08 (1H, dt, J 16.2, 2.3 and 2.3) (CH_2); δ_C 15.92 (CH_2), 28.52 (CH_2), 29.04 (CH_3), 29.20 (CH_2), 31.46 (CH_2), 34.34 ($C(CH_3)_2$), 37.55 (CH_2), 38.83 (CH_2), 51.04 (CH_2), 111.40 (OCO), 114,64 (C=*C*CO), 169.15 (C=*C*O), 173.02 (CO) and 194.69 (CO); m/z: M^+ 250 (8.5%) (Found M^+ 250.1205. $C_{14}H_{18}O_4$ requires M^+ 250.1205). (Found: C, 67.2; H, 7.3. $C_{14}H_{18}O_4$ requires C, 66.8; H, 7.3%)

3-Benzyloxycarbonyl-2-methyl-1,6-dioxaspiro[4,5]dec-2-ene-7-one (11)

Benzyl acetoacetate (1.71g), the lactone (2) (0.50g) and manganic acetate (2.40g) in acetic acid (10ml) by reaction at room temperature for 18h afforded an oil which slowly crystallised. Recrystallisation (ether) gave as white flakes the rather unstable title compound (11) (0.26g, 19% yield), m.p. 69-70^{0}C ν_{max} ($CHCl_3$) 3020, 1750, 1725, 1695 and 1655 $cm.^{-1}$; δ_H 1.78-2.19 (4H, complex, 2xCH_2), 2.22 (3H, t, J 1.9, CH_3), 2.45-2.60 (1H, m) and 2.65-2.80 (1H, m) (CH_2), 2.95 (1H, dq, J 16.2 and 1,9) and 3.10 (1H, dq, J 16.2 and 1.9) (CH_2), 5.18 (2H, s, $PhCH_2$) and 7.3-7.4 (5H, complex, Ar); δ_C 14.15 (CH_3), 15,82 (CH_2), 28.97 (CH_2),

31.27 (CH_2), 42.31 (CH_2), 65.74 (OCH_2), 102.24 (C=*C*CO), 111.54 (OCO), 128.10, 128.20 and 128.66 (CHAr), 136.42 (CAr), 164.83 (C=*C*O), 165.36 and 169.54 (CO); m/z: M^+ 302 (8.5%) (Found M^+ 302.1158. $C_{17}H_{18}O_5$ requires M^+ 302.1154).

3-Ethoxycarbonyl-2-methyl-1,6-dioxaspiro[4,5]dec-2-ene-7-one (12)

Ethyl acetoacetate (1.16g), the lactone (2) (0.50g) and manganese acetate (2.40g) in acetic acid (10ml) by reaction at room temperature for 18h. gave an oil, which slowly crystallised. Recrystallisation (ether-pentane) afforded as white plates the rather unstable title compound (12) (0.32g, 30% yield) m.p. 70-71^{0}C ν_{max} ($CHCl_3$) 3010, 1750, 1690 and 1660 cm.$^{-1}$; δ_H 1.30 (3H, t, J 7, CH_3), 1.85-2.20 (4H, m, 2xCH_2), 2.22 (3H, t, J 1.9, CH_3), 2.45-2.60 (1H, m,) and 2.65-2.80 (1H, m,) (CH_2), 2.95 (1H, dq, J 16, 1.9) and 3.10 (1H, dq, J 16, 1.9) (CH_2) and 4.18 (2H, m, OCH_2); δ_C 14.03 (CH_3), 14.51 (CH_3), 15.82 (CH_2), 28.97 (CH_2), 31.25 (CH_2), 42.34 (CH_2), 59.92 (OCH_2), 102.53 (C=*C*CO), 111.45 (OCO), 164.67 (C=*C*O), and 169.64 (CO); m/z: M^+240 (54%) (Found M^+ 240.0997. $C_{12}H_{16}O_5$ requires M^+ 240.0997).

6,6-Dimethyl-4',5',6',7'-tetrahydrospiro[benzofuran-1(3H)-2'(3'H)-isobenzofuran-3,4'-dione] (13)

Dimedone (0.33g), the lactone (3) (0.50g) and manganese acetate (1.00g) in acetic acid (15 ml) afforded as an oil the title compound (13) (0.58g, 87% yield) ν_{max} ($CHCl_3$) 2990, 2950, 1790, and 1650 cm.$^{-1}$; δ_H 1.06 (3H, s,CH_3), 1.08 (3H, s, CH_3), 2.20-2.40 (4H, complex, 2xCH_2), 3.31 (2H, m, CH_2) and 7.4-7.95 (4H, complex, Ar); δ_C 28.69 (CH_3), 28.94 (CH_3), 34.52 (*C*(CH_3)$_2$), 36.71 (CH_2), 37.49 (CH_2), 51.18 (CH_2), 111.94 (OCO), 113.93 (*C*=CO), 122.79, 125.36, 131.73 and 135.37 (CHAr), 126.36 and 145.85 (CAr), 166.97 (C=*C*O), 173.70 (CO) and 194.35 (CO); m/z: M^+284 (100%) (Found M^+ 284.1027. $C_{17}H_{16}O_4$ requires M^+ 284.1048).

4-Benzyloxycarbonyl-5-methyl-spiro[furan-2(3H),1'(3'H)isobenzofuran-3'-one] (14)

Benzyl acetoacetate (0.73g), the lactone (3) (0.8g) and manganese acetate (1.61g) in acetic acid gave an oil, which slowly crystallised. Recrystallisation (dichloromethane-pentane) afforded as white plates the title compound (14) (0.98g, 78% yield) m.p. 132-133^{o}C ν_{max} ($CHCl_3$) 2990, 1790, 1710 and 1660 cm.$^{-1}$; δ_H 2.28 (3H, t, J 1.7, CH_3), 3.38 (1H, dq, J 16.8 and 1.7) and 3.45 (1H, dq, J 16.8 and 1.7) (CH_2), 5.21 (2H, s, PhCH_2), 7.36-7.40 (5H, complex, Ar) and 7.58-7.90 (4H, complex, Ar); δ_C 14.03 (CH_3), 40.33 (CH_2), 65.94 (PhCH_2), 103.04 (*C*=CO), 111.60 (OCO), 122.81, 125.55, 128.14, 128.27, 128.65, 131.44 and 135.12 (CHAr), 126.53, 136.18 and 145.89 (CAr), 164.38 (C=*C*O), 165.98 (CO) and 167.09 (CO); m/z: M^+ 336 (56%) (Found M^+ 336.0988. $C_{20}H_{16}O_5$ requires M^+ 336.1004). (Found: C, 70.2; H, 4.8. $C_{20}H_{16}O_5$ requires C, 70.4; H, 4.8%)

4-Ethoxycarbonyl-5-methyl-spiro[furan-2(3H),1'(3'H)isobenzofuran-3'-one] (15)

Ethyl acetoacetate (0.50g), the lactone (3) (0.80g) and manganese acetate (1.61g) in acetic acid (15 ml) afforded as an oil the title compound (15) (0.89g, 85% yield) ν_{max} ($CHCl_3$) 2990, 1790, 1705 and 1665 cm.$^{-1}$; δ_H 1.32 (3H, t, J 7, CH_3), 2.38 (3H, t, J 1.9, CH_3), 3.38 (1H, dq, J 16.9 and 1.9) and 3.50 (1H, dq, J 16.9 and 1.9) (CH_2), 4.23 (2H, q, J 7, OCH_2) and 7.58-7.95 (4H, complex, Ar); δ_C 14.05 (CH_3), 14.55 (CH_3), 40.50

(CH_2), 60.30 (OCH_2), 103,42 (*C*=CO), 111.67 (OCO), 122.87, 125.67, 131.50 and 135.18 (CHAr), 126.67 and 146.12 (CAr), 164.80 (C=*C*O), 165.45 (CO) and 167.26 (CO); m/z: M^+ 274 (18%) (Found M^+ 274.0838. $C_{15}H_{14}O_5$ requires M^+ 274.0841).

4-Acetyl-5-methyl-spiro[furan-2(3H),1'(3'H)isobenzofuran-3'-one] (16)

Acetylacetone (0.38g), the lactone (3) (0.80g) and manganese acetate (1.61g) in acetic acid (15 ml) afforded as an oil the title compound (16) (0.84g, 91% yield) ν_{max} ($CHCl_3$) 2950, 1790, 1680 and 1665 $cm.^{-1}$; δ_H 2.23 (3H, t, J 1.7, CH_3), 2.34 (3H, s, CH_3), 3.39 (1H, dq J 17 and 1.7) and 3.58 (1H, dq, J 17 and 1.7) (CH_2) and 7.4-7.95 (4H, complex Ar); δ_C 14.85 (CH_3), 29.74 (CH_3), 40.97 (CH_2), 111.35 (OCO), 112.95 (*C*=CO), 122.83, 125.68, 131.57 and 135.12 (CHAr), 126.57 and 145.85 (CAr), 164.75 (C=*C*O), 167.10 (CO) and 193.71 (CO); m/z: M^+ 244 (25%) (Found M^+ 244.0733. $C_{14}H_{12}O_4$ requires M^+ 244.0735).

2-Ethoxycarbonylbutan-3-one-1-ylidene-3,4,5,6-tetrahydropyran-2-one (17)

Ethyl acetoacetate (0.16g), the lactone (2) (0.30g), manganese acetate (1.43g) and copper acetate (0.54g) in acetic acid afforded after reaction at 65^0C and chromatography over silica gel an oil which slowly crystallised. Recrystallisation (dichloromethane-pentane) afforded as white plates the title compound (17) (0.18g, 61% yield) m.p. 59-61^0C ν_{max}($CHCl_3$) 3000, and 1770 cm^{-1} (broad) δ_H 1.38 (3H, t J7, CH_3), 1.99 (2H, m, (CH_2), 2.42 (2H, t J7, (CH_2), 2.55 (3H, s, CH_3), 2.68 (2H, t J7, CH_2), 4.28 (2H, q J7, CH_2) and 6.30 (1H, s, C=CH); δ_C 13.89 (CH_3), 14.52 (CH_3), 22.93 (CH_2), 28.99 (CH_2), 33.07 (CH_2), 106.49 (CH), 114,02 (C=*C*CO), 152.78 (C=COH), 158.15 (C=CO) and 164.50 and 179.33 (CO); m/z M^+ 240 (70%) (Found M^+ 240.1000. $C_{12}H_{16}O_5$ requires M^+ 240.0998).

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