

# Photochemical reaction of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones in the presence of oxygen

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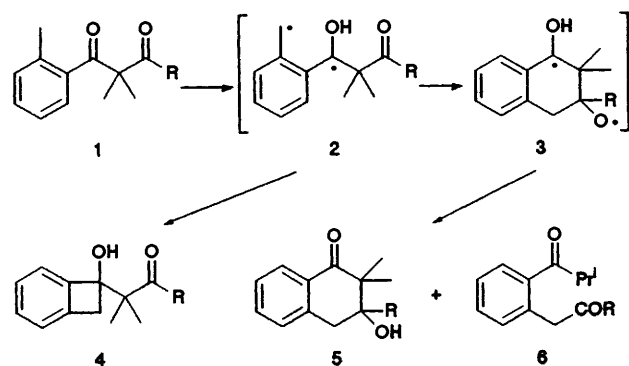
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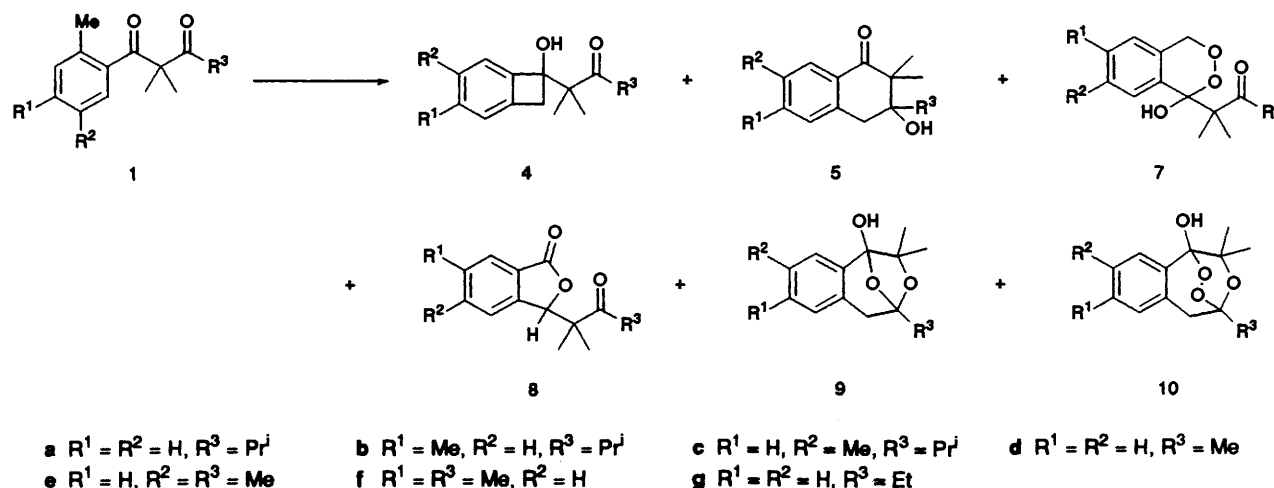
Irradiation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones 1a–c having an isopropyl group on C-3 in the presence of oxygen gave the peroxides 7a–c and the lactones 8a–c, whereas irradiation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones 1d–g having a methyl or ethyl group on C-3 gave 1,4-epoxy- and 1,4-epidioxo-3-benzooxepin-1-ols 9d–g and 10d–g, along with the peroxide 7d,g and the lactone 8d–g.

The photochemistry of *o*-alkylaryl ketones has been the subject of numerous studies and a number of comprehensive reviews has been published.<sup>1</sup> The triplet states of these ketones transform into diradicals (triplet states of enols<sup>1c</sup>) via intramolecular hydrogen abstraction. The resulting diradicals revert to the starting ketones or undergo ring closure to give benzocyclobutenols.<sup>2</sup> We have previously reported that 1-(*o*-methylphenyl)-2,2-dimethyl 1,3-diketones 1 underwent photo-reactions to give benzocyclobutenols 4, naphthalenones 5 and *o*-(2-oxoalkyl)isobutyrophenone 6 in hexane under nitrogen.<sup>3</sup> The naphthalenones 5 are thought to arise from the tetralin diradical 3 which is produced by intramolecular trapping of the aryl radical site in the initially formed diradical 2 by the  $\beta$ -

carbonyl group (Scheme 1). The benzocyclobutenol:naphthalenone ratio was influenced by the substituent R. This ratio increased with chain branching of R and with increasing size of R. When R = Me or Et the naphthalenone was the main product, and when R = Pr<sup>i</sup> both products were formed in nearly the same yield. When R = Pr<sup>i</sup> the intermediate diradical 2 could be trapped with oxygen to give the peroxide.<sup>3</sup> We report here that the photooxygenation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones with Pr<sup>i</sup> on C-3 gave the peroxide 7 and the lactone 8, while that of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones with Me or Et on C-3 gave 1,4-epoxy- and 1,4-epidioxo-3-benzooxepin-1-ols 9 and 10, along with the peroxide 7 and the lactone 8 (Scheme 2).



Scheme 1 Conditions: *h\nu*



Scheme 2 Conditions: *h\nu*

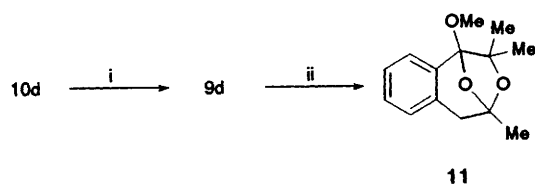
**Table 1** Yields of photoproducts obtained in the photolysis of **1** in the presence of oxygen<sup>a</sup>

Ketone <b>1</b>	Conversion (%) <sup>b</sup>	Yield (%) <sup>c</sup>					
		<b>4</b>	<b>5</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
<b>a</b>	75	16	—	29	19	—	—
<b>b</b>	86	5	—	23	34	—	—
<b>c</b>	83	4	—	27	33	—	—
<b>d</b>	60	trace	24	5	12	16	16
<b>e</b>	75	—	25	—	8	13	10
<b>f</b>	85	—	33	—	6	14	11
<b>g</b>	80	4	18	19	23	11	8

<sup>a</sup> A solution of the ketone (750 mg) in hexane (150 cm<sup>3</sup>) was irradiated with a 100 W high-pressure mercury lamp through a Pyrex filter under bubbling air. <sup>b</sup> Based on the amount of consumed starting material. <sup>c</sup> Based on converted starting material.

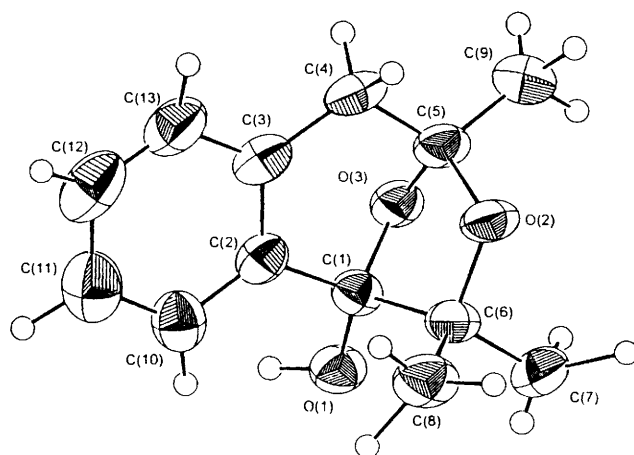
cyclization probably through the ketene **13**<sup>4</sup> to give the lactone **8a** on extended heating or by irradiation. The peroxide **7a** also underwent further photoreaction to give **8a**. The IR spectrum of the lactone **8a** showed the lactone carbonyl peak at 1760 cm<sup>-1</sup>. The <sup>13</sup>C NMR spectrum of **8a** showed lactone and isopropyl carbonyl peaks at  $\delta_c$  170.0 and 217.3, respectively. Irradiation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones **1b,c** having an isopropyl group on C-3 under the same conditions also gave peroxides **7b,c** and lactones **8b,c**, along with benzocyclobutenols **4b,c**.

In contrast to **1a-c**, irradiation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones **1d-g** having a methyl or ethyl substituent on C-3 in hexane under bubbling air gave the 1,4-epoxy- and 1,4-epidioxy-3-benzooxepin-1-ols **9d-g** and **10d-g**, the peroxide **7d,g**, the lactone **8d-g**, the benzocyclobutenol **4d,g**, and the naphthalenone **5d-g**. The yields of **9** and **10** were higher in **1d-f** than in **1g**, and those of **7** and **8** were lower in **1d-f** than in **1g**. Results on the photooxygenation of 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones **1a-g** are given in Table 1. The IR spectra of **9** and **10** showed hydroxy but no carbonyl absorptions. The <sup>1</sup>H NMR spectra of **9** showed two methylene protons as an AB quartet at around  $\delta_H$  2.8 and that of **10** showed them at around  $\delta_H$  3.1, also as an AB quartet. The <sup>13</sup>C NMR spectra of both **9** and **10** showed a peak due to a quaternary carbon attached to an oxygen atom at  $\delta_c$  82–83. The peaks due to quaternary carbons attached to two oxygen atoms of **9** were observed close together at around  $\delta_c$  104, while those of **10** appeared at  $\delta_c$  ca. 96 and 104. Deoxygenation of the epidioxy compound **10d** using triphenylphosphine gave the epoxy compound **9d**. The compound **9d** was transformed into the corresponding methyl ether **11** by refluxing in methanol in the presence of a catalytic amount of hydrochloric acid (Scheme 3). Finally the structure of **9d** was unequivocally established by an X-ray crystallographic analysis (Fig. 1).



**Scheme 3** Reagents: i, PPh<sub>3</sub>; ii, MeOH, HCl

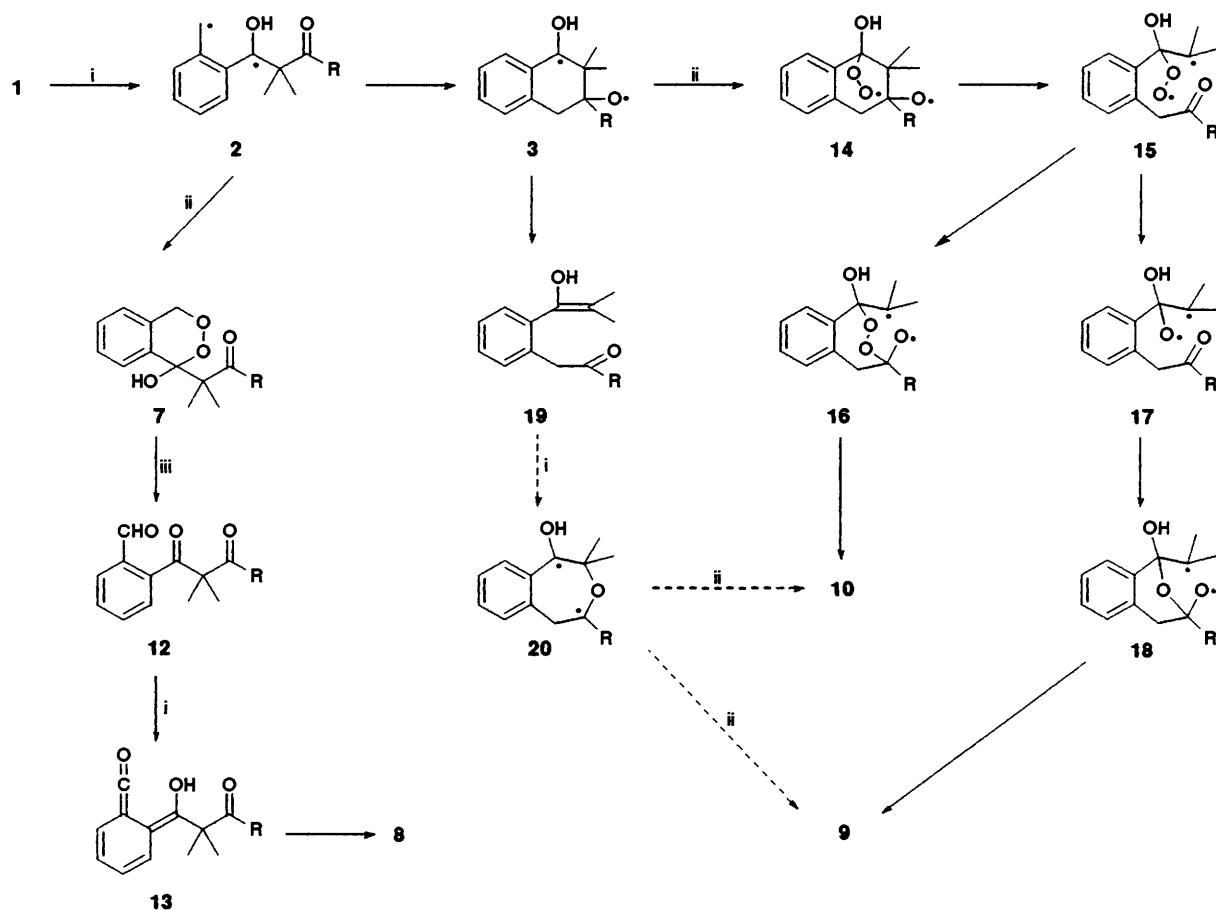
Since diradicals are efficiently trapped by molecular oxygen,<sup>5</sup> the peroxide **7** would arise by the reaction of the diradical **2** with oxygen. Under the reaction conditions, the peroxide **7** may undergo dehydration to give the aldehyde **12** which undergoes further photochemical reaction to give the lactone **8**. As already mentioned, the aldehyde **12** also undergoes thermal reaction to give **8**. It is known that *o*-alkylphenyl ketones undergo photooxygenation to give the peroxide,<sup>4,5a,6</sup> which undergoes further reaction to yield the lactone.<sup>4,6b</sup>



**Fig. 1** Structure of compound **9d** determined by X-ray crystallography

The formation of compounds **9** and **10** is probably caused through the reaction of oxygen with the tetralin diradical **3** formed from **2** (Scheme 4). The reaction of the tetralin diradical **3** with oxygen would give an intermediate oxygen adduct **14**.<sup>7</sup> The oxygen-diradical adduct **14** would be converted into the peroxy-carbon diradical **15** by  $\beta$ -scission of the alkoxy radical site. A potential reactive manifold for an alkoxy radical is to undergo  $\beta$ -scission to produce the carbonyl group and the carbon radical.<sup>8</sup> The peroxy radical in **15** may add to the carbonyl group producing a new alkoxy radical **16** which closes the ring to give the epidioxy compound **10**. Intramolecular reaction of the peroxy radical with a suitably positioned carbonyl group has been previously reported.<sup>9</sup> The peroxy-carbon diradical **15** may be partly reduced to the alkoxy-carbon diradical **17**. We have previously reported that peroxy radicals formed by the reaction of oxygen with diradicals generated in the type II reaction of some  $\beta$ -diketones are partly reduced to alkoxy radicals.<sup>5f,5g</sup> The compound **9** may be produced from **17** by the reaction of the alkoxy radical with the carbonyl group to form **18** followed by cyclization. Another plausible mechanism for the formation of **9** and **10** is that the diradical **3** undergoes fission of the ring to give the enol **19**. As described before, irradiation of **1a,d,g** in hexane under nitrogen gave *o*-(2-oxoalkyl)isobutyrophenones **6a,d,g**, though the yields of them were only 2, 5 and 6%, respectively.<sup>3</sup> Formation of the isobutyrophenone **6** can be reasonably explained in terms of ketonization of **19**. Intramolecular photochemical addition of the carbonyl group in **19** to the enol double bond would give **20** which reacts with oxygen to yield **9** and **10**. However, this second mechanism can be excluded because no trace of **6a,d,g** was detected in the photoreaction of **1a,d,g** in the presence of oxygen and the yields of **9d,g** and **10d,g** were much higher than those of **6d,g** in the photoreaction of **1d,g** in the absence of oxygen.

In conclusion, 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones having an isopropyl group on C-3 underwent photooxygenation to give the 1,4-dihydro-2,3-benzodioxin-1-ol species through the reaction of the initially formed diradical with oxygen. The benzodioxine underwent dehydration under the reaction conditions to give the 1-(*o*-formylaryl)-2,2-dimethyl 1,3-diketone, which is transformed into the lactone on further irradiation. The 1-(*o*-methylaryl)-2,2-dimethyl 1,3-diketones having a methyl or ethyl substituent on C-3 gave 1,4-epoxy- and 1,4-epidioxy-3-benzooxepin-1-ols, along with the benzodioxine and the lactone on irradiation in the presence of oxygen. Since the starting diketones having a methyl or ethyl group on C-3 undergo photoreaction under nitrogen to give 3-hydroxy-2,2-dimethyl-3,4-dihydronaphthalen-1(*2H*)-ones *via* the tetralin diradical formed by trapping of the aryl radical site in the initially formed diradical by the  $\beta$ -carbonyl group, the epoxy



Scheme 4 Conditions: i,  $h\nu$ ; ii,  $O_2$ ; iii, loss of  $H_2O$

and epidioxy compounds seem to be produced by the reaction of the tetralin diradical with oxygen to form the tetralin diradical-oxygen adduct. This then undergoes  $\beta$ -scission to give the peroxy-carbon diradical 15. The diradical 15 undergoes peroxy radical cyclization followed by ring closure to give 10. The diradical 15 undergoes partial reduction to alkoxy radical 17 which is converted into 9 by a similar process as above.

### Experimental

Mps are uncorrected and bps were measured from the oven temperatures in Kugelrohr distillation. IR spectra were recorded on a Hitachi 270-50 spectrometer for solutions in  $CHCl_3$  unless otherwise stated.  $^1H$  NMR spectra were obtained with a Bruker AM 400 spectrometer with  $CDCl_3$  as solvent. Tetramethylsilane was used as an internal standard and  $J$  values are given in Hz.  $^{13}C$  NMR spectra were measured on a Bruker AM 400 spectrometer with  $CDCl_3$  as solvent. Column chromatography was performed with Merck Kieselgel 60. An Ushio 100 W high-pressure mercury lamp was used as the irradiation source. Starting compounds 1a–g were prepared by previously described methods.<sup>10</sup> For the physical properties of 4a–d, g, 5d, g, 7a and 8a, see refs. 3 and 10. The X-ray crystallographic analysis was carried out with a Mac Science MXC3K diffractometer.

#### General procedure for the photooxidation of 1a–g

A solution of the diketone (750 mg) in hexane (150  $cm^3$ ) through which air was bubbled was irradiated with a 100 W high-pressure mercury lamp through a Pyrex filter for 4 h. The photoproducts were isolated by silica gel column chromatography with hexane–ethyl acetate (4:1) or benzene–ethyl acetate (4:1 to 10:1) as eluent.

#### 3-Hydroxy-2,2,3,7-tetramethyl-3,4-dihydronaphthalen-

**1(2*H*)-one 5e.** Bp 120 °C at 0.3 mmHg (Found: C, 77.2; H, 8.2.  $C_{14}H_{18}O_2$  requires C, 77.0; H, 8.3%);  $\nu_{max}(CCl_4)/cm^{-1}$  3500br (OH) and 1700 (C=O);  $\delta_H(400\text{ MHz})$  1.18 (3 H, s), 1.27 (3 H, s) and 1.32 (3 H, s) (2-Me<sub>2</sub> and 3-Me), 1.5–1.6 (1 H, OH), 2.37 (3 H, s, ArMe), 3.04 and 3.16 (2 H, AB system,  $J$  17, 4-H<sub>2</sub>) and 7.11 (1 H, d,  $J$  8), 7.31 (1 H, d,  $J$  8) and 7.84 (1 H, s) (3 × ArH);  $\delta_C(100\text{ MHz})$  18.1 (q), 20.7 (q), 20.9 (q) and 24.5 (q) (4 × Me), 40.6 (t, C-4), 51.0 (s, C-2), 75.5 (s, C-3), 127.9 (d), 129.0 (d), 130.4 (s), 134.4 (d), 136.1 (s) and 136.5 (s) (6 × ArC) and 202.4 (s, C=O).

#### 3-Hydroxy-2,2,3,6-tetramethyl-3,4-dihydronaphthalen-

**1(2*H*)-one 5f.** Bp 130 °C at 0.2 mmHg (Found: C, 77.1; H, 8.2.  $C_{14}H_{18}O_2$  requires C, 77.0; H, 8.3%);  $\nu_{max}(CCl_4)/cm^{-1}$  3650 (OH) and 1700 (C=O);  $\delta_H(400\text{ MHz})$  1.18 (3 H, s), 1.27 (3 H, s) and 1.32 (3 H, s) (2-Me<sub>2</sub> and 3-Me), 1.59 (1 H, OH), 2.38 (3 H, s, ArMe), 3.04 and 3.16 (2 H, AB system,  $J$  17, 4-H<sub>2</sub>) and 7.02 (1 H, s), 7.13 (1 H, d,  $J$  8) and 7.93 (1 H, d,  $J$  8) (3 × ArH);  $\delta_C(100\text{ MHz})$  18.1 (q), 20.4 (q), 21.4 (q) and 24.2 (q) (4 × Me), 40.7 (t, C-4), 50.7 (s, C-2), 75.1 (s, C-3), 127.5 (d), 127.6 (d), 128.1 (s), 129.4 (d), 139.2 (s) and 143.9 (s) (6 × ArC) and 202.2 (s, C=O).

#### 2-(1-Hydroxy-6-methyl-1,4-dihydro-2,3-benzodioxin-1-yl)-

**2,4-dimethylpentan-3-one 7b.** Obtained as a very unstable oil;  $\nu_{max}/cm^{-1}$  3400br (OH) and 1690 (C=O);  $\delta_H(400\text{ MHz})$  1.08 (3 H, d,  $J$  7) and 1.14 (3 H, d,  $J$  7) ( $CHMe_2$ ), 1.10 (3 H, s) and 1.44 (3 H, s) ( $CMe_2$ ), 2.37 (3 H, s, ArMe), 3.19 (1 H, sept,  $J$  7,  $CHMe_2$ ), 4.79 and 5.29 (2 H, AB system,  $J$  15, 4-H<sub>2</sub>), 6.16 (1 H, s, OH) and 6.92 (1 H, s), 7.11 (1 H, d,  $J$  8) and 7.44 (1 H, d,  $J$  8) (3 × ArH);  $\delta_C(100\text{ MHz})$  19.0 (q), 19.9 (q), 20.8 (q), 21.0 (q) and 23.6 (q) (5 × Me), 36.3 (d,  $CHMe_2$ ), 53.7 (s,  $CMe_2$ ), 72.0 (t, C-4), 105.6 (s, C-1), 125.0 (d), 126.6 (d), 128.0 (d), 129.5 (s), 134.4 (s) and 137.9 (s) (6 × ArC) and 222.8 (s, C=O).

#### 2-(1-Hydroxy-7-methyl-1,4-dihydro-2,3-benzodioxin-1-yl)-

**2,4-dimethylpentan-3-one 7c.** Obtained as a very unstable oil;

$\nu_{\max}/\text{cm}^{-1}$  3400br (OH) and 1680 (C=O);  $\delta_{\text{H}}$ (400 MHz) 1.09 (3 H, d, *J* 7) and 1.15 (3 H, d, *J* 7) (*CHMe*<sub>2</sub>), 1.11 (3 H, s) and 1.46 (3 H, s) (*CMe*<sub>2</sub>), 2.37 (3 H, s, *ArMe*), 3.19 (1 H, sept, *J* 7, *CHMe*<sub>2</sub>), 4.81 and 5.30 (2 H, AB system, *J* 15, 4-*H*<sub>2</sub>), 6.21 (1 H, s, OH) and 7.00 (1 H, d, *J* 8), 7.13 (1 H, d, *J* 8) and 7.37 (1 H, s) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 19.0 (q), 19.8 (q), 20.8 (q), 21.3 (q) and 23.7 (q) (5 × *Me*), 36.3 (d, *CHMe*<sub>2</sub>), 53.6 (s, *CMe*<sub>2</sub>), 71.9 (t, C-4), 105.6 (s, C-1), 124.5 (d), 127.2 (d), 128.8 (d), 131.6 (s), 132.1 (s) and 136.9 (s) (6 × *ArC*) and 222.9 (s, C=O).

**3-(1-Hydroxy-1,4-dihydro-2,3-benzodioxin-1-yl)-3-methylbutan-2-one 7d.** Mp 98 °C (decomp.) (from hexane-diethyl ether) (Found: C, 66.0; H, 6.9. *C*<sub>13</sub>*H*<sub>16</sub>*O*<sub>4</sub> requires C, 66.1; H, 6.8%);  $\nu_{\max}/\text{cm}^{-1}$  3375br (OH) and 1690 (C=O);  $\delta_{\text{H}}$ (400 MHz) 1.06 (3 H, s) and 1.43 (3 H, s) (*CMe*<sub>2</sub>), 2.31 (3 H, s, *COMe*), 4.85 and 5.43 (2 H, AB system, *J* 15, 4-*H*<sub>2</sub>), 5.89 (1 H, s, OH) and 7.1–7.6 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 21.4 (q), 22.9 (q) and 28.2 (q) (3 × *Me*), 53.5 (s, *CMe*<sub>2</sub>), 72.0 (t, C-4), 105.3 (s, C-1), 124.6 (d), 126.7 (d), 127.3 (d), 128.1 (d), 132.3 (s) and 134.5 (s) (6 × *ArC*) and 216.3 (s, C=O).

**2-(1-Hydroxy-1,4-dihydro-2,3-benzodioxin-1-yl)-2-methylpentan-3-one 7g.** Mp 97 °C (decomp.) (from hexane-diethyl ether) (Found: C, 67.0; H, 7.3. *C*<sub>14</sub>*H*<sub>18</sub>*O*<sub>4</sub> requires C, 67.2; H, 7.3%);  $\nu_{\max}/\text{cm}^{-1}$  3375br (OH) and 1690 (C=O);  $\delta_{\text{H}}$ (400 MHz) 1.04 (3 H, s) and 1.42 (3 H, s) (*CMe*<sub>2</sub>), 1.08 (3 H, t, *J* 7, *CH*<sub>2</sub>*Me*), 2.61 (1 H, dq, *J* 19 and 7) and 2.71 (1 H, dq, *J* 19 and 7) (*CH*<sub>2</sub>*Me*), 4.81 and 5.33 (2 H, AB system, *J* 15, 4-*H*<sub>2</sub>), 6.23 (1 H, s, OH) and 7.1–7.6 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 7.3 (q), 20.8 (q) and 23.3 (q) (*CMe*<sub>2</sub> and *CH*<sub>2</sub>*Me*), 33.0 (t, *CH*<sub>2</sub>*Me*), 53.2 (s, *CMe*<sub>2</sub>), 72.0 (t, C-4), 105.6 (s, C-1), 124.6 (d), 126.8 (d), 127.2 (d), 128.0 (d), 132.2 (s) and 134.5 (s) (6 × *ArC*) and 218.9 (s, C=O).

**6-Methyl-3-(1,1,3-trimethyl-2-oxobutyl)-1,3-dihydroisobenzofuran-1-one 8b.** Bp 130 °C at 0.2 mmHg (Found: C, 73.7; H, 7.7. *C*<sub>16</sub>*H*<sub>20</sub>*O*<sub>3</sub> requires C, 73.8; H, 7.7%);  $\nu_{\max}(\text{CCl}_4)/\text{cm}^{-1}$  1780 (lactone C=O) and 1710 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 0.97 (3 H, s) and 1.33 (3 H, s) (*CMe*<sub>2</sub>), 1.06 (3 H, d, *J* 7) and 1.16 (3 H, d, *J* 7) (*CHMe*<sub>2</sub>), 2.45 (3 H, s, *ArMe*), 3.11 (1 H, sept, *J* 7, *CHMe*<sub>2</sub>), 5.88 (1 H, s, CHO) and 7.20 (1 H, d, *J* 8), 7.42 (1 H, d, *J* 8) and 7.68 (1 H, s) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 17.6 (q), 19.7 (q), 19.9 (q), 21.1 (q) and 22.1 (q) (*CHMe*<sub>2</sub>, *CMe*<sub>2</sub> and *ArMe*), 35.0 (d, *CHMe*<sub>2</sub>), 52.2 (s, *CMe*<sub>2</sub>), 84.3 (d, CHO), 123.4 (d), 125.6 (d), 127.1 (s), 135.2 (d), 139.5 (s) and 145.2 (s) (6 × *ArC*), 170.6 (s, ring C=O) and 217.9 (s, side-chain C=O).

**5-Methyl-3-(1,1,3-trimethyl-2-oxobutyl)-1,3-dihydroisobenzofuran-1-one 8c.** Mp 84–85 °C (from hexane) (Found: C, 73.6; H, 7.7. *C*<sub>16</sub>*H*<sub>20</sub>*O*<sub>3</sub> requires C, 73.8; H, 7.7%);  $\nu_{\max}(\text{CCl}_4)/\text{cm}^{-1}$  1780 (lactone C=O) and 1710 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 0.99 (3 H, s) and 1.33 (3 H, s) (*CMe*<sub>2</sub>), 1.08 (3 H, d, *J* 7) and 1.17 (3 H, d, *J* 7) (*CHMe*<sub>2</sub>), 2.45 (3 H, s, *ArMe*), 3.12 (1 H, sept, *J* 7, *CHMe*<sub>2</sub>), 5.87 (1 H, s, CHO) and 7.11 (1 H, s), 7.32 (1 H, d, *J* 8) and 7.76 (1 H, d, *J* 8) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 17.6 (q), 19.6 (2q), 19.9 (q) and 22.1 (q) (*CHMe*<sub>2</sub>, *CMe*<sub>2</sub> and *ArMe*), 35.0 (d, *CHMe*<sub>2</sub>), 52.2 (s, *CMe*<sub>2</sub>), 84.1 (d, CHO), 124.0 (d), 124.4 (s), 125.4 (d), 130.3 (d), 145.2 (s) and 148.3 (s) (6 × *ArC*), 170.4 (s, ring C=O) and 217.9 (s, side-chain C=O).

**3-(1,1-Dimethyl-2-oxopropyl)-1,3-dihydroisobenzofuran-1-one 8d.** Bp 100 °C at 0.2 mmHg (Found: C, 71.6; H, 6.5. *C*<sub>13</sub>*H*<sub>14</sub>*O*<sub>3</sub> requires C, 71.5; H, 6.5%);  $\nu_{\max}(\text{CCl}_4)/\text{cm}^{-1}$  1770 (lactone C=O) and 1705 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 1.01 (3 H, s) and 1.27 (3 H, s) (*CMe*<sub>2</sub>), 2.27 (3 H, s, *COMe*), 5.88 (1 H, s, CHO) and 7.3–7.9 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 18.5 (q), 21.6 (q) and 26.2 (q) (3 × *Me*), 51.6 (s, *CMe*<sub>2</sub>), 84.3 (d, CHO), 123.4 (d), 125.7 (d), 126.8 (s), 129.3 (d), 134.0 (d) and 147.4 (s) (6 × *ArC*), 170.2 (s, ring C=O) and 211.3 (s, side-chain C=O).

**5-Methyl-3-(1,1-dimethyl-2-oxopropyl)-1,3-dihydroisobenzofuran-1-one 8e.** Bp 125 °C at 0.2 mmHg (Found: C, 72.5; H, 6.9. *C*<sub>14</sub>*H*<sub>16</sub>*O*<sub>3</sub> requires C, 72.4; H, 6.9%);  $\nu_{\max}(\text{CCl}_4)/\text{cm}^{-1}$  1780 (lactone C=O) and 1710 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 1.01 (3 H, s) and 1.28 (3 H, s) (*CMe*<sub>2</sub>), 2.27 (3 H, s, *COMe*),

2.47 (3 H, s, *ArMe*), 5.81 (1 H, s, CHO) and 7.14 (1 H, s), 7.33 (1 H, d, *J* 8) and 7.77 (1 H, d, *J* 8) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 18.5 (q), 21.7 (q), 22.1 (q) and 26.2 (q) (4 × *Me*), 51.6 (s, *CMe*<sub>2</sub>), 84.0 (d, CHO), 123.7 (d), 124.3 (s), 125.4 (d), 130.4 (d), 145.3 (s) and 148.0 (s) (6 × *ArC*), 170.2 (s, ring C=O) and 211.5 (s, side-chain C=O).

**6-Methyl-3-(1,1-dimethyl-2-oxopropyl)-1,3-dihydroisobenzofuran-1-one 8f.** Bp 120 °C at 0.3 mmHg (Found: C, 72.5; H, 6.9. *C*<sub>14</sub>*H*<sub>16</sub>*O*<sub>3</sub> requires C, 72.4; H, 6.9%);  $\nu_{\max}(\text{CCl}_4)/\text{cm}^{-1}$  1790 (lactone C=O) and 1720 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 1.00 (3 H, s) and 1.26 (3 H, s) (*CMe*<sub>2</sub>), 2.26 (3 H, s, *COMe*), 2.45 (3 H, s, *ArMe*), 5.82 (1 H, s, CHO) and 7.24 (1 H, d, *J* 8), 7.43 (1 H, d, *J* 8) and 7.69 (1 H, s) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 18.6 (q), 21.2 (q), 21.7 (q) and 26.3 (q) (4 × *Me*), 51.7 (s, *CMe*<sub>2</sub>), 84.3 (d, CHO), 123.1 (d), 125.8 (d), 127.1 (s), 135.2 (d), 139.7 (s) and 144.8 (s) (6 × *ArC*), 170.4 (s, ring C=O) and 211.5 (s, side-chain C=O).

**3-(1,1-Dimethyl-2-oxobutyl)-1,3-dihydroisobenzofuran-1-one 8g.** Bp 110 °C at 0.3 mmHg (Found: C, 72.3; H, 7.0. *C*<sub>14</sub>*H*<sub>16</sub>*O*<sub>3</sub> requires C, 72.4; H, 6.9%);  $\nu_{\max}/\text{cm}^{-1}$  1760 (lactone C=O) and 1700 (side-chain C=O);  $\delta_{\text{H}}$ (400 MHz) 1.04 (3 H, s) and 1.26 (3 H, s) (*CMe*<sub>2</sub>), 1.12 (3 H, t, *J* 7, *CH*<sub>2</sub>*Me*), 2.55 (1 H, dq, *J* 14 and 7) and 2.69 (1 H, dq, *J* 14 and 7) (*CH*<sub>2</sub>*Me*), 5.92 (1 H, s, CHO) and 7.3–7.9 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 7.5 (q), 18.4 (q) and 21.4 (q) (*CMe*<sub>2</sub> and *CH*<sub>2</sub>*Me*), 31.1 (t, *CH*<sub>2</sub>*Me*), 51.2 (s, *CMe*<sub>2</sub>), 84.4 (d, CHO), 123.1 (d), 125.4 (d), 126.6 (s), 129.1 (d), 133.9 (d) and 147.3 (s) (6 × *ArC*), 170.0 (s, ring C=O) and 213.6 (s, side-chain C=O).

**1,4-Epoxy-2,2,4-trimethyl-1,2,4,5-tetrahydro-3-benzoxepin-1-ol 9d.** Mp 138–139 °C (from hexane) (Found: C, 70.8; H, 7.4. *C*<sub>13</sub>*H*<sub>16</sub>*O*<sub>3</sub> requires C, 70.9; H, 7.3%);  $\nu_{\max}/\text{cm}^{-1}$  3580 and 3400br (OH);  $\delta_{\text{H}}$ (400 MHz) 0.81 (3 H, s), 1.37 (3 H, s) and 1.59 (3 H, s) (3 × *Me*), 2.77 and 2.93 (2 H, AB system, *J* 17, 5-*H*<sub>2</sub>), 3.61 (1 H, s, OH) and 7.0–7.4 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 23.4 (q), 23.8 (q) and 25.8 (q) (3 × *Me*), 40.8 (t, C-5), 83.8 (s, C-2), 103.9 (s) and 104.1 (s) (C-1 and -4) and 123.4 (d), 125.7 (d), 128.4 (d), 128.5 (d), 133.8 (s) and 137.1 (s) (6 × *ArC*).

**1,4-Epoxy-2,2,4,8-tetramethyl-1,2,4,5-tetrahydro-3-benzoxepin-1-ol 9e.** Mp 148–149 °C (from hexane-benzene) (Found: C, 71.5; H, 7.7. *C*<sub>14</sub>*H*<sub>18</sub>*O*<sub>3</sub> requires C, 71.8; H, 7.7%);  $\nu_{\max}/\text{cm}^{-1}$  3600 and 3450br (OH);  $\delta_{\text{H}}$ (400 MHz) 0.81 (3 H, s), 1.36 (3 H, s) and 1.58 (3 H, s) (2-*Me*<sub>2</sub> and 4-*Me*), 2.34 (3 H, s, *ArMe*), 2.72 and 2.86 (2 H, AB system, *J* 17, 5-*H*<sub>2</sub>), 3.57 (1 H, s, OH) and 6.94 (1 H, d, *J* 8), 7.00 (1 H, d, *J* 8) and 7.20 (1 H, s) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 21.2 (q), 23.5 (q), 23.8 (q) and 25.8 (q) (4 × *Me*), 40.5 (t, C-5), 83.6 (s, C-2), 103.9 (s) and 104.0 (s) (C-1 and -4) and 123.9 (d), 128.4 (d), 129.2 (d), 130.6 (s), 135.2 (s) and 136.8 (s) (6 × *ArC*).

**1,4-Epoxy-2,2,4,7-tetramethyl-1,2,4,5-tetrahydro-3-benzoxepin-1-ol 9f.** Mp 129–130 °C (from hexane) (Found: C, 71.9; H, 7.8. *C*<sub>14</sub>*H*<sub>18</sub>*O*<sub>3</sub> requires C, 71.8; H, 7.7%);  $\nu_{\max}/\text{cm}^{-1}$  3600 and 3400br (OH);  $\delta_{\text{H}}$ (400 MHz) 0.82 (3 H, s), 1.37 (3 H, s) and 1.60 (3 H, s) (2-*Me*<sub>2</sub> and 4-*Me*), 2.33 (3 H, s, *ArMe*), 2.78 and 3.01 (2 H, AB system, *J* 17, 5-*H*<sub>2</sub>), 3.21 (1 H, s, OH) and 6.91 (1 H, s), 7.03 (1 H, d, *J* 8) and 7.28 (1 H, d, *J* 8) (3 × *ArH*);  $\delta_{\text{C}}$ (100 MHz) 21.2 (q), 23.5 (q), 23.8 (q) and 25.8 (q) (4 × *Me*), 40.9 (t, C-5), 83.6 (s, C-2), 103.9 (s) and 104.0 (s) (C-1 and -4) and 123.2 (d), 126.5 (d), 129.2 (d), 133.7 (s), 134.2 (s) and 138.3 (s) (6 × *ArC*).

**1,4-Epoxy-4-ethyl-2,2-dimethyl-1,2,4,5-tetrahydro-3-benzoxepin-1-ol 9g.** Mp 117–118 °C (from hexane) (Found: C, 71.7; H, 7.9. *C*<sub>14</sub>*H*<sub>18</sub>*O*<sub>3</sub> requires C, 71.8; H, 7.7%);  $\nu_{\max}/\text{cm}^{-1}$  3550 and 3400br (OH);  $\delta_{\text{H}}$ (400 MHz) 0.80 (3 H, s) and 1.35 (3 H, s) (2-*Me*<sub>2</sub>), 1.07 (3 H, t, *J* *CH*<sub>2</sub>*Me*), 1.83 (2 H, q, *J* 7, *CH*<sub>2</sub>*Me*), 2.69 and 2.85 (2 H, AB system, *J* 17, 5-*H*<sub>2</sub>), 3.81 (1 H, s, OH) and 7.0–7.4 (4 H, m, *ArH*);  $\delta_{\text{C}}$ (100 MHz) 7.5 (q), 23.8 (q) and 23.9 (q) (2-*Me*<sub>2</sub> and *CH*<sub>2</sub>*Me*), 31.4 (t, *CH*<sub>2</sub>*Me*), 39.2 (t, C-5), 83.5 (s, C-2), 103.8 (s) and 105.8 (s) (C-1 and -4) and 123.3 (d), 125.6 (d), 128.4 (d), 128.6 (d), 133.7 (s) and 137.3 (s) (6 × *ArC*).

**1,4-Epidioxy-2,2,4-trimethyl-1,2,4,5-tetrahydro-3-benzooxepin-1-ol 10d.** Mp 85–86 °C (from hexane) (Found: C, 66.2; H, 6.8. C<sub>13</sub>H<sub>16</sub>O<sub>4</sub> requires C, 66.1; H, 6.8%);  $\nu_{\max}/\text{cm}^{-1}$  3580 (OH);  $\delta_{\text{H}}$ (400 MHz) 0.86 (3 H, s), 1.52 (3 H, s) and 1.66 (3 H, s) (3 × Me), 3.12 and 3.28 (2 H, AB system, *J* 18, 5-H<sub>2</sub>), 3.26 (1 H, s, OH) and 7.0–7.4 (4 H, m, ArH);  $\delta_{\text{C}}$ (100 MHz) 18.8 (q), 21.1 (q) and 24.9 (q) (3 × Me), 37.7 (t, C-5), 82.6 (s, C-2), 96.2 (s) and 103.9 (s) (C-1 and -4) and 125.1 (2 d), 127.2 (d), 128.4 (d), 135.5 (s) and 135.6 (s) (6 × ArC).

**1,4-Epidioxy-2,2,4,8-tetramethyl-1,2,4,5-tetrahydro-3-benzooxepin-1-ol 10e.** Mp 112–113 °C (from hexane) (Found: C, 67.2; H, 7.2. C<sub>14</sub>H<sub>18</sub>O<sub>4</sub> requires C, 67.2; H, 7.3%);  $\nu_{\max}/\text{cm}^{-1}$  3600 and 3450br (OH);  $\delta_{\text{H}}$ (400 MHz) 0.87 (3 H, s), 1.51 (3 H, s) and 1.66 (3 H, s) (2-Me<sub>2</sub> and 4-Me), 2.34 (3 H, s, ArMe), 3.08 and 3.25 (2 H, AB system, *J* 18, 5-H<sub>2</sub>), 3.18 (1 H, s, OH) and 6.98 (1 H, d, *J* 8), 7.10 (1 H, d, *J* 8) and 7.22 (1 H, s) (3 × ArH);  $\delta_{\text{C}}$ (100 MHz) 18.9 (q), 21.1 (2 q) and 24.8 (q) (4 × Me), 37.2 (t, C-5), 82.5 (s, C-2), 96.2 (s) and 103.9 (s) (C-1 and -4) and 125.1 (d), 127.1 (d), 129.1 (d), 132.4 (s), 134.3 (s) and 135.2 (s) (6 × ArC).

**1,4-Epidioxy-2,2,4,7-tetramethyl-1,2,4,5-tetrahydro-3-benzooxepin-1-ol 10f.** Mp 85–86 °C (from hexane) (Found: C, 67.4; H, 7.2. C<sub>14</sub>H<sub>18</sub>O<sub>4</sub> requires C, 67.2; H, 7.3%);  $\nu_{\max}/\text{cm}^{-1}$  3600 (OH);  $\delta_{\text{H}}$ (400 MHz) 0.84 (3 H, s), 1.51 (3 H, s) and 1.64 (3 H, s) (2-Me<sub>2</sub> and 4-Me), 2.33 (3 H, s, ArMe), 3.02 and 3.20 (2 H, AB system, *J* 18, 5-H<sub>2</sub>), 3.41 (1 H, s, OH) and 6.85 (1 H, s), 6.98 (1 H, d, *J* 8) and 7.26 (1 H, d, *J* 8) (3 × ArH);  $\delta_{\text{C}}$ (100 MHz) 18.8 (q), 21.0 (q), 21.1 (q) and 24.9 (q) (4 × Me), 37.6 (t, C-5), 82.6 (s, C-2), 96.3 (s) and 103.9 (s) (C-1 and -4) and 125.0 (d), 125.9 (d), 127.7 (d), 132.6 (s), 135.4 (s) and 138.1 (s) (6 × ArC).

**1,4-Epidioxy-4-ethyl-2,2-dimethyl-1,2,4,5-tetrahydro-3-benzooxepin-1-ol 10g.** Mp 90–90.5 °C (from pentane) (Found: C, 67.3; H, 7.3. C<sub>14</sub>H<sub>18</sub>O<sub>4</sub> requires C, 67.2; H, 7.3%);  $\nu_{\max}/\text{cm}^{-1}$  3600 (OH);  $\delta_{\text{H}}$ (400 MHz) 0.84 (3 H, s) and 1.64 (3 H, s) (2-Me<sub>2</sub>), 1.04 (3 H, t, *J* 7, CH<sub>2</sub>Me), 1.80 (2 H, q, *J* 7 CH<sub>2</sub>Me), 3.04 and 3.17 (2 H, AB system, *J* 18, 5-H<sub>2</sub>), 3.40 (1 H, s, OH) and 7.0–7.4 (4 H, m, ArH);  $\delta_{\text{C}}$ (100 MHz) 6.6 (q), 18.9 (q) and 21.9 (q) (2-Me<sub>2</sub> and CH<sub>2</sub>Me), 31.5 (t, CH<sub>2</sub>Me), 36.1 (t, C-5), 82.8 (s, C-2), 96.1 (s) and 105.2 (s) (C-1 and -4) and 125.0 (d), 125.1 (d), 127.2 (d), 128.2 (d), 135.6 (s) and 135.8 (s) (6 × ArC).

#### Deoxygenation of compound 10d

A solution of the 1,4-epidioxy compound **10d** (5 mg, 0.02 mmol) and triphenylphosphine (5.6 mg, 0.02 mmol) in benzene (1 cm<sup>3</sup>) was heated at 80 °C for 3 h, after which the mixture was evaporated. <sup>1</sup>H NMR analysis of the residue showed that 30% of **10d** was deoxygenated to give the 1,4-epoxy compound **9d**.

#### Treatment of compound 9d with acidic methanol

A solution of the 1,4-epoxy compound **9d** (400 mg) and conc. hydrochloric acid (3 drops) in methanol (12 cm<sup>3</sup>) was heated under reflux for 1 h after which it was evaporated. The residue was chromatographed on silica gel (hexane–ethyl acetate 6: 1) to give 1,4-epoxy-1-methoxy-2,2,4-trimethyl-1,2,4,5-tetrahydro-3-benzooxepine **11** (43%) mp 66–67 °C (from hexane) (Found: C, 71.7; H, 7.7. C<sub>14</sub>H<sub>18</sub>O<sub>3</sub> requires C, 71.8; H, 7.7%); IR spectrum shows neither carbonyl nor hydroxy absorptions;  $\delta_{\text{H}}$ (400 MHz) 0.77 (3 H, s), 1.32 (3 H, s) and 1.62 (3 H, s) (3 × Me), 2.79 and 3.08 (2 H, AB system, *J* 17, 5-H<sub>2</sub>), 3.48 (3 H, s, OMe) and 7.1–7.9 (4 H, m, ArH);  $\delta_{\text{C}}$ (100 MHz) 23.4 (q), 24.4 (q) and 26.0 (q) (2-Me<sub>2</sub> and 4-Me), 41.0 (t, C-5), 53.5 (q, OMe), 85.1 (s, C-2), 104.8 (s) and 107.6 (s) (C-1 and -4) and 124.8 (d), 125.3 (d), 128.2 (d), 129.0 (d), 134.3 (s) and 135.4 (s) (6 × ArC).

#### Crystallographic analysis of compound 9d

Crystal data. C<sub>13</sub>H<sub>16</sub>O<sub>3</sub>, *M* = 220.3, orthorhombic, *a* = 13.004(5), *b* = 15.100(7), *c* = 5.943(2) Å, *V* = 1167.0(8) Å<sup>3</sup>

[by least-squares refinement of 2 $\theta$  values of 22 reflections (54.0° < 2 $\theta$  < 60.0°,  $\lambda$  = 1.5418 Å)], space group *P*2<sub>1</sub>2<sub>1</sub>2<sub>1</sub> (No. 19), *Z* = 4, *D<sub>x</sub>* = 1.25 g cm<sup>-3</sup>,  $\mu$  = 6.80 cm<sup>-1</sup>. Colourless needle, crystal used had dimensions of 0.40 × 0.20 × 0.15 mm.

Data collection and processing. Mac Science MXC3K diffractometer,  $\omega$ -2 $\theta$  mode with  $\omega$  scan width = 1.67 + 0.20tan  $\theta$ ,  $\omega$  scan speed 6.0 deg min<sup>-1</sup>, graphite-monochromated Cu-K $\alpha$  radiation; 1317 unique reflections measured (1.5° <  $\theta$  < 70°, *h, k, l*). Three standard reflections monitored every 100 reflections indicated no significant crystal decay.

Structure analysis and refinement. The structure was solved by direct methods using STR.<sup>11</sup> Full-matrix least-squares refinement<sup>12</sup> (based on *F<sub>o</sub>*<sup>2</sup>) using 1114 reflections [*I* > 3 $\sigma$ (*I*)] were applied for all non-hydrogen atoms with anisotropic thermal parameters and for hydrogen atoms with isotropic parameters. Final *R* and *R<sub>w</sub>* values are 0.064, 0.059. A flat final difference synthesis:  $\rho_{\min}$  = -0.29 e Å<sup>-3</sup>,  $\rho_{\max}$  = 0.19 e Å<sup>-3</sup>. Atomic scattering factors were taken from *International Tables for X-Ray Crystallography* (1974, Vol. IV). Data collection and cell refinement were made by the MXC program system. Structure determination and refinement were made by the CRYSTAN-GM program system. All calculations were carried out on a SUN SPARC 10 workstation.

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