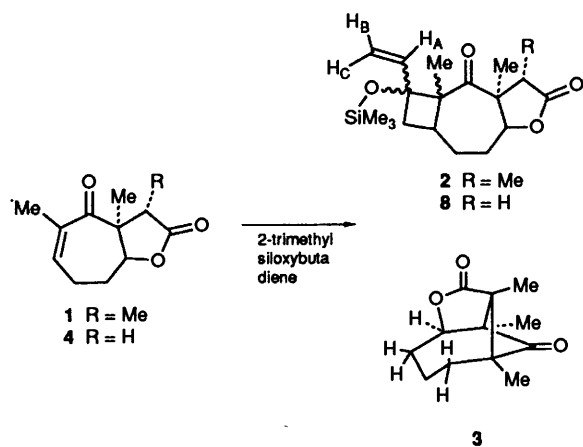


## The Photochemical Behaviour of 2-Methylcyclohept-2-enones

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An efficient dimerisation of 1,3-dimethyl-8-oxabicyclo[5.3.0]dec-3-ene-2,9-dione **4** has been discovered, and probably involves an initial photo-induced formation of the *trans* cyclohept-2-enone which then undergoes thermal dimerisation. Irradiation of the complex cycloheptenone, 1,3,10-trimethyl-8-oxabicyclo[5.3.0]dec-3-ene-2,9-dione **1** provided an 85% yield of a novel tricycle (and no dimer), tentatively identified as 1,8,10-trimethyl-3-oxatricyclo[6.2.0.0<sup>4,10</sup>]decane-2,9-dione.

During the development of a new route to the pseudoguaianolide skeleton,<sup>1</sup> we irradiated 1,3,10-trimethyl-8-oxabicyclo[5.3.0]dec-3-ene-2,9-dione **1** in the presence of an excess of 2-trimethylsilyloxybuta-1,3-diene (DME as solvent), and obtained two major products: the desired [2 + 2] cycloaddition product **2** (9%, mixture of stereoisomers), and the tricycle **3** (27%, tentative structure—*vide infra*) (Scheme 1). A change of solvent



to acetonitrile improved the yields of both products, and a further change to THF with elimination of the diene from the reaction mixture, resulted in an 85% isolated yield of tricycle **3**.

For these reactions, a relatively inefficient irradiation protocol was employed. This involved the use of two 500 W medium pressure mercury lamps placed externally to the Pyrex reaction vessel. In contrast, if we used a more efficient irradiation apparatus involving one 125 W lamp surrounded by the reaction mixture (immersion lamp), the tricycle **3** was the sole product (54% isolated yield) even in the presence of the diene. This suggested that the cycloadduct **2** was undergoing cycloreversion under the more forcing irradiation conditions, and this was shown to be the case. With the same irradiation protocol, the related cycloheptenone **4** (demethyl analogue of **1**) yielded the novel dimer **5** (Fig. 1) (50% isolated yield) and other stereoisomers (10%), but no trace of a tricyclic analogue to **3**.

All of these irradiations were carried out on at least 0.5 g, and yields were reproducible. A summary of all of the results is shown in Table 1.

Compound **3** has so far not undergone X-ray structure elucidation, but the structure assigned appears reasonable on

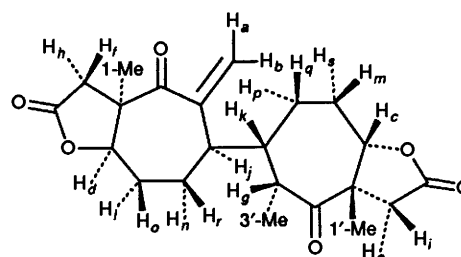
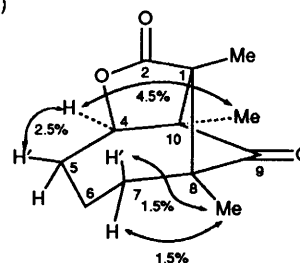


Fig. 1.

(a)



(b)

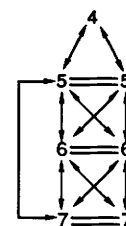


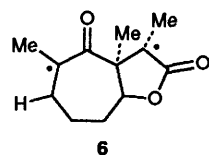
Fig. 2. NMR data for compound **3**: (a), NOE data; (b), major coupling constants in <sup>1</sup>H-COSY spectrum, = geminal and  $\longleftrightarrow$  vicinal coupling.

the basis of the spectral data summarised in Fig. 2. In particular, the <sup>13</sup>C NMR revealed the presence of three methyl groups (all singlets in the <sup>1</sup>H spectrum), three CH<sub>2</sub> groups, one CH, three quaternary carbons and two carbonyls. The 2D-COSY and NOE data were also consistent with the assigned structure. Finally, the formation of this tricyclic structure is also in accord with the likely mechanism of its formation *via* the triplet biradical **6**, which involves intramolecular abstraction of the tertiary hydrogen adjacent to the lactone carbonyl group. In compound **4** this hydrogen is secondary, and the biradical may be less stable, thus allowing the possibility of an alternative reaction pathway.

**Table 1.** Reaction of compounds **1** and **4**

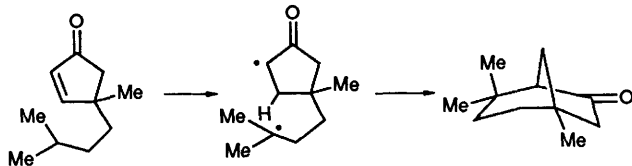
Lamp source	Reactant	Amount of diene (mol equiv.)	Product	Solvent	Yield (%)
External <sup>a</sup>	<b>1</b>	4.4	<b>2</b>	DME	9
			<b>3</b>	DME	27
			<b>2</b>	MeCN	22
	<b>1</b>	7.0	<b>2</b>	MeCN	61
			<b>3</b>	THF	0
			<b>3</b>	THF	85
<b>4</b>	12	<b>8</b>	cyclohexane	45	
		<b>4</b>	—	—	
		no reaction	—	—	
Immersion <sup>b</sup>	<b>1</b>	0	<b>3</b>	THF	54
	<b>4</b>	0	<b>5</b>	THF	50
	<b>4</b>	0	other isomers	THF	10

<sup>a</sup> Typical irradiations 7 h. <sup>b</sup> Irradiations for 7 h.

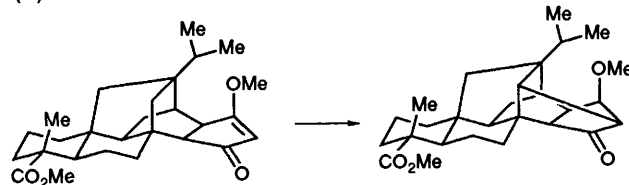


The type of photo-process envisaged for the conversion of bicycle **1** into tricycle **3**, although rare, is not without precedent, and the transformations described by Agosta<sup>2</sup> and Herz<sup>3</sup> (Scheme 2) have some similarity to the present reaction.

(a)

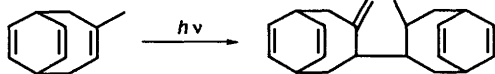


(b)



Scheme 2. (a), see ref. 2; (b), see ref. 3.

The formation of the dimer **5** can best be explained as proceeding *via* initial photo-induced formation of the *trans* cycloheptenone, followed by an intermolecular thermal ene reaction. Again, there is precedent for this kind of process, and this is best exemplified by the reaction shown in Scheme 3.<sup>4</sup>

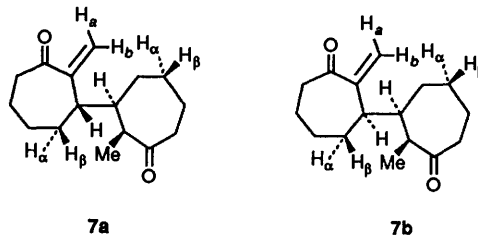


Scheme 3.

Interestingly, this kind of chemical transformation has never been observed with cyclohexenones, and this probably reflects the greater stability of the intermediate *trans* cycloheptenones. The presence of the extra methyl group in compound **1** may render this molecule too rigid to allow access to the *trans* form, thus increasing the chances of it reacting *via* the biradical **6**.

In order to demonstrate the generality of this dimerisation,

we irradiated 2-methylcyclohept-2-enone using the immersion lamp (*ca.* 20 h, THF) and obtained the dimers **7** (*ca.* 5% yield of



a 1:1 mixture of stereoisomers), with 90% recovery of starting ketone. When the reaction was carried out in the presence of 2-trimethylsilyloxybutadiene, no [2 + 2] cycloaddition product was obtained, but the yield of the dimers **7** was increased to 57% (with 20% recovery of starting material after 12 h irradiation). This can perhaps be explained if one invokes the intermediacy of an exciplex which is more easily attained in the presence of the diene.

In summary, we have discovered a practical method for the construction of functionalised bicycloheptanones. These structures are not without interest due to the significant biological activity exhibited by  $\alpha$ -methylene ketones and lactones.<sup>5</sup>

### Experimental

IR spectra were recorded with a Perkin-Elmer 881 double beam grating spectrophotometer. NMR spectra were recorded with a Perkin-Elmer R34 (220 MHz) instrument, a Bruker WH 400 spectrometer (400 MHz) at the University of Warwick or with a Varian T-60 (60 MHz) instrument, using tetramethylsilane as internal standard. Mass spectra were obtained at the University of Swansea using a VG ZAB-E high resolution mass spectrometer. Flash chromatography was performed using Crossfield Sorbsil C60 (40–60 m). Solvents were purified according to Perrin,<sup>6</sup> and light petroleum refers to the fraction with b.p. 40–60 °C, ether refers to diethyl ether.

7,8,10-Trimethyl-11-trimethylsilyloxy-11-vinyl-5-oxatricyclo-[8.2.0.0<sup>4,8</sup>]dodecane-6,9-dione **2** and 1,8,10-Trimethyl-3-oxatricyclo[6.2.0.0<sup>4,10</sup>]decane-2,9-dione **3**.—A solution of 1,3,10-trimethyl-8-oxabicyclo[5.3.0]dec-3-ene-2,9-dione **1** (0.33 g, 1.6 mmol) and 2-trimethylsilyloxybuta-1,3-diene (1.0 g, 7.02 mmol) in dry dimethoxyethane (DME, 50 ml) contained in a Pyrex irradiation vessel, was degassed using nitrogen. It was then irradiated for 10 h with two 500 W medium pressure mercury

lamps, with the temperature maintained at 20 °C. After removal of the solvent, the white residue was chromatographed using light petroleum-ether (1:1) as eluant to yield the two tricyclic compounds **2** (50 mg, 9% yield) and **3** (89 mg, 27%).

**Compound 2.** M.p. 150 °C (decomp.);  $\nu_{\max}/\text{cm}^{-1}$  (CHCl<sub>3</sub>) 3017, 2956, 2870, 1767 (lactone), 1691 (ketone), 1604 (C=C), 1457, 1251, 1027, 931 and 841;  $\delta(\text{CDCl}_3; 220 \text{ MHz})$  0.10 (s, SiMe<sub>3</sub>), 1.18 and 1.37 (2 × s, 2 × Me), 1.28 (d,  $J$  6.6 Hz, 7-Me), 1.50–2.50 (m, 1-H, 2 × 2-H, 2 × 3-H, 2 × 12-H), 2.68 (q,  $J$  6.6 Hz, 7-H), 4.45 (dd,  $J$  10.5 and 4 Hz, 4-H), 5.18 (dd,  $J_{\text{BA}}$  10.5 and  $J_{\text{BC}}$  1 Hz, H<sub>B</sub>), 5.28 (dd,  $J_{\text{CA}}$  17 and  $J_{\text{CB}}$  1 Hz, H<sub>C</sub>) and 5.98 (dd,  $J_{\text{AC}}$  17 and  $J_{\text{AB}}$  10.5 Hz, H<sub>A</sub>) (Found:  $M$ , 350.1913. C<sub>15</sub>H<sub>30</sub>O<sub>4</sub>Si requires  $M$ , 350.1913).

**Compound 3.** M.p. 150 °C (decomp.);  $\nu_{\max}/\text{cm}^{-1}$  (CHCl<sub>3</sub>) 3020, 2969, 1760 (lactone and ketone), 1148, 1085;  $\delta(\text{CDCl}_3; 400 \text{ MHz})$  1.10 (s, 10-Me), 1.18 (s, 1-Me), 1.20 (s, 8-Me), 1.61–1.76 (m, 5-H, 6-H, 7-H), 1.81–1.88 (m, 7'-H), 1.90–2.04 (m, 6'-H), 2.12–2.19 (m, 5'-H) and 4.45 (d,  $J_{\text{A5}}$  6.2 Hz, 4-H);  $\delta(\text{CDCl}_3; 22.5 \text{ MHz})$  12.8 (q), 13.0 (q), 17.4 (t), 18.6 (q), 29.8 (t), 31.0 (t), 46.5 (s), 70.7 (s), 73.1 (s), 79.6 (d, C-4), 179.3 (s, ester C=O) and 207.8 (s, ketone C=O) (Found: C, 69.10; H, 7.85. Calc. for C<sub>12</sub>H<sub>16</sub>O<sub>3</sub>: C, 69.21; H, 7.75%). An improved yield of compound **3** was obtained by irradiating a solution of bicycle **1** (0.5 g, 2.38 mmole) in dry THF (200 ml) in a Pyrex irradiation vessel with a 125 W medium pressure immersion lamp. After 7 h, TLC analysis revealed that compound **1** had been consumed, and after chromatography using ether as eluant, compound **3** was obtained as the sole product (0.27 g, 54%).

4-(1',3'-Dimethyl-2,9-dioxa-8'-oxabicyclo[5.3.0]decan-4-yl-1-methyl-3-methylene-8-oxabicyclo[5.3.0]decane-2,9-dione **5**.—A solution of 1,3-dimethyl-8-oxabicyclo[5.3.0]dec-3-ene-2,9-dione **4** (0.3 g, 1.55 mmol) in dry THF (200 ml) in a Pyrex irradiation vessel was degassed using nitrogen prior to irradiation with a 125 W medium pressure immersion lamp. After 7 h reaction was complete, and chromatography using ethyl acetate-light petroleum [(1:1) then (2:1)] yielded an isomeric mixture of dimers (0.195 g, 65%). Recrystallisation of this mixture yielded one isomer **5** (50% yield) with around 95% purity (as judged by NMR). It was not possible to free this compound from traces of other photo-products, m.p. 245–252 °C;  $\nu_{\max}/\text{cm}^{-1}$  (CHCl<sub>3</sub>) 3021, 2939, 2874, 1781 (lactone), 1702 (ketone), 1693 (unsaturated ketone), 1604 (C=C), 1452, 1189, 1092, 911 and 682;  $\delta(\text{CDCl}_3; 400 \text{ MHz})$ : see Fig. 1 for numbering system) 1.15 (d,  $J$  7.1, 3'-Me), 1.25–1.35 (m, H<sub>g</sub>), 1.43 (s, 1'-Me), 1.49 (s, 1-Me), 1.60–1.70 (m, H<sub>g</sub>, H<sub>r</sub>), 1.85–2.00 (m, H<sub>i</sub>, H<sub>m</sub>, H<sub>n</sub>, H<sub>o</sub>, H<sub>p</sub>), 2.02–2.10 (m, H<sub>k</sub>), 2.16–2.22 (m, H<sub>j</sub>), 2.26 (d,  $J_{\text{ie}}$  18.6 Hz, H<sub>i</sub>), 2.38 (d,  $J_{\text{hf}}$  17.9 Hz, H<sub>h</sub>), 2.77 (dq,  $J_{\text{gMe}}$  7.1 and  $J_{\text{gk}}$  3.1 Hz, H<sub>g</sub>), 3.23 (d,  $J_{\text{fh}}$  17.9 Hz, H<sub>f</sub>), 3.30 (d,  $J_{\text{ei}}$  18.6 Hz, H<sub>e</sub>),

4.34 (dd,  $J_{\text{do}}$  7.3 and  $J_{\text{dt}}$  2.7 Hz, H<sub>d</sub>), 4.43 (dd,  $J_{\text{cs}}$  11.9 and  $J_{\text{cm}}$  1.6 Hz, H<sub>c</sub>), 5.19 (s, H<sub>b</sub>) and 5.22 (s, H<sub>a</sub>) ( $M$ , 389.1892. C<sub>22</sub>H<sub>29</sub>O<sub>6</sub> requires 389.1963).

3-(2'-Methyl-3'-oxocycloheptyl)-2-methylenecycloheptanones **7**.—A degassed solution of 2-methylcyclohept-2-enone (0.74 g, 6 mmol) and 2-trimethylsiloxybuta-1,3-diene (4.27 g, 30 mmol) in dry THF was irradiated in a Pyrex vessel using a 125 W medium pressure immersion lamp. Reaction was incomplete after 12 h, and chromatography using light petroleum-ether (4:1) as eluant yielded a white crystalline product **7a** (0.215 g, 29%), a colourless oily product **7b** (0.205 g, 28%) and recovered starting material (0.144 g, 19%), data for **7a**: m.p. 90–92 °C;  $\nu_{\max}/\text{cm}^{-1}$  (CHCl<sub>3</sub>) 3025, 3014, 2932, 2861, 1693 (2 × C=O), 1608 (C=O), 1451, 1233, 1167, 720 and 662;  $\delta(\text{CDCl}_3; 400 \text{ MHz})$  1.06 (d,  $J$  7.0 Hz, Me), 1.09–1.13 (m, H-4'<sub>a</sub>), 1.21–1.33 (m, H-5'<sub>a</sub>), 1.45–1.85 (m, H-4'<sub>b</sub>, H-5'<sub>b</sub>, 6'-CH<sub>2</sub>, 4-CH<sub>2</sub>, 5-CH<sub>2</sub>, 6-CH<sub>2</sub>), 2.61–2.74 (m, H-2, 7'-CH<sub>2</sub>, 7-CH<sub>2</sub>), 5.19 (d,  $J$  1.5 Hz, H<sub>b</sub>), 5.74 (d,  $J$  1.5 Hz, H<sub>a</sub>); (Found: C, 77.35; H, 9.80. C<sub>16</sub>H<sub>24</sub>O<sub>2</sub> requires C, 77.4; H, 9.75%). Data for **7b**:  $\nu_{\max}/\text{cm}^{-1}$  (CHCl<sub>3</sub>) 3089, 2931, 2861, 1695 (2 × C=O), 1607 (C=C), 1414, 1110, 937 and 893;  $\delta(\text{CDCl}_3; 400 \text{ MHz})$  0.93 (d,  $J$  7.0 Hz, Me), 1.16–1.94 (m, 4-CH<sub>2</sub>, 5-CH<sub>2</sub>, 6-CH<sub>2</sub>, 4'-CH<sub>2</sub>, 5'-CH<sub>2</sub>, 6'-CH<sub>2</sub>), 2.27–2.45 (m, H-2'<sub>a</sub>, H-7'<sub>b</sub>, H-3, H-3'), 2.50 (ddd,  $J$  18.60, 10.5 and 2.45 Hz, H-7<sub>a</sub>), 2.62–2.76 (m, H-7'<sub>a</sub>, H-7<sub>b</sub>), 5.19 (d, 1.6 Hz, H<sub>b</sub>) and 5.79 (d,  $J$  1.6 Hz, H<sub>a</sub>); ( $M$ , 266.2120. C<sub>16</sub>H<sub>24</sub>O<sub>2</sub> requires 266.2120).

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