

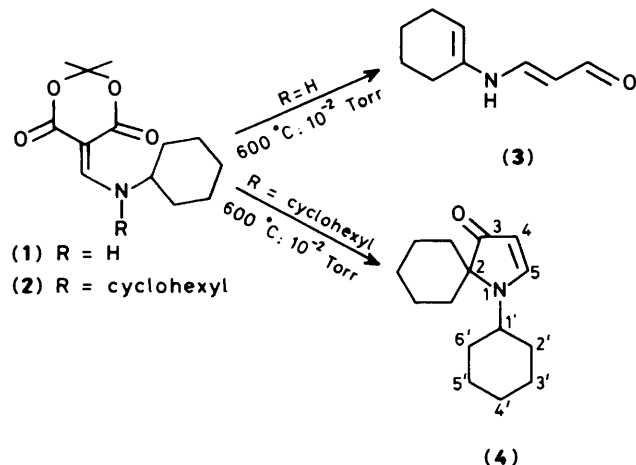
3-Hydroxypyrroles and 1*H*-Pyrrol-3(2*H*)-ones. Part 1. Formation and X-Ray Crystal and Molecular Structure of 1-Cyclohexyl-2,2-pentamethylene-1*H*-pyrrol-3(2*H*)-one

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The title compound (4) is formed by flash vacuum pyrolysis of a dicyclohexylaminomethylene derivative of Meldrum's acid, (2), and its structure was determined by X-ray crystallography. Deuterium-labelling studies show that the reaction mechanism involves a specific, intramolecular, rate-determining hydrogen transfer from the 1-position of a cyclohexyl ring to form the 4-hydrogen atom in the product.

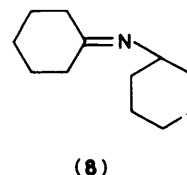
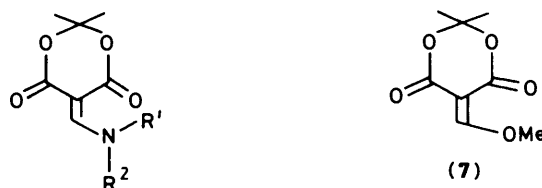
In a preliminary communication,¹ we have described the diverse thermal behaviour of *N*-alkylaminomethylene derivatives of Meldrum's acid (2,2-dimethyl-1,3-dioxane-4,6-dione). Secondary derivatives [e.g. (1)] give open-chain compounds [e.g. (3)] after a sequence of hydrogen shifts in a methyleneketene² intermediate, initiated by tautomerism to an iminoketene^{3,4} (Scheme). Tertiary derivatives cannot undergo this behaviour, and instead an unusual hydrogen-transfer-cyclisation process takes place to give an efficient synthesis of 1*H*-pyrrol-3(2*H*)-ones (Scheme).^{1,5-7} In this paper, we give details of a typical example of this reaction, together with a full structural characterisation of the product by X-ray crystallography. In addition, we describe the results of experiments which relate to the mechanism of the hydrogen-transfer step.



Scheme.

The precursors (2), (5), and (6) were synthesised by the standard 'one-pot' method⁸ from Meldrum's acid, triethyl orthoformate, and the appropriate amine at reflux temperature. However, the yield (based on the amine) could be improved significantly by treatment of the methoxymethylene derivative (7)⁸ with a slight excess of the amine, in acetonitrile at room temperature. [¹⁻²H]-Labelled dicyclohexylamine, required for the preparation of the deuteriated compound (5), was obtained by reduction (LiAl[²H]₄) of the imine (8).

Characterisation of the Meldrum's acid derivatives (2), (5), and (6) was effected by n.m.r. [which typically shows a sharp singlet at δ_H 8.0–8.5 (1 H) due to the methylene proton] and

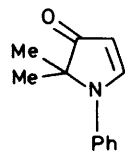


mass spectroscopy. In general, the mass spectra of Meldrum's acid derivatives exhibit sequential loss of acetone, CO₂, and CO from the molecular ion,^{9,10} and this pattern is followed by the *N*-isopropyl-*N*-phenyl compound (6). The spectrum of the *NN*-dicyclohexyl compound (2) is anomalous, since the most intense peak in the high-mass range is due to loss of H₂O following the cleavage of acetone [Found: *m/z*, 259.1568; (*M* - C₃H₆O - H₂O)⁺ (C₁₆H₂₁NO₂) requires *m/z*, 259.1572]. Significantly, the corresponding monodeuteriated compound (5) shows a corresponding doublet at *m/z* 260 and 259, which indicates that one N-CH hydrogen atom is lost in this process, though the structure of the ion formed is unclear at this stage.

Flash vacuum pyrolysis of the Meldrum's acid derivative (2) at 600 °C (10⁻² Torr) gave a good yield of a crystalline material, which condensed at the exit point of the furnace. It was shown by mass spectroscopy to be derived from compound (2) by loss of acetone and carbon dioxide. ¹H N.m.r. spectroscopy shows two mutually coupled protons in the alkene region, whose chemical shifts are widely separated [δ_H 7.82 (d) and 4.97 (d)], suggesting an enone (or enamionone) system, and whose coupling constant (³*J* 3.4 Hz) is typical of a five-membered ring. Whereas the starting material (2) has two C-N methine carbon atoms, the ¹³C n.m.r. spectrum of the product shows just one methine carbon atom and one quaternary carbon atom in this region (δ_C 52.56 and 67.96 respectively). A C-N methine group is therefore the source of the second alkene hydrogen atom (above). These data serve to establish the structure of the

product as the 1*H*-pyrrol-3(2*H*)-one (4), and are supported by a u.v. absorption maximum (λ_{max} , 328 nm) typical of such systems.¹¹

As a second example, the *N*-phenylpyrrolone (9) was formed in 64% yield from the Meldrum's acid derivative (6).



(9)

Because of the scarcity of information on 1*H*-pyrrol-3(2*H*)-ones with small and/or non-polar substituents the structure of compound (4) was determined by *X*-ray crystallography (Tables 1 and 2, and Figures 1 and 2). The five-membered ring is

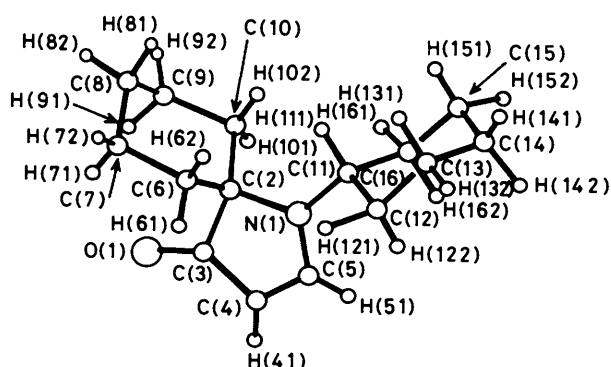


Figure 1. A view of the 1*H*-pyrrol-3(2*H*)-one (4), showing the crystallographic numbering scheme

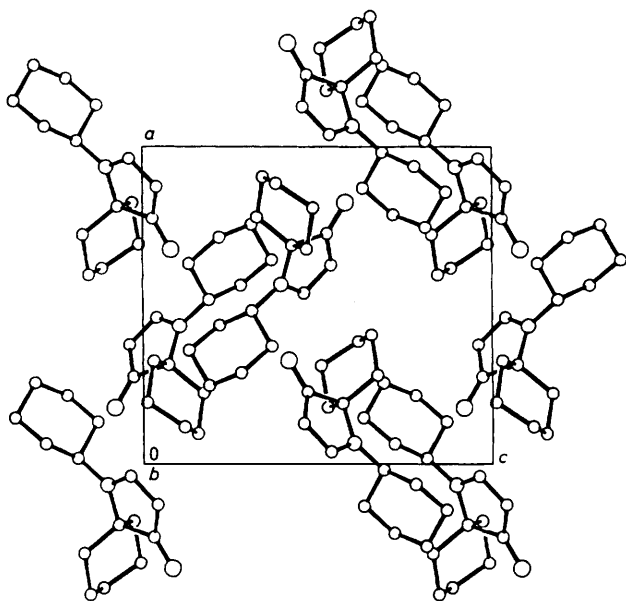


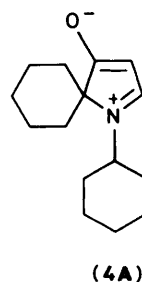
Figure 2. Packing diagram of the 1*H*-pyrrol-3(2*H*)-one (4)

essentially planar, with a maximum intra-ring torsion angle of 1.4°: angles round N(1) and C(3) add to 359.8 and 360.0° respectively and indicate planar co-ordination. The delocalisa-

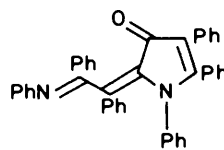
Table 1. Fractional atomic co-ordinates of non-hydrogen atoms of compound (4) with standard deviations in parentheses

x	y	z	
O(1)	0.175 8(6)	0.380 1(5)	0.918 5(5)
N(1)	0.435 2(6)	0.408 9(6)	1.103 6(5)
C(2)	0.311 5(7)	0.456 2(7)	1.072 4(7)
C(3)	0.274 0(9)	0.369 5(8)	0.971 8(7)
C(4)	0.374 0(10)	0.285 7(8)	0.960 3(8)
C(5)	0.462 0(10)	0.314 5(8)	1.038 1(9)
C(6)	0.222 0(9)	0.442 8(10)	1.172 2(9)
C(7)	0.095 0(10)	0.505 8(11)	1.155 1(11)
C(8)	0.115 8(14)	0.636 8(11)	1.117 5(15)
C(9)	0.192 3(11)	0.643 5(10)	1.011 0(11)
C(10)	0.323 1(8)	0.588 9(7)	1.029 8(9)
C(11)	0.517 7(7)	0.466 0(7)	1.188 1(7)
C(12)	0.562 8(9)	0.375 0(8)	1.280 0(7)
C(13)	0.643 1(8)	0.438 9(8)	1.368 4(7)
C(14)	0.754 3(10)	0.500 1(11)	1.310 4(10)
C(15)	0.714 4(10)	0.587 1(10)	1.218 7(9)
C(16)	0.631 1(9)	0.525 2(10)	1.131 4(8)

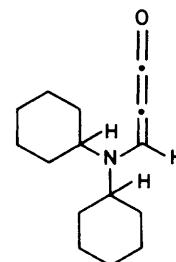
tion of the enaminone system, implicit in the canonical form (4A), is demonstrated by the lengths of the C(3)–C(4) and N(1)–C(5) bonds (1.416 and 1.317 Å) which are significantly shorter than in the analogous structure (10)¹² (1.462 and 1.402 Å respectively) in which exocyclic delocalisation can compete. Both cyclohexane rings adopt a chair conformation with similar structural parameters. All C–H bonds refine to between 0.80 and 1.16 Å. The low crystal density of 1.14 g cm⁻³ is explained by the packing pattern, which leaves unfilled channels throughout the crystal. The only notable non-bonded intermolecular contacts involve the carbonyl oxygen atom, and are O(1)···C(5) (3.17 Å), and also H(91)···H(121) (2.16 Å).



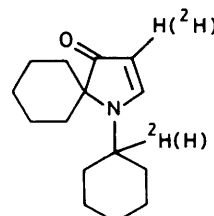
(4A)



(10)



(11)



(12)

Table 2. Bond lengths, bond angles, and torsion angles of compound (4) with standard deviations in parentheses

(a) Bond lengths			
O(1)–C(3)	1.221(11)	C(7)–C(8)	1.519(19)
N(1)–C(2)	1.464(10)	C(8)–C(9)	1.481(19)
N(1)–C(5)	1.317(12)	C(9)–C(10)	1.535(15)
N(1)–C(11)	1.458(10)	C(11)–C(12)	1.537(12)
C(2)–C(3)	1.557(12)	C(11)–C(16)	1.524(13)
C(2)–C(6)	1.507(13)	C(12)–C(13)	1.508(12)
C(2)–C(10)	1.544(12)	C(13)–C(14)	1.520(14)
C(3)–C(4)	1.416(13)	C(14)–C(15)	1.491(16)
C(4)–C(5)	1.339(14)	C(15)–C(16)	1.508(15)
C(6)–C(7)	1.535(16)		
(b) Bond angles			
C(2)–N(1)–C(5)	109.4(7)	C(2)–C(6)–C(7)	114.6(9)
C(2)–N(1)–C(11)	123.9(6)	C(6)–C(7)–C(8)	109.6(10)
C(5)–N(1)–C(11)	126.5(7)	C(7)–C(8)–C(9)	111.5(11)
N(1)–C(2)–C(3)	101.5(6)	C(8)–C(9)–C(10)	111.4(10)
N(1)–C(2)–C(6)	110.3(7)	C(2)–C(10)–C(9)	109.9(8)
N(1)–C(2)–C(10)	110.0(6)	N(1)–C(11)–C(12)	112.0(7)
C(3)–C(2)–C(6)	110.6(7)	N(1)–C(11)–C(16)	111.9(7)
C(3)–C(2)–C(10)	111.1(6)	C(12)–C(11)–C(16)	109.1(7)
C(6)–C(2)–C(10)	112.9(7)	C(11)–C(12)–C(13)	110.2(7)
O(1)–C(3)–C(2)	122.7(8)	C(12)–C(13)–C(14)	110.4(8)
O(1)–C(3)–C(4)	131.4(9)	C(13)–C(14)–C(15)	112.0(9)
C(2)–C(3)–C(4)	105.9(7)	C(14)–C(15)–C(16)	110.9(9)
C(3)–C(4)–C(5)	108.2(9)	C(11)–C(16)–C(15)	111.8(8)
N(1)–C(5)–C(4)	114.9(9)		
(c) Torsion angles			
C(5)–N(1)–C(2)–C(3)	–1.3(8)		
C(5)–N(1)–C(2)–C(6)	116.0(8)		
C(5)–N(1)–C(2)–C(10)	–118.9(8)		
C(11)–N(1)–C(2)–C(3)	174.2(7)		
C(11)–N(1)–C(2)–C(6)	–68.6(9)		
C(11)–N(1)–C(2)–C(10)	56.5(9)		
C(2)–N(1)–C(5)–C(4)	0.7(11)		
C(11)–N(1)–C(5)–C(4)	–174.6(8)		
C(2)–N(1)–C(11)–C(12)	128.2(7)		
C(2)–N(1)–C(11)–C(16)	–108.9(8)		
C(5)–N(1)–C(11)–C(12)	–57.2(11)		
C(5)–N(1)–C(11)–C(16)	65.7(10)		
N(1)–C(2)–C(3)–O(1)	–178.2(8)		
N(1)–C(2)–C(3)–C(4)	1.4(8)		
C(6)–C(2)–C(3)–O(1)	64.8(11)		
C(6)–C(2)–C(3)–C(4)	–115.7(8)		
C(10)–C(2)–C(3)–O(1)	–61.3(10)		
C(10)–C(2)–C(3)–C(4)	118.2(8)		
N(1)–C(2)–C(6)–C(7)	171.7(8)		
C(3)–C(2)–C(6)–C(7)	–76.8(10)		
C(10)–C(2)–C(6)–C(7)	48.2(11)		
N(1)–C(2)–C(10)–C(9)	–173.2(7)		
C(3)–C(2)–C(10)–C(9)	75.3(9)		
C(6)–C(2)–C(10)–C(9)	–49.6(10)		
O(1)–C(3)–C(4)–C(5)	178.5(10)		
C(2)–C(3)–C(4)–C(5)	–1.1(10)		
C(3)–C(4)–C(5)–N(1)	0.2(12)		
C(2)–C(6)–C(7)–C(8)	–50.5(13)		
C(6)–C(7)–C(8)–C(9)	56.8(14)		
C(7)–C(8)–C(9)–C(10)	–61.7(14)		
C(8)–C(9)–C(10)–C(2)	56.6(12)		
N(1)–C(11)–C(12)–C(13)	–177.5(7)		
C(16)–C(11)–C(12)–C(13)	57.9(9)		
N(1)–C(11)–C(16)–C(15)	178.4(7)		
C(12)–C(11)–C(16)–C(15)	–57.0(10)		
C(11)–C(12)–C(13)–C(14)	–57.7(10)		
C(12)–C(13)–C(14)–C(15)	56.6(11)		
C(13)–C(14)–C(15)–C(16)	–55.0(12)		
C(14)–C(15)–C(16)–C(11)	55.9(11)		

Table 3. Isotope effects (k_H/k_D) in the formation of spiropyrrone (12) from dioxanedione (5)

Pyrolysis temperature (°C)	Equation			Average
	Equation 1	Equation 2	Equation 3	
500	1.98 ± 0.14	1.69 ± 0.14	—	1.84
550	1.81 ± 0.07	1.67 ± 0.10	1.83	1.77
600	2.15 ± 0.13	1.71 ± 0.15	1.86	1.91
650	2.08 ± 0.15	1.69 ± 0.13	2.01	1.93

The mechanism of the formation of 1*H*-pyrrol-3(2*H*)-ones from aminomethylene Meldrum's acid derivatives probably involves a methyleneketene² intermediate, [*cf.* (11)], which has been observed spectroscopically in some related examples.¹³ Subsequent steps require the transfer of a *C*-hydrogen atom from a site adjacent to nitrogen, followed by the final cyclisation to form the five-membered ring. The hydrogen-transfer step is of particular interest, since it allows specific thermal functionalisation at a site α to a *non-activated* nitrogen atom. Although some related reactions have been reported recently^{14,15} the present example is especially suited for detailed study because of the ready availability of the precursors, and the absence of complicating side-reactions.¹⁴

First, we have established the specificity of the hydrogen transfer, by the pyrolysis of the monodeuterated compound (5), in which a protium atom and a deuterium atom are located at the two sites of potential reaction. Investigation of the product by ¹H and ²H n.m.r. spectroscopy reveals that the transferred deuterium atom is located exclusively at C(4) and, as expected, unchanged deuterium remains at the 1-position of the *N*-cyclohexyl ring, (12). Further, the mass spectrum of this material, formed by competitive transfer of protium and deuterium, shows the absence of dideuterated and undeuterated species, which strongly suggests that the reaction is intramolecular. This conclusion was confirmed by a copyrolysis of compounds (5) and (6): no cross-over incorporation of deuterium into product (9) could be detected by ¹H n.m.r. spectroscopy of the product mixture. We therefore conclude that the hydrogen transfer is a highly specific intramolecular process, though the present results give no indication of the mechanism of the transfer, which may be diradical,¹ dipolar,⁷ or concerted with the cyclisation.¹⁶ We hope to comment on these possibilities in a later Part of this series.

The distribution of protium and deuterium in compound (12), as formed from dione (5), gives a direct measure of the isotope effect for the transfer process. Little work has been carried out on isotope effects under flash vacuum pyrolysis conditions though small values of k_H/k_D (*ca.* 1.5–3.0 at 400–800 °C) have been reported in cases in which the hydrogen shift is clearly rate determining.^{17–19} In addition, isotope effects are expected to decrease with temperature,²⁰ though the interpretation of certain anomalous features in this context is a matter of recent debate.^{21,22} In the present case, we have studied the isotope effect (k_H/k_D) over the maximum temperature range (500–650 °C) at which a significant yield of product was obtained. The results were calculated from the integral values of peaks in three ways [equations (1)–(3)], which allows a direct assessment of their consistency (Table 3).

$${}^1\text{H n.m.r.: } k_H/k_D = \frac{{}^1\text{H}(4)}{{}^1\text{H}(5) - {}^1\text{H}(4)} \quad (1)$$

$$k_H/k_D = \frac{{}^1\text{H}(4)}{{}^1\text{H}(1)} \quad (2)$$

$${}^2\text{H n.m.r.: } k_H/k_D = \frac{{}^2\text{H}(1)}{{}^2\text{H}(4)} \quad (3)$$

[The numbering scheme is as shown in structure (4)].

The results (Table 3) show a small but significant isotope effect (k_H/k_D ca. 1.9) with only reasonable consistency (± 5 –10%). By comparison with the literature data^{17–19} it therefore seems likely that the hydrogen transfer is rate determining. Under our conditions and at our level of accuracy, the isotope effect is apparently independent of temperature, though the wider mechanistic implications of this result must await related studies on other hydrogen-transfer processes.

Experimental

Unless otherwise stated, ¹H, ²H, and ¹³C n.m.r. spectra were recorded at 80, 30, and 20 MHz respectively, on Bruker WP80, Bruker WP200, and Varian CFT 20 spectrometers. Chemical shifts are reported relative to SiMe₄.

N-[1-²H]Cyclohexylcyclohexylamine.—(a) *N*-Cyclohexylidene-cyclohexylamine (8). A solution of cyclohexylamine (20 g, 0.2 mol) and cyclohexanone (20 g, 0.2 mol) in toluene (200 ml) containing toluene-*p*-sulphonic acid (0.4 g) was heated under reflux for 3 h, using a Dean-Stark trap to remove the water which was formed. The solvent was evaporated off under reduced pressure and the residue was distilled (Kugelrohr) to give the imine (8) (18.7 g, 52%), b.p. 120–130 °C (1.0 Torr) [lit.²³ 135–137 °C (20 Torr)]; δ_C (CDCl₃) 170.04 (q), 57.39, 39.77, 33.70, 28.55, 27.42, 27.12, 25.75, 25.21, and 24.59.

(b) *N*-[1-²H]Cyclohexylcyclohexylamine. A solution of the above imine (5.03 g, 28 mmol) in dry ether (50 ml) was added under dry nitrogen to a suspension of [²H₄]lithium aluminium hydride (1.0 g, 23 mmol) in dry ether (150 ml). The mixture was heated under reflux for 35 min, cooled, and the excess of hydride was carefully decomposed with wet ether (20 ml) and water (30 ml). After the successive addition of aqueous potassium sodium tartrate (20%; 80 ml) and aqueous sodium hydroxide (10%; 30 ml), the organic layer was separated, and the aqueous layer was extracted with ether (2 × 100 ml). The combined organic layers were dried (MgSO₄), concentrated, and distilled (Kugelrohr) to give the title labelled amine (3.96 g, 78%), b.p. 140–145 °C (30 Torr), [lit.²⁴ 136–138 °C (26 Torr) for undeuterated compound].

5-(2,2-Disubstituted-2-azaethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione Derivatives.—Method A.^{3,8} A solution of Meldrum's acid (2,2-dimethyl-1,3-dioxane-4,6-dione) (1.44 g, 10 mmol) in triethyl-orthoformate (12 ml) was heated under reflux for 2 h. The appropriate secondary amine (12.5 mmol) was added, and the mixture was heated for a further 2 h. The product crystallised when the solution was cooled, or after partial evaporation of the solvent.

Method B. A solution of 5-methoxymethylene-2,2-dimethyl-1,3-dioxane-4,6-dione (7)⁸ (10 mmol) and the appropriate amine (11 mmol) in acetonitrile (10 ml) was set aside at room temperature for 5 min. Evaporation of the solvent under reduced pressure gave the product as a crystalline solid.

The following derivatives were made by these methods: 5-(2,2-Dicyclohexyl-2-azaethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione (2). (Method A, 67%; Method B, 99%), m.p. 170–171 °C (from ethanol) (Found: C, 67.8; H, 8.45; N, 4.3. C₁₉H₂₉NO₄ requires C, 68.05; H, 8.05; N, 4.2%); δ_H (CDCl₃) 8.15 (1 H, s), 4.36 (1 H, br s), 3.29 (1 H, br s), 1.0–2.1 (20 H, m), and 1.67 (6 H, s); δ_C (CDCl₃) (50 MHz) 163.47 (br q), 156.35, 102.08 (q), 83.03 (q), 63.89, 58.74, 34.40, 30.74, 26.43, 25.54, 25.21, 24.94, and 24.59; m/z 335 (*M*⁺, 1%), 277 (11), 259 (22), 204 (14), 150 (14), 110 (19), 98 (24), 83 (43), 67 (31), and 55 (100).

5-(2-[1-²H]Cyclohexyl-2-cyclohexyl-2-azaethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione (5) (Method A, 46%), m.p. 166–168 °C; δ (²H) (CHCl₃) 4.35 (s) and 3.30 (s); m/z 336 (*M*⁺, 10%), 278 (70), 260 (100), 205 (38), 204 (33), and 55 (83).

5-(2-Isopropyl-2-phenyl-2-azaethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione (6) (Method A, 63%), m.p. 166–167 °C (from ethanol) (Found: C, 66.2; H, 6.45; N, 4.5. C₁₆H₁₉NO₄ requires C, 66.45; H, 6.55; N, 4.85%); δ_H (CDCl₃) (peaks of minor rotamer given in parenthesis) 8.35 (8.12) (1 H, s), 7.0–7.5 (5 H, m), 5.10 (5.35) (1 H, m), 1.58 (1.72) (6 H, s), and 1.40 (1.21) (6 H, d); δ_C (CDCl₃) (major rotamer only) 160.08 (q), 156.05, 143.13 (q), 129.04, 127.98, 124.97, 102.61 (q), 86.50 (q), 62.79, 26.63, and 22.28; m/z 289 (*M*⁺, 9%), 232 (22), 231 (100), 186 (19), 158 (50), 144 (34), and 118 (56).

1H-Pyrrol-3(2H)-ones (General Method).—The appropriate Meldrum's acid derivative was sublimed at 10^{–2}–10^{–3} Torr through a furnace tube (35 × 2.5 cm) which was maintained at 600 °C. The product was collected in a U-tube which was cooled by liquid nitrogen, and situated at the exit point of the furnace. The following 1H-pyrrol-3(2H)-ones were prepared.

1-Cyclohexyl-2,2-pentamethylene-1H-pyrrol-3(2H)-one (4) [from the 2,2-dicyclohexyl derivative (2.0 g, 6 mmol); sublimation temperature 180–200 °C; pyrolysis time 5 h] (1.02 g, 73%), m.p. 200–202 °C (from toluene) (Found: C, 77.05; H, 9.9; N, 6.1. C₁₅H₂₃NO requires C, 77.2; H, 9.95; N, 6.0%); δ_H (CDCl₃) 7.82 (1 H, d, ³J_{4,5} 3.4 Hz), 4.97 (1 H, d, ³J_{4,5} 3.4 Hz), 3.14 (1 H, m), and 1.0–2.3 (20 H, m); δ_C (CDCl₃) 205.61 (q), 158.39, 94.23, 67.96 (q), 52.56, 34.61, 30.31, 25.77, 24.90, 24.69, and 19.42; m/z 233 (*M*⁺, 97%), 178 (100), 150 (48), 122 (27), 95 (28), 81 (35), and 55 (58); λ_{max} 328 nm (ϵ 12 400).

2,2-Dimethyl-1-phenyl-H-pyrrol-3(2H)-one [from the 2-isopropyl-2-phenyl derivative (0.60 g, 2.1 mmol); sublimation temperature 140–160 °C; pyrolysis time 1.5 h] (0.25 g, 64%), m.p. 85–87 °C (from hexane) (Found: C, 76.8; H, 7.15; N, 7.3. C₁₂H₁₃NO requires C, 77.0; H, 6.95; N, 7.5%); δ_H (CDCl₃) 8.10 (1 H, d, ³J_{4,5} 3.6 Hz), 7.0–7.5 (5 H, m), 5.37 (1 H, d, ³J_{4,5} 3.6 Hz), and 1.36 (6 H, s); δ_C (CDCl₃) 205.73 (q), 160.19, 139.88 (q), 129.39, 125.47, 121.99, 99.11, 68.65 (q), and 23.04; m/z 187 (*M*⁺, 59%), 172 (15), 158 (26), 144 (37), and 118 (100).

Pyrolyses of 5-(2-[1-²H]Cyclohexyl-2-cyclohexyl-2-azaethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione (5).—(a) 600 °C Pyrolysis. A sample of the [²H]-labelled compound (0.10 g) was pyrolysed under the standard conditions at 600 °C (5–10 × 10^{–3} Torr). The pyrrolone product (0.04 g, 58%) had δ_H (CDCl₃) 7.80 (1 H, superimposed s and d), 4.95 (<1 H, d), 3.10 (<1 H, br s), and 1.0–2.3 (20 H, m); δ (²H) (CHCl₃) 4.98 and 3.10; m/z 234 (*M*⁺, 100%) and 179 (83); significant (*M* + 1) and (*M* – 1) peaks were absent.

(b) *Co-pyrolysis with the 2-isopropyl-2-phenyl derivative (6).* Samples of the [²H]-labelled compound (5) (0.057 g, 0.16 mmol) and the 2-isopropyl-2-phenyl derivative (6) (0.064 g, 0.24 mmol) were sublimed at 155 °C and 10^{–3} Torr during 15 min into the furnace, which was maintained at 600 °C. Problems of differential volatility were overcome by placing the former compound on a foil boat, and the latter in a small test-tube, within the inlet heater. The mixture of pyrrolones so obtained, analysed by ¹H n.m.r. spectroscopy, showed clean doublets at δ_H 8.13 and 5.40 (integral ratio 1:1) due to the 2,2-dimethyl-1-phenyl compound (9), and a more intense superimposed doublet and singlet (δ_H 7.80) and a doublet (δ_H 4.94) (integral ratio 1:0.56) corresponding to the labelled 1-cyclohexyl-2,2-pentamethylene derivative (4). No scrambling of deuterium could be detected.

(c) *Measurement of isotope effect for the hydrogen transfer.* Problems of reproducibility were encountered, partly because of ready back-exchange of deuterium from the 4-position, and partly because of the requirement for very accurate peak integration. Control experiments at the optimum temperature (600 °C) showed that recrystallisation of the product from

toluene gave much better spectra without significant alteration of the relative areas, and so this procedure was adopted at all temperatures used (500, 550, 600, and 650 °C; only low yields of pyrrolone were obtained at temperatures below 500 and above 650 °C). In practice, pyrolysis of 150–300 mg generally gave a sample (40–80 mg) of purified material, which was divided into two portions and was analysed by ^1H and ^2H n.m.r. spectroscopy. The results are given in Table 3.

Crystal Data for 1-Cyclohexyl-2,2-pentamethylene-1H-pyrrol-3(2H)-one.— $\text{C}_{15}\text{H}_{23}\text{NO}$, $M_r = 233.4$, orthorhombic, space group $P2_12_12_1$, $a = 10.672(4)$, $b = 10.986(4)$, $c = 11.581(4)$ Å, $v = 1357.8$ Å³, $Z = 4$, $D_c = 1.141$ g cm⁻³, $\lambda(\text{Mo-K}\alpha) = 0.71069$ Å, $\mu = 0.66$ cm⁻¹, $F(000) = 512$, $T = 293$ K. Final $R = 0.055$ from 693 observed reflections.

A clear crystal of dimensions $0.2 \times 0.2 \times 0.2$ mm was used; intensities of 1300 unique reflections were measured out to θ 25° using a Nonius CAD-4 diffractometer with graphite monochromator; 693 reflections with $I > 2.5\sigma(I)$ were used in refinement; the structure was solved by direct methods.²⁵ All hydrogen atoms except the methylene hydrogens on C(13) were located on difference Fourier maps, and positional and isotropic thermal parameters were refined. H(131) and H(132) were included in their calculated position with fixed thermal parameters. Non-hydrogen atoms were refined anisotropically. The maximum ratio of least-squares fit to error was 0.11. Maximum and minimum peak heights in the final difference map are 0.19 and 0.17 e Å⁻³. The weighting scheme was $w = 1/[\sigma^2(F) + 0.0008F^2]$ which gave a final R 0.055 and R_w 0.058.

Fractional co-ordinates for all atoms are given in Table 1. Bond lengths, bond angles, and selected torsion angles are given in Table 2. Thermal parameters have been deposited as Supplementary Publication No. SUP 56565 (3 pp).^{*} A labelled drawing of the molecule is given in Figure 1 and a packing diagram in Figure 2.

^{*} For details of the Supplementary Publications Scheme, see Instructions for Authors (1986), *J. Chem. Soc., Perkin Trans. 1*, 1986, issue 1. Structure factor tables are available from the editorial office on request.

References

- H. J. Gordon, J. C. Martin, and H. McNab, *J. Chem. Soc., Chem. Commun.*, 1983, 957.
- J. Besida and R. F. C. Brown, *Aust. J. Chem.*, 1982, **35**, 1385, and earlier papers in the series.
- H. J. Gordon, J. C. Martin, and H. McNab, *J. Chem. Soc., Perkin Trans. 1*, 1984, 2129.
- H. Briehl, A. Lukosch, and C. Wentrup, *J. Org. Chem.*, 1984, **49**, 2772.
- H. McNab and L. C. Monahan, *J. Chem. Soc., Chem. Commun.*, 1985, 213.
- E. Anklam, R. Ghaffari-Tabrizi, H. Hombrecher, S. Lau, and P. Margaretha, *Helv. Chim. Acta*, 1984, **67**, 1402.
- H. Dhimane, J. C. Pommelet, J. Chucho, G. Lhommet, M. G. Richaud, and M. Haddad, *Tetrahedron Lett.*, 1985, **26**, 833.
- G. A. Bihlmayer, G. Derflinger, J. Derkosch, and O. E. Polansky, *Monatsh. Chem.*, 1967, **98**, 564.
- H. Egger, *Monatsh. Chem.*, 1967, **98**, 1245.
- H. McNab and I. Stobie, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1845.
- For example, J. Davoil, *J. Chem. Soc.*, 1953, 3802.
- K.-H. Klaska, O. Jarchow, T. Eicher, and H. Preut, *Acta Crystallogr., Sect. B*, 1979, **35**, 2788.
- H. Briehl and C. Wentrup, unpublished work, quoted in footnote 29 of ref. 4.
- H. McNab and E.-A. Murray, *J. Chem. Soc., Chem. Commun.*, 1981, 722, and unpublished results.
- W. Klop and L. Brandsma, *J. Chem. Soc., Chem. Commun.*, 1983, 988.
- Cf. A. Viola, J. J. Collins, and N. Filipp, *Prepn., Div. Pet. Chem., Am. Chem. Soc.*, 1979, **24**, 206.
- C. H. De Puy and R. W. King, *Chem. Rev.*, 1960, **60**, 431.
- W. S. Trahanovsky and C. C. Ong, *J. Am. Chem. Soc.*, 1970, **92**, 7174.
- W. S. Trahanovsky and M. E. Scribner, *J. Am. Chem. Soc.*, 1984, **106**, 7976.
- K. Wiberg, *Chem. Rev.*, 1955, **55**, 713.
- H. Kwart, *Acc. Chem. Res.*, 1982, **15**, 401.
- D. J. McLennan and P. M. W. Gill, *J. Am. Chem. Soc.*, 1985, **107**, 2971.
- Shell Devel. Co., U.S.P. 2 418 173/1944, quoted in 'Beilstein,' drittes Ergänzungswerk, 1972, vol. 12, p. 32.
- G. S. Hiers and R. Adams, *Chem. Ber.*, 1926, **59**, 162.
- G. Sheldrick. SHELX 84, Program for Crystal Structure Solution, University of Göttingen, 1984.

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