Conformation and Intermolecular Interactions of Meldrum's Acid: An X-Ray Structural Investigation of 2,2-Dimethyl-1,3-dioxane-4,6-dione

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The solid-state conformation of the title compound has been shown to be a boat, using single-crystal X-ray diffraction methods. Crystallographic data are: $a = 6.055(3)$, $b = 13.746(3)$, $c = 16.629(5)$ Å, orthorhombic, *Pbca*, $Z = 8$, $D_x = 1.382$ Mg m^{-3}. Full-matrix least-squares refinement of 1 100 diffractometer-measured unique reflections yielded a final weighted R of 0.040. The existence of a relatively short intermolecular C–H $\cdots$ O approach [H $\cdots$ O = 2.43 (3) Å], which is considered to be a hydrogen bond interaction, was established.

Meldrum[1] first carried out the condensation of malonic acid and acetone in the presence of acetic anhydride and sulphuric acid to produce a compound having acidic properties which he assumed to be the β-lactone of β-hydroxyisopropylmalonic acid. It was not until the work of Davidson and Bernhard[2] that 'Meldrum's Acid' was shown to to be the cyclic ester, 2,2-dimethyl-1,3-dioxane-4,6-dione, whose relatively high acidity, pK_a 4.83—4.93,[3,4] can be attributed to the presence of hydrogen atoms attached to a carbon atom which is α to two carbonyl groups. Despite this acidic character, i.r. spectroscopy,[5–7] u.v. spectrophotometry,[4,8] and ^{13}C n.m.r.[9] studies have shown that Meldrum's Acid does not enolize to any appreciable extent in either the solid state or in solution. The enolate anion, on the other hand, is a readily formed, stable, species whose susceptibility to electrophilic attack as well as the susceptibility to nucleophilic attack of the carbonyl groups of Meldrum's Acid accounts for most of its chemistry and makes it a compound of considerable synthetic versatility.[10,11]

The main points of interest in the structure of Meldrum's Acid, which were the incentives for this study, are: (a) the question of its conformation which has not been fully answered although the concensus of opinion favours a boat, and (b) its acidic character along with its lack of enolization which suggests the possibility of C–H $\cdots$ O hydrogen bonding.

Experimental

Meldrum's Acid was synthesized according to the procedure of Davidson and Bernhard.[2] Crystals, elongated along the *a* axis, were obtained by the slow cooling of a cyclohexane solution of the compound.

Crystal Data.—$C_6H_8O_4$, $M = 144.13$. Orthorhombic, $a = 6.055(3)$, $b = 13.746(3)$, $c = 16.629(5)$ Å, $V = 1$ 384.1(9) Å^3 (by least-squares refinement of observed 2θ values for 22 high-angle reflections well distributed in reciprocal space, $\lambda = 0.710$ 69 Å), space group *Pbca*, $Z = 8$, $D_x = 1.382$ Mg m^{-3}.

Data Collection and Processing.—A crystal having approximate dimensions $0.25 \times 0.35 \times 0.40$ mm and mounted with *a*** coincident with the axis of rotation (φ) was used for data collection. A Canberra Industries automated GE XRD-6 quarter-circle diffractometer (θ—2θ mode, $K_{\alpha}1 - _{\alpha}2$ dispersion corrected, scan speed 1° 2θ min^{-1}, 30 s background counts at both ends of scan range was used. No systematic changes in two reference reflections. Zr-filtered Mo-K_{α} radiation, 1 587 unique reflections measured ($\sin\theta/\lambda \leqslant 0.650$ Å^{-1}). Of the 1 587 measured reflections, a data set consisting of 1 100 reflections was obtained for use in the structure solution and refinement steps by excluding those reflections considered to be unobserved

Table. Atomic co-ordinates with e.s.d.s in parentheses

Atom	x	y	z
O(1)	0.417 5(4)	0.089 7(2)	0.079 2(1)
C(2)	0.579 4(7)	0.044 6(3)	0.130 0(2)
O(3)	0.583 9(4)	0.091 8(2)	0.208 2(1)
C(4)	0.573 9(6)	0.189 5(3)	0.213 3(2)
O(4)	0.592 2(4)	0.227 2(2)	0.278 0(1)
C(5)	0.532 6(6)	0.242 7(3)	0.136 7(2)
C(6)	0.397 5(7)	0.188 1(3)	0.076 3(2)
O(6)	0.275 6(5)	0.223 5(2)	0.028 7(2)
C(21)	0.804 7(8)	0.047 2(4)	0.092 0(3)
C(22)	0.498 0(11)	−0.056 5(3)	0.147 6(4)
H(1)	0.664(5)	0.260(2)	0.115(2)
H(2)	0.460(5)	0.310(2)	0.147(2)
H(3)	0.852(6)	0.108(3)	0.081(2)
H(4)	0.906(6)	0.015(3)	0.127(2)
H(5)	0.804(5)	0.003(2)	0.040(2)
H(6)	0.354(6)	−0.058(3)	0.179(2)
H(7)	0.601(7)	−0.094(3)	0.191(2)
H(8)	0.477(6)	−0.092(3)	0.099(2)

$[I \leqslant 3\sigma(I)]$ occurring above $2\theta = 45°$ ($\sin\theta/\lambda > 0.538$ Å^{-1}) while retaining all measured reflections below $2\theta = 45°$. Background and L_p corrections were applied. Absorption corrections were deemed unnecessary because of the small value of the linear absorption coefficient ($\mu = 1.1$ cm^{-1}, Mo-K_{α}) as well as the lack of a measured φ dependence of *h*00 reflections at $\chi = 90°$.

Structure Analysis and Refinement.—The structure was solved with MULTAN[12] and refined using full-matrix least-squares methods.[13] Atomic scattering factors were from ref. 14 except for hydrogen (from ref. 15). After anisotropic refinement of all non-hydrogen atoms, hydrogen atoms were placed in calculated positions and refined isotropically, assuming the two methyl group hydrogen atoms to be in a staggered configuration with an orientation which minimized the axial hydrogen atoms—axial α-carbon hydrogen atom (H-1) interactions. All least-squares refinements of the hydrogen atomic co-ordinates however converged to the eclipsed methyl group hydrogen atom configuration which can be seen in Figure 1. A final difference map confirmed this configuration as it was free of significant electron density (max. 0.21 e Å^{-3}). The final full-matrix least-squares refinement cycle (123 parameters) converged at R(conventional) = 0.074 and R(weighted) = 0.040. Final refined atomic co-ordinates for all atoms along with their estimated standard deviations are given in the Table. The values
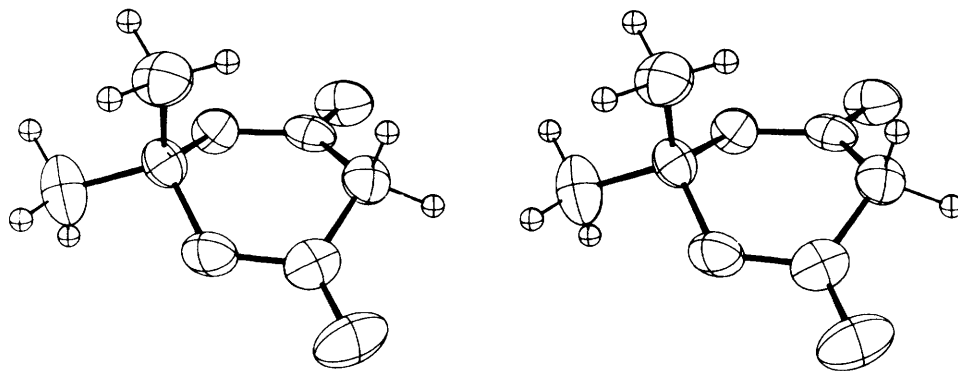
Figure 1. Stereoscopic drawing of Meldrum's Acid. Non-hydrogen thermal ellipsoids are drawn at 50% probability

O(1)-C(2)-C(21)=111·3°
O(3)-C(2)-C(22)=104·1°
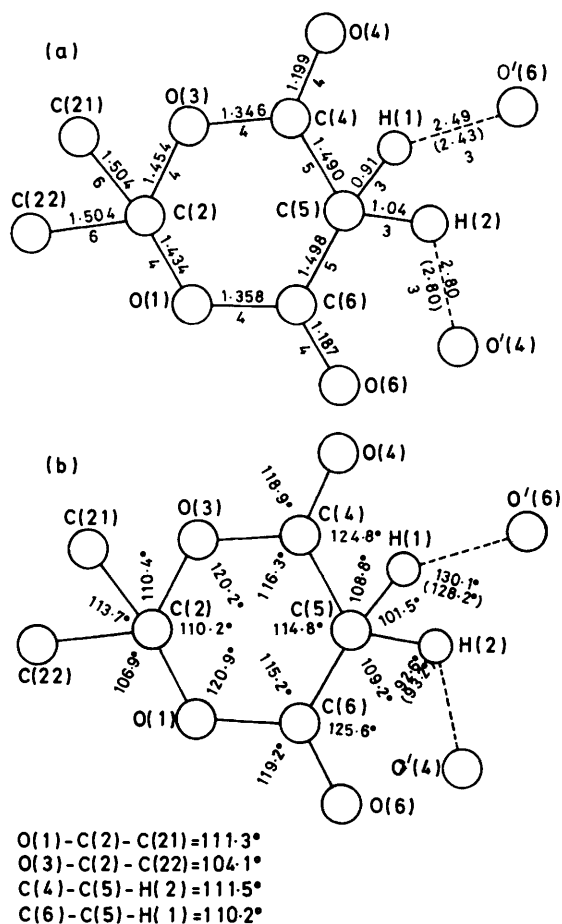C(4)-C(5)-H(2)=111·5°
C(6)-C(5)-H(1)=110·2°

Figure 2. (a) Bond distances (Å) and (b) bond angles (°) for Meldrum's Acid. The e.s.d. of the least significant digit for bond distances is given below each value. The e.s.d.s for bond angles involving non-hydrogen atoms only are *ca.* 0.3° whereas those including a hydrogen atom are *ca.* 2.0°. The values for intermolecular bond distances and angles given in parentheses were calculated using a neutron-diffraction value of 1.007 Å for the involved C-H bond distances

of the thermal parameters are in Supplementary Publication No. SUP 86295 (2 pp.).*

Results and Discussion

Bond distances and angles, along with their estimated standard deviations, are given in Figure 2 which also illustrates the

numbering scheme used. All intramolecular distances and angles are completely normal, agreeing very well with expected values and those found for two previously reported structures of substituted 1,3-dioxane-4,6-diones.[16,17]

Considering the question of the molecular conformation of Meldrum's Acid, it can be seen from Figure 1 that its solid-state conformation is boat. Although the early [1]H n.m.r. studies of Abramovitch *et al.*[18] and Schuster and Schuster[19] as well as the semi-empirical LCAO-MO-SCF calculations of Köberl and Schuster[20] concluded that Meldrum's Acid existed in the chair conformation, the dipole-moment measurements of Klimovit-skii, *et al.*[21] and the n.m.r. studies of Äyräs and Partanen[22] and Äyräs[23] on Meldrum's Acid and a series of its derivatives have shown that in the absence of significant 1,4-steric interactions, the boat conformation is the most favourable. The question thus arises as to the source of this demonstrated preference, both in solution and in the solid state, for the boat conformation. Mathieson[24] proposed, on the basis of reported crystal-structure analyses,[25,26] that the characteristic shape of the lactone group (C-O-CO-C) is planar. The fact that conjugation of the ether oxygen atom with the carbonyl group is at a maximum when the lactone group is planar is undoubtedly the basis for this observation. Since Meldrum's Acid is a cyclic compound free of significant 1,4-steric interactions, and it can be considered as consisting of two lactone groups, the imposition of lactone group planarity requires the molecular conformation to be boat. A least-squares best plane through each of the lactone groups [C(2)O(1)C(6)O(6)C(5) and C(2)O(3)C(4)O(4)C(5)] showed both to be essentially planar with the largest deviation from each plane being shown by C(2) [+0.064(4) and +0.057(4) Å, respectively], thus giving rise to a slightly tighter boat rather than a slightly flattened conformation predicted by Äyräs and Partanen.[22]

Considering the question of possible C-H•••O hydrogen bonding, a calculation of intermolecular approaches revealed the existence of two possible C-H•••O interactions. These approaches are illustrated in the stereo packing diagram of Figure 3. Figure 2 contains the distance and angle information for these approaches derived from both the X-ray-refined co-ordinates of the hydrogen atoms involved [H(1) and H(2)] as well as from the use of a typical neutron diffraction-determined bond length of 1.007 Å, the latter values obviously more closely reflecting reality for the geometrical parameters of the C-H•••O approaches in Meldrum's Acid. Of the two approaches, only one, C(5)-H(1)•••O'(6), falls within a range for which C-H•••O hydrogen-bond arguments can be

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* For details of Supplementary Publications see Instructions for Authors in *J. Chem. Soc., Perkin Trans. 2*, 1985, Issue 1.
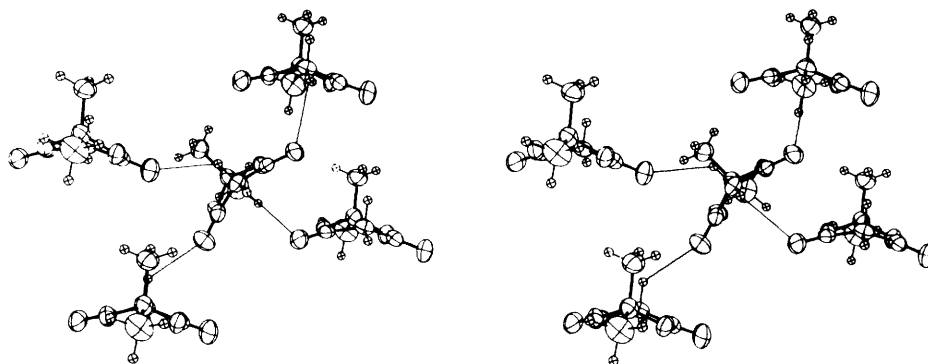
Figure 3. A stereo packing diagram of Meldrum's Acid showing C–H $\cdots$ O interactions

considered.[27] Although the other approach [C(5)–H(2) $\cdots$ O'(4)] is geometrically reasonable for a C–H $\cdots$ O interaction,[27] the H $\cdots$ O distance of 2.80(3) Å is longer than the sum of van der Waals radii[28,29] for oxygen and hydrogen atoms (2.70 Å). It is interesting to note, however, that Berkovitch-Yellin and Leiserowitz,[30] in their recently reported atom–atom potential-energy calculation approach to the question of Coulomb and van der Waals energy contributions to C(sp^3)–H $\cdots$ O, C(sp^2)–H $\cdots$ O, and C(sp)–H $\cdots$ O interactions in various crystal structures, concluded that Coulombic contributions are dominant and are important even for long H $\cdots$ O distances. It thus appears likely that the C(5)–H(2) $\cdots$ O'(4) approach in this structure may play a role in determining its molecular packing. The H $\cdots$ O distance of the C(5)–H(1) $\cdots$ O'(6) approach, on the other hand, is less than the sum of van der Waals radii by ca. 0.3 Å [2.43(3) Å] and thus, on the basis of the arguments presented by Taylor and Kennard[27] in their thorough study of the topic, may be reasonably described as a hydrogen-bond interaction.

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