

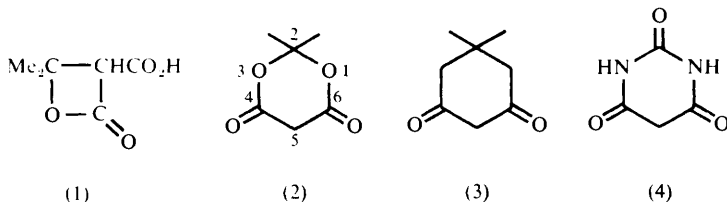
Meldrum's Acid

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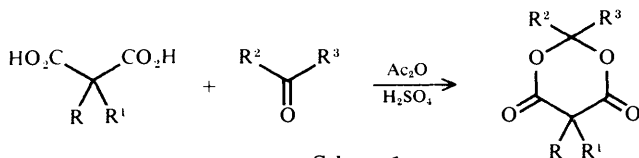
1 Introduction

In 1908, A. N. Meldrum reported that the condensation of malonic acid with acetone, in acetic anhydride containing a small amount of sulphuric acid, gave a white crystalline solid, $C_6H_8O_4$, which *titrated* as a *monobasic* acid and lost carbon dioxide on heating.¹ He reasonably stated that 'there can hardly be a doubt' that the compound was the carboxylic acid (1). Sadly, this structure proved to be quite wrong, though forty years were to elapse before it was deduced that the condensation must involve only the carboxyl groups of the malonic acid. On this basis, Davidson and Bernhard² correctly assigned the structure of 'Meldrum's acid' as 2,2-dimethyl-1,3-dioxan-4,6-dione (2), whose properties therefore relate to those of other cyclic 1,3-diones such as dimedone (3) and barbituric acid (4).



2 Preparation

The original method is invariably used for the preparation of 1,3-dioxan-4,6-diones² (Scheme 1). The procedure has some generality, and derivatives have



Scheme 1

been made by condensing aliphatic³ or aromatic⁴ ketones, or aryl aldehydes,⁵

¹ A. N. Meldrum, *J. Chem. Soc.*, 1908, **93**, 598.

² D. Davidson and S. A. Bernhard, *J. Amer. Chem. Soc.*, 1948, **70**, 3426.

³ B. Eistert and F. Geiss, *Chem. Ber.*, 1961, **94**, 929.

⁴ J. Swoboda, J. Derkosch, and F. Wesely, *Monatsh.*, 1960, **91**, 188.

⁵ A. Michael and N. Weiner, *J. Amer. Chem. Soc.*, 1936, **58**, 680.

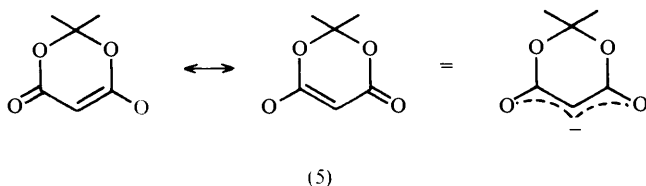
with un-, mono-,^{3,6} or di-substituted^{2,7} malonic acids. The reaction is apparently ineffective for all alkyl aldehydes.

Despite the novelty of the reaction (Scheme 1), its mechanism remains uninvestigated, though it has long been recognized that the first step involves acid catalysed formation of a mixed anhydride of malonic and acetic acids.^{6,8}

An alternative—and unusual—source of Meldrum's acid is from the action of carbon suboxide on acetone in the presence of oxalic acid.⁹ The function of the latter seems to be to supply the elements of water needed for the stoichiometry.¹⁰

3 Physical and Chemical Properties

By the standards of organic chemistry 1,3-dioxan-4,6-dione derivatives are indeed strong acids. Meldrum's acid itself (pK 4.83)¹¹ is comparable in strength to acetic acid (pK 4.76) and is some ten pK units more acidic than acyclic malonate esters. The explanation of this facile proton loss—as with dimedone (pK 5.2)²—lies in the stability of the resultant anion (5), in which the π -orbitals are rigidly held in the ideal configuration for overlap. The menedic¹² properties of this



profoundly stable structure rationalize much of Meldrum's acid chemistry. Surprisingly, the tautomeric properties of dimedone and Meldrum's acid are quite different. The former exists predominantly in the mono-enol form, whereas Meldrum's acid is overwhelmingly (>99.5%) the diketo tautomer.¹³ It seems that no special explanation may be required for this anomaly, since esters are generally enolized to a much smaller extent than ketones.¹⁴

The problem of the conformation of the 1,3-dioxan-4,6-dione system has been approached by n.m.r.¹⁵ and dipole-moment¹⁶ methods. Although there is no

⁶ E. Ott, *Annalen*, 1913, **401**, 159.

⁷ P. J. Scheuer and S. G. Cohen, *J. Amer. Chem. Soc.*, 1958, **80**, 4933.

⁸ A. Michael and J. Ross, *J. Amer. Chem. Soc.*, 1933, **55**, 3684.

⁹ O. Diels, R. Beckmann, and G. Tönnies, *Annalen*, 1924, **439**, 76.

¹⁰ T. Kappe and E. Ziegler, *Angew. Chem.*, 1974, **86**, 529; *Angew. Chem. Internat. Edn.*, 1974, **13**, 491.

¹¹ (a) K. Pihlaja and M. Seilo, *Acta. Chem. Scand.*, 1968, **22**, 3053; (b) K. Pihlaja and M. Seilo, *Acta. Chem. Scand.*, 1969, **23**, 3003.

¹² D. Lloyd and D. R. Marshall, *Angew. Chem.*, 1972, **84**, 447; *Angew. Chem. Internat. Edn.*, 1972, **11**, 404.

¹³ M. Eigen, G. Ilgenfritz and W. Kruse, *Chem. Ber.*, 1965, **98**, 1623.

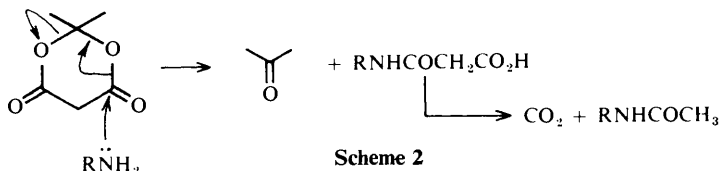
¹⁴ A. Gero, *J. Org. Chem.*, 1954, **19**, 1960.

¹⁵ P. Äyräs and A. Partanen, *Finn. Chem. Letters*, 1976, 110.

¹⁶ (a) D. Körberl and P. Schuster, *Monatsh.*, 1972, **103**, 1483; (b) D. Körberl and O. E. Polansky, *Monatsh.*, 1973, **104**, 1421; (c) E. N. Klimovitskii, L. K. Yuldasheva, and B. A. Arbuzov, *Izvest. Akad. Nauk. S.S.S.R., Ser. khim.*, 1973, 1527.

overall agreement as yet, the consensus of opinion favours a boat structure for most derivatives, with a chair structure for 2,2,5,5-tetrasubstituted compounds. This last conclusion is confirmed by the X-ray structure of an esoteric derivative.¹⁷ Other physical properties of the system which have been discussed include u.v.,³ i.r.,¹⁸ mass,¹⁹ ¹H-,²⁰ and ¹³C-n.m.r.²¹ spectra.

The chemistry of Meldrum's acid is dominated by its susceptibility to nucleophilic attack at positions 4 and 6 and to electrophilic attack (*via* the anion) at position 5. Simple hydrolysis to the malonic acid is a common example of nucleophilic attack, and may be accomplished under acidic or basic conditions.¹ The reaction mechanism has been studied.¹¹ Use of alcoholic hydrogen chloride yields the malonate diester,^{3,4} while 'solvolysis' by phenols gives monoaryl esters which can be easily converted to diaryl esters.²² Ketones react with Meldrum's acid by displacement of acetone to give 2,2-disubstituted-1,3-dioxan-4,6-diones.²³ Nitrogen nucleophiles give a possible route to monoamides of malonic acid,²⁴ although the cleavage of the ring may be followed by decarboxylation, as is the case with aniline,¹ and Hector's base²⁵ (Scheme 2). Fragmentation of the ring may also be accomplished directly by pyrolysis.



In contrast to these examples, the reactions of Meldrum's acid with electrophiles generally leave the ring intact. Scheme 3 gives the flavour of the chemistry involved, which is considered in detail in later sections. Reaction of electrophiles at the carbonyl oxygen does not give stable cyclic products.^{4,26,27}

4 5,5-Dialkyl Derivatives

These derivatives may be made by standard condensation methods, but an important alternative route is by the reaction of Meldrum's anion (5) with alkyl⁶

¹⁷ P. G. Jones and O. Kennard, *Cryst. Struct. Comm.*, 1977, **6**, 97.

¹⁸ (a) R. A. Abramovitch, *Canad. J. Chem.*, 1959, **37**, 361; (b) E. E. Ernstbrunner, *J. Mol. Structure*, 1973, **16**, 499.

¹⁹ H. Egger, *Monatsh.*, 1967, **98**, 1245.

²⁰ I. Schuster and P. Schuster, *Tetrahedron*, 1969, **25**, 199.

²¹ P. Åyrås, *Acta. Chem. Scand.*, 1976, **B30**, 957.

²² (a) H. Junek, E. Ziegler, U. Herzog, and H. Kroboth, *Synthesis*, 1976, 332; (b) G. Uray, H. Junek and E. Ziegler, *Monatsh.*, 1977, **108**, 423.

²³ E. Ziegler, H. Junek, and H. Kroboth, *Monatsh.*, 1976, **107**, 317.

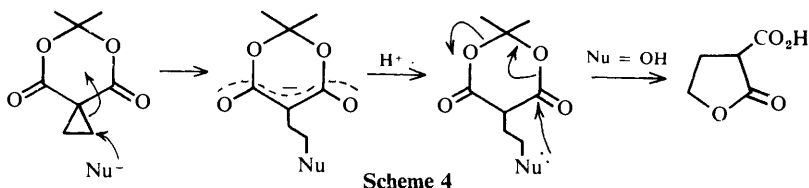
²⁴ (a) C. D. Hurd and S. Hayao, *J. Amer. Chem. Soc.*, 1954, **76**, 5563; (b) P. Crooy, R. De Neys, J. Eliaers, R. Liveyens, G. Simonet, and J. Vandeveldel, *Bull. Soc. chim. belges.*, 1977, **86**, 991.

²⁵ A. R. Butler, *J. Chem. Res. (S)*, 1978, 50; (M), 0855.

²⁶ S. I. Zav'yalov, *Izvest. Akad. Nauk S.S.S.R., Otdel. khim. Nauk*, 1961, 2042.

²⁷ G. A. Bihlmayer, P. Schuster, and O. E. Polansky, *Monatsh*, 1966, **96**, 145.

Of particular interest are the spiro cyclopropyl derivatives³² e.g. (14) whose Michael-type reactions with nucleophiles are reminiscent of those of the 5-methylene compounds (Section 5). Intramolecular decomposition of the ring-opened product may lead to lactones^{32,33} (Scheme 4) or lactams.³²



5 5-Methylene Derivatives³⁴

In some instances, reaction of a carbonyl compound (or its equivalent) with malonic acid proceeds directly by a double condensation to give 5-methylene derivatives of 1,3-dioxan-4,6-diones^{5,35} and a corresponding procedure using carbon suboxide is known.³⁶ However, the preparative method of choice involves Knoevenagel condensation of Meldrum's acid with a carbonyl component [Scheme 3, equation (B)]. This reaction proceeds easily for aromatic^{37,38} or hindered aliphatic aldehydes³⁸ or aliphatic ketones,^{39,40} though aromatic ketones require activation either by the use of a catalyst,⁴¹ or by their prior conversion to a ketimine.⁴² Simple aliphatic aldehydes often give the 2:1 condensation product, by Michael addition of Meldrum's acid to the intermediate 5-methylene compound^{3,39}—a process which is of paramount importance also in dimedone chemistry. In these examples, the 5-methylene compound is available by the cunning use of methoxide as a competitive nucleophile in the Michael addition. The adduct (6; Nu = OMe) so obtained may be decomposed with acid to the required product.⁴³

The activation of a carbonyl compound by *O*-methylation is particularly important when the resulting salt is resonance stabilized. Base catalysed condensation of such cations with Meldrum's acid has afforded 5-methylene

³² (a) S. Danishevsky and R. K. Singh, *J. Amer. Chem. Soc.*, 1975, **97**, 3239; (b) S. Danishevsky and R. K. Singh, *J. Org. Chem.*, 1975, **40**, 3807; (c) R. K. Singh and S. Danishevsky, *J. Org. Chem.*, 1976, **41**, 1668.

³³ F. P. Schmoock and O. E. Polansky, *Monatsh.*, 1969, **100**, 1631.

³⁴ For a review, see F. J. Kunz, P. Mzrgaretha, and O. E. Polansky, *Chimia (Switz.)*, 1970, **24**, 165.

³⁵ D. T. Mowry, *J. Amer. Chem. Soc.*, 1947, **69**, 2362.

³⁶ H. Hopff and G. Hegar, *Helv. Chim. Acta.*, 1961, **44**, 2016.

³⁷ E. J. Corey, *J. Amer. Chem. Soc.*, 1952, **74**, 5897.

³⁸ P. Schuster, O. E. Polansky, and F. Wessely, *Monatsh.*, 1964, **95**, 53.

³⁹ J. A. Hedge, C. W. Kruse, and H. R. Snyder, *J. Org. Chem.*, 1961, **26**, 3166.

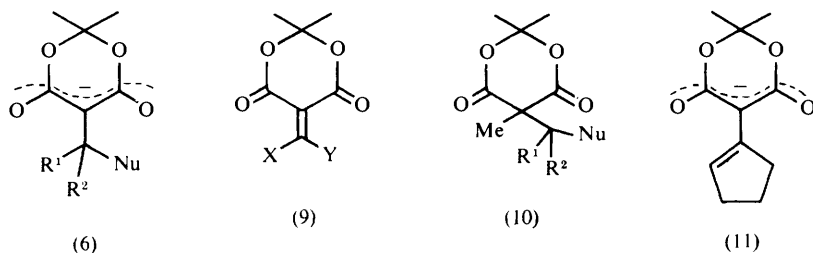
⁴⁰ G. Swoboda, J. Swoboda, and F. Wessely, *Monatsh.*, 1964, **95**, 1283.

⁴¹ G. J. Baxter and R. F. C. Brown, *Austral. J. Chem.*, 1975, **28**, 1551.

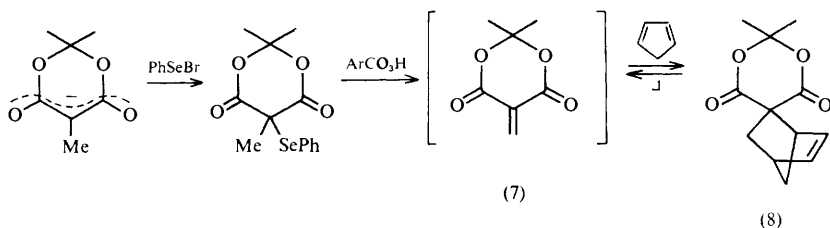
⁴² G. A. Bihlmayer, F. J. Kunz, and O. E. Polansky, *Monatsh.*, 1966, **97**, 1293.

⁴³ P. Margaretha and O. E. Polansky, *Tetrahedron Letters*, 1969, 4983.

compounds derived from cyclopropenium,⁴⁴ pyrylium,⁴⁵ and other heterocyclic⁴⁶ salts. Eistert has made similar products from chloropyrylium salts,⁴⁷ and even, in a peculiar redox reaction, from the unsubstituted pyrylium salt itself.⁴⁸



The parent 5-methylene compound (7) is apparently highly reactive, and cannot be prepared by standard methods. The sequence which was ultimately successful (Scheme 5) employs a unique oxidative process in the key step.⁴⁹



Scheme 5

A number of functional derivatives of 5-methylene compounds are known. Thus (9; X = H, Y = OEt) is readily available from Meldrum's acid and triethylorthoformate⁵⁰ [Scheme 3, equation (C)], while addition of an amine to this reaction mixture gives the amino compounds (9; X = H, Y = NHR) in a one-pot synthesis of wide generality.^{50,51} The diamino compound (9; X = Y = NHC₆-H₁₁), which is an extended urea, can be made from dicyclohexylcarbodi-imide,⁵² and the 'amides' (9; X = OH, Y = NHR) from isocyanates.⁵³

A remarkable property of 5-methylene derivatives in general is that like the parent 1,3-dioxan-4,6-dione, they are unexpectedly strong acids.^{34,54} In this

⁴⁴ T. Eicher, T. Pfister, and N. Kreuger, *Org. Prep. Proc. Internat.*, 1974, **6**, 63 (*Chem. Abs.*, 1974, **81**, 3403).

⁴⁵ (a) J. A. Van Allan and G. A. Reynolds, *J. Heterocyclic Chem.*, 1971, **8**, 803; (b) J. A. Van Allan and G. A. Reynolds, *J. Heterocyclic Chem.*, 1972, **9**, 669; (c) J. R. Wilt, G. A. Reynolds, and J. A. Van Allan, *Tetrahedron*, 1973, **29**, 795.

⁴⁶ R. Neidlein and M. H. Salzl, *Annalen*, 1977, 1938.

⁴⁷ B. Eistert and T. J. Arackal, *Chem. Ber.*, 1975, **108**, 2397.

⁴⁸ B. Eistert, A. Schmitt, and T. J. Arackal, *Chem. Ber.*, 1976, **109**, 1549.

⁴⁹ R. F. C. Brown, F. W. Eastwood, and G. L. McMullen, *Austral. J. Chem.*, 1977, **30**, 179.

⁵⁰ G. A. Bihlmayer, G. Derflinger, J. Derkosch, and O. E. Polansky, *Monatsh.*, 1967, **98**, 564.

⁵¹ Sterling Drug Inc., Brit. 1,147,759 (*Chem. Abs.*, 1969, 71, 70 125).

⁵² A. Stephen, *Monatsh.*, 1966, **97**, 695.

⁵³ U. Herzog and H. Reinshagen, *Eur. J. Med. Chem.-Chim. Ther.*, 1975, **10**, 323.

⁵⁴ P. Schuster, A. Stephen, O. E. Polansky, and F. Wessely, *Monatsh.*, 1968, **99**, 1246.

case, it is a manifestation of Lewis acidity,⁵⁵ due to the formation of pseudobase adducts or anbadons (6) for which the driving force is clearly the mendeic tendency of the stable anion. The whole range of hard and soft nucleophiles, from alkoxides⁵⁵ to phosphines⁵⁶ show this behaviour. The pseudobase may be quenched with iodomethane to give the alkylated products (10).^{40,56} In some cases where the 5-methylene compound has a β -hydrogen available, proton loss (*i.e.* Brønsted acid behaviour) can compete with pseudobase formation [*e.g.* (11)].⁵⁷

Clearly the pseudobases (6; Nu = OH) are simply intermediates in the hydrolysis of 5-methylene derivatives to Meldrum's acid and the carbonyl component, and the kinetics and mechanism of this process have been studied.⁵⁸ Under certain conditions, the heterocyclic ring may be preferentially hydrolysed, providing a route to 2-methylenemalonates.^{37,58} Reduction of 5-methylene-1,3-dioxan-4,6-diones to the corresponding 5-alkyl compound is possible catalytically,³⁰ or using lithium aluminium hydride.⁵⁹ Reaction with $\text{Fe}_2(\text{CO})_9$ gives a π -complex,⁶⁰ while the labile formyl derivative (9; X = H, Y = OH), produced by hydrolysis of the ethoxy compound, gives a chelate with copper acetate.⁵⁰

The 5-methylene derivatives of Meldrum's acid are excellent dienophiles, and give a potential route to cyclohexenes with unusual substituents.^{49,61} This reaction has recently been exploited by two groups in natural product synthesis^{62,63} and further developments in this area are awaited with interest. The 1,3-dipolar cycloaddition of diazoalkanes⁶⁴ has been studied in great detail. In all cases, cyclopropane derivatives are obtained, although the reaction may proceed twice⁶⁵ (Scheme 6; R¹ = Ph, R² = H) and traces of further alkylation can sometimes be detected.³³ That the initial reaction is indeed a standard 1,3-dipolar cycloaddition, was proved by an elegant kinetic study,⁶⁶ whose results were vindicated by the isolation of an intermediate pyrazoline⁶⁷ (Scheme 6; R¹ = Prⁱ, R = CO₂Et).

6 5-Halogeno Derivatives

Although the 5-chloro compound has been prepared,⁶⁸ the known chemistry of 5-halogeno derivatives of Meldrum's acid is almost wholly associated with brominated materials. Both the 5-bromo and the 5,5-dibromo compounds are formed by direct halogenation of Meldrum's acid in the presence of one⁶ or

⁵⁵ P. Schuster, O. E. Polansky, and F. Wessely, *Tetrahedron Suppl.* 8 Part 2, 1966, 463.

⁵⁶ P. Margaretha and O. E. Polansky, *Monatsh.*, 1969, 100, 576.

⁵⁷ J. Leitich, P. Schuster, and A. Eitel, *Tetrahedron*, 1967, 23, 2221.

⁵⁸ P. Margaretha, P. Schuster, and O. E. Polansky, *Tetrahedron*, 1971, 27, 71.

⁵⁹ A. Stephen and F. Wessely, *Monatsh.*, 1967, 98, 184.

⁶⁰ E. Korner von Gustorf, O. Jaenicke, and O. E. Polansky, *Z. Naturforsch. B.*, 1972, 27, 575.

⁶¹ F. J. Kunz and O. E. Polansky, *Monatsh.*, 1969, 100, 920.

⁶² W. G. Dauben, A. P. Kozikowski, and W. T. Zimmermann, *Tetrahedron Letters*, 1975, 515.

⁶³ G. A. Mock, A. B. Holmes, and R. A. Raphael, *Tetrahedron Letters*, 1977, 4539.

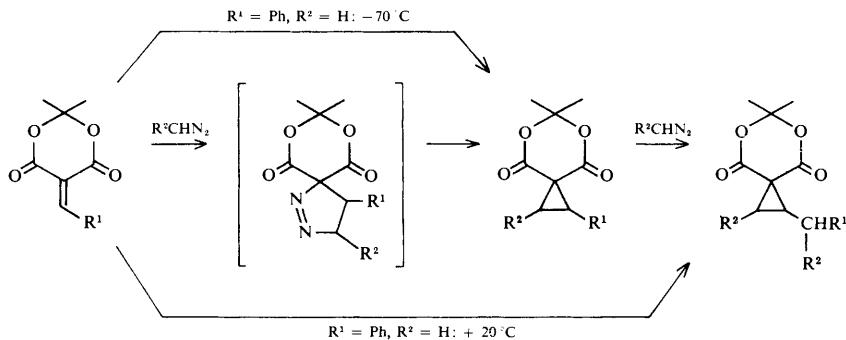
⁶⁴ F. Wessely and A. Eitel, *Monatsh.*, 1964, 95, 1577.

⁶⁵ G. Swoboda, A. Eitel, J. Swoboda, and F. Wessely, *Monatsh.*, 1964, 95, 1355.

⁶⁶ F. Nierlich, P. Schuster, and O. E. Polansky, *Monatsh.*, 1971, 102, 438.

⁶⁷ H. Kisch, F. Mark, and O. E. Polansky, *Monatsh.*, 1971, 102, 448.

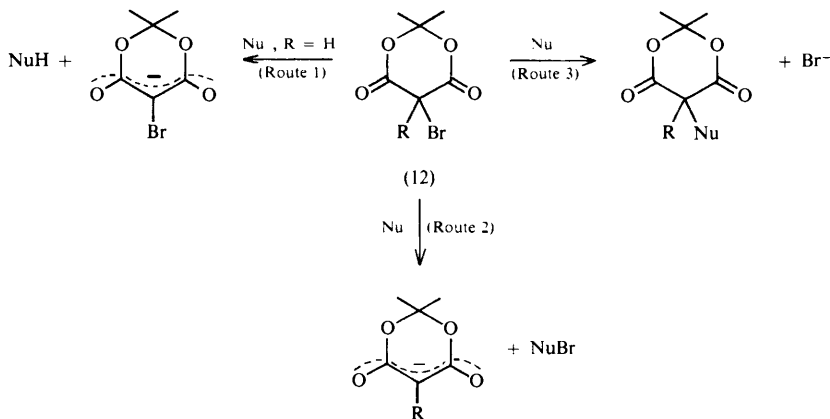
⁶⁸ O. Y. Neiland and B. Y. Karele, *Zhur. org. Khim.*, 1971, 1674.



Scheme 6

two⁶⁹ moles of base respectively [Scheme 3, equation (D)]. A unique situation pertains to iodine-containing derivatives, since a phenyliodonium ylid is well characterized⁶⁸ yet no classical iodo compound has ever been reported.

Treatment of the 5-bromo-derivative (12; $R = \text{H}$) with nucleophiles can give rise to three possible modes of reaction (Scheme 7). The trivial case, in which



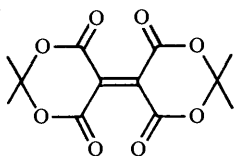
Scheme 7

the nucleophile acts as a base, is the dominant route even for such mild bases as aniline.⁶⁹ The ubiquitous anion may also be formed by nucleophilic attack at the halogen atom (Scheme 7, route 2). This route is particularly important

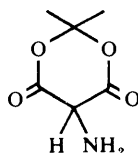
⁶⁹ H. R. Snyder and C. W. Kruse, *J. Amer. Chem. Soc.*, 1958, **80**, 1942.

for (12; R = Me), the use of which as a brominating agent for carbanions has been recommended.⁷⁰ Trost's process of 'transfer alkylation' is a subtle application of this principle, in which the anion leaving group re-attacks the brominated substrate at a remote site, to complete a chain extension sequence.⁷¹ Although there is no unambiguous example of a simple S_N reaction from (12; R = H), this mechanism can apparently give rise to products with hard nucleophiles and (12; R = Me).⁷²

The 5,5-dibromo compound (12; R = Br) is also a useful brominating agent,⁷³ but little else is known of its chemistry save for two astonishing reactions.⁶⁹ Basic hydrolysis gives carbon tetrabromide in a process which, for its total destruction of a stable system to C_1 fragments is reminiscent of the bromopicrin reaction.⁷⁴ Secondly, simple dissolution in dimethylformamide yields the coupled derivative (13) in 30% yield. The mechanisms of these reactions are overdue for investigation.



(13)



(14)

7 5-Nitrogen-containing Derivatives

Although Davidson and Bernhard reported a colour reaction of Meldrum's acid with sodium nitrite,² it was not until 1961 that two groups independently isolated the oxime as an unstable yellow solid^{3,26} [Scheme 3, equation (E)]. Its reduction over platinum dioxide provides the only known route to the 5-amino compound³ (14), but otherwise the properties of this compound are unknown. Similarly little studied are the hydrazones, prepared by coupling with appropriate diazo compounds⁷⁵ or diazonium salts³ [Scheme 3, equation (F)]. The parent 4,5,6-trione of which these compounds are formal derivatives, remains unprepared, despite a number of attempts.^{76,77}

The most important nitrogen-containing derivative of Meldrum's acid is the diazo-compound (15), formed by diazotization of the amine,³ or, more conveniently, by direct reaction with *p*-toluenesulphonyl azide⁷⁵ [Scheme 3, equation (G)]. Photolysis or thermolysis of (15) generates 'Meldrum's carbene'⁷⁸ which

⁷⁰ (a) J. P. Marino, *J.C.S. Chem. Comm.*, 1973, 861; (b) E. Vedejs, W. R. Wilber, and R. Twieg, *J. Org. Chem.*, 1977, **42**, 401.

⁷¹ B. M. Trost and L. S. Melvin jun., *J. Amer. Chem. Soc.*, 1976, **98**, 1204.

⁷² R. F. C. Brown, F. W. Eastwood, S. T. Lim, and G. L. McMullen, *Austral. J. Chem.*, 1976, **29**, 1705.

⁷³ R. Bloch, *Synthesis*, 1978, 140.

⁷⁴ A. R. Butler and H. F. Wallace, *J. Chem. Soc. (B)*, 1970, 1758.

⁷⁵ (a) M. Regitz and D. Stadler, *Annalen*, 1965, **687**, 214; (b) M. Regitz, A. Liedhegener, and D. Stadler, *Annalen*, 1968, **713**, 101.

⁷⁶ M. Regitz and H-G. Adolph, *Annalen*, 1969, **723**, 47.

⁷⁷ A. Hochrainer and F. Wessely, *Monatsh.*, 1966, **97**, 1.

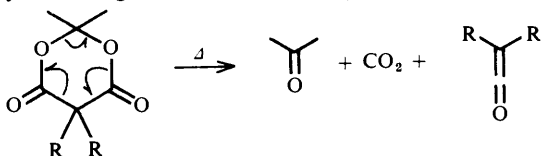
⁷⁸ M. Jones Jr., W. Ando, M. E. Hendrick, A. Kulczycki jun., P. M. Howley, K. F. Hummel, and D. S. Malament, *J. Amer. Chem. Soc.*, 1972, **94**, 7469.

pronounced thermal stability by comparison with related systems, while the stability of the selenonium and arsonium ylides (16b) and (16c) is reflected in their lack of reactivity with aldehydes in attempted Wittig reactions.

The iodonium ylid (16d) gives 5-chloro-1,3-dioxan-4,6-dione on treatment with hydrogen chloride.⁶⁸

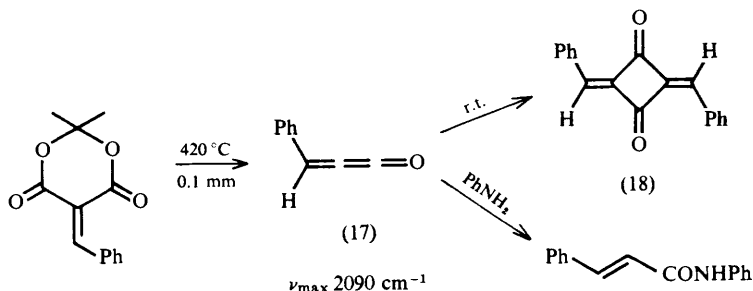
9 Pyrolysis

The pyrolysis of Meldrum's acid derivatives has long been known to give ketenes.⁶ The mechanism presumably involves homolysis of a C—O bond, followed by cleavage of acetone and carbon dioxide, both of which are found in the pyrolysate along with the ketene.⁸⁴ (Scheme 10). Using flash vacuum



Scheme 10

pyrolysis, this route may be used to prepare ketenes which are difficult to obtain by conventional methods—notably cyclopropylketene⁸⁵—but the technique has been applied most particularly to the generation of methyleneketenes from 5-methylene derivatives. Thus phenylmethyleneketene (17) has been identified by its i.r. spectrum at -196°C , by its dimerization to the cyclobutandione derivative (18), and by various trapping experiments⁸⁴ (Scheme 11). Methyleneketenes



Scheme 11

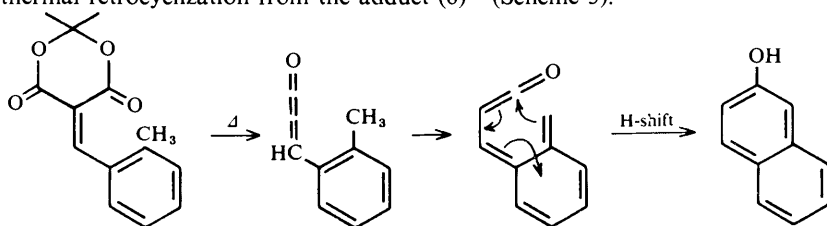
are available thus, in two steps, from aryl aldehydes⁸⁴ and ketones⁸⁶, or alkyl ketones:⁸⁴ those derived from aliphatic aldehydes tautomerize if possible to vinyl ketenes.⁸⁴ Other more interesting intramolecular reactions which may take place in the presence of a suitable trapping group, include an elegant phenol

⁸⁴ R. F. C. Brown, F. W. Eastwood, and K. J. Harrington, *Austral. J. Chem.*, 1974, **27**, 2373.

⁸⁵ G. J. Baxter, R. F. C. Brown, F. W. Eastwood, and K. J. Harrington, *Tetrahedron Letters*, 1975, 4283.

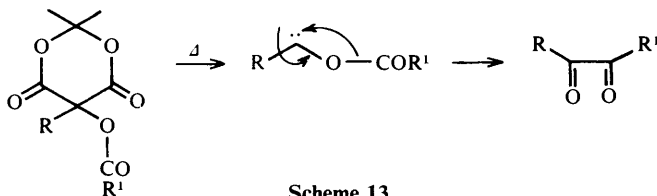
⁸⁶ R. F. C. Brown, F. W. Eastwood, K. J. Harrington, and G. L. McMullen, *Austral. J. Chem.*, 1974, **27**, 2393.

synthesis⁸⁷ (Scheme 12). Recently, the parent methyleneketene has been identified from the pyrolysis of the very reactive compound (7), itself generated *in situ* by thermal retrocyclization from the adduct (8)⁴⁹ (Scheme 5).



Scheme 12

Pyrolysis of Meldrum's acid derivatives at high temperatures causes decarbonylation of the intermediate ketene to give a carbene, which then rearranges to valence-satisfied products. Reactions of this type include the generation of acyloxycarbenes and their rearrangement to α -diketones in excellent yield (Scheme 13).⁷² Similarly, methylenecarbenes generated from methyleneketenes



Scheme 13

show hydrogen migration to give acetylenes, although intramolecular cyclization products may also be detected in favourable instances.⁸⁶

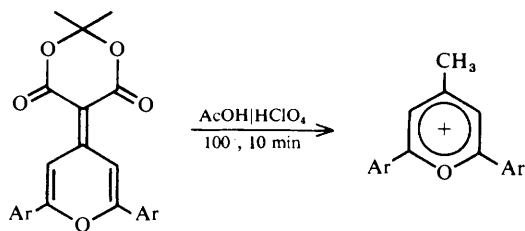
10 Some Synthetic Uses

As with simple malonic ester syntheses, the presence in Meldrum's acid of a highly active methylene group adjacent to an ester function, allows the molecule to be manipulated to give a wide range of possible products. At the simplest level, Meldrum's acid can act as a methylene synthon by hydrolysis and exhaustive decarboxylation of its derivatives. For certain heterocyclic systems, the conditions needed for this sequence are surprisingly mild^{28,45} (Scheme 14). Intermolecular cleavage by other nucleophiles can also give useful products; a particularly beautiful example is Dauben's two step synthesis of δ -damascone⁶² (19) Scheme 15). This is the only known example of a potentially general ketone synthesis from Meldrum's acid.

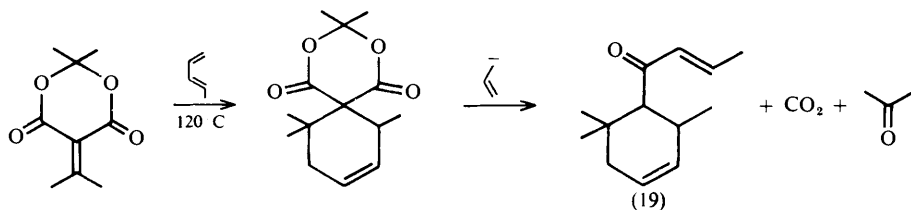
We have already met examples of intramolecular nucleophilic attack (Scheme 4). Under extreme conditions, cleavage of acetone may be followed by decarboxylation to give lactams⁸⁸ (Scheme 16); in these cases, Meldrum's acid acts as the synthetic equivalent of ketene.

⁸⁷ (a) R. F. C. Brown and G. L. McMullen, *Austral. J. Chem.*, 1974, **27**, 2385; (b) G. J. Baxter, R. F. C. Brown, and G. L. McMullen, *Austral. J. Chem.*, 1974, **27**, 2605.

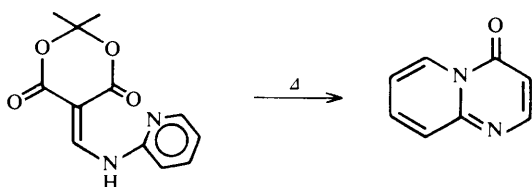
⁸⁸ G. Y. Leshner, U.S. 3,907,798 (*Chem. Abs.*, 1976, **84**, 44130).



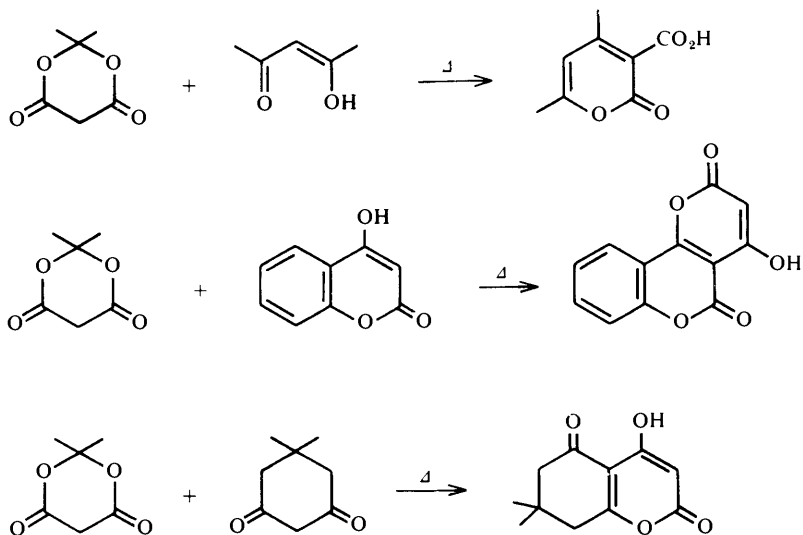
Scheme 14



Scheme 15



Scheme 16



Scheme 17

Meldrum's Acid

Finally, a widespread use of Meldrum's acid in heterocyclic chemistry is in the preparation of α -pyrones and 2-pyridones. A variety of such reactions is known, and some are of formidable complexity, but a common feature is that the Meldrum's acid behaves as a C_3O_2 synthon^{45,89,90} (Scheme 17).

I am grateful to Professor J. I. G. Cadogan for his encouragement, and to Dr. D. Lloyd for his invaluable comments on the manuscript.

⁸⁹ (a) E. Ziegler, H. Junek, and U. Herzog, *Monatsh*, 1971, **102**, 1096; (b) E. Ziegler, H. Junek and U. Herzog, *Monatsh*, 1971, **102**, 1626.

⁹⁰ O. S. Wolfbeis, *Monatsh*, 1977, **108**, 499.