The Carbon-13 Nuclear Magnetic Resonance Spectra of Tetronate and 2-Pyrone Derivatives

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The ^{13}C n.m.r. spectra of a variety of tetronic acids, methyl tetronates, 4-methoxy-2-pyrones, and 4-methoxy-5,6-dihydro-2-pyrones are reported. Signals have been assigned on the basis of a variety of techniques including gated decoupling, selective proton decoupling, and hydrogen–deuterium exchange experiments. The results should be of use for structural assignments and for biosynthetic studies of natural products.

We have recently isolated a number of methyl tetronate (4-methoxybutenolide) derivatives [1] and have investigated biomimetic routes to these compounds by ring syntheses.[3] Hence a wide variety of dihydropyrans, pyrenes, and methyl contractions of dihydropyrones [2] as well as *de novo* tetronates were available to us. It also became clear that with certain oxidised compounds it was not possible to unambiguously decide between the alternative γ- and δ-lactone forms on the usual basis of the i.r. spectra.[2] An essential part of our biosynthetic scheme for piperolide and related compounds [1,2] consisted of ring-contraction processes, and in our biomimetic experiments it was therefore critical to be able to detect ring-contraction and ring-expansion processes. For this reason we turned our attention to a study of the ^{13}C n.m.r. spectra or tetronic acid and pyrone derivatives, and in this paper we present our results which should be of general use in structural assignments, as well as in biosynthetic studies.

RESULTS AND DISCUSSION

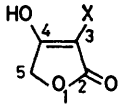
Assignments of many of the signals due to tetronates and 4-methoxypyrone derivatives can be made simply on the basis of chemical-shift values and the multiplicity of the signals in the off-resonance spectra. Problems arise in the assignments to quarternary carbon atoms, particularly those bearing oxygen atoms. This problem has been investigated in the 4-methoxy-2-pyrone series [4] but little that is unambiguous is known in the tetronate series.[5-9] We have therefore used gated decoupled spectra, selective porton decoupling,[10] and, where appropriate, deuterium–hydrogen exchange techniques [11,12] in order to clarify the problems that have arisen.

(1) *Tetronic Acids.*—Compounds (1)—(6) have been examined in [$^2H_6$]DMSO and the signals due to the butenolide ring have been assigned (Table 1).

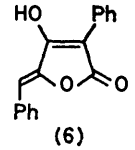
C-5 was readily discernible from its chemical shift and multiplicity, as well as from selective proton decoupling, whilst the signals due to C-3 were evident from the chemical shifts, the changes of chemical shift from compounds (1)—(6), and by comparison with the value of C-3 assigned to methyl *O*-methylmulticolate (7).[5]

Our assignments as between C-2 and C-4 were made on the basis of the diminished intensity of the signal due to the carbon bearing the hydroxy-group on exchange of the OH proton for deuterium,[12] and the suppression of the J_{C_4-OH} coupling constant.[11,13] The signal due to C-2 remained as a singlet throughout these experiments.[11]

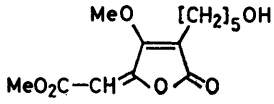
It would appear that all the tetronic acids, except perhaps (5), exist as a single enolic form in DMSO.



(1) X = Me
(2) X = Br
(3) X = CH_2Ph
(4) X = CO_2Me
(5) X = CO_2Et



(6)



(7)

This is by no means unexpected as it is known that whereas tetronic acids exist predominantly in the ketone form in solvents of low polarity,[14] in other solvents the existence of the mono-enol form shown in (1)—(6) has been established by i.r.[14,15] and u.v.[16] spectroscopy as well as by dipole-moment data.[17] It is strange that in the ethyl ester (5), the signals due to C-2 and C-4 appear as doublets in the noise-decoupled spectrum, a phenomenon not observed with the closely related methyl ester (4). It is not likely that this is due to interconverting enolic forms or an enol–ketone equilibrium, as C-3 and C-5, as well as the signals due to the carboethoxy-group, are seen as singlets. The pheno-

TABLE 1

Chemical shifts of ring carbon atoms in tetronic acids [a-c]

Compound	C-2	C-3	C-4	C-5
(1)	173.0	94.0	175.2	66.5
(2)	169.0	77.4	175.2	68.0
(3)	174.0	98.5	174.8	66.0
(4) [d]	161.5	92.0	186.2	66.6
(5) [e]	161.1 161.5	92.0	185.9 186.2	66.5
(6) [f,g]	167.8	132.7	163.6	142.4

[a] All spectra run in [$^2H_6$]DMSO. [b] All chemical shifts in this and subsequent Tables given in p.p.m. downfield from $SiMe_4$. [c] All multiplicities in this and subsequent Tables are in accord with the structures given in the text, and are not given in the Tables. [d] CO_2CH_3, 169.6, 50.7. [e] $CO_2CH_2CH_3$, 169.1, 59.3, 14.2. [f] On addition of D_2O, only the doublet assigned to C-4 (J_{C_4-OH} 3.6 Hz) becomes a sharp doublet ($J < 1$ Hz). [g] We thank Dr. R. S. Ward and Mr. R. Franklin for this compound.

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menon may be steric in origin but we have no clear explanation of this behaviour.

(2) *Methyl Tetronate and 5-Substituted Methyl Tetronates.*—Although the ^{13}C n.m.r. of some naturally-occurring methyl tetronates have been measured,[5-8] in δ 180.4 (Figure). We found that this was a general phenomenon and together with the long-range coupling constants readily allows the signals due to C-2 and C-4 of methyl tetronates to be distinguished.

The assignments of the signals of C-2—C-8 in compounds (9)—(34) follows readily from the assignments to methyl tetronate (8), plus the multiplicities and chemical shifts of C-6—C-8 in the various compounds.

TABLE 2

^{13}C Chemical shifts for methyl tetronates (8)—(34) [a]

	Heterocyclic carbons				Aliphatic carbons			
Compound	C-2	C-3	C-4	C-5	4-OMe	C-6	C-7	C-8
(8)	173.5	88.6	180.4	67.7	59.7			
(9)	172.2	89.9	180.4	69.9	59.6	81.7		
(10)	172.3	89.8	180.5	69.6	59.6	81.7		
(11)	172.2	89.9	180.4	72.1	59.5	81.9		
(12)	172.3 172.5	90.0	180.4 180.6	72.3	59.9	81.7		
(13)	172.3	89.8	180.5	69.7	59.6	81.7		
(14)	172.1	88.8	178.9	77.8	60.5	191.2		
(15)	172.0	88.8	178.7	77.9	60.6	190.3		
(16)	172.3	88.8	179.2	77.6	60.5	189.0		
(17)	172.5	89.5	180.9	67.2	59.6	80.9	31.4	35.0
(18)	172.3	89.9	180.8	68.9	59.7	81.7	31.6	32.7
(19)	172.6	89.5	181.0	67.2	59.5	80.9	30.4	35.3
(20)	172.6	89.4	181.0	67.2	59.5	80.9	31.0	35.2
(21)	172.6	89.5	181.0	67.1	59.6	80.9	31.1	35.2
(22)	172.4	89.8	180.3	69.1	59.1	81.0	127.5	130.4
(23)	172.2	89.9	180.4	70.8	59.8	81.5	126.3	131.2
(24)	172.1	89.7	180.6	77.6	59.6	79.1	31.0	32.4
(25)	172.1	89.8	180.6	78.9	59.9	78.8	30.2	31.1
(26)	172.1	89.8	180.2	80.0	59.8	78.9	124.9	133.8
(27)	172.0	90.1	180.0	80.6	59.9	79.7	122.9	134.5
(28) [b,c]	171.9	89.7	179.3	69.8	59.5	78.9	31.6	32.4
(29) [b,d]	171.8	90.0	179.6	71.7	59.7	78.8	30.3	31.1
(30) [b,e]	172.0 172.6	89.5 89.9	180.2 180.9	67.2 71.4	59.6	78.8 80.9	33.0 31.4	37.9 35.1
(31)	169.7 170.2	89.6 90.5	178.6 179.5	103.2 103.5	59.2 59.5	72.4 72.4		
(32)	170.1 170.5	89.6 90.8	178.8 179.6	104.0 104.5	59.4	69.4 71.6	31.4 32.5	31.8 32.0
(33) [f]	169.9	91.2	178.3	101.2	60.8	201.4 206.5	38.4	38.4
(34)	169.7	90.6	178.0	100.9	60.3	190.4	119.0	146.0

[a] All compounds run in [$^2H_6$]DMSO unless otherwise stated. [b] Determined in $CDCl_3$. [c] $OCOCH_3$, δ 169.8. [d] $OCOCH_3$, 170.4 [e] $OCH{\cdot}(OMe)_2$, 113.8. [f] Determined in $(CD_3)_2CO$.

one case [5] it was explicitly stated that the assignments to C-2 and C-4 (our numbering) were interchangeable and the same authors [8] later corrected these assignments for methyl multicolonate on the basis of the results [7] of studies with penicillic acid. The experiments detailed below independently support this change of assignment.

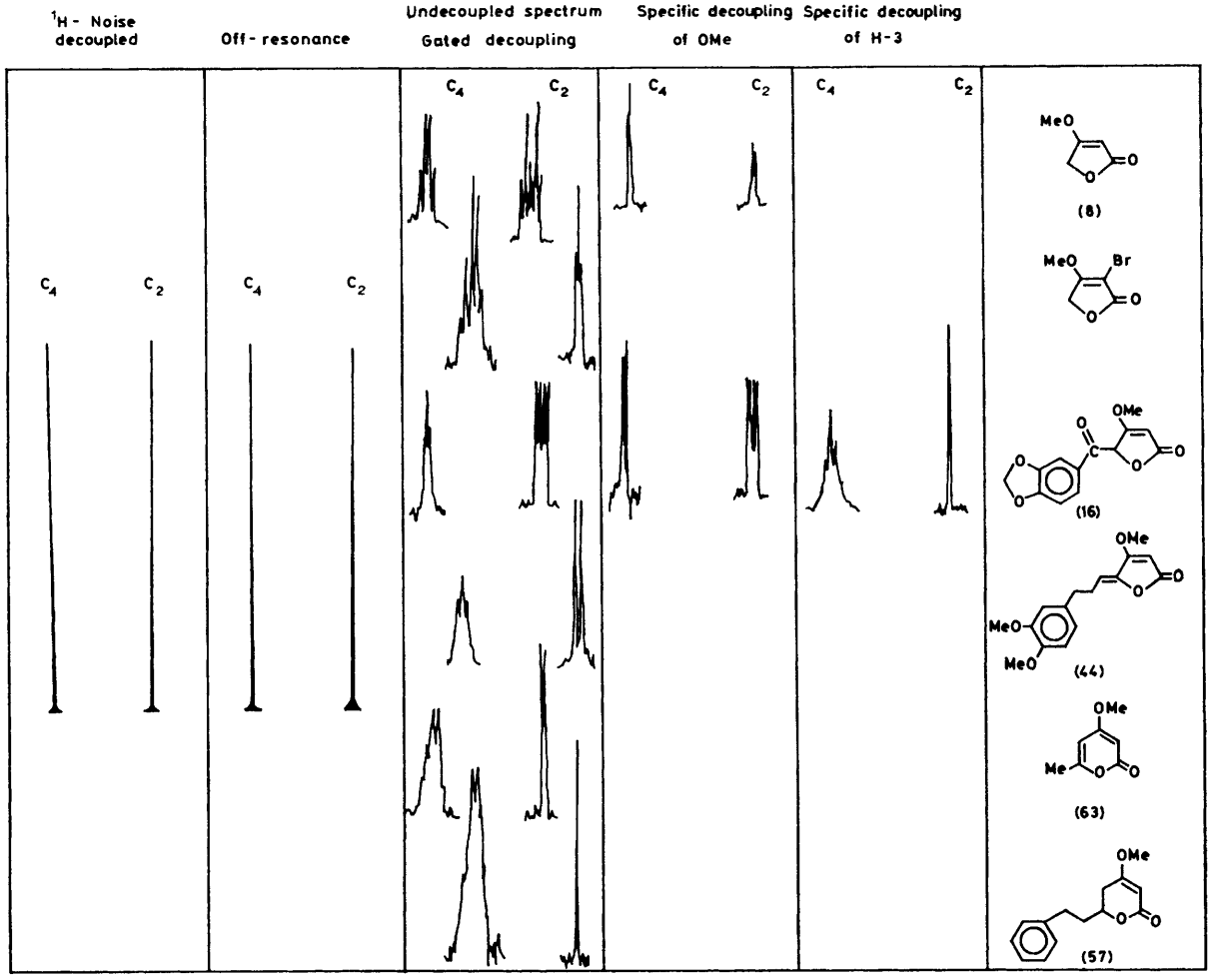
We first examined methyl tetronate (8) in detail (Table 2).* The signals due to the *O*-methyl group, C-3, and C-5 could be assigned unambiguously on the basis of their multiplicity and chemical shifts. The signal at δ 173.5 appears as a double triplet in the gated decoupled spectrum (Figure) with $J_{C_2-H_3}$ 6.3 Hz and $J_{C_2-H_5}$ 2.2 Hz, whilst the signal at δ 180.4 appears as a multiplet. Most intriguingly, coupling of this signal, assigned to C-4, occurs not only with H-3 and H-5 but also with the protons of the 4-methoxy-group. Thus selective proton decoupling using the proton frequency of this group led to a considerable simplification of the multiplet at

* In Table 2 and all subsequent Tables, the signals due to the aryl groups are unexceptional and of little interest. They are therefore omitted from the Tables as are all extraneous methyl, methoxy-groups *etc.*, except where they may be close in chemical shift to C-2—C-8 or otherwise of interest.

The 5-acyl compounds (14)—(16) are of interest. It might be expected that these compounds would exist in their enolic forms so that the compounds had fully extended conjugated systems. However, there is a strong steric inhibition to such enolisation and indeed the chemical shift for C-5 and its multiplicity (doublet) implies that it is the ketonic forms that predominate in DMSO. Similarly the chemical shift for C-6 is that to be expected of a phenyl ketone and is almost the same as that in (34), which is unable to enolise (Table 2). The conclusion that (14)—(16) exist as ketones rather than enols is in line with evidence based on ^1H and i.r. spectra.[18]

In the 7,8-dehydro-compounds (22), (23), (26), (27), and (34), C-7 and C-8 appear characteristically as six-line multiplets rather than as doublets in their off-resonance spectra. This may be due to virtual coupling ($J_{C-H} \approx J_{H-H}$) as has previously been noted in chalcones.[19]

It was somewhat difficult to distinguish between C-5 and C-6 in compounds (24)—(27) and therefore selective proton-decoupling experiments confirmed by ^{13}C–^{1}H couplings were used. The couplings for representative compounds substituted at C-5 and C-6 are summarised in Table 3. The chemical shifts of C-5 and C-6 are



those to be expected from the various substituents,[13] but it was interesting to note that methylation of a 6-hydroxy-group led consistently to a downfield shift of *ca.* 10 p.p.m. in the C-5 signal, *e.g.* (17) compared with (24) and (22) compared with (26) (Table 2), in line with the previously noted β-effect.[13]

TABLE 3

^{13}C–^{1}H Coupling constants (Hz) for representative tetronates

	$J_{C_4-H_3}$	$J_{C_2-H_5}$	$J_{C_3-H_5}$	$J_{C_3-H_5}$	$J_{C_5-H_5}$	$J_{C_6-H_5}$
(8)	6.3	2.2	179.0	1.4	152.0	
(17)	6.5	2.1	181.3	5.7	142.0	150.0
(22)	6.2	2.2	181.3	7.2	146.0	152.0
(24)	6.4	2.2	181.4		143.0	144.0

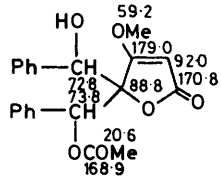
Butenolides doubly substituted at C-5 form an important class of natural product.[18] Compounds (35) and (36) provide some data about such compounds. The disubstitution causes a downfield shift of *ca.* 10 p.p.m. at C-5 and *ca.* 3 p.p.m. at C-3.

(3) *Methyl Tetronates with Extended Conjugation between C-5 and C-6.*—A wide variety of natural products, including the piperolides, fimbrinolides, pulvinic acid derivatives, multicolic acid, and marine sesterpenes such as strobilin and related compounds, are tetronates with extended conjugation between C-5 and C-6.[18] These compounds are produced biosynthetically by a range of processes.[2,5,8]

We have measured the ^{13}C n.m.r. of compounds (37)—(53) and have been able to unambiguously assign all signals due to C-2—C-8 (Table 4) for each compound.

Each spectrum is for a single isomer as shown in the formulae. Structures (37)—(41) were assigned on the basis of an *X*-ray structure of (38) [18] followed by spectroscopic analogies for the other compounds. The structures of (46)—(49) follow from the J_{H-H} coupling constants plus an *X*-ray structure for (46).[18] As these compounds were prepared from compounds (42)—(45), the stereochemistry of the latter compounds is assured.

As yet we have no data regarding the results of isomerisation about the C-5, C-6 double bond of compounds (37)—(49). However, we were able to prepare and separate [3b] both 5*Z*- and 5*E*-piperolides, (50) and (51), and compare their spectra. As might be expected it was the C-5 and C-6 carbon atoms that were most affected (Table 4) the change in C-6 being particularly noteworthy. It is possible that the direction of the



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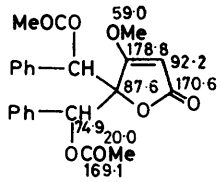
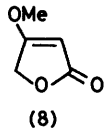


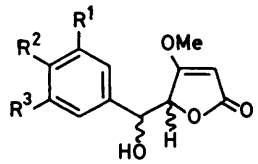
(36)

change is diagnostic and can be used for preliminary assignment of structure as it is in the same sense as for the 5*Z*- and 5*E*-isomers of both methyl multicolate (54) [6] and the corresponding isomers of (55) [20] (Table 5). Of course, this similarity may be coincidental as the piperolides have a 6-methoxy-group. However in each case it is the most electronegative group attached to C-6 which is described by the *EZ*-nomenclature and the point is worth pursuing, particularly for compounds such as the piperolides in which C-6 is quarternary and *X*-ray analysis must currently be used to establish the structure. The difference in the 6-OMe groups may also be diagnostic (Table 4). We are attempting to prepare other C-5,C-6-isomeric pairs.

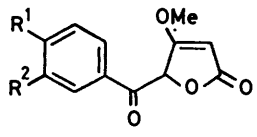
In compounds (37)—(41), the signals due to C-3 and C-6 can be distinguished as usual from their chemical shifts and multiplicity as well as by selective proton decouplings. The quaternary carbon atom C-5 was readily distinguished by its chemical shift but it was not obvious that C-2 and C-4 could be established by analogy with compounds (8)—(34). We therefore resorted, as previously, to an examination of long-range C–H couplings accompanied by selective irradiation of the



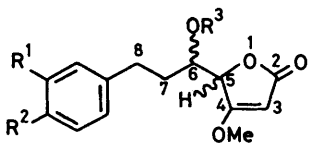
(8)



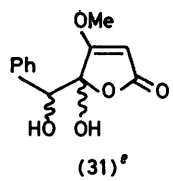
(9) $R^1,R^2,R^3=H$ [a]
(10) $R^1,R^3=H; R^2=OMe$ [a]
(11) $R^1,R^2=OMe; R^3=H$ [a]
(12) $R^1,R^2,R^3=OMe$ [e]
(13) $R^1,R^2=-OCH_2O-; R^3=H$ [a]



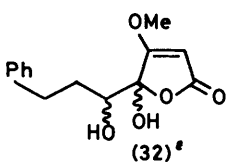
(14) $R^1,R^2=H$
(15) $R^1=H, R^2=Cl$
(16) $R^1,R^2=-OCH_2O-$



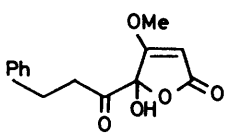
(17) $R^1,R^2,R^3=H$ [b]
(18) $R^1,R^2,R^3=H$ [c]
(19) $R^1,R^3=H; R^2=OMe$ [b]
(20) $R^1,R^2=OMe; R^3=H$ [b]
(21) $R^1,R^2=-OCH_2O-; R^3=H$ [b]
(22) $R^1,R^2,R^3=H$; 7,8-dehydro [b,d]
(23) $R^1,R^2,R^3=H$; 7,8-dehydro [c]
(24) $R^1,R^2=H; R^3=Me$ [b]
(25) $R^1,R^2=H; R^3=Me$ [c]
(26) $R^1,R^2=H; R^3=Me$, 7,8-dehydro [b]
(27) $R^1,R^2=H; R^3=Me$, 7,8-dehydro [c]
(28) $R^1,R^2=H; R^3=COMe$ [e]
(29) $R^1,R^2=OMe; R^3=COMe$ [e]
(30) $R^1,R^2=H; R^3=CH(OMe)_2$ [e]



(31) [e]

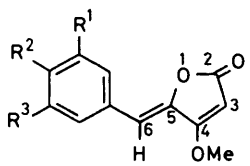


(32) [e]

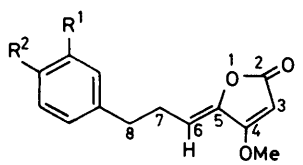


(33)
(34) 7,8-dehydro

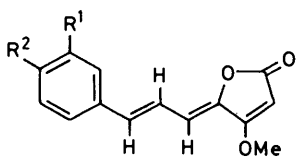
[a] One crystalline isomer of unknown geometry. [b] *threo*-Isomer. [c] *erythro*-Isomer. [d] All 7,8-dehydro-compounds have a *trans* double bond. [e] Mixture of two isomers.



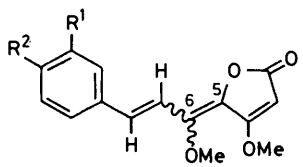
(37) $R^1,R^2,R^3=H$
(38) $R^1,R^3=H; R^2=OMe$
(39) $R^1,R^2=OMe; R^3=H$
(40) $R^1,R^2,R^3=OMe$
(41) $R^1,R^2=-OCH_2O-; R^3=H$



(42) $R^1,R^2=H$
(43) $R^1=H; R^2=OMe$
(44) $R^1,R^2=OMe$
(45) $R^1,R^2=-OCH_2O-$



(46) $R^1,R^2=H$
(47) $R^1=H; R^2=OMe$
(48) $R^1,R^2=OMe$
(49) $R^1,R^2=-OCH_2O-$



(50) $R^1,R^2=H$, 5*Z*
(51) $R^1,R^2=H$, 5*E*
(52) $R^1,R^2=-OCH_2O-$, 5*Z*
(53) $R^1,R^2=-OCH_2O-$, 5*E*

TABLE 4

^{13}C Chemical shifts for methyl tetronates (37)—(53)

Compound	Heterocyclic carbons				Aliphatic carbons			
	C-2	C-3	C-4	C-5	4-OMe	C-6	C-7	C-8
(37) [a]	168.2	88.2	171.1	142.2	59.3	107.7		
(38) [a]	168.2	88.1	171.1	140.4	59.8	106.7		
(39) [a]	168.1	88.0	171.1	140.7	59.8	107.0		
(40) [a]	167.8	88.3	171.0	139.0	59.8	106.7		
(41) [a]	167.1	88.0	170.7	140.3	59.7	106.5		
(42) [b]	168.4	90.2	169.9	142.2	59.2	109.6	27.4	34.7
(43) [b]	168.6	88.9	169.8	143.9	59.0	109.7	27.4	34.0
(44) [b]	168.6	91.1	169.9	143.9	59.1	109.6	27.3	34.4
(45) [b]	168.4	89.2	169.9	143.4	59.1	109.1	27.5	34.8
(46) [b]	168.0	89.1	170.0	142.8	59.1	109.1	120.7	137.7
(47) [b]	168.2	88.7	170.0	142.0	59.1	109.5	118.6	137.5
(48) [b]	167.5	89.7	169.8	141.3	59.8	109.2	118.2	138.2
(49) [b]	167.4	89.1	169.9	142.1	59.5	108.4	118.8	137.5
(50) [b,c]	167.1	87.9	171.0	142.7	59.6	131.9	119.3	134.2
(51) [b,d]	167.3	89.7	170.2	144.6	59.6	135.8	118.3	133.9
(52) [b,e]	166.3	88.3	170.7	141.9	60.2	130.4	117.1	133.5
(53) [a,f,g]	166.6	89.9	170.7	143.7	60.4	135.6	115.9	133.6

[a] Determined in [$^2H_6$]DMSO. [b] Determined in $CDCl_3$. [c] C-6-OCH_3, 61.4. [d] C-6-OCH_3, 62.9. [e] C-6-OCH_3, 61.0. [f] C-6-OCH_3, 62.5 [g] Obtained by substraction from a spectrum containing a mixture of (52) and (53).

4-OMe group. In fact C-4 is invariably at lower field than C-2, as before, but as the shift upfield for C-4 is *ca.* 9 p.p.m. and that for C-2 is *ca.* 5 p.p.m. the differences between the two are less for the conjugated tetronates

TABLE 5

Values for C-6 of 5*Z*- and 5*E*-isomers

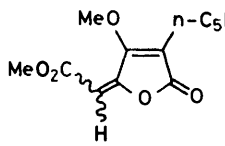
Compound	Chemical shift 5*Z*	5*E*	$\Delta\delta(Z\rightarrow E)$
(50) and (51)	131.9	135.9	+4.0
(52) and (53)	130.4	135.6	+5.2
(54)	95.0	101.1	+6.1
(55)	107.5	113.0	+5.5

(37)—(52) (1—4 p.p.m.) than for the unconjugated compounds (8)—(34) (*ca.* 7—8 p.p.m.), *cf.* Tables 2 and 4. Of course, substitution of a hydrogen by a methoxy-group on C-6 in the piperolides causes a downfield shift in the signal. Its magnitude is *ca.* 23 p.p.m.

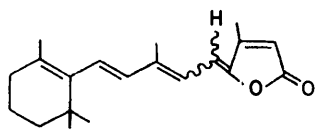
(4) 4-*Methoxy*-5,6-*dihydro*-2-*pyrones*.—Assignment of the signals due to a 5,6-dihydropyrone has been made on tetrahydronectriapyrone [21] (56) but the basis of the assignments to C-2 and C-4 is unclear, and stands in contradiction to those we would predict from our examination of compounds (57)—(62) (Table 6).

The assignment of the signals for C-5 and C-6 follows, in general, from their chemical shifts and multiplicity. Even when C-6 is quaternary as in (61) and (62), its chemical shift readily distinguishes it from the other carbon atoms present.

It is relatively easy to distinguish C-2 and C-4 in this series as C-2 appears as a singlet in the gated-decoupled spectra of 7,8-dihydrokawain (57) and dihydrokawain-5-ol (58), used as model compounds. There is a slight coupling to H-3, but this is <1 Hz in both cases.



(54)



(55)

(Figure). The signal assigned to C-4, however, appears as a complex multiplet, considerably simplified on selective irradiation at the proton frequency of the 4-methoxy-group. The various substituents at C-5 and

TABLE 6

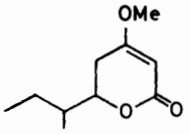
^{13}C Chemical shifts of 4-methoxy-5,6-dihydro-2-pyrones (57)—(62) [a]

Compound	Heterocyclic carbons						Aliphatic carbons	
	C-2	C-3	C-4	C-5	C-6	4-OMe	C-7	C-8
(57)	166.2	89.9	173.1	32.2	74.7	56.2	30.5	35.7
(58)	165.6	90.9	173.2	64.2	78.2	56.2	30.5	31.1
(59)	165.7	90.2	172.5	32.5	75.2	56.2	127.9	132.1
(60) [b]	163.8	93.5	166.9	66.8	78.5	56.8	123.8	133.7
(61) [c]	162.9	92.5	167.9	67.0	102.7	57.1	122.5	135.7
(62) [d]	158.3	104.5	161.4	184.4	102.0	57.2	122.3	135.5

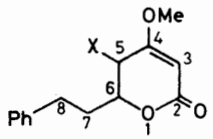
[a] All spectra run in [$^2H_6$]DMSO. [b] O$COCH_3$, 169.5, 20.5. [c] O$COCH_3$, 169.0, 20.2; 6-OCH_3, 50.7. [d] 6-OCH_3, 51.6.

C-6 have the expected effects of shifting the signals downfield. Compound (62) is particularly interesting as it serves as a model for the keto-form of 5-hydroxy-2-pyrones and so helps to distinguish between the two possible forms of these compounds (see below).

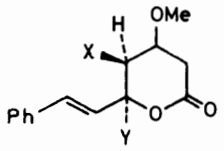
(5) 6-*Substituted*-4-*methoxy*-2-*pyrones*.—The ^{13}C n.m.r. of 2-pyrone itself has been thoroughly investigated and a complete analysis made of the signs and magnitudes of the long range coupling constants.[22] 4-Methoxy-2-pyrones are commonly occurring natural products [23] which are produced naturally by a variety of routes.



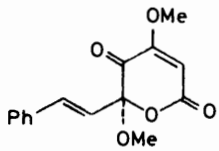
(56)



(57) X = H
(58) X = OH



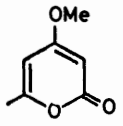
(59) X,Y = H
(60) X = OCOMe; Y = H.
(61) X = OCOMe; Y = OMe



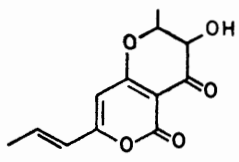
(62)

^{13}C N.m.r. offers an insight into the various possible biosynthetic routes and it is therefore a matter of importance that unambiguous assignments of signals should be made. Despite this the field has been fraught with arbitrarily made assignments and after one thorough study of aleonin and its derivatives [4] it was stated that ' caution should be exercised in assinging 2-pyrone ring signals until a firm substitution rule is found for the chemical shifts of the pyrone ring.'

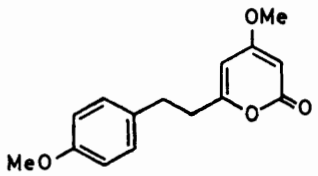
6-Methyl-4-methoxy-2-pyrone (63) has been studied [24] ($J_{C_6-H_6}$ 1.6 Hz) and, in line with our results for the 5,6-dihydropyrones, is assigned to C-2. By single-frequency decoupling experiments, using the well-separated frequencies of the 6-methyl and the 4-methoxy-groups, the



(63)



(64)



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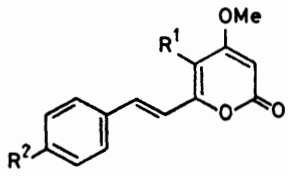
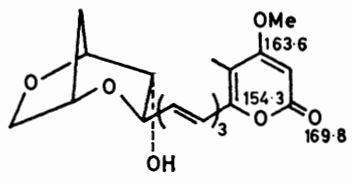


(66) R^1,R^2 = H
(67) R^1 = OH; R^2 = H
(68) R^1 = OCOMe; R^2 = H
(69) R^1 = H; R^2 = OMe



(70)

multiplets at δ 171.2 and 163.7 were assigned to C-4 and C-6, respectively. The signal at C-3 was assigned on the basis of its chemical shift compared to the dihydro-series, its relative invariance as 5-H is substituted by oxygen in (67) and (68) (Table 7) and also in that the signal at

TABLE 7

^{13}C Chemical shifts of 4-methoxypyrones [a]

	Heterocyclic carbons					Aliphatic carbons		
Compound	C-2	C-3	C-4	C-5	C-6	4-OMe	C-7	C-8
(63)	162.3	87.0	171.2	99.9	163.7	56.2		
(65) [b]	164.6	87.3	170.9	99.8	163.6	56.2	31.2	34.5
(66)	162.6	88.8	170.7	101.5	158.2	56.3	119.6	134.1
(67)	160.9	89.9	165.1	131.1	142.8	56.8	114.9	129.9
(68) [c]	160.6	89.5	164.7	125.1	149.7	57.2	113.4	135.1

[a] All spectra determined in [$^2H_6$]DMSO. [b] 4-OCH_3, 54.9. [c] $OCOCH_3$, 168.6, 20.1.

and assignments of the ring signals made. In the same study a revision for the assignment of signals in radicinin (64) [25] was suggested.

We first examined (63) in some detail as a model for compounds (65)—(68). In its gated-decoupled spectrum the signal at δ 162.3 appeared as a sharp doublet δ 89.5 in the spectrum of (69) appears as a simple doublet ($J_{C_3-H_3}$ 172 Hz) and C-2 as a singlet. The values for C-5 follow from this. The signals assigned to C-7 and C-8 are based on analogy with yangonin (69).[24]

It is clear that the introduction of a 5-oxygen substituent effects a marked upfield shift of the signals due to

C-6 (*ca.* 15 p.p.m. for 5-OH and 9 p.p.m. for 5-OAc), C-4 (5—6 p.p.m.), and C-2 (17—20 p.p.m.) as well as moving C-5 downfield by *ca.* 24—30 p.p.m. It is of interest that the 5-hydroxy-compound (67), which could exist in a ketone form analogous to (62), in fact exists wholly as the 2-pyrone in DMSO (Table 7).

The results in Table 7, particularly that of compound (66), would indicate that a re-investigation of the assignments made to C-2 and C-4 of aurovertin (70) [26] is indicated. The assignments made are shown in structure (70) but it seems more likely that C-4 is represented by one of the signals at δ 170.4 or 169.4 and C-2 by the signal at δ 163.6.

EXPERIMENTAL

The ^{13}C n.m.r. spectra were determined with a Varian XL-100 instrument and 620L-100 computer. Chemical shifts are recorded as p.p.m. downfield from $SiMe_4$, which was used as internal standard. The samples were dissolved in [$^2H_6$]DMSO or $CDCl_3$ according to solubility. The samples were either isolated from natural sources, or prepared in this laboratory or in the laboratory of Professor R. Hänsel, Free University, Berlin,* by methods reported elsewhere.[1-3,18]

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