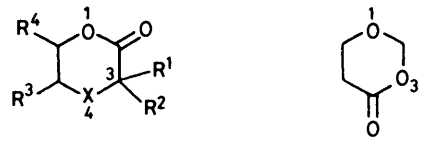
A ^{1}H Nuclear Magnetic Resonance Study of Alkyl- and Aryl-substituted 1,4-Oxathian-2-ones

Jorma K. Koskimies
Department of Chemistry, University of Helsinki, Vuorikatu 20, SF-00100 Helsinki 10, Finland

^{1}H N.m.r spectra for a number of alkyl- or aryl-substituted 1,4-oxathian-2-ones were analysed using the LAOCOON III program. The coupling constants imply that the C-S-C-C portion of the ring has a normal cyclohexane-like conformation which is compatible with either a classical boat or a half-chair. Chemical shift, geminal coupling constant, and long-range coupling constant evidence is presented which suggests that the former conformation is prevalent for oxathianones. Compounds with a single alkyl or phenyl substituent at C-3 or C-6 are conformationally biased, whereas the substituents at C-5 are mobile with ΔG° 1.0 and 1.7 kJ mol^{-1} for 5-methyl and 5-phenyl, respectively.

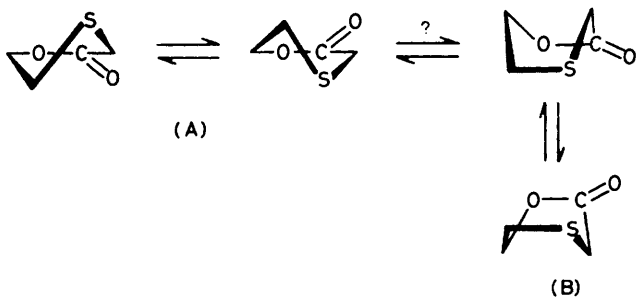
1,4-Oxathian-2-ones have received relatively little attention.[1] Recently several reports have appeared on the synthesis of these compounds.[2-8] The oxime derivatives have been patented for pesticidal use.[9-11] Oxathianones are easily hydrolysed or polymerized.[1e,7] It has been suggested that this is because of the strain in the ring arising from the mutually incompatible geometric requirements of the planar ester functionality and puckered C-S-C-C part of the ring.[7] The solution conformation of the oxathianone (**1**) is not known but a recent *X*-ray molecular structure of *p*-bromophenyl-1,4-oxathian-2-one (**2**) indicates the classical boat conformation for this compound in the solid state.[12] The solution conformation of 6-methyl-1,4-oxathian-2-one (**3**) has been briefly discussed by Kelstrup.[8] On the basis of the proton vicinal coupling constants he concluded that the compound has either a boat or a half-chair conformation or is a rapidly equilibrating mixture of the two. The only other report dealing with the conformation of oxathianones is by Jankowski and Coulombe[13] concerning the ring inversion. Thus it was deemed desirable to study ^{1}H n.m.r. spectra of differently substituted oxathianones to see what might be learned of the conformation of these compounds.

The conformational situation in the carbocyclic analogue δ-valerolactone (**4**) is known. Thus Phillips *et al.* found two different conformations for δ-valerolactone (**4**) in the gas phase by microwave spectroscopy and calculated, by the force field method, that the energy difference between the two likely conformations, the half-chair and the boat, was in favour of the half-chair by 2.3 kJ mol^{-1}.[14] This compares favourably with the value of 2.5 kJ mol^{-1} obtained from the microwave spectrum.[14] The small energy difference between the chair and the boat forms comes about because the chair form is considerably strained (*ca.* 20.5 kJ mol^{-1} [14]) as the adjustment to the planarity of the ester moiety results in substantial deformation of bond angles and lengths. In the boat, on the other hand, there is no bond strain although the eclipsing C–H bonds and the close hydrogens at the prow and the stern of the boat raise the energy level of this conformation above that of the chair. The planarity of the C-O-C(=O)C part of the ring is explained by resonance and is well documented[15-19] though significant bending out of the plane is possible.[20,21] Substituted valerolactones assume the half-chair conformation in solution[14,22-28] though boat forms are not unknown.[19,21,27] However, the latter arrangement occurs only when the chair is exceptionally strained. Their conformational assignments have been based on the carbonyl frequency in the i.r. spectrum[17,22,23,26] and on the vicinal and long-range coupling constants in the ^{1}H n.m.r. spectrum[22-26,28,29] and on the solid-state structure determination by *X*-ray diffraction.[27,28] Of heterocyclic analogues of δ-valerolactone (**4**) 1,3-dioxan-4-one (**5**) has been studied by



(5)

	X	R^1	R^2	R^3	R^4
(1)	S	H	H	H	H
(2)	S	H	H	H	*p*-BrC$_6$H$_4$
(3)	S	H	H	H	CH$_3$
(4)	CH$_2$	H	H	H	H
(6)	S	CH$_3$	H	H	H
(7)	S	(CH$_3$)$_3$C	H	H	H
(8)	S	H	H	CH$_3$	H
(9)	S	H	H	H	(CH$_3$)$_3$C
(10)	S	H	H	H	(CH$_3$)$_2$CH
(11)	S	H	H	H	C$_6$H$_5$
(12)	S	H	H		(CH$_2$)$_4$
(13)	S	CH$_3$	CH$_3$	H	H
(14)	S	CH$_3$	H	H	C$_6$H$_5$
(15)	S	CH$_3$	CH$_3$	H	C$_6$H$_5$
(16)	S	H	H	C$_6$H$_5$	H



(A)

(B)

Äyräs.[30] In this case also the half-chair is the favoured conformation although an axial substituent at C-6 will force the ring at least partly into the chair form.[31-34] It may be concluded based on the evidence of other six-membered lactones that 1,4-oxathian-2-one (**1**) assumes either a half-chair (A) or a boat conformation (B), or possibly an equilibrium mixture of the two. The other boat and the twist forms are all unlikely since they involve a non-planar ester group. Ring inversion will, of course, be possible in both types of conformations. Inspection of Dreiding models for the oxathianone reveals that there must be some angle strain in the chair form whereas the boat is quite strain free. Furthermore, the boat is expected to be relatively more stable than the chair compared to the valerolactone case, since there are no unfavourable eclipsing C-H interactions in

the sulphur analogue. Thus it is no surprise that 6-(*p*-bromophenyl)-1,4-oxathian-2-one (**2**) exists as a boat in the crystal state.[12]

Results

Preparation of Oxathianones.—The synthesis of compounds (**1**)—(**3**), (**6**)—(**9**), and (**12**) has been described elsewhere.[7] Compounds (**10**), (**11**), and (**13**)—(**15**) were prepared by similar methods. 5-Phenyl-1,4-oxathian-2-one (**16**) was made from phenylbromoacetaldehyde acetal [$C_6H_5CHBrCH(OC_2H_5)_2$] and thioglycolate dianion by substitution followed by lactonization. All new compounds gave satisfactory n.m.r. and i.r. spectra, molecular weights by high-resolution mass spectrometry, and elemental analyses.

Analysis of ^{1}H N.m.r. Spectra.—The spectra were usually obtained in $CDCl_3$ on a 100 or a 200 MHz instrument. They were analysed with the aid of the LAOCOON III program.[35] The initial solution, a guess or one obtained by hand analysis, was iterated until the root mean square error was less than 0.1 Hz. When several solutions appeared possible for a given data set the following criteria were used in choosing the correct one: the smallest root mean square error, the best visual fit between the experimental spectrum and the plotted calculated spectrum, the lowest probable errors for the calculated variable parameters, and the compatibility of the calculated parameters with those of other compounds in the series. The geminal coupling constants were assumed to be negative and the vicinal positive. The AA'BB' pattern of compound (**1**) was insensitive to the change in the geminal coupling constants in the iteration, whereas for (**13**) these couplings could be obtained from the AA'BB' pattern. The AB portion of the ABX pattern of compound (**2**) consisted of only five lines which led to a considerable error in the iterated parameter set. This problem was overcome by running a 200 MHz spectrum in [$^2H_6$]benzene in which all eight lines were visible. The C-5 and C-6 protons of compound (**16**) were nearly isochronous in $CDCl_3$ and the resulting singlet could be resolved only at 400 MHz into an ABC pattern which was analysed using LAOCOON. Iterative optimization of the small long-range couplings was not usually done, since these couplings mainly broaden the spectral lines and since the input of the broadened reference peaks was difficult. The spectral parameters obtained by iterative analysis were checked in the case of (**8**) by selective irradiation techniques.

Assignment of the Chemical Shifts.—For assignment purposes the protons are termed axial (H_a) and equatorial (H_e). The two types of C-3 hydrogens do not coincide in the two conformations in question. Thus in a chair the axial protons H-3a and H-6a are *trans* to each other while in a boat they are *cis*. The assignment of the chemical shifts was straightforward since the protons at C-3, C-5, and C-6 were generally well separated. H-5 and H-6 were identified on the basis of the vicinal coupling constants: the largest coupling is between the axial protons. Of the C-3 protons (an AB) the upfield one was assigned to the equatorial proton, mainly because this proton is also coupled to H-5e (see Discussion section). For the 5-phenyl compound (**16**) this assignment was confirmed by a Eu(fod)$_3$ experiment. It was found that the europium-induced shift is larger for the high-field proton (δ 3.38) than for the low-field proton (δ 3.70) of the AB quartet. In either conformation the equatorial proton will lie closer to the carbonyl oxygen, the probable chelation site of europium, than to the axial proton. Thus the more shifted proton at δ 3.38 is H_e and the proton at δ 3.70 is H_a. A similar situation has been reported for cyclohexanone.[36] The bicyclic oxathianone (**12**) has been shown to have a *trans*-configuration.[7] 3-Methyl-6-phenyl-1,4-oxathian-2-one (**14**) is most likely diequatorial, since essentially only one isomer (deemed to be the more stable one) was formed in the ring-closure step. This is supported by the methyl chemical shifts: In compound (**13**) the averaged methyl resonates at δ 1.62 and the equatorial methyl of

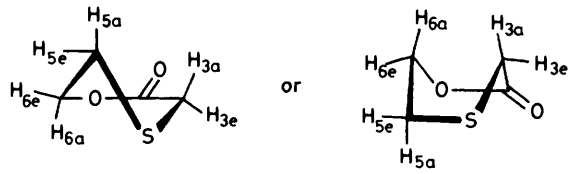


Table 1. The proton chemical shifts[a] (Hz) and the C=O stretching frequencies (cm^{-1}) of 1,4-oxathian-2-ones

Compound[b]	Spectrum	H-3e	H-3a	H-5e	H-5a	H-6e	H-6a	Others	C=O
(**1**)	200 MHz	3.400		3.016		4.539			1 740[2]
	100 MHz	3.402		3.018		4.542			
(**13**)	200 MHz			3.017		4.703		Me 1.620	1 723 (KBr)
(**6**)	100 MHz		3.848	3.031	3.096	4.599	4.454	Me 1.374	1 735 (neat)
(**7**)	100 MHz		3.559	3.041	3.053	4.584	4.429	Bu^t 1.177	1 735 (neat)
(**16**)	60 MHz[c]	2.85	3.04		3.92	3.81	3.74		1 727 (KBr)
	200 MHz	3.376	3.703		4.476	4.493	4.441	Phe 7.29—7.45	
	400 MHz	3.420	3.735		4.513	4.546	4.473	Phe 7.30—7.45	
(**8**)	100 MHz	3.342	3.473		3.446	4.449	4.218	Me 1.350	1 740[2]
	250 MHz	3.349	3.479		3.468	4.455	4.221	Me 1.35	
(**3**)	100 MHz	3.173	3.581	2.944	2.773		4.640	Me 1.477	1 735 (neat)
(**9**)	100 MHz	3.152	3.585	2.966	2.806		4.096	Bu^t 1.019	1 745 (neat)
	200 MHz	3.168	3.582	2.964	2.807		4.085		
(**10**)	200 MHz	3.175	3.557	2.928	2.808		4.191	CH 1.984	1 836 (neat)
								Me 1.014 and 1.048	
(**11**)	200 MHz	3.272	3.677	3.055	3.055		5.429	Phe 7.361	1 715 (KBr)
(**2**)	100 MHz[d]	3.310	3.686	3.052	3.012		5.427	Phe 7.525 and 7.271	1 740 (neat)
	200 MHz[e]	2.751	2.856	2.124	2.273		4.436	Phe 6.54—7.19	1 751 ($CHCl_3$)
	60 MHz[d,f]	3.34	3.97	3.22	3.07		5.73		
(**14**)	200 MHz		3.942	3.123	3.114		5.454	Phe 7.368, Me 1.462	1 719 (KBr)
(**15**)	200 MHz			2.916	3.221		5.726	Phe 7.369, Me 1.704	1 722 (KBr)
(**12**)	100 MHz[d]	3.199	3.710		2.998		4.182	$(CH_2)_4$ 1.35—2.26	1 723 (KBr)

[a] In $CDCl_3$ from internal Me_4Si. [b] See ref. 7. [c] In C_6H_6. [d] Large probable errors in some of the iterated parameters. [e] In C_6D_6. [f] In $(CD_3)_2SO$.

Table 2. Geminal coupling constants (Hz) of oxathianones

Compound		J_{33}	J_{55}	J_{66}
(1)			(−12.00)	(−12.00)
(13)			−12.08	−14.10
(6)			−11.97	−12.14
(7)			−11.85	−11.98
(16)	C_6H_6	−14.71		−12.04
	$CDCl_3$	−14.76		−10.96
(8)	100 MHz	−14.92		−12.03
	250 MHz	−14.71		−12.05
(3)		−14.74	−12.33	
(9)	100 MHz	−14.57	−11.90	
	200 MHz	−14.59	−11.96	
(10)		−14.44	−12.22	
(11)		−14.77	−12.59	
(2)	$CDCl_3$	−14.89	−12.12	
	C_6H_6	−14.51	−12.33	
	$(CD_3)_2SO$	−14.0[a]	−12.4[a]	
(14)			−12.24	
(15)			−14.04	
(12)		−14.59		

[a] Large probable error.

Table 3. Vicinal coupling constants (Hz) of oxathianones

Compound		J_{5e6e}	J_{5e6a}	J_{5a6e}	J_{5a6a}	Others
(1)	100 MHz	7.41		3.89		
	200 MHz	7.51		3.72		
(13)		7.36		3.62		
(6)		2.35	3.17	4.68	12.72	
(7)		2.35	3.70	5.18	11.52	J_{Me} 6.36
(16)	C_6H_6		5.33		8.64	
	$CDCl_3$		3.82		8.59	
(8)	100 MHz		3.68		7.99	J_{Me} 7.12
	200 MHz		3.62		7.96	
(3)			3.21		11.12	J_{Me} 6.23
(9)	100 MHz		2.48		11.81	
	200 MHz		2.46		11.92	
(10)			2.41		11.51	J_{H6CH}5.74, J_{Me} 6.71
(11)			2.52		11.78	
(2)	$CDCl_3$		3.51[a]		10.66[a]	Aryl J_{AB} 8.42
	C_6D_6		2.75		11.57	
	$(CD_3)_2SO$		2.2		12.4	
(14)			3.14		11.60	J_{Me} 6.53
(15)			2.92		11.10	
(12)					10.49	

[a] Large probable error.

(6) at δ 1.37 (the assignments are based on similar cases in valerolactones[26]). Thus the methyl in compound (14) at δ 1.46 is clearly equatorial.

The other assignments were unambiguous. The phenyl multiplets were not analysed. The n.m.r. data are listed in Tables 1—5.

Discussion

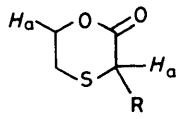
I.r. Spectra.—The frequency of the carbonyl stretch has been used for identification of chair or boat conformations of δ-valerolactones. Thus absorption at 1 730—1 750 cm^{-1} implies the chair form and that in the region 1 758—1 765 cm^{-1} is indicative of the boat form.[17,22] This rule has been successfully applied to several substituted valerolactones,[23,25,26] but has been questioned by Allinger, who argued that the i.r. frequency is dependent on the endocyclic bond angle of the carbonyl

Table 4. The *R* values and S-C-C-O dihedral angles of some oxathianones and analogues

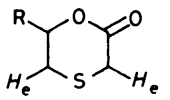
Compound	*R*	Dihedral angle (°)
(1)	1.90	56
(13)	2.03	57.0
(6)	1.92	56.2
(7)	1.56	52
Cyclohexane	2.16	58[a]
1,4-Oxathiane	2.85	62[b]
1,4-Oxathiene	3.10	63[a]

[a] Ref. 50. [b] Ref. 49.

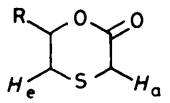
Table 5. Long-range coupling constants (Hz) in 1,4-oxathian-2-one



(6)	R = CH_3	0.49
(7)	R = $C(CH_3)_3$	0.56



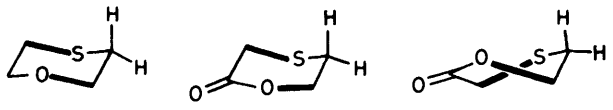
(3)	R = CH_3	0.61
(9)	R = $C(CH_3)_3$	0.67
(10)	R = $CH(CH_3)_2$	0.62
(2)	R = C_6H_4Br	0.61



(3)	R = CH_3	0.5
(2)	R = C_6H_4Br	0.4

carbon rather than the conformation of the lactone ring.[37] Inspection of the carbonyl frequencies of the oxathianones reveals that the above rule is not directly applicable to the oxathianones (Table 1).[8,12] The C=O absorptions lie between 1 715 and 1 745 cm^{-1} suggesting the half-chair conformation. However, lactone (2) (1 740 cm^{-1} in solid and 1 750 cm^{-1} in $CHCl_3$) is known to be a boat in the solid state, which makes the whole i.r. criterion questionable. Furthermore, 6-(*p*-bromophenyl)- (2) and 6-phenyl-oxathianone (11) should have similar conformations since the steric requirements of the attached groups are alike, yet their C=O frequencies differ considerably: 1 715 and 1 740 cm^{-1}.

Chemical Shifts.—In all present compounds the C-3 protons form a well separated AB where the axial proton (δ 3.5—3.9) is downfield from the equatorial proton (δ 3.1—3.4) (see Table 1). Though this order of shifts is not unknown[38] it is contrary to the situation in valerolactone in which the axial proton α to carbonyl is upfield from the equatorial one.[24,28] The latter compound is a known chair so that the reversal of the chemical shifts in oxathianone may be due to the α sulphur[39] or to the predominance of another conformation (boat). In the boat the axial flagpole proton is close to the bowsprit proton and thus deshielded. The ring inversion in compound (1) causes averaging of the axial and equatorial signals (δ 3.40). In compounds (16) and (8) the chemical shift difference between the C-3 protons is small, apparently due to the partial averaging of the signals. Thus these compounds appear to be conformationally mobile with sizable amounts of axial conformers. The equilibrium constant between the two conformers can be calculated using the Eliel equation $K = (\nu - \nu_a)/(\nu_e - \nu)$,[40] where ν is the shift of the averaged proton, and ν_e and ν_a are shifts for pure equatorial and axial protons. With



Scheme 1.

Scheme 2.

ν_e = 3.17 and ν_a = 3.58, K = 1.38 and K = 2.00 for (**8**) and (**16**) respectively.

The compounds with a single substituent at C-3, (**6**), (**7**), and (**14**), are evidently conformationally biased with the substituents equatorial, because the proton shifts, δ 3.85, 3.56, and 3.94, are all within the axial range even when the downfield shift effect of the alkyl group (*ca.* 0.2 p.p.m.) is taken into account. The least downfield shifted is the axial C-3 proton of compound (**7**). This need not be caused by a conformational equilibrium but merely by a twisting of the ring to accommodate the bulky t-butyl group *gauche* to the carbonyl oxygen.

According to Äyräs the benzene-induced shift is larger for the axial than for the equatorial proton α to the lactone carbonyl in the boat form but about the same in the half-chair conformation.[41,42] This is presumably because in the half-chair the two methylene protons are equidistant from the carbonyl plane, unlike in the boat. Comparison of the 3-methylene shifts of compound (**2**) in $CDCl_3$ and [$^2H_6$]benzene reveals that the benzene-induced shifts are dissimilar in the axial and equatorial proton, suggesting that the oxathianone (**2**) has a boat conformation. A similar tendency is observed in compound (**16**), though the shift difference is smaller, apparently due to the conformational inversion of the ring.

In both thiane[43] and 1,4-oxathiane[39] the equatorial protons α to sulphur resonate upfield of the axial protons: 0.19 p.p.m. in thiane and 0.64 p.p.m. in oxathiane. Hence one expects to find a similar situation in the C-5 protons of 1,4-oxathian-2-one. In fact, a reversal of the order is observed in compounds (**2**), (**3**), (**9**)—(**11**), and (**14**) and in the rest the shift difference is very small. A possible explanation for this behaviour of the C-5 protons is that oxathianone has a different conformation from the reference compounds thiane and 1,4-oxathiane, which have the usual chair structure. According to Lambert[44] the anisotropy of the magnetic susceptibility of bonds 3—4 and 6—1 would determine the relative chemical shifts at C-5. In the half-chair the spatial relationship of the 3—4 bond with respect to C-5 is comparable to that in 1,4-oxathiane whereas in the boat the situation is completely different (Scheme 1) suggesting that oxathianones have a boat rather than chair structure. This reversal of the chemical shifts order cannot be due to the ester carbonyl *per se* since in valerolactone no such effect is seen for the C-5 protons.

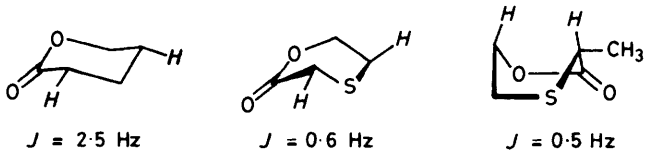
Inspection of the relative chemical shifts of the C-6 protons shows that in each case [compounds (**6**)—(**8**) and (**16**)] the axial is the more shielded of the pair in accordance with the analogous protons in valerolactone,[24,28] oxane,[43] and 1,4-oxathiane.[39] In this case, the relative positions of the 1—2 and 4—5 bonds, which determine the chemical shifts, are alike in the two alternative conformations. The decrease in the chemical shift difference in the oxathianones (0.2—0.1 p.p.m.) compared with oxane (0.5 p.p.m.) and 1,4-oxathiane (0.46 p.p.m.) may be attributed to flattening of the oxathianone ring, on one hand, and the averaging of the shifts in compounds (**16**) and (**8**) on the other hand.

The Geminal Coupling Constants.—Of the geminal coupling constants the most informative is that between the C-3 protons. Barfield and Grant have stated that the coupling constant between geminal protons is dependent on the dihedral angle the adjacent C=O bond forms with these protons.[45] The coupling should be smallest when the C=O bond bisects the H-C-H angle. This phenomenon has been used by Carroll[25] in δ-valerolactones and by Äyräs[31] in 1,3-dioxan-4-ones for determination of the lactone conformation. Thus in valerolactones the value of −18 to −17 Hz is known to arise from the half-chair conformation[24,26,28,46] and in 1,3-dioxan-4-ones −17.8 Hz has been ascribed to the chair and −16.7 Hz to the boat form.[31] Accordingly, the expected value of $^2J_{33}$ for the chair form of 1,4-oxathian-2-one would also be around −17 to −18 Hz. As the observed values for these lactones vary between −14.4 to −14.9 Hz (Table 2) the compounds presumably have the boat conformation. In the boat the C=O bond almost eclipses with the equatorial C-H bond and thus makes $^2J_{33}$ more positive, as observed. With $^2J_{33}$ in oxane around −12 to −13 Hz[47] and that in δ-valerolactone −18 Hz[28] the decrease in coupling constant, in going from oxane to valerolactone (both known chairs), becomes *ca.* 5—6 Hz. On the other hand, the change in the geminal coupling constant in going from 1,4-oxathiane (J −13.1 Hz[39]) to 1,4-oxathian-2-one (J −14.7 Hz) is only 1.6 Hz. Clearly, a different conformation is implied for oxathiane and oxathianone. Since the former is known to assume the normal chair conformation, a logical conclusion is that the latter must be in the boat form. As this coupling constant is known to be quite sensitive towards the position of conformational equilibrium[31] and because the C-3 couplings found are remarkably constant, one can only conclude that these lactones must have similar conformations with respect to their O-C-C-S fragment. The hybridization, and hence the bond angle, also affects the geminal coupling in such a way that the smaller C-C-S angle (increased *s* character in the C-H bonds) increases the coupling constant. This angle 109.7° is not unusually small,[12] so that the angle deformation cannot be a significant contributor to the increased coupling observed.

The C-5 geminal coupling constants also are remarkably constant in all the compounds and fall around −12.0 Hz. This is somewhat larger than that of 1,4-oxathiane (−13.1 Hz[39]) and thiane (−13.6 Hz[48]), both chairs, suggesting that the oxathianone endocyclic bond angle is smaller than in thiane and oxathiane. The dimethyl compound (**15**) is an exception with its coupling constant of −14.0 Hz. This is explained by the increase of the bond angle at C-5, caused by flattening of the ring, or even flipping into the half-chair. This deformation arises from a strong steric interaction between the flagpole methyl and the bowsprit hydrogen, which is also seen in the deshielding of the 3-methyls (δ 1.70). If the oxathianones preferred the half-chair structure, the deviation in the geminal coupling constant would be more difficult to explain, since steric interaction between the pseudo-axial methyl and the syn-axial hydrogen is not great in half-chair (**2**). Moreover, in valerolactone, which has a half-chair conformation, this coupling constant ($^2J_{55}$) is *ca.* −14 Hz.[23,24,28]

The geminal coupling constants for C-6 are *ca.* −12 Hz, which compares favourably with −11.8 of 1,4-oxathiane[39] and −11.2 of oxane[48] as well as −11.2 of δ-valerolactone.[23,24] Again the 3,3-*gem*-dimethyl compound (**13**) has an abnormally small coupling, −14.10 Hz. As discussed above, this may indicate increase in the C-6 bond angle, probably caused by the conformational change.

Scheme 3.



J = 2·5 Hz *J* = 0·6 Hz *J* = 0·5 Hz

The Vicinal Coupling Constants.—The vicinal coupling constants give valuable information about the shape of the ring (Table 3). The oxathianone couplings, 2.4—3.5 and 10.5—12.7 Hz, are typical for J_{ea} and J_{aa} of a cyclohexane-like ring. The same couplings in the chair-shaped cyclohexane are 2.2 and 10.6 Hz respectively.[49] Also, valerolactone[28] and 1,4-oxathiane[39] display similar vicinal couplings. These values are clearly compatible with a chair form or a boat form or an equilibrium of the two. However, the twist-boat would involve significantly different coupling constants, so that that conformer is decidedly out of the question. *R* Values[50,51] have been employed for determination of the shape of the ring. The *R* values, and the dihedral angles calculated from them, have been listed in Table 4 for lactones (**1**), (**6**), (**7**), and (**13**). It can be seen that lactones (**1**), (**6**), and (**13**) are slightly more flattened than cyclohexane, but considerably more flattened than 1,4-oxathiane or 1,4-oxathiene. This flattening is most likely caused by incompatible geometries of the ester and the C-C-S-C parts of the ring.[7] The dihedral angle of 54° obtained from the *X*-ray structure of lactone (**2**) is in agreement with the n.m.r. results.[12] Compound (**7**) is significantly more flattened than the other three. Evidently the bulky t-butyl group distorts the ring in order to avoid eclipsing with the carbonyl, the overall effect being flattening. This effect was also seen in the chemical shift of the C-3 proton (see above).

As expected lactones (**1**) and (**13**) are conformationally averaged. The values of J_t and J_c are clearly mean values of vicinal couplings. Lactones (**16**) and (**8**) also have exceptional vicinal couplings, which can be explained by the conformational mobility of these compounds. Using the equation $K = (J_{ee} - J)/(J - J_{aa})$ and $J_{ee} = 2.35$ and $J_{aa} = 11.67$ Hz, equilibrium constants of 2.03 in $CDCl_3$ and 2.08 in [$^2H_6$]benzene are obtained for (**16**) and 1.53 in $CDCl_3$ for (**8**). The corresponding equilibrium constants 2.1 and 1.4, calculated from the chemical shifts, agree quite well. Thus the conformational energy of the methyl group at position 5 is 1.05 kJ mol^{-1} and for phenyl 1.75 kJ mol^{-1}, both smaller than those of cyclohexane.[52] In the other positions, 3 and 6, these groups prefer to be equatorial and the conformational energies are too large to be calculated from the vicinal coupling constants. The vicinal coupling constants show that lactones (**2**), (**3**), (**6**), (**7**), (**9**)—(**12**), (**14**), and (**15**) all must have similar anancomeric conformations, possibly with a chair-boat equilibrium (Scheme 3) which does not reflect itself in the coupling constants. However, the fact that there is no discernible solvent effect on equilibrium in mobile 5-phenyloxathianone (**16**) or biased 6-(*p*-bromophenyl)-oxathianone (**2**) speaks for the existence of only one type of ring conformation.

The methyl vicinal couplings have been used to identify the axial–equatorial position of a methyl group in valerolactones.[26,33] Axial methyls have larger coupling constants. This rule appears to hold also for oxathianones. Lactones (**3**), (**6**), and (**14**) all have J_{CHMe} about 6.2—6.5 Hz, whereas compound (**8**), with a sizable population of the methyl axial conformer, has a larger coupling, 7.1 Hz. The comparison of the methyl vicinal couplings also supports the assignment of the methyl of (**14**) as equatorial.

Long-range Couplings.—δ-Valerolactones display in their n.m.r. spectra a *W*-type long-range coupling ^4J of the order of 1.5—2.5 Hz as in other six-membered rings.[22–25,28,46] Appearance of a coupling of this magnitude has been used as evidence that the compound has a chair conformation, since such is necessary for the *W*-arrangement. In sulphur-containing rings similar couplings are known.[53] A long-range coupling of this kind is visible in lactones (**2**), (**3**), (**9**), and (**10**) and is assigned between protons H-3e and H-5e. The coupling appears also in other oxathianones as line broadening, but is absent in (**2**), (**8**), and (**16**). The magnitude, 0.5—0.6 Hz, is clearly smaller than that in valerolactones (Table 5). The small size of the *W*-coupling suggests less than perfect alignment of the coupled protons, *i.e.* deformation of the *W*-system. Since in valerolactones no such decrease in the *W*-coupling is observed, it is reasonable to assume that the oxathianones have a different conformation. Even in the boat form, H-3e and H-5e are roughly in a *W*-arrangement. Furthermore, there is a long-range coupling between H-5e and H-3a, at least in lactones (**2**) and (**3**), of the order of 0.3—0.5 Hz. This is possible only if the ring has the boat conformation, since in the half-chair these couplings are very small compared to J_{3e5e}.[23,24] In lactones (**8**) and (**16**) there is a small coupling between H-3e and H-5a, observed as line broadening, in accordance with the previous finding that these two lactones are mobile.

In the biased compounds (**6**) and (**7**) the axial protons H-3a and H-6a are coupled by 0.6 Hz. This coupling is of the homoallylic type and can only occur when the ring has a boat structure with C-3 and C-6 at the bow and the stern of the boat (Table 5). Äyräs has cited a similar coupling (0.7 Hz) for the boat form in 1,3-dioxan-4-ones.[33] It is known that the *cis*-diaxial homoallylic coupling is largest in the boat form.[54] Clearly, this coupling proves that 3-methyl- and 3-t-butyl-oxathianones (**6**) and (**7**) are boats. In addition, the signals of H-3a and H-6a are noticeably broadened also in the spectra of (**3**), (**8**), and (**9**) suggesting the existence of the homoallylic coupling in these lactones also.

Conclusions.—^{1}H N.m.r. evidence shows that 1,4-oxathian-2-one is either a boat (B) or a half-chair (A), with a planar ester group and the rest of the ring slightly flattened (relative to cyclohexane). The constancy of the n.m.r. parameters in differently substituted compounds and in different solvents seems to rule out the half-chair–boat equilibrium. Lactones (**1**), (**8**), (**13**), and (**16**) are conformationally mobile* with conformational energies of 1.0 kJ mol^{-1} for 5-methyl and 1.7 kJ mol^{-1} for 5-phenyl. Thus lactones (**8**) and (**16**) have quite large populations of the axial isomer. On the other hand, methyl substituents at C-3 and C-6 make the lactone strongly biased. The question as to which ring conformation is dominant in solution cannot be decided with absolute certainty on the basis of present data. The following factors favour the more unusual boat conformer. Reversal of the chemical shifts order of the geminal protons, size of the geminal coupling constant at C-3, and occurrence of homoallylic coupling. Besides, there is the conformational evidence of the mobile 5-substituent. In the half-chair the axial 5-substituent would be syn-axial to the pseudo-axial hydrogen of C-3 whereas in the boat conformer there is no steric hindrance as the axial substituent will be closest to the

* Contrary to earlier claims,[13] ring inversion in 1,4-oxathian-2-ones is rapid at room temperature, at least in those cases where the two interconvertible forms are detectable from the ^{2}H n.m.r. spectra.

lone pair of O-1. Thus the lactone with an axial 5-substituent is likely to be the boat. Moreover, since compounds with 5-substituents do not possess different $^2J_{33}$ values it is reasonable to assume that all lactones are boats.

To test the presence of the boat conformer the 3,3-dimethyl compounds were prepared. Since the axial bowsprit methyl comes very close to the flagpole hydrogen in these compounds (Scheme 2) they are expected to deform in some way. The change observed in the n.m.r. spectra of (**13**) and (**15**) was in the geminal coupling constants, which was interpreted to imply increase of the endocyclic bond angle in question. This increase could arise either from flattening of the ring or flipping into the half-chair conformation entirely. If the molecule were a half-chair to start with no change would be expected, because the interaction of axial methyl with syn-axial hydrogen would not be severe.

Electrostatically the boat form (dipole moment 4.08 D) should be slightly more favoured in high-dielectric media than the half-chair (dipole 3.62 D).[12] However, no significant change in $^2J_{33}$ nor in the vicinal coupling constants could be found in different solvents ([$^2H_6$]benzene to [$^2H_6$]dimethyl sulphoxide). This suggests that the energy difference between the boat and the half-chair cannot be very small.

Oxathianone, if indeed a boat, seems to be one of the few six-member rings that prefer the boat conformation. The reason for this is evident on comparison to δ-valerolactone. In the latter compound the boat is 2.5 kJ mol^{-1} higher in energy than chair. In oxathianone the strain of the boat is relieved by 8.4 kJ mol^{-1} (two pairs of eclipsing hydrogens) because the unfavourable eclipsed hydrogens are absent. Another factor which may contribute to the altered energy difference is the angle strain which seems to be larger in the half-chair than in the boat on the basis of Dreiding models.

Experimental

The ^{1}H n.m.r. spectra were recorded with JEOL PMN-60, JNM-100, and JNM-FX-200 MHz spectrometers, usually in 5—15% $CDCl_3$ solutions, employing tetramethylsilane as internal standard. The LAOCOON III program,[35] including the plotting program, was adapted to CANDE of Burroughs 8700 computer by Mr. M. Nurmela from the University Computing Center. I.r. spectra were recorded with a Perkin-Elmer 1310 spectrometer. Elemental analyses were performed by Dornis und Kolbe, Mülheim a. d. Ruhr.

Preparation of Compounds.—3,3-*Dimethyl*-1,4-*oxathian*-2-*one* (**13**). A mixture of ethyl bromoisobutyrate (10.5 g, 55 mmol) and mercaptoethanol (5 ml, 71 mmol) was added under nitrogen to a stirred suspension of anhydrous potassium carbonate (7.6 g, 55 mmol) in dimethylformamide (50 ml). The resulting solution was heated at 100 °C for 15 h, then poured into water and taken up in ether. Removal of ether gave the ester which was hydrolysed by adding 50% aqueous potassium hydroxide. The aqueous solution was acidified and extracted with ether. The ether extracted were concentrated and quickly lactonized using an ion-exchange resin (Dowex 50 X8) catalyst.[7] Distillation gave the desired lactone (4.0 g, 50%), b.p. 71—77 °C at 0.3 mmHg. An analytical sample was purified by low-temperature recrystallization from ether, $\nu_{max.}$ (neat film) 1 723 cm^{-1} (C=O) (Found: C, 48.9; H, 7.4%; M^+, 146.0401. Calc. for $C_6H_{10}O_2S$: C, 49.3; H, 6.9%; *M*, 196.0401).

5-*Phenyl*-1,4-*oxathian*-2-*one* (**16**). A methanolic solution of 2-bromo-2-phenylacetaldehyde diethyl acetal[55] (8.0 g, 33 mmol) was added to a stirred solution of sodium hydroxide (3 g) and 80% thioglycolic acid (3.5 ml, 39 mmol) in aqueous methanol (30 ml). The mixture was stirred for 1 h and then acidified with hydrochloric acid. Methanol and water were distilled off until the b.p. rose to 92 °C. The remaining aqueous solution was made alkaline with dilute sodium hydroxide solution and then treated with sodium borohydride (3 g) and stirred overnight. The resulting hydroxy acid was isolated and lactonized with toluene-*p*-sulphonic acid catalyst in refluxing benzene. The lactone was washed with aqueous hydrogencarbonate and dried. The solvent was removed and the residue distilled in a Kugelrohr apparatus to give a solid (1.4 g, 22%), b.p. 180 °C at 0.1 mmHg; m.p. 91—95 °C (lit.,[1e] 89 °C); $\nu_{max.}$(KBr) 1 727 cm^{-1} (C=O).

6-*Isopropyl*-1,4-*oxathian*-2-*one* (**10**) was prepared from 3-bromo-3-methylbutan-2-one[56] and thioglycolic acid by known methods[7] in 29% yield, b.p. 120—130 °C at 0.6 mmHg; $\nu_{max.}$(neat) 1 740 cm^{-1} (C=O) (Found: C, 52.1; H, 7.8%; M^+, 160.0569. Calc. for $C_7H_{12}O_2S$: C, 52.5; H, 7.55; *M*, 160.0557).

6-*Phenyl*-1,4-*oxathian*-2-*one* (**11**) was prepared from α-bromoacetophenone and thioglycolic acid[7] in 22% yield, m.p. 116—117 °C (lit.,[1e] 117 °C); $\nu_{max.}$(KBr) 1 715 cm^{-1} (C=O).

cis-3-*Methyl*-6-*phenyl*-1,4-*oxathian*-2-*one* (**14**) was made from thiolactic acid and α-bromoacetopheone[7] in 45% yield, m.p. 99—100 °C; $\nu_{max.}$(KBr) 1 719 cm^{-1} (C=O) (Found: C, 63.2; H, 6.15%; M^+, 208.0564. Calc. for $C_{11}H_{12}O_2S$: C, 63.4; H, 5.8%; *M*, 208.0557).

3,3-*Dimethyl*-6-*phenyl*-1,4-*oxathian*-2-*one* (**15**). Thiourea (9.6 g, 0.13 mol) and ethyl bromoisobutyrate (22.5 g, 0.11 mol) were refluxed in ethanol for 3 h. Then solid potassium hydroxide (22 g) was added and the mixture was refluxed under nitrogen for 12 h followed by addition of styrene oxide (15 ml, 0.13 mol) and a reflux period of 3 h. The ethanol was removed on the rotary evaporator and the residue was made acidic with 10% hydrochloric acid. The acid was isolated by extraction with aqueous hydrogen carbonate and then lactonized in the usual manner using an ion-exchange resin catalyst.[7] The product (5.8 g, 23%) crystallized from benzene, m.p. 115—116°C; $\nu_{max.}$(KBr) 1 722 cm^{-1} (C=O) (Found: C, 64.9; H, 6.4%; M^+ 222.0731. Calc. for $C_{12}H_{14}O_2S$: C, 64.8; H, 6.35%; *M*, 222.0714). From the mother liquor additional lactone was obtained.

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