

## Conformational Analysis

## NMR Spectra of Six-Membered Cyclic Acetals

KALEVI PIHLAJA and PERTTI ÄYRÄS

*Department of Chemistry, University of Turku, Turku, Finland*

The NMR spectra of forty-four 1,3-dioxanes were recorded in benzene and carbon tetrachloride solutions. The chemical shifts and coupling constants are presented and the structural effects are discussed in the light of these parameters. The benzene solvent shifts [ $\Delta\delta(\text{CCl}_4 - \text{C}_6\text{H}_6)$ ] were found very suitable for the assignment of some signals.

The NMR spectra of ten 4,5,6-trimethyl-substituted 1,3-dioxanes were described in detail in an earlier paper.<sup>1</sup> 1,3-Dioxane and its methyl derivatives are very suitable objects for PMR investigation since the chemical shifts of the protons in positions 2, 4/6 and 5 are usually quite distinct as are also the chemical shifts of the methyl groups in these positions. Moreover, the coupling pattern is frequently resolvable by approximate first-order analysis.<sup>2-15</sup> The aim of the present study was to continue our research program for the clarification of conformational and other structural effects in methyl-substituted 1,3-dioxanes.<sup>16-20</sup>

## EXPERIMENTAL

1,3-Dioxane (I; two equivalent conformations), 2-methyl-1,3-dioxane (II), 4-methyl-1,3-dioxane (III), *cis*-2,4-dimethyl-1,3-dioxane (V), *trans*-2,5-dimethyl-1,3-dioxane (VI), *cis*-4,5-dimethyl-1,3-dioxane (VII), *trans*-4,5-dimethyl-1,3-dioxane (VIII), *cis*-4,6-dimethyl-1,3-dioxane (IX), *trans*-4,6-dimethyl-1,3-dioxane (X; two equivalent conformations), 2,2-dimethyl-1,3-dioxane (XI; two equivalent conformations), 5,5-dimethyl-1,3-dioxane (XII; two equivalent conformations), 2,2,4-trimethyl-1,3-dioxane (XIII), 2,5,5-trimethyl-1,3-dioxane (XIV), *cis*-2,4,5-trimethyl-1,3-dioxane (XVA), *cis*-2,4, *trans*-5-trimethyl-1,3-dioxane (XVB), *cis*-2,4,6-trimethyl-1,3-dioxane (XVI), *cis*-2,4, *trans*-6-trimethyl-1,3-dioxane (XVII), 4,4,6-trimethyl-1,3-dioxane (XIX), *cis*-4,5,6-trimethyl-1,3-dioxane (XXA), *cis*-4, *trans*-5, *cis*-6-trimethyl-1,3-dioxane (XXB), 2,2,5,5-tetramethyl-1,3-dioxane (XXII; two equivalent conformations), 2,2, *cis*-4,6-tetramethyl-1,3-dioxane (XXIII), 2,2, *trans*-4,6-tetramethyl-1,3-dioxane (XXIV; two equivalent conformations), *cis*-2,4,5,6-tetramethyl-1,3-dioxane (XXVA), *cis*-2,4, *trans*-5, *cis*-6-tetramethyl-1,3-dioxane (XXVB), *cis*-2,4,5, *trans*-6-tetramethyl-1,3-dioxane (XXVI), *cis*-2,4, *trans*-5,6-tetramethyl-1,3-dioxane (XXVII), *cis*-2,4,4,6-tetramethyl-1,3-dioxane (XXVIII), *trans*-2,4,4,5-tetramethyl-1,3-dioxane (XXIX), 4,4,6,6-tetramethyl-1,3-dioxane (XXXI; two equivalent conformations), *cis*-2,4,5,5-

tetramethyl-1,3-dioxane (XXXII), 2,2,*cis*-4,5,6-pentamethyl-1,3-dioxane (XXXIII A), 2,2,*cis*-4,*trans*-5,*cis*-6-pentamethyl-1,3-dioxane (XXXIII B), 2,2,*cis*-4,5,*trans*-6-pentamethyl-1,3-dioxane (XXXIV), *cis*-2,4,4,5,6-pentamethyl-1,3-dioxane (XXXVA), *cis*-2,4,4,*trans*-5,*cis*-6-pentamethyl-1,3-dioxane (XXXVB) and 2,4,4,6,6-pentamethyl-1,3-dioxane (XXXVI) were prepared earlier (Fig. 1).<sup>16,17</sup> 5-Methyl-1,3-dioxane (IV), 4,4,5-trimethyl-1,3-dioxane (XVIII), and *cis*-4,5,*trans*-6-trimethyl-1,3-dioxane (XXI), which were also prepared earlier,<sup>3,10</sup> were equilibrium mixtures of two non-equivalent conformers (Fig. 2).<sup>3,3</sup>

*cis*-2,4,4,5,5,6-Hexamethyl-1,3-dioxane (XXXVII) and 2,4,4,5,6,6-hexamethyl-1,3-dioxane (XXXVIII) were prepared by the usual method<sup>16</sup> by boiling an equimolar mixture of acetaldehyde (as paraldehyde) and a suitable 1,3-alkanediol with hexane in a water-entrainment unit. *p*-Toluenesulfonic acid was used as catalyst. XXXVII boiled at 181.9–182.1°C and had a refractive index  $n_D^{20}$  1.4406 and a density  $d_4^{20}$  0.9278. XXXVIII was a mixture of *cis* (B) and *trans* (A) configurations (33:67), and it was not purified further since it tends to decompose during distillation.

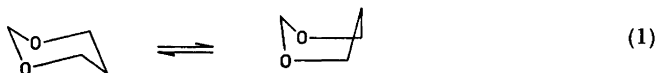
4,4,5,5-Tetramethyl-1,3-dioxane (XXX) was prepared by adding dropwise 42 g (0.5 mole) of 2,3-dimethylbutene-2 to a mixture of 100 ml of 30 % formalin and 70 g of concentrated sulfuric acid at 32°C. After the reaction had subsided the organic layer was isolated and distilled. B.p. 170–180°C, the yield was 75 %. This compound may be a crystalline liquid since it cannot be isolated in pure crystalline or liquid form.

Of the other compounds studied, 4,5-dimethyl-1,3-dioxane was a 62:38 mixture of *cis* (VII) and *trans* (VIII) forms, 2,4,5-trimethyl-1,3-dioxane (XV) a 50:50 mixture of *cis*-2,4,5- (XVA) and *cis*-2,4,*trans*-5-trimethyl-1,3-dioxanes (XVB), 4,5,6-trimethyl-1,3-dioxane (XX) a 67:33 mixture of *cis*-4,5,6 (XXA) and *cis*-4,*trans*-5,*cis*-6 (XXB) configurations,<sup>1</sup> 2,4,5,6-tetramethyl-1,3-dioxane (XXV) a 37:63 mixture of *cis,cis,cis,cis* (XXVA) and *cis,cis,trans,cis* (XXVB) configurations, 2,2,4,5,6-pentamethyl-1,3-dioxane (XXXIII) a 50:50 mixture of *cis*-4,5,6 (XXXIII A) and *cis*-4,*trans*-5,*cis*-6 (XXXIII B) forms, and 2,4,4,5,6-pentamethyl-1,3-dioxane (XXXV) a 77:23 mixture of *cis*-2,5,6 (XXXVA) and *cis*-2,*trans*-5,*cis*-6 (XXXVB) configurations. The isomers of 4,5-dimethyl-1,3-dioxane (VII + VIII), *meso*-2,4,5,6-tetramethyl-1,3-dioxane (XXVA + XXVB), and 2,4,4,5,6-pentamethyl-1,3-dioxane (XXXVA + XXXVB) are not resolvable by gas chromatography using columns which are suitable for the other isomer mixtures and hence it is understandable that the assignment of configuration based on kinetic results may be erroneous.<sup>1,16</sup>

The NMR spectra were recorded on a 60 Mcps Perkin-Elmer R 10 NMR spectroscope at 33.5°C. The solvents were carbon tetrachloride and benzene. The substrate concentration varied from 15 to 20 vol. %. Tetramethylsilane was used as internal standard. The chemical shifts of the different protons and methyl groups are shown in Tables 1–6. Tables 7–9 show the benzene solvent shifts for groups in different positions on the 1,3-dioxane ring. The values of the different coupling constants are collected in Tables 10 and 11.

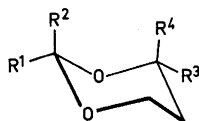
## RESULTS AND DISCUSSION

Some years ago very little was known about the structures of 1,3-dioxanes,<sup>4,16,21</sup> but during the last few years these compounds have been intensively investigated by several research groups.<sup>1–22</sup> It has been established that 1,3-dioxane prefers to exist in the chair form. The energy parameters for the equilibrium (1) were found to be slightly higher than those for the corresponding equilibrium of cyclohexane.<sup>18,20,21</sup>

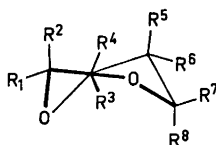


$$\Delta H^\circ = 7.1 \text{ kcal/mole}^{18} \quad (6.8 \text{ kcal/mole}^{20})$$

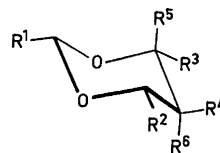
$$\Delta G^\circ = 5.7 \text{ kcal/mole}^{18} \quad (5.6 \text{ kcal/mole}^{20})$$



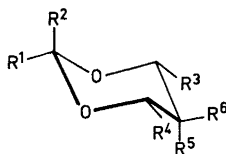
- I  $R^1=R^2=R^3=R^4=H$   
 II  $R^1=Me, R^2=R^3=R^4=H$   
 III  $R^3=Me, R^1=R^2=R^4=H$   
 V  $R^1=R^3=Me, R^2=R^4=H$   
 XI  $R^1=R^2=Me, R^3=R^4=H$   
 XIII  $R^1=R^2=R^3=Me, R^4=H$



- XXIV  $R^1=R^2=R^4=R^8=Me, R^3=R^5=R^6=R^7=H$   
 XXXIV  $R^1=R^2=R^4=R^6=R^8=Me, R^3=R^5=R^7=H$   
 XXXI  $R^3=R^4=R^7=R^8=Me, R^1=R^2=R^5=R^6=H$   
 XXXVI  $R^1=R^3=R^4=R^7=R^8=Me, R^2=R^5=R^6=H$   
 XVIIIA  $R^1=R^3=R^4=R^5=R^7=R^8=Me, R^2=R^6=H$   
 XVIIIIB  $R^1=R^3=R^4=R^6=R^7=R^8=Me, R^2=R^5=H$



- VI  $R^1=R^4=Me, R^2=R^3=R^5=R^6=H$   
 VII  $R^3=R^6=Me, R^1=R^2=R^4=R^5=H$   
 VIII  $R^3=R^4=Me, R^1=R^2=R^5=R^6=H$   
 IX  $R^2=R^3=Me, R^1=R^4=R^5=R^6=H$   
 X  $R^2=R^5=Me, R^1=R^3=R^4=R^6=H$   
 XII  $R^4=R^6=Me, R^1=R^2=R^3=R^5=H$   
 XIV  $R^1=R^4=R^6=Me, R^2=R^3=R^5=H$   
 XV A  $R^1=R^3=R^6=Me, R^2=R^4=R^5=H$   
 XV B  $R^1=R^3=R^4=Me, R^2=R^5=R^6=H$   
 XVI  $R^1=R^2=R^3=Me, R^4=R^5=R^6=H$   
 XVII  $R^1=R^2=R^5=Me, R^3=R^4=R^6=H$   
 XIX  $R^2=R^3=R^5=Me, R^1=R^4=R^6=H$   
 XX A  $R^2=R^3=R^6=Me, R^1=R^4=R^5=H$   
 XX B  $R^2=R^3=R^4=Me, R^1=R^5=R^6=H$   
 XXV A  $R^1=R^2=R^3=R^6=Me, R^5=R^4=H$   
 XXV B  $R^1=R^2=R^3=R^4=Me, R^5=R^6=H$   
 XXVI  $R^1=R^2=R^6=R^8=Me, R^4=R^3=H$   
 XXVII  $R^1=R^2=R^4=R^5=Me, R^3=R^6=H$   
 XXVIII  $R^1=R^2=R^3=R^5=Me, R^4=R^6=H$   
 XXIX  $R^1=R^3=R^4=R^5=Me, R^2=R^6=H$   
 XXX  $R^3=R^4=R^5=R^6=Me, R^1=R^2=H$   
 XXXII  $R^1=R^2=R^4=R^5=Me, R^3=R^6=H$   
 XXXV A  $R^1=R^2=R^6=R^3=R^5=Me, R^4=H$   
 XXXV B  $R^1=R^2=R^4=R^3=R^5=Me, R^6=H$   
 XXXVII  $R^1=R^2=R^3=R^4=R^5=R^6=Me$



- XXII  $R^1=R^2=R^5=R^6=Me, R^3=R^4=H$   
 XXIII  $R^1=R^2=R^3=R^4=Me, R^5=R^6=H$   
 XXXIIIA  $R^1=R^2=R^3=R^4=R^5=Me, R^6=H$   
 XXXIIIB  $R^1=R^2=R^3=R^4=R^5=Me, R^6=H$

Fig. 1. The stable conformations of the compounds I–III, V–XVII, XIX, XX, XXII–XXXVIII. Chair form may also contribute more or less in compounds XXXI, XXXVI and XXXVIII–B.

In our opinion,<sup>1</sup> the NMR spectrum of XXXIV (Fig. 1) clearly shows that this compound as well as XXIV<sup>4,18,20</sup> prefers the skew-boat conformation owing to the large 1,3-diaxial interaction between the axial 2- and 4-methyl groups in these compounds.<sup>18</sup> From the other studied compounds *cis*-2,4,4,5,6,6-hexamethyl-1,3-dioxane (XXXVIII B) may also have the flexible ring conformation in view of the unexpectedly low chemical shift of the acetal proton (307.4 cps in CCl<sub>4</sub> and 313.2 cps in C<sub>6</sub>H<sub>6</sub> as compared with the normal values around 295 cps in the other compounds having *syn*-axial methyl groups in respect to the axial acetal proton). If we assume that the diaxial 4,6-Me—Me interaction is about 4 kcal/mole<sup>18</sup> and take also into account the diaxial Me—H interactions between 2 and 4 (6) positions and the interaction energy of the axial methyl group in position 5 we obtain a total interaction of about 9 kcal/mole.\* Many of these interactions vanish in the flexible ring conformation and hence XXXVIII B may well exist in a skew-boat form or at least, a dynamic equilibrium may prevail between the chair and twist forms. The benzene solvent shift of the 5-methyl group is also of a very unexpected magnitude (−13.8 cps) as compared with the very small and even positive shifts of the axial 5-methyl groups in the other studied compounds.

On the basis of the above discussion it is probable that also compounds XXXI, XXXVI, and XXXVIII A occur in a skew-boat conformation to some extent. The "axial" acetal proton in these compounds is somewhat displaced downfield from the normal position. The axial acetal proton of the *syn*-axial methyl substituted compounds (XVII, XXVI—XXIX, XXXVA, and XXXVB) is placed at 287.5—295.7 cps in CCl<sub>4</sub> and 287.7—299.0 cps in C<sub>6</sub>H<sub>6</sub> whereas this proton in XXXVI and XXXVIII A is located at 298.4 and 295.4 cps in CCl<sub>4</sub> and 300.7 and 301.9 cps in C<sub>6</sub>H<sub>6</sub>, respectively. *trans*-4,6-Dimethyl-1,3-dioxane gives an averaged signal of the acetal protons at 284.6 cps in CCl<sub>4</sub> and at 287.5 cps in C<sub>6</sub>H<sub>6</sub>, whereas XXXI gives the corresponding averaged signals at 284.7 and 294.5 cps.

The spectra of compounds XXIV, XXXI, and XXXIV were also recorded at −95°C, −102°C and −112°C, respectively using CS<sub>2</sub> as solvent. No significant broadening of the signals was observed in the case of XXIV and XXXI, which observation is consistent with a flexible ring conformation since it is very probable that pseudorotation of a twist form cannot be "frozen out" even at low temperatures.<sup>4</sup> The spectrum of XXXIV at −112°C is quite similar to that at the "normal" temperature (33.5°C), which is in good agreement with the assumed "biased" skew-boat conformation.\*\* In contrast to these results, compounds X, XI, XII, XXII, and XXX which exist in the chair form are easily "frozen out", although the ring inversion barrier of 2,2-dimethyl-substituted 1,3-dioxanes (XI and XXII) is already lowered owing to the ground state compression effected by the axial methyl group in position 2.<sup>4,23-26</sup>

*The NMR shifts of the acetal protons.* All of the studied formaldehyde derivatives, III, IV, VII, VIII, IX, XVIII—XXI and XXX undoubtedly exist in the

\* The magnitude of the diaxial Me—H interaction between positions 2 and 4 or 2 and 6 is about 2 kcal/mole<sup>18,21</sup> and the interaction energy of an axial methyl group in position 5 about 1 kcal/mole.<sup>1,2,4,16,21</sup>

\*\* With the methyl group in position 5 pointing outward (Fig. 2), see also Ref. 1.

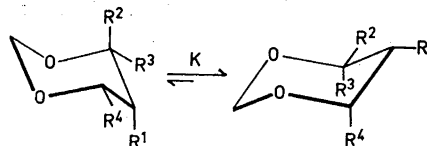


Fig. 2. The equilibria between the stable conformers of 5-methyl-1,3-dioxane (IV), 4,4,5-trimethyl-1,3-dioxane (XVIII) and *cis*-4,5,*trans*-6-trimethyl-1,3-dioxane (XXI).<sup>2,3</sup>

IV	R <sup>1</sup> =Me, R <sup>2</sup> =R <sup>3</sup> =R <sup>4</sup> =H	K ≈ 3.8
XVIII	R <sup>1</sup> =R <sup>2</sup> =R <sup>3</sup> =Me, R <sup>4</sup> =H	K ≈ 7.7
XXI	R <sup>1</sup> =R <sup>2</sup> =R <sup>4</sup> =Me, R <sup>3</sup> =H	K ≈ 2.6

chair form. The axial acetal protons of these compounds are located at 270.9–275.5 cps in CCl<sub>4</sub> and 268.1–273.6 cps in C<sub>6</sub>H<sub>6</sub> except for the compounds XVIII, XIX and XXI which have a *syn*-axial methyl group in position 4. Similarly the acetal protons of 2-methyl-1,3-dioxanes without *syn*-axial methyl group are found at 272.5–278.4 cps in CCl<sub>4</sub> and 269.4–277.6 cps in C<sub>6</sub>H<sub>6</sub>. The signal of this proton in compounds IV, VI, and XIV is shifted slightly upfield which may be due to the flattening of the ring in the C<sub>4-5-6</sub> region caused by the 5-methyl substitution.

The normal range of the equatorial acetal proton is 292.2–293.5 cps in CCl<sub>4</sub> and 299.7–304.5 cps in C<sub>6</sub>H<sub>6</sub>. The *syn*-axial substitution in formaldehyde derivatives changes the relative positions of the acetal protons in CCl<sub>4</sub> (Table 1) but in benzene the equatorial acetal protons of these compounds still remain in a lower field. In acetaldehyde derivatives the deshielding effect of the *syn*-axial methyl group is even greater since the signals of acetal protons are found at 287.5–295.8 cps in CCl<sub>4</sub> and at 287.7–299.0 cps in C<sub>6</sub>H<sub>6</sub>.

In agreement with the results of Anderson<sup>5</sup> the equatorial acetal proton is moved on average about 10 cps downfield by benzene.\* Generally, the benzene solvent shift of the axial acetal proton is smaller. Usually the proton is slightly shielded except in the 2-methyl-1,3-dioxanes with a *syn*-axial methyl group in which it is slightly deshielded (Table 7).

The NMR shifts of the methyl groups in position 2. The equatorial 2-methyl group of acetals is placed at 67.9–74.1 cps in CCl<sub>4</sub> and 78.3–82.9 cps in C<sub>6</sub>H<sub>6</sub>. In compounds XVII, XXVI–XIX, and XXXVI–XXXVIII the 2-methyl group is in a somewhat higher field (67.9–69.6 cps in CCl<sub>4</sub>) than in the compounds without axial methyl groups in position 4 or 6 (70.5–74.1 cps in CCl<sub>4</sub>).

The signals of the equatorial 2-methyl groups of 2,2-dimethyl-1,3-dioxanes are found at 74.5–76.5 cps in CCl<sub>4</sub> and at 87.5–89.7 cps in C<sub>6</sub>H<sub>6</sub>. The chemical shifts of the axial 2-methyl groups in these compounds are 80.6–81.5 cps in CCl<sub>4</sub> and 79.2–79.7 cps in C<sub>6</sub>H<sub>6</sub>. (Table 2).

The signals of both methyl groups of XXXIV, which prefers the skew-boat form<sup>1</sup> (Fig. 2), are located at 74.0 cps in CCl<sub>4</sub> and 81.4 cps in C<sub>6</sub>H<sub>6</sub>. These values are in close agreement with the occurrence of the averaged methyl signals of XXIV, which also prefers the twist form,<sup>18,20</sup> at 75.1 cps (74.1 in Ref. 4) in CCl<sub>4</sub> and at 81.4 cps in C<sub>6</sub>H<sub>6</sub>. The mean benzene solvent shifts for acetal protons and 2-methyl groups are shown schematically in Fig. 3 (Tables 2 and 7).

\* In this connection the shifts induced by benzene are equal to  $\Delta\delta(\text{CCl}_4 - \text{C}_6\text{H}_6)$  (Tables 7–9).

Table 1. The NMR shifts of the acetal protons in  $\text{CCl}_4$  and  $\text{C}_6\text{H}_6$ .

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	2e-H	2a-H	2e-H	2a-H
I	282.0 (av.)		283.4 (av.)	
	282.0; <sup>a</sup>	282.6 <sup>b</sup>		
II	—	273.0	—	269.4
	—	272.0 <sup>b</sup>		
	—	273.0 <sup>c</sup>		
III	293.5	273.1	301.7	269.5
	293.4; <sup>c</sup> 294.0 <sup>a</sup>	273.0; <sup>a</sup> 274.2 <sup>c</sup>		
IV <sup>d</sup>	289.5	270.1	294.4	267.9
	289.2; <sup>c</sup> 291.0 <sup>a</sup>	270.0; <sup>a</sup> 269.4 <sup>c</sup>		
V	—	272.6	—	271.7
	—	272.6 <sup>b</sup>		
VI	—	267.6	—	268.2
	—	266.2 <sup>b</sup>		
VII	292.2	273.8	299.7	269.7
	292.8 <sup>c</sup>	275.4 <sup>c</sup>		
VIII	292.2	270.9	303.3	268.1
	294.6 <sup>c</sup>	273.0 <sup>c</sup>		
IX	292.8	272.6	303.0	269.3
	295.2 <sup>c</sup>	275.4 <sup>c</sup>		
	292.3 <sup>b</sup>	272.6 <sup>b</sup>		
X	284.6 (av.)		287.5 (av.)	
XII	281.1 (av.)		279.3 (av.)	
XIV	—	266.2	—	266.5
XVA	—	278.4	—	272.1
XVB	—	277.0	—	272.1
XVI	—	274.8	—	271.5
	—	272.8 <sup>b</sup>		
XVII	—	293.7	—	297.6
	—	292.9 <sup>b</sup>		
XVIII <sup>d</sup>	279.4	283.8	290.3	281.4
	280.2 <sup>e</sup>	285.0 <sup>e</sup>		
XIX	280.0	288.5	290.3	284.4
	284.4 <sup>e</sup>	290.4 <sup>e</sup>		
	288.0 <sup>a</sup>	277.8 <sup>a</sup>		
XXA	292.5	275.5	302.4	273.6
XXB	292.5	275.5	304.5	273.6
XXI <sup>d</sup>	280.8	288.0	289.3	289.3
XXVA	—	275.8	—	275.5
XXVB	—	275.8	—	277.6
XXVI	—	295.7	—	296.7
XXVII	—	293.6	—	299.0
XXVIII	—	288.0	—	290.7
XXIX	—	287.5	—	287.7
XXX	285.5 (av.)		281.3 (av.)	
XXXI	284.7 (av.)		294.5 (av.)	
XXXII	—	272.5	—	272.5
XXXVA	—	291.6	—	291.9
XXXVB	—	291.6	—	293.2
XXXVI	—	298.4	—	300.7
XXXVII	—	295.8	—	298.4
XXXVIIIA	—	295.4	—	301.9
XXXVIIIIB	—	307.4	—	313.2

<sup>a</sup> Ref. 22. <sup>b</sup> Ref. 4. <sup>c</sup> Ref. 10. <sup>d</sup> These compounds are not conformationally homogeneous (Fig. 2). <sup>e</sup> Ref. 11.

Table 2. The NMR shifts of the methyl groups in position 2 of 1,3-dioxanes in  $\text{CCl}_4$  and  $\text{C}_6\text{H}_6$ .

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	2e-Me	2a-Me	2e-Me	2a-Me
II	70.8	—	78.3	—
	71.3; <sup>a</sup> 70.8 <sup>b</sup>	—		—
V	70.5	—	80.0	—
	70.8 <sup>a</sup>	—		—
VI	71.3	—	81.3	—
	71.2 <sup>a</sup>	—		—
XI		77.1 (av.)		80.8 (av.)
		78.0 <sup>a</sup>		
XIII	74.5	81.1	88.5	79.2
XIV	74.1	—	80.6	—
XVA	70.5	—	80.6	—
XVB	70.5	—	82.9	—
XVI	71.8	—	81.8	—
	71.7 <sup>a</sup>	—		—
XVII	67.9	—	79.5	—
	67.5 <sup>a</sup>	—		—
XXII		77.5 (av.)		
XXIII	75.6	80.6	89.7	79.4
	75.6 <sup>a</sup>	80.6 <sup>a</sup>		
XXIV <sup>c</sup>		75.1 (av.)		81.6 (av.)
		74.1 <sup>a</sup>		
XXVA	72.2	—	80.8	—
XXVB	72.2	—	82.6	—
XXVI	69.3	—	78.6	—
XXVII	68.3	—	78.8	—
XXVIII	69.6	—	80.8	—
XXIX	68.1	—	79.9	—
XXXII	71.4	—	81.6	—
XXXIIIA	76.5	81.5	89.5	79.7
XXXIIIB	76.5	81.5	87.5	79.7
XXXIV <sup>c</sup>	74.0	74.0	81.4	81.4
XXXVA	<sup>d</sup>	—	80.4	—
XXXVB	<sup>d</sup>	—	79.3	—
XXXVI	69.2	—	81.5	—
XXXVII	68.9	—	78.3	—
XXXVIIIA	68.8	—	80.4	—
XXXVIIIB	68.8	—	77.4	—

<sup>a</sup> Ref. 4. <sup>b</sup> Ref. 10. <sup>c</sup> Skew-boat conformation. <sup>d</sup> Lost under other signals.

Table 3. The NMR shifts of the protons in position 4 or 6 of 1,3-dioxanes in  $\text{CCl}_4$  and  $\text{C}_6\text{H}_6$ .

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	4,6e-H	4,6a-H	4,6e-H	4,6a-H
I		228.5 (av.)		216.0 (av.)
		228.0 <sup>a</sup>		
II	234.6	217.3	231.3	203.0
	240 <sup>b</sup>	216 <sup>b</sup>		
III	241 (6e)	215 (6a)	232.3 (6e)	200.6 (6a)
	238.8 <sup>b</sup>	214.8 <sup>b</sup>		
		216.6 <sup>b</sup> (4a)		

Table 3. Continued.

IV <sup>c</sup>	235.0	191.6	227.7	183.7
	234.0 <sup>b</sup>	193.2 <sup>b</sup>		
V	*	*	232.6 (6e)	203.4 (6a)
VI	232.8	189.4	230.7	181.0
VII	224.4 (6e)	224.4 (6a)	*	*
		226.9 (4a)		*
	224.4 <sup>b</sup> (6e)	224.4 <sup>b</sup> (6a)		
		228.0 <sup>b</sup> (4a)		
VIII	232.6 (6e)	185.9 (6a)	*	*
		190.9 (4a)		*
	231.0 <sup>b</sup> (6e)	187.8 <sup>b</sup> (6a)		
		191.4 <sup>b</sup> (4a)		
IX	—	214.4	—	200.6
	—	216.0 <sup>b</sup>		
X		239.6 (av.)		228.2 (av.)
		241.2 <sup>a</sup>		
XI		229.0 (av.)		217.0 (av.)
XII		203.2 (av.)		194.6 (av.)
XIV	209.4	198.4	207.0	192.3
XVA	224.8 (6e)	220.1 (6a)	*	*
		223 (4a)		*
XVB	231.0 (6e)	184.5 (6a)	*	*
		191.9 (4a)		*
XVI	—	217.4	—	204.8
XVII	248.7	226.5	248.6	220.1
XVIII <sup>c</sup>	220.4	198.2	214.1	189.0
	219.0 <sup>d</sup>	199.8 <sup>d</sup>		
XIX	—	223.1	—	212.3
	—	226.2 <sup>d</sup>		
XXA	—	221.2	—	208.5
XXB	—	190.6	—	180.9
XXI <sup>c</sup>	237.8	215.3	234.0	206.1
XXII		202.5 (av.)		
XXIII	—	230.9	—	220.7
XXIV <sup>e</sup>		232.2 (av.)		214.5 (av.)
XXVA	—	223.7	—	212.2
XXVB	—	192.9	—	186.9
XXVI	230.8	241.7	229.3	232.8
XXVII	237.2	211.4	238.3	205.1
XXVIII	—	224.7	—	216.5
XXIX	217.8	198.9	216.0	192.3
XXX		205.5 (av.)		200.7 (av.)
XXXII	207.3	194.9 (6a)	206.3	185.8 (6a)
		201.6 (4a)		192.9 (4a)
XXXIIIA	—	238.8	—	230.2
XXXIIIB	—	208.2	—	204.2
XXXIV <sup>e</sup>	238.5	198.5	238.5	201.3
XXXVA	—	244.1	—	236.7
XXXVB	—	204.0	—	198.9
XXXVII	—	228.5	—	228.3

<sup>a</sup> Ref. 22. <sup>b</sup> Ref. 10. <sup>c</sup> These compounds are not conformationally homogeneous, see Fig. 2. <sup>s</sup> <sup>d</sup> Ref. 11. <sup>e</sup> Skew-boat conformation.

\* Overlapping signals.



Table 4. The NMR shifts of the methyl groups in position 4 or 6 of 1,3-dioxanes in CCl<sub>4</sub> and C<sub>6</sub>H<sub>6</sub>.

Compound	CCl <sub>4</sub>		C <sub>6</sub> H <sub>6</sub>	
	4,6e-Me	4,6a-Me	4,6e-Me	4,6a-Me
III	70.2	—	63.3	—
	69.3; <sup>a</sup>	70.2 <sup>b</sup>	—	—
V	68.6	—	64.5	—
	68.6 <sup>a</sup>	—	—	—
VII	64.5	—	59.7	—
	66.0 <sup>b</sup>	—	—	—
VIII	70.6	—	69.5	—
	72.0 <sup>b</sup>	—	—	—
IX	69.5	—	64.3	—
	70.2; <sup>b</sup>	68.2 <sup>a</sup>	—	—
X		72.5 (av.)		63.2 (av.)
		73.5 <sup>a</sup> (av.)		
XIII	65.1	—	63.9	—
XVA	63.2	—	61.5	—
XVB	67.7	—	68.0	—
XVI	67.9	—	66.0	—
	67.7 <sup>a</sup>	—	—	—
XVII	68.8	77.8	67.0	65.3
	68.8 <sup>a</sup>	77.0 <sup>a</sup>	—	—
XVIII <sup>c</sup>	68.2	72.9	68.1	56.1
	69.0 <sup>d</sup>	72.6 <sup>d</sup>	—	—
XIX	70.6 (4e)	74.2 (4a)	68.4 (4e)	62.2 (4a)
	67.8 (6e)	—	63.6 (6e)	—
	73.2 <sup>d</sup> (4e)	70.2 <sup>d</sup> (4a)	—	—
	70.2 <sup>d</sup> (6e)	—	—	—
XXA	67.3	—	63.9	—
XXB	71.0	—	68.5	—
XXI <sup>c</sup>	69.7	71.3	65.3	59.7
XXIII	64.3	—	65.1	—
	64.4 <sup>a</sup>	—	—	—
XXIV <sup>e</sup>		66.9 (av.)		65.9 (av.)
		66.1 <sup>a</sup> (av.)		
XXVA	66.5	—	64.2	—
XXVB	69.7	—	68.7	—
XXVI	63.8	79.2	61.8	68.6
XXVII	67.0	70.7	64.0	59.1
XXVIII	70.1	73.8	66.5	65.1
	67.0 (6e)	—	66.5 (6e)	—
XXIX	67.6	70.5	69.4	58.4
XXX		70.1 (av.)		60.2 (av.)
XXXI		73.3 (av.)		68.5 (av.)
XXXII	60.6	—	59.7	—
XXXIIIA	66.5	—	62.7	—
XXXIIIB	63.5	—	67.0	—
XXXIV <sup>e</sup>	67.8	59.9	68.0	59.1
XXXVI	69.3	76.1	73.4	73.4
XXXVII	64.9 (4e)	75.9	65.8 (4e)	68.8
	61.1 (6e)	—	62.4 (6e)	—
XXXVIII A	69.5	72.1	70.6	66.0
XXXVIII B	69.5	72.1	73.3	67.0

<sup>a</sup> Ref. 4. <sup>b</sup> Ref. 10. <sup>c</sup> These compounds are not conformationally homogeneous, see Fig. 2.<sup>2,3</sup>  
<sup>d</sup> Ref. 11. <sup>e</sup> Skew-boat conformation.

*The NMR shifts of the protons in positions 4 and 6.* Generally, the equatorial 4,6-proton is located in a lower field than the axial 4,6-proton in both solvents. Normally the equatorial proton is found between 230 and 235 cps in both solvents and the axial proton between 215 and 225 cps in  $\text{CCl}_4$  and between 200 and 220 cps in  $\text{C}_6\text{H}_6$ . An axial methyl group in position 5 shields equatorial 4,6-protons. The axial 4,6-protons in compounds having an equatorial 5-methyl group are highly shielded and their signals occur at about 190 cps in  $\text{CCl}_4$  (Table 3).<sup>1</sup> The benzene solvent shifts of these protons are shown in Table 8. In all cases these signals are moved upfield in benzene, the axial 4,6-protons except those of the *syn*-axially substituted compounds being specially shielded. The axial 4,6-protons in the latter group of compounds and the equatorial 4,6-protons in the formaldehyde derivatives are almost equally shielded by benzene (about 6 cps).<sup>1</sup>

Because of the complexity of the influence of different substitution and benzene on the relative shifts of the 4,6-protons more accurate analysis of the signals of these protons is too tedious and we refer the reader to Tables 3 and 7 for more detailed results (Fig. 3).

*The NMR shifts of the methyl groups in positions 4 and 6.* Equatorial 4,6-methyl groups usually appear at higher field than axial 4,6-methyl groups in  $\text{CCl}_4$  but in  $\text{C}_6\text{H}_6$  the situation is usually reversed (Table 4). Normally, the equatorial methyl groups are found in the range 67.7–71.0 cps in  $\text{CCl}_4$

Table 5. The NMR shifts of the protons in position 5 of 1,3-dioxanes in  $\text{CCl}_4$  and  $\text{C}_6\text{H}_6$ .

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	5e-H	5a-H	5e-H	5a-H
I		101.6 (av.) 102.0 <sup>a</sup> (av.)		82.5 (av.)
II	74.6 73.8 <sup>b</sup>	119.3 118.8 <sup>b</sup>	46.2	108.3
III	82.6 82.2 <sup>b</sup>	101.5 99.0 <sup>b</sup>	58.5	94.4
IV <sup>c</sup>	—	119.1 118.8 <sup>b</sup>	—	111.0
VI	—	117.5	—	112.6
VII	83.4 <sup>b</sup>	—	—	—
VIII	—	97.8 <sup>b</sup>	—	—
X		93.6 (av.)		78.9 (av.)
XI		96.7 (av.)		80.8 (av.)
XVII	*	105.6	54.9	101.1
XVIII <sup>c</sup>	—	112.2	—	107.3
	—	112.2 <sup>d</sup>		
XXI <sup>c</sup>	—	96.2	—	93.0
XXIV		89.7 (av.)		81.1 (av.)
XXVII	—	107.3	—	109.1
XXIX	—	109.9	—	109.1
XXXI		89.2 (av.)		79.0 (av.)
XXXVIII A	—	97.4	—	*
XXXVIII B	106.0	—	*	—

<sup>a</sup> Ref. 22. <sup>b</sup> Ref. 10. <sup>c</sup> These compounds are not conformationally homogeneous, see Fig. 2.<sup>2,3</sup>  
<sup>d</sup> Ref. 11. \* Overlapping signals.

and in the range 63.3–68.0 cps in  $C_6H_6$ . Deformation, frequently caused by 5-methyl substitution, tends to shift the signals of the equatorial 4,6-methyl protons somewhat upfield (usually below 65 cps in both solvents).<sup>4</sup>

Eliel and Knoeber<sup>4</sup> have stated that the signals of the axial methyl groups in positions 4 and 6 are normally located at 76.9–77.5 cps in  $CCl_4$ . Our results, however, show clearly that this is true only in some di- or trimethyl-substituted 1,3-dioxanes (see also Ref. 4). Generally, the chemical shift of the axial 4,6-methyl groups seems to be very sensitive to conformational interactions. For instance, the axial methyl groups of compounds XXVI and XXVII are found at 79.2 cps and at 70.7 cps in  $CCl_4$  and at 68.6 cps and 59.1 cps in  $C_6H_6$ , respectively, although the only difference in the configurations of these compounds is in the orientation of the 5-methyl groups (axial in XXVI and equatorial in XXVII). In the other compounds excluding the compounds in which the skew-boat form may contribute the shifts of the axial 4,6-methyl groups range from 70.5 to 77.8 cps in  $CCl_4$  and from 58.4 to 68.8 cps in benzene.

Table 6. The NMR shifts of the methyl groups in position 5 of 1,3-dioxanes in  $CCl_4$  and  $C_6H_6$ .

Compound	$CCl_4$		$C_6H_6$	
	5e-Me	5a-Me	5e-Me	5a-Me
IV <sup>a</sup>	47.3 45.0 <sup>b</sup>	—	27.8	—
VI	39.6	—	17.7	—
VII	—	63.7 64.2 <sup>b</sup>	—	59.7
VIII	41.3 42.0 <sup>b</sup>	—	21.4	—
XII	—	57.4 (av.)	—	46.5 (av.)
XIV	41.1	69.1	24.2	68.6
XVA	—	60.4	—	61.7
XVB	40.9	—	22.5	—
XVIII <sup>a</sup>	45.2 43.8 <sup>c</sup>	—	25.0	—
XXA	—	51.9 <sup>d</sup>	—	54.1 <sup>d</sup>
XXB	46.3	—	27.2	—
XXI <sup>a</sup>	50.4	—	35.2	—
XXII	—	54.7 (av.)	—	—
XXVA	—	50.6 <sup>d</sup>	—	52.3 <sup>d</sup>
XXVB	44.7	—	27.9	—
XXVII	43.0	—	21.5	—
XXIX	41.0	—	23.3	—
XXX	—	54.9 (av.)	—	49.0 (av.)
XXXII	37.7	57.7	24.0	61.9
XXXIIIA	—	48.9 <sup>d</sup>	—	52.1 <sup>d</sup>
XXXIIIB	45.8	—	31.0	—
XXXIV <sup>e</sup>	47.0	—	41.0	—
XXXVB	43.0	—	27.4	—
XXXVII	40.2	58.0	28.5	61.9
XXXVIII A	49.6	—	34.6	—
XXXVIII B	—	53.8	—	40.2

<sup>a</sup> These compounds are not conformationally homogeneous, see Fig. 2.<sup>2,3</sup> <sup>b</sup> Ref. 10. <sup>c</sup> Ref. 11. <sup>d</sup> The main peaks of  $AB_3$ -systems. <sup>e</sup> Skew-boat conformation.

Table 7. The benzene solvent shifts [ $\Delta\delta(\text{CCl}_4-\text{C}_6\text{H}_6)$ ] of the protons or methyl groups in position 2.

Compound	2e-H	2a-H	2e-Me	2a-Me
II	—	-3.6 <sup>a</sup>	+7.5 <sup>a</sup>	—
III	+8.2 <sup>h</sup>	-3.6 <sup>h</sup>	—	—
IV <sup>b</sup>	+11.4 <sup>h</sup>	-2.2 <sup>h</sup>	—	—
V	—	-0.9 <sup>a</sup>	+7.9 <sup>a</sup>	—
VI	—	+0.6 <sup>b</sup>	+10.0 <sup>c</sup>	—
VII	+7.5 <sup>h</sup>	-4.1 <sup>h</sup>	—	—
VIII	+11.1 <sup>h</sup>	-2.8 <sup>h</sup>	—	—
IX	+10.2 <sup>h</sup>	-3.3 <sup>h</sup>	—	—
XIII	—	—	+14.0 <sup>i</sup>	-1.9 <sup>i</sup>
XIV	—	+0.3 <sup>c</sup>	+6.5 <sup>c</sup>	—
XVA	—	-6.3 <sup>a</sup>	+10.1 <sup>a</sup>	—
XVB	—	-4.9 <sup>a</sup>	+12.4 <sup>a</sup>	—
XVI	—	-3.3 <sup>a</sup>	+10.0 <sup>a</sup>	—
XVII	—	+3.9 <sup>d</sup>	+11.6 <sup>d</sup>	—
XVIII <sup>e</sup>	+10.9 <sup>h</sup>	-2.4 <sup>h</sup>	—	—
XIX	+10.3 <sup>h</sup>	-4.1 <sup>h</sup>	—	—
XXA	+9.9 <sup>h</sup>	-1.9 <sup>h</sup>	—	—
XXB	+12.0 <sup>h</sup>	-1.9 <sup>h</sup>	—	—
XXI <sup>f</sup>	+8.5 <sup>h</sup>	+1.3 <sup>h</sup>	—	—
XXIII	—	—	+14.1 <sup>i</sup>	-1.2 <sup>i</sup>
XXVA	—	-0.3 <sup>c</sup>	+8.6 <sup>h</sup>	—
XXVB	—	+1.8 <sup>c</sup>	+10.4 <sup>c</sup>	—
XXVI	—	+1.0 <sup>d</sup>	+9.3 <sup>d</sup>	—
XXVII	—	+5.4 <sup>d</sup>	+10.5 <sup>d</sup>	—
XXVIII	—	+2.7 <sup>d</sup>	+11.2 <sup>d</sup>	—
XXIX	—	+0.2 <sup>d</sup>	+11.8 <sup>d</sup>	—
XXXII	—	+0.0 <sup>c</sup>	+10.2 <sup>c</sup>	—
XXXIIIA	—	—	+13.0 <sup>i</sup>	-1.8 <sup>i</sup>
XXXIIIB	—	—	+11.0 <sup>i</sup>	-1.8 <sup>i</sup>
XXXIV <sup>g</sup>	—	—	(+7.4)	(+7.4)
XXXVA	—	+0.3 <sup>a</sup>	* <sup>d</sup>	—
XXXVB	—	+1.6 <sup>d</sup>	* <sup>d</sup>	—
XXXVI	—	+2.3 <sup>d</sup>	+12.3 <sup>d</sup>	—
XXXVII	—	+2.6 <sup>d</sup>	+9.4 <sup>d</sup>	—
XXXVIII A	—	+6.5 <sup>d</sup>	+11.6 <sup>d</sup>	—
XXXVIII B	—	+5.8 <sup>d</sup>	+8.6 <sup>d</sup>	—
Average	+10.0 ± 0.5	<sup>a</sup> -4.0 ± 0.9	<sup>a</sup> +9.6 ± 0.9	<sup>i</sup> -1.7 ± 0.2
Range	<sup>h</sup> 7.5-12.0	(-0.9)-(-6.3)	7.5-12.4	(-1.2)-(-1.9)
Average		<sup>c</sup> +0.5 ± 0.4	<sup>c</sup> +9.1 ± 0.7	
Range		(-0.3)-(+1.8)	6.5-10.4	
Average		<sup>d</sup> +2.9 ± 0.7	<sup>d</sup> +10.7 ± 0.4	
Range		(+0.2)-(+6.5)	8.6-12.3	
Average		<sup>h</sup> -2.9 ± 0.3	<sup>i</sup> +13.0 ± 0.8	
Range		(-1.9)-(-4.1)	11.0-14.1	

<sup>a,c,d</sup> Derived from acetaldehyde. <sup>b,e,f</sup> Not conformationally homogeneous, see footnotes to Table 1. <sup>g</sup> Skew-boat form. <sup>h</sup> Derived from formaldehyde. <sup>i</sup> Derived from acetone. \* Not detected.

Table 8. The benzene solvent shifts [ $\Delta\delta(\text{CCl}_4-\text{C}_6\text{H}_6)$ ] of the protons or methyl groups in positions 4 and 6 of 1,3-dioxanes.

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	4,6e-H	4,6a-H	4,6e-Me	4,6a-Me
II	-3.3 <sup>a</sup>	-14.3 <sup>a</sup>	-	-
III	-8.7 <sup>h</sup> (6e)	-14.4 <sup>h</sup> (6a)	-6.9 <sup>h</sup>	-
IV <sup>b</sup>	-7.3 <sup>h</sup>	-7.9 <sup>h</sup>	-	-
V	*	*	-4.1 <sup>a</sup>	-
VI	-2.1 <sup>c</sup>	-8.4 <sup>c</sup>	-	-
VII	*	*	-4.8 <sup>h</sup>	-
VIII	*	*	-4.8 <sup>h</sup>	-
IX	-	-13.8 <sup>h</sup>	-5.2 <sup>h</sup>	-
XIII	-	-	-1.2 <sup>i,d</sup>	*
XIV	-2.4 <sup>c</sup>	-6.1 <sup>c</sup>	-	-
XVA	*	*	-1.7 <sup>a</sup>	-
XVB	*	*	+0.3 <sup>a</sup>	-
XVI	-	-12.6 <sup>a</sup>	-1.9 <sup>a</sup>	-
XVII	-0.1 <sup>d</sup>	-6.4 <sup>d</sup>	-1.8 <sup>d</sup>	-12.5 <sup>d</sup>
XVIII <sup>c</sup>	-6.3 <sup>h</sup>	-9.2 <sup>h</sup>	-0.1 <sup>h</sup>	-16.8 <sup>h</sup>
XIX	-	-10.8 <sup>h</sup>	-2.2 <sup>h</sup>	-12.0 <sup>h</sup>
			-4.2 <sup>h</sup>	
XXA	-	-12.7 <sup>h</sup>	-3.4 <sup>h</sup>	-
XXB	-	-9.7 <sup>h</sup>	-2.5 <sup>h</sup>	-
XXI <sup>f</sup>	-3.8 <sup>h</sup>	-9.2 <sup>h</sup>	-4.4 <sup>h</sup>	-11.6 <sup>h</sup>
XXIII	-	-10.2 <sup>i,d</sup>	+0.8 <sup>i,d</sup>	-
XXVA	-	-11.5 <sup>c</sup>	-2.3 <sup>c</sup>	-
XXVB	-	-6.0 <sup>c</sup>	-1.0 <sup>c</sup>	-
XXVI	-1.5 <sup>d</sup>	-8.9 <sup>d</sup>	-2.0 <sup>d</sup>	-10.6 <sup>d</sup>
XXVII	+1.1 <sup>d</sup>	-6.3 <sup>d</sup>	-3.0 <sup>d</sup>	-11.6 <sup>d</sup>
XXVIII	-	-8.2 <sup>d</sup>	-3.6 <sup>d</sup>	-8.7 <sup>d</sup>
			-0.5 <sup>d</sup>	
XXIX	-1.8 <sup>d</sup>	-6.6 <sup>d</sup>	+1.8 <sup>d</sup>	-12.1 <sup>d</sup>
XXXII	-1.0 <sup>c</sup>	-9.1 <sup>c</sup> (6a)	-0.9 <sup>c</sup>	-
		-8.7 <sup>c</sup> (4a)		
XXXIIIA	-	-8.6 <sup>i,d</sup>	-3.8 <sup>i,d</sup>	-
XXXIIIB	-	-4.0 <sup>i,d</sup>	+3.5 <sup>d,i</sup>	-
XXXIV <sup>g</sup>	$\pm 0$	+2.8	+0.2	-0.8
XXXVA	-	-7.4 <sup>d</sup>	*	*
XXXVB	-	-5.1 <sup>d</sup>	*	*
XXXVI	-	-	+4.1 <sup>j</sup>	-2.7 <sup>j</sup>
XXXVII	-	-0.2 <sup>j</sup>	+0.9 <sup>j</sup>	-7.1 <sup>j</sup>
			+1.3 <sup>j</sup>	
XXXVIIIA	-	-	+1.1 <sup>j</sup>	-6.1 <sup>j</sup>
XXXVIIIB	-	-	+3.8 <sup>j</sup>	-5.1 <sup>j</sup>
Average	<sup>h</sup> -6.5 $\pm$ 1.0	<sup>a,h</sup> -11.5 $\pm$ 0.8	<sup>a</sup> -1.8 $\pm$ 0.9	<sup>d,h</sup> -12.0 $\pm$ 0.8
Range	(-3.8)-(-8.7)	(-7.9)-(-14.4)	(+0.3)-(-4.1)	(-8.7)-(-16.8)
	<sup>a,c,d</sup> -1.4 $\pm$ 0.5	<sup>c</sup> -8.3 $\pm$ 0.9	<sup>c</sup> -1.4 $\pm$ 0.5	<sup>i</sup> -5.2 $\pm$ 0.9
	(+1.1)-(-3.3)	(-6.1)-(-11.5)	(-0.9)-(-2.3)	(-0.8)-(-7.1)
		<sup>d,(f,d)</sup> -7.2 $\pm$ 0.7	<sup>d</sup> -1.5 $\pm$ 0.8	
		(-5.1)-(-10.2)	(+1.8)-(-3.6)	
			<sup>h</sup> -3.8 $\pm$ 0.6	
			(-0.1)-(-6.9)	
			<sup>i,d</sup> -0.2 $\pm$ 1.5	
			(+3.5)-(-3.8)	
			<sup>j</sup> +2.2 $\pm$ 0.7	
			(+0.2)-(+3.8)	

<sup>a,c,d</sup> Derived from acetaldehyde. <sup>b,e,f</sup> Not conformationally homogeneous, see Fig. 2.2,<sup>3</sup>

<sup>g</sup> Skew-boat conformation. <sup>h</sup> Derived from formaldehyde. <sup>i</sup> Derived from acetone. <sup>j</sup> Highly substituted compounds.

The equatorial 4,6-methyl groups are usually slightly shielded by benzene (see footnotes a, c, d, h in Table 8) but in 2,2-dimethyl-1,3-dioxanes they are not affected whereas in the highly substituted 1,3-dioxanes they are slightly deshielded by benzene. More characteristic benzene solvent shifts are found when the axial 4,6-methyl groups are in question. Except for highly substituted compounds in which the axial methyl groups are shielded by about 5 cps, the benzene shielding effect amounts to 12 cps on average (Table 8 and Fig. 3).

*The NMR shifts of the protons and methyl groups in position 5.* As a result of shielding by oxygen atoms the equatorial 5-protons absorb at higher field than the axial 5-protons (Table 5). This effect is even enhanced by benzene (Table 9) in which the equatorial protons are much more shielded than the axial ones. In polysubstituted 1,3-dioxanes, the signals of these protons, especially the equatorial protons, are frequently lost under the methyl signals.

Table 9. The benzene solvent shifts [ $\Delta\delta(\text{CCl}_4-\text{C}_6\text{H}_6)$ ] of the protons or methyl groups in position 5 of 1,3-dioxanes.

Compound	$\text{CCl}_4$		$\text{C}_6\text{H}_6$	
	5e-H	5a-H	5e-Me	5a-Me
II	-28.4	-11.0	-	-
III	-24.1	-7.1	-	-
IV <sup>a</sup>	-	(- 8.1)	(-19.5)	-
VI	-	-4.9	-21.9	-
VII	*	-	-	-4.0
VIII	-	*	-19.9	-
XIV	-	-	-16.9	-0.5
XVA	*	-	-	+1.3
XVB	-	*	-18.4	-
XVII	*	-4.5	-	-
XVIII <sup>a</sup>	-	(-4.9)	(-20.2)	-
XXA	*	-	-	+2.2
XXB	-	*	-19.1	-
XXI <sup>a</sup>	-	(-3.2)	(-15.2)	-
XXVA	*	-	-	+1.7
XXVB	-	*	-16.8	-
XXVII	-	+1.8	-21.5	-
XXIX	-	-0.8	-17.7	-
XXXII	-	-	-13.7	+4.2
XXXIII A	*	-	-	+3.3
XXXIII B	-	*	-14.8	-
XXXIV <sup>b</sup>	*	*	(-6.0)	(-6.0)
XXXVB	-	*	-15.6	-
XXXVII	-	-	-11.7	+3.9
XXXVIII A	-	*	-15.0	-
XXXVIII B <sup>c</sup>	*	-	-	(-13.8)

<sup>a</sup> These compounds are not conformationally homogeneous, see Fig. 2.<sup>2,3</sup> <sup>b</sup> Skew-boat conformation. <sup>c</sup> This compound may be in dynamic equilibrium between chair and skew-boat forms, see also text.

\* Not detected owing to overlapping signals.

The orientation of a 5-methyl substituent can be determined with certainty by NMR spectroscopy since the 5-equatorial methyl group is shifted from about 40–45 cps in  $\text{CCl}_4$  to about 20–30 cps in benzene while the 5-axial methyl group has almost the same chemical shift (about 50–60 cps) in both solvents (Table 6). The only exceptions are found when the ring has not a pure chair conformation (see above). The benzene solvent shifts of the 5-protons and 5-methyl groups are schematically shown in Fig. 3.

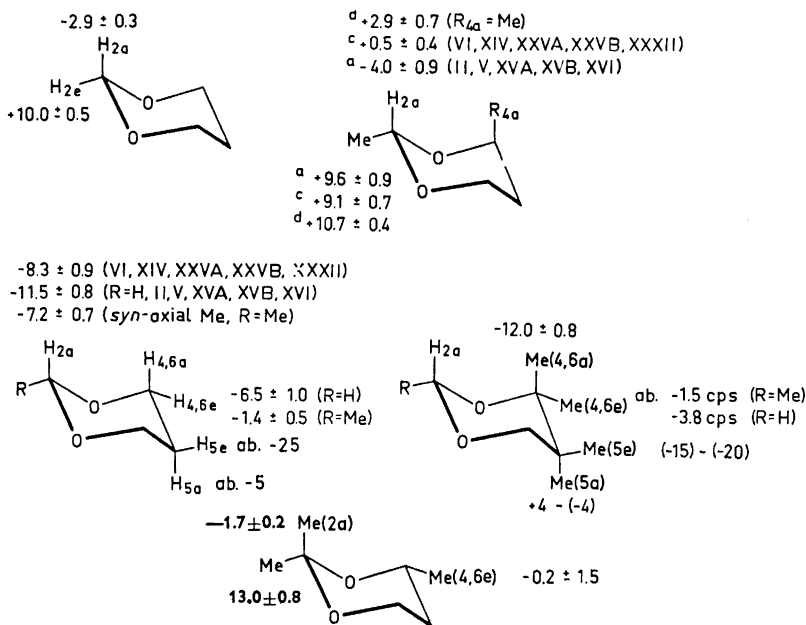


Fig. 3. The mean benzene solvent shifts  $[\Delta\delta(\text{CCl}_4 - \text{C}_6\text{H}_6)]_{\text{av}}$  for the studied compounds. For details see Tables 7–9. Positive values mean downfield shifts. All values in cps.

*The geminal proton-proton and Me—H coupling constants.* The values of the geminal coupling constants of the studied compounds are about 6.2 cps for acetal protons, 11.3 cps for 4- and 6-protons and 13.0 cps for 5-protons (Table 10). They are in general agreement with the values given by Anteunis *et al.*<sup>14</sup> and in the references cited by them. The values of Me—H coupling constants of 1,3-dioxanes are about 5.0 cps for the 2-position, about 6.2 for the 4- or 6-position (equatorial methyl groups) or about 7.0 cps (axial methyl groups) and about 6.8 cps for the 5-position. (Table 10).

*The vicinal coupling constants of the ring protons.* The ranges of the different vicinal coupling constants were the following (Table 11):  $J_{4e5e}$ , 1.1–2.2;  $J_{4e5a}$ , 4.6–6.0;  $J_{4a5e}$ , 2.1–3.5;  $J_{4a5a}$ , 9.2–11.8. These values are in good agreement with those reported earlier.<sup>4,8–11</sup> The influence of the ring deformation

Table 10. The values of the geminal and Me-H coupling constants of 1,3-dioxanes.

Compound	$^2J_{gem}$	$^4,^6J_{gem}$	$^5J_{gem}$	$^2J_{Me}$	$^4J_{Me}$	$^5J_{Me}$	$^6J_{Me}$
II		11.4	13.1	5.1	—	—	—
III	6.2	11.4	13.0	—	6.0	—	—
IV	6.1	11.3	—	—	—	6.7	—
V	—	11.2	13.2	5.0	6.0	—	—
VI	—	11.4	—	5.0	—	6.8	—
VII	6.0	11.2	—	—	5.8	*	—
VIII	6.0	11.2	—	—	5.8	6.8	—
IX	6.2	—	13.0	—	5.9	—	5.9
XIII	—	*	*	—	6.2	—	—
XIV	—	10.4	—	4.8	—	—	—
XVA	—	11.2	—	5.0	6.1	7.1	—
XVB	—	11.2	—	5.0	6.3	6.8	—
XVI	—	—	*	5.2	6.2	—	6.2
XVII	—	—	13.0	4.8	6.2	—	6.8 <sup>a</sup>
XVIII	6.2	11.3	—	—	—	6.9	—
XIX	6.5	—	13.0	—	—	—	6.0
XXA	6.2	—	—	—	6.4	*	6.4
XXB	6.2	—	—	—	6.2	6.5	6.2
XXI <sup>b</sup>	6.3	—	—	—	6.2 <sup>b</sup>	7.1	6.4 <sup>b</sup>
XXIII	—	—	*	—	6.0	—	6.0
XXVA	—	—	—	5.1	6.4	*	6.4
XXVB	—	—	—	5.1	6.2	6.6	6.2
XXVI	—	—	—	5.1	6.4	*	7.1 <sup>a</sup>
XXVII	—	—	—	5.2	6.1	7.0	7.0 <sup>a</sup>
XXVIII	—	—	*	5.0	6.2	—	—
XXIX	—	11.3	—	5.2	—	7.2	—
XXXII	—	11.1	—	5.0	6.4	—	—
XXXIIIA	—	—	—	—	6.4	*	6.4
XXXIIIB	—	—	—	—	6.2	6.3	6.2
XXXVA	—	—	—	4.9	—	*	6.4
XXXVB	—	—	—	5.0	—	6.9	6.1
XXXVI	—	—	*	5.0	—	—	—
XXXVII	—	—	—	4.9	—	—	6.3
XXXVIIIA	—	—	—	4.9	—	6.6	—
XXXVIIIB	—	—	—	4.9	—	7.0	—

<sup>a</sup> Axial methyl. <sup>b</sup> See Fig. 2.<sup>2,3</sup> \* Not detected.

and other structural effects on these values has been extensively discussed by several authors<sup>1,9,4</sup> and therefore the following discussion is limited to compounds with skew-boat conformation.

In our previous paper we have reported the values of the vicinal coupling constants of XXXIV to be 5.3 and 7.7 cps which are consistent with a skew-boat conformation.<sup>1,27,28</sup> Unfortunately, XXIV has two equivalent conformations and hence only the averaged coupling constant can be estimated. The averaged Me-H coupling constant of this compound is 6.4 cps in good agreement with the mean of the values of these coupling constants in XXXIV ( $1/2 \times (6.3 + 6.7) = 6.5$  cps).<sup>1</sup> The width of the averaged signal of the 4- and 6-



Table 11. The values of the vicinal coupling constants of 1,3-dioxanes.<sup>a</sup>

Compound	$J_{4e5e}$	$J_{4e5a}$	$J_{4a5e}$	$J_{4a5a}$
II	1.5 1.4 <sup>b</sup>	5.2 5.1 <sup>b</sup>	2.7 2.0 <sup>b</sup> 2.7 <sup>c</sup>	11.1 11.2 <sup>b</sup>
III	1.4	5.2	2.8	10.3
IV <sup>d,e</sup>	1.1 <sup>f</sup>	4.6 <sup>g</sup>	3.1 <sup>f</sup>	$J_{6a5a} = 11.7$ 11.5 <sup>g</sup>
V	1.7	5.2	2.9	11.8
VI	—	4.6 4.6 <sup>b</sup>	—	11.2 11.1 <sup>b</sup>
VII	1.8 2 <sup>c</sup>	—	2.6 2.6 <sup>c</sup>	—
VIII	—	5.6	—	11.2
IX	—	—	3.5 3.1 <sup>b</sup> 3.6 <sup>h</sup>	10.0 9.5 <sup>b</sup> 10.1 <sup>h</sup>
XIII	2.2	*	3.1	*
XVA	1.6	—	3.3	—
XVB	—	5.0	—	11.2
XVI	—	—	3.5	10.0
XVII	1.3	6.0	2.8	11.4
XVIII <sup>d,e</sup>	1.4 <sup>f</sup> 1.6 <sup>c</sup>	5.5 <sup>g</sup> 4.8 <sup>c</sup>	2.6 <sup>e</sup>	11.8 <sup>g</sup> 12.0 <sup>c</sup>
XIX	—	—	3.2 2.8 <sup>c</sup>	10.5 10.8 <sup>c</sup>
XXA	—	—	2.3	—
XXB	—	—	—	9.3
XXI	1.1 <sup>f</sup>	5.4 <sup>g</sup>	2.2 <sup>f</sup>	10.0 <sup>g</sup>
XXIII	—	—	3.1 3.2 <sup>b</sup>	10.6 10.9 <sup>b</sup>
XXVA	—	—	2.1	—
XXVB	—	—	—	9.2
XXVI	1.3	—	2.4	—
XXVII	—	5.6	—	10.0
XXVIII	—	—	2.6	11.2
XXIX <sup>d</sup>	—	5.2	—	11.8
XXXIIIA	—	—	2.1	—
XXXIIIB	—	—	—	9.3
XXXVA	—	—	2.1	—
XXXVB	—	—	—	9.7

<sup>a</sup> Owing to the symmetry of 1,3-dioxanes  $J_{4,e}$  is usually equal to  $J_{6,e}$ . <sup>b</sup> Ref. 4. <sup>c</sup> Refs. 10 and 11. <sup>d</sup> ABX-type analysis. <sup>e</sup> Also low temperature experiments, see Refs. 2 and 3. <sup>f</sup> For the 5-axial conformer. <sup>g</sup> For the 5-equatorial conformer. <sup>h</sup> Ref. 9.

Ranges of other values in Ref. 4:  $J_{4e5e}$ , 1.1–2.3;  $J_{4a5e}$ , 2.0–4.3;  $J_{4e5a}$ , 4.3–5.6;  $J_{4a5a}$ , 9.5–12.7. In Ref. 9:  $J_{4e5e}$ , 1.3–1.8;  $J_{4a5e}$ , 2.6–4.4;  $J_{4e5a}$ , 3.3–5.9;  $J_{4a5a}$ , 9.0–11.6. In Ref. 8:  $J_{4e5e}$ , 1.2–1.9;  $J_{4a5e}$ , 2.5–3.1;  $J_{4e5a}$ , 5.0–6.6;  $J_{4a5a}$ , 10.0–12.0.

\* Not detected.

protons of XXIV is 34.2 cps, from which it follows that  $2J_{av. (4,5)} = 34.2 - 3 \times 6.4 = 15.0$  cps. Thus  $J_{av. (4,5)} = 7.5$  cps. Eliel and Knoeber<sup>4</sup> reported the value 6.5 cps, but obviously the Me-H coupling has not been subtracted ( $34.2/5 = 6.8$  cps). Our value is very close to that, (7.8 cps)<sup>29</sup> reported by Tavernier and Anteunis for *trans*-4,6-di-*t*-butyl-1,3-dioxane which probably exists in the twist form.

For 1,3-dioxane (I) and *trans*-4,6-dimethyl-1,3-dioxane (X) which undoubtedly exist in the chair form, the corresponding averaged coupling constants are 5.6 and 5.3 cps, respectively. For the latter compound (X) the values 5.6 cps<sup>4</sup> and 5.4 cps<sup>29</sup> have been reported. Let us take the vicinal coupling constants of *cis*-2,4-dimethyl-1,3-dioxane (V) to represent those for a "normal" chair form. Hence,  $J_{av. (4,5)} = 1/4(1.7 + 5.2 + 2.9 + 11.8) = 5.4$  cps. This is in close agreement with the value found for I and X but differs from the value, 7.5 cps, for XXIV. The existence of 2,4-diaxially methyl-substituted 1,3-dioxanes in the twist form was at first deduced from heats of formation of XXIII and XXIV<sup>28,20</sup> and has been later well established by this and other NMR investigations.<sup>1,4,29</sup>

However, 2,2-dimethyl-1,3-dioxane (XI) exists undoubtedly in the chair form at 33.5°C since its averaged  $J_{4,5}$  is 5.6 cps which is very close to the values of  $J_{4,5}$  for I and X (see above).

#### REFERENCES

- Pihlaja, K. and Äyräs, P. *Acta Chem. Scand.* **24** (1970) 204.
- Pihlaja, K. *Suomen Kemistilehti B* **41** (1968) 229.
- Pihlaja, K. and Äyräs, P. *Suomen Kemistilehti B* **42** (1969) 65.
- Eliel, E. L. and Knoeber, M. C. *J. Am. Chem. Soc.* **88** (1966) 5347; **90** (1968) 3444.
- Anderson, J. E. *Tetrahedron Letters* **1965** 4713.
- Ramey, K. C. and Messick, J. *Tetrahedron Letters* **1965** 4423.
- Tavernier, D. and Anteunis, M. *Tetrahedron Letters* **1966** 5851.
- Anderson, J. E., Riddell, F. G. and Robinson, M. J. T. *Tetrahedron Letters* **1967** 2017.
- Anteunis, M., Tavernier, D. and Borremans, F. *Bull. Soc. Chim. Belges* **75** (1966) 396.
- Delmau, J., Duplan, J. C. and Davidson, M. *Tetrahedron* **23** (1967) 4371.
- Delmau, J., Duplan, J. C. and Davidson, M. *Tetrahedron* **24** (1968) 3939.
- Cookson, R. C., Crabb, T. A. and Vary, S. *Tetrahedron* **24** (1968) 4559.
- Cookson, R. C. and Crabb, T. A. *Tetrahedron* **24** (1968) 2385.
- Anteunis, M., Coene, M. and Tavernier, D. *Tetrahedron Letters* **1966** 4579.
- For further references see citations in Refs. 1, 2, 3, 4, 9, and 16.
- Pihlaja, K. *Ann. Univ. Turkuensis Ser. A I* (1967) No. 114.
- Pihlaja, K. and Heikkilä, J. *Acta Chem. Scand.* **21** (1967) 2390, 2430.
- Pihlaja, K. and Luoma, S. *Acta Chem. Scand.* **22** (1968) 2401.
- Pihlaja, K. *Suomen Kemistilehti B* **42** (1969) 74.
- Pihlaja, K. *Acta Chem. Scand.* **22** (1968) 716.
- Eliel, E. L. *Private communication*.
- Aftalion, F., Lumbroso, D., Hellin, M. and Coussemant, F. *Bull. Soc. Chim. France* **1965** 1958.
- Friebolin, H., Kabuss, S., Meier, W. and Lüttringhaus, A. *Tetrahedron Letters* **1962** 683.
- Schmid, H. G., Friebolin, H., Kabuss, S. and Mecke, R. *Spectrochim. Acta* **22** (1966) 623.

25. Anderson, J. E. and Brand, J. C. D. *Trans. Faraday Soc.* **62** (1966) 39.
26. Åyräs, P. and Pihlaja, K. *Unpublished results.*
27. Booth, H. and Gidley, G. C. *Tetrahedron Letters* **1964** 1449.
28. Williamson, K. L. and Johnson, W. S. *J. Am. Chem. Soc.* **83** (1961) 4623.
29. Tavernier, D. and Anteunis, M. *Bull. Soc. Chim. Belges* **76** (1967) 157.

Received May 30, 1969.