Table II

Time, min	Nmr signal intensities: Relative height H_t	H_l	$H_t/(H_t + H_l)$	$(A_0 - A_e)/(A - A_e)$
0.0	100	0.0	1.00	31/31
2.8	20.1	0.9	0.957	31/26.7
4.8	21.5	1.3	0.943	21/25.3
7.0	21.1	1.6	0.929	1.30
9.3	20.4	1.8	0.919	1.35
12.5	19.0	2.0	0.905	1.44
15.0	18.9	2.6	0.879	1.64
18.8	17.8	3.0	0.856	1.87
25.0	18.3	4.0	0.820	2.38
31.0	19.0	4.7	0.802	2.77
41.5	20.4	5.7	0.782	3.38
48.4	20.4	5.7	0.748	5.35
64.0	19.7	7.4	0.727	8.37
72.0	20.4	8.1	0.716	11.91
82.0	20.3	8.4	0.707	18.25
94.0	19.9	8.8	0.694	77.50

value. The data of Table II were recorded over a period of 94 min. The sum of the forward and reverse rate constants was obtained with eq 1,[20] where A_0 = original moles of the 12-isomer,

$$\ln\left[\frac{A_0 - A_e}{A - A_e}\right] = (k_1 + k_{-1})t \qquad (1)$$

A_e = equilibrium number of moles of the 12-isomer, A = instanteous moles of the 12-isomer, and k_1 and k_{-1} are rate constants for the equilibrium

$$\text{12-isomer} \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} \text{15-isomer}$$

From a plot of ln $[(A_0 - A_e)/(A - A_e)]$ *vs.* t is obtained $(k_1 + k_{-1}) = 5.55 \pm 0.60 \times 10^{-4}\ \text{sec}^{-1}$. Applying $k_1/k_{-1} = 0.45 \pm 0.02$ (which was obtained from the final value of H_t/H_l), $k_1 = 1.72 \pm 0.26 \times 10^{-4}\ \text{sec}^{-1}$ and $k_{-1} = 3.83 \pm 0.57 \times 10^{-4}\ \text{sec}^{-1}$ at −13.5°.

Ring Rotation Rates for 12-Aldehydo[2.2]metaparacyclophane (IIe) at 140°. When aldehyde IIe was dissolved in hexachlorobutadiene and the solution degassed, the coalescence of the aldehyde protons in the nmr spectrum appeared at 140°. Since the populations were not equivalent a computer treatment of the data was necessary. By applying the Saunders'[8] computer program for exchange between multiple sites the best fit between the experimental spectrum and computer spectra was obtained for $k_1 = 85\ \text{sec}^{-1}$ and $k_{-1} = 175\ \text{sec}^{-1}$. The following equations were then applied to determine activation parameters: $\Delta H^{\ddagger} = R(T'T/T' - T) \ln (k'T/kT')$, $k = \kappa(kT/h) \exp(-G/RT)$ assuming κ, transmission coefficient, = 1 or $\Delta G^{\ddagger} = 2.303RT(10.319 - \log k + \log T)$, and $\Delta G = \Delta H - T\Delta S$.[20]

Equilibrium Constants between 12-Substituted- and 15-Substituted-[2.2]Metaparacyclophanes (II ⇄ III). These constants were determined by integration of the nmr spectra of their equilibrium mixtures. For IIa, IIc, and IIf the methyl protons were employed. For IId the methylene protons of the CH_2OH group were used. For IIe, the aldehyde proton was integrated. In all cases, the spectra were integrated about 10 min after the solutions were prepared to allow for equilibration ($t_{1/2}{}^{25°} \sim 14$ sec).

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[20] A. A. Frost and R. G. Pearson, "Kinetics and Mechanism," 2nd ed, Wiley, New York, N. Y., 1961.

Carbon-13 Magnetic Resonance. Conformation in Some *tert*-Butyl-1,3-dioxanes[1a]

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Abstract: The natural abundance carbon-13 nuclear magnetic resonance spectra of 12 *tert*-butyl-1,3-dioxanes and pertinent supporting data are described. The chemical shifts of the ring and substituent carbon atoms are affected by the positions and by the conformations of the substituents. It is suggested that substituent shift correlations can in most instances be transferred from cyclohexane derivatives to their heterocyclic analogs provided one takes into consideration the deshielding effects of the ring oxygens on axial 5-substituents.

The potential of carbon-13 magnetic resonance spectroscopy as a tool in conformational analysis has by now become generally recognized. It is clear that the carbon-13 chemical shift is not only capable of providing detailed information concerning charge distribution in a molecular system,[2] but also is a sensitive index of the nature of the conformational environment in which a given carbon atom may be found.[3-9]

Classically cyclohexane and its derivatives have provided the most important test case for any criteria concerning conformational analysis. It is perhaps, therefore, not too surprising that most of the preceding

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[1] (a) Presented at the 161st National Meeting of the American Chemical Society, Los Angeles, Calif., April 1, 1971; (b) University of Alberta; (c) University of Notre Dame; (d) University of Utah.

[2] *E.g.*, A. J. Jones, D. M. Grant, M. W. Winkley, and R. K. Robins, *J. Amer. Chem. Soc.*, **92**, 4079 (1970), and references therein.

[3] K. S. Dhami and J. B. Stothers, *Tetrahedron Lett.*, 631 (1964); *Can. J. Chem.*, **43**, 479 (1965); D. H. Marr and J. B. Stothers, *ibid.*, 43, 596 (1965).

[4] W. R. Woolfenden and D. M. Grant, *J. Amer. Chem. Soc.*, **88**, 1496 (1966).

[5] G. W. Buchanan, D. A. Ross, and J. B. Stothers, *ibid.*, **88**, 4301 (1966); G. W. Buchanan and J. B. Stothers, *Chem. Commun.*, 1250 (1967); *Can. J. Chem.*, 47, 3605 (1969).

[6] D. K. Dalling and D. M. Grant, *J. Amer. Chem. Soc.*, **89**, 6612 (1967).

[7] D. K. Dalling and D. M. Grant, *ibid.*, to be submitted.

[8] G. W. Buchanan, J. B. Stothers, and S. Wu, *Can. J. Chem.*, **47**, 3113 (1969); Gurudata and J. B. Stothers, *ibid.*, **47**, 3601 (1969).

[9] D. E. Dorman, S. J. Angyal, and J. D. Roberts, *J. Amer. Chem. Soc.*, **92**, 1351 (1970); D. E. Dorman and J. D. Roberts, *ibid.*, **92**, 1355 (1970).

studies[5-7] have been directed toward conformation in cyclohexanes. The apparent dependence of the carbon-13 shift on geometrical and conformational features in a variety of methylcyclohexanes[6] stimulated the derivation of a set of additive parameters which subsequently have enabled characterization of the carbon-13 spectra of the perhydronaphthalenes, anthracenes, and phenanthrenes,[7] in addition to a number of naturally occurring steroids.[10] Similarly, the carbon-13 shieldings of the alicyclic carbons bearing oxygen in several cyclohexanols, their acetates, and methyl esters have been shown to be dependent on the orientation of the oxygen function and have enabled determination of conformational free energies in close agreement with those obtained by other methods.[5] It is also apparent that carbon-13 shift data can be of value in determining conformations in at least some simple sugars.[9]

To test the generality of some of the relationships so derived we chose to study a variety of *tert*-butyl substituted 1,3-dioxanes in which the conformational features have previously been defined by other techniques.[11] Recently, Riddell[12] has reported the carbon-13 shifts in a series of methyl-1,3-dioxanes which were subject to minor errors due to the referencing procedure used.[13] From newly determined data these authors[13] have indicated that the substituent shift correlations for the cyclohexanes and the 1,3-dioxanes are, in general, comparable but may differ in magnitude. Our own results on the *tert*-butyl-1,3-dioxanes studied lead to a similar conclusion.

Experimental Section

Carbon-13 spectra were determined using either a Varian AFS-60 spectrometer as described previously[14] or a Bruker Scientific HFX-8 spectrometer operating in conjunction with a Fabri-Tek-1074/PDP-8L fast Fourier transform signal averager. The majority of compounds studied were freshly prepared by techniques previously described and all were purified by gas–liquid chromatography. The solids studied were dissolved in the minimum of carbon disulfide and tetramethylsilane (TMS) was added as the internal reference. All other spectra were run on neat liquids containing TMS (~20%) as reference. (The nature of the solution used is indicated in the appropriate table of data.) Where necessary some part of the spectra were accumulated on a time averaging device. Chemical shifts were calculated relative to the internal TMS signal and for purposes of comparison may be converted to the benzene scale (TMS to benzene, 128.54 ppm).

Results

The conventional labeling system for the 1,3-dioxane ring is employed throughout this discussion. However, carbon atoms in substituents are labeled *n*C-α, *n*C-β. . .etc. The designation *n* indicates the position of the substituent on the ring and α,β indicate the attached and subsequent carbons in the substituent chain. Where there is more than one carbon substituent on a given ring position, *e.g.*, in 2,2-dimethyl-5-*tert*-butyl-1,3-dioxane (IV), the methyl carbons are designated 2C-α and 2C-α′ where α′ refers to the axial substituent. Figure 1 provides a summary of this labeling system.

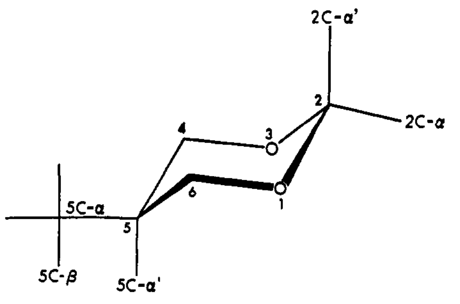

Figure 1. Labeling system employed for the 1,3-dioxanes.

The compounds studied and the carbon-13 shift data obtained are summarized in Table I.

Assignments of the carbon-13 resonances in the compounds studied were made through use of one or more of three established methods: (a) observation of the relative intensities of the proton-decoupled carbon-13 resonances, (b) the absence of observable proton induced splittings of the carbon-13 resonances in the coupled spectra, indicating quaternary carbons, and (c) selective proton decoupling of an assigned proton from a given carbon-13 resonance line. The effect of substituent groups on the appropriate carbon-13 resonances served to confirm some of the assignments made. Thus, in all of the *tert*-butyl-1,3-dioxanes the intensity of the signal due to the three equivalent β-methyl carbon atoms in the *tert*-butyl group made possible their assignment. Similarly, the assignment of the resonances due to C-4,6 in all but *cis*-4-methyl-2-*tert*-butyl- (XI) and *cis*-2,4-dimethyl-1,3-dioxane (XIV) was dependent on the double intensity of the line associated with the two magnetically equivalent methylene carbons in these systems. With the exception of the ortho and meta carbon resonances in the phenyl-substituted derivatives all other carbon resonances in the systems studied have, in comparison, only single intensity.

Of these single intensity resonances those due to the quaternary carbons (C-α) of the *tert*-butyl groups were the most readily identified. The absence of proton induced splittings in the coupled, or observation of no change in the intensity of a given line in the selectively decoupled spectra of 5-*tert*-butyl- (I), *trans*-2-methyl-5-tert-butyl- (II), 2-*tert*-butyl- (V), *cis*-2-*tert*-butyl-5-methyl- (VII), and *trans*-2-phenyl-5-*tert*-butyl-1,3-dioxane made possible unequivocal assignment of the C-α-*tert*-butyl carbons in these molecules. For the remaining compounds the corresponding quaternary carbon resonances were assigned by comparison of the observed shifts with those in the appropriate model system selected from the above group.

In the 5-*tert*-butyl derivatives total spectral assignments were based on detailed studies of a selected group of molecules in the series. Thus, in 5-*tert*-butyl-1,3-dioxane (I) the assignment of the two remaining single intensity lines due to C-2 and C-5 relied on the observation of the off-resonance decoupled spectrum which exhibited a triplet about 93.65 ppm and a doublet about 44.39 ppm, thus establishing that these resonances are due to the methylene carbon C-2 and the methine carbon C-5, respectively. In the case of *trans*-2-methyl-5-*tert*-butyl-1,3-dioxane (II)[11] a selective decoupling experiment[14] was carried out to establish the assignment of all the resonance lines in-

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(10) H. J. Reich, M. Jautelat, M. J. Messe, F. J. Weigert, and J. D. Roberts, *J. Amer. Chem. Soc.*, **91**, 7445 (1969).

(11) (a) E. L. Eliel and M. C. Knoeber, *ibid.*, **88**, 5347 (1966); **90**, 3444 (1968); (b) E. L. Eliel and F. W. Nader, *ibid.*, **92**, 3050 (1970).

(12) F. G. Riddell, *J. Chem. Soc. B*, 331 (1970).

(13) G. M. Kellie and F. G. Riddell, private communication.

(14) A. J. Jones, T. D. Alger, D. M. Grant, and W. M. Litchman, *J. Amer. Chem. Soc.*, **92**, 2386 (1970).

Table I. Carbon-13 Chemical Shifts in Some *tert*-Butyl-1,3-dioxanes[a]

	Compound	C-2(1)	C-4(2)	C-5(1)	2C-α(1)	2C-α′(1)	2C-β(3)	5C-α(1)	5C-α′(1)	5C-β or β′(3)
I	5-*tert*-Butyl (neat liquid)	93.65	68.53	44.39				30.66		27.58
II	*trans*-2-Methyl-5-*tert*-butyl (neat liquid)	99.07	68.58	44.62	21.24			30.54		27.68
III	*cis*-2-Methyl-5-*tert*-butyl (neat liquid)	99.37	67.31	43.61	21.35				32.63	29.71
IV	2,2-Dimethyl-5-*tert*-butyl (neat liquid)	97.44	60.85	44.23	27.98	20.28		30.96		27.54
V	2-*tert*-Butyl (neat liquid)	107.83	66.92	26.37	35.28		25.01			
VI	*trans*-2-*tert*-Butyl-5-methyl (neat liquid)	107.72	73.61	29.71	35.27		24.87	12.40		
VII	*cis*-2-*tert*-Butyl-5-methyl (neat liquid)	108.11	71.98	29.72	35.31		24.70		15.93	
VIII	2-*tert*-Butyl-5,5-dimethyl (solution in CS_2)	108.41	77.31	30.13	34.99		25.17	22.18	23.36	
IX	*trans*-2,5-Di-*tert*-butyl (solution in CS_2)	107.18	68.59	43.68	34.70		24.92	30.02		27.47
X	*cis*-2,5-Di-*tert*-butyl (solution in CS_2)	108.58	67.98	43.54	35.21		25.05		32.73	29.78
XI[b]	*cis*-2-*tert*-Butyl-4-methyl (neat liquid)	107.26	72.47 (1)	33.69	35.06		24.95			
XII[c]	*trans*-2-Phenyl-5-*tert*-butyl (solution in CS_2) (solution in CS_2)	101.40	69.27	44.00				30.55		27.88
XIII[d]	*cis*-2-Phenyl-4,6-dimethyl (solution in CS_2)	100.84	72.83	40.89						
XIV[e]	*cis*-2,4-Dimethyl (neat liquid)	98.86	72.46 (1)	33.39	21.39					

Carbon position and relative intensity (of observed signal)

[a] Given in parts per million downfield relative to internal tetramethylsilane (TMS to benzene 128.54 ppm). [b] 4C-α-methyl at 21.92 ppm, C-6 at 66.41 ppm. (1) indicates relative intensity at C-4. [c] Phenyl ring carbons at 139.91 (α-C), 128.87 (*p*-C), 128.25 and 126.93 ppm (*m*-C and *o*-C). [d] 4C-α and 6C-α methyls at 21.87 ppm and phenyl ring carbons at 139.97 (α-C), 128.39 (*p*-C), 127.94 and 126.71 ppm (*o*-C and *m*-C). [e] 4C-α-methyl at 21.96 ppm, C-6 at 66.33 ppm. (1) indicates relative intensity at C-4.

cluding those established independently on the basis of their relative intensities. Thus, the 5C-β carbon resonance was decoupled at the lowest proton frequency to yield a line of triple intensity. Stepping the proton decoupler frequency through the 2-methyl, 5-methine, 4-methylene, and 2-methine proton shifts led to the assignments given in Table I. The single intensity line at 30.54 ppm exhibited no change in intensity during the frequency stepping procedure and consequently is assigned to the quaternary 5C-α carbon. Figure 2 shows the spectrum of this molecule and some of the decoupling effects discussed. Assignment of the resonances in the corresponding cis isomer (III) was based on intensity relationships and comparison of the observed shifts with those in the trans isomer (II). Changes in the absolute shift values, in particular for the *tert*-butyl group, are considered to reflect a conformational change and will be discussed. In the case of 2,2-dimethyl-5-*tert*-butyl-1,3-dioxane (IV) only the assignment of the 2C-α and 2C-α′ resonances remains in doubt. However, data for 1,1,2-trimethylcyclohexane[6] and 1,1,3-trimethylcyclohexane[6] (Table III) suggest that the axial 2C-α′ carbon occurs at highest field.

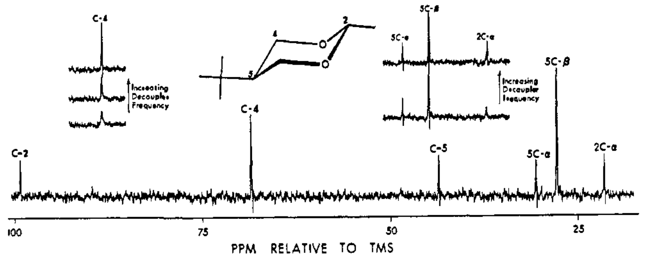

Figure 2. The natural abundance carbon-13 magnetic resonance spectrum of *trans*-2-methyl-5-*tert*-butyl-1,3-dioxane (II). Insets show the effects of stepping the ^1H decoupler frequency in the selective decoupling experiment.

Table II. Carbon-13 Chemical Shifts in Selected Methyl-1,3-dioxanes[a]

	Compound	C-2	C-4	C-5	2C-α	5C-α
XV	1,3-Dioxane (neat liquid)	96.77	68.71	27.95		
XVI	2-Methyl-1,3-dioxane (neat liquid)	101.86	68.38	26.95	21.98	
XVII	2,2-Dimethyl-1,3-dioxane (neat liquid)	99.98	61.20	26.96	24.97	
XVIII	5,5-Dimethyl-1,3-dioxane (neat liquid)	96.22	79.10	31.71		23.20

Carbon position

[a] Given in parts per million downfield relative to internal TMS.

In the 2-*tert*-butyl systems a similar detailed study on selected molecules led to the assignments given in Table I. Thus, in 2-*tert*-butyl-1,3-dioxane (V) selective proton decoupling showed the carbon-13

Table III. Carbon-13 Chemical Shifts[a] in Selected Methylcyclohexanes Taken from the Literature[6]

Compound	Carbon position C-1	C-2,6	C-3,5	C-4	1C-α
Cyclohexane	27.4				
1-Methylcyclohexane	33.4	36.1	26.8	26.7	23.0
1,1-Dimethylcyclohexane	30.3	40.1	22.9	27.0	29.1
1,1,2-Trimethylcyclohexane[b]	33.2	(42.1, 41.5)	(31.6, 23.1)	27.1	30.8
1,1,3-Trimethylcyclohexane[c]	31.1	(49.6, 39.8)	(28.6, 22.9)	36.0	34.0
cis-1,4-Dimethylcyclohexane	30.4	31.2		30.4	20.4
trans-1,4-Dimethylcyclohexane	32.9	35.9		32.9	23.0

[a] Given in parts per million relative to TMS. [b] 1C-α′-axial methyl at 19.4 and 2C-α at 16.6 ppm. Parentheses indicate C-2, C-6 and C-3, C-5 assignments in these unsymmetrical systems. [c] 1C-α′-axial methyl at 25.2 and 3C-α at 23.4 ppm. Parentheses indicate C-2, C-6 and C-3, C-5 assignments in these unsymmetrical systems.

lines at 25.01 and 107.83 ppm to be decoupled at the lowest and highest proton frequencies, respectively, corresponding to the *tert*-butyl and 2-methine proton shifts. The quaternary carbon 2C-α exhibited no change with irradiation frequency. A selective decoupling experiment was also performed on 2-*tert*-butyl-5,5-dimethyl-1,3-dioxane (VIII) establishing the assignments given in Table I with the exception of those given for the 5C-α and 5C-α′ carbons. These geminal carbon atoms exhibit only a minor shift difference (1.18 ppm) compared with the *gem*-dimethyl carbon shifts in the corresponding 2,2-dimethyl derivative (7.70 ppm) IV and their assignment remains uncertain. However, it is suggested that the axial 5C-α′ carbon atom is deshielded by the 1,3-ring oxygens and consequently is shifted downfield and not upfield as occurs in situations where *syn*-axial hydrogen interactions dominate, as in 1,1,2-trimethyl- and 1,1,3-trimethylcyclohexane[6] and in IV above. This suggestion is amplified further in the Discussion section. In *cis*-2-*tert*-butyl-5-methyl-1,3-dioxane (VII) the resonance due to 5C-α′ was assigned from the observation that it was decoupled at a lower frequency[11] than that required to decouple the C-2 and C-5 resonances. Remaining assignments in VII and in *trans*-2-*tert*-butyl-5-methyl-1,3-dioxane (VI) were made by comparison between the sets of data obtained in this group (V–VIII).

In *trans*- and *cis*-2,5-di-*tert*-butyl-1,3-dioxane (IX and X) the triple intensity of the signals attributable to 2C-β and 5C-β or 5C-β′, and the double intensity of those due to C-4,6 made possible their assignment in each of these spectra. The relatively complex pattern of shifts for the carbons 2C-α, 2C-β and 5C-α, 5C-β or 5C-α′, 5C-β′ was resolved by comparing the magnitudes of the observed shifts in the spectra of each of these molecules with those observed in compounds I–VIII.

The chemical shifts presented in Table I for the remaining compounds XI–XIV were obtained to verify the generality of the trends we have observed. For *trans*-2-phenyl-5-*tert*-butyl-1,3-dioxane (XII) only the assignment of the shifts due to the ortho and meta carbons in the phenyl ring can be considered uncertain. All other assignments were made by selective irradiation at the appropriate proton frequency. In *cis*-2-phenyl-4,6-dimethyl-1,3-dioxane (XIII) the double intensity of the 4C-α methyl carbon resonance in the high-field region at 21.87 ppm compared with the only other double intensity peak due to C-4 observed at 72.83 ppm enables their assignment. Only the shifts due to the carbons C-2 and C-5 need be assigned by comparison with previous data. The remaining compounds *cis*-2-*tert*-butyl-4-methyl- (XI) and *cis*-2,4-dimethyl-1,3-dioxane (XIV) provide no significant changes that would not be predicted from the effects of substitution indicated in the previous examples. Consequently, assignment of these spectra relied on approximate additivity relationships suggested by the previous spectra.

Discussion

Attention should first be drawn to the remarkable constancy shown in the carbon-13 chemical shifts for molecules of similar structure and conformation as given in Table I. A variety of general trends can also be observed in these data and a comparison of similar data for the methylcyclohexanes[6] and 1,3-dioxanes[12,13] is suggested. In the present research the carbon-13 chemical shifts were determined from high-resolution carbon-13 spectra. Consequently, we have reevaluated the carbon-13 shifts for a selected group of methyl-1,3-dioxanes (XV–XVIII) using high-resolution conditions. These values are presented in Table II and show some deviations, though relatively small, compared with values obtained using other techniques.[12,13,15] In the discussion following we will frequently make comparisons of the data given in Tables I and II with those for the methylcyclohexanes. For convenience we provide a selection of carbon-13 shift data for the latter compounds in Table III.

Changes in chemical shift on introduction of a substituent to the basic ring system are clearly evident from the data given in Tables I–III. Introduction of a 2-methyl group, which should be very predominately equatorial,[11] results in C-2 experiencing downfield shifts of 5.4 and 5.1 ppm relative to those in the 5-*tert*-butyl compound (I) and in 1,3-dioxane, respectively. In cyclohexane–methylcyclohexane a similar downfield shift of 6.0 ppm was observed.[6] The 2,2-*gem*-dimethyl groups in the 5-*tert*-butyl derivative (IV) and in 2,2-dimethyl-1,3-dioxane (XVII) result in a downfield shift at C-2 of 3.8 and 3.2 ppm, respectively. These values compare favorably with that observed for the corresponding cyclohexanes by Dalling and Grant[6] where the average downfield shift for *gem*-dimethyl substitution was 4.45 ppm.[6] A summary of these shift changes on methyl substitution is illustrated in Figure 3. From Figure 3 it is also clear that C-4,6 experiences an upfield shift on substitution of the axial methyl group as in

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(15) G. E. Maciel and G. B. Savitsky, *J. Phys. Chem.*, **69**, 3925 (1965).

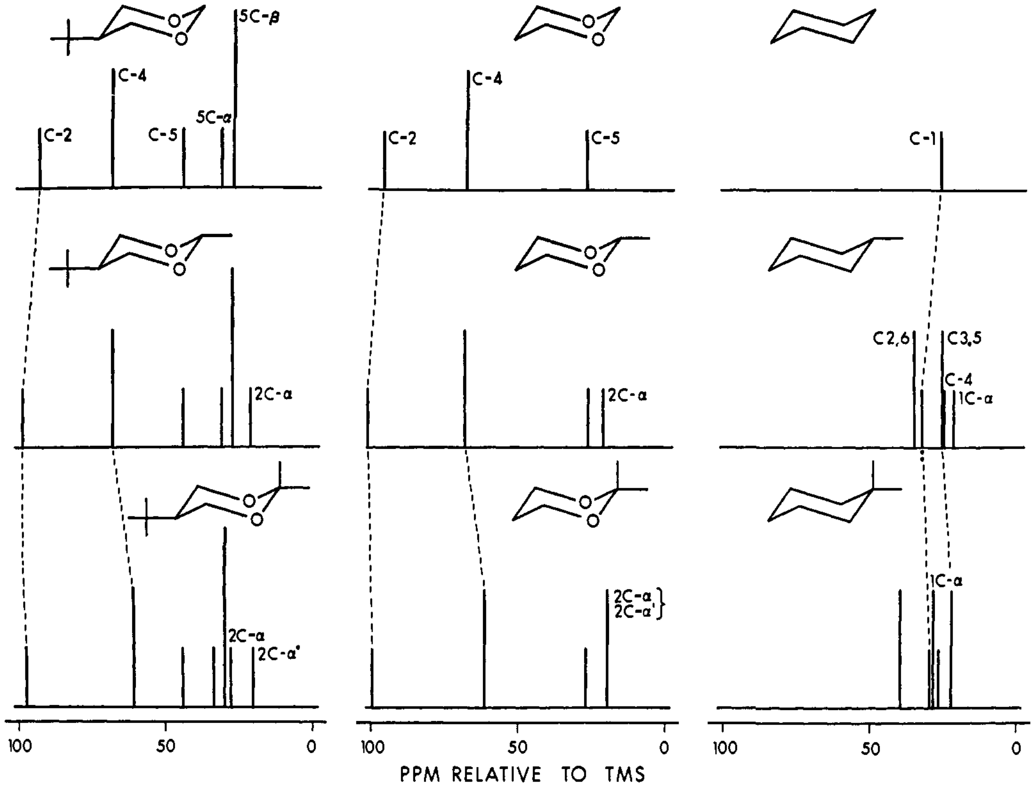

Figure 3. Carbon-13 chemical shift correlations in methyl and *gem*-dimethyl substituted (a) 5-*tert*-butyl-1,3-dioxanes, (b) 1,3-dioxanes, and (c) cyclohexanes.

the geminal systems. This upfield shift is attributed to the *syn*-axial "1,3-steric interactions" which occur between the axial methyl and the methylene protons at C-4,6 in the 1,3-dioxanes and the corresponding positions C-3,5 in the cyclohexanes[6] and presumably is greater in magnitude in the dioxane case (6.46 ppm compared to 3.9 ppm) due to the decreased interatomic distance at these sites.[11b]

In the 2-*tert*-butyl-substituted derivatives (V–VIII) the methyl substituent effect at C-5 is less pronounced than that at C-2 in the 5-*tert*-butyl series. Only a 3.3-ppm downfield shift is observed at C-5 in *trans*-2-*tert*-butyl-5-methyl-1,3-dioxane (VI) while *gem*-dimethyl substitution, as in VIII or XVIII, produces a downfield shift of 3.8 ppm. In addition, in the 2-*tert*-butyl isomers the absolute chemical shifts for the methyl carbon 5C-α in the trans derivative (VI) or 5C-α′ in the corresponding cis isomer (VII) also present an anomaly since they are high compared with, for example, the 2-methyl substituent shifts in the 5-*tert*-butyl compounds I–IV. The shift at the axial methyl 5C-α′ carbon may be a reflection of the much less hindered environment of C-5 compared to C-2. It should be noted that the shifts at 5C-α and 5C-α′ in VI and VII are also considerably higher than those for similar carbons in the methylcyclohexanes.[6] The explanation for these apparently anomalous shifts is uncertain and is the subject of further investigations. However, other characteristics of the shifts for the methyl amd *tert*-butyl carbons are more readily accounted for.

The chemical shifts exhibited by the *tert*-butyl groups in all of the systems studied appear to provide the most informative index on both position of substitution and of stereoisomeric properties. Methyl substitution at C-2 in the 5-*tert*-butyl compounds I, II, and IV clearly has no effect on the *tert*-butyl chemical shifts. From the data provided by these compounds it is apparent that where the *tert*-butyl group is equatorial it is characterized by the carbon-13 shifts 30.5–31.0 and 27.5–27.7 ppm for 5C-α and 5C-β, respectively. Further, a downfield and relatively constant shift of 16.3–16.7 ppm with respect to the parent 1,3-dioxane is observed at C-5, the position of *tert*-butyl substitution in these compounds. Similarly, the *tert*-butyl shifts in the 2-*tert*-butyl compounds V–VIII also show near invariance to methyl substitution at C-5 or even at C-4 as in XI. The equatorial 2-*tert*-butyl group in V–VIII and XI is thus characterized by the shifts 35.0–35.3 and 24.7–25.2 ppm for 2C-α and 2C-β′ respectively. In addition, in V–VIII a relatively constant downfield shift of 11.0–11.6 ppm with respect to the parent 1,3-dioxane is observed at C-2, the position of *tert*-butyl substitution. These characteristic shifts have made total assignments possible for the *tert*-butyl substituents in all of the compounds studied.

Perhaps more interesting are the effects observed on the carbon-13 shifts of the *tert*-butyl or methyl groups in the cis–trans isomeric pairs II and III, and VI and VII. In these four compounds the C-2 substituents are equatorial[11] while the conformations of the C-5 substituents change from equatorial to axial in the trans and cis isomers, respectively. In the cis isomer (III) downfield shifts of approximately 2 ppm, compared to I, II, and IV, are observed between 5C-α, 5C-β and 5C-α′, 5C-β′, while upfield shifts of *ca.* 1 ppm occur at both C-4 and C-5. As expected C-2 and 2C-α exhibit only minor changes since the methyl group remains equatorial in both isomers.[16] Similar

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[16] It has been shown (ref 11a) that *cis*-2-methyl-5-*tert*-butyl-1,3-dioxane exists almost exclusively in the conformation in which 2C-α

relatively large changes occur for the methyl carbon shifts in the 2-*tert*-butyl isomers VI and VII. That is, comparing the cis isomer (VIII) to the trans (VI), a downfield shift of 3.5 ppm occurs for the methyl carbon 5C-α', while an upfield shift of 1.6 ppm is found at C-4. The shifts at C-5, C-2, 2C-α, and 2C-β are relatively invariant to the stereoisomeric change. Again the invariance of the shifts at C-2, 2C-α, and 2C-β is not too surprising since the substituent at C-2 remains equatorial. In Table III we have included the data for the *cis*- and *trans*-1,4-dimethylcyclohexanes.[6] In these isomers upfield shifts of 2.6 to 4.8 ppm were observed for all positions in the cis isomer compared with the trans. 1,3-Steric (syn-axial) interactions are considered to play a major role in accounting for these shifts.[6,7] However, in the 1,3-dioxanes an axial substituent at C-5, as in the cis isomers III and VII, has no syn axial hydrogen with which to interact but rather appears to be deshielded by the ring oxygen atoms, which thus cause a downfield shift of the 5-axial substituents. As noted in the Results section this effect is also evident in the shift at 5C-α' in the *gem*-dimethyl-substituted compound VIII as compared with the 5C-α shift. The upfield shifts at C-4 and C-5 in III compared with II and at C-4 in VII compared with VI are similar to those observed by Dalling and Grant[7] and presumably are steric in origin. The lack of a steric effect at C-5 in the 2-*tert*-butyl isomers VI and VII compared with changes in the corresponding cyclohexanes further emphasizes a reduction in steric compression by the 1,3-ring oxygens on an axial 5C-α' methyl carbon compared with the *syn*-1,3-axial hydrogens in the cyclohexanes.[6,7]

At this point it is of interest to evaluate the data obtained for the remaining cis–trans isomeric pair IX and X. In *trans*-2,5-di-*tert*-butyl-1,3-dioxane (IX) (both *tert*-butyl groups equatorial) the shifts of the ring carbons C-2, C-4, and C-5 are relatively consistent with the *tert*-butyl substituent effects in the compounds I–VIII. A similar observation is also true for the cis isomer X in which the 5-*tert*-butyl group is axial. The shifts at the ring carbons C-2 and C-4 in the cis isomer (X), compared to the trans (IX), are similar in magnitude and direction to those in the other isomeric pairs, though the absence of a change in the shift at C-5 may be indicative of a dominant substituent effect from the 2-*tert*-butyl group. The relatively small shifts at 2C-α (0.48 ppm) and 2C-β (0.13 ppm) between these isomers once again is as anticipated since no configurational change occurs at the 2 position in this molecule. In contrast, the axial–equatorial 5-*tert*-butyl group shifts are upfield 2.71 ppm (at the α-carbon) and 2.31 ppm (at the β-carbon) in the cis (X) compared with the trans (IX) isomer. These latter shifts are similar to those noted for the 5-*tert*-butyl carbons in the isomers II and III.

The additive trends in the observed substituent shifts for the 1,3-dioxanes are further emphasized by the supporting data given in Table I. Thus in *cis*-2-*tert*-butyl-4-methyl-1,3-dioxane (XI) the characteristic downfield shifts of 5.6 ppm (at C-4) and 7.3 ppm (at C-5) are observed on methyl substitution at C-4. The shifts at C-4, C-5, and C-6 in XI are also remarkably similar to those observed at the corresponding positions in *cis*-2,4-dimethyl-1,3-dioxane (XIV). Similarly, the constancy of the carbon-13 shifts is exhibited by the data for *trans*-2-phenyl-5-*tert*-butyl-1,3-dioxane (XII) in which only the position of substitution (a downfield shift of 7.8 ppm at C-2) is affected as compared with 5-*tert*-butyl-1,3-dioxane (I).

Taking an overall view it is apparent that one major conclusion arises from the results presented above. It is clear that the carbon-13 substituent shifts observed in the 1,3-dioxanes are to a major extent transferrable from the corresponding cyclohexane derivatives provided one takes into consideration the difference in steric compression attributable to the ring oxygen atoms compared to the methylene group. As a corollary, the observed additivity relationships in this series of compounds must also be considered indicative of the fact that 2- or 5-*tert*-butyl groups do not unduly distort the 1,3-dioxane ring.[17]

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is equatorial and the *tert*-butyl group at C-5 axial. This is due to the high steric compression of an axial group at C-2 by the nearby *syn*-axial hydrogens at C-4 and C-6 and the low compression of an axial group at C-5 due to the absence of axial hydrogens at the oxygen sites O-1 and O-3.

(17) H. R. Buys and E. L. Eliel, *Tetrahedron Lett.*, 2779 (1970); C. Altona and M. Sundaralingam, *Tetrahedron*, **26**, 925 (1970).