$C(9)H_2$: *D*, 5,35 ppm, 2 Pr; $N(2)H_2$: *br S*, 8,4 ppm, 2 Pr. Das UV.-Spektrum (Fig. 4) entspricht jenem eines 7,8-Dihydropterins (siehe z.B. [7]).

$C_7H_8O_5N_5PLi_2 \cdot 5H_2O$	Ber.	C 22,29	H 4,82	N 18,55	P 8,21%
(377,11)	Gef	,, 22,57	,, 4,67	,, 18,95	,, 7,91%

7,8-Dihydro-6-hydroxymethyl-pterin-diphosphat (*VI*) Dieser Dihydroester wird als Li-Salz nach der gleichen Methode hergestellt. Das UV.-Spektrum stimmt mit jenem des Dihydroesters V überein.

$C_7H_8O_8N_5P_2Li_3 \cdot 7H_2O$	Ber.	C 16,85	H 4,41	N 14,03	P 12,41%
(4,99,07)	Gef.	,, 17,50	,, 3,34	,, 13,38	,, 12,34%

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170. Nuclear Quadrupole Resonance and Stereochemistry I. α – Chloro Ethers

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(11. IV. 73)

Summary. ^{35}Cl nuclear quadrupole resonance spectra of cyclic α-chloro ethers of known configuration are presented. The resonance frequencies of chlorine atoms in equatorial positions are in every case some 2.5 MHz higher than those of corresponding chlorine atoms in axial positions. Similar results are obtained for open-chain trichloromethyl ethers and the effect is sufficiently well-defined to distinguish between configurational isomers and establish their conformation. These results may be rationalised in terms of a model in which the lone-pair electrons on the oxygen atom hyperconjugate with the electrons of the C-Cl bond.

Introduction. – One of the main problems in the interpretation of nuclear quadrupole coupling constants is the number of approximations necessary to relate them to an electronic structure. The most radical of these sets of approximation, that associated with the names of *Townes & Dailey* [1], assumes that the quadrupole coupling constant arises only from incomplete filling of the valence p-shell. The use of such approximations is likely to involve the fewest errors if they are used to compare the coupling constants of related sets of molecules, whose structures are as similar as possible. A case in which this criterion is realised probably as closely as it is possible to realise it, is in the case of molecules differing only in their stereochemistry. Here differences in coupling constants can be related with fair confidence to differences in electronic structure and compared with the predictions of the more and more refined molecular orbital theories which are now available.

A further reason to study stereochemical effects on NQR. frequencies is the possibility that it might reveal a useful analytical application of NQR. Such applications have so far been lacking and indeed this lack has been part of the reason that NQR. has developed much more slowly than for example NMR.

The origin of the present study lay in observations of the effect of fluoro and methoxy substituents on ^{35}Cl pure quadrupole resonance frequencies [2]. These were lower than those expected on the grounds of the electronegativity of the substituent and it was postulated that this was due to a hyperconjugative interaction between the C–Cl bond and the lone-pair electrons of the substituent (I)

$$R\overset{\oplus}{O} = CH_2 \qquad Cl^{\ominus}$$

(I)

Such an interaction is orientation-dependent, being a minimum when the atoms of the C–O–C-Cl fragment are coplanar, and this was indeed noted in a preliminary communication [3]. In the present paper we report the results of a study of a more extensive series of chloroethers, mainly chlorodioxanes, of known structure.

Experimental. *^{35}Cl pure quadrupole resonance spectra.* Samples immersed in a bath of liquid nitrogen were measured on a *Decca* nuclear quadrupole resonance spectrometer, the frequencies being measured both by the crystal-controlled internal marker and a *Hewlett-Packard* digital frequency-meter.

Preparation: *2-chlorodioxane* [4]; *2,5-dichlorodioxane*-cis [5] and -trans [6] *2,3-dichlorodioxane* and *2-chlorotetrahydropyrane* [8] were prepared by published methods. We thank Dr. *L.A. Cort* of the University of Surrey for kindly supplying the three 2,3,5,6,-tetrachlorodioxanes and Professor *E.T. Mc Bee* for the trichloromethyl ethers.

Results and Discussion. – The ^{35}Cl pure resonances frequencies of the various chloro ethers are shown in Table 1. The relationship between frequency and coupling constant for $I = 3/2$ nuclei is the well-known:

$$\nu_Q = \frac{e^2Qq}{2}\left(1 + \frac{\eta^2}{3}\right)^{1/2}.$$

The asymmetry parameters (η) of these compounds are unknown but they are unlikely to be greater than 0.1 so that the coupling constant is given by $2\,\nu_Q$ with an error of less than 0.2%.

The crystal structure of several of the compounds shown in Table 1 has been determined and the structures of the majority have in fact been established by a variety of methods, particularly NMR. In the crystal of *trans*-2,5-dichlorodioxane the symmetry of the isolated molecule is preserved while in *trans*-2,3-dichlorodioxane and *trans-syn-trans*-2,3,5,6-tetrachlorodioxane crystal formation results in a loss of symmetry and the subsequent creation of two slightly different C–Cl bonds. These differences are reflected in the multiplicity of the ^{35}Cl NQR. spectrum. One of the vicinal disubstituted molecules and one of the tetrachloro derivatives contains only axial chlorine atoms. In both cases the resonance frequencies are much lower than those of corresponding isomers containing equatorial chlorine atoms. Furthermore, in the *cis-anti-cis*-tetrachlorodioxane where there are two equivalent axial chlorine atoms and two equivalent equatorial atoms there are just two frequencies, one corresponding to that observed in the *trans-syn-trans*-compound (from axial chlorines) while in the *cis-trans*-derivative (one equatorial three axial) three

Table 1. *^{35}Cl NQR. frequencies (MHz at 77 K) of α-chloroethers*

	ν_q (MHz)	Ref.	Configuration	Ref. for structure
chloromethylmethylether	30.181	[2]		
1,1′-dichloromethylether	32.381 32.587	[2]		
2-chlorotetrahydropyrane	29.939			
2-chlorodioxane	29.908			
2,5-*trans*-dichlorodioxane	31.03	[3]	ax/ax	[10]
2,3-*trans*-dichlorodioxane	31.908 32.976	[3]	ax/ax	[11]
2,3-*cis*-dichlorodioxane	32.176 34.986	[3]	ax/eq	[12]
2,3,5,6-*cis-anti-cis*-tetrachlorodioxane	34.831 37.010		ax/eq/ax/eq	[13]
2,3,5,6-*cis-trans*-tetrachlorodioxane	34.160 34.816 35.693 37.141		ax/eq/ax/ax	[13]
2,3,5,6-*trans-syn-trans*-tetrachlorodioxane	34.713 35.034		ax/ax/ax/ax	[14]
m-fluoro-ω,ω,ω,-trichloroanisole	37.679 37.870 38.012 38.544 39.826 40.090			
p-fluoro-ω,ω,ω-trichloroanisole	37.869 38.515 39.761			
2,3,4,6-tetra-O-acetyl-α-D-glucopyranosylchloride	32.76	[9]		
2,3,4,6-tetra-O-acetyl-β-D-glucopyranosylchloride	34.92	[9]		
2,3,4,6-tetra-O-acetyl-α-D-galactopyranosylchloride	32.20	[9]		
2,3,4,6-tetra-O-acetyl-β-D-galactopyranosylchloride	35.20	[9]		
2,3,4-tri-O-acetyl-α-D-xylopyranosylchloride	32.86	[9]		
2,3,4-tri-O-acetyl-β-D-xylopyranosylchloride	35.03	[9]		

frequencies are in the 35 MHz region and only one in the 37 MHz region. All these facts lead to the conclusion that in this system axial chlorine substituents have their ^{35}Cl NQR resonance frequency some 2.5 MHz lower than a corresponding equatorial one.

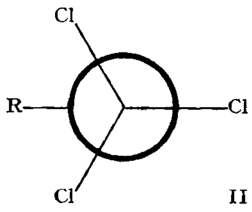
This result implies that in 2-chlorodioxane, and 2-chlorotetrahydropyrane the chlorine substituent is in the axial position and that chloromethyl methyl ether and 1,1'-dichlorodimethylether have the *gauche* conformation. Both these conclusions are in agreement with previous experience.

Also shown in Table 1 are the resonance frequencies of three pairs of α and β isomers of chloro sugars [9]. The conformation of the pyranose ring in these compounds is not known but the results for the dioxans imply that in all three cases the α isomer has the chlorine atom in the axial position while the β isomer has it in the equatorial position. This conclusion may also be arrived at from consideration of the usual criteria for determining the conformation of chair-form six-membered rings; the results of such a procedure are set out in Table 2.

Table 2. *Conformational analysis of the six chlorotetraacetyl sugars of Table 1*

	Cl	OA_c	CH_2OA_c	1:3 axial interactions	Σ_{ax}	Σ_{eq}	Preferred configuration of Cl
α-gluco	ax	3eq	eq	0	1	4	AX
	eq	3ax	ax	2	4	1	
β-gluco	ax	3ax	ax	4	5	0	EQ
	eq	3eq	eq	0	0	5	
α-galacto	ax	1ax 2eq	eq	0	2	3	AX
	eq	2ax 1eq	ax	1	3	2	
β-galacto	ax	2ax 1eq	ax	3	4	1	EQ
	eq	1ax 2eq	eq	0	1	4	
α-xylo	ax	3eq	–	0	1	3	AX
	eq	3ax	–	1	3	1	
β-xylo	ax	3ax	–	2	4	0	EQ
	eq	3eq	–	0	0	4	

The results discussed so far have all been those of cyclic derivatives for it is mainly for these that independent information as to their conformation is available. Trichloromethyl ethers however offer the advantage that even if the crystal structure is unknown the three C–Cl bonds cannot all have the same orientation with respect to the R–O–C plane and the most likely orientation of the CCl_3 group is the *trans* conformation II. This implies two chlorine atoms in the 'axial' positions and one in



II

the 'equatorial'. In accordance with this and with the results for the cyclic systems for *p*-fluoro-ω,ω,ω-trichloroanisole there are two resonance frequencies centered round 38.2 MHz and one at 39.76 MHz and for *m*-fluoro-ω,ω,ω-trichloroanisole there are four resonances centered at 38.0 MHz and two at 39.9 MHz.

The frequency difference between axial and equatorial chlorine atoms in this series appears to be thus well-established. The difference is moreover in the direction predicted by conjugative interaction depicted in I. Although it is proposed to defer further discussion of this point to a later paper in this series where the results of molecular orbital calculations on this and other systems will be presented, a further examination of the frequencies of the compounds shown here reveals another phenomenon which can be interpreted in this way. Thus the frequency difference between $CH_3CH_2CH_2Cl$ (32.968 MHz) and $CH_2Cl.CH_2.CH_2Cl$ (32.952; 33.130 MHz) is almost negligible. There are several other such pairs of frequencies in the carbon series showing that the inductive effect is almost completely attenuated after a passage through three carbon atoms. The frequency difference between CH_3OCH_2Cl and CH_2ClOCH_2Cl however is 2.2 MHz, and a study of the data in Table 1 reveals several other examples of this phenomenon. For comparison the frequency difference between CH_3Cl (34.023 MHz) and CH_2Cl_2 (35.991 MHz) is only 1.97 MHz: Thus an oxygen atom seems to transmit an electron withdrawing inductive effect much more effectively than a carbon atom and this is exactly what could be expected if the two C–Cl bonds were competing for the oxygen atoms lone-pair electrons (III).

(III)

In conclusion it has been demonstrated that there exists a marked and consistent difference between the resonance frequencies of axial and equatorial α-chloro substituents in six-membered cyclic ethers and this difference can be used with confidence for assignment of molecular conformation. In addition inductive effects are transmitted very efficiently through an oxygen atom and both this and the preceding conformational effect is qualitatively explicable in terms of a hyperconjugative interaction between the C–Cl bond and the oxygen atom lone-pair electrons.

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