Conformation and Equilibria: Complex Formation between Substituted Cyclohexanecarbonitriles and Iodine Monochloride

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RECENTLY there has been criticism of the assumptions underlying Winstein and Holness's suggestion regarding the use of a t-butyl substituent as a conformation-holding device in cyclohexane systems. That reactivity is occasionally influenced by the t-butyl group is evident from the results of several investigations. In particular Kwart and Takeshita[2] and N. B. Chapman *et al.*,[3] report kinetic results where the rate coefficient for a supposedly conformationally mobile system lies outside limits set for axial or equatorial behaviour by the use of t-butyl group "locking", and Eliel *et al.*,[4] report a wide spread of acetylation rates for a series of 3-, 4-, and 3,5-alkyl substituted cyclohexanols in all of which the OH group is equatorial.

We attempted to determine the conformational free energy of the nitrile group. Equilibration of *cis*- and *trans*-4-t-butylcyclohexanecarbonitriles indicates that the nitrile group is small with an *A*-value of 0·17—0·25.[5] It is therefore an ideal substituent to study using the Winstein–Holness method, as the relevant parameter for the mobile system should fall well between the limits set for axial and equatorial behaviour by rigid model compounds. Other possible complications have been avoided in this study by measuring equilibria, thus requiring no assumptions concerning the geometry of transition states, and by studying the chosen equilibrium in carbon tetrachloride solution, thus minimising ambiguities due to strong or specific solvation.

The extent of complex formation between substituted cyclohexane carbonitriles and iodine monochloride was determined by ultraviolet spectroscopy in the manner described by Klaboe *et al.*[6] The Benesi–Hildebrand equation[7] was used to calculate formation constants using the London University Atlas computer. The results are given in the Table.

The results for the 4-alkylbenzonitriles indicate that electron donation favours complex formation. It is noteworthy that the value of the formation constant for the conformationally mobile cyclohexanecarbonitrile lies outside the limits set for equatorial and axial behaviour by the conformationally rigid compounds 4 and 5, respectively. That the method is sensitive enough to detect intermediate behaviour is seen from the determination of K for a 64 : 36 mixture of *trans*- and *cis*-4-t-butylcyclohexanecarbonitriles; K (obs.) = 16·92 whereas using the values for the pure isomers 4 and 5 K (calc.) = 16·67. This is apparently the first example of the Winstein–Holness method failing for an equilibrium system.

The t-butyl group does not seemingly exert a polar influence on the equilibrium. A polar effect

TABLE

Formation constants in carbon tetrachloride at 20°

$$RC{\equiv}N + ICl \overset{K}{\rightleftharpoons} RC{\equiv}N \cdots ICl$$

	R	(K, l.moles^{-1})	Number of separate determinations
1.	Phenyl	8·07 ± 0·20	3
2.	*p*-Tolyl	13·82 ± 0·30	3
3.	*p*-t-Butylphenyl	14·04 ± 0·45	4
4.	*trans*-4-t-Butylcyclohexyl	18·50 ± 0·43	5
5.	*cis*-4-t-Butylcyclohexyl	13·42 ± 0·30	2
6.	Cyclohexyl	19·91 ± 0·50	11
7.	*trans*-4-Methylcyclohexyl	19·27 ± 0·37	4
8.	4-t-Butylcyclohexyl *cis* 36% *trans* 64%	16·92 ± 0·62	4

inhibiting complex formation would be electron-withdrawing and therefore an electrostatic effect based on complex dipoles of the type, $^{\delta-}CR_3{}^{\delta+}$. It follows that the methyl group would be more strongly electron-withdrawing than the t-butyl group.[2] This cannot be so as in the *trans*-4-alkylcyclohexanecarbonitriles the methyl group inhibits complex formation less than the t-butyl group relative to the unsubstituted compound. *trans*-4-Methylcyclohexanecarbonitrile is considered to be > 95% in the di-equatorial conformation.

In these complexes only the nitrogen of the nitrile group and the iodine atom are involved in the interaction and the nitrile group and iodine monochloride are co-linear.[8] Complex formation is not therefore especially sensitive to direct steric interactions and this is confirmed by the low value of 1·38 for K_{eq}/K_{ax} We suggest that our results can best be explained as a consequence of ring deformation caused by the t-butyl group. Cornubert[9] has suggested that a t-butyl group, even in an equatorial position, is involved in significant steric interaction with the adjacent axial hydrogen atoms. Eliel has recently opined that such interaction is unlikely to be important.[4] A study of models (Dreiding) leads us to suggest that the most likely conformations of a t-butyl group in an equatorial position are those shown in Figure 1.

H^1 and H^2 both suffer repulsive interactions with hydrogens of the nearest methyl group. The hydrogen–hydrogen distances of 1·95 Å were estimated by scale drawing using normal bond lengths and the tetrahedral angle. The normal distance of nearest approach of hydrogen atoms is

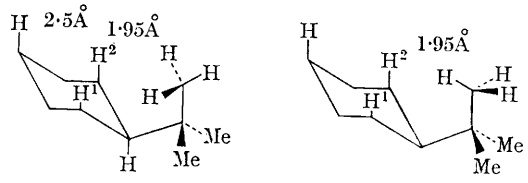

FIGURE 1

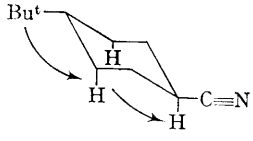

FIGURE 2

in the region of 2·5 Å and the steric repulsion indicated by interhydrogen distances of 1·95 Å is probably considerable. The energy required to deform angles is small and the repulsions would probably find relief in the flattening of the cyclohexane ring (Figure 2). We speculate that such a process that would increase the *s* character of the ring carbon atoms and the t-butyl group would therefore seemingly exert an electron-withdrawing effect upon other ring subsitutents, in our case axial and equatorial nitrile groups. The formation constants for *cis*- and *trans*-4-t-butylcyclohexanecarbonitrile would thereby be depressed and would not be suitable measures of axial and equatorial behaviour.

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