241. *Infrared Spectra of Natural Products. Part X.* Conformations and Infrared Spectra of Substituted* cyclo*Hexanols.*

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Small but significant differences in the stretching frequencies of axial (3627—3632 cm.$^{-1}$) and equatorial (3622·5—3623 cm.$^{-1}$) hydroxyl groups are reported for a series of methyl*cyclo*hexanols and are used to determine the stable conformation of the compounds. The methyl group has a greater tendency to be equatorial than the hydroxyl, in agreement with kinetic studies. A similar difference in methyl bending frequency is reported (axial 1381, equatorial 1376—1377 cm.$^{-1}$) and this together with the difference in hydroxyl stretching frequency is attributed to steric interference by axial hydrogen atoms. Integrated intensities of the hydroxyl absorption band have been determined (mean value $0{\cdot}50 \times 10^4$ l. mole^{-1} cm.$^{-2}$) for nine compounds.

ALREADY [1-3] we have shown that axial and equatorial hydroxyl groups on *cyclo*hexane rings exhibit small, but characteristic, differences in stretching frequency with the axial frequency always slightly higher, and that primary, secondary, and tertiary groups can be identified by their stretching frequencies. In the present paper we report work on substituted *cyclo*hexanols in relation to hydroxyl absorption and stable conformations. The compounds include *cis*- and *trans*-2-, -3-, and -4-methyl*cyclo*hexanol, *cis*- and *trans*-4-*iso*propyl*cyclo*hexanol, and three methyl*cyclo*hexylmethanols. The experimental conditions were essentially the same as in the preceding paper.

The hydroxyl frequencies and intensities * are given in the Table. There is no doubt [2] that *trans*-dihydrocryptol exists in the diequatorial conformation (I; R^1 = OH, R^2 = H) and its *cis*-isomer as (I; R^1 = H, R^2 = OH), and the hydroxyl stretching frequencies of these [3623 (equatorial) and 3627 cm.$^{-1}$ (axial)] form a basis for determining the predominant conformation in the methyl*cyclo*hexanols. Both frequencies are lower than for the triterpenoids,[1, 3] and this is probably related to the greater rigidity of the ring system in the more complex compounds. The menthols, with an extra substituent, and hence more inertia, give intermediate values. We previously [2] used an argument based on the tendency of *cyclo*hexanediols to form intramolecular hydrogen bonds to deduce that *neoiso*menthol exists predominantly as (II; R^1 = R^3 = H, R^2 = Me, R^4 = OH) and at that time did not fully realize the significance of slight differences in hydroxyl frequencies. Menthol (3628 cm.$^{-1}$) would be expected to have all groups equatorial (II; R^1 = Me, R^2 = R^4 = H, R^3 = OH) and it is immediately apparent from the Table that *iso*menthol exists in the conformation (II; R^1 = R^4 = H, R^2 = Me, R^3 = OH) in which the hydroxyl group is also equatorial (3627 cm.$^{-1}$), while both *neo*menthol and *neoiso*menthol (3632 cm.$^{-1}$) adopt the conformation in which it is axial. There is no doubt, then, that the relatively large *iso*propyl group acts as an equatorial anchor.

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* See Part IX, preceding paper, for details. Some of the compounds were too volatile for quantitative measurements of intensity.

[1] Part IX, Cole, Müller, Thornton, and Willix, preceding paper.

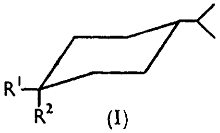
[2] Cole and Jefferies, *J.*, 1956, 4391.

[3] Allsop, Cole, White, and Willix, *J.*, 1956, 4868.

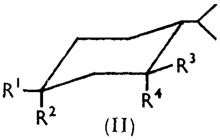
Clearly, *cis*-2-methyl-, *trans*-3-methyl-, and *cis*-4-methyl-*cyclo*hexanol exist predominantly in the forms with axial hydroxyl groups (3627—3632 cm.$^{-1}$) while their isomers have equatorial hydroxyl groups (3622·5—3623 cm.$^{-1}$). For the diequatorial compounds this is to be expected, but for the others these results give a direct experimental proof of the tendency of the methyl group to adopt the equatorial configuration at the expense of the hydroxyl group, in agreement with Eliel and Lukach's results [4] based on a study of rates of esterification of *cyclo*hexanols. The broad band width compared with the small frequency difference between equatorial and axial hydroxyl groups prevents the detection of small amounts of the less stable conformation, so that infrared measurements in this region do not provide enough results for calculation of equilibrium constants for the conformational transformation.

Hydroxyl frequencies (*cm.*$^{-1}$) *and intensities* (*in carbon tetrachloride*)

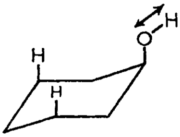
	ν (cm.$^{-1}$)	$\varepsilon_{\max.}$	$\Delta\nu_{\frac{1}{2}}{}^{a}$	$10^{-4}A$	Stable conformn. of OH group
cis-2-Methyl*cyclo*hexanol	3632	50	27	0·48	Axial
trans- ,, ,,	3622·5	—	—	—	Equatl.
cis-3-Methyl*cyclo*hexanol	3622·5	60	21·5	0·46	Equatl.
trans- ,, ,,	3627	60	19	0·41	Axial
cis-4-Methyl*cyclo*hexanol	3628	—	—	—	Axial
trans- ,, ,,	3623	60	21	0·45	Equatl.
cis-4-*iso*Propyl*cyclo*hexanol (*cis*-dihydrocryptol)	3627	65	21	0·49	Axial
trans- ,, ,,	3623	65	22	0·51	Equatl.
Menthol	3628	—	—	—	Equatl.
*iso*Menthol	3627	—	—	—	Equatl.
*neo*Menthol	3632	—	—	—	Axial
*neoiso*Menthol	3632	—	—	—	Axial
cis-2-Methyl*cyclo*hexylmethanol	3640	60	24	0·51	(Primary)
trans- ,, ,,	3641	65	25	0·58	(Primary)
cis-3-Methyl*cyclo*hexylmethanol	3641	65	25	0·58	(Primary)
trans-*p*-Menthan-4-ol	3619	—	—	—	Axial (tert.)



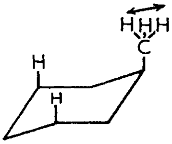
(I)



(II)



(III)
O–H Stretching



(IV)
CH$_3$ Bending

The results for the hydroxymethyl derivatives lend further support to the view [1] that primary hydroxyl groups can be readily identified by their high stretching frequency (3640—3641 cm.$^{-1}$ in CCl_4). It would be expected that the primary hydroxyl group, being the larger, would force the methyl group into the axial position in the *cis*-2-methyl compound while in the others both groups would be equatorial. We have confirmed this by examining the methyl bending region of the spectrum. The symmetrical bending frequencies of the equatorial methyl groups of *trans*-2- and *cis*-3-methyl*cyclo*hexylmethanol are at 1377 and 1376 cm.$^{-1}$ respectively, in agreement with methyl*cyclo*hexane [5] (1376 cm.$^{-1}$), while the corresponding frequency for the *cis*-2-methyl compound is higher (1381 cm.$^{-1}$). The steric repulsion of axial hydrogen atoms has been suggested [1] as the cause of the higher frequency of the OH stretching frequency (III) in axial secondary alcohols compared with equatorial, and if this is true the steric interference would be expected to raise the bending frequency (IV) of an axial methyl group relative to an equatorial. The unsymmetrical bending absorption of the methyl group is often obscured by ring-methylene

[4] Eliel and Lukach, *J. Amer. Chem. Soc.*, 1957, **79**, 598.
[5] Jones and Cole, *ibid.*, 1952, **74**, 5648.

bending absorption near 1450—1460 cm.$^{-1}$ but in these alcohols there is a significant shift of a band from 1456 cm.$^{-1}$ in the case of the two equatorial methyl groups to 1467 cm.$^{-1}$ for the *cis*-2-methyl (axial) compound, while the ring-methylene absorption remains at 1446—1447 cm.$^{-1}$. This higher axial bending frequency also supports the hypothesis above.

The frequency (3619 cm.$^{-1}$) of the tertiary hydroxyl group of *p*-methan-4-ol has been considered in the preceding paper. There can be no doubt that this group is axial since both the *iso*propyl and the methyl group oppose it for the equatorial orientation.

Hydroxyl Intensities.—The integrated intensities (Table) are slightly lower than those measured for triterpenoids,[1] but are in good agreement with results for simpler alcohols.[6] The measurements do not indicate any significant intensity difference between axial and equatorial groups.

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[6] See preceding paper, ref. 12.