during neutralization by the usual mechanism, rather than by a new ring-opening reaction in concentrated sulfuric acid.

Experimental Section

Melting points were taken on a Kofler hot-stage microscope, calibrated with melting point standards from Arthur H. Thomas Co. Ultraviolet spectra were run on a Cary 14 spectrophotometer and nmr spectra on a Varian A-60 spectrometer. The nmr data refers to deuteriochloroform solution, and chemical shifts are in τ values relative to tetramethylsilane as an internal standard (τ 10.00). Elemental analyses were performed by Scandinavian Microanalytical Laboratories and Dr. C. Daesslé of Montreal.

N,5-Diphenylisoxazolium (II) Bisulfate.—Concentrated sulfuric acid (12 ml) was stirred in an ice bath while 2.4 g (10 mmoles) of I was added. When the solid had all dissolved, the reaction mixture was poured over 50 g of ice. The precipitate was filtered with suction, washed three times with acetone, and air dried in the funnel, giving 3.0 g (94%) of yellow solid: mp 114–117°. The crude product was dissolved in 45 ml of absolute ethanol and precipitated with 180 ml of ether. The precipitated yellow needles of the bisulfate weighed 1.7 g (50%): mp 115–117°. The light-sensitive compound was stored in the dark.

Anal. Calcd for $C_{15}H_{13}NO_5S$: C, 56.41; H, 4.10; N, 4.39; S, 10.04. Found: C, 56.36; H, 4.29; N, 4.39; S, 10.00.

The ultraviolet spectrum of the bisulfate salt contained $\lambda_{max}^{0.1\ N\ HCl}$ 220 mμ (ϵ 7400) and 320 mμ (ϵ 22,500).

N,5-Diphenylisoxazolium (II) Perchlorate.—Concentrated sulfuric acid (60 ml) was stirred in an ice bath while 12 g (0.05 mole) of I was added. When the solid had all dissolved, the reaction mixture was poured over 250 g of ice. Addition of 1 l. of water and stirring redissolved the bisulfate of II, and the solution was filtered. Next, a solution of 14.0 g of sodium perchlorate monohydrate (0.10 mole) in 20 ml of water was added with stirring. The cream precipitate was filtered, washed three times with water, and air dried in the funnel, giving 15 g of crude product, decomposing to dark tar at 159–160°. Precipitation from 150 ml of acetonitrile with 450 ml of ether gave 14 g (88%) of pale yellow crystals: dec pt 159–160°. The perchlorate salt did not detonate when tiny samples were heated to 250°, pounded, or ground. When heated in an open flame, the compound burns with a flash, but the small samples used did not explode. The light-sensitive compound was stored in the dark.

Anal. Calcd for $C_{15}H_{12}ClNO_5$: C, 56.00; H, 3.76; Cl, 11.02; N, 4.35. Found: C, 56.03; H, 3.97; Cl, 10.71; N, 4.54.

The ultraviolet spectrum of the perchlorate salt contained $\lambda_{max}^{0.1\ N\ HCl}$ 222 mμ (ϵ 7400) and 320 mμ (ϵ 23,000).

N-*t*-Butyl-5-phenylisoxazolium (III) Perchlorate.—A mixture of 14.5 g (0.10 mole) of 5-phenylisoxazole (IV) and 7.4 g (0.10 mole) of *t*-butyl alcohol was stirred in an ice bath, and 42.3 g (0.30 mole) of 71% perchloric acid was added dropwise. A white precipitate formed during the addition. When all the acid had been added, the precipitate gradually thickened as stirring was continued. After 12 hr at room temperature, the mixture had solidified. About 100 ml of water was added, the suspension was stirred until homogeneous, and the solid was filtered. Washing with water, air drying, and washing with dichloromethane left 27 g (90%) of the crude perchlorate salt, decomposing at *ca.* 170° (turns yellow). Precipitation from 300 ml of acetonitrile with 600 ml of ether gave 24 g (80%) of colorless rods, decomposing to yellow oil at 170–175° on rapid heating. When heated above the melting point, the substance darkened to a black tar and bubbled, but did not detonate up to 250°. The light-sensitive compound was stored in the dark.

Anal. Calcd for $C_{13}H_{16}ClNO_5$: C, 51.75; H, 5.35; Cl, 11.75; N, 4.64. Found: C, 51.90; H, 5.49; Cl, 11.90; N, 4.52.

The ultraviolet spectrum of the perchlorate salt contained $\lambda_{max}^{CH_2Cl_2}$ 296 mμ (ϵ 21,800).

N-(2-Methyl-4-oxopent-2-yl)-5-phenylisoxazolium (V) Perchlorate.—A mixture of 7 g of 5-phenylisoxazole and 5 g of mesityl oxide was added dropwise very slowly to 20 ml of concentrated sulfuric acid, which was stirred in an ice-salt bath. The viscous orange solution was allowed to stand 2 days in a refrigerator, diluted with ice and water to 250 ml, washed with three 25-ml portions of dichloromethane, and filtered. Addition of a solution of 14 g of sodium perchlorate monohydrate to the aqueous phase precipitated a yellow oil. The oil was taken up in dichloromethane, and the aqueous solution was washed with more of the organic solvent. The organic extracts were washed with dilute hydrochloric acid, dried over sodium sulfate, and filtered. Removal of the solvent under reduced pressure left 14 g (80%) of a yellow-brown, viscous oil, which partly crystallized in the deep freeze. The crude material was mixed with 50 ml of ether, and acetone (*ca.* 50 ml) was added at the boiling point, until all but a few seed crystals had dissolved. Chilling in the deep freeze overnight gave 7 g of large, colorless crystals. A second crop, 3 g, was collected by saturating the mother liquor at the boiling point with more ether. The two crops were ground together: mp 81–83°. For further purification the product was dissolved in acetone (5 ml/g) and precipitated in an ice–salt bath by slowly adding ether (10 ml/g, crystallization induced by scratching at the cloud point): mp 82–83°.

Anal. Calcd for $C_{15}H_{18}ClNO_6$: C, 52.40; H, 5.28; Cl, 10.31; N, 4.08. Found: C, 52.33; H, 5.26; Cl, 10.37; N, 3.98.

The ultraviolet spectrum of the perchlorate salt contained $\lambda_{max}^{CH_2Cl_2}$ 298 mμ (ϵ 22,400).

The nmr spectrum contained signals at τ 8.10 (singlet, 6.1 H), τ 7.85 (singlet, 3.1 H), τ 6.53 (singlet, 1.9 H), τ 2.73 (doublet, J = 3 cps, 1.1 H), τ 2.66–2.00 (complex, 4.9 H), and τ 0.76 (doublet, J = 3 cps, 0.9 H).

Hydroxyl Coupling Constants in Conformational Analysis

J. J. UEBEL AND H. W. GOODWIN[1]

Department of Chemistry, The University of New Hampshire, Durham, New Hampshire

Received January 19, 1966

The conformational preference of the hydroxyl group in cyclohexanol and related compounds has been determined in many ways, including nmr spectroscopy. The nmr spectral parameters which have been used to diagnose conformational equilibria include the chemical shift of the α protons[2-4] (O–C–H), the chemical shift of the hydroxyl protons,[5] and vicinal, ring proton–proton coupling constants.[6] We would like to suggest that an additional parameter, the vicinal coupling constant between the hydroxyl proton and the α proton, J_{CHOH}, may be used as a conformational probe.[7]

The hydroxyl group in cyclohexanol can readily equilibrate among its possible rotomeric conformations within the lifetime of either of the two chair cyclohexanol conformations.[8] An equatorial hydroxyl group probably partitions itself among the three rotomeric conformations which may be identified by their average dihedral angle (θ) between the O–H/C–H bonds of 60, 180, and 300°. An axial hydroxyl group probably has only two important rotomeric conformations,

---

[1] National Science Foundation Undergraduate Research Participant.

[2] E. L. Eliel and M. H. Gianni, *Tetrahedron Letters*, 97 (1962).

[3] A. H. Lewin and S. Winstein, *J. Am. Chem. Soc.*, **84**, 2464 (1962).

[4] J. Reisse, J. C. Celotti, D. Zimmerman, and G. Chiurdoglu, *Tetrahedron Letters*, 2145 (1964).

[5] R. J. Ouellette, *J. Am. Chem. Soc.*, **86**, 4378 (1964).

[6] F. A. L. Anet, *ibid.*, **84**, 1053 (1962).

[7] This coupling can be observed in dimethyl sulfoxide because of a relatively slow hydroxyl proton exchange rate.[14]

[8] The activation energy for interconversion between chair conformations is about 10 kcal/mole, while the rotational energy barrier in methanol is about 1.1 kcal/mole; *cf.* E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience Publishers, New York, N. Y., 1965, pp 41, 140.

which are mirror images of one another, and have θ equal to 60 and 300°. The third rotomer, with θ equal to 180°, is probably significantly less populated because of nonbonded hydroxyl hydrogen–axial hydrogen interactions. These expectations are supported both by infrared and nmr data. Thus, Aaron and Radar pointed out that the free hydroxyl O–H stretching absorption is usually symmetric (implying one band) for axially oriented alcohols and asymmetric (implying two overlapping bands) for equatorially oriented alcohols.[9] This is understandable in terms of the rotomer populations given above when one assumes that nonequivalent hydroxyl rotomers have different O–H stretching frequencies. The vicinal O–H/C–H coupling constants also support this view if one assumes that a $\cos^2$ relationship[10] or some other similar relationship holds for this coupling. Thus the data in Table I and that found in the literature all show that coupling is larger for equatorial alcohols than axial ones.[5,11,12]

Table I

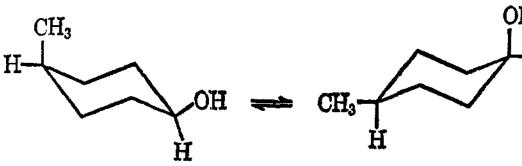
Chemical Shifts and Coupling Constants[a]

Compound	δ^b (OH)	δ^c (CHO)	J^d (CHOH)
trans-4-*t*-Butylcyclohexanol	40.5	46.5	4.53
cis-4-*t*-Butylcyclohexanol	23.5	76.0	3.22
trans-4-Methylcyclohexanol	41.0		4.64
cis-4-Methylcyclohexanol	28.0		3.60
Cyclohexanol	37.5	53.0	4.40

[a] Values are for 1 *M* solutions in dimethyl sulfoxide (DMSO) or DMSO-d_6. [b] In cycles per second downfield from the low-field C-13–H satellite of DMSO. [c] In cycles per second downfield from DMSO; spectra were taken in DMSO-d_6 using 2,2,6,6-d_4 alcohols. [d] In cycles per second; *ca.* ±0.05 cps.

This immediately suggests that this parameter may be useful as a conformational probe. If a proper choice of conformational models were made, perhaps J_{CHOH} could be analyzed in terms of conformational equilibria. As suitable models for the conformational equilibria present in *cis*-4-methylcyclohexanol, equilibrium 1, and cyclohexanol, equilibrium 2, one might choose *cis*- and *trans*-4-*t*-butylcyclohexanol and *trans*-4-methylcyclohexanol.

The spectral parameters for these compounds are reported in Table I; the mole fraction of the more stable conformer and the free energy change for these equilibria are reported in Table II. For comparison the equilibria were also determined using the chemical shifts of the O-C-H and O-H protons. The results are in satisfactory agreement with one another and with those in the literature (see Table III). Ouellette[5] has reported a $-\Delta G$ value of 0.80 kcal/mole for equilibrium 2 in dimethyl sulfoxide (DMSO) using the hydroxyl proton chemical shift, δ (OH). This value agrees fairly well with the values reported here of 0.98 and 0.77 kcal/mole, determined by use of J_{CHOH} and δ (CH-O), respectively. The $-\Delta G$ values for equilibrium 2 correspond directly to $-\Delta G$ (OH)[13] for which extensive listings of reported literature values are available.[14] Those values reported in Table III were determined by nmr methods in both hydrogen bond accepting and hydrogen bond donating solvents[15] and are fairly representative of the values obtained by nmr methods. A complete listing which includes a wider range of solvent types has been made by Eliel and Schroeter.[14] For equilibrium 1 a $-\Delta G$ value of 0.61 kcal/mole was obtained using J_{CHOH} in DMSO. This is in good agreement with the value reported in this work of 0.66 kcal/mole, determined by δ (OH) in DMSO, and with the literature value of 0.72 kcal/mole, which was obtained using δ (CH-O) in 2-propanol.[3]


(1)

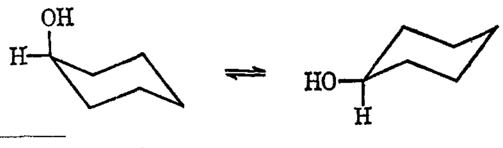

(2)

Table II

Mole Fraction of Favored Conformer and ΔG Equilibrium[a]

Equil	Calcd using δ (OH) N^b	Calcd using δ (OH) $-\Delta G^c$	Calcd using J_{CHOH} N^b	Calcd using J_{CHOH} $-\Delta G^c$	Calcd using δ (CH-O) N^b	Calcd using δ (CH-O) $-\Delta G^c$
1	0.74	0.66	0.73	0.61 ± 0.11		
2	0.80	0.85	0.83	0.98 ± 0.15	0.78	0.77

[a] Calculated using *cis*-4-*t*-butylcyclohexanol and *trans*-4-methylcyclohexanol as models, with $T = 35°$. [b] Mole fraction of the favored conformer. [c] The free energy for the designated equilibrium in kcal/mole. The $-\Delta G$ values listed for equilibrium 2 represent what is commonly termed $-\Delta G$ (OH).[13]

Table III

Free-Energy Change for Equilibria 1 and 2

Solvent	T, °C	Equil	$-\Delta G^a$	Remarks	Ref
2-*d*-2-Propanol	30	2	0.88	Using δ (OCH)	3
2-Methyl-2-propanol	36	2	1.05	Using δ (OCH)	4
D_2O	28	2	1.25	Using ring coupling constants	6
2-*d*-2-Propanol	30	1	0.72	Using δ (OCH)	3
DMSO	40	2	0.80	Using δ (OH)	5
Pyridine	40	2	0.80	Using δ (OH)	5

[a] The free energy for the designated equilibrium in kcal/mole. The $-\Delta G$ value listed for equilibrium 2 represents what is commonly termed $-\Delta G$ (OH).[13]

In conclusion, it appears that the coupling constant, J_{CHOH}, can be used for conformational analysis. This method, however, must be regarded as being more limited than those employing chemical shifts because of the small difference in coupling constants for the

---

(9) H. S. Aaron and C. P. Radar, *J. Am. Chem. Soc.*, **85,** 3046 (1963).

(10) M. Karplus, *J. Chem. Phys.*, **30,** 11 (1959). Qualitatively the angular dependence of J_{CHOH} would be expected to parallel that of J_{CHOH}: M. Karplus, private communication.

(11) B. Casu, M. Reggiani, G. G. Gallo, and A. Vigevani, *Tetrahedron Letters*, 2839 (1965); 2253 (1965).

(12) For a discussion of other factors which affect J_{CHOH}, see W. B. Moniz, C. F. Poranski, Jr., and T. N. Hall, *J. Am. Chem. Soc.*, **88,** 190 (1966).

(13) The free-energy difference between the two chair conformations of cyclohexanol.

(14) E. L. Eliel and S. H. Schroeter, *J. Am. Chem. Soc.*, **87**, 5031 (1965); also ref 8, pp 437, 438.

(15) While it is clear that $-\Delta G$ (OH) should be higher (*ca.* 0.9) in hydrogen bond donating solvents than in hydrogen bond accepting and nonhydrogen-bonding solvents (*ca.* 0.6) the values obtained by nmr techniques do not clearly show this difference.[14]

two conformations and the difficulties involved in slowing the hydroxyl proton exchange in many solvents.[16] The former difficulty is illustrated by the data in Table I, which lists a slightly smaller J_{CHOH} value for *trans*-4-*t*-butylcyclohexanol than for *trans*-4-methylcyclohexanol. The two values are, however, nearly within the combined experimental uncertainty of each. If *trans*-4-*t*-butylcyclohexanol had been used as the model system in place of *trans*-4-methylcyclohexanol, the calculated $-\Delta G$ values for equilibria 1 and 2 would have been 0.54 and 1.35 instead of 0.61 and 0.98 kcal/mole, respectively.

Experimental Section

All nmr spectra were obtained on a Varian A-60 nmr spectrometer equipped with a variable-temperature probe. The reported spectral data are the result of several independent measurements, using different batches of solvent and sample. The water concentration in the DMSO varied from about 1% to less than 0.3%. The reported error limits for the ΔG values are the standard deviations obtained using the quoted average deviation (Table I) in the measured parameters. The probe temperature was 35°.

DMSO was dried by heating over calcium hydride and distilling from calcium hydride under reduced pressure (bp *ca.* 80°). It was found that solvent which had been dried by heating over extended periods of time or which was distilled at higher temperatures gave unreliable results.

4-*t*-Butylcyclohexanol was obtained both from a commercial source (Aldrich Chemical Co., Milwaukee, Wis.) and by lithium aluminum hydride reduction of 4-*t*-butylcyclohexanone. Individual samples of each isomer were obtained by preparative gas chromatography of mixtures on a Carbowax 20M column. 4-*t*-Butylcyclohexanol-2,2,6,6-d_4 was obtained through exchange of the ketone in 50% D_2O–dioxane using sodium carbonate, followed by lithium aluminum hydride reduction.

4-Methylcyclohexanol was obtained from a commercial source (Eastman Kodak). Individual samples of each isomer were obtained by preparative gas chromatography on a Carbowax 20M column.

Acknowledgment.—The Varian A-60 spectrometer was made available by Grant G 22718 from the National Science Foundation.

---

(16) O. L. Chapman and R. W. King, *J. Am. Chem. Soc.*, **86**, 1256 (1964); (b) D. E. McGreer and M. M. Mocek, *J. Chem. Educ.*, **40**, 358 (1963); (c) J. M. Bruce and P. Knowles, *Proc. Chem. Soc.*, 294 (1964); (d) J. G. Traynham and G. A. Knesel, *J. Am. Chem. Soc.*, **87**, 4220 (1965).

Behavior of Some Halogenated Alcohols upon Electron Impact

E. R. McCarthy

General Chemical Research Laboratory,
Allied Chemical Corporation, General Chemical Division,
Morris Township, New Jersey

Received December 14, 1965

The fragmentation patterns of lower molecular weight aliphatic alcohols have been exhaustively tabulated[1] and more recently elucidated.[2] With the exception of the cracking pattern of 2,2,2-trifluoroethanol[3] and a brief discussion of the mass spectrum of 2-chloroethanol,[4] there is no other information available on the mass spectra of low molecular weight halogenated alcohols. Because these compounds are an interesting class in themselves and because of our interest in the broader problem of the effects of halogen incorporation upon electron-impact decomposition modes, we have undertaken a study of some of the simpler members of this series. We present here some data relating to six primary alcohols, seven secondary alcohols, and two tertiary alcohols. To provide a direct comparison, data for some representative nonhalogenated alcohols that have been examined with our instrument are presented in Table I. The fragmentation patterns of these compounds are in essential agreement with those listed by Friedel.[1] All spectra were obtained using a CEC 21-103 (modified) mass spectrometer equipped with a stainless steel inlet which was maintained at 150°. The source temperature was 250°, and 70-ev ionizing electrons were used.

Primary Alcohols.—The primary alcohols are listed in Table II. The predominant mode of fragmentation is similar to that of the nonhalogenated primary alcohols. For these latter compounds it has been postulated that fragmentation proceeds *via* removal of a nonbonding electron on the oxygen atom followed by α cleavage to form the oxonium ion $CH_2{=}\overset{+}{O}H$ (*m/e* 31).[2] In the present case, *m/e* 31 is the most abundant fragment and accounts for at least 50% of the total ionization in five of the six compounds studied. For the alcohol HCF_2CF_2—CH_2OH *m/e* 31 has a value of 41%. This decrease may be explainable in terms of the appearance of an intense peak at *m/e* 82 corresponding to $C_2F_3H^+$. This ion could arise from the above-mentioned α cleavage followed by some charge retention by the halogenated alkyl portion of the molecule. Subsequent loss of F would yield $C_2F_3H^+$. This ion, however, does not correspond to an intermediate trifluoroethylene molecule ion. Trifluoroethylene[5] when run under similar conditions was found to be characterized by an abundant *m/e* 63 ($C_2F_2H^+$) and this ion is absent in the spectrum of the alcohol. This would indicate that F is being lost from the β-carbon atom of the molecule. Since CF^+ will make some contribution to the *m/e* 31 ion intensity, we have examined *m/e* 31 in the spectrum of $CF_3CF_2CF_2$—CH_2OH obtained under high-resolution conditions.[6] It was found that 95% of *m/e* 31 was due to CH_2OH^+. The second most intense ion in all of the spectra was the formyl ion $CH{\equiv}O^+$ (*m/e* 29). A broad characteristic metastable peak centered at about *m/e* 27.5 (calcd *m/e* 27.1) suggests that this ion may form from CH_2OH^+ by elimination of H_2. An interesting fragment that was found in all spectra was a rearrangement ion of composition CH_2FO^+ which may correspond to the fluoro analog of CH_2OH^+. Although α-fluoro alcohols are extremely unstable,[7] it may be that such

---

(1) R. A. Friedel, J. L. Schultz, and A. J. Sharkey, *Anal. Chem.*, **28**, 926 (1956).

(2) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Interpretation of Mass Spectra of Organic Compounds," Holden-Day, Inc., San Francisco, Calif., 1964, Chapter 2.

(3) Mass Spectral Data, Manufacturing Chemists Association Research Project, Serial No. 142.

(4) K. Biemann, "Mass Spectrometry, Organic Chemical Applications," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp 87, 88.

(5) Trifluoroethylene was obtained from Peninsular Chemresearch, Inc., Gainesville, Fla.

(6) A Hitachi RMU-6D mass spectrometer with double-focusing attachment was used. We are indebted to A. H. Struck of Perkin-Elmer Corp. for this result.

(7) W. J. Middleton and R. V. Lindsey, Jr., *J. Am. Chem. Soc.*, **86**, 4948 (1964).