CALIFORNIA INSTITUTE OF TECHNOLOGY

N.M.R. STUDY OF THE HYDROGEN BONDING PROPERTIES OF 1,8-CINEOLE

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Contents:

ABSTRACT

A study of the concentration dependence of the proton resonance signal of chloroform due to solvent-solute hydrogen bonding has indicated that 1,8-cineole is an appreciably stronger hydrogen bonding agent than is tetrahydrofuran, dioxane or diethyl ether. Comparisons were based on the magnitude of the difference between the positions of the chloroform resonance in the limits of dilute and concentrated solutions.

INTRODUCTION

Early workers observed a temperature and concentration dependence of the proton n.m.r. signal of alcohols, phenols, and carboxylic acids. The shift to lower fields with increase of concentration or lowering of temperature has been attributed to changes in the electron shielding of the proton caused by intermolecular hydrogen bonding.

It has been found that chloroform forms 1:1 hydrogen bonded complexes with a number of donor molecules. (1) It is postulated that the magnitude of the shift of the chloroform proton signal, extrapolated to infinite dilution in the donor solvent (presumably at complete hydrogen bonding) with respect to the proton signal of pure chloroform is proportional to the strength of the donor as a hydrogen-bonding agent. Chloroform serves as a good acceptor molecule because its self-association (i.e. $HCCl_3$--$HCCl_3$) is small (~11.5 cps. at 40 Mcps.) and can readily be corrected for. (2)

It is necessary to apply a bulk magnetic susceptibility correction to observed chemical shifts. The following equations apply: (3)

$$\delta_{Actual} = \delta_{Observed} + \frac{2\pi}{3}\left(\chi_{v,\,Reference} - \chi_{v,\,Sample}\right)$$

$$\chi_v = \sum_i v_i \chi_{v,i}$$

where δ represents the chemical shift in ppm., χ_v the volume diamagnetic susceptibility, and v_i the volume fraction of the i^{th} component of a mixture.

As no complete, recent table of the needed susceptibility data could be found, an attempt was made to obtain the necessary susceptibilities by reversing the above equations. That is, relative susceptibilities $(\chi_{v,A} - \chi_{v,B})$ were obtained from the slopes of straight line plots of v_A versus $\delta_{observed}$ where the signals observed were those of protons inert in hydrogen bonding.

Using this empirical susceptibility data, comparisons of 1,8-cineole, tetrahydrofuran, dioxane, and diethyl ether in terms of their strength as hydrogen-bonding donors were made.

EXPERIMENTAL

Preparation of samples:

Chloroform, dioxane, and diethyl ether solutions purified by standard methods (4), previously distilled tetrahydrofuran, spectral grade cyclohexane and carbon tetrachloride, and research grade 1,8-cineole obtained from the Aldrich Chemical Company were used to prepare solutions of varying concentrations. Solutions were handled volumetrically with an accuracy of ± 1-2%.

Spectra:

N.M.R. spectra at 60 Mcps. were taken using 5 mm. o.d. tubes in a Varian A-60 spectrometer. Probe temperature was constant at approximately 40°C. (± 2°C.). A significant temperature dependence of the proton signal was observed.

Each data point represented the average of at least five readings. A drift correction was applied to compensate for field instability. Shifts were obtained with a precision of ± 0.2 cps.

RESULTS

Measured chemical shifts in cps (at 60 Mcps.) relative to the proton signal of pure chloroform are listed in Table I. These shifts are all measured downfield of the pure chloroform resonance. No susceptibility corrections have been applied.

Table I. Measured Hydrogen Bonding Shifts*in c.p.s. at 60 Mcps.

1,8-Cineole		Diethyl ether		Dioxane		Tetrahydrofuran	
υ_{HCCl_3}	$\delta_{H\text{-}Bond}$	υ_{HCCl_3}	$\delta_{H\text{-}Bond}$	υ_{HCCl_3}	$\delta_{H\text{-}Bond}$	υ_{HCCl_3}	$\delta_{H\text{-}Bond}$
0.794	3.4	0.981	2.1	0.729	6.4	0.729	7.1
0.598	9.2	0.750	3.0	0.504	9.8	0.504	13.4
0.520	11.5	0.667	3.9	0.355	10.4	0.355	17.0
0.428	16.2	0.500	5.0	0.290	10.7	0.290	18.8
0.306	20.7	0.167	7.5	0.177	10.6	0.177	19.6
0.141	29.4	0.059	7.0	0.111	10.8	0.111	19.4
0.039	33.7	0.020	6.6	0.075	10.5	0.075	20.4
0.019	33.5			0.038	10.4	0.038	20.5

*Uncorrected for diamagnetic susceptibility or self-association of chloroform.

The following table lists diamagnetic susceptibility data drawn from the literature.

Table II. Volume Diamagnetic Susceptibilities*

Substance	$\chi_v \times 10^6$	References
Carbon tetrachloride	-0.684	(5)(7)
Carbon tetrachloride	-0.693	(6)
Chloroform	-0.731	(5)
Chloroform	-0.738	(6)
Chloroform	-0.735	(7)
Cyclohexane	-0.631	(5)(7)
Cyclohexane	-0.612	(6)
Dioxane	-0.600	(6)
Dioxane	-0.589	(7)
Diethyl ether	-0.547	(5)(7)
Diethyl ether	-0.530	(6)
Eucalyptol (1,8-Cineole)	-0.697	(5)(6)

*This data is derived for a temperature of 20°C.

Table III contains a tabulation of the hydrogen bonding shifts with correction for the volume diamagnetic susceptibility differences between the solutions. Here the susceptibilities which are listed in reference (7) were used whenever possible.

Table III. Corrected*Hydrogen Bonding Shifts in c.p.s. at 60 Mcps.

1,8-Cineole		Diethyl ether		Dioxane	
υ_{HCCl_3}	$\delta_{H\text{-}Bond}$	υ_{HCCl_3}	$\delta_{H\text{-}Bond}$	υ_{HCCl_3}	$\delta_{H\text{-}Bond}$
0.794	4.3	0.981	2.6	0.729	11.4
0.598	11.1	0.750	8.9	0.504	18.9
0.520	13.8	0.667	11.8	0.355	22.2
0.428	19.0	0.500	16.8	0.290	23.8
0.306	24.0	0.167	27.2	0.177	25.7
0.141	33.5	0.059	29.2	0.111	27.1
0.039	38.3	0.020	29.8	0.075	27.5
0.019	38.2			0.038	28.0

*Susceptibility data used is from Table I as noted above. These shifts are uncorrected for self-association of chloroform.

A large number of relative diamagnetic susceptibilities were obtained by fitting measured shifts of non-hydrogen bonding protons to a linear least squares approximation. Relative diamagnetic susceptibilities can be obtained from the slope of a plot of υ_i versus δ_i. These are listed in Table IV.

Figure I shows the various molecules investigated. The various equivalent protons are lettered for use in Table IV.

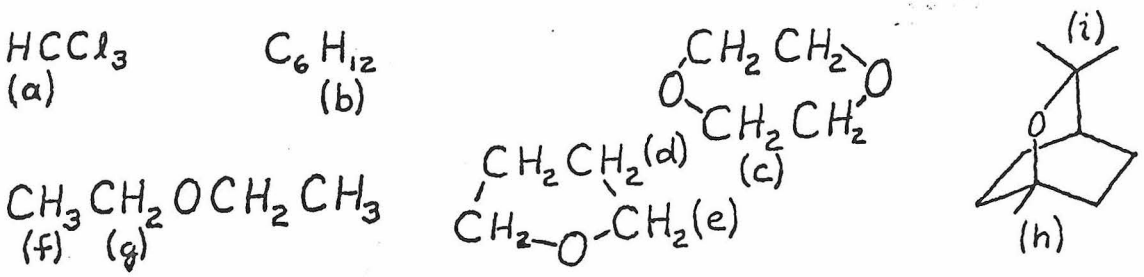

Figure I. Nomenclature used in Table IV.

Table IV. Relative Diamagnetic Susceptibilities

A	B	i*	N**	$(\chi_A-\chi_B)\times10^6$
Internal standard within the donor molecule:				
Cineole	$HCCl_3$	(h)	2	+0.1033
Cineole	$HCCl_3$	(i)	2	+0.0936
Dioxane	$HCCl_3$	(c)	8	+0.1966
Et_2O	$HCCl_3$	(g)	7	+0.2620
Et_2O	$HCCl_3$	(f)	7	+0.2566
THF	$HCCl_3$	(e)	8	+0.1970
THF	$HCCl_3$	(d)	3	+0.1729
Cineole	CCl_4	(h)	2	+0.0335
Cineole	CCl_4	(i)	2	+0.0287
Dioxane	CCl_4	(c)	2	+0.0911
THF	CCl_4	(d)	2	+0.1226
Cineole	C_6H_{12}	(h)	4	-0.0760
Cineole	C_6H_{12}	(i)	4	-0.0735
Dioxane	C_6H_{12}	(c)	4	-0.0348
Et_2O	C_6H_{12}	(f)	3	+0.0754
THF	C_6H_{12}	(d)	4	-0.0191
Cyclohexane signal as an internal standard:				
C_6H_{12}	CCl_4	(b)	3	+0.0972
C_6H_{12}	$HCCl_3$	(b)	5	+0.1224
C_6H_{12}	Cineole	(b)	4	+0.0659
C_6H_{12}	Dioxane	(b)	2	+0.0064
C_6H_{12}	Et_2O	(b)	3	-0.0813
C_6H_{12}	THF	(b)	5	+0.0008

*i refers to the proton resonance which is plotted
**N refers to the number of points to which the straight was fitted.

Hydrogen bond shifts with volume magnetic susceptibility corrections are presented in Tables V and VI. These corrections are based on the relative susceptibilities derived empirically. In Table V those relative susceptibilities derived from the concentration dependence of the proton signals in the donor molecule in chloroform solution are used. In Table VI relative susceptibilities derived from the concentration dependence of the cyclohexane signal in donor-cyclohexane solution are used. In both cases we are essentially using an internal standard.

Table V. Corrected*Hydrogen Bonding Shifts in c.p.s. at 60 Mcps.

1,8-Cineole[a]		Diethyl ether[b]		Dioxane		Tetrahydrofuran[c]	
υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$
0.794	6.0	0.981	2.7	0.729	13.1	0.729	13.0
0.598	14.4	0.750	11.0	0.504	22.0	0.504	24.1
0.520	17.7	0.667	14.6	0.355	26.3	0.355	30.7
0.428	23.7	0.500	21.1	0.290	28.3	0.290	34.2
0.306	29.7	0.167	34.4	0.177	31.0	0.177	37.4
0.141	40.6	0.059	37.3	0.111	32.8	0.111	38.7
0.039	46.2	0.020	38.2	0.075	33.4	0.075	40.5
0.019	46.2			0.038	34.1	0.038	41.4

*Susceptibility data used is that from Table IV (β equals $HCCl_3$). No correction for the self-association of chloroform has been applied.

a. The upfield, single methyl resonance (h) is used.
b. The upfield, methyl triplet resonance (f) is used.
c. The upfield, methylene quintuplet resonance (d) is used.

Table VI. Corrected*Hydrogen Bonding Shifts in c.p.s. at 60 Mcps.

1,8-Cineole		Diethyl ether		Dioxane		Tetrahydrofuran	
υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$	υ_{HCCl_3}	$\delta_{H\text{Bond}}$
0.794	4.8	0.981	2.6	0.729	10.4	0.729	11.3
0.598	12.0	0.750	9.3	0.504	17.0	0.504	20.9
0.520	14.9	0.667	12.4	0.355	19.8	0.355	26.8
0.428	20.3	0.500	17.8	0.290	21.1	0.290	29.6
0.306	25.6	0.167	28.9	0.177	22.6	0.177	32.1
0.141	35.5	0.059	31.1	0.111	23.7	0.111	33.0
0.039	40.5	0.020	31.7	0.075	24.0	0.075	34.5
0.019	40.5			0.038	24.4	0.038	35.2

*Susceptibility data used is that from Table IV (i equals (b)). No correction for the self-association of chloroform has been applied.

DISCUSSION

Although relative diamagnetic susceptibility data could not be determined with sufficient accuracy by this method to arrive at an inter-consistent set of susceptibilities, results do correlate roughly with reported data. Inaccuracies were caused principally by two factors -- temperature changes and intramolecular inductive effects.

The presence of such inductive effects is indicated by the different concentration dependent shifts observed for methylene and methyl protons in ethyl ether, in tetrahydrofuran, and for the different methyl groups in 1,8-cineole.

At any rate, the results indicate that 1.8-cineole is the strongest hydrogen bonding donor of those ethers investigated. Polar tetrahydrofuran appears to be weaker than 1,8-cineole but stronger than non-polar ethyl ether or dioxane.

Table VII provides a comparison with previously published hydrogen bonding shifts.

Table VII. Total Hydrogen Bonding Shifts (Comparison)

Donor liquid	(ppm.)	(cps. @ 60 Mcps.)
Triethylamine	1.20	72.0
Acetone	0.81	48.6
Diethyl ether	0.76	45.6
Propionitrile	0.55	33.0
Propyl fluoride	0.32	19.2

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BIBLIOGRAPHY

(1) Korinek and Schneider, Can. Jour. Chem., 35, 1157 (1957)

(2) Reeves and Schneider, Can. Jour. Chem., 35, 2 (1957)

(3) Pople, Schneider and Bernstein, High-Resolution Nuclear Magnetic Resonance, McGraw-Hill, New York, 1959, p. 81

(4) Fieser, Experiments in Organic Chemistry, Heath, Boston, 1955, p. 280 ff.

(5) "International Critical Tables," Vol. 6, McGraw Hill, New York, 1929

(6) "Tables de Constantes et Données Numériques," Vol. 7, Masson, Paris, 1957

(7) Pople, op cit., p. 488