BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN VOL. 41 2297—2305 (1968)

Solvent Effect in NMR Spectroscopy. II. A Repulsive Interaction between the Benzene Solvent Molecule and the Nitrogen Lone-Pair, and the Effects Induced by the Addition of Protic Substances

Teijiro YONEZAWA, Isao MORISHIMA and Kazuhiko FUKUTA

Department of Hydrocarbon Chemistry, Faculty of Engineering, Kyoto University, Sakyo-ku, Kyoto

(Received March 28, 1968)

The variations in the chemical shifts of proton resonances in imines, aziridines, and oximes, all of which have oriented nitrogen lone-pair electrons, on going from a carbon tetrachloride solution to a benzene solution ("benzene solvent shift") are determined. Also determined are the changes in the corresponding proton chemical shifts in a benzene solution when protic substances, such as methanol or trifluoroacetic acid, are added ("addition shift"). It is generally found that the upfield benzene-solvent shift is more sensitive to the protons *trans* to the oriented nitrogen lone-pair than to the *cis*. This observation indicates that the formation of a benzene-solute collisional complex is most likely to occur at a site as far as possible from the nitrogen lone-pair. The repelling of a benzene solvent molecule by the nitrogen lone-pair may occur due to the repulsive interaction between lone-pair electrons and benzene π-electrons. It is also found that the addition shift is upfield and is larger for the proton *trans* to the nitrogen lone-pair than for that *cis*. These general observations are of predictive value in the determination of the orientation of the nitrogen lone-pair electrons and in the assignment of the signals of proton groups in the vicinity of the nitrogen lone-pair.

A great number of studies of the specific solvent effects on the proton chemical shifts of polar solutes in aromatic solvents have been reported,[1,2] and the study of these effects has been proved to be a very powerful technique for use in structure elucidation and conformational analysis. For a complex molecule, the size and sign of the benzene-solvent shft (the difference in the chemical shift of a signal in a benzene solvent and in an inactive solvent) have been linked with the position of the protons relative to the polar functional groups.[2]

This benzene-induced chemical shift depends on the equilibrium formation of a stereospecific collisional complex between the solute and the benzene solvent.[2c] The orientation of the solvent molecule

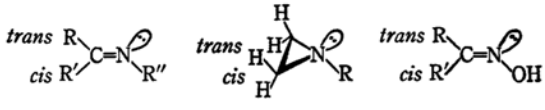
1) T. Yonezawa, I. Morishima and K. Takeuchi, This Bulletin, **40**, 1807 (1967).

2) a) N. S. Bhacca and D. H. Williams, "Application of NMR Spectroscopy in Organic Chemistry," Holden-Day, San Francisco, Calif. (1964), Chap. 7. b) See T. Ledaal, *Tetrahedron Letters*, **1966**, 1653 and the references cited therein. c) J. Ronayne and D. H. Williams, *J. Chem. Soc., (B)*, **1967**, 540.

with respect to the dipolar functional groups is non-random. The ketones in a benzene solution form a solute-solvent collisional complex in which the π-electrons of the benzene ring interact with the partial positive charge on the carbonyl carbon atom in such a manner that the benzene ring locates as far as possible from the partial negative charge on oxygen.[2]

In addition to these benzene solvent shifts, we have found a solvent effect induced by the addition of protic substances, such as methanol or trifluoroacetic acid, to a benzene solution of several polar solute molecules.[1] In the previous paper,[1] we have pointed out that the addition of a protic substance to the benzene solution of the carbonyl compounds causes an upfield shift of the protons of the solute molecules. This effect is more pronounced on the protons lying in close proximity to the proton-accepting site of a solute molecule than on those remote from it. The use of this addition shift in structural analysis has been described.

Despite these abundant potential uses of the benzene-induced shift in solving structural and other physical problems, there have been few investigations aimed at elucidating the intrinsic nature of this stereospecific intereaction in aromatic solvents. In the present study we have tried to investigate the benzene-solvent effect of the nitrogen-containing molecules with oriented lone-pair electrons from two viewpoints. First, in order to make clear the nature of the repulsive interaction of the benzene solvent molecule with the negatively-charged site of the polar functional groups of a solute; a limiting case of this interaction between a benzene-solvent molecule and the nitrogen lone-pair electrons is studied. Second, the effect induced by the addition of a protic substance to the benzene solution is further examined for solute molecules with an oriented nitrogen lone-pair which is available as a proton-accepting site. In this work we have determined the benzene-solvent shift and the effect induced by the addition of protic substances on the protons of imines (I), aziridines (II), and oximes (III).



I II III

We now wish to propose the generalization that a benzene-solvent molecule is repelled by the nitrogen lone-pair and has a more remarkable shielding effect on the protons remote from the lone pair; this phenomenon to be of considerable predictive value in structural determination. The addition shift is also shown to have a definite tendency for various solute molecules.

Experimental

Materials. All the chemicals used in this study were obtained from commerical sources unless otherwise noted, and all were carefully purified by distillation before use. The aldimines and ketimines were prepared according to the procedure of Campbell *et al.*[3] To 29.5 g (0.5 mol) of *n*-propylamine, 29.0 g (0.5 mol) of acetone were added gradually over a period of two hours in a nitrogen atmosphere. Potassium hydroxide flakes were then added, and the mixture was allowed to stand in a refrigerator overnight. The dried material was distilled over a few pellets of potassium hydroxide. The *N*-phenylacetonimine was prepared by the condensation of the corresponding ketal[4] with aniline by the method of Hoch.[5] The 1-methyl- and 1-ethylaziridines were prepared from commercially-avaiable 2-methylaminoethanol and 2-ethylaminoethanol respectively by the method of Cairn.[6] The *O*-methylacetoxime ether was prepared by adding dimethylsulfate to a sodium hydroxide solution of acetoxime.[7]

NMR Measurements. Solutions for NMR measurements were prepared in such a way that the concentrations were 7.5 mol% in both the benzene and the carbon tetrachloride solutions. The details of the preparation of the samples for measuring the addition shift have been reported in a previous paper.[1] All the samples were run on a JEOL JNM-3H-60 spectrometer operation at 60 MHz, using an internally-locked field-frequency stabilization control system.[1] The chemical shifts were monitored by an electronic-frequency counter in Hz from an internal TMS.

Results and Discussion

Benzene-solvent Shift. Tables 1, 2, and 3 summarize the chemical shift, in benzene and carbon tetrachloride solutions, of protons of imines (Table 1), aziridines (Table 2), and oximes and oxime ether (Table 3). Before discussing the benzene-solvent shift, however, we wish to discuss briefly the signal assignment of the *cis* and *trans* proton groups for imines (I), aziridines (II), and oximes (III). The basis of the assignment of I is the proton-proton coupling constant between N–$CH_2(\alpha)$ and C–CH_3 protons. The lower-field methyl signal of *N-n*-propylacetonimine shows a splitting (J=1.4 Hz) by N–$CH_2(\alpha)$ protons, while the higher-field one gives J=0.7 Hz. For *N-n*-propylaldimine the corresponding coupling constant is 1.4 Hz. In light of the general trend, *trans* coupling constant > *cis* coupling constant, the lower-field methyl signal, resonating at about τ=8.1, can be assigned to *trans* methyl protons. Accordingly, the NMR spectrum giving a single

3) K. N. Campbell, A. H. Sommers and B. K. Campbell, *J. Am. Chem. Soc.*, **66**, 82 (1944).
4) W. J. Croxall, F. J. Clavis and H. T. Neher, *ibid.*, **70**, 2805 (1948).
5) M. J. Hoch, *C. R. Acad. Sci. Paris*, **199**, 1428 (1934).
6) T. L. Cairn, *J. Am. Chem. Soc.*, **63**, 871 (1941).
7) Ponzio and Charrier, *Gazzetta Chimica Italiana*, **37**, I, 506 (1907).

TABLE 1. CHEMICAL SHIFTS INDUCED BY THE ADDITION OF METHANOL TO THE BENZENE SOLUTIONS OF IMINES

Solute	Proton	ν_{CCl_4}[a,b]	$\nu_{C_6H_6}$[a,b]	$\Delta\nu_{CCl_4}^{C_6H_6}$[c]	$\Delta\nu_{C_6H_6}^{MeOH}$[d]
N-*n*-Propylacetonimine	*trans*-CH_3	114.5	110.6	+ 3.9	+ 8.8
	cis-CH_3	104.4	83.7	+20.7	+10.6
trans[e] CH_3, *cis*[e] CH_3, $C=N$, $CH_2CH_2CH_3$	α-CH_2	184.2	184.5	− 0.3	+10.7
	β-CH_2	89.9	99.0	− 0.1	+ 8.3
α β γ	γ-CH_3	54.4	59.2	− 4.8	+ 7.5
N-*n*-Propylacetaldimine	*trans*-CH_3	112.6	100.9	+11.7	+ 5.2
	cis-H	450.3	437.7	+12.6	+ 9.4
trans CH_3, *cis* H, $C=N$, $CH_2CH_2CH_3$	α-CH_2	193.4	191.4	+ 2.0	*
	β-CH_2	89.0	77.5	+11.5	+ 4.2
α β γ	γ-CH_3	52.3	51.5	+ 0.8	+ 5.6
N-Phenylacetonimine	*trans*-CH_3	122.5	112.0	+10.5	+ 1.9
trans CH_3, *cis* CH_3, $C=N$, C_6H_5	*cis*-CH_3	103.0	83.7	+19.3	+ 3.4

a) Chemical shift in Hz from an internal TMS.
b) 7.5 mol in carbon tetrachloride and benzene solution.
c) Benzene solvent shifts in Hz.
d) Addition shifts in Hz (added methanol; 1.4 mmol).
e) The notation "*trans*" or "*cis*" is referred to the *N*-substituent.

methyl proton signal for *N*-*n*-propylaldimine shows the presence of a single *trans* isomer. These assignments correspond to results of recent work by Olah *et al.*[8] The assignment of the ring methylene proton signals for 1-methyl- and 1-ethylaziridine has been well established,[9] as have the facts that the higher-field one of the two separate ring proton signals belongs to the *cis* group, and the remaining one, the *trans*. For oximes, C-methyl protons when *cis* to the hydroxy group resonate at higher fields than when *trans*; both C-methylene and C-methine protons when *cis* to the hydroxyl group resonate at lower fields than when *trans*. These assignments are based upon the studies by Karabatsos[10] and Huitric.[11] The benzene-solvent shift, $\Delta\nu_{CCl_4}^{C_6H_6}$, is defined as the difference in the chemical shift of a signal between that in a benzene solution and in a carbon tetrachloride solution.

It can be seen from Table 1 that benzene causes a shielding of C-alkyl proton resonances relative to the carbon tetrachloride solution and a shielding or deshielding of N-alkyl protons for several imines. The benzene-solvent shift values, $\Delta\nu_{CCl_4}^{C_6C_6}$, for

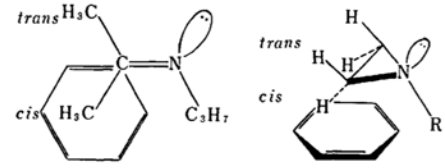
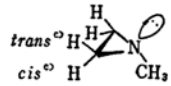
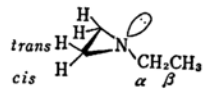


Fig. 1. Model representation of benzene-imine complex. Benzene solvent molecules are repelled by the nitrogen lone pair.

C-alkyl groups of *N*-*n*-propylacetonimine are very different for the *cis* and *trans* groups. A larger shift is observed for the *cis* methyl protons than for the *trans* ones; indeed, the difference is unexpectedly large. This observation makes one picture a benzene-imine stereospecific collisional complex in which the benzene-solvent molecule is repelled by the nitrogen lone-pair, as is shown in Fig. 1. This type of complex has a more effective shielding effect on the *cis* protons than on the *trans* ones. Table 1 also shows the results for *N*-*n*-propylacetaldimine. Contrary to the results for *N*-*n*-propylacetonimine, both C-alkyl and N-alkyl protons are shielded by the benzene solvent here. No shielding or deshielding effect by the benzene solvent for *n*-propyl protons of *N*-*n*-propylacetonimine and *N*-*n*-propylacetaldimine is yet clear in its origin. The larger value of the benzene-solvent shift for methine protons than for methyl protons on the C-alkyl group also indicates that aldimine exists in a single conformation with the C-alkyl group *trans* to the N-alkyl group. In the case of

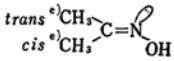
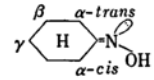
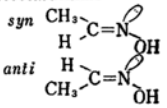
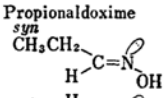
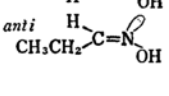
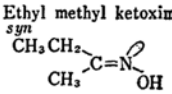
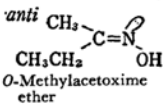
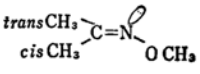
8) G. A. Olah and P. Kreienbühl, *J. Am. Chem. Soc.*, **89**, 4756 (1967).
9) T. Yonezawa, I. Morishima and K. Takeuchi, *ibid.*, Submitted for the publication; H. Saitô, K. Nuckada, T. Kobayashi and K. Morita, *ibid.*, **89**, 6605 (1967).
10) G. J. Karabatsos, R. A. Taller and F. M. Vane, *ibid.*, **85**, 2326, 2327 (1963).
11) A. C. Huitric, D. B. Roll and J. R. DeBoer, *J. Org. Chem.*, **32**, 1661 (1967).

TABLE 2. CHMICAL SHIFTS INDUCED BY THE ADDITION OF METHANOL TO THE BENZENE SOLUTIONS OF AZIRIDINES

Solute	Proton	ν_{CCl_4} [a,b]	$\nu_{C_6H_6}$ [a,b]	$\Delta\nu_{CCl_4}^{C_6H_6}$ [c]	$\Delta\nu_{C_6H_6}^{MeOH}$ [d]
1-Methylaziridine	*trans*-H	94.2	90.3	+ 3.9	+11.5
	*cis*-H	52.3	38.6	+13.7	+12.2
	N-CH_3	131.0	122.6	+ 8.4	+13.1
1-Ethylaziridine	*trans*-H	93.2	90.8	+ 2.4	+11.8
	*cis*-H	54.0	41.8	+12.2	+12.6
	α-CH_2	126.6	118.7	+ 7.9	+12.9
	β-CH_3	64.7	63.5	+ 1.2	+ 8.4

a) Chemical shifts in Hz from an internal TMS.
b) 7.5 mol in carbon tetrachloride and benzene solution.
c) Benzene solvent shifts in Hz.
d) Addition shifts in Hz (added methanol; 1.4 mmol).
e) The notation "*trans*" or "*cis*" is referred to the *N*-substituent.

TABLE 3. CHEMICAL SHIFTS INDUCED BY THE ADDITION OF TFA TO THE BENZENE SOLUTION OF OXIMES AND OXIME ETHER

Solute	Proton	ν_{CCl_4} [a,b]	$\nu_{C_6H_6}$ [a,b]	$\Delta\nu_{CCl_4}^{C_6H_6}$ [c]	$\Delta\nu_{C_6H_6}^{TFA}$ [d]
Acetoxime	*trans*-CH_3	112.0	96.3	+15.7	+16.9
	*cis*-CH_3	111.1	101.5	+ 9.6	+18.7
Cyclohexanone oxime	α-*trans*	132.3	128.2	+ 4.1	+14.2
	α-*cis*	154.6	148.0	− 1.7	+16.6
	β,γ-CH_2	97.6	77.5	+20.1	+ 9.6
Acetaldoxime					
	*syn* CH_3	112.8	84.8	+28.0	+ 9.3
	syn H	440.8	431.0	+ 9.8	+10.9
	anti CH_3	112.8	93.1	+19.7	+12.4
	anti H	404.9	386.1	+18.8	+19.6
Propionaldoxime					
	*syn* β-CH_3	66.0	46.0	+20.0	+ 8.5
	syn α-CH_2	133.9	112.8	+21.1	+ 8.3
	syn α-H	439.7	435.7	+ 4.0	+14.8
	*anti* β-CH_3	65.3	43.7	+21.6	+ 7.4
	anti α-CH_2	140.8	134.5	+ 6.3	+17.7
	anti α-H	396.4	383.6	+12.8	+23.7
Ethyl methyl ketoxime					
	*syn* α-CH_3	109.8	103.0	+ 6.8	+15.0
	syn β-CH_3	65.6	52.6	+13.0	+10.2
	syn α-CH_2	131.9	118.4	+13.5	+14.2
	*anti* α-CH_3	110.3	96.3	+14.0	+16.8
	anti β-CH_3	64.5	51.7	+12.8	+12.8
	anti α-CH_2	133.3	137.5	− 4.2	+18.5
O-Methylacetoxime ether	O-CH_3	227.7	223.0	+ 4.7	+22.1
	*trans*-CH_3	107.8	96.3	+11.5	+24.0
	cis-CH_3	105.3	97.4	+ 7.9	+26.5

a) Chemical shift in Hz from an internal TMS.
b) 7.5 mol in carbon tetrachloride and benzene solution.
c) Benzene solvent shifts in Hz.
d) Addition shifts in Hz (added trifluoroacetic acid; 0.167 mmol).
e) The notation "*trans*" or "*cis*" is referred to the *N*-substituent.

the *N*-phenylacetonimine in Table 1, *cis* methyl protons are shifted more upfield by the benzene solvent than are *trans* methyl protons; this implies also that the benzene molecule is repelled by the nitrogen lone-pair and that it approaches the *cis* methyl group. The replacement of the *n*-propyl group by the phenyl group does not significantly affect this specific solvent shift.

This repulsive interaction between a benzene molecule and lone-pair electrons is further evident from the data for aziridine compounds compiled in Table 2. All the compounds in Table 2 perform a slow internal inversion at the nitrogen atom and show the *cis* and *trans* proton signals separately at room temperature. The $\Delta\nu_{CCl_4}^{C_6H_6}$ values are larger for *cis* methylene protons than for *trans* ones. This observation again indicates that the benzene-solvent molecule locates preferentially as far away as possible at the opposite side of the effective lone-pair (the nitrogen lone-pair) (Fig. 1). This repulsive interaction does not depend on the *N*-substituent alkyl group, as can be seen in Table 2, on passing from 1-methyl- to 1-ethylaziridine. Namely, for 1-ethylaziridine, which has the bulkier ethyl group, the $\Delta\nu_{CCl_4}^{C_6H_6}$ values are not significantly changed; this indicates that the benzene-solvent molecules lying at the *cis* ring methylene protons are not sterically repelled by the 1-substituent alkyl group. The difference in the solvent shift, $\Delta\nu_{CCl_4}^{C_6H_6}$, between the protons of the lone-pair side (the *trans* group) and the opposite side (*cis* group and 1-alkyl protons) is quite large, indicating that the benzene-solvent molecule locates preferentially on one side (the 1-alkyl side) of the three-membered-ring plane.

From these data and from our discussion of the benzene-solvent shift, it can now be concluded that the benzene π-electrons and the nitrogen lone-pair electrons interact repulsively and that this interaction causes a specific benzene-solvent effect on the nitrogen-containing solute molecules.

Oxime has two interaction sites with the benzene-solvent molecule; the nitrogen lone-pair and the hydroxyl group. The partial negative charge on the hydroxyl oxygen repels the benzene molecule and causes a more effective specific shielding of the *trans* C-alkyl protons than of the *cis*. This is analogous to the effect frequently encountered with the polar carbonyl group.[1,2] However, another repulsive site, the nitrogen lone-pair, is also active in benzene-oxime solvent interaction.

The observed benzene-solvent shift may result from the two competitive repulsive interactions between the benzene-hydroxyl group and the benzene-nitrogen lone-pair electrons. Although the benzene-solvent shifts for a few examples of oximes have been determined by Karabatsos,[10] we carried out further, extended studies in order to examine the above-mentioned type of competitive interaction. As is evident in Table 3, the difference in the $\Delta\nu_{CCl_4}^{C_6H_6}$ values for the *cis* and *trans* protons of acetoxime and cyclohexanone oxime is small compared with that between such protons of imines and aziridines (Tables 1 and 2), the value for the *trans* protons being only slightly larger. This observation may reflect the two competitive repulsive interactions mentioned above. Compared with the $\Delta\nu_{CCl_4}^{C_6H_6}$ values of imines with only one repulsive interaction site of the nitrogen lone-pair (Table 1), the reduced value of the difference in $\Delta\nu_{CCl_4}^{C_6H_6}$ for *cis* and *trans* protons of oximes supports the competitive repulsive interaction. This observation has also been encountered in a previous paper[1] regarding nitrosamine, which has two possible repulsive sites, the nitrogen lone-pair and the negatively-charged oxygen atom of the nitroso group.

For acetaldoxime and propionaldoxime, which are mixtures of the *syn* and *anti* isomers consisting of 67% and 45% *syn* isomers for the two aldoximes respectively, the repulsive interaction mentioned above can be expected. For acetaldoxime, the $\Delta\nu_{CCl_4}^{C_6H_6}$ value of the methyl protons is larger for the *syn* isomer than for the *anti*, while for the methine protons the situation is just the reverse. This observation also reflects the fact that the benzene-hydroxyl group repulsive interaction is stronger than the benzene-nitrogen lone-pair interaction. It should be noted that the difference in the $\Delta\nu_{CCl_4}^{C_6H_6}$ values for methyl and methine protons is quite a bit smaller for the case of the *anti* isomer of acetaldoxime compared with that of the *syn* isomer. A similar trend of the solvent shifts is also obtained for ethyl methyl ketoxime.

The last example is *O*-methyl acetoxime ether. In a carbon tetrachloride solution *cis* methyl protons (*cis* to the *O*-methyl group) resonate at a slightly lower field. The addition of benzene to this solution causes the signals to cross, and in the benzene solution the *cis* methyl protons resonate at a very slightly higher field, as may be seen in Table 3. Therefore, the value of $\Delta\nu_{CCl_4}^{C_6H_6}$ is larger for *trans* methyl protons than for *cis* methyl protons. This oxime ether also has two interaction centers with the benzene molecule, the nitrogen lone-pair and the oxygen lone-pair. From the above observation, it can also be said that the benzene-solvent molecule is repelled more effectively by the oxygen lone-pair electrons. This finding is compatible with the finding of Karabatsos and Hsi.[12]

Chemical Shifts Induced by the Addition of Protic Substances to Benzene Solutions. Tables 1—3 also present the chemical shifts for protons induced by the addition of portion of methanol (MeOH) or trifluoroacetic acid (TFA) to

12) G. J. Karabatsos and N. Hsi, *Tetrahedron*, **23**, 1079 (1967).

benzene solutions of imines, aziridines, oximes, and oxime ether. The addition shift, $\Delta\nu^{TFA}_{C_6H_6}$ or $\Delta\nu^{MeOH}_{C_6H_6}$ corresponds to the difference between the chemical shift induced by the addition of the protic substances to a benzene solution of the solute and the chemical shift induced by the addition of a protic substance to a carbon tetrachloride solution of the same solute.[1] This correction for the protonation shift is important for the solute molecules of the present case, which are sensitive to the protic additivities resulting from the hydrogen bonding interaction with the nitrogen lone-pair, causing downfield shifts of the protons in the vicinity of the nitrogen atom.

Figures 2—12 give the plots of the addition shift, $\Delta\nu^{TFA}_{C_6H_6}$ or $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* the concentration of the added protic substances. A considerable induced upfield shift for the protons in the vicinity of the nitrogen lone-pair is observed, as is to be expected from the various carbonyl compounds discussed in the previous work.[1] For *N*-*n*-propylacetonimine, the protons of the *n*-propyl group suffer larger upfield addition shifts in the groups closer to the nitrogen atom (Table 1 and Fig. 2). It may be seen in Fig. 2 that the aparent addition shift is enhanced by the increase in the concentration of added methanol, until the downfield shift induced by the OH···N hydrogen bond formation appears. For the methyl protons of the $N{=}C(CH_3)_2$ fragment, the relative value of the addition shift is in the order of the solvent shift for *cis* and *trans* methyl groups, and the general tendency of the addition shift does not hold, as was established for carbonyl compounds in the previous work.[1] In the case of carbonyl compounds, the order of the upfield addition shift is just the opposite of that of the solvent shift, and this addition shift is more sensitive to the protons lying in close proximity to the proton-accepting site of the solute molecule than to those remote from it.[1]

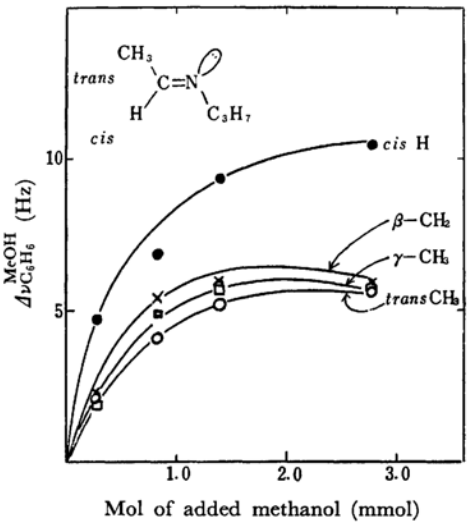


Fig. 3. Plots of $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* mol of added methanol for *N*-*n*-propylacetaldimine.

For *N*-*n*-propylacetaldimine, upfield addition shifts are observed for all the protons. It may be observed in Fig. 3 that this addition shift is more remarkable with the methine proton than with the methyl protons, which are *cis* to the nitrogen lone-pair. This addition shift has the same order as the solvent shift. The upfield addition shift increases with the concentration of added methanol, as is shown in Fig. 3. The upfield addition shift for the *N*-*n*-propyl proton is in the order of β-methylene $>\gamma$-methyl (the α-methylene signal is hidden in the methanol methyl proton signal). This

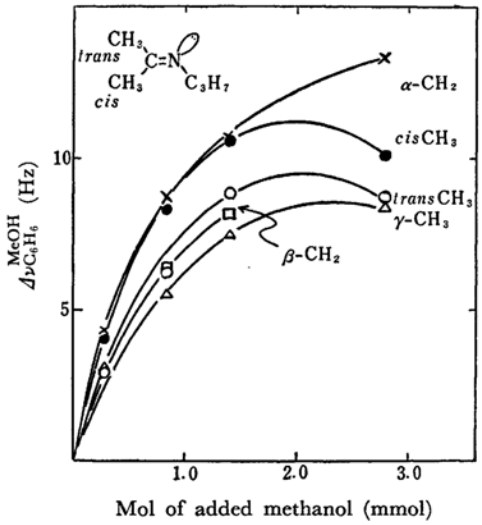


Fig. 2. Plots of $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* mol of added methanol for *N*-*n*-propylacetonimine.

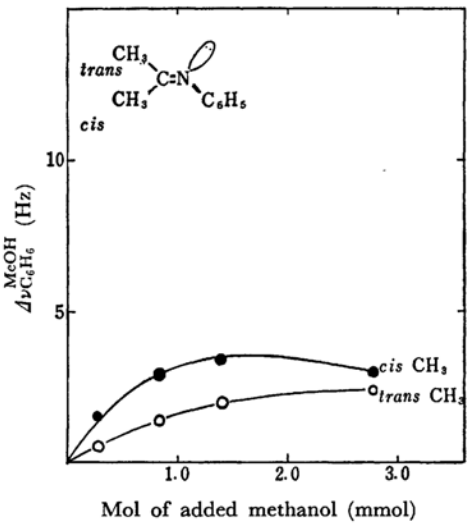


Fig. 4. Plots of $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* mol of added methanol for *N*-phenylacetonimine.

may also be seen for *N*-phenylacetonimine in Table 1 and Fig. 4 and for *N*-*n*-propylacetonimine in Fig. 2.

For 1-methyl- and 1-ethylaziridines, *cis* ring methylene protons undergo greater upfield addition shifts than do the *trans* protons, but the difference is very small (Figs. 5 and 6).

Oxime has two possible proton-accepting sites, the nitrogen lone-pair and the oxygen lone-pair of the hydroxyl group. Saito and Nukada[13] investigated the structure of oxime hydrochloride and showed that the protonation of the oximes occurs exclusively at the nitrogen lone-pair rather than at the hydroxyl oxygen atom. We will, therefore, in interpreting the addition shift for oximes, henceforth assume that, in solution with protic substances, the hydrogen-bonding interaction of oxime occurs exclusively at the nitrogen lone-pair. Judging from the addition shift for imines, the slightly larger value (Table 3 and Figs.

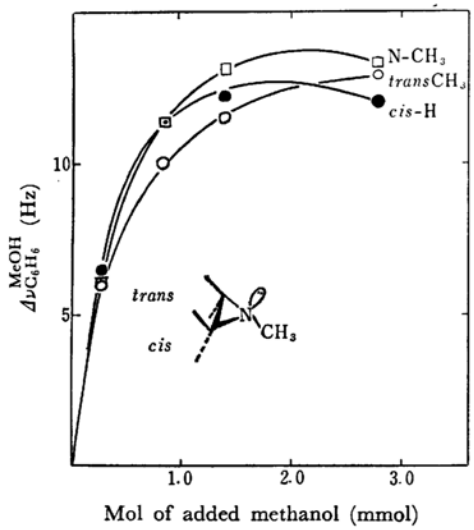


Fig. 5. Plots of $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* mol of added methanol for 1-phenylacetonimine.

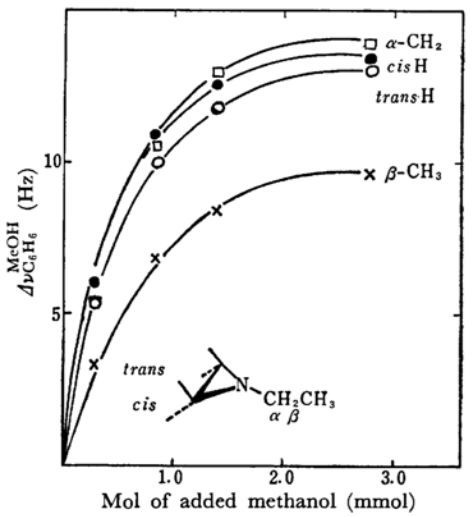


Fig. 6. Plots of $\Delta\nu^{MeOH}_{C_6H_6}$ *vs.* mol of added methanol for 1-methylaziridine.

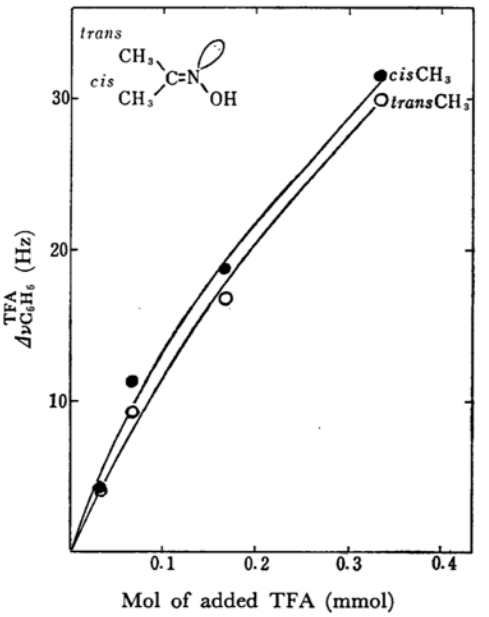


Fig. 7. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for acetoxime.

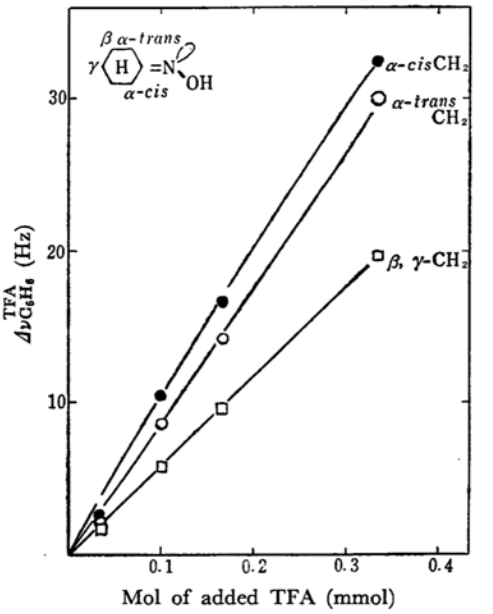


Fig. 8. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for cyclohexane oxime.

13) H. Saito, K. Nukada and M. Ohno, *Tetrahedron Letters*, **1964**, 2124; H. Saitô, *Nippon Kagaku Zasshi (J. Chem. Soc. Japan, Pure Chem. Sect.)*, **85**, 724 (1964).

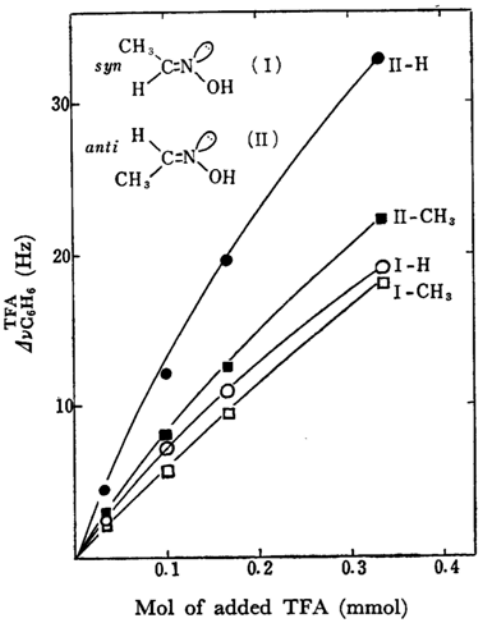


Fig. 9. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for acetaldoxime.

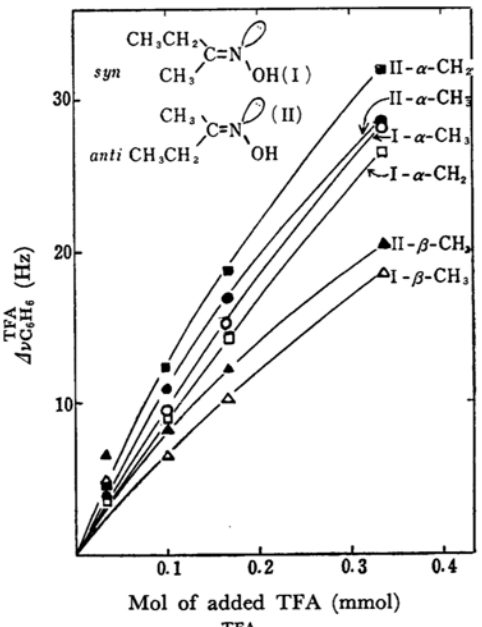


Fig. 11. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for ethyl methyl ketoxime.

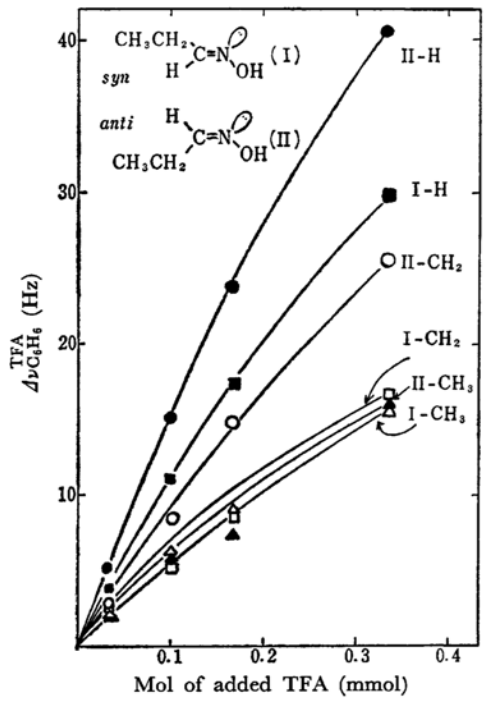


Fig. 10. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for propionaldoxime.

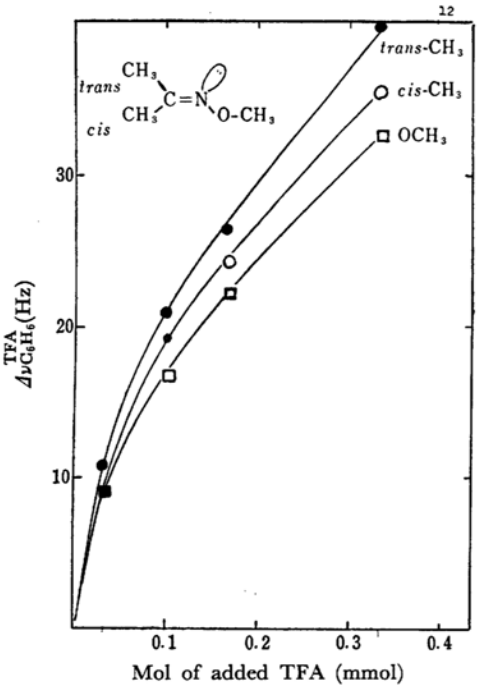


Fig. 12. Plots of $\Delta\nu^{TFA}_{C_6H_6}$ *vs.* mol of added TFA for *O*-methylacetoxime ether.

7—11) of $\Delta\nu^{TFA}_{C_6H_6}$ for the *cis* protons than for the *trans* protons of acetoxime and cyclohexanone oxime may reflect the fact that the hydrogen-bonding interaction preferentially occurs at the nitrogen lone-pair rather than at the hydroxyl oxygen. This will be verified in the discussion below of the results for *O*-methylacetoxime ether. It indicates that the generalization valid for the carbonyl compounds regarding the specific addition shift does not hold for oximes or for imines and aziridines.

As is shown in Table 3 and Fig. 9, the $\Delta\nu^{TFA}_{C_6H_6}$ values for methyl protons of acetaldoxime are larger for the *anti* isomer than for the *syn*. The $\Delta\nu^{TFA}_{C_6H_6}$ values of the methine proton are also larger for the *anti* isomer than for the *syn* isomer, as is also the case for $\Delta\nu^{TFA}_{C_6H_6}$ values. The same relation is observed for the methylene and methine protons of propionaldoxime. We interpreted this observation by assuming that the *anti* isomer is more subject to the hydrogen-bond interaction than the *syn* isomer, thus causing the greater upfield addition shift for the *anti* isomer than for the *syn*. The $\Delta\nu^{TFA}_{C_6H_6}$ value for the methyl protons of propionaldoxime is quite small and is slightly larger for the *syn* isomer than for the *anti* isomer, as is shown in Table 3 and Fig. 10. Ethyl methyl ketoxime gives results (Table 3 and Fig. 11) analogous to the case of propionaldoxime, as well as to that of the solvent shift.

Figure 12 shows the results for O-methylacetoxime ether. These results are anologous to those for acetoxime (see Fig. 8). The *cis* methyl group undergoes a larger upfield addition shift, $\Delta\nu^{TFA}_{C_6H_6}$, than does the *trans* methyl group when more methanol is added. The value of the addition shift, $\Delta\nu^{TFA}_{C_6H_6}$, for O-methyl protons is the smallest of those for the three methyl groups. These two observations imply that the hydrogen-bonding interaction preferentially occurs at the nitrogen lone-pair rather than at the oxygen lone-pair, as is the case with oximes. If the hydrogen-bonding interaction preferentially occurs at the oxygen lone-pair, the O-methyl group should undergo the largest upfield addition shift.

In conclusion, it is clear that, for compounds with a fixedly-oriented nitrogen lone-pair, the upfield addition shift is larger for the protons *trans* to the nitrogen lone-pair than for those *cis* to it. This tendency is different from the trend earlier established for the carbonyl compounds.[1] The origin of these conflicting observations is not clear at present; the problem will be investigated in the future.

However, it should be remarked that the present measurements of the benzene-solvent shift and the addition shift may themselves be useful in strucutal and stereochemical problems concerning the nitrogen lone-pair orientation.