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^{19}F and ^{1}H NMR Study of Intermolecular Hydrogen Bond between Phenols and a Fluoroalkane in Solution

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Synopsis. Although the intermolecular hydrogen bonds between the fluorine atom attached to the carbon and the hydroxy group have hitherto been observed only in crystals, the hydrogen bond was confirmed by ^{19}F and ^{1}H NMR spectroscopy in solution for the first time.

Thus far, the intermolecular hydrogen bonds between the fluorine atom attached to the carbon and the hydroxy group have been found in only a few crystal structures; Murray-Rust et al. have reported that the hydrogen bonds can be formed only in crystals.$^{1)}$ In a previous paper,$^{2)}$ however, we have indirectly suggested that the C–F···H–O intermolecular hydrogen bond between the fluorine atom of the 2- or 3-fluoro-4-nitrophenolate anion and the hydroxy group of α-cyclodextrin also exists in solution. For further confirming the presence of the hydrogen bond, we investigated the interactions in other model systems. We now wish to report here that the C–F···H–O intermolecular hydrogen bond in a $CDCl_3$ solution was confirmed for the first time by ^{19}F and ^{1}H NMR spectroscopy.

A hydrogen bond generally induces a low field shift in a proton or fluorine atom in NMR spectra.$^{3)}$ Thus, to confirm the C–F···H–O bond, we first examined the chemical shift changes in two model systems: the ^{1}H NMR chemical shift changes in the hydroxy proton of *p*-chlorophenol (*p*-CP) with the addition of fluorocyclohexane (FCy) and/or cyclohexane (Cy), and the ^{19}F NMR chemical shift changes in FCy with the addition of phenol and/or toluene. As shown in Fig. 1, an inverse proportionality between the molar ratio and the ^{1}H NMR chemical shift change was observed in the case of FCy, although the chemical shift changes in Cy were nearly zero. Figure 2 shows that the ^{19}F NMR chemical shift changes only by adding phenol. The most reasonable explanation regarding these results is that fluorine atom can form a C–F···H–O bond.

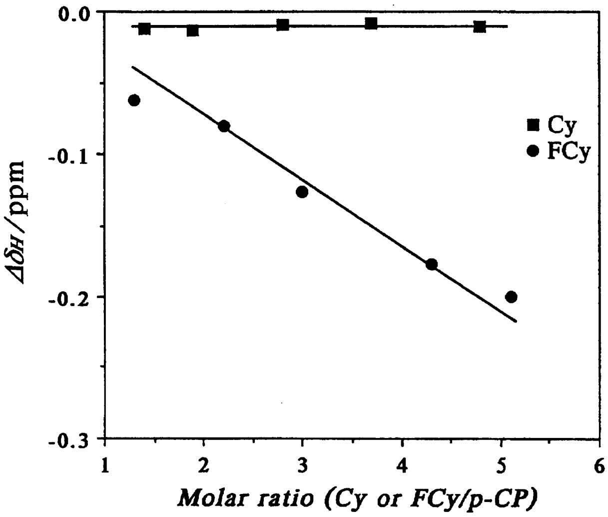

Fig. 1. Relation between the molar ratio (Cy or FCy/*p*-CP) and ^{1}H chemical shift change of hydroxy proton of *p*-CP ($\Delta\delta_{H^a}$) $^{a}\Delta\delta_H=\delta_H$ (chemical shift of *p*-CP in the absence of an additive) $-\delta_H$ (chemical shift of *p*-CP in the presence of an additive).

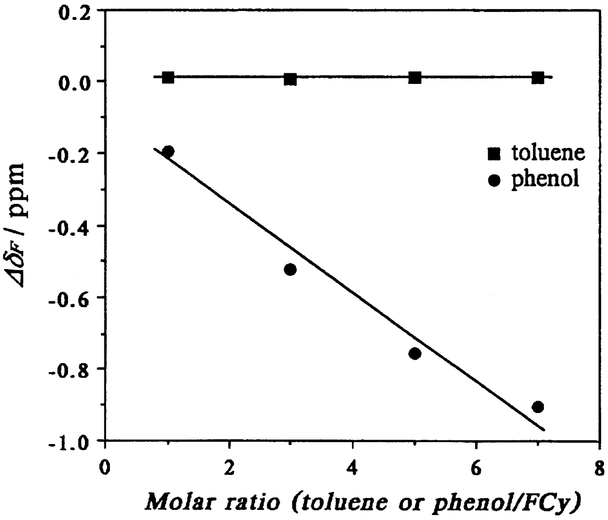

Fig. 2. Relation between the molar ratio (toluene or phenol/FCy) and ^{19}F chemical shift change of FCy ($\Delta\delta_{F^a}$) $^{a}\Delta\delta_F=\delta_F$(chemical shift of FCy in the absence of an additive) $-\delta_F$ (chemical shift of FCy in the presence of an additive).

Next, the interaction in other systems was investigated in order to further ascertain the presence of a C–F···H–O bond. In general, the strength of the hydrogen bond affects the magnitude of the chemical shift change.$^{4)}$ Thus, by using the pK_a value$^{5)}$ as the index of the hydrogen bond-forming ability, we investigated the relation between the hydrogen bond strength and the chemical shift change; i.e., induced changes in the ^{19}F NMR chemical shifts of FCy due to the addition of substituted phenols$^{6)}$ with different pK_a values were measured. As shown in Fig. 3, a linear relationship with a positive slope exists between the induced change and the pK_a value in the case of *m*- or *p*-substituted phenols. Since the hydroxy groups of *m*- or *p*-substituted phenols do not form any intramolecular hydrogen bonds with the substituent groups, the hydroxy groups have

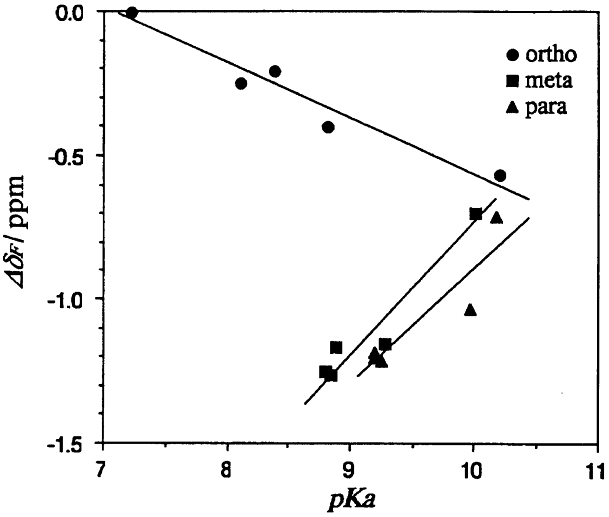

Fig. 3. Relations between pK_a of substituted phenols and the ^{19}F chemical shift change of FCy ($\Delta\delta_{F^a}$) $^a\Delta\delta_F=\delta_F$(chemical shift of FCy in the absence of an additive) $-\delta_F$ (chemical shift of FCy in the presence of an additive).

the ability to form intermolecular hydrogen bonds with other molecules. Hence, the induced changes are due to intermolecular hydrogen bonds. Due to the above reason, the good linearity shown in Fig. 3 suggests that the intermolecular hydrogen bond-forming ability is closely related to the strength of the intermolecular hydrogen bond, which is surely consistent with the idea that C–F···H–O exists. In contrast to *m*- or *p*-substituted phenols, *o*-substituted phenols, except for *o*-cresol, can form an intramolecular hydrogen bond. Thus, as the strength of the intramolecular hydrogen bond increases, it becomes more difficult to form an intermolecular hydrogen bond. In fact, the linearity with a negative slope in Fig. 3 surely indicates that the intramolecular hydrogen bond prevents any formation of an intermolecular hydrogen bond. This result also supports the existence of an intermolecular C–F···H–O hydrogen bond between FCy and *m*- or *p*-substituted phenols. In conclusion, the C–F···H–O intermolecular hydrogen bond can be formed in solutions as well as in crystals.

Experimental

All of the substances were used after the purification of commercially available reagents. Both the ^{1}H and ^{19}F NMR spectra were obtained in $CDCl_3$ on a JEOL EX-270 spectrometer at 298K. The ^{1}H and ^{19}F NMR chemical shifts were referred to TMS as internal and $CFCl_3$ as external references, respectively.

For studying the induced ^{1}H NMR chemical shift change in the hydroxy proton of *p*-CP, the *p*-CP concentrations were kept at 0.1 mol dm^{-3}, and the Cy and FCy concentrations ranged from 0.13 to 0.48 mol dm^{-3} and from 0.12 to 0.51 mol dm^{-3}, respectively. For studying the induced ^{19}F NMR chemical shift change of FCy, the FCy concentrations were held constant at 0.1 mol dm^{-3}. Both the toluene and phenol concentrations were varied between 0.1 and 0.7 mol dm^{-3}. The changes in the ^{19}F NMR spectra of FCy, as induced by adding substituted phenols, were obtained with the FCy concentrations held at 0.1 mol dm^{-3} and the substituted phenol concentrations held at 0.5 mol dm^{-3}.

References

1) P. Murray-Rust, W.C. Stallings, C.T. Monti, R. K. Preston, and J. P. Glusker, *J. Am. Chem. Soc.*, **105**, 3206 (1983).

2) M. Shibakami and A. Sekiya, *Chem. Express*, **6**, 837 (1991).

3) A. D. Cohen and C. Reid, *J. Chem. Phys.*, **25**, 790 (1956); E. D. Becker, U. Liddel, and J. N. Shoolery, *J. Mol. Spectrosc.*, **2**, 1(1958); P. E. Hansen, H. D. Dettman, and B. D. Sykes, *J. Magn. Reson.*, **62**, 487 (1985).

4) M. Saunders and J. B. Hyne, *J. Chem. Phys.*, **29**, 1319 (1958) ; A. L. Porte, H. S. Gutowsky, and I. M. Hunsberger, *J. Am. Chem. Soc.*, **82**, 5057 (1960).

5) A linear relationship with a negative slope exists between the ability to form hydrogen bond of phenols and their pK_a values.: A. Massat, A. Cosse-Barbi, and J. -P. Doucet, *J. Chim. Phys.*, **82**, 821(1985).

6) The substituted phenols were as follows: *o*-, *m*-, and *p*-cresol, *o*-, *m*-, and *p*-fluorophenol, *o*-, *m*-, and *p*-chlorophenol, *o*-, *m*-, and *p*-bromophenol, *m*- and *p*-iodophenol, and *o*- and *m*-nitrophenol.