Hydrogen Bonds and Hydrogen-Bonded Chains in Complexes of 3-(Hydroxymethyl)-2,2′-biphenol with N-Bases. FTIR and ^{1}H NMR Studies

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A new compound 3-(hydroxymethyl)-2,2′-biphenol (HMBP) was synthesized. Complexes of this compound with three N-bases were studied by FTIR and ^{1}H NMR spectroscopy. In the 1:1 mixture of HMBP and triethylamine (TEA) in chloroform, the complexes are formed completely. The hydrogen-bonded chain of these complexes shows large proton polarizability due to collective proton fluctuation. In acetonitrile the alcoholic group of HMBP is no longer bonded to the hydrogen-bonded chain. The rest of the hydrogen-bonded chain still shows proton polarizability. In the 1:1 mixtures of HMBP with a stronger base 7-methyl-1,5,7-triazabicyclo[4.4.0]dec-5-ene (MTBD) the phenolic proton transfers to MTBD and is localized there. In chloroform the protonated MTBD is weakly bonded to HMBP via two other hydrogen bonds. In acetonitrile the complex dissociates. The complex between HMBP and urotropine is not formed completely and all hydrogen bonds within this complex are asymmetrical and weak.

1. Introduction

In biology alcoholic and phenolic groups play an important role (refs 1 and 2 and references given there as well as refs 3−11). In this aspect we studied model systems of hydrogen-bonded chains which approximately correspond to those occurring in proteins, particularly in ionic and protonic channels in membranes. The first system was a mono- and di-Mannich base obtained on the basis of biphenylol.[12−14] Within this system a hydrogen-bonded chain with two intramolecular hydrogen bonds was formed. The intense IR continuum assigned to this chain indicates that it has large proton polarizability due to collective proton fluctuations. The other systems, which we studied extensively, were the complexes between phenol and N-bases, especially the N-base with basicity comparable to that of the guanidin residue of arginine (MTBD).[15,16] We also studied a tyrosine−lysine copolymer.[17]

In this study we were concerned with a new molecule, i.e., 3-(hydroxymethyl)-2,2′-biphenol (HMBP) and its complexes with three N-bases: triethylamine (TEA), MTBD and urotropine. The new compound contains two phenolic OH groups and one alcoholic group, which are comparable to the tyrosine and serine residues, respectively. The pK_a values of TEA and MTBD are comparable to the amine and guanidine groups existing in lysine and arginine residues, respectively.

2. Experimental Section

Triethylamine (TEA), 7-methyl-1,5,7-triazabicyclo[4.4.0]dec-5-ene (MTBD), urotropine, all solvents as well as all compounds used in the syntheses were purchased from Fluka. Chloroform and acetonitrile as well as deuterated solvents (spectroscopic grade chloroform-d_1 and acetonitrile-d_3) were stored over 3 Å molecular sieves. All preparations and transfers of the solutions were carried out in a carefully dried glovebox.

The samples for ^{1}H NMR and FTIR measurements were prepared by adding pure N-base (MTBD, TEA and urotropine) to the solutions of HMBP in the concentration ratio 1:1. The concentration of the complexes was 0.1 mol dm^{-3}. Deuterated mixtures were obtained by preparing the mixture and then by dissolving it in CH_3OD and evaporating several times under reduced pressure.

2.1. ^{1}H NMR Measurements. ^{1}H NMR measurements were carried out in $CDCl_3$ and CD_3CN at the operating frequency of 300.075 MHz; flip angle pw = 45°; spectral width sw = 4500 Hz; acquisition time at = 2.0 s; T = 293.0 K and TMS as the internal standard. The digital resolution was 0.2 Hz per point.

2.2. FTIR Measurements. The IR spectra of the samples were taken with a FTIR spectrophotometer (Bruker IFS 113 v) using a cell with Si windows and a wedge-shaped layer to avoid interference (sample thickness 0.176 mm, detector DTGS, resolution 2 cm^{-1}). The temperature of the samples was 293 K.

2.3. Synthesis of 3-(Hydroxymethyl)-2,2′-biphenol. *n*-Butylmagnesium bromide was obtained from 1306 g (0.0538 mol) of magnesium and 5.768 cm^{-3} (0.0538 mol) of *n*-butyl bromide in 50 cm^{-3} of dry diethyl ether in argon atmosphere. An ether solution of the 2,2′-biphenol (5 g, 0.0269 mol) in 50 cm^{-3} of dry diethyl ether was added carefully dropwise to a solution of 1-butylmagnesium bromide with stirring at room temperature. The ether was distilled off and 150 cm^{-3} of anhydrous benzene was added. To the suspension of bis-(phenoxymagnesium bromide) was added 9.4 cm^{-3} (0.0538 mol) of dry hexamethylphosphoramide (HMPA). The mixture was heated under reflux in argon atmosphere with stirring for 6 h. After cooling, 75 cm^{-3} of 10% HCl was added to the mixture. The mixture was placed in a separation funnel, and the benzene layer was washed (3 × 50 cm^{-3}) with water. The organic phase was dried with anhydrous Na_2SO_4 and filtered, and finally the benzene was evaporated, giving a low yellow oil. The oil was dissolved in 50 cm^{-3} of $CHCl_3$:hexane (3:7) mixture. In this way the 1.3 g of crude 3-(hydroxymethyl)-2,2′-biphenol was

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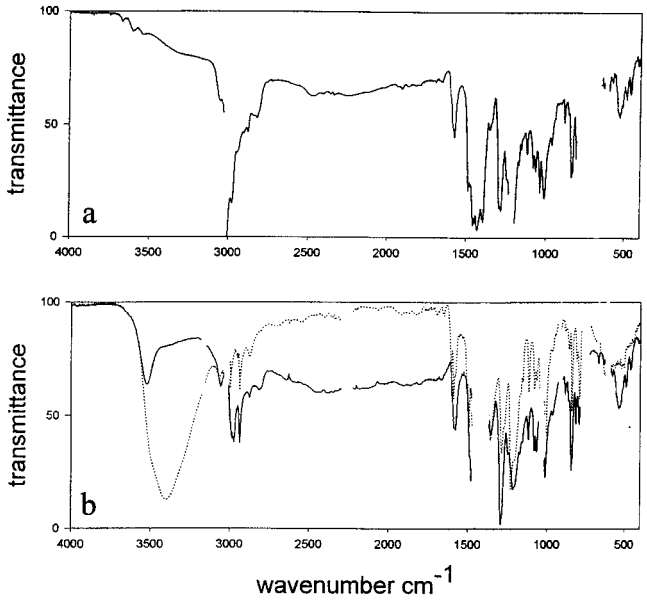
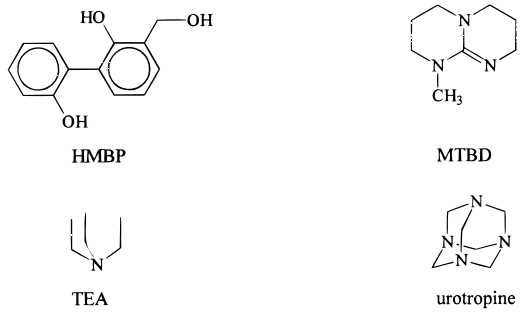


Figure 1. FTIR spectra of (—) a 1:1 mixture of HMBP and TEA and for comparison (···) HMBP: (a) in chloroform; (b) in acetonitrile.

SCHEME 1



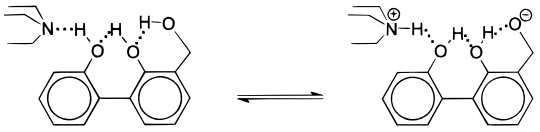
obtained. The crude product was recrystallized from 7 cm^{-3} of CH_3CN giving 1.185 g (yield 20,4%) of pure 3-(hydroxymethyl)-2,2′-biphenol. Melting point: 127−127.5 °C, $R_f = 0.36$ (kieselgel 60 F_{254}, diethyl ether).

3. Results and Discussion

The compounds studied are shown in Scheme 1.

In Figure 1a the IR spectrum of a 1:1 mixture of HMBP and triethylamine (TEA) in chloroform is shown. No band corresponding to free OH groups of the HMBP molecules is found in the region 3600−3500 cm^{-1}, indicating that all OH groups of HMBP are hydrogen-bonded. Furthermore, no band assigned to the $\nu(N^+H)$ vibrations of protonated TEA molecules is observed in the region 3200−3100 cm^{-1}as well as there are no so-called Bohlman bands[18−20] of free triethylamine molecules in the region 2750−2600 cm^{-1}. Thus, all TEA molecules are also hydrogen-bonded in the 1:1 mixture. Instead of the corresponding bands, a continuous absorption is observed in the region 3700−200 cm^{-1} in the spectrum demonstrating that all hydrogen bonds form a hydrogen-bonded chain, which shows large proton polarizability due to collective fluctuation of the protons within the chain. The only possible structure of this chain is presented in Scheme 2. The formation of a hydrogen bond between the other OH group of HMBP and the TEA molecule is improbable for the steric reasons in both solvents chloroform and acetonitrile If it was present, the spectrum of the 1:1 mixture in chloroform should reveal a band assigned to free ν(OH) vibrations of alcoholic groups. Thus, the structure

SCHEME 2



SCHEME 3

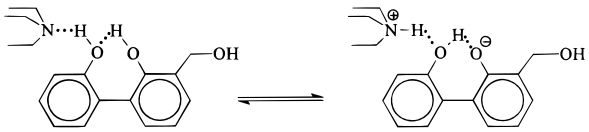


TABLE 1: ^{1}H NMR Chemical Shifts of OH Protons of HMBP and Its Complexes with Various N-Bases in $CDCl_3$and CD_3CN

compd	$CDCl_3$		CD_3CN	
HMBP	insoluble		6, T34	2H
HMBP + TEA	9, 61	3H	9, 22	3H
HMBP + MTBD	14, 65	2H	14, 90	2H
	6, 8	1H	6, 4	1H
HMBP + urotropine	6, 95	3H	6, 86	3H

of the complex shown in Scheme 2 fully explains the spectroscopic observations.

In Figure 1b the IR spectrum of the 1:1 mixture of HMBP and TEA in acetonitrile is shown. In this spectrum besides the continuum a band assigned to the alcoholic OH groups is observed at 3550 cm^{-1}. The position of this band shows that the alcoholic OH groups are free. Thus, the hydrogen-bonded chain is formed by two phenolic OH groups and the TEA molecules. As proved by the presence of the continuum, this chain (Scheme 3) shows also large proton polarizability due to collective proton motions. The intensity of this continuous absorption (two collective hydrogen bonds) is comparable with that in chloroform (three collective hydrogen bonds). The absorption of the continua has a complex nature and it was discussed in details previously.[21,22] In short, it depends not only on collective hydrogen bonds numbers but also on the local fields and the polarity of the solvent.

The ^{1}H NMR spectra of these systems (Table 1) show in both cases only one signal for the three OH protons. In chloroform the signal is found at 9.61 ppm whereas in acetonitrile this signal is observed at 9.2 ppm. The fact that in both cases only one signal is observed shows that the chemical exchange between the OH protons is fast. This is also true if one OH group is non-hydrogen-bonded and it is reflected by the shift of the signal from 9.6 to 9.2 ppm.

The spectra of 1:1 mixtures of HMBP with MTBD in chloroform and acetonitrile are shown in Figure 2a and 2b, respectively. For the sake of comparison, in Figure 2 the spectra of MTBD tetrachlorourate in respective solvents are given. In the spectrum of the 1:1 mixture shown in Figure 2a no N^+H stretching vibration band of free protonated MTBD molecules is found at 3377 cm^{-1}, indicating that the protonated MTBD molecule is bonded to the phenolate group. The fact that MTBD is protonated is proved by the doublet of the ν(CN) vibrations in the region 1600−1650 cm^{-1}. In the case of nonprotonated free MTBD or nonprotonated hydrogen-bonded MTBD molecules only one band at about 1600 cm^{-1} was always present.[23,24] In the region 3100−2400 cm^{-1} a very broad band assigned to the stretching vibration of the hydrogen-bonded alcoholic group is observed. Furthermore, a continuous absorption is found in the region 1800−500 cm^{-1}. This continuous absorption is caused by the $(OH\cdots O)^-$ hydrogen bond between two phenolic

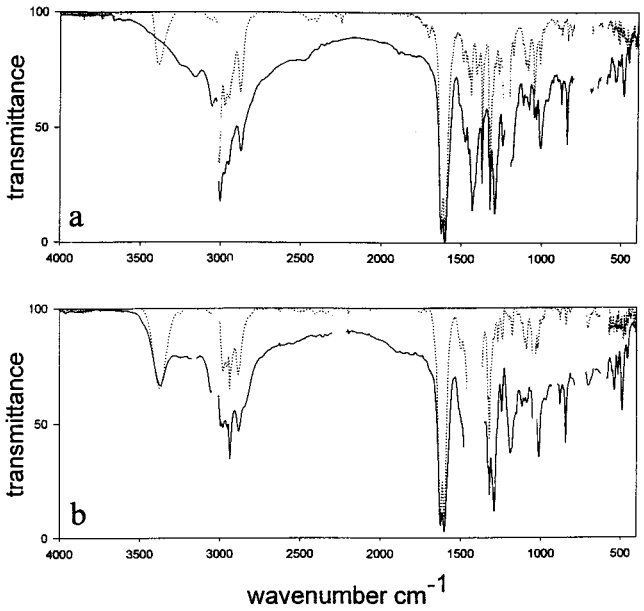


Figure 2. FTIR spectra of (—) a 1:1 mixture of HMBP and MTBD and (···) tetrachlorourate of MTBD for comparison: (a) in chloroform; (b) in acetonitrile.

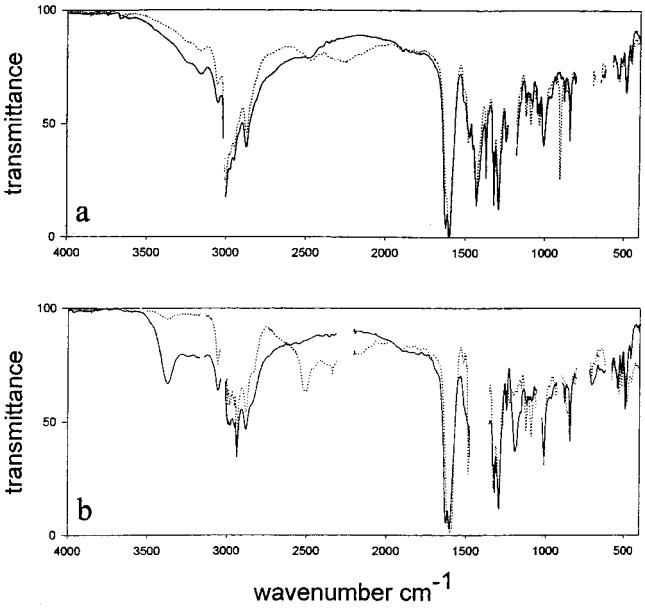
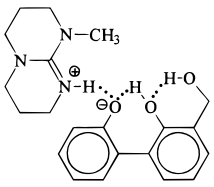


Figure 3. FTIR spectra of (—) a 1:1 mixture of HMBP and MTBD and (···) its deuterated analogue: (a) in chloroform; (b) in acetonitrile.

SCHEME 4



groups. This band shows large proton polarizability (see Scheme 4). This interpretation is confirmed by the spectrum of deuterated 1:1 mixture of HMBP with MTBD in chloroform shown in Figure 3a. In this spectrum two bands in the region 2500−2000 cm^{-1} are well observed. The relatively sharp band at 2470 cm^{-1} assigned to hydrogen-bonded N^+D group of deuterated MTBD and the other broad band with a maximum at 2255 cm^{-1} corresponding to bonded deuterated alcoholic group are observed. The homoconiugated phenolic groups show no absorption changes after deuteration, i.e., isotopic effect is about 1, which is typical of strong hydrogen bonds.

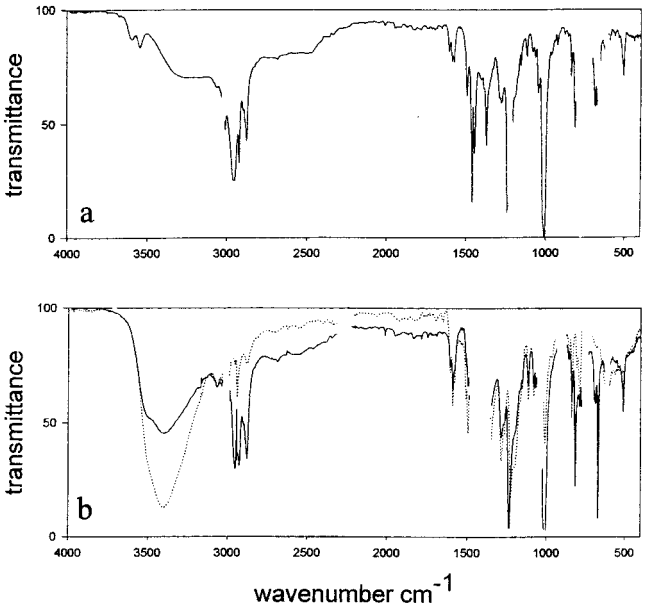
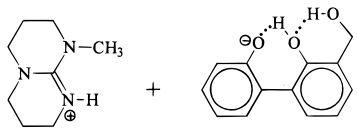


Figure 4. FTIR spectra of (—) a 1:1 mixture of HMBP and urotropine and (···) of HMBP for comparison: (a) in chloroform; (b) in acetonitrile.

SCHEME 5



The spectrum of the 1:1 HMBP − MTBD mixture in acetonitrile (Figure 2b) indicates that the protonated MTBD molecule is dissociated from the phenol-phenolate bond since its N^+H stretching vibration appears at 3377 cm^{-1} (Scheme 5). A comparison of the band with that observed in the spectrum of the protonated MTBD confirms this interpretation. The broad band in the region 3400−2400 cm^{-1} and the continuum are found almost in the same position as in the chloroform solution. Thus, the assignments of these spectral observations must be comparable with those in chloroform. Furthermore, this interpretation is also confirmed by the spectrum of deuterated complex in acetonitrile (Figure 3b).

The ^1H NMR data (Table 1) confirm the FTIR results. The ^1H NMR signal of the protonated MTBD molecules is found in chloroform at the 6.8 ppm, whereas in acetonitrile at 6.4 ppm. These chemical shifts prove that in chloroform the protonated MTBD forms a very week hydrogen bond to the phenol-phenolate bond. For the alcoholic proton and the phenolic proton only one signal is observed indicating the fast chemical exchange of these protons. This signal is found at 14.65 ppm. The strong shift of this signal to lower frequencies especially in comparison to spectrum of the complex of HMBP with TEA, demonstrates that one of those two protons responsible for this signal is very strongly bonded in the $(OH\cdots O)^-$ hydrogen bond, as expected.

Figure 4a and 4b show the spectra of the mixture of HMBP with urotropine in chloroform and acetonitrile, respectively. In the spectrum of chloroform solution two broad bands in the region 3600−2500 cm^{-1} are observed. One band at higher wavenumbers is assigned to the hydrogen-bonded complex between HMBP and urotropine. The other one is attributed to the intramolecular hydrogen bonds between two phenols and one alcohol group. The protons in the hydrogen bonds in the

complex are localized. Thus, these bands show no noticeable proton polarizability. Furthermore, two-week bands are found, one at the 3598 cm^{-1} and the other one at 3546 cm^{-1}, assigned to the noncomplexed alcoholic and phenolic group, respectively. In acetonitrile the hydrogen-bonded complex becomes more asymmetrical and to a large extend dissociate as shown by the bands at 3500 and 3398 cm^{-1}.

This result is confirmed by the ^1H NMR data (Table 1) that show one signal assigned to the three OH protons at about 6.9 ppm. This chemical shift is slightly higher than that of HMBP in acetonitrile.

4. Conclusion

From the complexes of HMBP with three different N-bases in chloroform only the complexes with TEA form a hydrogen-bonded chain N···HO···HO···HO $\rightleftharpoons$ N^+H···OH···OH···O^-. This chain shows large proton polarizability due to collective proton fluctuation, as indicated by the very intense IR continuous absorption. Such system is an excellent proton pathway. In complexes of HMBP with much stronger or weaker N-bases, respectively, the hydrogen-bonded chains show no proton polarizability. In acetonitrile solution of 1:1 mixture of HMBP with TEA the alcoholic group of HMBP is no longer bonded to the hydrogen-bonded chain. Only in the complex with TEA the rest of hydrogen-bonded chain still shows proton polarizability. In acetonitrile with the N-bases stronger then TEA, the proton transfers to MTBD and the complex dissociates to a large extend. With the weaker N-base (urotropine) no proton transfer occurs in chloroform and acetonitrile solutions. These results also show that a nonpolar environment is necessary for the formation of the hydrogen-bonded chains.

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