

¹H NMR Studies of some heterocyclic compounds Part-III. Tautomerism in 1,2,3, Benzotriazole

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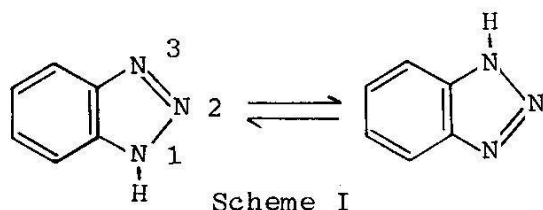
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Summary: The exchange of the NH proton in 1,2,3, benzotriazole has been studied by total line shape analysis of ¹H NMR spectra. The rates of this process have been found to be dependant on concentration, temperature and the presence of water. The activation parameters (E_a , Δ^*H , Δ^*S , Δ^*G_{298}) for this rate process have been determined.

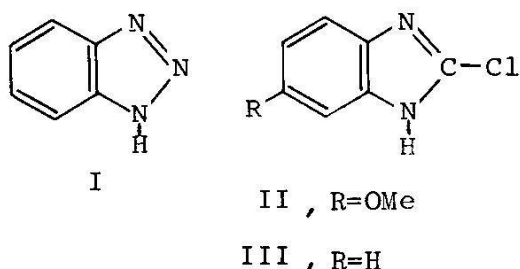
Introduction

There is a rapid tautomerism in benzotriazole¹ where the NH proton exchanges its position between nitrogen atoms 1 and 3 as shown in scheme 1.



The exchange process has also been observed in benzimidazole^{2/3} and imidazole^{4/5}. And change in the rate of exchange of proton between two sites is reflected in the ¹H and ¹³C spectra of the aromatic portion of these compounds.

When the exchange is fast the four ring protons in I appear as AA BB in the ¹H NMR spectrum and an ABCD type spectrum is obtained in the slow or zero exchange limit.



A.N. Nesmeyanov et.al¹¹ have shown that the rate of exchange in I can be reduced by cooling the system in THF and at -100°C the exchange is very slow.

F. Taddei et.al² report that the spectrum of compound II has a coalescence temperature (T_c) at -35°C and in the case of III only broadening of the spectrum starts at -100°C in THF. All these authors have considered temperature as a major factor which can effect the exchange rates in these systems and they have also attached some importance to the dryness of the solvent. We report here that the rate of NH proton exchange in benzotriazole is a sensitive function of concentration which may go unnoticed if the solvent is not completely dry.

Experimental

Purification of compounds

1,2,3, benzotriazole was obtained from Aldrich Chemical Co. and was yellowish in colour. It was recrystallised from water in the presence of activated charcoal. The white shining crystals were dried in vacuum at $50-60^\circ\text{C}$ (m.p. $96-97^\circ\text{C}$).

Tetrahydrofuran (THF) was used as a solvent in this study. The commercial THF was dried over sodium wire and it was ampouled under nitrogen.

NMR Spectra

A Varian XL-100 NMR spectrometer was used for recording all the spectra reported here. Solutions of ben-

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zotriazole were prepared at various concentrations (0.3098M, 0.2564M, 0.2219M) in THF.

The preparation of the solution was carried out in a glove box, which was flushed with nitrogen gas dried over silica gel column and contained P_2O_5 as a drying agent. The sample was placed in a 10 mm NMR tube. A 5 mm NMR tube sealed with methanol and TMS in it was held in the sample tube with the help of two plastic inserts. The sample tube was sealed with a suba seal.

The spectra of the ring protons of this compound were recorded at different temperatures in the range of 55° to 58° for each concentration using sweep width of 100Hz. The accurate temperature was measured with the help of methanol capillary.

For low temperature experiments nitrogen gas cooled in liquid nitrogen was used to cool the sample. For each spectrum the sample was given at least 10 minutes to acquire the desired temperature.

The temperatures were measured before and after recording of each spectrum. The good resolution of the spectrometer was always maintained by optimising the methanol resonances using TMS as a locking sample.

Results and Discussion

Line Shape Analysis of 1,2,3, Benzotriazole :

The rate of exchange of the NH proton between the two sites shown in Scheme 1, is a sensitive function of temperature and concentration.

The rate of exchange is slow (Fig.1) even at ambient temperature (23°C) for a dilute (0.3098M) solution in dry THF. Precipitation occurs, if this solution, or a more concentrated one is cooled below -65°C. Using a saturated solution in dry THF, the AA BB type spectrum corresponding to fast exchange is obtained even at ambient temperature (23°C). If the solvent is wet or has any basic or acidic impurity an AA BB type spectrum is obtained at ambient temperature for any concentration.

A low concentration solution which shows slow exchange i.e. an ABCD type spectrum, is suitable for the low temperature study and could probably give AA BB type spectrum if it were heated to higher temperature (> + 100°C) which is not possible with THF as a solvent (B.P.=64°C).

A computer programme named DENSMAT⁶ was used to calculate the theoretical spectra. This programme is applicable to coupled systems of a maximum number of four nuclei.

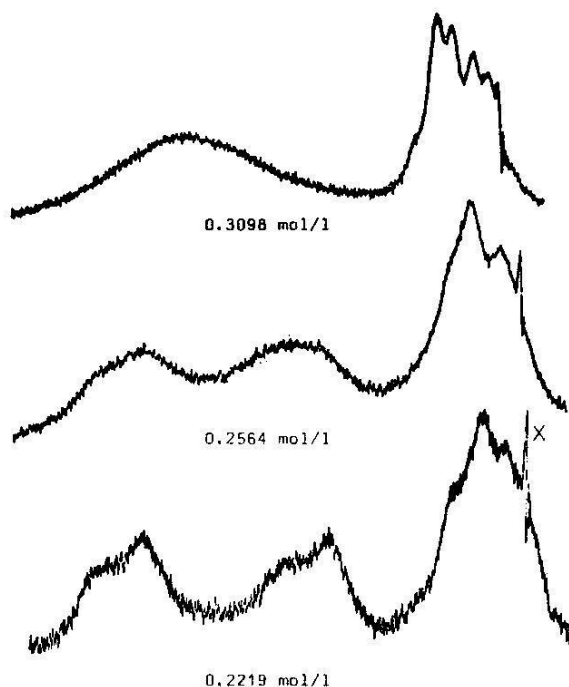


Fig. 1: The spectra of the aromatic protons of 1,2,3, benzotriazole at various concentrations at ambient temperature (23°C). X = benzene

The input parameters for this programme are:

- (i) Number of nuclei,
- (ii) Residence time (τ),
- (iii) Spin-spin relaxation time (T_2),
- (iv) Lower limit of frequency,
- (v) Sweep width,
- (vi) Chemical shifts,
- (vii) Coupling constants.

The output consists of a calcomp plot of the same size as Varian 100MHz chart paper and the input parameters.

In the present study the expanded (sweep width = 100 Hz) spectra of ring protons at various τ values have been simulated. A suitable residence time for each theoretical spectrum was obtained by visual fitting to the experimental one.

The coupling constants (Table-1) used in this study are the literature values⁷. The AA BB type spectrum was calculated with these values and was found to be in excellent agreement with the experimental one.

Theoretical spectra (right) in the slow exchange range were reproduced using these coupling constant

Table 1.

Chemical Shifts (Hz)



H _A	H _B	H _C	H _D
-70.0	-13.0	0.0	-40.0
Coupling Constants (Hz)			
J _{AB} =	J _{CD}	=	8.27
J _{AC} =	J _{BD}	=	1.01
	J _{AD}	=	0.810
	J _{BC}	=	6.95

values and they also show agreement with the experimental ones (left) Figs. 2,3,4. The chemical shifts in Table 1 for the ABCD type spectrum are referred to nucleus C.

The high field portion of the ABCD type spectrum is very sensitive to the chemical shift difference ν_{BC} while the low field one varies with ν_{CD} and ν_{AD} . At

a given temperature these parameters have to be adjusted to bring the calculated spectrum in close resemblance to experimental one. The value of $T_2 = 0.45$ was used for all the calculated spectra reported here. At a given temperature the order of reaction (n) was found to be approximately 3. The third order rate constants were calculated at various temperatures for a given concentration. The activation parameters obtained from Arrhenius and Eyring's plots are listed in Table 2.

Table 2

Thermodynamic parameters of benzotriazole

Conc. mol/l	E _a KJ/mol	log A	Δ^*H KJ/mol	Δ^*S J deg ⁻¹ Mol ⁻¹	Δ^*G KJ/mol
0.3098	14.788	4.84	12.152	-161.01	60.1342
0.2564	17.4099	5.314	15.367	-149.88	60.040
0.2219	18.405	5.543	16.278	-145.85	59.74

Effect of H-Bonding

The chemical shifts of the protons (-OH,SH,NH) are generally sensitive to concentration, solvent, and temperature and the degree of sensitivity will vary with the type of group and molecular environment, e.g. the hydroxylic proton of phenol at infinite dilution in CCl₄ has $\delta = 4.25$ and reaches a limiting value of 6.75 at higher concentration⁸. Roger et.al⁷ have reported the variation of the NH peak position (737Hz-970Hz) of benzotriazole in CDCl₃ with concentration (1-20 mol%) at 60 MHz.

We have made similar observations in the present study i.e. the NH resonance moves downfield with increasing the concentration in THF.

It has been shown⁵ that proton transfer in concentrated (1-2M) imidazole or pyrazole proceeds through self-association of solute via an intermolecular mechanism. The NH chemical shifts of pyrazole and imidazole vary⁵ with temperature.

This type of variation was also observed in benzotriazole. This evidence provides enough reason to believe

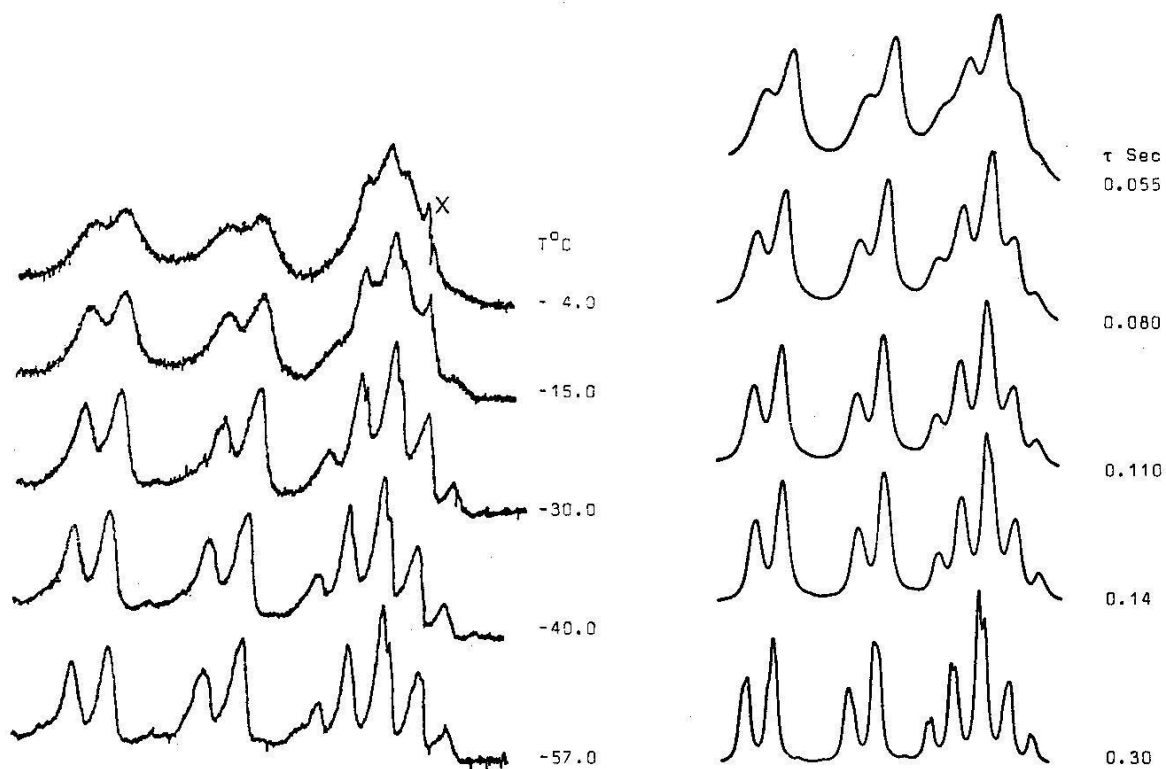


Fig. 2: 0.3098 mol/l, X = benzene

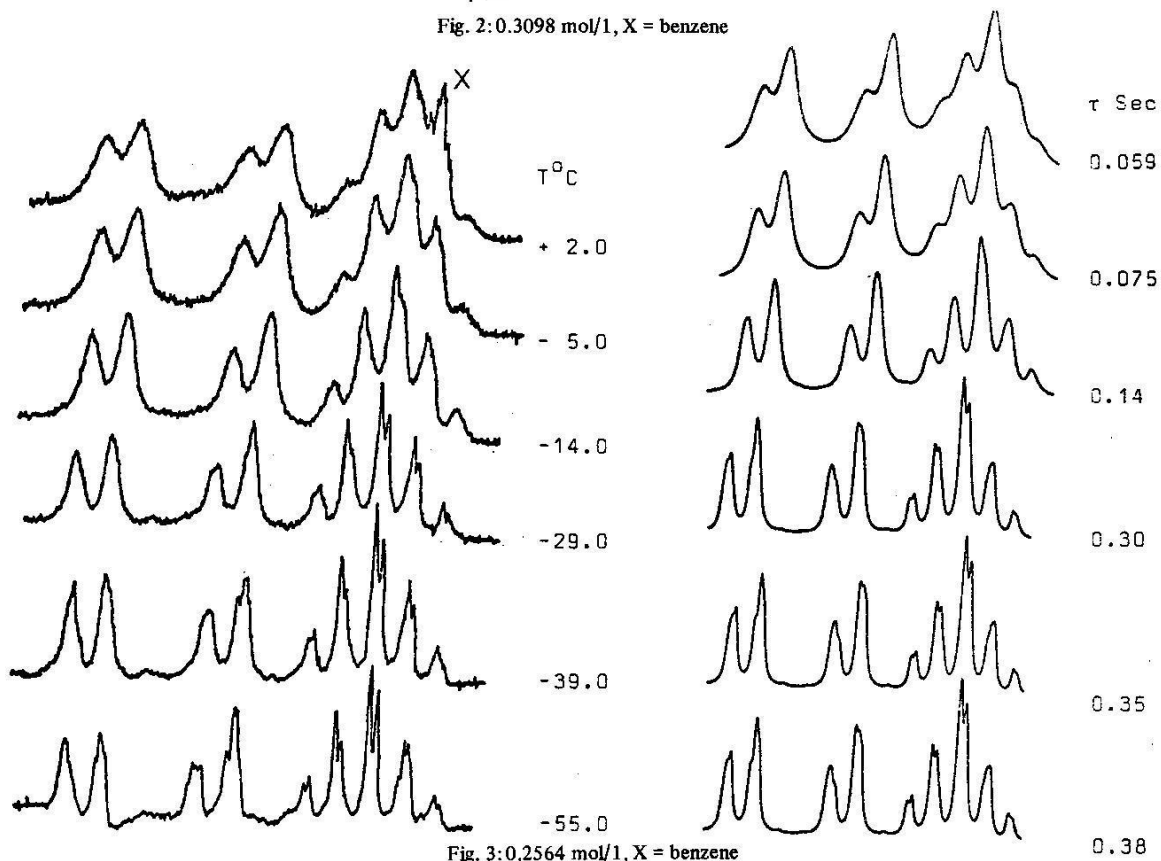


Fig. 3: 0.2564 mol/l, X = benzene

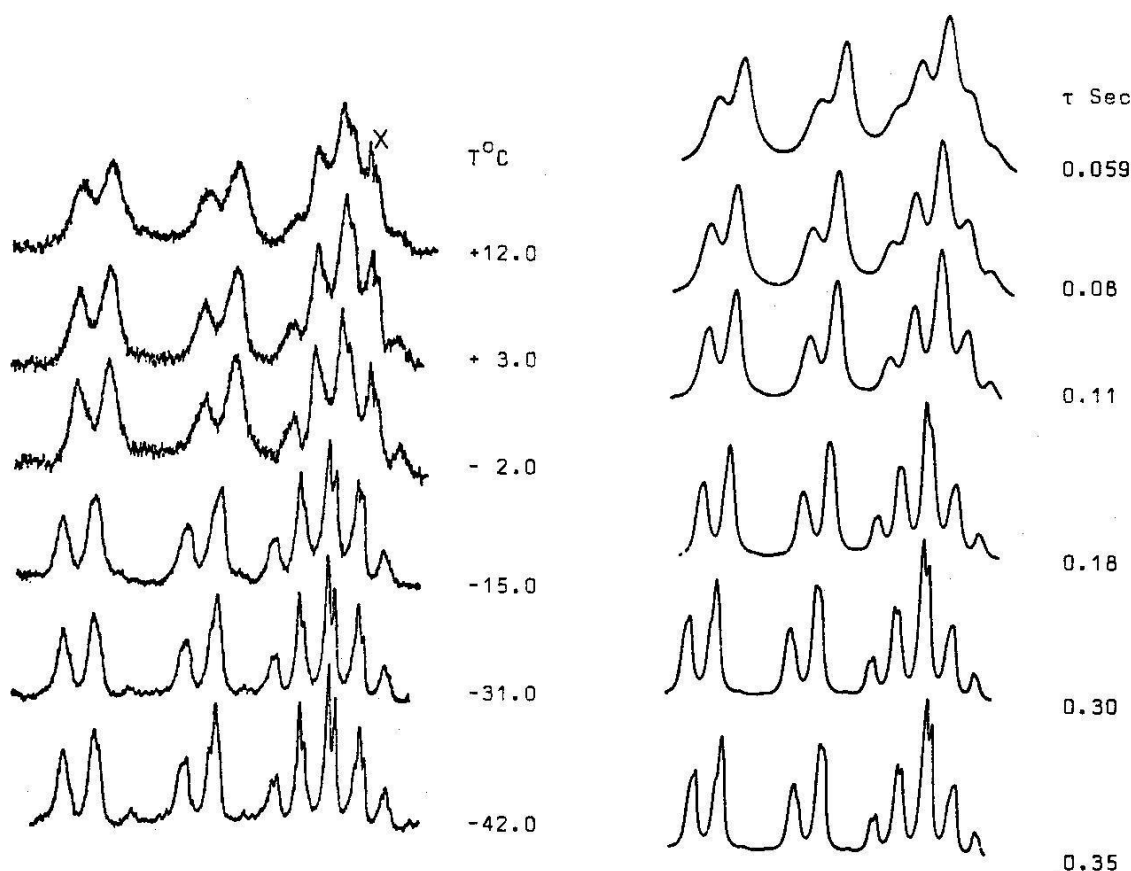


Fig. 4: 0.2219 mol/l, X = benzene

that benzotriazole molecules are self associated through H-bonds. The intermolecular H-bonding in the system in question would increase the rate of exchange process.

Effect of Water

The exchange of NH proton in benzotriazole and benzimidazole is catalysed by water. This fact is demonstrated by Fig. 5 where (a) was obtained before adding water and (b) after introducing a trace of water, at ambient temperature. In the presence of water it is impossible to see any concentration effect and the sample has to be cooled to very low temperature to slow down the exchange rate. Perhaps this is the reason why A.N. Nesmeyanov et al.¹ had to cool 1,2,3. benzotriazole solution in THF to -100°C to obtain spectrum (a) in Fig. 6 while the spectrum (b) in the present investigation was obtained at a much higher temperature (-22°C).

Mechanism of Proton Transfer in Benzotriazole

The concentration dependance of NH exchange reactions in the systems under investigation, shows that they have an order of reaction higher than unity. The observed value of the order of reaction in benzotriazole is 3. This shows that in the transition state more than one molecule is involved in proton transfer between two nitrogen atoms (N_1) and (N_3) of this compound.

In benzotriazole, probably the proton transfer occurs within the cyclic trimer (A). This type of proton transfer is not uncommon. It has been suggested⁵ that intermolecular proton transfer in pyrazole takes place within the cyclic trimer (B).

Activation Parameters

The activation parameters e.g. $\Delta^*\text{H}$ and $\Delta^*\text{S}$ appear to be varying with concentration (Table 2).

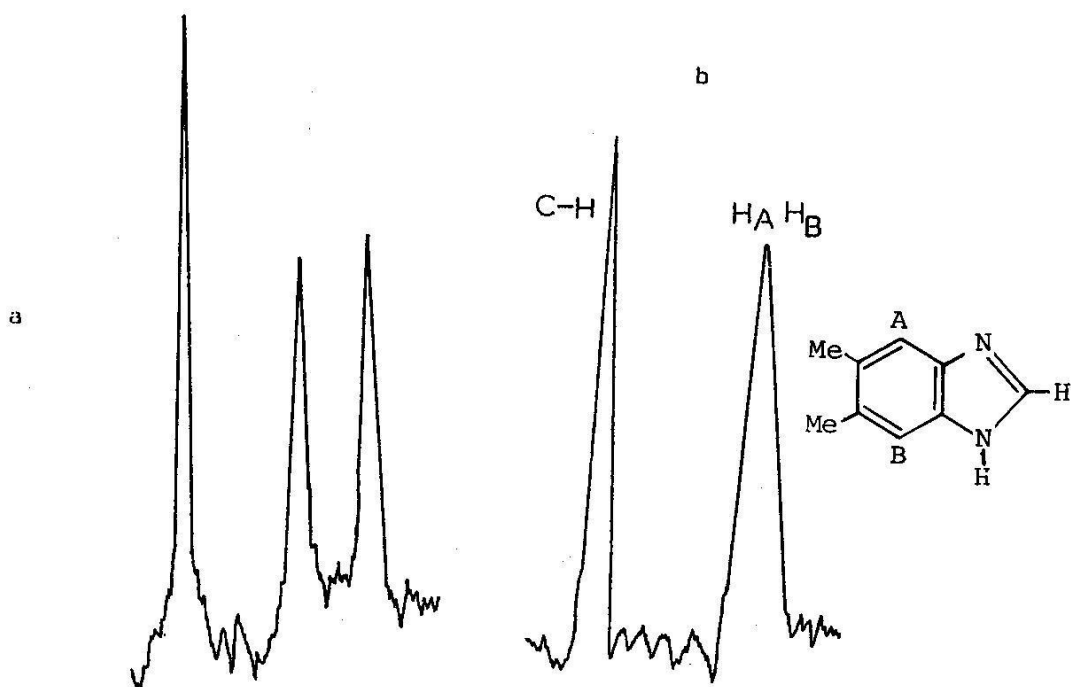
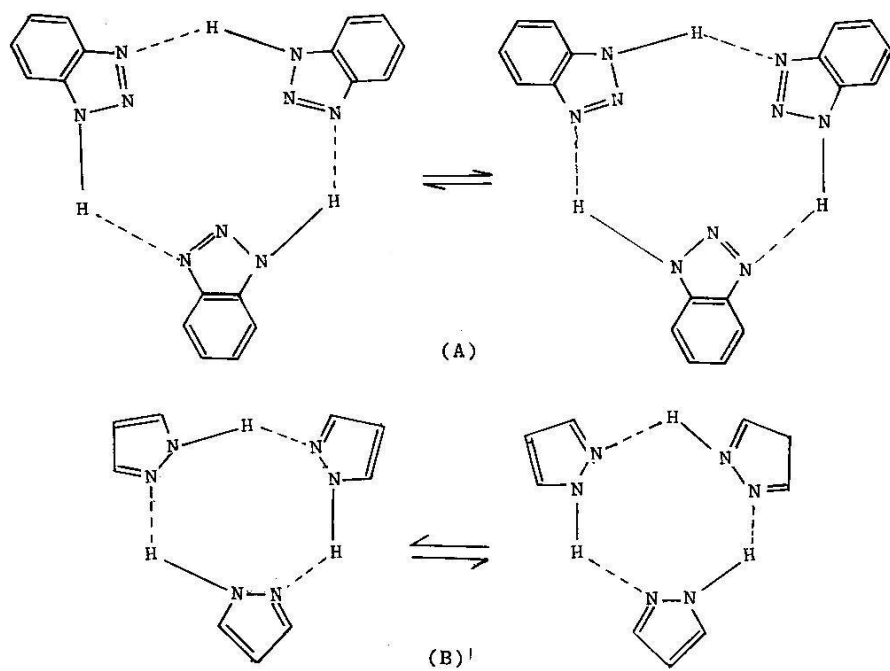


Fig.5: (a) Before adding water to 0.05M solution of 5,6 dimethyl benzimidazole, (b) After introducing a trace of water in the same solution.

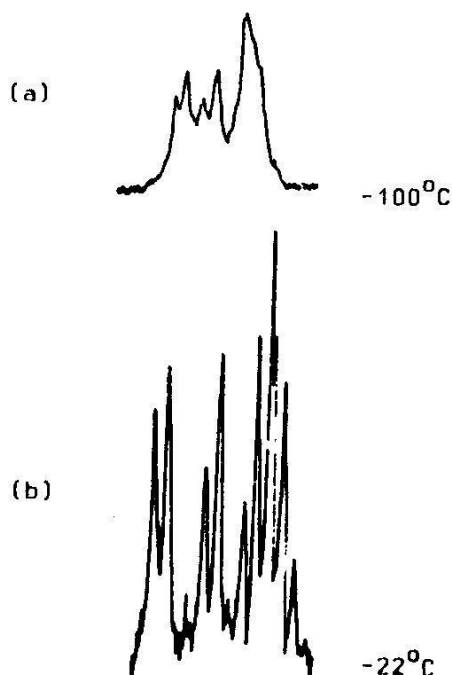


Fig. 6:(a) Aromatic proton spectrum of benzotriazole in THF at 100 MHz reported by A.N. Nesmeyanov et al. (1); (b) Aromatic proton spectrum of the same compound obtained for 0.2219M solution in THF.

These parameters are very sensitive to systematic errors and for a given compound one can not say that whether or not these variations are real. The activation parameter Δ^*G_{298} for a given compound remains fairly constant at different concentrations, because it is very insensitive to systematic errors.

Thus out of four activation parameters E_a , Δ^*S , Δ^*G and Δ^*H only Δ^*G is measured with reliable accuracy and many authors prefer to report the value of Δ^*G at standard temperature (298°K). An inaccuracy in temperatures or rate measurement may cause large errors in E_a , Δ^*S , Δ^*H but very small error in Δ^*G .

The value of Δ^*G of a reaction helps in understanding nature of the transition state of the reaction. A loosely bound activated complex has a higher entropy (Δ^*S) value than a tightly bound one.

In a bimolecular reaction the complex is formed by association of two individual molecules and there is a loss of translational and rotational freedom, so that

Δ^*S is usually negative, e.g. $\Delta^*S = -76.6 \text{ J deg}^{-1} \text{ mol}^{-1}$ has been reported for the dimerisation of butadiene. For a reaction between imidazole¹⁰ and benzoyl fluoride ($\text{Ph}-\text{C}=\text{O}$) $\Delta^*S = -2.00.832 \pm 8.368$ and $\Delta^*S = -213.384 \pm 16.736 \text{ J Deg}^{-1} \text{ mol}^{-1}$ have been calculated for 3rd order and fourth order rate constants respectively.

These examples show that for higher order reactions Δ^*S may have very large negative values because of their highly ordered transition states. Similar conclusion may be drawn from $\Delta^*S = -152.2566 \pm 11.13 \text{ J Deg}^{-1} \text{ mol}^{-1}$ for benzotriazole obtained from the present investigation i.e. the structure of its transition state is highly ordered.

The existence of a trimer (A) is very likely because this value is comparable to that for the 3rd order process in the previous example.

Acknowledgement

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