Amidines. Part 40.[1] Amidine–deuteriochloroform complexes. Influence of amidine basicity on the frequency of C–D stretching vibrations

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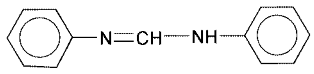
Formation of deuteriochloroform complexes with four series of N^1,N^1-dimethylamidines ($R^xN{=}CR^1NMe_2$; 75 compounds) containing a variable substituent R^x at the imino nitrogen atom has been studied by infrared spectroscopy. It is found that for complexed $CDCl_3$ molecules a new, additional C–D stretching band appears at lower frequencies. The changes in frequency of this band depend on the basicity of the amidine and correlate with the pK_a values of complexing amidines, however for N^2-alkyl and N^2-aryl derivatives separate correlations are obtained. The slope of the correlation line depends on substituent R^1 at the amidino carbon atom, and for N^2-aryl derivatives it increases with the increase of the volume of a substituent at the amidino carbon atom, whereas for N^2-alkyl derivatives it decreases. The inverse order of the change of the slopes is attributed to the *E*–*Z* isomerism in amidines.

Amidines may form complexes with metal ions or proton-donating compounds. Metal complexes of amidines have been thoroughly studied because they are stable and have found many practical applications, mainly as analytical reagents.[2,3] Much less known are unstable collision complexes formed by hydrogen bonding of proton-donating molecules to nitrogen atoms of amidines.

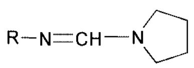
In the early 1970s it was found that chloroform may form hydrogen-bonded complexes. For the study of complexation by chloroform, however, it is more convenient to use its deuterated form because its characteristic absorption occurs in the region where it is easily recognizable. In pure deuteriochloroform the C–D stretching band occurs at 2254 cm^{-1}. In mixtures with electron-donating compounds, such as amines, a new C–D stretching band appears at lower frequencies.[4–6] Both bands are well recognizable and separated. For that reason the frequency variations of this new band may be regarded as a convenient basis for study of intermolecular interactions.

Since that time papers concerning collision complexes of chloroform or deuteriochloroform with amines[7,8] and other compounds containing electron-donating groups such as nitro,[9] C=N,[10] C=C,[11] or C=O groups[12–15] have been published. The most thoroughly studied were complexes with acetone reviewed by Fell and Shurvell.[13] In our laboratory it was found that amidines form complexes with chloroform molecules.[16] In the IR spectra of mixtures of deuteriochloroform with various formamidines, such as *N*,*N′*-diphenylformamidine (**FDPh**), N^1,N^1-tetramethylene-N^2-phenylformamidine (**FTM**, $R = C_6H_5$), N^1,N^1-tetramethylene-N^2-cyclohexylformamidine (**FTM**, $R = C_6H_{11}$), N^1,N^1-pentamethylene-N^2-phenylformamidine (**FPM**, $R = C_6H_5$), and N^1,N^1-pentamethylene-N^2-cyclohexylformamidine (**FPM**, $R = C_6H_{11}$), in the region 2140–2350 cm^{-1} three bands can be discerned.

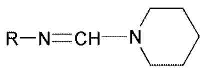
The relative intensities of these bands in the spectra of mixtures of various ratios of amidine to deuteriochloroform have shown that one band, sharp, intense, and shifted by 6–15 cm^{-1} to lower frequencies, can be assigned to the stretching C–D vibrations of the uncomplexed chloroform molecules. The other two bands, also intense but broad, shifted further to lower frequencies, are due to the formation of the C–D···N hydrogen bond in two complexes: a 1 : 1 complex, and a second where one amidine molecule is complexed by two molecules of chloroform, and where both nitrogen atoms are involved in hydrogen bonds.



FDPh



FTM



FPM

Vaes, Faubert and Zeegers-Huyskens[17] have found that N^1,N^1-dimethyl-N^2-phenylformamidines (**FDM**, $R^x = RC_6H_4$) in carbon tetrachloride solutions form complexes with ethanol and phenols, and that the formation of the hydrogen bond takes place on the imino nitrogen atom. In the case of complexes with phenols, on the basis of stability constants of the 2 : 1 complexes it was found that "*the second molecule of phenol seems to be bonded to the oxygen atom of the first phenol molecule rather than to the amino nitrogen atom*".[17]

For complexes with ethanol it was found[17] that a new band appears at lower frequencies, and the differences between the O–H stretching vibration frequencies in complexed and uncomplexed ethanol molecules $\Delta\nu$(OH) correlate with the Hammett σ constants of the substituents on the phenyl ring in the amidine molecule according to eqn. (1).

$$\Delta\nu(\mathrm{OH}) = 300 - 53.7\Sigma\sigma \qquad (1)$$

Complexation of proton-donating compounds by amidines occurs by hydrogen bonding to the imino nitrogen atom, in other words by acid–base interactions.[3] On the other hand the basicity of amidines is related to the values of the Hammett type constants of substituents at any of the sites of the amidino group *i.e.* at the amidino carbon atom and at both nitrogen atoms.[3] Thus it seemed very probable that the more basic is the amidine the stronger will be the hydrogen bonding and in consequence the C–D bond in deuteriochloroform will be weaker and thus its stretching frequency lower. As a result the differences between the C–D stretching frequency in complexed and

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Table 1 Shift of the C–D stretching frequencies ($\Delta\nu$) in deuteriochloroform–amidine complexes with respect to uncomplexed $CDCl_3$ molecules

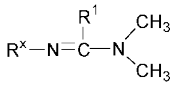
	$\Delta\nu$(C–D)				pK_a of amidine			
R	FDM	ADM	iBtrDM	PivDM	FDM[a]	ADM[b]	iBtrDM[c]	PivDM[c]
m-$C_6H_4NO_2$	29	27	—	—	5.58	6.31	—	—
m-C_6H_4Br	33	30	27	22	6.55	7.19	7.03	6.81
m-C_6H_4Cl	33	31	28	23	6.50	7.25	7.10	7.01
p-C_6H_4I	34	32	—	25	6.75	7.53	7.54	7.17
p-C_6H_4Br	34	32	30	25	6.69	7.55	7.41	7.20
p-C_6H_4Cl	35	33	31	26	6.84	7.65	7.51	7.19
m-$C_6H_4OCH_3$	36	35	32	29	7.45	8.22	8.12	7.91
m-$C_6H_4OC_2H_5$	36	35	33	30	7.45	8.26	8.15	7.93
C_6H_5	37	36	34	31	7.45	8.32	8.22	8.03
m-$C_6H_4CH_3$	38	37	36	32	7.63	8.41	8.41	8.24
p-$C_6H_4CH_3$	39	38	37	34	7.75	8.65	8.63	8.43
p-$C_6H_4OC_2H_5$	40	39	38	35	7.83	8.90	8.93	8.63
p-$C_6H_4OCH_3$	40	40	39	36	7.91	8.96	8.89	8.62
p-$CH_2C_6H_4Cl$	47	—	—	38	9.71	—	11.13	9.96
m-$CH_2C_6H_4OCH_3$	51	—	—	41	10.14	—	11.31	10.28
$CH_2C_6H_5$	51	49	50	40	10.04	11.70	11.36	10.30
Allyl	52	—	51	43	10.18	11.88	—	10.65
*Iso*butyl	60	57	58	—	10.70	12.30	11.93	10.76
Cyclohexyl	63	60	—	—	10.90	12.55	12.16	10.91
n-Propyl	63	59	62	—	10.84	12.46	12.22	10.91
n-Butyl	61	59	61	49	10.80	12.34	12.33	10.94
n-Hexyl	60	—	60	47	10.75	12.37	11.95	10.98

[a] Acc. to ref. 27. [b] Acc. to ref. 19. [c] Acc. to ref. 23.

uncomplexed $CDCl_3$ molecules for 1 : 1 complexes should be related to the basicity of the amidine expressed as its pK_a value.

To verify this hypothesis we have studied in this work the relationship between the basicity of amidines and the C–D stretching frequency for the example of 1 : 1 complexes of deuteriochloroform with 75 amidines divided into four series depending on the substituent at the amidino carbon atom *i.e.* with formamidines, acetamidines, isobutyramidines and pivalamidines.

Studied compounds:



$$R^x{-}N{=}C(R^1){-}N(CH_3)_2$$

R^1	Amidines	Series
H	N^1,N^1-dimethylformamidines	**FDM**
CH_3	N^1,N^1-dimethylacetamidines	**ADM**
$CH(CH_3)_2$	N^1,N^1-dimethylisobutyramidines	**iBtrDM**
$C(CH_3)_3$	N^1,N^1-dimethylpivalamidines	**PivDM**

Substituents R^x variable in the series are listed in Table 1.

Results and discussion

For this study N^1,N^1-dimethylamidines were chosen because trisubstituted amidines do not display tautomerism and therefore there is no doubt at which of the two nitrogen atoms complexation occurs and on account of the identity of the two substituents at the amino nitrogen atom conformational problems, resulting from hindered rotation around the C–N single bond, could be neglected. Moreover N^1,N^1-dialkylamidines are much more basic than the N^1-phenylamidines used in our previous study;[16] thus larger differences between the C–D stretching frequencies in complexed and uncomplexed $CDCl_3$ molecules were expected.

Protonation of amidines occurs at the imino (N^2) nitrogen atom,[3] and the second nitrogen (amino N^1) is protonated only in stronger acidic media.[18] Therefore in 1 : 1 complexes the hydrogen of deuteriochloroform is bonded to the imino nitrogen atom. To exclude the possibility of competitive formation of amidine complexes containing more than one molecule of deuteriochloroform, observed in our previous study,[16] the spectra were recorded for very dilute solutions in a solvent which does not form hydrogen bonds with amidines *i.e.* in carbon tetrachloride. We have found that for such solutions in the IR spectra only one new band appears at lower frequency with respect to the C–D stretching band of uncomplexed $CDCl_3$ molecules. The differences $\Delta\nu$ between the C–D stretching frequency in uncomplexed (ν_u) and complexed (ν_c) molecules of $CDCl_3$ [eqn. (2)] obtained for complexes of $CDCl_3$ with the studied amidines are summarized in Table 1.

$$\Delta\nu = \nu_u(\text{C–D}) - \nu_c(\text{C–D}) \qquad (2)$$

We have found that in the case of N^2-alkyl- and N^2-aralkyl-amidines the two bands are well separated and the $\Delta\nu$ values are in the range 47 to 60 cm^{-1}. For pivalamidines these differences are considerably lower and range from 38 to 47 cm^{-1}. For N^2-arylamidines, which are less basic than N^2-alkyl derivatives, the differences $\Delta\nu$ are lower, but still discernible.

The determination accuracy of the C–D stretching frequency in complexes depends on its distance (in cm^{-1}) from that of uncomplexed $CDCl_3$ molecules. In the case of complexes where this difference is below 29 cm^{-1} determination accuracy is lower because of band overlap, even though the error, as estimated, does not exceed ±3 cm^{-1}. For all other complexes the error does not exceed ±1 cm^{-1}.

Assuming that the shifts of the C–D stretching frequencies will depend mainly on the basicity of the amidine, like the shifts of the O–H stretching vibrations in the above mentioned complexes of dimethylformamidines with ethanol,[17] we attempted a correlation of the $\Delta\nu$(CD) values with the pK_a values of the amidines according to eqn. (3).

$$\Delta\nu(\text{CD}) = a\text{p}K_a(\text{Amidine}) + b \qquad (3)$$

Obtained results provide sound evidence for the hypothesis that the differences between the frequencies of C–D stretching vibrations in complexed and uncomplexed molecules depend mainly on the basicity of the amidine.

However, the pattern of experimental points obtained in the first attempts at this correlation indicated that there is no straightforward relation between the pK_a values and the $\Delta\nu$ values. The slopes of correlation lines [term *a* in eqn. (3)]

Table 2 Linear regression parameters between the shift ($\Delta\nu$) of the C–D stretching frequency in complexes and the pK_a values of amidines [eqn. (3)]

Substituent at N^2	Series	a	b	r	n^a
Aryl	FDM	4.55	3.39	0.978	13
	FDM	4.74	2.26	0.995	11^b
	ADM	4.91	−4.73	0.991	13
	iBtrDM	5.79	−13.38	0.981	11
	iBtrDM	5.86	−13.61	0.994	9^b
	PivDM	7.20	−26.88	0.992	12
Alkyl	FDM	13.98	−89.64	0.993	9
	ADM	13.30	−106.75	0.987	5
	iBtrDM	12.26	−88.42	0.957	5
	PivDM	10.07	−62.90	0.964	6

[a] Number of experimental points. [b] Without *m*-OMe and *m*-OEt derivatives.

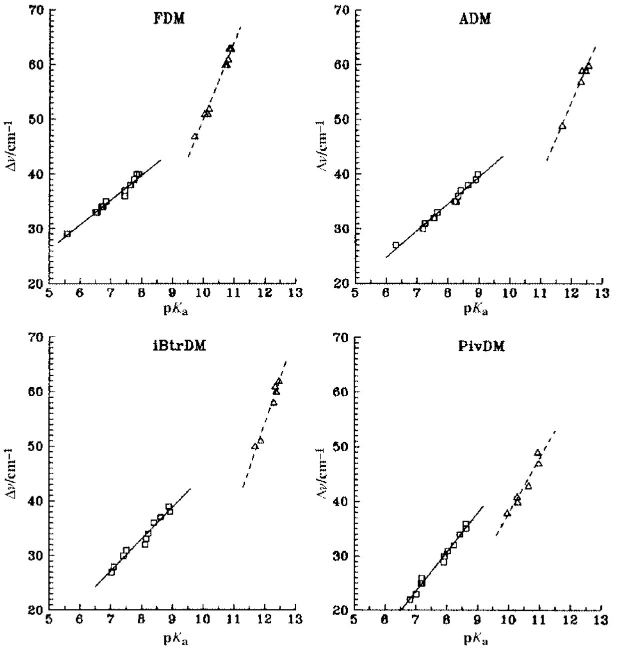


Fig. 1 Correlation of differences ($\Delta\nu$) between the C–D stretching frequency in uncomplexed and complexed $CDCl_3$ molecules and the pK_a values of amidines. **FDM**—N^1,N^1-dimethylformamidines (R^xN=CH-NMe_2); **ADM**—N^1,N^1-dimethylacetamidines (R^xN=CMeNMe_2); **iBtrDM**—N^1,N^1-dimethylisobutyramidines (R^xN=C(iPr)NMe_2); **PivDM**—N^1,N^1-dimethylpivalamidines (R^xN=C(tBu)NMe_2). □, N^2-aryl derivatives, Δ, N^2-alkyl and -aralkyl derivatives.

depend on the substituent at the amidino carbon atom, and for each series another relation is obtained. Moreover, N^2-aryl and N^2-alkyl derivatives should be treated separately (Fig. 1).

The parameters of separate correlations for N^2-aryl and N^2-alkyl derivatives in each series are summarized in Table 2. Correlation coefficients r indicate that for all studied series there is a good linear relation between $\Delta\nu$(C–D) and pK_a values of amidines. The differences between the $\Delta\nu$ values obtained experimentally and those calculated from obtained relations fall within the limits of estimated experimental error. The largest deviations are observed for amidines containing a phenyl ring substituted with a methoxy or ethoxy group in the *m*-position in the **FDM** and **iBtrDM** series. Without these experimental points correlations are of much higher quality (Table 2).

Table 3 Parameters of correlation between the shift of the C–D stretching frequency ($\Delta\nu$) in complexes with N^2-arylamidines and Hammett $\sigma°$ constants of substituents [eqn. (4)]

Series	R^1	σ^{*a}	ρ	$\Delta\nu°$	r	n^b
FDM	H	0.49	−11.69 ± 0.54	37.31	0.998	12
ADM	Me	0.00	−13.95 ± 1.26	36.13	0.992	12
iBtrDM	Pr^i	−0.19	−18.19 ± 1.94	34.47	0.992	10
PivDM	t-Bu	−0.30	−21.87 ± 1.21	30.84	0.997	11

[a] Taken from ref. 30. [b] Number of experimental points.

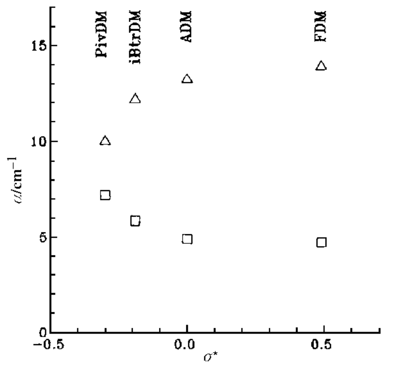


Fig. 2 Relationship between the a values [eqn. (3)] and σ^* values of the substituent at the amidino carbon atom; □, N^2-aryl derivatives, Δ, N^2-alkyl and -aralkyl derivatives.

Additional evidence for the hypothesis that the shift of the C–D stretching frequency is related to the basicity of the amidine is provided by correlations for complexes of amidines containing a substituted phenyl ring at the imino nitrogen with the Hammett type constants. Correlations are in the form of eqn. (4), analogous to the one for complexes with ethanol[17] mentioned above [eqn. (1)]. $\Delta\nu°$ is the shift in a complex with an amidine containing an unsubstituted phenyl ring. For the correlations the $\sigma°$ values were chosen because they are the most appropriate for characterization of the polar effects of substituent R^x on the phenyl ring at the nitrogen atom in amidines.[3,19,20]

$$\Delta\nu(\mathrm{CD}) = \rho\sigma° + \Delta\nu° \qquad (4)$$

$\Delta\nu°$ is the shift in a complex with an amidine containing an unsubstituted phenyl ring.

Obtained regression parameters are summarized in Table 3. The values of correlation coefficients r indicate that correlations with the $\sigma°$ values are of higher quality than those with the pK_a values, which is most probably due to much higher precision of determination of the $\sigma°$ substituent constants.

The data in Table 3 indicate that the value of the regression coefficient a for correlations of the $\Delta\nu$(CD) values with the pK_a values of amidines [eqn. (3)] is changing gradually with the increase of the volume and electron-donating effect (σ^* value) of the substituent.

The changes of the term a for N^2-arylamidines are analogous to those observed for correlations of the pK_a values of amidines with the Hammett-type constants of substituents at the imino carbon atom[3,21–23] for the same series of amidines, and are in agreement with the general conclusion that the sensitivity of the amidino group to polar effects of a substituent at any of the nitrogen atoms increases with the increase of the electron density in the N–C=N group caused by a substituent at the amidino carbon atom.[3]

However, the inverse order of changes of the a values observed for the series of N^2-alkyl- and N^2-aralkyl-substituted amidines (Fig. 2) indicates that in these cases other effects besides polar ones are involved. This is most probably due to the *E*–*Z* isomerism of amidines.

Acyclic amidines may show *E*–*Z* isomerism with respect to the formal C=N bond (substituent at the imino nitrogen atom with respect to the amino nitrogen). The *E* isomer is mostly energetically more favored than the *Z* one but the actual geometry depends on the substituents at the amidino group.[18] Structural investigations by the X-ray method have shown that in the crystalline state most amidines are *E*-isomers.[24] Steric repulsion between substituents at the imino nitrogen and amidino carbon atom may make the *Z* form more stable. The preference for the *Z* isomer in the case of amidines containing an alkyl substituent at the imino nitrogen atom was indicated by the results of correlations of the pK_a values of symmetrically *N*,*N'*-disubstituted amidines $R^xNH–CR{=}NR^x$ with the pK_a values of the corresponding primary amines (R^xNH_2).[25] Recently theoretical calculations have shown that even the polar effects of a substituent at a nitrogen atom may invert the preference for the *E*–*Z* isomerism.[18]

An alkyl or aralkyl group in N^2-alkyl- or N^2-aralkylamidines may make the *Z* configuration preferable. The preference will depend on the volume of the substituent at the amidino carbon atom and will increase in the following order: methyl (acetamidines, **ADM**), isopropyl (isobutyramidines, **iBtrDM**) and *tert*-butyl (pivalamidines, **PivDM**). A phenyl ring at the imino nitrogen atom does not involve a steric effect sufficient for preference of the *Z*-isomer even in the case of pivalamidines.

The strength of the hydrogen bond between deuteriochloroform and amidines and thus the $\Delta\nu$ values will depend on two factors: electron density on the imino nitrogen atom, and on the access to this atom.

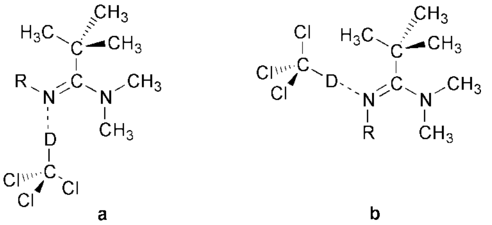


Fig. 3 Complexation of (a) *E* (*trans*) and (b) *Z* (*cis*) pivalamidines by deuteriochloroform.

Electron densities are not identical in *E* and *Z* isomers and their changes caused by the same substituent at a nitrogen atom are also different.[26] In the case of N^2-alkyl derivatives, which are more basic than N^2-aryl derivatives, the changes are more prominent and therefore the *a* values for alkyl derivatives are much higher (10.06–13.98) than for aryl derivatives (4.55–7.19).

In the *E* isomers (Fig. 3a) a dimethylamino group may adopt a conformation facilitating access to the imino nitrogen atom due to the possibility of rotation around the single C–N bond. In the *Z* isomers, in contrast, access to the imino nitrogen atom for the deuteriochloroform molecule is obstructed by steric hindrance of a substituent at the amidino carbon atom (Fig. 3b). The highest obstruction occurs in the case of the *tert*-butyl group (pivalamidines), therefore in the interactions between the two molecules the differences in electron densities on the imino nitrogen atom play a less important role and the *a* value is the smallest. In formamidines the hydrogen atom does not cause any steric hindrance and thus the *a* values are the highest.

Experimental

Materials

All studied amidines were synthesized and purified in our laboratory as described elsewhere: FDM,[27] ADM,[19] iBtrDM,[23] PivDM.[23] According to the gas chromatography analysis they were over 99% pure and free of starting amines and amides. The purity of the amidines was checked on a 3 m column packed with 15% silicone gum rubber GE SE-30 on Chromosorb W AW 60–80 mesh. Analyses were made at 240 °C using nitrogen at a flow rate of 40 cm^3 min^{-1}, and a flame ionization detector. Retention indices of the amidines are given elsewhere.[28,29] Deuteriochloroform from Unipan containing 99% of $CDCl_3$ was used at commercial purity.

Infrared measurements

Infrared spectra were studied by means of a UR-20 spectrometer (VEB Carl Zeiss, Jena) with a LiF prism. The spectra of complexes were recorded in the range 2000–2500 cm^{-1} for samples containing about 0.1–0.01 mmol of amidine and *ca.* 80 mol% of that amount of $CDCl_3$ in 1 ml of CCl_4, using NaCl and KBr cells of 0.25–1.00 cm thickness.

Acknowledgements

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References

1 Part 39. J. Oszczapowicz and J. Osek, *J. Chem. Soc.*, *Perkin Trans. 2*, 1998, 1919.
2 (*a*) J. Ševčik and F. Grambal, in *The Chemistry of Amidines and Imidates* (Ed. S. Patai), John Wiley and Sons, London, New York, 1975, p. 603; (*b*) J. Ševčik and F. Grambal, in *The Chemistry of Amidines and Imidates* (Ed. S. Patai), John Wiley and Sons, London, New York, 1975, p. 602.
3 J. Oszczapowicz, in *The Chemistry of Amidines and Imidates*, vol. 2, (Eds. S. Patai and Z. Rappoport), John Wiley and Sons, London, New York, 1991, p. 623 and references therein.
4 K. Jurkowska and R. Mierzecki, *Rocz. Chem.*, 1973, **47**, 627.
5 K. Jurkowska and R. Mierzecki, *Rocz. Chem.*, 1974, **48**, 337.
6 R. Mierzecki, *Adv. Mol. Relax. Processes*, 1973, **5**, 129.
7 B. Das, *Indian J. Chem.*, *Sect. A*, 1999, **38**, 95.
8 R. Farasram, P. L. Farasram and C. M. Decai, *Asian J. Chem.*, 1998, **10**, 385.
9 I. E. Boldeskul, I. F. Tsymbal, E. V. Ryltsev, Z. Latajka and A. J. Barnes, *J. Mol. Struct.*, 1997, **437**, 167.
10 J. Vaara, J. Lounila and J. Jokisaari, *Chem. Phys. Lett.*, 1998, **296**, 541.
11 T. Steiner and M. Tamm, *J. Organomet. Chem.*, 1998, **570**, 235.
12 V. A. Durov and I. Y. Shilov, *J. Chem. Soc.*, *Faraday Trans.*, 1996, 3559.
13 L. M. Fell and H. F. Shurvell, *Can. J. Appl. Spectrosc.*, 1996, **41**, 90 and references therein.
14 L. M. Fell and H. F. Shurvell, *Can. J. Appl. Spectrosc.*, 1996, **41**, 95.
15 T. S. Perova, D. H. Christensen and O. F. Nielsen, *Vib. Spectrosc.*, 1997, **15**, 61.
16 R. Mierzecki, J. Oszczapowicz and G. Kozakowski, *Pol. J. Chem.*, 1979, **53**, 1139.
17 J. Vaes, F. Faubert and Th. Zeegers-Huyskens, *Can. J. Chem.*, 1975, **53**, 604.
18 G. Häfelinger and F. K. H. Kuske, in *The Chemistry of Amidines and Imidates*, vol. 2, (Eds. S. Patai and Z. Rappoport), John Wiley and Sons, London, New York, 1991, p. 1.
19 J. Oszczapowicz and E. Raczyńska, *J. Chem. Soc.*, *Perkin Trans. 2*, 1984, 1643.
20 J. Oszczapowicz and W. Krawczyk, *J. Chem. Soc.*, *Perkin Trans. 2*, 1989, 21.
21 J. Oszczapowicz, C. U. Regelman and G. Häfelinger, *J. Chem. Soc.*, *Perkin Trans. 2*, 1990, 1551.
22 J. Oszczapowicz and M. Kumińska, *J. Chem. Soc.*, *Perkin Trans. 2*, 1994, 103.
23 J. Oszczapowicz and K. Ciszkowski, *J. Chem. Soc.*, *Perkin Trans. 2*, 1987, 663.
24 C. L. Perrin, in *The Chemistry of Amidines and Imidates*, vol. 2, (Eds. S. Patai and Z. Rappoport), John Wiley and Sons, London, New York, 1991, p. 147.
25 J. Oszczapowicz, J. Jaroszewska-Manaj and K. Ciszkowski, *Pol. J. Chem.*, 1993, **67**, 2159.
26 G. Häfelinger, J. Oszczapowicz and F. K. H. Kuske, *J. Prakt. Chem.*, 1996, **338**, 37.
27 J. Oszczapowicz and E. Raczyńska, *Pol. J. Chem.*, 1983, **57**, 419.
28 J. Oszczapowicz, J. Osek and E. Dolecka, *J. Chromatogr.*, 1984, **315**, 95.
29 J. Oszczapowicz, K. Ciszkowski and J. Osek, *J. Chromatogr.*, 1986, **362**, 383.
30 M. Charton, in *Similarity Models in Organic Chemistry*, *Biochemistry and Related Fields*, Eds. R. I. Zalewski, T. M. Krygowski and J. Shorter, Elsevier, Amsterdam, Oxford, New York, Toronto, 1991, p. 629.