Tautomerism in some Acetamido Derivatives of Nitrogen-containing Heterocycles: X-ray Structural Analysis of 2-Amino and 2-Imino Forms of Benzothiazole Derivatives

Marco Annese,[a] Anna Bonamartini Corradi,[b] Luciano Forlani,[a] Corrado Rizzoli[c] and Paolo Sgarabotto[c]

[a] *Dipartimento di Chimica Organica 'A. Mangini', Università di Bologna, viale Risorgimento 4, I-40136 Bologna, Italy*

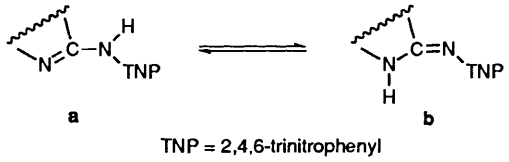
[b] *Dipartimento di Chimica, Facoltà di Ingegneria, Università di Modena, via Campi 183, I-41100 Modena, Italy*

[c] *Istituto di Strutturistica Chimica, Università di Parma, Centro di Studio per la Strutturistica Diffrattometrica del CNR, viale delle Scienze, I-43100 Parma, Italy*

Amide and acylimine derivatives of nitrogen-containing heterocycles have been investigated by X-ray diffraction and IR and UV–VIS spectroscopy. X-Ray crystal diffraction indicated that the product of the reaction between 2-aminobenzothiazole and α-chloropropionyl chloride is in the amide form, whereas the product of the reaction between 2-aminobenzothiazole and trichloroacetyl chloride is in the acylimine form. The UV–VIS spectroscopic data define the position of the tautomeric equilibrium; the previously reported quantitative method to evaluate the position of the tautomeric equilibrium without the direct use of parameters arising from fixed parents is suitable for the compounds considered. Medium polarity, electron-withdrawing power of the acyl group, acidity of the exocyclic N–H bond, and ring size and aromaticity of the heterocyclic moiety were the main starting points for investigating the tautomeric properties in potential prototropic systems.

Knowledge of the structure of amine groups in nitrogen-containing heterocycles is an important starting point in evaluating the reactivity and the geometrical and spectroscopic properties of amine groups in heterocycles and related compounds.[1] Tautomerism in heterocyclic chemistry is an old problem and it has been extensively studied from a qualitative point of view. The main method which has been used to state the relative population of tautomeric species is to compare the spectroscopic properties of the prototropic species with those of fixed parents (both amine and imine) obtained by substitution of hydrogen with an alkyl group (frequently methyl). However, this method grows out of the assumption that spectroscopic properties are unchanged by substitution of the hydrogen (usually bonded to a heteroatom such as oxygen, sulfur or nitrogen) with an alkyl group. Instances of the importance of the substitution of the hydrogen with a methyl group on the spectroscopic properties in 2,4,6-trinitrodiphenyl amines[2] and in 2-*N*-(2,4,6-trinitrophenyl)heteroaryl amines[3] have been reported by us.

Recently, a simple method for the evaluation of the position of amine–imine tautomerism in the heterocyclic series illustrated in Scheme 1 was proposed by using particular



TNP = 2,4,6-trinitrophenyl

Scheme 1

derivatives of azoles.[4] This method originates in the observation that the predominance of form **a** (or **b**) is very high in a particular solvent (or medium, *i.e.* solvent and solute) and that the equilibrium can be shifted toward the predominance of the second tautomer by changes in the properties of the medium. Generally, it is assumed that the medium polarity and the differences in polarity of forms **a** and **b** are the important parameters affecting the position of the tautomeric equilibrium. The use of the fixed parents' properties (if available, or related compounds which are clearly only in one isomeric form in the selected solvent system if not) constitutes the only indirect ('external') comparison.

The evaluation of the ratio C_a/C_b by spectroscopic measurements (C_x refers to the concentration value of form x at equilibrium) includes the assumption that in a particular solvent, **a** and **b** are the only detectable forms. Furthermore, the ratio of the concentration of the tautomers must be near to unity for there to be the possibility of shifting the position of the equilibrium of Scheme 1 by small modifications in the medium polarity. In previous models, the addition of variable amounts of a salt to solutions of the derivatives in Scheme 1 has been shown to produce a shift in λ_{max} (UV–VIS spectrum) from that of the amino aromatic form (which may be considered the less polar form) toward that of the more polar form. In this way, a 'titration-like' plot of λ_{max} against the salt concentration allowed us to obtain the extinction coefficients of both tautomers and the observed absorbance values of the mixtures of **a** and **b** when the ratio C_a/C_b was near to unity. Obviously, the compounds used must be of known structure; positional isomerism in the compounds considered may cause misinterpretations.[5]

With the aim to identify other compounds suitable for checking the proposed method for evaluating C_a/C_b ratios, we devoted some attention to literature reports on substituted 2-acetamido-benzothiazole[6] and -thiazoles.[7,8]

Results and Discussion

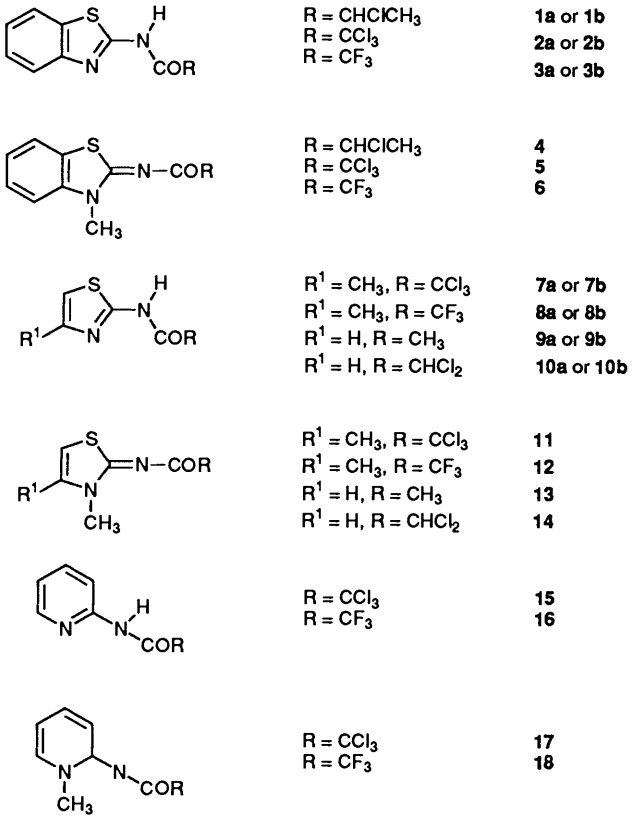
Table 1 reports the physical properties of compounds **2–18**. The separation by crystallization of tautomers has been reported[6] for some 2-amidobenzothiazoles, so we were encouraged to use 2-amidoazoles for our purposes.

Following the literature reports, we attempted the separation of the tautomers of **1**. Costakis *et al.* report[6] the separation of two forms of **1** with m.p.s 114–115 °C and 124–125 °C by manual collection of crystals which they assigned to be **1a** and

Table 1 Physical properties of derivatives **2–18**

Compound	M.p./°C (solvent[a])	Mass spectra (*m/z*) Found	Formula	Requires	UV–VIS spectrum λ_{max}/nm (log ε) CCl_4	DMSO
2	198–99 (Et_2O)	293.917 9	$C_9H_5Cl_3N_2OS$	293.918 81	292 (4.03)	321 (4.34)
3	215–17 (MeOH)	246.008 6	$C_9H_5F_3N_2OS$	246.007 46	282 (4.07)	317 (4.31)
4	95–96 (MeOH)	254.030 0	$C_{11}H_{11}ClN_2OS$	254.028 06	317 (4.32)	317 (4.37)
5	198–99 (MeOH)	307.934 6	$C_{10}H_7Cl_3N_2OS$	307.934 47	319 (4.31)	323 (4.31)
6	165–68 (MeOH)	260.024 1	$C_{10}H_7F_3N_2OS$	260.023 12	315 (4.35)	319 (4.32)
7	215–16 (MeOH)	257.918 4	$C_6H_5Cl_3N_2OS$	257.910 88	287 (3.81)	316 (4.11)
8	115–17 (Et_2O)	210.000 7	$C_6H_5F_3N_2OS$	210.007 46	281 (3.84)	308 (4.07)
9	205–07 (Et_2O)	142.020 1	$C_5H_6N_2OS$	142.020 08	258 (3.91)	267 (3.95)
10	181–82 (MeOH)	209.941 8	$C_5H_4Cl_2N_2OS$	209.942 13	275 (3.91)	287 (3.92)
11	154–55 (MeOH)	271.934 7	$C_7H_7Cl_3N_2OS$	271.934 47	313 (4.09)	318 (4.13)
12	180–81 (Et_2O)	224.023 2	$C_7H_7F_3N_2OS$	224.023 12	308 (4.15)	313 (4.14)
13	124–26 (Et_2O)	156.034 4	$C_6H_8N_2OS$	156.035 73	297 (4.03)	300 (4.13)
14	126–28 (Et_2O)	223.958 4	$C_6H_6Cl_2N_2OS$	223.957 79	306 (4.17)	310 (4.12)
15	81–82 (MeOH)	237.947 3	$C_7H_5Cl_3N_2O$	237.946 75	276 (4.01)	276 (3.91)
16	72–73 (MeOH)	190.035 9	$C_7H_5F_3N_2O$	190.035 40	344 (4.03)	345 (4.06)
17	118–19 (MeOH)	252[b]	$C_8H_7Cl_3N_2O$	251.962 39	273 (3.89)	274 (3.83)
18	119–20 (Et_2O)	204[b]	$C_8H_7F_3N_2O$	204.051 03	342 (4.01)	338 (4.12)

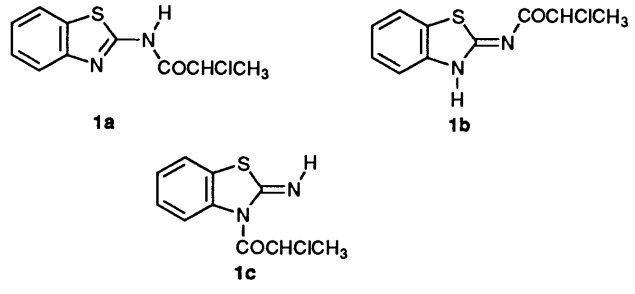
[a] Crystallization solvent. [b] Molecular ion unsuitable for determination of correct M^+.



Scheme 2

1b, respectively, on the basis of IR spectral data (KBr) (Scheme 2). We tried a number of crystallizations (see Experimental) and a compound which melted at 114–115 °C was obtained in almost quantitative amunts from all the solvents used except petroleum (b.p. 100–150 °C). Very slow (> 1 month) crystallization from this solvent yielded three forms with m.p.s 124–125 (**X**), 114–115 (**Y**) and 132–133 °C (**Z**) for which characterising data are given in Table 2.

The structure of form **X**, was investigated by us by X-ray diffraction and confirmed to be the aromatic amide **1a**. Unfortunately, crystals of **Y** and **Z** were unsuitable for X-ray diffraction analysis. By considering that **X** and **Y** in solution are practically indistinguishable by their spectroscopic properties (see Table 2), but that they differ in their m.p.s and in IR spectra in the solid (KBr), there are two main possibilities: either form **Y** is a tautomeric isomer of **X** (*i.e.* the acylimine form **1b**) or it is a polymorphic form of the same tautomer, **1a**. The nature of the



considered acyl group (which is poorly electron-withdrawing) and the spectroscopic behaviour of **1a** in comparison with the behaviour of similar compounds are arguments in favour of **Y** being a second polymorphic form of **1a**.

The third form **Z** is different from **X** and **Y** both in solid and in solution, and assignment to structure **1c** is consistent with the data of Table 2. This isomer is absent in the crude reaction product and probably arises from a slow migration of the acyl group.

As a consequence, the previous IR spectral data assignment for 2-acetamidobenzothiazoles and -thiazoles (in solid) needs revision. The first absorption[6] band near to 1700 cm^{-1} (see Table 3) may be attributed to the C=O group. Compounds **4–6**, **11–14** and **17**, **18** are imide fixed parents. For these compounds, the C=O band (which is in the range 1589–1647 cm^{-1}) may be attributed to the acylimine group C=N–C=O. With the purpose of obtaining evidence for the existence of a genuine acylimine tautomer, we undertook the X-ray diffraction analysis of the 2-(2,2,2-trichloroacetamido)benzothiazole **2b** which is an acylimine (non-aromatic) (see section on *Molecular Geometry*). Compound **2b** shows a C=O stretch (1670 cm^{-1}) outside the range

Table 2 Physical properties of the products obtained by crystallization from petroleum (b.p. 100–150 °C) of the reaction between 2-aminobenzothiazole and α-chloropropionyl chloride

Product	M.p./°C	$M^+(m/z)$[b]	δ_H	[λ_{max}/nm (log ε)]	ν/cm^{-1} [d]
X[a]	124–25	240.0130	1.82 (d, 3 H) 4.60 (q, 1 H) 8.1 (br s, 1 H) 7.1–7.6 (m, 4 H)	CCl_4 300 (4.01) DMSO 300 (4.16)	1671s, 1602m, 1557s, 1456m, 1440m
Y[a]	114–15	240.0124	1.80 (d, 3 H) 4.55 (q, 1 H) 8.0 (br s, 1 H) 7.1–7.6 (m, 4 H)	CCl_4 301 (4.02) DMSO 300 (4.16)	1714s, 1600m, 1559s, 1456m, 1441s
Z[a]	132–33	240.0112	1.75 (d, 3 H) 4.60 (q, 1 H) 7.2–7.9 (m, 4 H) 10.4 (br s, 1 H)	CCl_4 264 (3.98) DMSO 268 (4.10)	1636s, 1600m, 1583m, 1533w, 1466m

[a] See text for structural assignments. [b] $C_{10}H_9ClNOS$ requires 240.012 41. [c] In $CDCl_3$; internal reference tetramethylsilane; broad N–H signal which disappears on addition of D_2O. [d] In KBr; s = strong, m = medium, w = weak.

Table 3 IR spectra data (in KBr) of derivatives **2–18** in the double bond (C=O, C=N) region

Compound	ν_{max}/cm^{-1} [a]			
2	1617m	1601w	1534m	1492m
3	1619s	1603s	1534s	1506m
4	1623m	1507s	1472m	1457m
5	1638s	1507s	1459s	1405s
6	1647s	1501s	1469s	1423m
7	1620w	1569s	1490s	1419m
8	1670s	1646m	1584w	1438m
9	1693s	1566s	1496m	1428m
10	1711s	1666w	1596s	1499w
11	1616s	1590s	1485s	1414m
12	1623s	1592m	1495s	1473m
13	1589m	1567m	1496m	1403m
14	1607s	1559m	1490s	1408s
15	1718s	1576m	1507m	1500m
16	1734s	1602m	1582m	1549m
17	1637s	1552s	1464m	1455m
18	1675s	1591s	1528w	1475w

[a] s = strong, m = medium, w = weak.

Table 4 Effect of the addition of DMSO to a solution of 2-(2,2,2-trifluoroacetamido)benzothiazole (**3**)[a] in CCl_4 at 25 °C

10^4[DMSO]/mol dm^{-3}	λ_{max}/nm	10^4[DMSO]/mol dm^{-3}	λ_{max}/nm
b	281.4	4.72	309.2
0.124	281.4	5.90	310.2
0.236	281.4	7.08	311.3
0.345	281.5	8.26	311.5
0.472	281.3	9.44	312.2
0.503	281.4	10.6	312.2
0.708	281.6	11.8	312.7
0.944	282.1	14.2	312.9
1.42	282.9	23.6	313.4
1.89	283.6	47.2	313.6
2.36	285.0	66.3	313.8
2.60	288.1	70.8	313.7
2.95	292.1	94.4	313.8
3.20	296.5	118	313.8
3.54	306.3	177	313.8
4.02	305.0	236	313.9

[a] [**3**] = 3.0×10^{-5} mol dm^{-3}. [b] The Beer-Lambert law was checked in the range of [**3**] from 2.0×10^{-5} to 8.0×10^{-5} mol dm^{-3}.

above attributed to an acylimine group. Compound **1a** shows a C=O band at 1671 cm^{-1} and is an amide form. Probably compounds with $\nu_{C=O}$ close to 1700 cm^{-1} (**9**, **10**, **15**, **16**) are amide aromatic forms. Consequently, **Y** ($\nu_{C=O}$ = 1714 cm^{-1}) is confirmed to be an amide form (polymorph of **1a**).

In conclusion, the above considerations indicate that the structure of a tautomer (in the solid state) can hardly be assigned only on the basis of a comparison of IR spectral data (solid state) of fixed parents. Polymorphism or other structural situations, such as hydrogen bonding, may cause misleading spectral differences. In addition, the attribution of the structure of positional isomers by considering the nature of the reagent [7,9] may be erroneous. The monoacetylation of 2-aminoazoles is indicated to occur at the exocyclic nitrogen. Probably form **Z** is an example of a derivative with the COR group bonded to the endocyclic nitrogen (**1c**). In fact, the regioselectivity [5,9] of 2-aminoazoles toward electrophilic reagents is a balance of several parameters and any prediction is difficult.

The UV spectroscopic data of Tables 1 and 2 show that the λ_{max} differences in the two considered solvents may be related to the position of the tautomeric equilibria. Acylimine forms (**4–6**, **11–14**, **17**, **18** and **1c**) show small differences [$\Delta = \lambda_{max}$(DMSO) − $\lambda_{max}(CCl_4)$] (DMSO = dimethyl sulfoxide) upon changing the solvent. Possible amide derivatives **1–3**, **7–10** present Δ values near to 30 nm when R is a strong electron-withdrawing group ($COCl_3$, $COCF_3$) for thiazole and benzothiazole derivatives, but Δ values are very low for the pyridine system and for thiazole (and benzothiazole), when acyl groups are moderately electron-withdrawing.

It is possible to conclude that compounds **2**, **3**, **7**, **8** are in the amide aromatic forms in CCl_4 while the acylimine forms predominate in DMSO. This conclusion agrees with previous findings.[4,7,10–12] Compounds **1**, **9**, **10**, **15**, **16** are amide aromatic forms in both solvents. In fact, the importance of the heterocyclic moiety (and of the medium) on the tautomeric ratio of some di- and tri-nitrophenyl derivatives of 2-aminoazoles [3,11] was previously checked; for pyridine and pyrimidine systems, the amine aromatic form predominates in both polar and non-polar solvents. For the thiazole derivatives, when strong electron-withdrawing groups are bonded to the exocyclic nitrogen, the tautomeric equilibrium in toluene (in which solvent the amino aromatic form predominates) may be shifted from amine aromatic form to imine, by simple addition of small amounts of DMSO or salt. Addition of DMSO to a CCl_4 solution of compounds **2**, **3**, **7**, **8**, after an initial range of [DMSO] values over which λ_{max} value was unaffected by DMSO, produced a red shift in the λ_{max} value, in the UV–VIS spectrum (see Table 4). λ_{max} Is increased by increasing [DMSO] until it reaches a maximum value which is near to the value in CCl_4 of fixed imine parents (see Tables 1 and 4). The behaviour of compounds **2**, **3**, **7**, **8** may be explained by the presence of only the amide form in CCl_4, and by higher values of the C_b/C_a ratio on addition of DMSO. C_b/C_a Ratios are calculated in the range of [DMSO] which favours the presence of both species (K_T

value near to 1). The slopes of plots of C_b/C_a against [DMSO] indicate the sensitivity of the equilibrium of Scheme 2 to the addition of DMSO. The slopes of plots are reported in Table 5, and they allow us to compare C_b/C_a values at a fixed value of [DMSO].

Some points are worthy of consideration: (*i*) The position of the equilibrium in Scheme 2 is strongly affected by the electron-withdrawing power of R—this fact is probably connected with the acidity of the exocyclic N–H. (*ii*) Data here reported confirm the importance of the heterocyclic moiety. Pyridine derivatives do not exhibit any acylimine form even when strong electron-withdrawing groups are bonded to the exocyclic nitrogen. The five-membered ring is more prone to transform itself in a non-aromatic form than the six-membered one. This fact may be related to the relative stabilization by the resonance energy which is higher for six- than for five-membered heterocycles. This conclusion agrees with the benzo-condensation effect; benzothiazole derivatives are more prone to exist in non-aromatic forms than thiazole derivatives. (*iii*) The method used to compare the tautomeric properties of heterocyclic derivatives is a quantitative evaluation of the idea that the medium polarity is a very important parameter to study the position of the equilibrium of Schemes 1 and 2. Present findings agree in attributing higher charge separation to the acylimine than the amide form. This fact agrees with a non-specific polarity effect of the medium, while specific interactions (which were previously indicated to be operative) need further investigations. (*iv*) In our investigations on amino nitrogen-heterocycles, we were not able to obtain evidence for the presence of self-associated species,[10] which are usually observed in the presence of hydroxy (or mercapto) groups[13] as represented in Scheme 3. It appears possible to associate the presence of large amounts of dimers with the acidity of the X–H group and the predominance of the non-aromatic tautomer (X = O, S), while poor self-association and low acidity of X–H may be associated with the presence of an aromatic form (X = NR).

Table 5 Slopes of plots of ratios C_b/C_a *vs.* concentration values of DMSO in CCl_4 at 25 °C

Compound	λ/nm[a]	Slope/dm^3 mol^{-1}	n[c]	R[d]
2	310	451 ± 21	7	0.994
3	310	1319 ± 3	9	0.998
7	300	224 ± 9	7	0.995
8	300	321 ± 11	7	0.997

[a] Used in the determinations. [b] Errors are standard deviations. [c] n = Number of points. [d] Correlation coefficient.

Scheme 3

Molecular Geometry.—Selected bond distances and angles are given in Table 6 and the arbitrary numbering scheme used in the crystal analyses is shown in Figs. 1 and 2, which represent perspective views of 2-(2-chloropropionamido)benzothiazole **1a** and 2-(2,2,2-trichloroacetimido)benzothiazole **2b**, respectively. The conformational analysis of the molecules, deduced from the torsion angles reported in Table 6, indicates that the

Table 6 Selected bond distances (Å), angles (°) and torsion angles (°) for non-hydrogen atoms; esds in parentheses

	1a		**2b**
	X = 1	X = 2	X = 1
Cl(X1)–C(X8)	1.763 (8)	1.817 (9)	1.749 (9)
Cl(X2)–C(X8)			1.745 (9)
Cl(X3)–C(X8)			1.761 (10)
S(X)–C(X)	1.733 (6)	1.741 (6)	1.739 (8)
S(X)–C(X6)	1.744 (7)	1.733 (7)	1.749 (10)
O(X)–C(X7)	1.215 (8)	1.210 (8)	1.259 (10)
N(X1)–C(X)	1.290 (8)	1.278 (8)	1.327 (10)
N(X1)–C(X1)	1.391 (9)	1.396 (9)	1.389 (11)
N(X2)–C(X)	1.420 (9)	1.387 (9)	1.342 (11)
N(X2)–C(X7)	1.338 (9)	1.350 (9)	1.316 (10)
C(X7)–C(X8)	1.523 (10)	1.516 (10)	1.544 (12)
C(X8)–C(X9)	1.494 (12)	1.542 (15)	
C(X)–S(X)–C(X6)	87.2 (3)	87.7 (4)	91.0 (4)
C(X)–N(X1)–C(X1)	108.4 (5)	109.8 (6)	115.7 (6)
C(X)–N(X2)–C(X7)	124.9 (5)	125.6 (6)	116.7 (7)
S(X)–C(X)–N(X1)	118.9 (5)	117.8 (5)	111.5 (6)
S(X)–C(X)–N(X2)	121.7 (5)	121.8 (5)	126.8 (6)
N(X1)–C(X)–N(X2)	119.4 (5)	120.4 (6)	121.7 (7)
N(X1)–C(X1)–C(X2)	125.3 (6)	124.9 (7)	127.9 (8)
N(X1)–C(X1)–C(X6)	115.6 (6)	114.4 (6)	111.8 (7)
S(X)–C(X6)–C(X1)	110.0 (5)	110.6 (5)	110.0 (6)
S(X)–C(X6)–C(X5)	128.6 (6)	129.2 (7)	129.7 (7)
O(X)–C(X7)–N(X2)	122.8 (6)	123.0 (6)	126.9 (7)
O(X)–C(X7)–C(X8)	122.7 (6)	122.8 (6)	117.6 (7)
N(X2)–C(X7)–C(X8)	114.5 (6)	114.1 (6)	115.5 (7)
N(X1)–C(X)–N(X2)–C(X7)	−178.9 (6)	−177.1 (7)	−180.0 (8)
C(X)–N(X2)–C(X7)–O(X)	1.8 (10)	−5.7 (11)	−11.5 (13)
O(X)–C(X7)–C(X8)–C(X1)	−57.0 (8)	51.0 (8)	−13.4 (10)
O(X)–C(X7)–C(X8)–C(X9)	67.6 (9)	−71.3 (10)	
S(X)–C(X)–N(X2)–N(X7)	2.9 (9)	0.2 (10)	−1.8 (11)

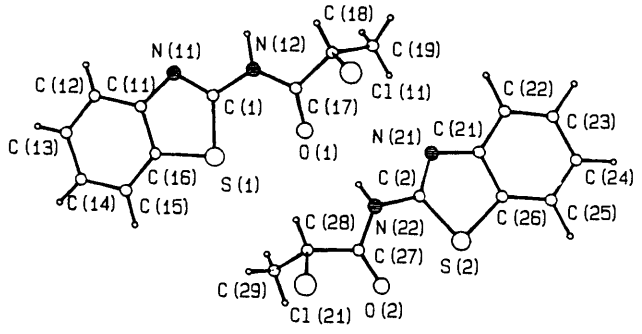


Fig. 1 Perspective view of the two independent molecules of 2-(2-chloropropionamido)benzothiazole **1a**

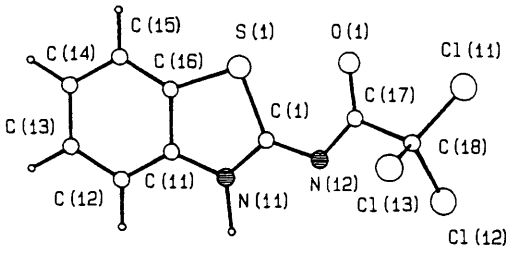


Fig. 2 Perspective view of 2-(2,2,2-trichloroacetimido)benzothiazole **2b**

two compounds in the solid state adopt the same configuration, the (*Z*)-type, [the sulfur and carbonyl group *cis* with respect the C(X)–N(X2) bond]. A comparison of the values of bond distances and angles shows that in the two symmetry independent molecules of compound **1a** in which a strong C=N endocyclic bond is present, the tautomeric form is the amine one, and this fact is confirmed by the location of the H atom on N(X2). On the contrary, the imine form of the compound **2b** can be deduced only by the localization of the H atom on N(11); on the other hand, the trend of the bond angles of **2b** with respect to those of **1a**, in line with the results of the analysis reported by Argay *et al.*[15] on various 2-amino(imino)thiazoli(di)nes, [considerably smaller endocyclic angle on C(X), greater on N(X1) and exocyclic angle on C(X)], is in favour of the predominance of the imine form for compound **2b**, also in the absence of an expected strong C=N exocyclic bond.

The two symmetry-independent molecules of compound **1a** are similar only as regards the hybridization of the atoms, the main peculiarity concerning the configuration of the C(X8) atom which is reversed in the two molecules as it appears by torsion angles on C(X7)–C(X8) of Table 6. The significant differences in the geometrical parameters in this last portion of the two molecules can be interpreted in terms of a slight disorder in the crystal of molecule 2, as suggested by the thermal parameters of the Cl(21), C(28) and C(29) atoms. If the analysis is extended to the other bond lengths belonging to the amide moiety, it becomes evident that the two molecules are characterized by two different values of the exocyclic N–C bonds with a significant shortening of that adjacent to the carboxylic group [N(X2)–C(X) 1.429(9) and 1.387(9) Å and N(X2)–C(X7) 1.338(9) and 1.350(9) Å in molecules 1 and 2, respectively]. These values are in good agreement with those reported in the literature for acetylamine–CO–NH–C(sp^2)– groups [1.411(2) and 1.341(2) Å in *p*-acetotoluidine,[16] 1.422(6) and 1.345(6) Å in 2-acetylaminofluorene,[17] 1.446(3) and 1.354(3) Å in 4-acetylaminofluorene[18]] but are significantly different from those found in analogous compounds where C(sp^2) belongs to a thiazolic ring with an S atom involved, as in our compound, in short intramolecular contact with the carboxylic oxygen; in these cases, the two amine bond lengths have comparable values [1.38(1) and 1.38(1) Å in ethyl 5-benzamido-2-benzoylimino-1,3-dithiol-4-carboxylate,[19] 1.375(5) and 1.371(5) Å in 2-cyclohexanecarboxamido-2-thiazoline[20]].

As regards compound **2b**, the absence of a strong C=N exocyclic bond is in contrast to the geometries in the other imine groups (with the exception of that reported by Kutoglu and Jepsen[21] in which a discrepancy between atomic coordinates and distances and angles involving imine N is present). Our values are in agreement with the hypothesis of Chohen-Addad *et al.*,[22] which, in the neutron structural analysis of 2-(2-chlorobenzoylimino)-1,3-thiazolidine, produced values substantially similar in the two exocyclic C–N bonds and practically identical in both the charge density on the three C–N bonds of the N(1)–C(1)–N(2)–C(7) moiety and the deformation density in the lone pair region of the N(1) and N(2); this fact is in favour of the hypothesis previously supposed of a tautomeric equilibrium between the amine and imine forms.

The structures of the two compounds reveal the presence of a short intramolecular S ··· O approach [2.741(4) and 2.754(4) Å in molecules 1 and 2, respectively, of **1a** and 2.608(8) Å in **2b**], considerably less than the sum of the van der Waals radii, 3.3 Å, but comparable with that found in the related compound reported in literature.[20,22,23] In agreement with Abrahamsson and Zacharis,[24] who affirm that the interaction between the negatively polarized carbonyl O atom with the positively charged S is strong enough, even at a distance of 2.8 Å, to compensate the repulsion forces between S and O, there are also slight deviations from the theoretical values observed in this moiety of the molecule, *viz* (*a*) a lengthening of C=O [1.215(8) and 1.210(8) Å in **1a** and 1.259(10) Å in **2b**]; (*b*) values of the C(X6)–S(X) ··· O(X) angle [161 and 164° in **1a** and **2b**, respectively] suggesting possible weak participation of the p and d orbitals of sulfur in the S ··· O bonding; (*c*) formation of an almost planar pseudo S(X)–C(X)–N(X2)–C(X7)–O(X) cycle [the highest deviation from coplanarity being 0.1 Å shown by C(X7) of molecule **2b**]. The S ··· O interaction, confirming the electron donating power of the sulfur atom in the thiazole system can also explain the presence of only the (*Z*) geometry in these molecules.

All the rings of the two structures are planar within the experimental errors; the carboxylic oxygen atom is out of the plane of the thiazoline ring by 0.021(5) and −0.074(5) Å in molecules 1 and 2 of **1a** and 0.121(8) Å in **2b**. The benzothiazine moiety can be considered rigorously planar, there being dihedral angles of 1.0(2), 1.9(2) and 0.8(3)° in molecule 1 and 2 of **1a** and in **2b**, respectively, between the five- and six-membered rings. Packing in the two structures is determined by hydrogen bonds of type N–H ··· O; in compound **1a**, two link the two independent molecules of the asymmetric unit {[N(22) ··· O(1) 2.905(7), H(22) ··· O(1) 2.14(5) Å; N(22)–H(22) ··· O(1) 171(6)°] and [N(12) ··· O(2) 2.900(6), H(12) ··· O(2) 1.91(7) Å; N(12)–H(12) ··· O(2) 165(5)°]}, contributing to generate a ribbon undulating by 29° in the *x* direction. In compound **2b**, [N(11) ··· $O(1)^i$ 2.813(8), H(11) ··· $O(1)^i$ 1.68(11) Å; N(11)–H(11) ··· $O(1)^i$ 145(10)°, where $i = 1/2 - x, y - 1/2, 1/2 + z$]. Other contacts are consistent with van der Waals interactions.

Experimental

Materials.—Amide derivatives of **1**–**18** were prepared by the usual procedures from related amines and anhydrides or acyl chlorides as appropriate.

The crude 2-(3-chloropropionamido)benzothiazole was crystallized from several solvents: methanol, ethanol, tetrahydrofuran, diethyl ether, toluene, ethyl acetate and methylene dichloride. All the collected samples melted at 114–115 °C. From petroleum (boiling range 100–150 °), three compounds

were obtained by manual separation: (**1a**) in large amount, (**1b**) and (**1c**) in low yields (< 10%). Their physical properties are collected in Table 2. M.p.s are uncorrected.

Carbon tetrachloride was purified by usual procedures.[14] DMSO was freshly distilled from calcium hydride.[14]

The UV–VIS spectra were recorded with a Perkin-Elmer Lambda 5 spectrophotometer. The Beer–Lambert law was checked (in both solvents) in the concentrations range 0.4–2.5 × 10^{-4} mol dm^{-3}. IR spectra were recorded with an FTIR Perkin-Elmer 1600 spectrophotometer.

Determination of C_b/C_a *Ratios.*—This was carried out using eqns. (1) and (2) where C_a and C_b are the concentration values of

$$A = \varepsilon_b C_b + \varepsilon_a C_a \quad (1)$$

$$C_{st} = C_b + C_a \quad (2)$$

amino and imino forms, respectively, of the considered compound dissolved in carbon tetrachloride, C_{st} is the total concentration value, A is the experimental absorbance value measured at an appropriate λ value (see Table 5), ε_a is the molar absorption coefficient in the absence of DMSO and ε_b is the molar absorption coefficient measured in the presence of excess of DMSO. Table 5 reports an example of the effect of addition of DMSO to a solution of compound **1c** in CCl_4. Slopes of plots of [DMSO] values against C_b/C_b values (see Table 5) were calculated by least-squares method.

Crystal Structure of 2-(2-*Chloropropionamido*)*benzothiazole* (**1a**).—Crystals, obtained from ethyl acetate solution, were colourless prisms. Lattice constants were determined by least-square refinement of angular settings of 30 reflections.

Crystal data. $C_{10}H_9ClN_2OS$, M = 240.7. Monoclinic a = 9.646(2), b = 17.345(4), c = 13.439(3) Å, β = 98.1°, V = 2226.1(10) $Å^3$; Z = 8, D_c = 1.44 g cm^{-3}; Cu-Kα radiation λ = 1.5418 Å, μ = 46.1 cm^{-1}. Space group $P2_1/c$ (C_{2h}^5, no. 14) from systematic absences.

X-Ray measurements were performed at T = 294 K on a Siemens AED single-crystal diffractometer in the range $3 < \theta < 70°$ using Ni-filtered Cu-Kα radiation. The diffraction angle θ for every reflection was determined on the basis of the orientation matrix and the outline of the diffraction peak was collected in the θ–2θ step scanning mode using a scan width from $(\theta–0.60)°$ to $(\theta + 0.60 + \Delta\lambda/\lambda \tan\theta)°$. The intensities I_{hkl} were determined by analysing the reflection profiles with the Lehmann and Larsen[25] procedure. Of 4565 independent reflections measured ($-11 \leqslant h \leqslant 11$, $0 \leqslant k \leqslant 21$, $0 \leqslant l \leqslant 16$), 1764 (internal R merging factor 0.021) were used in the crystal analysis. During the data collection, a decay of about 10% showed up in the intensity of the 'standard' reflection and therefore an appropriate correction on the data was applied. The dimensions of the crystal were 0.28 × 0.21 × 0.28 mm. No absorption corrections were applied.

Structure analysis and refinement. The structure was solved by direct methods using SHELXS86[26] and refined by SHELX76[27] by cycles of full-matrix anisotropic least-squares (hydrogen atoms isotropically) up to R = 0.050, R_w = 0.053. The weighting function was of the form $w = 0.552/(\sigma^2 F_0 + 0.0013 F_0^2)$.

Crystal Structure of 2-(2,2,2-*Trichloroacetimido*)*benzothiazole* (**2b**).—Crystals were flat, colourless prisms. Lattice parameters were derived as before.

Crystal data. $C_9H_5Cl_3N_2OS$, M = 295.6. Orthorhombic a = 18.795(4), b = 11.184(3), c = 5.536(2) Å, V = 1163.7(6) $Å^3$; Z = 4, D_C = 1.69 g cm^{-3}, Cu-Kα radiation λ = 1.5418 Å, μ = 88.0 cm^{-1}. Space group $Pna2_1$ (C_{2v}^9, no. 33) from structure determination.

X-ray measurements were performed as before. 1331 Independent reflections ($0 \leqslant h \leqslant 22$, $0 \leqslant k \leqslant 13$, $0 \leqslant l \leqslant 6$) were measured of which 787 having $I_{hkl} > 2\sigma(I_{hkl})$ [$\sigma(I)$ based on statistic counting] were used in the refinement. One standard reflection, measured every 50 collected reflections, showed no significant variations. The dimensions of the crystal were 0.05 × 0.19 × 0.24 mm. Corrections for Lorentz and polarization efects were performed. Absorption effects were corrected using ABSORB,[28] the maximum and minimum value of the transmission factor in the two polar angles φ and μ of the incident and diffracted beam paths were 1.209 and 0.672, respectively.

Structure analysis and refinement. The structure was solved and refined as before up to R = 0.041, R_w = 0.046. The weighting function was of the form $w = 0.260/(\sigma^2 F_0 + 0.0066 F_0^2)$. All the hydrogen atoms were located in the difference Fourier map.

For all the compounds atomic scattering factors were from ref. 29 for non-hydrogen atoms and from ref. 30 for hydrogen.

Lists of bond lengths and angles, fractional atomic coordinates and thermal parameters have been deposited as supplementary data at the Cambridge Crystallographic Data Centre.* All the calculations were carried out on the GOULD 6040 POWERNODE computer of the *Centro di Studio per la Strutturistica Diffrattometrica del CNR* of Parma. Bibliographic searches were carried out using the Cambridge Structural Database Files through the *Servizio Italiano di Diffusione Dati Cristallografici*, Parma.

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* For details of the CCDC deposition scheme, see '*Instructions for Authors*,' *J. Chem. Soc., Perkin Trans. 2*, 1994, issue 1.

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