Synthesis and Structural Assignment of Oxanilo-*N*-arylhydrazonoyl Chlorides[‡]

Petra Frohberg,*[a] Guntram Drutkowski,[a] and Christoph Wagner[b]

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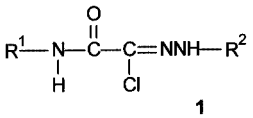
Oxanilo-*N*-arylhydrazonoyl chlorides have been prepared from appropriate *N*-aryl-2-chloro-3-oxobutanamides by the Japp–Klingemann reaction. The structures of the title compounds have been established in the solid state by single-crystal X-ray structure determination and IR spectroscopy, and in solution by IR, UV, and ^{1}H and ^{13}C NMR spectroscopy. The results indicate that the hydrazonoyl chloride moiety adopts the (*Z*)-configured form. In the crystal, intramolecular hydrogen bonds generally exist between the chloride function and the hydrazone hydrogen atom, and also between the amide hydrogen atom and the double-bonded nitrogen atom of the hydrazone moiety. In solution, this intramolecular hydrogen bonding could not be detected. In compounds with an *ortho*-chloro-substituted NH–aryl moiety, however, the chlorine atom is involved in hydrogen bonding to the NH hydrogen atom both in the crystal and in solution.

Introduction

The chemistry of *N*-arylhydrazonoyl halides has been the subject of much interest in recent years. This situation has developed both from studies of the mechanism by which they are formed but even more so from their use in organic synthesis. Various reviews concerning reactions of hydrazonoyl halides have been published,[1] but only little attention has yet been given to their structures. In molecules containing the C=NNH system, there is the possibility of distinct (*E*) and (*Z*) isomers. In comparison with phenylhydrazones derived from α-dicarbonyl compounds, a further characteristic feature should include strong intra- and intermolecular hydrogen-bonding interactions. The literature indicates that hydrazonoyl halides exist as (*Z*) isomers, confirmed both by spectroscopic studies[2–4] and by X-ray diffraction analysis.[3b,5–7] It is known that (*Z*) isomers are thermodynamically more stable[8] and that (*E*) and (*Z*) isomers of different hydrazonoyl halides do not rapidly interconvert under various conditions known to favour equilibration among simple imine isomers.[5,9] Exner et al.[10] found that derivatives of benzoylcarbohydrazonoyl bromides occurred as (*E*) isomers. Numerous works concerning structural aspects of α-carbonyl-substituted arylhydrazones, particularly with respect to intra- and intermolecular hydrogen bonding, are to be found in the literature. Nevertheless, the structures of α-carbonyl-substituted *N*-arylhydrazonoyl halides are seldom discussed,[2,4,10] although investigation is possible with the aid of NH signals of the C=NNH group as observed in NMR[2,4] and IR spectra.[2,10] In the context of our studies on structure and hydrogen bonding, we now report the synthesis and spectroscopic characterisation of oxanilo-*N*-arylhydrazonoyl chlorides **1** and the establishment of the molecular structures of these compounds both in the solid phase and in solution. To investigate the structural features, we were interested in variation of substituents R^1 and R^2. Furthermore, we also decided to synthesise oxanilo-*N*-methyl-*N*-phenylhydrazonoyl chloride (**2**).



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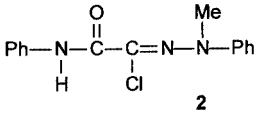

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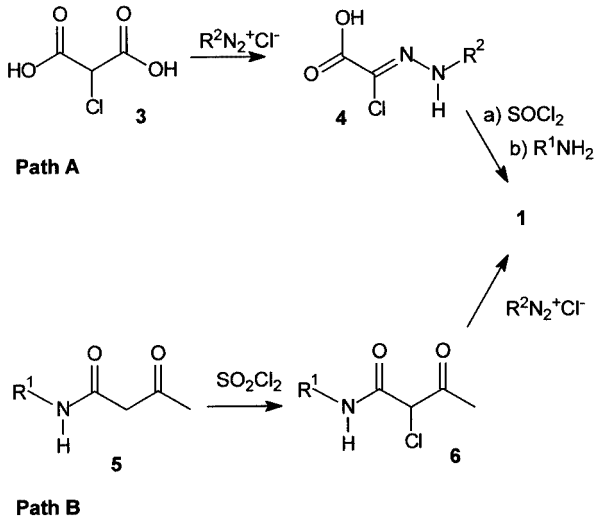
Results and Discussion

Synthesis

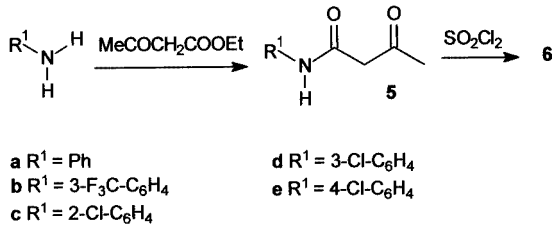
Two literature routes for the preparation of oxanilo-*N*-arylhydrazonoyl chlorides are known (see Scheme 1). By the sequence outlined in Scheme 1, Path A, Lozinskij et al.[11] obtained derivatives of **1** with a limited R^2 substitution pattern. It was found that the intermediate oxalo-*N*-monoarylhydrazonoyl chlorides **4** were only stable if the R^2 aryl ring bore *para* or *ortho* substituents.[12] For our purposes, we prepared title compounds **1** by the steps shown

[‡] Derivatives of Arylhydrazonic Acids, 1

[a] Institute of Pharmaceutical Chemistry, Martin Luther University Halle-Wittenberg
Wolfgang-Langenbeck-Straße 4, 06120 Halle, Germany,
Fax: (internat.) + 49-(0)345/552-7027
E-mail: frohberg@pharmazie.uni-halle.de
[b] Institute of Inorganic Chemistry, Martin Luther University Halle-Wittenberg
Kurt-Mothes-Straße 2, 06120 Halle, Germany



Scheme 1. Routes to oxamo-*N*-arylhydrazonoyl chlorides



Scheme 2. Synthesis of 2-chloro-3-oxobutanamides **6**

in Scheme 1, Path B, allowing unlimited variation of R^1 and R^2. The general route to 2-chloro-3-oxobutanamides **6** that we used is shown in Scheme 2.

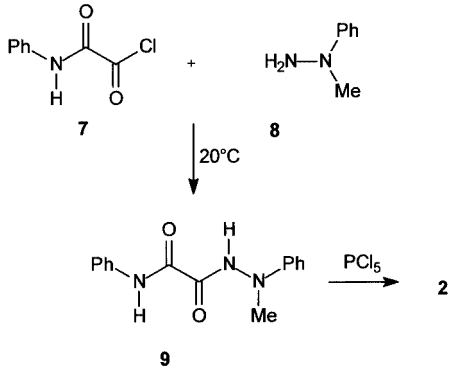
N-Aryl-3-oxobutanamides **5** can be prepared by two main methods: i) the diketene−amine reaction[13] or ii) the ester−amine method.[14] We synthesised derivatives **5** by the ester−amine method; an optimised general procedure is given in the Exp. Sect. The crude products were chlorinated with sulfuryl chloride in toluene to provide 2-chloro-3-oxobutanamides **6a−e** as white crystals.

The title compounds were prepared by Japp−Klingemann cleavage of butanamides **6** with diazotised anilines according to known procedures.[15] The substitution patterns of **1** are summarised in Table 1.

Table 1. Substitution patterns of $R^1NHCOC(Cl)=NNHR^2$ (**1**)

	R^1	R^2		R^1	R^2
1a	Ph	3-F_3C-C_6H_4	**1g**	2-Cl-C_6H_4	2-NC-C_6H_4
1b	Ph	2-F-C_6H_4	**1h**	3-Cl-C_6H_4	Ph
1c	3-F_3C-C_6H_4	Ph	**1i**	3-Cl-C_6H_4	2-Cl-C_6H_4
1d	2-Cl-C_6H_4	Ph	**1j**	3-Cl-C_6H_4	3-Cl-C_6H_4
1e	2-Cl-C_6H_4	2-Cl-C_6H_4	**1k**	3-Cl-C_6H_4	1-naphthyl
1f	2-Cl-C_6H_4	3-Cl-C_6H_4	**1l**	4-Cl-C_6H_4	3-Cl-C_6H_4

Details of the synthesis of oxanilo-*N*-methyl-*N*-phenylhydrazonoyl chloride (**2**) were not available in the literature. An attempt to methylate the corresponding *N*-phenylhydrazonoyl chloride, as described for aryl(phenyl)hydrazines,[16] was unsuccessful. The applicability of the methods for preparation of hydrazonoyl halides is limited. Halogenation of hydrazones is accompanied by halogenation in the *N*-aryl part of the hydrazone unless the aryl nucleus is deactivated. Furthermore, the Japp−Klingemann reaction is unfortunately restricted to *N*-monoaryl-substituted hydrazones. We therefore had to chlorinate the appropriate hydrazide, and the synthetic route we chose is outlined in Scheme 3. Treatment of oxanilide chloride (**7**), prepared according to ref.[17] with *N*-methyl-*N*-phenylhydrazine (**8**) was carried out in toluene at room temperature, monitored by TLC (see Exp. Sect). Oxanilo-*N*-methyl-*N*-phenylhydrazide (**9**) was produced in 50% yield. The subsequent chlorination was first attempted with thionyl chloride,[18] but no product **2** could be isolated. Treatment of **9** with phosphorus pentachloride in toluene, however, effected the chlorination, affording **2**, which was purified by flash chromatography.



Scheme 3. Synthesis of oxanilo-*N*-methyl-*N*-phenylhydrazonoyl chloride (**2**)

Structural Assignment − Solid Phase

Crystal Structure

Searches in the database of the Cambridge Crystallographic Data Centre and conventional literature searches revealed that crystal structures of arylhydrazonoyl halides have been reported only in a very few cases. The structures of two compounds with a carbonyl group (nitrile)[6] or a corresponding structure (P=O)[3a] in the position α to the hydrazone function have been obtained by X-ray diffraction analysis. In contrast, the crystal structures of a large number of phenylhydrazones have been determined, and several structural features have emerged.[19] In virtually all instances, the hydrazone molecule adopts a planar conformation. When aromatic substituents or functional groups capable of conjugation with the C=N bond are present, the C−N portion of the hydrazone linkage becomes lengthened, and this is accompanied by a commensurate decrease in the N−N bond length.

We determined the molecular structures of the derivatives **1d** and **1k** by X-ray diffraction analysis; the molecular structures and atom-numbering schemes are shown in Figures 1 and 2, respectively. The hydrazonoyl chloride moiety is (*Z*)-configured in both structures. In addition, the two aryl moieties (aryl amide and aryl hydrazone) are essentially coplanar. Least-squares calculations showed that these moieties are twisted with respect to each other by angles of 3° in molecule A and 7° in molecule B of **1d**, and 9° in the structure of **1k** (see Table 2). The key bond lengths in **1d** and **1k** are listed in Table 3. The N(1)−N(2) bond lengths (1.33 Å) in both structures are consistent with the values found in the structures of pyridazine rings (1.35 Å), but not of hydrazines (1.45 Å).[20] Both the C(1)−N(2) distances and the C(1)−Cl(1) bond lengths are well within the ranges typically occurring in other hydrazonoyl chlorides (1.26−1.29 Å for C−N and 1.70−1.76 Å for C−Cl).[3a,7,21,22] The structures of the molecules in the crystals of **1d** and **1k**, with intra- and intermolecular hydrogen bonding, are outlined in Figures 3 and 4.

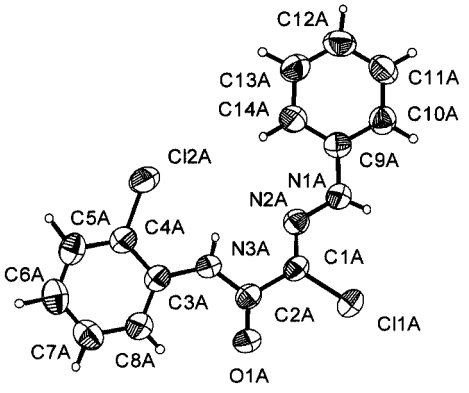


Figure 1. Molecular structure and atom-numbering scheme of one of the two independent molecules of **1d** (displacement ellipsoids with 50% probability)

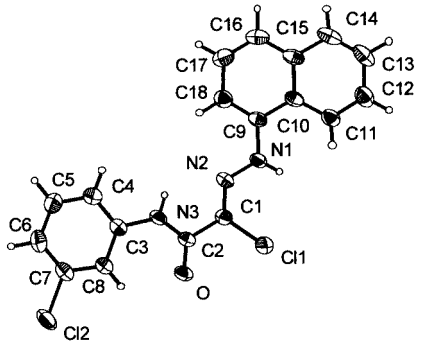


Figure 2. Molecular structure of **1k** with atom-numbering scheme (displacement ellipsoids with 50% probability)

Two intramolecular hydrogen bonds N(1)−H(1)···Cl(1) and N(3)−H(2)···N(2) are present in both compounds (see Table 4). The formation of such an intramolecular N−H···Cl hydrogen bond in hydrazonoyl chlorides has also been described by Cherepinski−Malow[7] and Buzykin.[3]

Table 2. Deviations [Å] of the atoms of the hydrazone structure from the calculated least-squares planes through atoms C(9)−C(14) (phenyl ring of **1d**) or C(9)−C(18) (naphthyl ring of **1k**)

	1d		**1k**
	Molecule A	Molecule B	
N(1)	0.004(5)	0.008(4)	−0.028(2)
N(2)	−0.023(5)	0.005(5)	0.146(3)
C(1)	0.031(7)	0.030(7)	0.011(3)
C(2)	0.005(9)	−0.007(8)	0.184(4)
O	−0.017(10)	−0.217(10)	−0.201(4)

Table 3. Characteristic bond lengths [Å] in the molecule structures of **1d** and **1k**

	1d		**1k**
	Molecule A	Molecule B	
C(9)−N(1)	1.401(4)	1.396(3)	1.404(2)
N(1)−N(2)	1.333(3)	1.329(3)	1.329(2)
C(1)−N(2)	1.268(3)	1.271(3)	1.268(2)
C(1)−C(2)	1.490(4)	1.482(4)	1.491(2)
C(1)−Cl(1)	1.732(3)	1.729(3)	1.736(2)

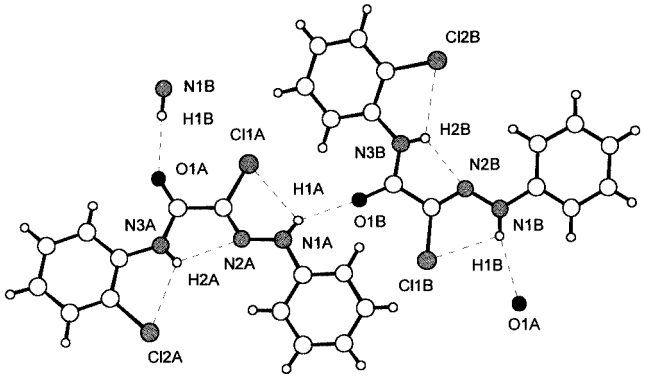


Figure 3. Structures of two independent molecules in the crystal of compound **1d**, showing intra- and intermolecular hydrogen bonding (dashed lines)

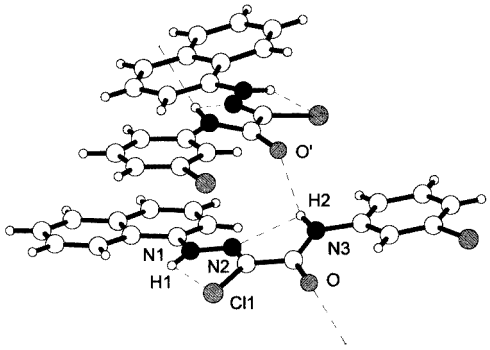
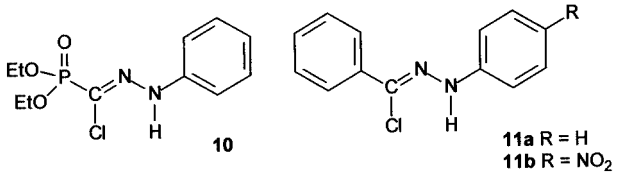


Figure 4. Structure of two molecules in the crystal of compound **1k**, showing intra- and intermolecular hydrogen bonding (dashed lines)

Table 4. Potential intra- and intermolecular hydrogen bonds; distances (D−H, H···A, D···A) are given in Å, angles (D−H···A) in °

Type, Donor−H···Acceptor	D−H	H···A	D···A	D−H···A
Intra N(1)−H(1)···Cl(1)				
1d, molecule A	0.87(3)	2.57(3)	2.93(3)	106(3)
1d, molecule B	0.88(3)	2.53(3)	2.937(3)	109(3)
1k	0.86(2)	2.54(2)	2.926(2)	108(2)
Intra N(3)−H(2)···N(2)				
1d, molecule A	0.78(3)	2.23(3)	2.659(4)	115(3)
1d, molecule B	0.81(3)	2.23(3)	2.674(4)	115(3)
1k	0.83(3)	2.29(2)	2.688(2)	109(2)
Intra N(3)−H(2)···Cl(2)				
1d, molecule A	0.78(3)	2.50(3)	2.938(3)	117(3)
1d, molecule B	0.81(3)	2.54(3)	2.95(3)	113(2)
Inter N(1)−H(1)···O				
1d, molecule A	0.87(3)	2.59(3)	3.371(4)	150(3)
1d, molecule B	0.88(3)	2.29(3)	3.141(4)	162(3)
Inter N(3)−H(2)···O				
1k	0.83(3)	2.18(3)	2.918(2)	148(2)



In the related compounds **10**, **11a**, and **11b**, these workers measured 2.96 Å (**10**) and 2.87 Å (**11a**,**b**) for the Cl···N distances and 2.64 Å (**10** and **11a**) for the Cl···H distances. In our structures, distances of 2.93−2.94 Å for Cl(1)···N(1) and of 2.53−2.58 Å for Cl(1)···H(1) are found.

An additional intramolecular hydrogen bond is formed in the structure of **1d** between the anilide H atom and the *o*-chloro substituent of the anilide moiety. However, the nature of intermolecular hydrogen bonding is different (see Table 4). In the crystal of **1d**, two unequal intermolecular hydrogen bonds are formed between the hydrazone H atom and the carbonyl oxygen atom (see Figure 3). In compound **1k**, one intermolecular bond occurs between the anilide hydrogen atom and the oxygen atom of a neighbouring molecule (see Figure 4).

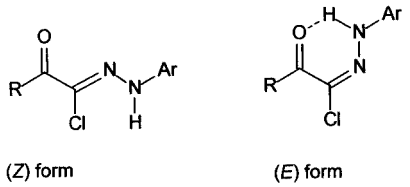
IR Spectroscopy

Derivatives of structure **1** with R^1 = Ph were described previously by Shawali et al.[15b,15c] However, no attempts were undertaken either to assign the observed NH bands in the IR spectra or to study the configurations and conformations of these anilides. Related compounds with ester and ketone structures as well in the position α to the hydrazone moiety were assumed to exist in the (*Z*) configuration.[2] The authors explained the likelihood of the (*Z*) form in terms of the absence of strong intramolecular hydrogen bonds, which should exist in the (*E*)-configured structure (see Scheme 4). Such an associated NH group would cause a red shift of the NH stretching band to 3080 cm^{-1}.[23]

Table 5. Characteristic spectroscopic data of hydrazonoyl chlorides **1** and **2**

	R^1	R^2	IR (KBr) ν [cm^{-1}]		IR ($CDCl_3$)[a] ν [cm^{-1}]		^{1}H-NMR ($CDCl_3$) δ values		^{1}H-NMR ([D_6]DMSO) δ values		^{13}C-NMR ([D_6]DMSO) δ values		UV λ_{max} [nm] (log ε)
			NH	C=O	NH	C=O	CONH	NNH	CONH	NNH	C=O	C=N	Band C
1a	Ph	3-F_3C-C_6H_4	3384, 3240	1667	3405, 3327	1683	8.46	8.30	10.20	10.54	156.9	119.8	330 (4.40)
1b	Ph	2-F-C_6H_4	3324 br.	1658	3400, 3335	1680	8.52	8.37	10.14	9.41	157.0	121.5	327 (4.35)
1c	3-F_3C-C_6H_4	Ph	3375, 3231	1667	3400, 3325	1684	8.60	8.24	10.32	10.38	157.8	117.8	336 (4.41)
1d	2-Cl-C_6H_4	Ph	3356, 3291, 3235	1672	3368, 3321	1681	9.35	8.24	9.74	10.48	157.2	117.4	342 (4.38)
1e	2-Cl-C_6H_4	2-Cl-C_6H_4	3371, 3320	1693	3370, 3317	1684	9.36	8.73	10.00	9.01	157.1	121.8	331 (4.32)
1f	2-Cl-C_6H_4	3-Cl-C_6H_4	3348, 3275	1680	3368, 3322	1688	9.38	8.24	9.89	10.61	157.2	118.9	339 (4.42)
1g	2-Cl-C_6H_4	2-NC-C_6H_4	3354, 3208	1687	3381, 3316	1693	9.32	8.73	9.57	10.62	156.9	121.2	338 (4.29)
1h	3-Cl-C_6H_4	Ph	3379, 3281, 3236	1663	3401, 3327	1687	8.49	8.22	10.16	10.35	158.0	118.2	337 (4.44)
1i	3-Cl-C_6H_4	2-Cl-C_6H_4	3313, 3272	1651	3405, 3324	1688	8.45	8.71	10.33	8.89	156.9	122.3	330 (4.41)
1j	3-Cl-C_6H_4	3-Cl-C $_6H_4$	3375, 3247	1668	3400, 3320	1681	8.46	8.21	10.28	10.49	157.8	119.7	333 (4.45)
1k	3-Cl-C_6H_4	1-naphthyl	3300 br.	1653	3393, 3338	1680	8.58	8.76	10.31	10.00	157.9	120.9	350 (4.32)
1l	4-Cl-C_6H_4	3-Cl-C_6H_4	3370, 3246	1669	3402, 3324	1685	8.48	8.21	10.26	10.46	157.4	119.5	334 (4.47)
2[b]	Ph	Ph	3315	1651	3388	1681	8.63	–	10.05	–	158.5	117.7	331 (4.25)

[a] Concentration 0.03 M, cell thickness 0.5 mm. [b] N^1 = methyl- and phenyl-substituted.



Scheme 4. Isomeric forms of α-carbonyl-substituted hydrazonoyl chlorides

In the phenylhydrazone of dimethyl 2-oxopropanedioate, other authors found a band near 3150 cm^{-1} for intramolecular association of the NH moiety to the carbonyl function.[24] Prasad et al. observed NH stretching bands between 3240 and 3280 cm^{-1} and ruled out the (*E*) configuration.[2] Additionally, Buzykin et al. described NH stretching bands for benzenecarbohydrazonoyl chlorides **11** between 3290 and 3315 cm^{-1}.[3b] Characteristic infrared absorption bands of hydrazonoyl chlorides **1** and **2** in KBr are given in Table 5.

For comparison, some of the samples were also prepared in nujol, but only very small differences were found. In all cases, medium to strong bands due to NH stretching were observed in the 3400−3200 cm^{-1} region. Furthermore, the spectra showed strong bands for C=O stretching (1690−1670 cm^{-1}), aromatic C=C stretching (near 1600 cm^{-1}) and C=N stretching (1560−1570 cm^{-1}).

All crystal structures of arylhydrazones with an α-anilide moiety, such as that in chlorides **1d** and **1k** and related amidrazones,[25] demonstrate intramolecular association between the anilide hydrogen atom and the double-bonded hydrazone nitrogen atom. There is no evidence for a free CONH moiety in the solid phase. In addition, it has been found that the hydrazone NH group in hydrazonoyl chlorides displays an absorption band in the range of 3150 cm^{-1} to at most 3340 cm^{-1}.[2,3,10,21,26] We observed three regions for the CONH moiety, one main and two additional regions of NNH stretching. With the aid of the results of the crystal structure analyses of **1d** and **1k**, together with literature data, the assignment of NNH stretching was performed (see Table 6).

However, exceptions are noted in the spectra of *ortho*-substituted derivatives **1e** and **1g**. We assume that both NH hydrogen atoms in **1e** are involved in hydrogen bonding to the corresponding *o*-Cl atoms of the aryl moieties but not in the general NNH···Cl−C=N and CONH···N=C bonding. The red shift of the NNH stretching band in the spectrum of **1g** could be explained with a hydrogen strongly associated atom to the *o*-CN group of the phenyl substituent.

Table 6. Regions of NH stretching bands in the IR spectra of hydrazonoyl chlorides **1** and **2** in KBr

ν [cm^{-1}] for	
CONH··· associated to	
···N=C (intra)	3370−3390
···N=C (intra) and ···*o*-Cl (intra)	3340−3360
···N=C (intra) and ···O=C (inter)	3300−3330
NNH···associated to	
···*o*-Cl/F (intra)	3310−3325
···Cl-C=N (intra) and ···O=C (inter, weak)	3270−3290
···Cl-C=N (intra) and ···O=C (inter, strong)	3220−3250

In summary of the X-ray and IR spectroscopic results for solid samples, we were able to conclude that all compounds except **1e** formed an intramolecular hydrogen bond between the anilide hydrogen atom and the double-bonded nitrogen atom of the hydrazone moiety. In four compounds (**1b**, **1i**, **1k**, and **2**), an additional intermolecular bond between the mentioned anilide hydrogen atom and the carbonyl function of a neighbouring molecule is assumed. In contrast to the anilide, the hydrazone hydrogen atom is probably doubly associated in nearly all substances, intramolecularly to the Cl atom of the hydrazonoyl chloride structure and intermolecularly to the carbonyl oxygen atom of a neighbouring molecule. The differently associated NNH···O=C moieties, as observed in the structure of **1d**, could be differentiated in the IR spectra. The results indicate that intramolecular association does not exist between the hydrazone hydrogen atom and the carbonyl oxygen atom and, accordingly, that all compounds are (*Z*)-configured.

Structural Assignment − in Solution

IR Spectroscopy

Key IR spectroscopic data of **1** and **2** in $CDCl_3$ solution are listed in Table 5. Most of the samples were insoluble in cyclohexane and benzene, and so we chose deuteriochloroform as solvent, with the advantage of being able to use the same solution for NMR and IR experiments. We expected that interaction with chloroform as solvent should not influence intramolecular associations. On changing from the solid state to the $CDCl_3$ solution, the bands for both NH atoms were shifted to a greater or lesser extent to higher wavenumbers, indicating that intermolecular hydrogen bonds were abolished. However, the region for the anilide hydrogen atom intramolecularly associated to the C=N nitrogen atom in solid samples was displaced as well. It hence followed that the NH stretching band at around 4000 cm^{-1} was attributable to the free anilide NH group without any association, confirmed by the solvent and concentration dependence of this band.

Literature data indicate that the free hydrazone hydrogen band appears at 3335−3342 cm^{-1}.[3b,10,22,27] In the IR spectra of chlorides **1b** and **1k**, recorded in $CDCl_3$, this band was found. All the other IR spectra exhibited a band slightly shifted to lower wavenumber by about 10 cm^{-1}. Interactions of the hydrazone hydrogen atom with the solvent (NH···Cl) were probably observed, although these were not present in **1b** and **1k** because of steric effects. In addition, small differences of about 3−4 cm^{-1} occurred with changing concentration (from 0.15 to 0.015 M in $CDCl_3$). No substantial dependence on the nature of substituents on the aromatic moiety was found [$\Delta\nu$(NH) = ±5 cm^{-1}]. As

known for anilides, the electrons are delocalised and substituent effects are evened out.[3b]

NMR Spectroscopy

In general, variations in the intensity and position of ν(NH) stretching frequencies correlated with chemical shift [δ(NH)] variations, but qualitative differentiation and the degree of hydrogen bonding involved has been based principally on the latter. As discussed previously, δ(NH) values have proved to be an extremely sensitive monitor of hydrogen bonding in phenylhydrazone derivatives.[26] ^{1}H and ^{13}C NMR spectroscopic data for **1** and **2** are listed in Table 5. The chemical shift of NNH protons of hydrazonoyl halides are found in the regions of δ = 8−9 in $CDCl_3$ and 10−11 in [D_6]DMSO.[3a,4,7,10] In contrast, the value of δ(NH) in phenylhydrazones that form intramolecular hydrogen bonds to carbonyl oxygen atoms is reported to be in the range of δ = 13−15, independent of the solvent.[28−30] Comparison of ^{1}H NMR signals of NH in $CDCl_3$ and [D_6]DMSO indicated that most of them were dependent on the solvent, as is demonstrated in Figure 5.

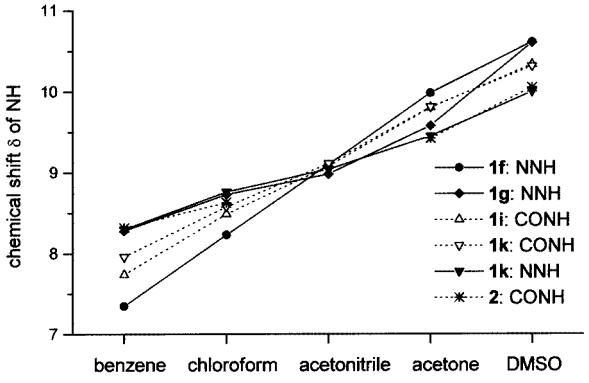


Figure 5. Solvent dependence of the chemical shifts (δ) of the anilide (CONH, open symbols) and the hydrazone (NNH, closed symbols) protons

However, it was immediately obvious that the chemical shifts of some of the signals showed small differences, especially in the less polar solvents benzene or deuteriochloroform, or were largely unchanged. In accordance with the IR spectroscopic results, it was found that these NH moieties formed intramolecular hydrogen bonds to *o*-Cl atoms in hydrazonoyl chlorides **1d−1g** and **1i** (see Figure 6). The chemical shift of the NNH proton of the *ortho*-fluoro-substituted derivative **1b** was weakly dependent on the solvent, but even less so than the δ(NH) values of compounds without an *ortho* substituent. The unchanged chemical shift of the NNH proton in the spectrum of naphthylhydrazonoyl chloride **1k** could be explained by a steric effect of the naphthyl substituent. In accordance, this proton behaves in the essentially nonpolar solvents benzene and chloroform like a NH moiety associated with an *o*-Cl atom, as does the NNH group in the *o*-cyanophenylhydrazonoyl chloride **1g** (see Figure 6).

Interactions between the hydrazone hydrogen atom and deuteriochloroform, observed in the IR spectra, were also

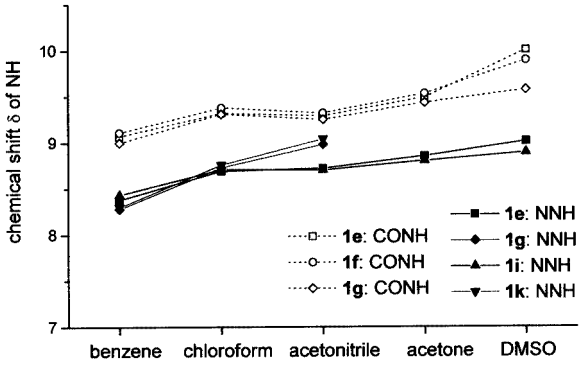


Figure 6. Solvent dependence of the chemical shifts (δ) of the anilide (CONH, open symbols) and the hydrazone (NNH, closed symbols) protons

detected in the ^{1}H NMR spectra. However, these interactions were weak, and caused only small differences in the chemical shift of the NH signal. For instance, on changing the concentration of the naphthyl-substituted hydrazonoyl chloride **1k** from 5% to 0.5%, the NNH proton signal was shifted by about 0.07 ppm.

The appearance of intramolecular hydrogen bonds, as observed in the crystal structures (C=O···HN and Cl···HN), could not be investigated in all cases because of the limited solubility of nearly all the compounds in nonpolar benzene.

In the ^{13}C NMR spectra, it is worth mentioning that the signals of the hydrazone C atoms in ^{13}C NMR spectra were shifted by about 2−3 ppm in the spectra of **1b**, **1e**, **1g**, **1i**, and **1k**. The signals appeared near δ = 121−122. This effect is attributable to the *ortho* substitution of the hydrazone moiety and is in accordance with ^{1}H NMR spectroscopic results.

Except for the intramolecular hydrogen bond between anilide or hydrazone hydrogen atom and corresponding *ortho* substituents of the aryl moiety (see Figure 6), there was no evidence of the existence of other intramolecular associations in any of the experiments.

UV Spectroscopy

The UV absorption spectra of compounds **1** and **2**, similarly to those of typical phenylhydrazones, showed three very intense ($\varepsilon_{max} > 1000$) absorption bands with their maxima situated at approx. 250 nm (band A), in the range of 280−300 nm (band B) and 330−340 nm (band C). Key UV spectroscopic data are summarised in Table 5.

Small differences were found in the intensity of the band with the largest wavelength (band C), which indicates the degree of electron delocalisation. In the spectra of derivatives **1e**, **1g**, **1k**, and **2**, the band had a slightly lower intensity than those in the other spectra. This could point to a deviation in the planarity of the C=NNH fragment, as observed by Buzykin.[3b] The X-ray data of **1k** support this assumption; deviations of this fragment from planarity are larger than those in the structure of **1d**. It may be speculated that, in solution, the molecules adopt another conformation that is energetically favourable. In hydrazonoyl

chloride **2**, the influence of alkyl substitution of hydrazone N^1 is evident. The resonating system is diminished, which correlates with the decreased absorption intensity. A correlation has been found between the electronic properties of substituents on the arylhydrazone moiety and UV λ_{max} for compounds that have proved to form strong intramolecular hydrogen bonds, such as C=NNH···O=C.[31] Only small differences in the range of 320−340 nm were observed in the λ_{max} values of hydrazonoyl chlorides **1**, which would preclude such a correlation. The high value of λ_{max} of **1k** indicates a large system of electron delocalisation over the naphthyl ring.

Conclusion

In summary of all the spectroscopic data, it could be concluded that the hydrazonoyl chlorides **1** and **2** exist in the (*Z*)-configured form in the solid state as well as in solution. The observed CO···NH and NNH···Cl intramolecular hydrogen bonds in the crystal structure could not be detected in solution. It is evident that the independence of ν(NH) and δ(NH) in the spectra of *ortho*-substituted NH−aryl moieties reflects intramolecular hydrogen bonding of the appropriate NH group to the *ortho* substituent in the phenyl ring. In contrast to the findings of Exner et al.,[10] who assumed an intramolecular association NNH···O=C in substituted benzoylcarbohydrazonoyl bromides, there was no evidence of such association in the molecules of the compounds under discussion.

Experimental Section

General: Melting points were determined with a Kofler hot-stage apparatus. IR spectra were recorded with a Specord 75 IR (Carl Zeiss Jena). UV spectra were determined with an HP8452A diode array spectrophotometer and were recorded in ethanol; mass spectra with an AMD 402 from AMD INTEDRA (70 eV); the NMR spectra were recorded with a Gemini 2000 and a Gemini 200, operating at 399.96 and 199.95 MHz for ^{1}H NMR and at 100.6 and 50.3 MHz for ^{13}C NMR spectra. TMS was used as internal standard. Chemical shifts are given in δ units and refer to the centre of the signal (s = singlet, d = doublet, t = triplet, m = multiplet). *N*-Phenyl-3-oxobutanamide (**5a**) was purchased from Aldrich.

General Procedure for the Preparation of *N*-Aryl-3-oxobutanamides 5 (Ester−Amine Method, GP 1): In a three-necked distillation flask of a distillation apparatus, ethyl acetoacetate (1.5 mol, 190 mL) was heated to 150−160 °C. Freshly distilled or recrystallised arylamine (0.3 mol, solid arylamines were dissolved in a small amount of dry dimethylformamide) was added with stirring over 30 min. The temperature of the solution was kept between 150 and 160 °C until no more ethanol or ethanol/ester azeotrope distilled. The mixture was cooled to 80 °C and most of the excess ethyl acetoacetate was distilled under reduced pressure. The residue was transferred to a porcelain dish for crystallisation. After 12 h, the solid was pulverised and washed with ice-cooled ether. The colourless crude products were used without further purification. The obtained crude products were: 3-oxo-*N*-[3-(trifluoromethyl)phenyl]butanamide (**5b**), *N*-(2-chlorophenyl)-3-oxobutanamide (**5c**), *N*-(3-chlorophenyl)-3-oxobutanamide (**5d**), and *N*-(4-chlorophenyl)-3-oxobutanamide (**5e**).

General Procedure for the Preparation of *N*-Aryl-2-chloro-3-oxobutanamides 6 (GP 2): The synthesis was based on ref.[32] Sulfuryl chloride (1.5 g, 11 mmol) was added dropwise to the stirred suspension of the appropriate *N*-aryl-3-oxobutanamide (10 mmol, in 15 mL of dried toluene) if necessary with ice cooling. The reaction was monitored by TLC. If required, the mixture was warmed to complete the reaction. The solid product was filtered off, dried and recrystallised. If the product did not crystallise, the toluene was evaporated and the residue was recrystallised from the given solvent. In accordance with literature data, the following compounds were obtained: 2-chloro-3-oxo-*N*-phenylbutanamide (**6a**),[32a] 2-chloro-3-oxo-*N*-[3-(trifluoromethyl)phenyl]butanamide (**6b**) (m.p. 65−67 °C; ref.[33] 61−63 °C), 2-chloro-*N*-(2-chlorophenyl)-3-oxobutanamide (**6c**),[34] 2-chloro-*N*-(3-chlorophenyl)-3-oxobutanamide (**6d**),[34] 2-chloro-*N*-(4-chlorophenyl)-3-oxobutanamide (**6e**).[34]

General Procedure for the Preparation of Arylhydrazonoyl Chlorides 1 (GP 3):[15] The appropriate arylamine (0.01 mol) was dissolved in 24 mL of half-concentrated HCl and diazotised with a solution of sodium nitrite (0.01 mol, 0.69 g) in 3 mL of water at 0−5 °C. The freshly prepared solution of the diazotised aniline was added dropwise to a cooled mixture of sodium acetate (4.0 g) and *N*-aryl-2-chloro-3-oxobutanamide **6** (0.01 mol) in 50 mL of methanol at 5−10 °C. After the mixture was stirred for 2 h, the solid was filtered off, washed with water, dried, and recrystallised from the given solvent.

(1*Z*)-2-Anilino-2-oxo-*N*-[3-(trifluoromethyl)phenyl]ethanehydrazonoyl Chloride (1a): This compound was prepared from 3-trifluoromethylaniline (0.01 mol, 1.6 g) and 2-chloro-3-oxo-*N*-phenylbutanamide (0.01 mol, 2.1 g). Yield: 2.3 g (68%) of pale yellow needles from heptane/acetone, m.p. 206−208 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.11−7.90 (9 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 111.1−143.6 (13 C, arom. C and CF$_3$). MS (70 eV): *m*/*z* (%) = 341 (45) [M$^+$], 305 (40), 93 (100). $C_{15}H_{11}ClF_3N_3O$ (341.72): calcd. C 52.72, H 3.24, Cl 10.37, F 16.68, N 12.30; found C 52.57, H 3.31, Cl 10.39, F 16.49, N 12.33.

(1*Z*)-2-Anilino-*N*-(2-fluorophenyl)-2-oxoethanehydrazonoyl Chloride (1b): This compound was prepared from 2-fluoroaniline (0.01 mol, 1.1 g) and 2-chloro-3-oxo-*N*-phenylbutanamide (0.01 mol, 2.1 g). Yield: 2.5 g (87%) of pale yellow needles from chloroform/heptane, m.p. 130−134 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.02−7.92 (9 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 115.6−138.2 (11 C, arom. C), 149.8, 152.2 (d, 1 C, arom. CF). MS (70 eV): *m*/*z* (%) = 291 (100) [M$^+$], 255 (73), 110 (50), 93 (100), 83 (50). $C_{14}H_{11}ClFN_3O$ (291.72): calcd. C 57.65, H 3.80, Cl 12.15, F 6.51, N 14.40; found C 57.26, H 3.67, Cl 12.16, F 6.41, N 14.44.

(1*Z*)-2-Oxo-*N*-phenyl-2-{[3-(trifluoromethyl)phenyl]amino}ethanehydrazonoyl Chloride (1c): This compound was prepared from aniline (0.01 mol, 0.93 g) and 2-chloro-3-oxo-*N*-[3-(trifluoromethyl)-phenyl]butanamide (0.01 mol, 2.8 g). Yield: 2.2 g (66%) of pale yellow solid from heptane/acetone, m.p. 200−204 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 6.96−8.18 (9 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 115.0−142.9 (13 C, arom. C and CF$_3$). MS (70 eV): *m*/*z* (%) =

341 (100) [M$^+$], 161 (48), 92 (53) 65 (40). $C_{15}H_{11}ClF_3N_3O$ (341.72): calcd. C 52.72, H 3.24, Cl 10.37, F 16.68, N 12.30; found C 52.54, H 3.31, Cl 10.36, F 16.51, N 12.30.

(1*Z*)-2-[(2-Chlorophenyl)amino]-2-oxo-*N*-phenylethanehydrazonoyl Chloride (1d): This compound was prepared from aniline (0.01 mol, 0.93 g) and 2-chloro-*N*-(2-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 1.6 g (51%) of yellow crystals from chloroform/heptane, m.p. 200−203 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 6.96−7.91 (9 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 114.9−137.7 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 307 (65) [M$^+$], 127 (100), 91 (45). $C_{14}H_{11}Cl_2N_3O$ (308.17): calcd. C 54.57, H 3.60, Cl 23.01, N 13.63; found C 54.51, H 3.62, Cl 23.00, N 13.62.

(1*Z*)-*N*-(2-Chlorophenyl)-2-[(2-chlorophenyl)amino]-2-oxoethanehydrazonoyl Chloride (1e): This compound was prepared from 2-chloroaniline (0.01 mol, 1.3 g) and 2-chloro-*N*-(2-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 2.1 g (60%) of pale yellow, needle felt from chloroform/heptane, m.p. 162−165 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.03−7.94 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 117.0−137.7 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 341 (50) [M$^+$], 306 (22), 127 (100). $C_{14}H_{10}Cl_3N_3O$ (342.62): calcd. C 49.08, H 2.94, Cl 31.04, N 12.26; found C 48.63, H 2.81, Cl 31.05, N 12.20.

(1*Z*)-*N*-(3-Chlorophenyl)-2-[(2-chlorophenyl)amino]-2-oxoethanehydrazonoyl Chloride (1f): This compound was prepared from 3-chloroaniline (0.01 mol, 1.3 g) and 2-chloro-*N*-(2-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 1.9 g (55%) of fine, pale yellow needles from chloroform/acetone, m.p. 206−209 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 6.99−7.80 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 113.5−144.5 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 341 (35) [M$^+$], 127 (100). $C_{14}H_{10}Cl_3N_3O$ (342.62): calcd. C 49.08, H 2.94, Cl 31.04, N 12.26; found C 48.63, H 2.76, Cl 30.52, N 12.26.

(1*Z*)-2-[(2-Chlorophenyl)amino]-*N*-(2-cyanophenyl)-2-oxoethanehydrazonoyl Chloride (1g): This compound was prepared from 2-aminobenzonitrile (0.01 mol, 1.2 g) and 2-chloro-*N*-(2-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 2.1 g (63%) of short, fine, yellow needles from chloroform, m.p. 165−167 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.14−7.84 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 97.7 (s, 1 C, arom. **C**CN), 113.6−144.6 (12 C, CN and arom. C). MS (70 eV): *m*/*z* (%) = 332 (20) [M$^+$], 297 (100), 127 (100), 117 (50). $C_{15}H_{10}Cl_2N_4O$ (333.18): calcd. C 54.08, H 3.02, Cl 21.28, N 16.81; found C 53.87, H 3.02, Cl 21.27, N 16.76.

(1*Z*)-2-[(3-Chlorophenyl)amino]-2-oxo-*N*-phenylethanehydrazonoyl Chloride (1h): This compound was prepared from aniline (0.01 mol, 0.93 g) and 2-chloro-*N*-(3-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 1.7 g (56%) of plate-like, yellow crystals from chloroform/heptane, m.p. 171−173 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.01−7.88 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 114.9−142.8 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 307 (95) [M$^+$], 91 (100), 127 (95). $C_{14}H_{11}Cl_2N_3O$ (308.17): calcd. C 54.57, H 3.60, Cl 23.01, N 13.63; found C 54.40, H 3.67, Cl 22.98, N 13.70.

(1*Z*)-*N*-(2-Chlorophenyl)-2-[(3-chlorophenyl)amino]-2-oxoethanehydrazonoyl Chloride (1i): This compound was prepared from 2-chloroaniline (0.01 mol, 1.3 g) and 2-chloro-*N*-(3-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 1.7 g (50%) of flat, plate-like, light yellow crystals from chloroform/acetone, m.p. 184−188 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.04−7.99 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 117.2−139.7 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 341 (65) [M$^+$], 127 (100), 99 (45). $C_{14}H_{10}Cl_3N_3O$ (342.62): calcd. C 49.08, H 2.94, Cl 31.04, N 12.26; found C 49.01, H 2.99, Cl 30.92, N 12.20.

(1*Z*)-*N*-(3-Chlorophenyl)-2-[(3-chlorophenyl)amino]-2-oxoethanehydrazonoyl Chloride (1j): This compound was prepared from 3-chloroaniline (0.01 mol, 1.3 g) and 2-chloro-*N*-(3-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 2.4 g (72%) of a yellow-orange, amorphous solid from chloroform, m.p. 143−145 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 6.97−7.88 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 113.5−144.3 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 341 (65) [M$^+$], 127 (100), 99 (45). $C_{14}H_{10}Cl_3N_3O$ (342.62): calcd. C 49.08, H 2.94, Cl 31.04, N 12.26; found C 48.75, H 3.03, Cl 31.03, N 12.29.

(1*Z*)-2-[(3-Chlorophenyl)amino]-*N*-naphthyl-2-oxoethanehydrazonoyl Chloride (1k): This compound was prepared from 1-naphthylamine (0.01 mol, 1.4 g) and 2-chloro-*N*-(3-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). The product was purified by dry column chromatography, with toluene as eluent. Yield: 2.0 g (57%) of brown prisms from chloroform/heptane, m.p. 172−175 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 7.17−8.22 (11 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 113.6−140.2 (16 C, arom. C). MS (70 eV): *m*/*z* (%) = 357 (80) [M$^+$], 141 (100), 115 (65). $C_{18}H_{13}Cl_2N_3O$ (358.32): calcd. C 60.35, H 3.66, Cl 19.79, N 11.73; found C 60.17, H 3.59, Cl 19.87, N 11.71.

(1*Z*)-*N*-(3-Chlorophenyl)-2-[(4-chlorophenyl)amino]-2-oxoethanehydrazonoyl Chloride (1l): This compound was prepared from 3-chloroaniline (0.01 mol, 1.3 g) and 2-chloro-*N*-(4-chlorophenyl)-3-oxobutanamide (0.01 mol, 2.5 g). Yield: 3.1 g (90%) of pale yellow, needle felt from chloroform/acetone, m.p. 200−204 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 6.98−7.76 (8 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 113.7−144.6 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 341 (35) [M$^+$], 127 (100), 99 (20). $C_{14}H_{10}Cl_3N_3O$ (342.62): calcd. C 49.08, H 2.94, Cl 31.04, N 12.26; found C 48.89, H 2.91, Cl 31.01, N 12.17.

X-ray Diffraction Analysis: The data collection was carried out with a STOE-STADI-IV (**1d**) or a STOE-IPDS (**1k**) diffractometer. Graphite-monochromated Mo-K_α radiation, and corrections for Lorenz and polarisation were used. The structure was solved by direct methods with the program SHELXS-86,[35] refinement was carried out by a full-matrix, least-squares refinement with the program SHELXL-93,[36] all non-hydrogen atoms anisotropic. Crystallographic data are collected in Table 7. Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication nos. CCDC-169319 (**1d**) and -169320 (**1k**). Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: (internat.) + 44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

Table 7. Crystallographic data for **1d** and **1k**

	1d	**1k**
Empirical formula	$C_{28}H_{22}Cl_4N_6O_2$	$C_{18}H_{13}Cl_2N_3O$
Formula mass	616.32	358.21
Crystal system	monoclinic	monoclinic
Space group	$P2_1/a$	$P2_1/c$
Temperature [K]	293	220
Cell dimensions		
a [Å]	20.836(4)	7.906(2)
b [Å]	4.870(3)	22.452(6)
c [Å]	29.398(3)	9.402(2)
β [°]	110.265(11)	96.92(3)
Volume [Å^3]	2798.4(18)	1656.8(7)
Z	4	4
ρ [g·cm^3]	1.463	1.436
θ range [°]	1.95−24.95	2.60−25.00
μ [mm^{-1}]	0.462	0.401
Limiting indices	$-25 \le h \le 24$	$-9 \le h \le 9$
	$0 \le k \le 5$	$-26 \le k \le 26$
	$-34 \le l \le 34$	$-11 \le l \le 11$
Reflections collected/unique	9474/4898	11750/2835
Reflections with $I > 2\sigma(I)$	3416	2387
R(int)	0.0358	0.0352
parameters	449	269
$R1$; $wR2$ $[I > 2\sigma(I)]$	0.0447; 0.0970	0.0355; 0.0848
$R1$; $wR2$ (all data)	0.0781; 0.1138	0.0429; 0.0886
ρ_{max}; ρ_{min} [eÅ^{-3}]	0.202; −0.286	0.453; −0.432

(1*Z*)-2-Anilino-*N*-methyl-2-oxo-*N*-phenylethanehydrazonoyl Chloride (2): This compound was synthesised according to a published procedure.[37] 2-(2-Methyl-2-phenyl)hydrazino-2-oxoacetanilide (**9**, 7 mmol, 2.0 g) was suspended in 80 mL of toluene. Phosphorus pentachloride (14 mmol, 2.9 g) was added to the stirred suspension at room temperature. The mixture was stirred at 50 °C until the reaction was complete (monitored by TLC; hexane/ether, 7:3) and then poured onto crushed ice. The organic layer was separated, and the aqueous layer was washed twice with ether. The organic solution was dried, the solvent was removed, and the crude product was purified by dry column chromatography, with toluene as eluent. Yield: 0.9 g, (46%) of light yellow needles from heptane, m.p. 126−131 °C. ^{1}H NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 3.72 (s, 3 H, CH_3), 7.06−7.70 (10 H, arom. H). ^{13}C NMR ([D$_6$]DMSO): see Table 5; additional signals: δ = 41.1 (s, 1 C, CH_3), 117.5−147.9 (12 C, arom. C). MS (70 eV): *m*/*z* (%) = 287 (45) [M$^+$], 105 (100), 77 (51). $C_{15}H_{14}ClN_3O$ (287.75): calcd. C 62.61, H 4.90, Cl 12.32, N 14.60; found C 62.30, H 4.91, Cl 12.36, N 14.52.

2-(2-Methyl-2-phenyl)hydrazino-2-oxoacetanilide (9): The synthesis was based on ref.[38] 1-Methyl-1-phenylhydrazine (0.02 mol, 2.4 g) and 2-anilino-2-oxoacetyl chloride (0.02 mol, 3.7 g) in toluene were stirred at room temperature until completion of reaction, as monitored by TLC (hexane/ethyl acetate, 7:3). Yield: 2.7 g (50%) of an amorphous solid from chloroform/heptane, m.p. 229−231 °C. IR (KBr): $\tilde{\nu}$ = 3300, 3244 (NH ass.), 1755 (C=O, amide, hydrazide), ^{1}H NMR ([D$_6$]DMSO): δ = 3.13 (s, 3 H, CH_3), 6.77−7.83 (10 H, arom. H), 10.69 (s, 1 H, CONH, amide), 11.00 (s, 1 H, CONHN, hydrazide). ^{13}C NMR ([D$_6$]DMSO): δ = 39.9 (CH_3), 112.7−149.3 (12 C, arom. C), 158.8 (CONH, amide), 159.9 (CONHN, hydrazide). MS (70 eV): *m*/*z* (%) = 269 (100) [M$^+$], 148 (53), 121 (62), 77 (56). $C_{15}H_{15}N_3O_2$ (269.31): calcd. C 66.90, H 5.61, N 15.60; found C 66.61, H 5.63, N 15.33.

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