SHORT PAPER

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Structure elucidation of *N*-aryl-2-chloro-3-oxobutanamides with respect to intra– and intermolecular hydrogen bonding[†]

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In general, *N*-aryl-2-chloro-3-oxobutanamides form in solid state an intermolecular hydrogen bond between the anilide hydrogen and the anilide carbonyl oxygen of a neighbouring molecule, which is disrupted in solution. An intramolecular association could not be detected.

Keywords: N-aryl-2-chloro-3-oxobutanamides, hydrogen bonding

N-Aryl-2-chloro-3-oxobutanamides $RNHCOCH(Cl)COCH_3$ **1** are well known compounds which are considered to be important intermediates for construction of manifold heterocyclic systems. The preparation of **1a** with R = C_6H_5 was first reported by Buelow and King.[1] We are interested in structural aspects of this class of compounds particularly with respect to intra- and intermolecular hydrogen bonding. No information is available about hydrogen bonding, which is known for different associated NH moieties.[2]

We have synthesised derivatives **1b–e** by chlorination of *N*-aryl-3-oxobutanamides with sulfuryl chloride in toluene.[1,3,4] *N*-Aryl-3-oxobutanamides have been obtained from substituted anilines and ethyl acetoacetate by the ester–amine method.[5] The characterisation of derivatives **1b–d** corresponds to literature data.[6] Apart from butanamides **1a**[3,7,8] and **1d**[3,8] no spectroscopic data of *N*-aryl-2-chloro-3-oxobutanamides have been found in the literature. Therefore, IR spectra in KBr as well as in $CDCl_3$ solution and ^1H NMR spectra were recorded, see Table 1. The characteristic signal of the anilide proton in the ^1H NMR spectra using $CDCl_3$ as solvent occurs in the range of 8.1–8.3 ppm which is in good agreement with the observed signal at 8.07 ppm for **1a**.[7] This NH signal is shifted for about 2 ppm downfield in $[D_6]$DMSO.

The IR spectra of the solid probes in KBr exhibit the expected NH stretching band near 3250 cm^{-1} and carbonyl bands at about 1730 and 1650 cm^{-1}. However, further bands with medium intensity appear in the range of 3200 and 3150 cm^{-1} originating possibly from additional vibrations of associated NH functions.[2] In order to prove this assumption we determined the molecular structure of **1e** by X-ray diffraction analysis. The molecular structure and atom numbering scheme are shown in Fig. 1.

Two differently bonded or associated NH functions could not be detected. One intermolecular hydrogen bond between the anilide NH and the anilide carbonyl oxygen of a neighbouring molecule is formed [H1...O1 2.111(2) Å, N...O1 2.871(3) Å, N-H1...O1 161.29(1)°] which is illustrated in Fig. 2.

The intermolecular hydrogen bond was confirmed by recording the IR spectra in $CDCl_3$ solution. A shift of the NH stretching band of about 160 cm^{-1} to higher wavenumbers was noted and may be explained by the disruption of the intermolecular association in solution. The difference of the wavenumbers between the dissolved and the solid phase is quite large and indicates the formation of a strong hydrogen bond in the solid phase. Nevertheless, it is worth mentioning that the absorption bands near 3200 cm^{-1} disappear in solution. The assignment of these bands, occurring only in the solid state, seemed to be difficult. Therefore, we attempted a comparison of the experimentally observed vibration bands in the IR spec-

Table 1 Characteristic IR and ^1H NMR spectral data of *N*-aryl-2-chloro-3-oxobutanamides $RNHCOCH(Cl)COCH_3$ **1**

		IR, KBr ν/cm^{-1}		IR, $CDCl_3$[a] ν/cm^{-1}		^1H NMR, $[D_6]$DMSO δ/ppm			^1H NMR, $CDCl_3$ δ/ppm		
	R	NH	CH_3CO, HNCO	NH	CH_3CO, HNCO	CH_3	CHCl	CONH	CH_3	CHCl	CONH
1a	C_6H_5	3225[b]	1740, 1654[b]						2.44[b]	4.92[b]	8.07[b]
		3240, 3200[c]	1738, 1654[c]			2.34[d]	4.95[d]				
1b	$3\text{-}CF_3\text{-}C_6H_4$	3272	1732, 1668	3391	1724, 1680	2.31	5.39	10.96	2.46	4.95	8.29
1c	$3\text{-}Cl\text{-}C_6H_4$	3259	1729, 1654	3393	1725, 1682	2.30	5.36	10.81	2.44	4.93	8.17
1d	$4\text{-}Cl\text{-}C_6H_4$	3251	1700, 1653	3393	1717, 1676	2.29	5.35	10.77	2.44	4.93	8.13
		3255[c]	1734, 1657[c]			2.33[d]	4.95[d]				
1e	$4\text{-}F\text{-}C_6H_4$	3236	1728, 1647	3393	1724, 1672	2.29	5.33	10.71	2.44	4.93	8.13

[a]Concentration 0.03 M, cell thickness 0.5 mm. [b]See ref. 7. [c]See ref. 3. [d]In $[D_8]$Dioxan, see ref. 8.

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[†] This is a Short Paper, there is therefore no corresponding material in *J Chem. Research (M)*.

Table 2 Found and calculated bands in the IR spectrum of compound **1e** in the region of 3300–2800 cm^{-1}

Wavenumber [cm^{-1}] found	Wavenumber [cm^{-1}] calc.	Valence vibration
3236	3350	N*H*
3208	3190	Coupled symmetric C*H*$_3$-Ar*H*
3150	3115	Coupled asymmetric C*H*$_3$-Ar*H*
3050 br	3075	Asymmetric C*H*$_3$
3050 br	3070	Ar*H*
2960	2900	C*H*Cl

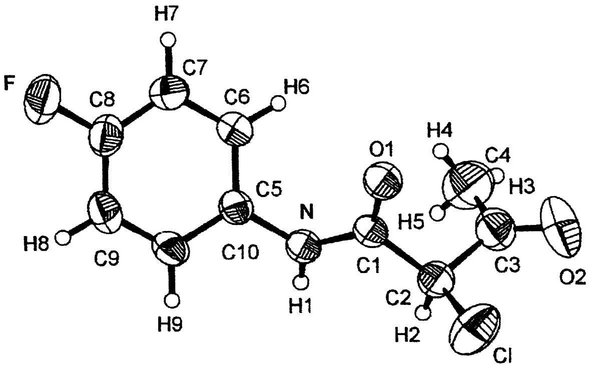

Fig. 1 Molecular structure of **1e** with atom numbering scheme (displacement ellipsoids with 50% probability).

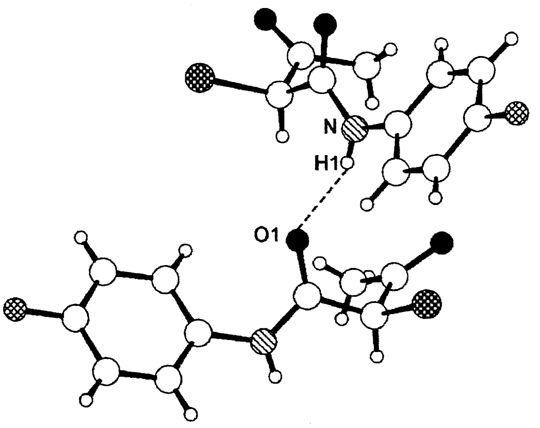

Fig. 2 Orientation of two molecules in the crystal of **1e** showing the intermolecular hydrogen bond (dashed lines).

trum of **1e** with the results of quantum chemical calculations. The starting point of the calculations was a dimer, consisting of two molecules of **1e** which form an intermolecular hydrogen bond. The atom coordinates of this dimer were obtained from the X-ray data. The structure was geometry optimised using the PM3 method[9] with following force calculation. The simulated IR spectrum exhibits the NH stretching band at 3350 cm^{-1} and additional bands in the 3200–2800 cm^{-1} region, see Table 2. The wavenumber of the NH valence vibration depends sensitively on the existence of a hydrogen bond. The geometrical optimisation via the PM3 method leads to a considerable oversized bond length between the hydrogen atom of the NH group and the oxygen atom of the CO group of the neighboured molecule, than derived from X-ray diffraction data. Therefore, the corresponding calculated value for the vibration differs from the one experimentally obtained. Nevertheless, the force calculation has to be performed after a geometrical optimisation of a molecule in order to get force constants and wavenumbers of an energetically minimised structure. The bands at 3190 and 3115 cm^{-1} were assigned to coupled symmetric and asymmetric CH_3–ArH vibrations. The simulated IR spectrum of the model compound 4-acetylaminobenzaldehyde points at similar spectroscopic properties. The observed bands near 3200 cm^{-1} do not result from NH valence vibrations of unknown origin as discussed in[10] but from such coupled CH_3–ArH vibrations.

Experimental

The synthesis of **1e** was based on refs.[1,3,4] Compound was prepared from *N*-(4-fluorophenyl)-3-oxobutanamide (10 mmol, 1.9 g of the crude product). Yield 0.9 g (40 %), white needles; m.p. 126–127 °C (ethanol/water). IR (KBr, $CDCl_3$), see Table 1. ^1H NMR ([D_6]DMSO), see Table 1, further signals: $\delta = 7.16$ (dd, $J = 9$ Hz, 2H, arom. H), 7.59 (dd, $J = 9$ Hz, 2H, arom. H). ^{13}C NMR ([D_6]DMSO): $\delta = 26.9$ (CH_3), 63.8 (CH), 115.8 (d, $J(^{19}F,^{13}C) = 22$ Hz, 2C, arom. C–3,5), 122.0 (d, $J(^{19}F,^{13}C) = 8$ Hz, 2C, arom. C–2,6), 134.5 (1C, arom. C–1), 159.1 (d, $J(^{19}F,^{13}C) = 242$ Hz, 1C, arom. C–4), 163.2 (CONH), 197.5 ($COCH_3$). MS (EI): *m*/*z* (%) = 229 (M^+, 25), 111 (100), 92 (45). $C_{10}H_9ClFNO_2$ (229.6): calcd. C 52.30, H 3.95, Cl 15.44, F 8.27, N 6.10; found C 52.11, H 3.95, Cl 15.40, F 7.92, N 6.12.

X-ray crystal structure of **1e:** Crystal data: $C_{10}H_9O_2ClFN$, monoclinic, $P2_1/a$, $Z = 4$, $a = 9.256(2)$, $b = 9.840(2)$, $c = 11.851(3)$ Å, V = 1056.1(3) Å^3, ρcalc. = 1.44 gcm^{-3}; $\mu = 0.354$ mm^{-1}, λ (Mo-Kα) = 0.71069 Å, graphite monochromator. Data collection was carried out by $\omega/2\theta$-scan technique ($3.52° < 2\theta < 51.92°$) at room temperature using a STOE STADI-IV diffractometer. 4059 collected reflections, 1634 independent reflections with $I > 2\sigma(I)$, $R_{int} = 0.0563$. Structure analysis and refinement: direct methods with the program SHELXS-86,[11] full-matrix least square refinement with the program SHELXL-93[12], all non-hydrogen atoms anisotropic, 172 parameters, final *R* values ($I > 2\sigma(I)$): $R1 = 0.0480$, $wR2 = 0.1307$. For further information see ref. 13.

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13 Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-144473. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: int. code + 44(1223)336-033; E-mail: deposit@ccdc.cam.ac.uk]