Restricted Rotation around the Carbon–Nitrogen Amide Bond in (E)-2-Formylthiophene N-Acetylhydrazone. X-Ray Structures of the Resulting Conformers

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The rotation around the C–N amide bond in the title compound produces two conformational isomers *trans* (1) and *cis* (2), which have been isolated in the solid state. Their i.r. spectra show significant differences in the 1 800—1 200 cm^{-1} region, in particular the disappearance of the amide II band for (2). Their crystal structures have been determined from X-ray diffractometer data to R = 0.051 for both compounds.

While studying the co-ordination chemistry of acyl- and aroyl-hydrazones of aromatic aldehydes and ketones,[1] we were interested in elucidating the structural features of these molecules, in order better to understand their chelating behaviour. We recently found,[2] by means of ^{1}H and ^{13}C n.m.r. data, that the N-acetylhydrazones of some aromatic aldehydes $CH_3C(O)NHN=CHR$ (R = phenyl, 2-pyridyl, 2-thienyl) can exist in solution as a mixture of conformers (1) and (2)† owing to hindered rotation around the amide C–N bond.

In fact the ^{1}H n.m.r. spectra of these species, recorded in $CDCl_3$ or [$^2H_6$]DMSO, show well separated double signals for CH_3, NH, and =CH, whose intensity ratio changes with the nature of the solvent, the less polar ($CHCl_3$) favouring the form (2). Probably this occurs as a consequence of the formation of centrosymmetric hydrogen-bonded dimer pairs, as in the case of N-substituted amides.

Spectroscopic data in solution provided no evidence of tautomeric equilibria (leading to iminol forms) and of E–Z isomerization around the –N=CH– double bond, the less hindered E-configuration being maintained. The iminol or hydroxyazine forms are often postulated to be produced from tautomeric equilibria involving these species when free in solution; however all experimental data (see also refs. 3 and 4) indicate that their existence is far from proved.

During some preparations of these hydrazones and of certain metal acetates we obtained two different crystalline forms of the title compound, hereafter Hait. Thus, in order to confirm the interpretation of the n.m.r. data, single crystal X-ray analyses of the two isomers were performed. The crystal and molecular structures of these species together with their i.r. spectra are described here.

Experimental

Reagents.—Reagent grade metal acetates, ethyl acetate, hydrazine hydrate, and 2-formylthiophene (C. Erba and Merck) were used without further purification. Solvents were distilled before use.

Physical Measurements.—I.r. spectra (KBr disc; 4 000—250 cm^{-1}) were recorded on a Perkin-Elmer 283B spectrophoto-

(1)(*trans*)   (2)(*cis*)
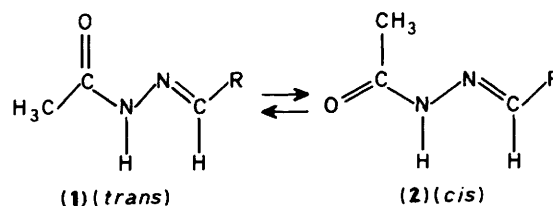
R = C_6H_5 (Haib)
R = C_5H_4N (Haip)
R = C_4H_3S (Hait)

meter; ^{1}H (100 MHz) n.m.r. spectra in deuteriated dimethyl sulphoxide, with tetramethylsilane as internal reference, were recorded at different temperatures on a Varian XL100 instrument. Mass spectra were run on a Varian CH5 spectrometer. Elemental C, H, and N analyses were performed with a Perkin-Elmer 240 automatic analyser.

Preparations.—The ligand Hait, in its *trans* (1) configuration, was prepared by heating in ethanol (1:1 molar ratio) acetylhydrazine and 2-formylthiophene under reflux for 30 min. The prismatic crystals, obtained on cooling, were filtered off, washed and dried *in vacuo* and identified by means of their i.r., n.m.r., and mass spectra and the results of C, H, and N analysis.

Hait was treated with various divalent transition metal acetates (1:2 molar ratio) in boiling ethanol. Only in the case of Ni and Cu, neutral, 1:2 square planar complexes of formula M(ait)$_2$ were obtained and these will be discussed in a further paper, whereas in the case of other divalent metals, in particular Cd, unchanged $Cd(CH_3COO)_2$ was recovered together with needles of an organic product. This gave the same analytical figures as the starting ligand Hait, but showed some major differences in the i.r. spectrum, especially in the range 1 800–1 200 cm^{-1} (see Figure 1).
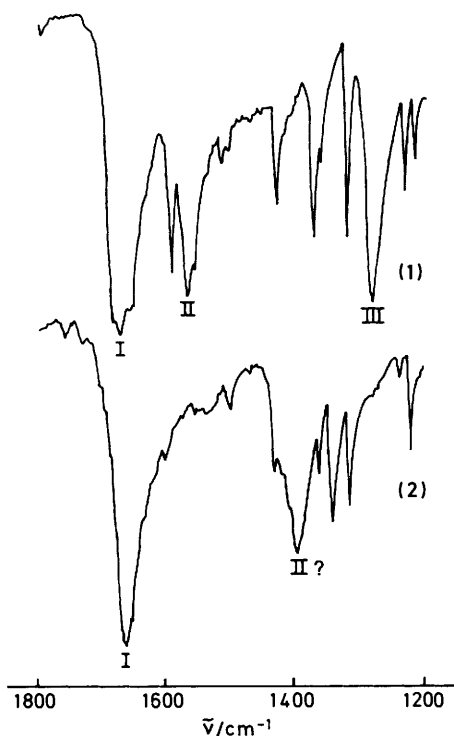
At this stage we decide to carry out an X-ray structural analysis on the two crystalline forms of Hait in order to establish their molecular structure and hence the kind of isomerism relating them.

Structure Analysis.—The dimensions of the crystals selected for data collection were 0.60 × 0.40 × 0.50 mm for the prisms

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† The terms *cis* and *trans* or *syn* and *anti* are widely used for N-substituted amides.

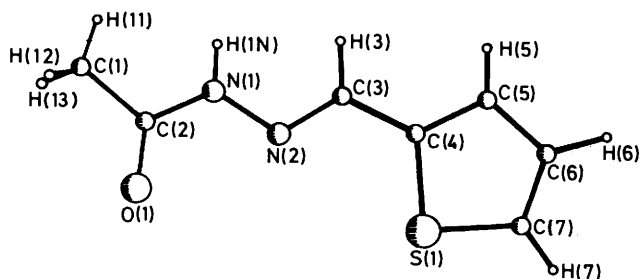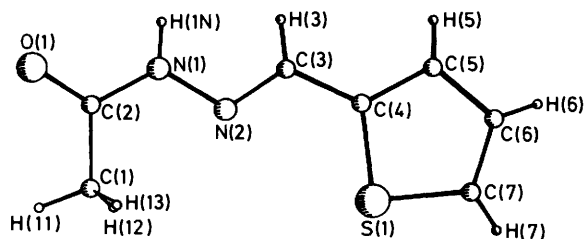**Table.** Crystal data of the two isomers of Hait $C_7H_8N_2OS$, M 168.2

(1) *trans*: monoclinic, $P2_1/c$, $a = 7.388(2)$, $b = 12.387(4)$, $c = 8.691(2)$ Å, $\beta = 97.97(2)°$, $V = 787.7(4)$ Å^3, $Z = 4$, $D_c = 1.418$ g cm^{-3}, $F(000) = 352$, $\mu(Cu-K_\alpha) = 30.29$ cm^{-1}

(2) *cis*: triclinic, $P\bar{1}$, $a = 10.256(3)$, $b = 9.312(2)$, $c = 4.566(1)$ Å, $\alpha = 101.14(2)$, $\beta = 103.70(3)$, $\gamma = 83.21(2)°$, $V = 414.5(2)$ Å^3, $Z = 2$, $D_c = 1.348$ g cm^{-3}, $F(000) = 176$, $\mu(Cu-K_\alpha) = 28.9$ cm^{-1}

Figure 2. Perspective view of (1)

Figure 3. Perspective view of (2)

Figure 1. I.r. spectra of (1) and (2) in the range of the 'amide' frequencies

(1) and $0.15 \times 0.25 \times 0.38$ mm for the needles (2). Their crystal data are reported in the Table.

Intensity data were collected for both crystals with Cu-K_α (Ni-filtered) radiation on a Siemens AED computer-controlled diffractometer, within the range $3 < \theta < 70°$. 1 667 independent reflections, 1 289 with $I > 2\sigma(I)$, for (1) and 1 543, 1 271 with $I > 2\sigma(I)$, for (2), were obtained. The observed intensities were corrected for Lorentz and polarization, but not for absorption effects. The structure was solved by direct methods, using the SHELX-76 system of programs,[5] in which the atomic scattering factors take into account the anomalous scattering effects, following ref. 6. Full-matrix least-squares calculations were carried out with anisotropic thermal parameters (isotropic for hydrogen) and the R and R_w values converged to 0.051 and 0.058 and to 0.051 and 0.052 for (1) and (2) respectively (0.055, 0.055 and 0.056, 0.051 considering all reflections). The scattering factors for *non*-hydrogen atoms were taken from ref. 6 whereas, for hydrogen atoms, the factors given by Stewart[7] were used. The weighting scheme employed was $w = [\sigma(F)^2 + cF^2]^{-1}$, where $c = 0.017$ for (1) and $c = 0.6$ for (2).

All calculations were performed on the CYBER-76 computer of the Centro di Calcolo Interuniversitario dell'Italia Nordorientale, with the financial support of the University of Parma.

Deviations from least-square planes and dihedral angles are in Supplementary Publication No. 56446 (2 pp.) (see *J. Chem. Soc., Perkin Trans 2*, 1986, Issue 1 for details). Other data are available from the Cambridge Crystallographic Data Centre.

Results and Discussion

The title compound can crystallize from alcohols in its *trans* conformation (1), but it exists in solution as a mixture of the *trans* (1) and *cis* (2) conformers, owing to slow rotation about the C–N amide bond. As in the case of amides the high barrier to rotation enables one to observe separate signals for otherwise equivalent hydrogen atoms. In fact coalescence occurs, in dimethyl sulphoxide, at a relatively high temperature (79 °C) and the approximate values of the free energies of activation $\Delta G^{\ddagger}$ are 18.1 and 18.3 kcal mol^{-1} for (1) and (2), respectively. These values, obtained following the method for unequal doublets of Shanan-Atidi and Bar-Eli,[8] reported by Sand-stroem[9] (T_c, 352.1 K; δv 21 Hz; Δp 0.14), compare rather well with those currently found for amides.[10]

The correctness of the interpretation of the spectroscopic data has been confirmed after the separation of the crystals of Hait in the *cis* conformation (2), as established by the X-ray structural analysis.

I.r. Spectra.—As Hait contains the –CO–NH– moiety, its i.r. spectra can be regarded in the same way of those of the secondary amides. In fact, as shown in Figure 1, the major absorption bands derive from the so-called 'amide' bands, including the CO stretching and the NH deformation mode. The values of these absorption frequencies are in good agreement with those normally observed for the secondary amides.[4] Passing from the *trans*- to the *cis*-structure, the amide I band remains practically unchanged, whereas the amide II and III bands, which are well distinguished in the spectrum of the *trans*-form, collapse into a single absorption band in the spectrum of the *cis*-compound.

This significant difference, which has also been observed in the case of secondary amides,[4,11] is expected to be general for such compounds and hence can constitute an effective diagnostic tool for recognizing their molecular arrangements.
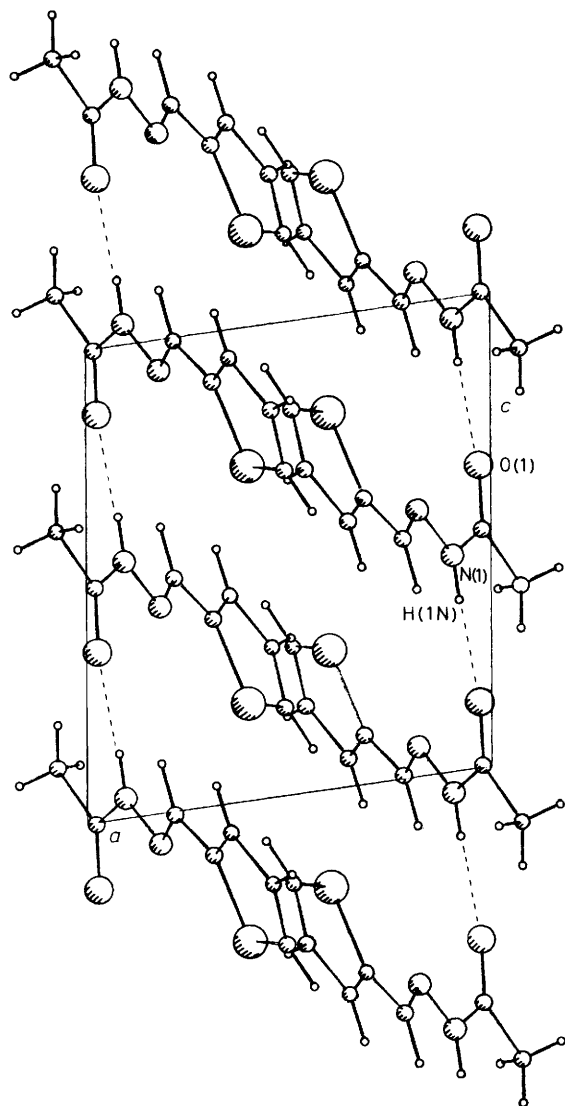
Figure 4. Crystal packing of (1)

Figure 5. Crystal packing of (2)

X-Ray Structures.—Perspective views of the two molecules are depicted in Figures 2 and 3, for (1) and (2), respectively.

Hait, in both conformations, is essentially planar, as expected from the occurrence of some degree of conjugation between the hydrazide chain and the heteroaromatic ring. The greatest deviations from the weighted least-squares planes are given by O(1) [0.275(2)Å] for the *trans*-isomer and by C(1) [0.242(4)Å] for the *cis*-one.

Nevertheless there are some small differences in the geometrical parameters, which can reflect an actual difference in the bonding situation of the two conformers. The steric hindrance produced by the methyl group *syn* to the –N=C grouping in (2) forces the former to assume an eclipsed configuration [staggered in (1)] with regard to O(1); in addition it causes a broadening of the C(1)–C(2)–N(1) angle and a lengthening of the C(2)–N(1) amide distance relative to the values found in (1), which compare with the corresponding ones normally found in amides.[11] Furthermore the amide C(1)C(2)O(1)N(1) grouping is planar in (1), the maximum deviation being 0.004(2)Å for O(1), whereas the same group in (2) deviates significantly from planarity. On the other hand the
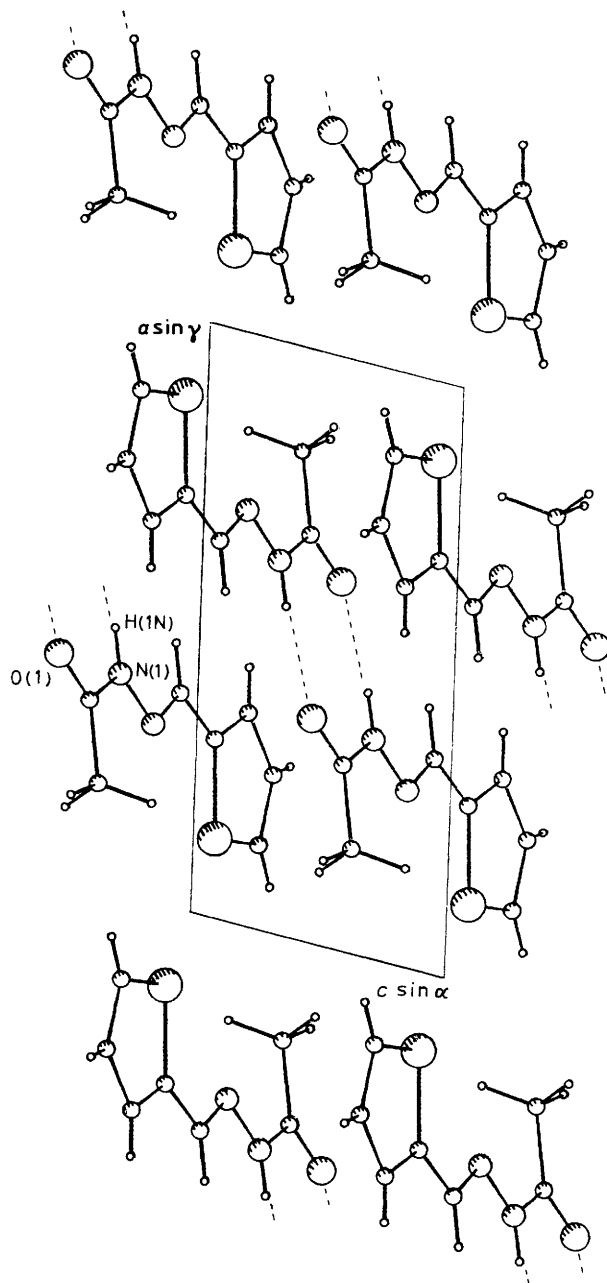
C(2)N(1)N(2)C(3) fragment is more planar in (2) than in (1), as is shown by the deviations from the least-squares planes. Accordingly the torsion angle C(2)N(1)N(2)C(3) is −179.4(2)° in (2), whereas it is only −168.6(2)° in (1).

These data support the picture, previously depicted,[2] that the *non*-bonding pair of the amide nitrogen is more available in (2) for conjugation with the hydrazine chain and the peripheral thiophene ring, owing to the reduced contribution of the conjugative form ⁺N=C–O⁻. This trend is also shown by some small but significant differences in bond lengths along the chain: in (2) N(1)–N(2) and C(3)–C(4) are shorter, whereas the N(2)–C(3) and C(4)–C(5) bond lengths are longer than in (1). Finally, the dihedral angle between the hydrazone chain and the thiophene ring is only 5.96(6)° in (2), whereas it reaches 11.22(5)° in (1).

As shown in Figures 4 and 5, packing is mainly determined by

a system of hydrogen bonds, which produce an infinite zig-zag chain in the *trans*-form [N $\cdots$ O = 2.834(2)Å] and a centrosymmetric dimer in the *cis*-one [N $\cdots$ O = 2.896(3)Å]. These association patterns are the same as those found for secondary amides in the solid state.[12]

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