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# Intermolecular CH···N/CH···O hydrogen bonds in the crystal structures of α,β-unsaturated ketones carrying a terminal pyridine subunit

Monika Mazik,[a,*] Dieter Bläser[b] and Roland Boese[b]

[a]*Institut für Organische Chemie der Universität Essen,Universitatsstrasse 5, D-45117 Essen, Germany*
[b]*Institut für Anorganische Chemie der Universität Essen, D-45117 Essen, Germany*

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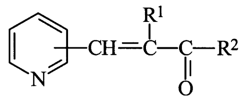
**Abstract**—α,β-Unsaturated ketones **1–4** carrying a terminal pyridine subunit form aggregates in the crystalline state with the molecules linked together through CH···N/CH···O hydrogen bonds. The hydrogen-bonding motifs are discussed. © 2001 Published by Elsevier Science Ltd.

The C–H group is the most controversially discussed of the weak hydrogen bond donors in crystals.[1] Among the weak hydrogen-bonding interactions, investigations have been concentrated mostly on CH···O interactions.[2] Other weak CH···Y interactions, such as CH···N or CH···Cl, have been less studied.[3,4] However, unequivocal criteria for the establishment of the limits between 'true' hydrogen bonds and van der Waals interactions are still lacking, especially the van der Waals radii cut-off criterion is a point at issue.

Weak hydrogen bonds based on C–H donors can be important both as secondary and, in fewer cases, as primary interactions in determining the crystal structures, in the stabilization of inclusion complexes, and in molecular recognition processes. These interactions can be valuable for crystal engineering [2e] and also play an important role in biological systems,[1a,5] they constitute therefore a topic of great current interest.

Recently, we have shown that CH···N hydrogen bonds play a dominant role in determining the crystal packing of pyridinyl-isoxazoles [6] and that they are also important as secondary interactions for the stabilization of the crystal structures of pyridinyl-α,β-unsaturated ketoximes.[7] In this paper we present the potential of CH···N/CH···O interactions in determining the crystal structures of α,β-unsaturated ketones carrying a terminal pyridine subunit. The compounds under study were 3-phenyl-4-pyridin-4′-yl-3-buten-2-one (**1**), 1,2-diphenyl-3-pyridin-4′-yl-2-propen-1-one (**2**), 2-methyl-1-phenyl-3-pyridin-4′-yl-2-propen-1-one (**3**) and 3-phenyl-4-pyridin-3′-yl-3-buten-2-one (**4**).



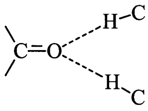
**1:** pyridin-4-yl, $R^1 = C_6H_5$, $R^2 = CH_3$

**2:** pyridin-4-yl, $R^1 = C_6H_5$, $R^2 = C_6H_5$

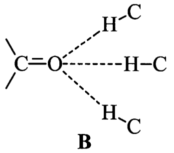
**3:** pyridin-4-yl, $R^1 = CH_3$, $R^2 = C_6H_5$

**4:** pyridin-3-yl, $R^1 = C_6H_5$, $R^2 = CH_3$

The characteristic feature of the crystal structures of **1–4** is the presence of C–H···N-pyr hydrogen bonds and the participation of the C═O group in multiple hydrogen bonds of type **A** and **B** (configuration **A**, where the acceptor is involved in two hydrogen bonds, is also referred to as 'bifurcated bonds').



**A**



**B**

In the crystal structures of **1–4** the pyridine nitrogen participates in C($sp^2$)–H···N-pyr hydrogen bonds and the carbonyl oxygen is involved in both C($sp^2$)–H···O═C and C($sp^3$)–H···O═C bonds.

X-Ray crystallographic analysis of a single crystal of **1** established that the molecules of **1** form hydrogen bonded chains with relatively short CH···N and CH···O contacts. Between these chains CH···N interactions were found (Scheme 1, Fig. 1). Within an individual chain the molecules of **1** act alternatingly only as hydrogen bond

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*Keywords*: hydrogen bonds; crystal engineering; supramolecular chemistry.

[*] Corresponding author. Tel.: +49-201-1833095; fax: +49-201-1834259; e-mail: monika.mazik@oc1.orgchem.uni-essen.de

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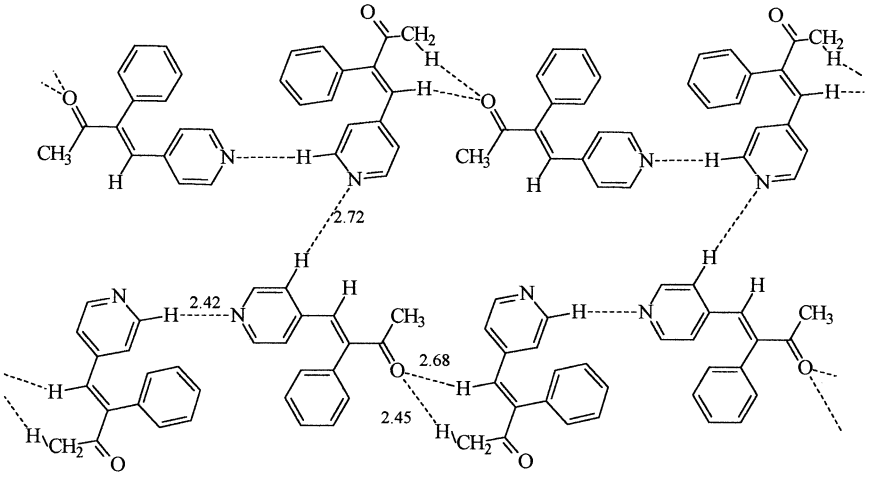


**Scheme 1.** Schematic structure of the packing of **1** in the crystal.

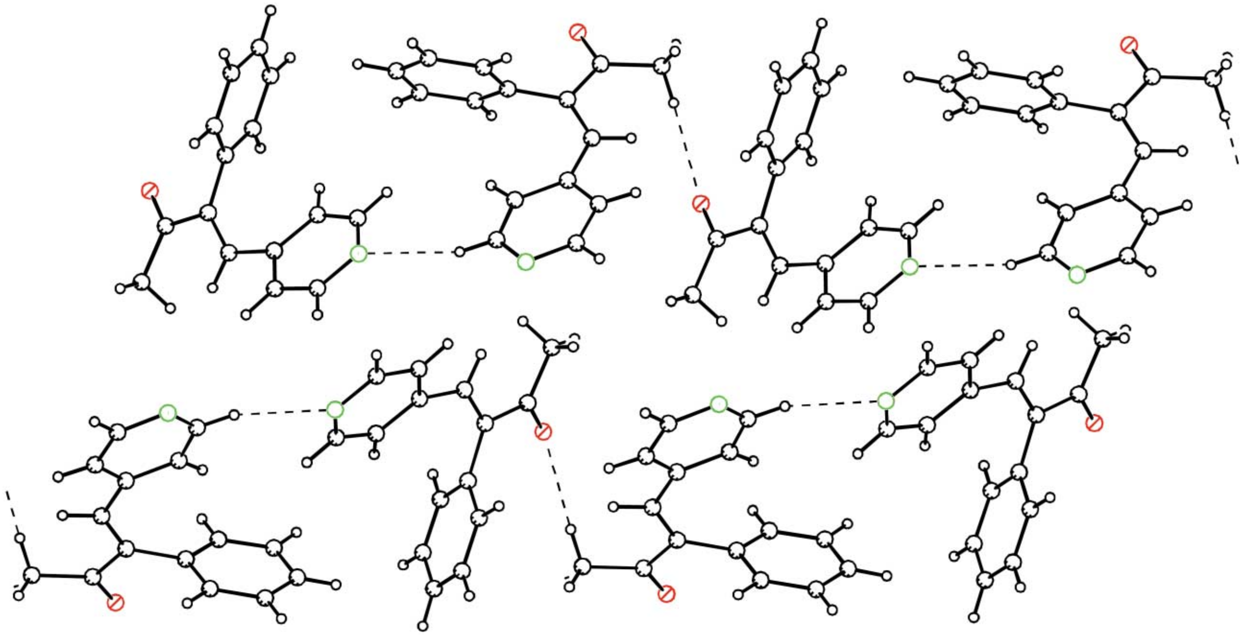


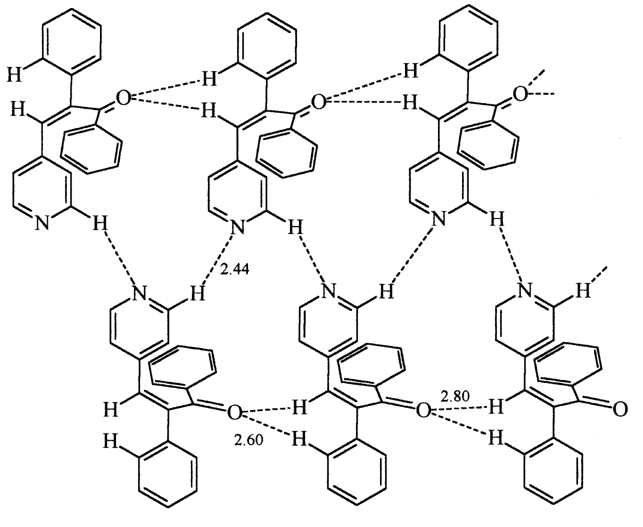
**Figure 1.** Crystal structure of **1** (only the shortest CH···N and CH···O contacts are shown).

**Table 1.** CH···N/O distances and angles for **1**–**4**

| Compound | C–H···N/O interactions | C–H···Y (Å) | C···Y (Å) | C–H···Y angle (°) |
|---|---|---|---|---|
| **1** | pyr-C–H···N-pyr | 2.42 | 3.46 | 161.2 |
| | | 2.72 | 3.74 | 156.5 |
| | Methyl-C–H···O═C | 2.45 | 3.52 | 169.5 |
| | ═C–H···O═C | 2.68 | 3.46 | 129.0 |
| **2** | pyr-C–H···N-pyr | 2.44 | 3.41 | 150.7 |
| | Ph-C–H···O═C | 2.60 | 3.47 | 137.4 |
| | ═C–H···O═C | 2.80 | 3.15 | 98.0 |
| **3** | Phenyl-C–H···N-pyr | 2.73 | 3.71 | 150.7 |
| | Methyl-C–H···O═C | 2.61 | 3.40 | 129.4 |
| | Phenyl-C–H···O═C | 2.60 | 3.65 | 165.0 |
| | pyr-C–H···O═C | 2.42 | 3.38 | 147.0 |
| **4** | pyr-C–H···N-pyr | 2.73 | 3.58 | 134.7 |
| | Methyl-C–H···O═C | 2.47 | 3.47 | 153.8 |
| | | 2.52 | 3.49 | 148.7 |
| | pyr-C–H···O═C | 2.57 | 3.53 | 146.0 |
| | | 2.60 | 3.54 | 145.1 |
| | ═C–H···O═C | 2.31 | 3.36 | 161.3 |
| | | 2.33 | 3.36 | 159.2 |

donors or only as hydrogen bond acceptors. The pyridine CH, the methyl hydrogen, and the olefinic hydrogen atoms act as donors for hydrogen bonding with the nitrogen and oxygen atoms, respectively.

The distances of the pyr-CH···N-pyr hydrogen bonds are in the range of 2.42–2.72 Å with C–H···N angles of 156–161° (see Table 1). The carbonyl oxygen participates in two hydrogen bonds, including methyl-C–H···O=C and =C–H···O=C bonds with H···O distances between 2.45 and 2.68 Å and C–H···O angles of 129–169°. In both C–H···N and CH···O interactions the distance between the hydrogen and the acceptor atom is shorter than the sum of their van der Waals radii (2.75 and 2.70 Å, respectively).[8] The donor–acceptor distances are given in Table 1. Between the phenyl rings of neighbouring molecules stabilizing edge-to-face interactions can be recognized. The closest phenyl-C–H···C-phenyl distance amounts to 2.85 Å, interplanar angle between adjacent phenyl rings is about 72°.



**Scheme 2.** Schematic structure of the packing of **2** in the crystal.

Replacement of the methyl group of **1** by a phenyl group (compound **2**) leads to similar hydrogen-bonding motifs in the crystalline state. Once again pyr-CH···N-pyr hydrogen bonds with an H···N distance of 2.44 Å and a C–H···N angle of 151° were found (Scheme 2, Fig. 2). The oxygen atom accepts two C–H groups forming the phenyl-C–H···O=C and =C–H···O=C interactions with H···O distances in the range of 2.60–2.80 Å and C–H···O angles of 98–137° (Table 1). The phenyl rings and the pyridine rings of the adjacent molecules adopt an offset face-to-face geometry stabilized by phenyl–phenyl and pyridine–pyridine interactions.

Compound **3** forms a network of hydrogen bonds with

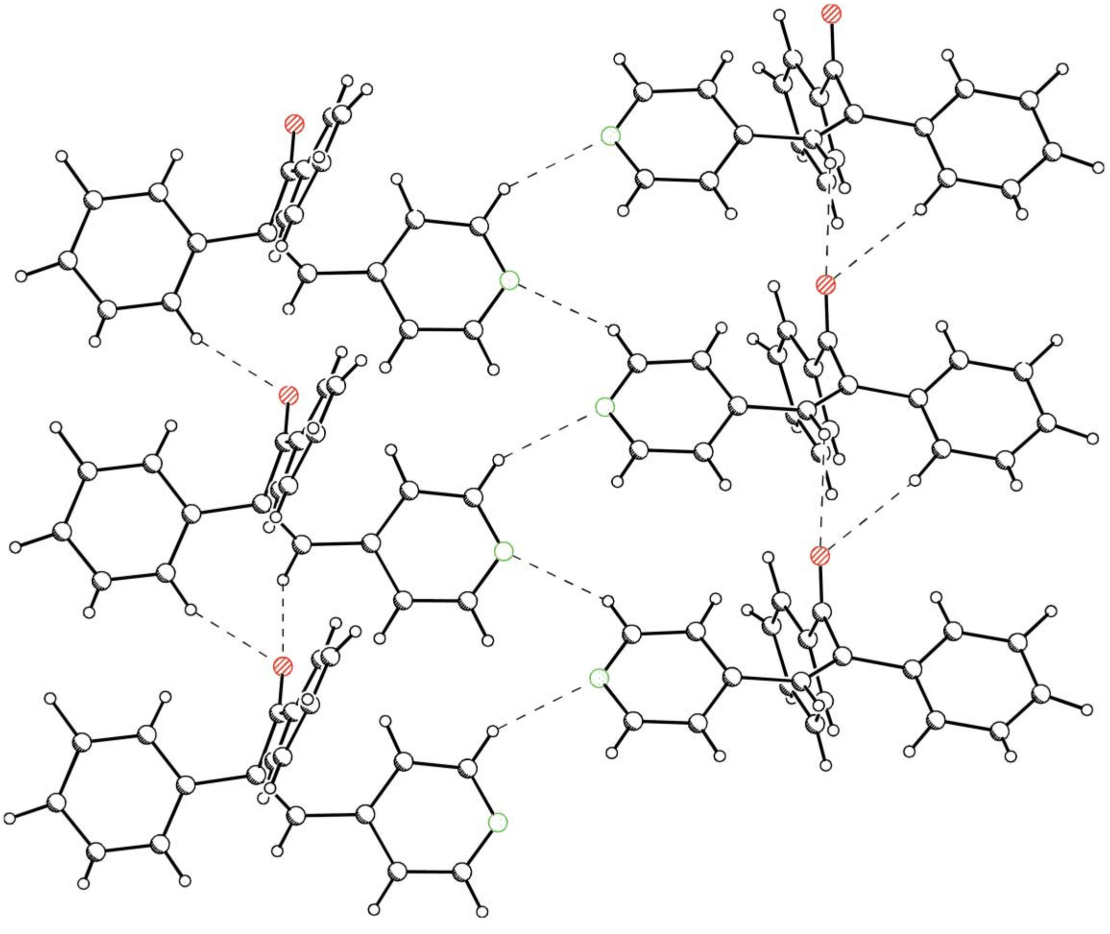
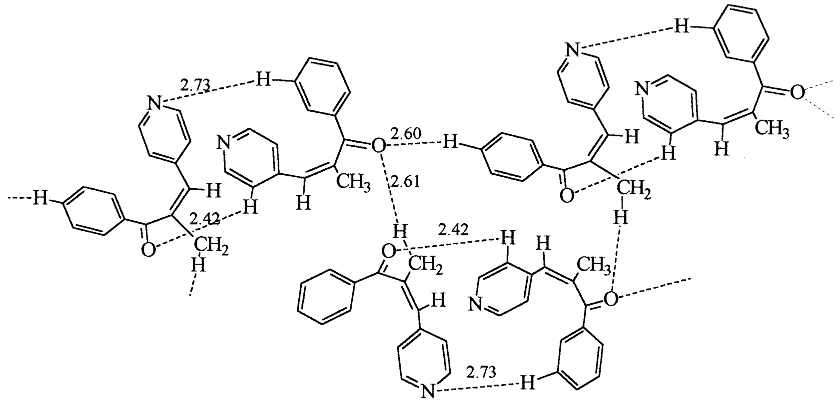


**Figure 2.** Crystal packing of **2**.



**Scheme 3.** Schematic structure of the packing of **3** in the crystal.

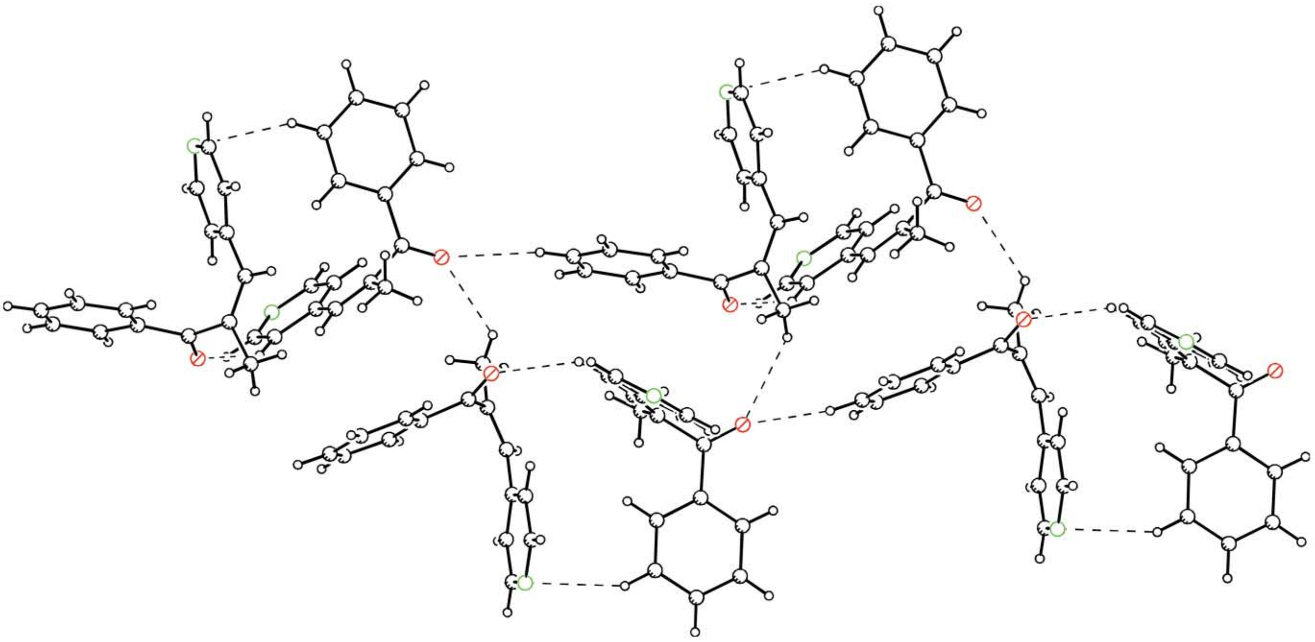


**Figure 3.** Crystal packing of **3**.

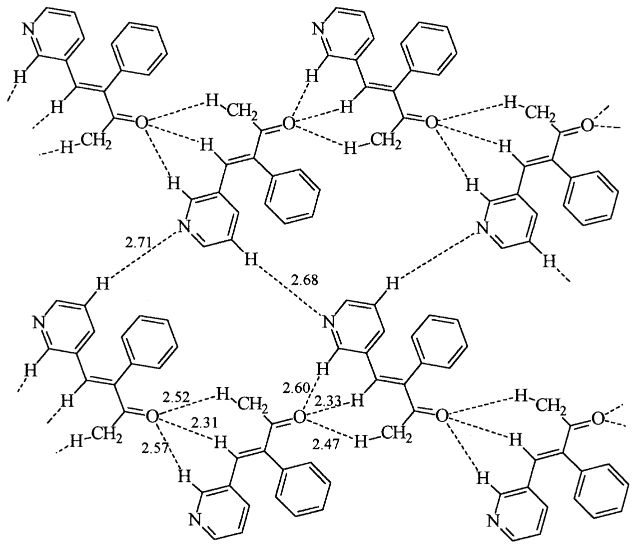
the molecules linked in pairs by phenyl-CH···N-pyr and pyr-CH···O=C interactions (Scheme 3, Fig. 3). These hydrogen bonded dimers interplay with the other dimers by methyl-C–H···O=C and phenyl-C–H···O=C interactions, thus the carbonyl oxygen tends to accept two hydrogen bonds, similar as in the crystal structures of **1** and **2**. The H···O distance of the CH···O bonds range from 2.42 to 2.61 Å (C–H···O angles 129–165°) and the CH···N distance amounts to 2.73 Å (C–H···N angle 151°, see Table 1). Again, the phenyl and pyridine rings of the neighbors participate in edge-to-face interactions (phenyl–pyridine interactions).

Compound **4**, possessing the 3-pyridinyl residue instead of 4-pyridinyl group (as in **1**), forms a chain arrangement with the molecules linked by CH···O interactions and the chains crosslinked by CH···N interactions (Scheme 4, Fig. 4).

Within the chains the molecules of **4** adopt a head-to-tail packing motif with the C=O group displaying a triple acceptor property, accepting hydrogen bonds from the olefinic CH, pyridine CH and methyl CH group. Three short CH···O contacts, two C(sp$^2$)–H···O and one C(sp$^3$)–H···O with H···O distances in the range of 2.31–2.60 Å and C–H···O angles of 145–161° were found (Table 1). The H···N distance for pyr-CH···N-pyr interaction amounts to 2.73 Å and the C–H···N angle is 135°. The phenyl-rings and the methyl groups of neighboring molecules show the orientations in which the methyl hydrogen interact with π-system on the phenyl residue (CH···π interactions). The closest methyl-H···phenyl centroid distance amounts to 3.40 Å.

Compounds **1**–**4** crystallize with two independent molecules in the asymmetric unit. It is interesting to note that molecules **1** and **4** ($R^1=C_6H_5$, $R^2=CH_3$) adopt the *E* configuration of the C=C bond, whereas **2** and **3** ($R^1=C_6H_5$ or $CH_3$, $R^2=C_6H_5$), possessing as $R^2$ an aromatic group, adopt the *Z* configuration. Fig. 5 shows the monomeric units of **1**–**4** in the crystal.

In summary, the crystal structures of **1**–**4** represent new examples for the potential of CH···N/CH···O interactions



**Scheme 4.** Schematic structure of the packing of **4** in the crystal.

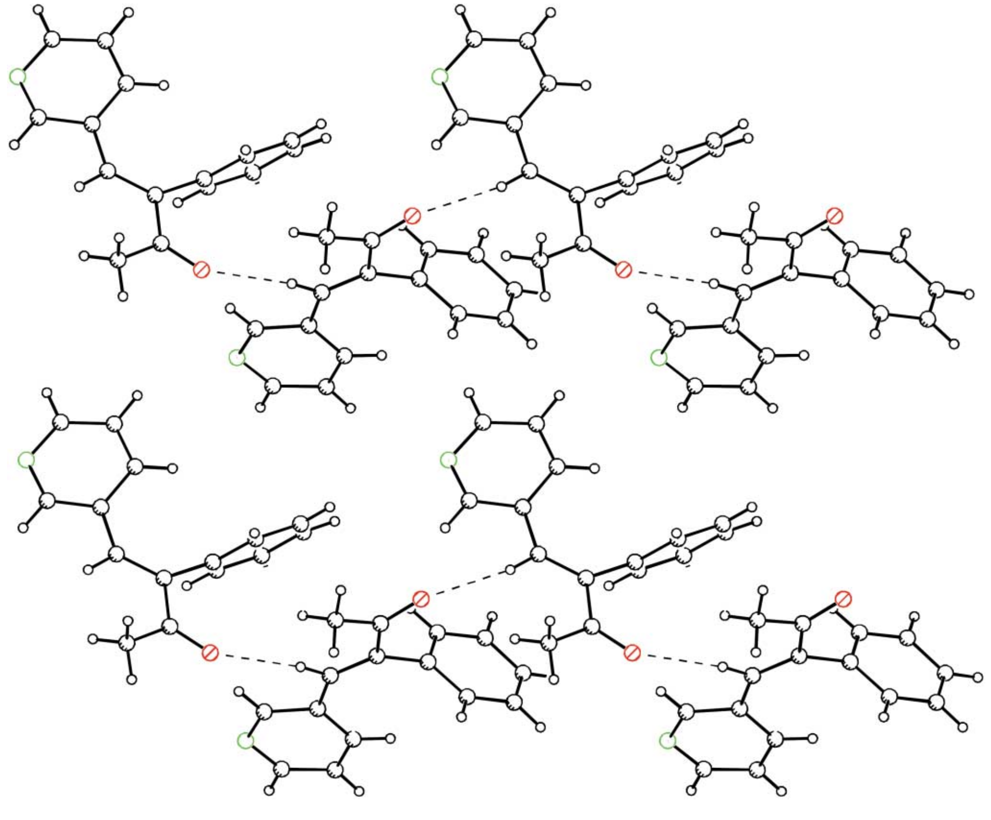


**Figure 4.** Crystal packing of **4** (only the shortest CH···O contacts are shown).

in directing the crystal packing. The CH···N/CH···O interactions exhibit a directionality typical for hydrogen bonding interactions. The observed hydrogen-bonding motifs may be useful for crystal engineering and their analysis should be helpful for the better understanding of the role of weak hydrogen bonds in supramolecular and biological systems.

## 1. Experimental

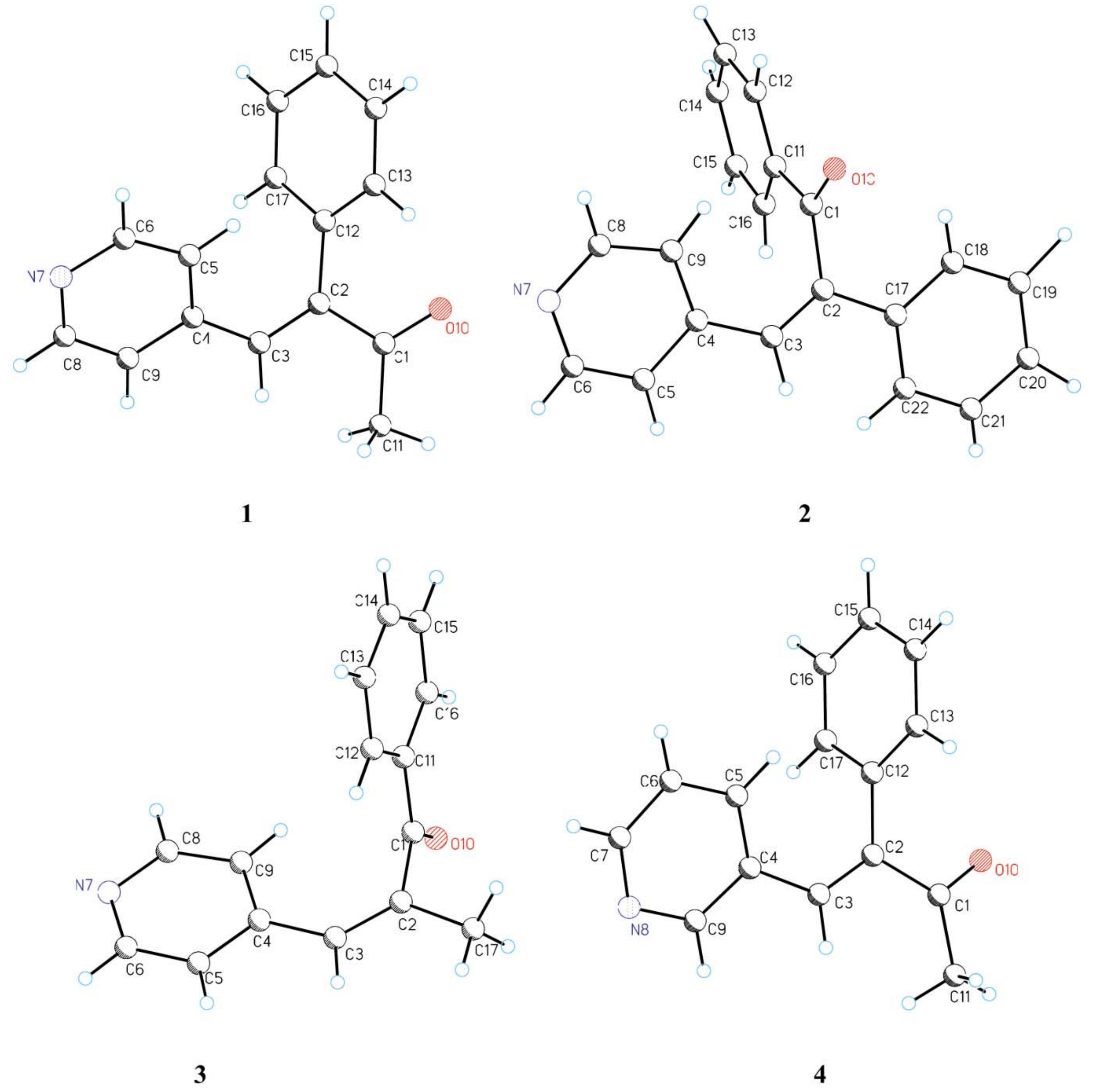
$^1$H- and $^{13}$C NMR spectra were recorded on a Bruker DRX 500 spectrometer; chemical shifts are reported in ppm downfield from TMS as internal standard (solvent $CDCl_3$). Mass spectra were measured with a Fisons VG Prospec 3000 and a Hewlett–Packard HP 5971A MSD spectrometer.

### 1.1. General procedure for synthesis of 1–4

A mixture of pyridine-3- or pyridine-4-carbaldehyde (0.05 mol) and ketone (0.1 mol), such as 1-phenyl-2-propanone, 1.2-diphenylethanone or 1-phenyl-1-propanone, in chloroform (200 ml) was saturated with gaseous hydrogen chloride (0.1 mol). The reaction mixture was kept at 25°C for 48 h. Chloroform was evaporated, and the residue was washed several times with diethyl ether. The residual product was dried under vacuum. The crude pyridinyl α,β-unsaturated ketone hydrochlorides were obtained as yellowish powder. These crude hydrochlorides were dissolved in water and alkalized with 5% NaOH. The products were extracted with chloroform and crystallized from hexane or toluene.

**1.1.1. 3-Phenyl-4-pyridin-4′-yl-3-buten-2-one (1).**[9] Mp 93–93.5°C (hexane). $^1$H NMR: $\delta$=2.25 (s, 3H, $CH_3$), 6.78 (d, $2H_{pyr}$, $J$=6.0 Hz), 7.07–7.09 (m, $2H_{ph}$), 7.34–7.35 (m, $3H_{ph}$), 7.43 (s, 1H, =CH), 8.34 (d, $2H_{pyr}$, $J$=6.0 Hz). $^{13}$C NMR: 199.37, 150.27, 144.98, 142.53, 136.10, 135.63, 129.61, 129.53, 128.93, 124.68, 28.51. MS $m/z$ (rel. int. %): 223 ($M^+$, 70), 208 (9), 180 (100), 162 (22), 152 (29), 132 (7), 127(6), 105 (24), 77 (17), 51 (12), 43 (26). HR-MS, calcd for $C_{15}H_{13}NO$: 223.0997; found: 223.0995.

**1.1.2. 1,2-Diphenyl-3-pyridin-4′-yl-2-propen-1-one (2).**



**1**

**2**

**3**

**4**

**Figure 5.** Monomeric units of **1**–**4** in the crystal.

Mp 142–144°C (toluene). $^1$H NMR: $\delta$=7.06 (s, 1H, =CH), 7.13 (d, 2H$_{pyr}$, $J$=6.0 Hz), 7.33–7.38 (m, 5H$_{ph}$), 7.45–7.50 (m, 3H$_{ph}$), 7.93–7.95 (m, 2H$_{ph}$), 8.40 (d, 2H$_{pyr}$, $J$=6.3 Hz). $^{13}$C NMR: 198.15, 150.27, 149.86, 145.03, 142.82, 136.84, 135.78, 134.16, 129.63, 129.09, 129.05, 128.96, 126.66, 126.44, 122.91. MS $m/z$ (rel. int. %): 285 (M$^+$, 43), 267 (5), 212 (5), 180 (5), 162 (10), 152 (7), 132 (15), 105 (100), 85 (16), 83 (20), 77 (36), 51 (9), 43 (6). HR-MS, calcd for $C_{20}H_{15}NO$: 285.1154; found: 285.1155.

**1.1.3. 2-Methyl-1-phenyl-3-pyridin-4′-yl-2-propen-1-one (3).** Mp 69–71°C (hexane). $^1$H NMR: $\delta$=2.18 (d, 3H, CH$_3$, $J$=1.5 Hz), 6.60 (q, 1H, =CH, $J$=1.5 Hz), 6.97 (d, 2H$_{pyr}$, $J$=6.3 Hz), 7.34–7.37 (m, 2H$_{ph}$), 7.47–7.50 (m, 1H$_{ph}$), 7.84–7.86 (2H$_{ph}$), 8.31 (d, 2H$_{pyr}$, $J$=6.3 Hz). $^{13}$C NMR: 199.84, 149.78, 143.00, 142.19, 134.55, 133.97, 129.28, 128.84, 127.11, 122.57, 22.95. MS $m/z$ (rel. int. %): 223 (M$^+$, 73), 222 (23), 208 (8), 194 (12), 180 (6), 117 (8), 105 (100), 91 (6), 77 (50), 65 (5), 51 (15), 44 (4), 28 (10). HR-MS, calcd for $C_{15}H_{13}NO$: 223.0997; found: 223.0996.

**1.1.4. 3-Phenyl-4-pyridin-3′-yl-3-buten-2-one (4).**[10] Mp 81–82°C (hexane). $^1$H NMR: $\delta$=2.29 (s, 3H, CH$_3$), 6.99–7.02 (m, 1H$_{pyr}$), 7.11–7.15 (m, 1H$_{pyr}$, 2H$_{ph}$), 7.35–7.42 (m, 3H$_{ph}$), 7.57 (s, 1H, =CH), 8.36–8.39 (m, 2H$_{pyr}$). $^{13}$C NMR: 198.83, 151.99, 149.69, 142.80, 136.73, 136.15, 134.71, 130.57, 129.32, 129.17, 128.36, 122.99, 27.99. MS $m/z$ (rel. int. %): 223 (M$^+$, 43), 208 (9), 180 (100), 152 (28), 127 (7), 77 (7), 51 (7), 43 (14). HR-MS, calcd for $C_{15}H_{13}NO$: 223.0997; found: 223.0992.

### 1.2. X-Ray crystallographic analyses

The data of the crystals of **1–3** were obtained with a Siemens SMART-CCD three circle diffractometer ($MoK_{\alpha}$-radiation, graphite-monochromator) at 293 K. The structures were solved using direct methods and refined on $F^2$ using SHELXTL (Vers. 5.03). All non-H atoms were anisotropically refined and aromatic and methyl H atoms were treated as riding groups with the 1.2 fold U-value (1.5 for methyl hydrogens) of the corresponding C-atoms. The mentioned distances to H-atoms are based on normalized C–H distances ($d_{C-H}$=1.08 Å).

**1.2.1. Crystal data for 1.** $C_{15}H_{13}NO$, $M$=223.26, crystal dimensions 0.24×0.18×0.07 mm, crystal system monoclinic, space group $C2$, $a$=27.0519(4), $b$=5.8363(2), $c$=16.2194(4) Å, $\alpha$=90, $\beta$=105.6630(10), $\gamma$=90°, $V$=2465.68(11) Å$^3$, $Z$=8, $\rho_{calcd}$=1.203 g cm$^{-3}$, wavelength 0.71073 Å, 10850 reflections collected (full sphere, $\theta$-range 2.65–28.28°), 2721 independent reflections ($R_{int}$=0.0467, empirical absorption correction), 1815 observed [$F_o \geq 4\sigma(F_o)$], 307 parameters, $R1$=0.0587, $wR2$=0.1215, residual electron density 0.202$e$ Å$^{-3}$, $\mu$=0.076 mm$^{-1}$.

**1.2.2. Crystal data for 2.** $C_{20}H_{15}NO$, $M$=285.33, crystal dimensions 0.21×0.08×0.08 mm, crystal system monoclinic, space group $P2_1$, $a$=10.465(2), $b$=5.9264(13), $c$=13.006(3) Å, $\alpha$=90, $\beta$=113.039(6), $\gamma$=90°, $V$=742.3(3) Å$^3$, $Z$=2, $\rho_{calcd}$=1.277 g cm$^{-3}$, wavelength 0.71073 Å, 6397 reflections collected (full sphere, $\theta$-range 2.13–28.39°), 2736 independent reflections ($R_{int}$=0.0461, empirical absorption correction), 1774 observed [$F_o \geq 4\sigma(F_o)$], 223 parameters, $R1$=0.068, $wR2$=0.1215, residual electron density 0.353$e$ Å$^{-3}$, $\mu$=0.079 mm$^{-1}$.

**1.2.3. Crystal data for 3.** $C_{15}H_{13}NO$, $M$=223.26, crystal dimensions 0.43×0.38×0.28 mm, crystal system monoclinic, space group $P2_1$, $a$=9.500(2), $b$=15.239(3), $c$=9.688(2) Å, $\alpha$=90, $\beta$=119.316(10), $\gamma$=90°, $V$=1222.9(4) Å$^3$, $Z$=4, $\rho_{calcd}$=1.213 g cm$^{-3}$, wavelength 0.71073 Å, 5916 reflections collected (full sphere, $\theta$-range 2.41–27.50°), 5585 independent reflections ($R_{int}$=0.0223, empirical absorption correction), 4499 observed [$F_o \geq 4\sigma(F_o)$], 308 parameters, $R1$=0.0475, $wR2$=0.1257, residual electron density 0.126$e$ Å$^{-3}$, $\mu$=0.076 mm$^{-1}$.

**1.2.4. Crystal data for 4.** $C_{15}H_{13}NO$, $M$=223.26, crystal dimensions 0.34×0.31×0.12 Å$^3$, crystal system triclinic, space group $P-1$, $a$=9.8290(13), $b$=10.6035(13), $c$=12.0380(2) Å, $\alpha$=97.703(3), $\beta$=101.435(3), $\gamma$=90.974(4)°, $V$=1217.4(3) Å$^3$, $Z$=4, $\rho_{calcd}$=1.218 g cm$^{-3}$, wavelength 0.71073 Å, 3981 reflections collected (full sphere, $\theta$-range 2.12–25.00°), 2305 independent reflections ($R_{int}$=0.0446, empirical absorption correction), 1524 observed [$F_o \geq 4\sigma(F_o)$], 307 parameters, $R1$=0.0479, $wR2$=0.1200, residual electron density 0.164$e$ Å$^{-3}$, $\mu$=0.076 mm$^{-1}$.

Crystallographic data for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-145035 (**1**), 145036 (**2**), 145037 (**3**), 145038 (**4**). Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44-1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).

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