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The Crystal and Molecular Structure of Hydroxyurea

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The crystal and molecular structure of N-hydroxyurea, $H_2NCONHOH$, has been determined from three-dimensional X-ray data. The crystals are monoclinic, space group $P2_1/c$, $z = 4$, the b-axis is short. All the atoms of the molecule except the hydroxyl hydrogen are coplanar. The molecules are connected by a three-dimensional system of hydrogen bonds of the types OH---O and NH---O.

By substituting ammonium sulphate with hydroxylammonium sulphate in the classical Wöhler-synthesis of urea, two isomeric compounds are formed, *viz.* hydroxyurea, $O=C(NH_2)NHOH$ and O-carbamoylhydroxylamine, $O=C(NH_2)ONH_2$. Both compounds have been thoroughly investigated by chemical and physicochemical methods [1–3] and their chemical constitutions have been established unequivocally. Hydroxyurea has recently been introduced into cancer chemotherapy.[4,5] The aims of the present work have been to describe in details the molecular structure of hydroxyurea as found in the crystalline state and to study the positions of the hydrogen atoms in order to discuss the molecular conformation and the system of hydrogen bonds. A similar study of O-carbamoylhydroxylamine is in progress.

EXPERIMENTAL

Hydroxyurea was synthesized from urethan and hydroxylamine.[6] Single crystals suitable for X-ray diffraction work were obtained by recrystallisation from ethanol. The melting point was 140–141° (decomp.). Examination of the crystals under the polarization microscope showed monoclinic needles elongated in the b-direction. The faces (001), (100), and (101) were well developed.

Single crystals no larger than 0.3 mm in cross section were chosen for study ($\mu = 13.5$ cm^{-1} for Cu$K\alpha$). Oscillation and Weissenberg photographs showed systematic extinction of $h0l$ reflections when l is odd and of $0k0$ when k is odd, thus indicating the space group $P2_1/c$. The unit cell dimensions were determined from zero-level Weissenberg photographs: $a = 8.46$ Å, $b = 4.89$ Å, $c = 8.86$ Å, and $\beta = 121.9°$. The assumption of four molecules per unit cell leads to a calculated density of 1.625 in good agreement with the observed value of 1.621, measured by flotation.

Multiple film equi-inclination Weissenberg photographs were collected, using Cu$K\alpha$ radiation, of levels hkl for $0 \leq h \leq 4$ and for $0 \leq k \leq 2$. The intensities were esti-

mated visually with the use of standard scales. Of the 650 independent reflexions within the sphere of reflexion a total of 579 independent diffraction maxima were registered. Of these 435 were observed and 144 reflexions were below the minimum observable intensity. The shape of the spots of the non-equatorial layers were taken into account following Phillips.[7] Lorentz and polarization corrections were performed and the intensities measured in different layers were brought on a common scale. No corrections for absorption or extinction were made.

STRUCTURE DETERMINATION

From the Patterson projections $P(xz)$ and $P(yz)$ only a rough idea about the position of the molecule in the unit cell was obtained. The solution of the structure was achieved by means of a sharpened Patterson projection ${}^{s}P(xz)$, the Harker section $P(x\frac{1}{2}z)$ and the Harker line $P(0y\frac{1}{2})$, followed by Fourier syntheses, $\varrho(xz)$ and $\varrho(yz)$. Refinement was carried out according to the method of Bhuiya and Stanley.[8] An ALGOL program written by Danielsen [9] was used.

In the initial computations the analytic constants for the atomic scattering factor for nitrogen [10] were used for the five heavy atoms. When the R-value for $F(h0l)$ had dropped to 0.22 it was still impossible to distinguish between oxygen and nitrogen in the electron density map $\varrho(xz)$. At this stage two molecular structures were compatible with the electron density map, *viz.* the two oxygen atoms placed in *cis* or *trans* positions with respect to the central C—N bond. The decision between the two possibilities was made after further refinement [8,9] and it was found, that the *trans* arrangement of the oxygens gave the lowest R-value and also the best possibilities for hydrogen bonding.

All observed reflections were now introduced into a least-squares refinement which was carried out first by means of a diagonal matrix approximation and individual, isotropic temperature factors (ALGOL program, written by Danielsen [11]). The R-value dropped from 0.28 to 0.16 in 6 cycles. After 3 cycles one very strong reflexion, $(\bar{2}11)$, which was apparently seriously affected by extinction, was removed. Further refinement was carried out by means of a block-diagonal matrix program, written by Grønbæk,[12] with anisotropic refinement of the temperature factors. The weighting scheme used was that proposed by Hughes. [13] After 3 cycles the R-value was 0.128, and a three-dimensional $F_o - F_c$ synthesis was calculated, using a program written by Lauesen.[14] Maxima were found where the hydrogen atoms were expected, *i.e.* in a distance of about 1 Å from O_1, N_1, and N_2 (*cf.* Figs. 1 and 2) and in directions from these atoms favourable for hydrogen bonding. Some spurious peaks of the same magnitude were situated so far away from the C, N, and O atoms, that no ambiguity as to the positions of the hydrogen atoms was introduced. These peaks must be due to inaccuracies in the data, and/or extinction on some few strong reflexions with small indices; *cf.* Table 5.

Introduction of the four H-atoms lowered the R-value from 0.128 to 0.113. After 2 cycles of anisotropic refinement of the heavy atoms and isotropic refinement of the H-atoms (initially $B = 4$ for all H-atoms) the final R was 0.103. The refinement was considered ended, when the shifts of coordinates were less than $^1/_3$ of the standard deviations,[15] except for two of the H-atoms,

the shifts of which were considered insignificant. The unobserved reflexions were not included in the refinements. The R-values finally obtained are given in Table 1, the atomic parameters in Tables 2 and 3.

Table 1. The final R-values.

All reflexions	$R = 0.136$
All observed reflexions	$R = 0.113$
All observed reflexions except $(\bar{2}11)$	$R = 0.103$
All observed reflexions except the 6 strongest	$R = 0.093$

"All reflexions" means 435 observed + 144 unobserved included as $F_{obs} = \frac{1}{2}F_{min.}$

Table 2. Final positional parameters and their standard deviations, in fractions of the corresponding cell edges.

Atom	x	y	z	σx	σy	σz
C	0.2252	0.5260	0.4735	0.0007	0.0010	0.0006
N_1	0.3417	0.3778	0.6167	0.0008	0.0010	0.0006
N_2	0.1450	0.7429	0.4947	0.0009	0.0009	0.0006
O_1	0.3749	0.4608	0.7832	0.0008	0.0008	0.0005
O_2	0.1988	0.4509	0.3252	0.0008	0.0008	0.0005
H_1	0.299	0.164	0.297	0.019	0.020	0.013
H_2	0.422	0.297	0.103	0.020	0.022	0.011
H_3	0.186	0.708	0.115	0.020	0.021	0.011
H_4	0.045	0.819	0.400	0.021	0.021	0.011

Table 3. Anisotropic temperature parameters U_{ij} Å^2 ($\times 10^2$).

Atom	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
C	3.53	1.32	2.30	−0.43	1.74	−0.18
N_1	5.20	3.09	2.67	1.18	2.25	0.27
N_2	4.81	3.00	2.67	0.36	1.53	−0.09
O_1	4.97	2.99	2.01	−0.48	1.53	−0.14
O_2	4.91	2.95	2.32	0.33	1.86	−0.27

Table 4. Interatomic distances and angles with their standard deviations.

Atoms	Distance (Å)	St.dev.
$C-N_1$	1.336	0.006
$C-N_2$	1.325	0.008
$C-O_2$	1.265	0.008
O_1-N_1	1.408	0.007
O_1-H_1	0.94	
N_1-H_2	1.13	
N_2-H_3	0.96	
N_2-H_4	0.90	
$O_1-O_2'(x, 0.5-y, 0.5+z)$	2.645	0.008
$O_1-N_1'(1-x, -0.5+y, 1.5-z)$	2.906	0.008
$N_2-O_2''(-x, 0.5+y, 0.5-z)$	2.969	0.006
$N_2-O_2'''(x, 1.5-y, 0.5+z)$	3.101	0.007
$N_2-N_2'''(-x, 1-y, 1-z)$	3.452	> 0.009

Atoms	Angle (°)	St. dev.
N_1-C-N_2	118.4	0.5
N_1-C-O_2	117.7	0.6
N_2-C-O_2	123.9	0.4
$C-N_1-O_1$	118.5	0.5
$N_1-O_1\cdots O_2'$	96.5	0.4
$C-N_1\cdots O_1'$	138.3	0.5
$C-N_2\cdots O_2''$	117.1	0.3
$C-N_2\cdots O_2'''$	133.7	0.4
$C'=O_2'\cdots N_2'''$	129.6	
$C'=O_2'\cdots N_2$	121.3	
$C'=O_2'\cdots O_1$	124.0	
$N_2'''\cdots O_2'\cdots N_2$	70.7	
$N_2\cdots O_2'\cdots O_1$	92.7	
$N_2'''\cdots O_2'\cdots O_1$	85.9	

DISCUSSION OF THE STRUCTURE

Interatomic distances between 0.5 and 3.5 Å and valence angles, calculated from the coordinates in Table 2, are listed in Table 4.

The conformation of hydroxyurea in the crystal phase is found to be just as proposed by Kofod.[3]

It is interesting to compare the geometry of the molecule (Fig. 1) with that found for urea in the detailed X-ray study at room temperature.[16] In the planar urea molecule the following bond lengths and valency angles were found: The C=O bond 1.264 ± 0.006 Å, the two identical C—N bonds 1.336 ± 0.007 Å, the N—C—N angle 118.2 ± 0.3°, and the two N—C—O angles 120.9 ± 0.3°.

The hydroxyurea molecule is planar, with the exception of one hydrogen atom. The atoms C and O_1 deviate only slightly from a plane through O_2, N_1, and N_2, and though the deviations of the N-bonded H-atoms from that plane are larger, they are probably not significant, considering the inaccuracy of the H-atom positions. The coplanarity does not include the hydroxyl hydrogen; the O—H bond forms an angle of about 70° with the molecular plane and is directed approximately towards the atom O_2 in a neighbouring

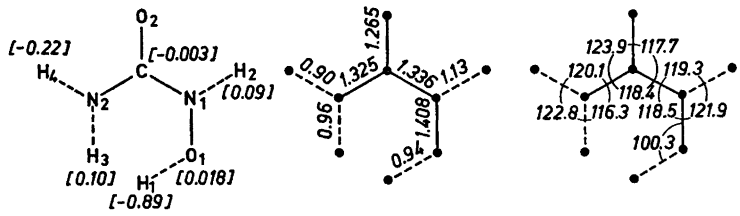

Fig. 1. Intra-molecular bond lengths (Å) and valency angles (°). The numbers in angular parentheses are the distances of the atoms in Ångström from a plane through N_1, N_2, and O_2.

molecule, to which it is hydrogen bonded. The hydroxyl hydrogen is situated approximately in the plane of this neighbouring molecule (deviation 0.04 Å).

The bond lengths found in hydroxyurea are, within the accuracy of the measurements, identical to the corresponding bond lengths in urea, and the difference found between the lengths of the two C—N bonds can not be considered significant. Also the N—C—N angle appears to be identical in both compounds, whereas the asymmetry of the hydroxyurea molecule is reflected in a large difference between the angles $N_1—C—O_2$ and $N_2—C—O_2$. This may be due to attraction between the oxygen and the hydroxyl group in the neighbouring molecule, to which it is connected by a short OH---O hydrogen bridge. It is further worth mentioning, that an N—O bond of exactly the same length as in hydroxyurea was found in the detailed X-ray study of *syn-p*-chlorobenzaldoxime.[17]

The most prominent feature of *inter*molecular contacts in the crystal structure of hydroxyurea is a three-dimensional system of hydrogen bonds, involving all the hydrogen, nitrogen and oxygen atoms. Fig. 2 shows a single layer of molecules viewed along the *b*-axis. Broken lines indicate hydrogen bonds between atoms in this layer, dotted lines hydrogen bonds to atoms above or below this layer. A zig-zag line of OH---O bonds of the length 2.645 Å connects the molecules related by the glide plane ($x\ \frac{1}{4}\ z$). This agrees very well with Kofod's[3] prediction of an *inter*molecular OH---O bond of an estimated length of 2.67 Å, which was based upon evidence obtained from the IR-spectrum of the substance in the solid state.

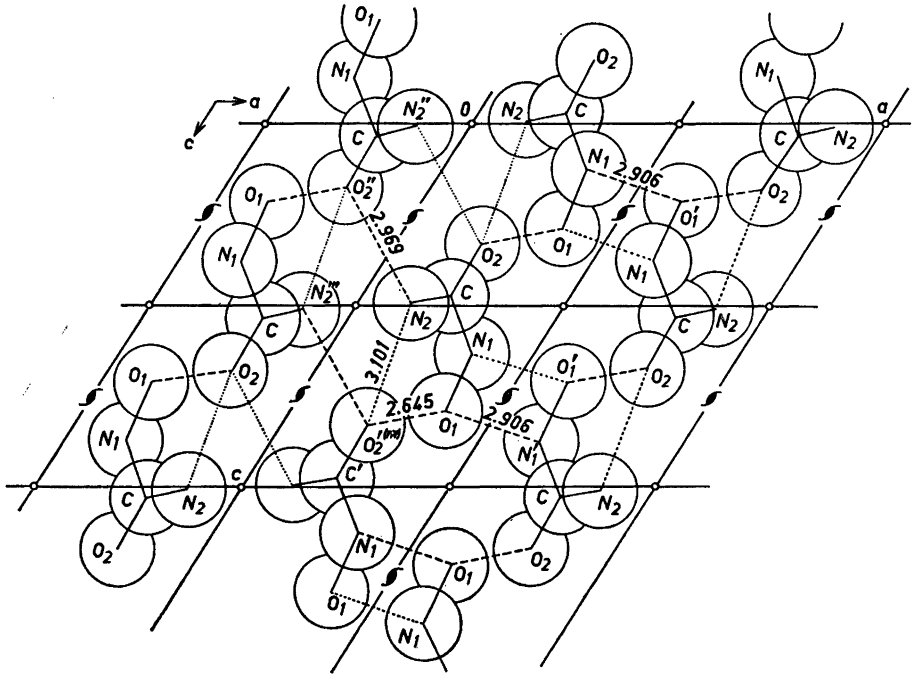

Fig. 2. The structure viewed along the *b*-axis.

Table 5. Observed and calculated structure factors for hydroxyurea.

h	k	l	F_o	F_c
1,	0,	0,	-7.200,	-7.619,
2,	0,	0,	-44.400,	-65.108,
3,	0,	0,	-8.400,	-8.025,
4,	0,	0,	-23.700,	-23.592,
5,	0,	0,	19.800,	21.613,
6,	0,	0,	8.700,	9.299,
7,	0,	0,	-9.000,	-9.554,
9,	0,	0,	2.400,	2.263,
-10,	0,	2,	-1.500,	-2.596,
-9,	0,	2,	4.800,	5.784,
-7,	0,	2,	9.000,	9.867,
-6,	0,	2,	-11.400,	-10.695,
-5,	0,	2,	-18.300,	-21.099,
-4,	0,	2,	32.100,	35.945,
-3,	0,	2,	-17.700,	-18.736,
-2,	0,	2,	-33.300,	-43.285,
-1,	0,	2,	17.700,	18.412,
0,	0,	2,	1.500,	1.680,
1,	0,	2,	39.000,	47.395,
2,	0,	2,	14.100,	14.835,
3,	0,	2,	-24.300,	-26.107,
4,	0,	2,	-8.100,	-9.335,
6,	0,	2,	5.100,	5.703,
-10,	0,	4,	-4.200,	-4.737,
-9,	0,	4,	-3.900,	-4.768,
-8,	0,	4,	7.800,	8.062,
-7,	0,	4,	7.500,	8.649,
-6,	0,	4,	7.200,	6.981,
-5,	0,	4,	-7.200,	-6.684,
-4,	0,	4,	-21.300,	-19.111,
-3,	0,	4,	-15.600,	-15.598,
-2,	0,	4,	-20.700,	-19.383,
-1,	0,	4,	33.000,	36.973,
0,	0,	4,	14.400,	15.295,
1,	0,	4,	-14.100,	-14.327,
2,	0,	4,	5.900,	5.828,
3,	0,	4,	-12.600,	-12.183,
5,	0,	4,	7.200,	7.994,
6,	0,	4,	-6.300,	-6.110,
-8,	0,	6,	4.800,	6.136,
-6,	0,	6,	-13.200,	-13.355,
-5,	0,	6,	26.400,	24.991,
-4,	0,	6,	9.600,	7.687,
-3,	0,	6,	-33.600,	-33.668,
-1,	0,	6,	-15.900,	-16.096,
0,	0,	6,	16.500,	16.808,
1,	0,	6,	29.100,	33.558,
2,	0,	6,	-16.500,	-18.106,
3,	0,	6,	-10.200,	-11.815,
-10,	0,	8,	-10.200,	-12.467,
-9,	0,	8,	3.300,	4.543,
-8,	0,	8,	11.400,	11.802,
-6,	0,	8,	4.200,	4.634,
-5,	0,	8,	-13.500,	-14.148,
-3,	0,	8,	17.400,	19.530,
-2,	0,	8,	-12.700,	-12.831,
-1,	0,	8,	-7.200,	-7.981,
0,	0,	8,	4.800,	4.995,
1,	0,	8,	4.800,	5.095,
2,	0,	8,	6.000,	7.136,
-9,	0,	10,	-5.100,	-6.005,
-7,	0,	10,	9.600,	10.708,
-6,	0,	10,	3.300,	4.032,
-4,	0,	10,	-7.200,	-7.745,
1,	1,	0,	-6.900,	-6.421,
2,	1,	0,	36.000,	47.376,
3,	1,	0,	4.800,	3.444,
4,	1,	0,	-9.900,	-9.177,
6,	1,	0,	-8.700,	-7.475,
8,	1,	0,	4.200,	4.137,
9,	1,	0,	2.400,	2.152,
-9,	1,	1,	9.600,	8.335,
-7,	1,	1,	-13.800,	-11.998,
-5,	1,	1,	-6.300,	-5.140,
-4,	1,	1,	32.100,	30.884,
-3,	1,	1,	24.600,	21.677,
-1,	1,	1,	10.500,	9.262,
0,	1,	1,	31.500,	45.520,
2,	1,	1,	18.900,	18.298,
3,	1,	1,	-30.000,	-31.758,
4,	1,	1,	-9.000,	-8.836,
5,	1,	1,	17.400,	15.797,
-9,	1,	2,	-4.800,	-4.066,
-5,	1,	2,	19.200,	17.405,
-4,	1,	2,	20.400,	17.988,
-3,	1,	2,	-25.200,	-24.160,
-2,	1,	2,	-26.700,	-26.539,
-1,	1,	2,	-24.900,	-25.666,
0,	1,	2,	-11.400,	-10.360,
1,	1,	2,	29.100,	34.813,
2,	1,	2,	15.000,	13.817,
3,	1,	2,	-6.300,	-5.503,
4,	1,	2,	-4.500,	-3.606,
5,	1,	2,	-3.600,	-3.214,
-8,	1,	3,	9.000,	7.055,
-7,	1,	3,	9.60,	7.684,
-6,	1,	3,	-20.700,	-17.044,
-5,	1,	3,	-3.900,	-3.246,
-4,	1,	3,	6.000,	4.888,
-3,	1,	3,	11.400,	7.837,
-2,	1,	3,	21.300,	18.786,
-1,	1,	3,	-19.500,	-20.804,
0,	1,	3,	-3.000,	-1.693,
3,	1,	3,	10.200,	9.943,
4,	1,	3,	-4.400,	-4.219,
7,	1,	3,	-4.400,	-3.545,
-10,	1,	4,	-3.300,	-2.525,
-9,	1,	4,	-3.000,	-3.247,
-6,	1,	4,	3.300,	2.544,
-5,	1,	4,	13.500,	10.601,
-4,	1,	4,	8.100,	6.309,
-3,	1,	4,	-3.000,	-2.716,
-1,	1,	4,	-23.400,	-22.075,
0,	1,	4,	-16.500,	-16.523,
1,	1,	4,	18.300,	17.295,
2,	1,	4,	9.600,	10.438,
5,	1,	4,	-8.400,	-7.604,
6,	1,	4,	-3.000,	-2.614,
-4,	1,	5,	20.100,	17.150,
-3,	1,	5,	-30.000,	-27.123,
-2,	1,	5,	-13.500,	-11.863,
-1,	1,	5,	24.600,	25.311,
0,	1,	5,	-3.000,	-2.900,
1,	1,	5,	12.300,	10.640,
2,	1,	5,	-7.400,	-6.930,
3,	1,	5,	-15.900,	-16.067,
4,	1,	5,	11.700,	11.624,
5,	1,	5,	5.100,	4.188,
-9,	1,	6,	-3.300,	-3.465,
-8,	1,	6,	-3.600,	-3.486,
-6,	1,	6,	11.400,	10.460,
-5,	1,	6,	11.400,	9.886,
-4,	1,	6,	-7.400,	-5.843,
-3,	1,	6,	7.200,	5.430,
-2,	1,	6,	-6.300,	-5.620,
-1,	1,	6,	-15.000,	-13.858,
0,	1,	6,	7.800,	6.947,
3,	1,	6,	7.800,	7.392,
4,	1,	6,	-2.400,	-2.260,
-10,	1,	7,	-3.600,	-3.593,
-8,	1,	7,	15.000,	14.079,
-7,	1,	7,	-11.400,	-10.965,
-6,	1,	7,	-14.400,	-13.712,
-5,	1,	7,	11.700,	10.244,
-3,	1,	7,	17.700,	17.655,
-2,	1,	7,	-8.400,	-7.161,
-1,	1,	7,	-24.300,	-26.801,
0,	1,	7,	14.700,	14.625,
1,	1,	7,	9.600,	9.019,
-8,	1,	8,	-8.100,	-7.786,
-6,	1,	8,	4.400,	4.548,
-4,	1,	8,	11.700,	10.286,
-2,	1,	8,	-12.000,	-11.186,
-1,	1,	8,	-3.600,	-3.474,
0,	1,	8,	-2.100,	-0.975,
1,	1,	8,	2.900,	2.592,
2,	1,	8,	6.300,	5.503,
-7,	1,	9,	9.900,	9.209,
-5,	1,	9,	-15.600,	-14.689,
-4,	1,	9,	3.600,	3.173,
-3,	1,	9,	5.400,	5.400,
-2,	1,	9,	4.400,	3.765,
0,	1,	9,	-6.300,	-6.333,
-8,	1,	10,	-2.400,	-1.930,
-4,	1,	10,	5.400,	4.168,
-2,	1,	10,	-2.700,	-2.641,
-1,	1,	10,	-1.800,	-1.833,
-6,	1,	11,	3.900,	3.836,
0,	2,	0,	28.500,	34.389,
1,	2,	0,	-18.900,	-20.091,
2,	2,	0,	-19.500,	-21.928,
3,	2,	0,	8.400,	7.444,
4,	2,	0,	8.400,	6.692,
5,	2,	0,	19.500,	18.575,
6,	2,	0,	-5.100,	-5.050,
7,	2,	0,	-14.700,	-13.352,
-8,	2,	1,	-3.900,	-4.074,
-7,	2,	1,	6.900,	5.470,
-5,	2,	1,	-3.000,	-2.638,
-4,	2,	1,	26.700,	17.406,
-3,	2,	1,	-23.100,	-22.727,
-2,	2,	1,	-11.100,	-8.973,
-1,	2,	1,	27.600,	31.222,
0,	2,	1,	-13.200,	-14.138,
1,	2,	1,	8.700,	8.679,
2,	2,	1,	5.100,	5.068,
3,	2,	1,	-17.100,	-18.133,
4,	2,	1,	6.300,	5.615,
5,	2,	1,	6.900,	6.575,
6,	2,	1,	-2.400,	-2.254,
-9,	2,	2,	6.600,	5.897,
-7,	2,	2,	-4.200,	-4.091,
-6,	2,	2,	-20.100,	-17.939,
-5,	2,	2,	-5.700,	-4.965,
-4,	2,	2,	37.800,	39.599,
-3,	2,	2,	15.000,	13.214,
-2,	2,	2,	-2.600,	-1.477,
-1,	2,	2,	-25.800,	-24.771,
0,	2,	2,	-29.700,	-34.206,
1,	2,	2,	20.100,	20.916,
2,	2,	2,	1.800,	1.327,
3,	2,	2,	-2.100,	-1.411,
4,	2,	2,	11.400,	10.324,
5,	2,	2,	-2.400,	-2.448,
7,	2,	2,	-2.400,	-2.322,
-9,	2,	3,	-2.700,	-2.156,
-8,	2,	3,	7.500,	6.137,
-6,	2,	3,	-11.100,	-10.298,
-5,	2,	3,	7.800,	6.013,
-4,	2,	3,	5.400,	5.188,
-3,	2,	3,	6.900,	6.350,
-2,	2,	3,	1.800,	1.440,
-1,	2,	3,	-18.000,	-18.327,
0,	2,	3,	-8.400,	-6.443,
1,	2,	3,	16.500,	14.976,
2,	2,	3,	11.400,	11.065,
3,	2,	3,	-6.900,	-7.020,
4,	2,	3,	-3.300,	-3.184,
-10,	2,	4,	-1.500,	-1.268,
-8,	2,	4,	3.300,	2.287,
-7,	2,	4,	-7.800,	-7.744,
-5,	2,	4,	-3.000,	-2.617,
-3,	2,	4,	27.000,	23.603,
-2,	2,	4,	-5.400,	-4.047,
0,	2,	4,	3.300,	1.967,
1,	2,	4,	-21.300,	-21.881,
3,	2,	4,	5.400,	4.857,
4,	2,	4,	5.900,	6.551,
5,	2,	4,	7.800,	7.094,
6,	2,	4,	-6.000,	-5.941,
-10,	2,	5,	-3.300,	-3.070,
-9,	2,	5,	-2.400,	-2.596,
-8,	2,	5,	3.300,	3.208,
-7,	2,	5,	3.300,	2.904,
-4,	2,	5,	-15.600,	-13.974,
-3,	2,	5,	2.700,	2.151,
-2,	2,	5,	21.300,	20.799,
-1,	2,	5,	-14.100,	-12.688,
0,	2,	5,	-6.000,	-5.322,
1,	2,	5,	5.700,	5.172,
2,	2,	5,	-6.600,	-6.296,
3,	2,	5,	8.100,	7.296,
5,	2,	5,	-6.000,	-5.638,
-10,	2,	6,	3.300,	3.572,
-9,	2,	6,	1.800,	2.496,
-7,	2,	6,	-4.500,	-4.726,

Table 5. Continued.

h	k	l	F_o	F_c
-6,	2,	6,	-18.600,	-18.339,
-5,	2,	6,	10.800,	9.611,
-4,	2,	6,	22.500,	21.129,
-3,	2,	6,	-3.000,	-2.909,
-1,	2,	6,	-12.900,	-12.887,
1,	2,	6,	9.600,	10.492,
2,	2,	6,	-8.700,	-9.494,
3,	2,	6,	-2.000,	-1.715,
4,	2,	6,	3.900,	4.084,
-10,	2,	7,	-1.200,	-1.726,
-7,	2,	7,	-3.900,	-4.320,
-6,	2,	7,	12.600,	12.100,
-5,	2,	7,	-3.300,	-3.239,
-4,	2,	7,	-4.500,	-3.639,
-3,	2,	7,	6.600,	6.435,
-2,	2,	7,	-12.900,	-12.569,
0,	2,	7,	7.500,	7.632,
1,	2,	7,	-5.700,	-5.515,
2,	2,	7,	1.800,	1.682,
-9,	2,	8,	4.800,	4.112,
-8,	2,	8,	6.600,	6.687,
-7,	2,	8,	-4.400,	-4.206,
-6,	2,	8,	-7.800,	-7.584,
-5,	2,	8,	-13.200,	-12.778,
-4,	2,	8,	10.800,	10.181,
-3,	2,	8,	20.700,	20.699,
-2,	2,	8,	-4.500,	-4.808,
-1,	2,	8,	-5.700,	-6.202,
0,	2,	8,	-8.100,	-7.432,
1,	2,	8,	-1.800,	-1.556,
-7,	2,	9,	5.400,	5.312,
-6,	2,	9,	-3.900,	-4.163,
-5,	2,	9,	-3.600,	-3.906,
-4,	2,	9,	6.300,	5.832,
-3,	2,	9,	3.900,	1.478,
-1,	2,	9,	-1.800,	-1.971,
0,	2,	9,	-3.000,	-2.516,
-8,	2,	10,	2.100,	2.609,
-7,	2,	10,	1.500,	1.626,
-6,	2,	10,	-5.400,	-5.501,
-4,	2,	10,	-1.800,	-1.797,
-2,	2,	10,	6.600,	7.034,
1,	3,	0,	-29.400,	-32.554,
3,	3,	0,	-8.700,	-9.174,
4,	3,	0,	5.700,	5.274,
-4,	3,	1,	13.800,	13.200,
-2,	3,	1,	-16.500,	-19.172,
0,	3,	1,	5.700,	5.180,
1,	3,	1,	12.300,	12.604,
3,	3,	1,	-16.200,	-18.571,
4,	3,	1,	8.100,	7.357,
-4,	3,	2,	6.900,	5.865,
-3,	3,	2,	-6.600,	-6.285,
-2,	3,	2,	11.700,	11.066,
-1,	3,	2,	-3.000,	-2.532,
0,	3,	2,	5.100,	4.586,
1,	3,	2,	10.200,	11.073,
2,	3,	2,	-10.500,	-12.552,
3,	3,	2,	-11.400,	-11.272,
-4,	3,	3,	-6.900,	-6.168,
-3,	3,	3,	6.600,	8.051,
-2,	3,	3,	11.100,	10.368,
-1,	3,	3,	-22.200,	-21.155,
0,	3,	3,	9.900,	6.172,
1,	3,	3,	3.600,	3.688,
2,	3,	3,	-4.500,	-10.455,
3,	3,	3,	8.100,	8.094,
-4,	3,	4,	-4.800,	-2.213,
-3,	3,	4,	12.000,	12.316,
-2,	3,	4,	16.200,	16.281,
0,	3,	4,	-17.100,	-16.047,
3,	3,	4,	-3.900,	-4.382,
-4,	3,	5,	12.000,	10.615,
-2,	3,	5,	-16.500,	-16.082,
-1,	3,	5,	8.400,	6.973,
0,	3,	5,	5.400,	5.229,
2,	3,	5,	-3.600,	-3.455,
3,	3,	5,	-4.800,	-5.112,
4,	3,	5,	3.900,	3.579,
-4,	3,	6,	-20.700,	-20.449,
-3,	3,	6,	5.700,	5.759,
-2,	3,	6,	12.600,	11.739,
0,	3,	6,	9.600,	9.318,
1,	3,	6,	-9.600,	-9.873,
2,	3,	6,	-7.500,	-7.987,
3,	3,	6,	3.900,	3.806,
-4,	3,	7,	9.300,	8.246,
-3,	3,	7,	9.300,	8.550,
-2,	3,	7,	-8.100,	-7.705,
-1,	3,	7,	-9.300,	-8.792,
0,	3,	7,	4.200,	4.702,
2,	3,	7,	2.700,	2.369,
-4,	3,	8,	5.100,	4.923,
-1,	3,	8,	6.000,	5.158,
-4,	3,	9,	6.000,	5.452,
-2,	3,	9,	5.400,	4.506,
0,	4,	0,	15.900,	15.231,
1,	4,	0,	7.800,	7.025,
2,	4,	0,	-7.200,	-7.094,
-4,	4,	1,	7.800,	6.141,
-3,	4,	1,	-7.400,	-8.003,
-2,	4,	1,	-4.500,	-3.819,
-1,	4,	1,	8.700,	8.213,
1,	4,	1,	9.600,	8.811,
2,	4,	1,	-8.400,	-8.454,
3,	4,	1,	-9.900,	-10.360,
4,	4,	1,	7.500,	6.703,
-3,	4,	2,	-9.300,	-9.949,
-1,	4,	2,	-4.500,	-3.691,
0,	4,	2,	6.000,	5.529,
1,	4,	2,	18.000,	18.737,
2,	4,	2,	-9.600,	-9.433,
3,	4,	2,	-9.000,	-8.966,
4,	4,	2,	4.500,	2.834,
-4,	4,	3,	2.700,	2.643,
-3,	4,	3,	13.800,	15.390,
-2,	4,	3,	-6.300,	-6.032,
-1,	4,	3,	-12.900,	-12.633,
0,	4,	3,	3.300,	1.807,
1,	4,	3,	2.700,	2.845,
2,	4,	3,	7.800,	8.311,
3,	4,	3,	-3.600,	-3.568,
4,	4,	3,	-9.900,	-8.466,
-4,	4,	4,	-10.200,	-8.761,
-3,	4,	4,	4.200,	4.138,
-2,	4,	4,	-10.800,	-9.977,
0,	4,	4,	16.800,	17.828,
2,	4,	4,	-10.500,	-4.118,
4,	4,	4,	-5.400,	-3.948,
-4,	4,	5,	-3.300,	-3.058,
-2,	4,	5,	15.000,	15.417,
0,	4,	5,	-9.600,	-9.103,
3,	4,	5,	3.900,	4.431,
-4,	4,	6,	6.000,	5.624,
-3,	4,	6,	-4.200,	-3.945,
-2,	4,	6,	-9.900,	-9.491,
0,	4,	6,	8.100,	8.194,
1,	4,	6,	6.600,	5.938,
-2,	4,	7,	-5.100,	-4.798,
-1,	4,	7,	5.100,	4.295,
0,	4,	7,	2.100,	2.369,
-4,	4,	8,	4.500,	4.062,
-2,	4,	8,	-6.300,	-5.255,
2,	5,	0,	5.700,	5.217,
3,	5,	0,	-2.100,	-2.504,
4,	5,	0,	2.700,	2.427,
-4,	5,	1,	2.700,	3.819,
-3,	5,	1,	-3.000,	-3.823,
-2,	5,	1,	-2.400,	-2.634,
1,	5,	1,	4.500,	4.399,
3,	5,	1,	-4.800,	-5.216,
4,	5,	1,	3.300,	3.759,
-4,	5,	2,	3.900,	4.256,
-2,	5,	2,	-6.600,	-6.698,
-1,	5,	2,	-16.200,	-17.081,
0,	5,	2,	9.300,	8.593,
1,	5,	2,	12.000,	12.186,
2,	5,	2,	-7.500,	-7.058,
-4,	5,	3,	-2.700,	-2.184,
-1,	5,	3,	-6.000,	-5.891,
0,	5,	3,	7.500,	7.499,
1,	5,	3,	3.900,	3.930,
2,	5,	3,	-5.700,	-6.475,
-4,	5,	4,	8.100,	7.582,
-3,	5,	4,	7.500,	8.106,
-2,	5,	4,	-6.000,	-5.808,
-1,	5,	4,	-3.300,	-3.216,
0,	5,	4,	-9.600,	-10.338,
1,	5,	4,	2.100,	2.739,
2,	5,	4,	12.000,	13.382,
-4,	5,	5,	3.600,	3.024,
-2,	5,	5,	-6.600,	-6.649,
0,	5,	5,	4.500,	4.531,
3,	5,	5,	-4.500,	-2.347,
-4,	5,	6,	-3.600,	-4.255,
-3,	5,	6,	-2.700,	-1.843,
-2,	5,	6,	2.400,	2.189,
-1,	5,	6,	-3.300,	-2.673,
0,	6,	0,	-1.500,	-1.793,
1,	6,	0,	-2.400,	-1.920,
-3,	6,	1,	-1.800,	-1.703,
-1,	6,	1,	-3.000,	-2.913,
1,	6,	1,	7.800,	7.647,
2,	6,	1,	-3.900,	-4.454,
-1,	6,	2,	-1.500,	-1.297,
-2,	6,	3,	-6.600,	-6.731,
-1,	6,	3,	-7.500,	-8.101,
3,	4,	0,	-12.000,	-12.828,
-2,	1,	1,	-45.000,	-93.073,

Table 5. Continued.

h	k	l	$\frac{1}{2}F_{min}$	F_c
8,	0,	0,	0,600,	2,750,
-8,	0,	2,	0,600,	1,322,
5,	0,	2,	-0,600,	-1,990,
4,	0,	4,	-0,600,	-0,776,
-10,	0,	6,	-0,600,	-0,891,
-9,	0,	6,	-0,600,	-1,563,
-7,	0,	6,	0,600,	2,035,
-2,	0,	6,	-0,600,	-0,322,
-7,	0,	8,	-0,600,	-1,340,
-4,	0,	8,	-0,600,	-1,854,
-8,	0,	10,	0,600,	0,636,
-5,	0,	10,	-0,600,	-2,677,
5,	1,	0,	-0,600,	-0,728,
7,	1,	0,	-0,600,	-1,470,
-10,	1,	1,	-0,600,	-1,502,
-8,	1,	1,	0,600,	0,326,
-6,	1,	1,	0,600,	2,034,
1,	1,	1,	0,600,	0,645,
6,	1,	1,	-0,600,	-0,749,
7,	1,	1,	-0,600,	-1,838,
-10,	1,	2,	0,600,	1,044,
-8,	1,	2,	-0,600,	-3,145,
-7,	1,	2,	0,600,	0,931,
-6,	1,	2,	-0,600,	-1,870,
6,	1,	2,	-0,600,	-2,977,
-10,	1,	3,	-0,600,	-0,755,
-9,	1,	3,	-0,600,	-1,175,
1,	1,	3,	-0,600,	-0,740,
2,	1,	3,	-0,600,	-1,377,
5,	1,	3,	0,600,	0,744,
6,	1,	3,	-0,600,	-0,984,
-8,	1,	4,	0,600,	0,575,
-7,	1,	4,	-0,600,	-1,589,
-2,	1,	4,	-0,600,	-1,463,
3,	1,	4,	0,600,	2,081,
4,	1,	4,	0,600,	0,115,
-10,	1,	5,	-0,600,	-1,095,
-9,	1,	5,	0,600,	1,216,
-8,	1,	5,	-0,600,	-2,482,
-7,	1,	5,	0,600,	1,451,
-6,	1,	5,	-0,600,	-0,013,
-5,	1,	5,	0,600,	1,726,
-10,	1,	6,	-0,600,	-1,812,
-7,	1,	6,	-0,600,	-3,130,
1,	1,	6,	0,600,	0,196,
2,	1,	6,	0,600,	1,762,
-9,	1,	7,	0,600,	1,499,
-4,	1,	7,	-0,600,	-0,027,
2,	1,	7,	-0,600,	-1,691,
-10,	1,	8,	0,600,	0,511,
-9,	1,	8,	0,600,	0,080,
-7,	1,	8,	-0,600,	-0,780,
-5,	1,	8,	0,600,	1,207,
-3,	1,	8,	0,600,	0,584,
-9,	1,	9,	0,600,	1,030,
-8,	1,	9,	0,600,	1,899,
-6,	1,	9,	-0,600,	-1,540,
-1,	1,	9,	-0,600,	-1,562,
-7,	1,	10,	0,600,	1,877,
-6,	1,	10,	-0,600,	-0,476,
-5,	1,	10,	0,600,	1,438,
-3,	1,	10,	0,600,	0,203,
-10,	2,	1,	0,600,	0,886,
-9,	2,	1,	-0,600,	-0,485,
-6,	2,	1,	-0,600,	-0,195,
7,	2,	1,	-0,600,	-1,601,
-10,	2,	2,	0,600,	0,566,
-8,	2,	2,	0,600,	0,695,
6,	2,	2,	-0,600,	-0,965,
-10,	2,	3,	-0,600,	-0,673,
-7,	2,	3,	-0,600,	-1,635,
5,	2,	3,	0,600,	0,190,
6,	2,	3,	-0,600,	-0,200,
-9,	2,	4,	0,600,	1,712,
-6,	2,	4,	-0,600,	-0,064,
-4,	2,	4,	-0,600,	-0,449,
-1,	2,	4,	0,600,	0,520,
2,	2,	4,	0,600,	0,817,
-6,	2,	5,	0,600,	0,141,
-5,	2,	5,	0,600,	0,131,
4,	2,	5,	0,600,	2,121,
-8,	2,	6,	-0,600,	-0,290,
2,	2,	6,	-0,600,	-0,790,
0,	2,	6,	0,600,	1,243,
-9,	2,	7,	0,600,	1,961,
-8,	2,	7,	-0,600,	-3,678,
-1,	2,	7,	0,600,	2,945,
-8,	2,	9,	-0,600,	-1,524,
-2,	2,	9,	-0,600,	-0,733,
-5,	2,	10,	0,600,	0,289,
-3,	2,	10,	0,600,	3,865,
2,	3,	0,	0,600,	0,426,
-3,	3,	1,	0,600,	0,484,
-1,	3,	1,	-0,600,	-0,090,
2,	3,	1,	0,600,	2,174,
4,	3,	2,	-0,600,	-1,179,
4,	3,	3,	0,600,	1,199,
-1,	3,	4,	0,600,	1,523,
1,	3,	4,	0,600,	2,499,
2,	3,	4,	0,600,	1,866,
4,	3,	4,	0,600,	2,153,
-3,	3,	5,	0,600,	0,391,
1,	3,	5,	-0,600,	-0,464,
-1,	3,	6,	0,600,	1,615,
1,	3,	7,	0,600,	2,240,
-3,	3,	8,	0,600,	0,609,
-2,	3,	8,	-0,600,	-1,874,
-3,	3,	9,	-0,600,	-1,254,
4,	4,	0,	-0,600,	-0,060,
0,	4,	1,	-0,600,	-0,817,
-4,	4,	2,	0,600,	0,383,
-2,	4,	2,	0,600,	1,332,
-1,	4,	4,	-0,600,	-1,335,
1,	4,	4,	-0,600,	-0,646,
3,	4,	4,	-0,600,	-1,392,
-3,	4,	5,	-0,600,	-0,534,
-1,	4,	5,	-0,600,	-0,865,
1,	4,	5,	0,600,	0,343,
2,	4,	5,	-0,600,	-1,346,
-1,	4,	6,	0,600,	0,234,
-4,	4,	7,	-0,600,	-2,592,
-3,	4,	7,	0,600,	2,266,
-3,	4,	8,	-0,600,	-0,996,
1,	5,	0,	0,600,	1,258,
-1,	5,	1,	0,600,	1,734,
0,	5,	1,	0,600,	1,533,
2,	5,	1,	-0,600,	-3,153,
-3,	5,	2,	0,600,	1,557,
2,	5,	2,	-0,600,	-0,868,
3,	5,	2,	0,600,	1,482,
-3,	5,	3,	0,600,	0,462,
-2,	5,	3,	0,600,	0,091,
3,	5,	3,	0,600,	0,603,
3,	5,	4,	0,600,	0,058,
-3,	5,	5,	0,600,	2,649,
-1,	5,	5,	0,600,	0,039,
1,	5,	5,	0,600,	0,673,
2,	5,	5,	0,600,	0,142,
2,	6,	0,	-0,600,	-1,385,
-2,	6,	1,	-0,600,	-1,093,
0,	6,	1,	0,600,	1,198,
-3,	6,	2,	0,600,	0,806,
-2,	6,	2,	-0,600,	-0,239,
0,	6,	2,	-0,600,	-0,726,

Another type of hydrogen bonds, NH---O bonds, connect the molecules related by the glide plane (x $\frac{3}{4}$ z). The lengths of these bonds are 3.101 Å. Furthermore NH---O bonds of the lengths 2.969 and 2.906 Å connect the molecules related by the screw axes.

It is remarkable, that the oxygen atom O_2 of the carbonyl group is involved in three hydrogen bonds, since a hydrogen bond usually can be considered to involve one electron pair of the acceptor atom. Among other exceptions to this rule is urea,[16] in which the oxygen atom forms four hydrogen bonds (two pairs of the lengths 2.998 $\pm$ 0.005 and 3.036 $\pm$ 0.007 Å, respectively). In the crystal structure of hydroxyurea the steric conditions seem reasonable for O_2 to be involved in three hydrogen bonds. The directions from O_2 to the three hydrogen donating atoms and to the covalently bound carbon atom deviates somewhat but not too much, from a regular tetrahedric arrangement. This can be seen from Fig. 2 and the interatomic angles given in Table 4.

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