ACTA CHEMICA SCANDINAVICA 26 (1972) 760–768

Crystal Structure of 5-Fluoropyrimidine-2-one

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The crystal structure of monoclinic 5-fluoropyrimidine-2-one has been determined from three-dimensional X-ray data collected by counter methods. The space group is $P2_1/c$, with four molecules in the unit cell. The structure was refined by full matrix least squares techniques to $R = 0.069$ for 527 observed reflections. The estimated standard deviations in bond lengths involving non-hydrogen atoms are 0.004 – 0.005 Å. The structure is compared with that of pyrimidine-2-one. By fluorine substitution the bond angle at C5 is increased by 2.9° and small, but probably significant changes in bond lengths are observed. The C – F distance is 1.356 Å. The intermolecular N – H···O hydrogen bond of length 2.718 Å is 0.078 Å shorter than in pyrimidine-2-one.

From chemical and physical properties, and from spectroscopical evidence, conclusions have been drawn as to the effect of substituent groups on the electron distribution in aromatic molecules. The effects of halogen substitution have been much discussed,[1,2] and experimental investigations of the electron distribution would appear to be of interest. In the present study we have determined the molecular structure of 5-fluoropyrimidine-2-one and compared it with that of pyrimidine-2-one, which recently has been derived in this laboratory.[3]

Fluorinated pyrimidines are compounds of considerable biological interest.[4] They have been widely used as tools to study biochemical systems and as chemotherapeutic agents. The present compound has been tested as regards its growth-inhibitory properties.[5]

EXPERIMENTAL

The synthesis of 5-fluoropyrimidine-2-one has been described by Helgeland and Laland[6] and by Undheim and Gacek.[7] Samples were supplied by these workers. Recrystallization from ethyl acetate yielded two types of crystals, one needle-shaped, the other of more irregular habit. The densities were measured by flotation and found to be 1.63 g/cm³ for both types.

The X-ray diagrams showed the two crystal types to be polymorphs of 5-fluoropyrimidine-2-one. The needle-shaped crystals are triclinic, with approximate cell parameters $a = 3.8$ Å, $b = 6.0$ Å, $d_{001} = 11.6$ Å, $\alpha^* = 76°$, $\beta^* = 85°$. Two molecules in the unit cell correspond to a density of 1.64 g/cm³.

Table 1. Positional and thermal parameters ($B_{ij} \times 10^5$)[a] with estimated standard deviations in parentheses. Librational corrections are also given.

Atom	x	y	z	B_{11}(B)	B_{22}	B_{33}	B_{12}	B_{13}	B_{23}
C2	0.34445(35) 48	0.70239(78) 113	0.31373(52) −6	782(45)	2854(184)	1926(113)	393(148)	837(121)	115(226)
C4	0.15858(37) 74	0.61906(84) 90	0.38525(60) 13	639(43)	3583(189)	2483(127)	590(152)	944(123)	251(257)
C5	0.18480(35) −45	0.39119(78) −109	0.39103(56) 6	731(45)	2798(164)	2398(127)	− 717(144)	1059(124)	−104(240)
C6	0.29066(38) 31	0.32048(77) −180	0.35671(58) −7	939(49)	2152(186)	2309(124)	−389(157)	940(126)	−247(239)
N1	0.36839(29) 76	0.47465(56) −84	0.31580(43) −17	709(37)	2293(143)	2325(97)	384(114)	1105(99)	−172(181)
N3	0.23415(28) −30	0.76730(52) 182	0.34703(48) 4	821(37)	2494(133)	3101(109)	7(116)	1499(104)	377(182)
O2	0.42041(25) 70	0.83522(42) 150	0.28075(43) −4	960(31)	2456(107)	4196(106)	−837(101)	2245(95)	167(179)
F5	0.10124(20) −70	0.24720(38) −150	0.43144(35) 8	1096(30)	3922(102)	4101(84)	−1311(85)	1623(77)	619(144)
H1	0.4404 (31) 9	0.4358 (57) −10	0.2818 (44) −3	3.5(1.0)					
H4	0.0774 (32) −9	0.6646 (58) 10	0.4105 (46) 2	4.0(0.9)					
H6	0.3133 (37) 4	0.1579 (80) −21	0.3552 (58) −1	7.4(1.3)					

[a] The B_{ij} are the thermal parameters in the expression: exp $[-(B_{11}h^2+B_{22}k^2+B_{33}l^2+B_{12}hk+B_{13}hl+B_{23}kl)]$.
For numbering of atoms see Fig. 1.

The other polymorph, which was chosen for further investigations, belongs to the monoclinic system. Systematic absences lead to the space group $P2_1/c$. The cell parameters measured on a manual four circle diffractometer are $a = 11.118(4)$ Å, $b = 6.012(4)$ Å, $c = 7.147(4)$ Å, $\beta = 104.31(2)°$. The unit cell contains four molecules and the calculated density is 1.64 g/cm³.

The intensity measurements were made on a crystal of size $0.16 \times 0.20 \times 0.25$ mm mounted along b, using a Picker four-circle automatic diffractometer and Mo$K\alpha$ radiation ($\lambda = 0.71069$ Å) with graphite monochromator. Reflections out to $2\theta = 53°$ were collected by the $\omega - 2\theta$ scanning mode, rate 2°/min. Of 1244 reflections measured 527 had intensities greater than twice the standard deviation and only these were used in the structure analysis. Absorption and extinction corrections were not applied. The atomic form factors used were those of Hanson *et al.*,[8] except for hydrogen.[9] All programs applied are written or revised for CDC 3300 by T. Dahl *et al.*[10]

STRUCTURE DETERMINATION

A computer procedure based on direct methods [10] was used to determine the signs of 142 reflections. The corresponding Fourier map contained eight peaks of heights $5 - 8$ e Å^{-3} and the molecule could be clearly localized.

Full-matrix least squares refinements were carried out. The weighting scheme was based on standard deviations from counter statistics and 2 % fluctuations in diffractometer stability. After refinement of positional and anisotropic thermal parameters, a Fourier difference map gave a good indication of the positions of the hydrogen atoms. Additional refinements included positional and isotropic thermal parameters of the hydrogen atoms. The conventional R-value arrived at was 6.9 % (weighted value $R_w = 4.6$ %) for 527 observed reflections.

The fractional atomic coordinates and thermal parameters are given in Table 1, and observed and calculated structure factors in Table 2. In Table 3 is presented the principal axes of the thermal vibration ellipsoids, given by the components of a unit vector in fractional coordinates e_x, e_y, e_z, the corresponding r.m.s. amplitudes and the B-values.

A rigid-body analysis of translational and librational motion was carried out. The r.m.s. difference between atomic vibration tensor components U_{ij} calculated from thermal parameters of Table 1 and those derived from the rigid body model was 0.0038 Å². A better fit might have been expected for a molecule of this size. The coordinates were, however, corrected for rigid-body libration and the corrections are included in Table 1. The r.m.s. translational amplitudes were 0.211, 0.189, and 0.187 Å, while the r.m.s. librational amplitudes were 7.6, 5.5, and 3.8 degrees.

RESULTS AND DISCUSSION

Molecular structure. Interatomic distances and bond angles (corrected for libration) are given in Fig. 1 and Table 4. The standard deviations are calculated from the correlation matrix of the last least-squares refinement cycle.

The distances from a least-squares plane defined by all non-hydrogen atoms are given in Table 5. Although the molecule is essentially planar, the largest displacements from the plane (0.02 Å) are probably significant. N1 and N3 are about the same distance away from the plane on one side as O2 on the

Table 2. Observed and calculated structure factors. The columns are h, k, l, F_o and F_c.

2	0	0	46.23	46.44	11	1	3	4.20	3.30	5	2	1	2.03	2.24	2	3	7	3.17	1.48
3	0	0	4.22	3.08	13	1	2	3.86	2.47	4	2	1	6.62	6.24	1	3	6	5.28	5.22
4	0	0	43.35	42.99	12	1	2	6.55	4.66	3	2	1	7.36	7.36	-3	3	6	4.01	4.60
5	0	0	6.97	6.98	11	1	2	6.19	5.45	2	2	1	7.58	7.67	-6	3	6	4.32	4.72
6	0	0	8.56	8.73	10	1	2	4.85	4.75	1	2	1	28.62	27.04	-8	3	6	3.77	3.73
7	0	0	3.32	2.98	8	1	2	3.07	1.42	0	2	1	27.18	25.50	-8	3	5	6.20	6.57
11	0	0	4.94	4.99	7	1	2	7.66	7.47	-1	2	1	12.04	11.92	-6	3	5	2.61	3.27
12	0	0	3.93	3.37	5	1	2	17.01	17.17	-2	2	1	7.04	7.24	-5	3	5	7.03	6.76
15	0	0	5.45	4.02	4	1	2	2.17	2.65	-3	2	1	6.52	6.29	-4	3	5	3.26	3.36
-16	0	2	4.82	3.34	3	1	2	15.46	15.67	-5	2	1	21.75	21.93	-1	3	5	5.59	5.96
14	0	2	8.50	7.35	2	1	2	7.93	7.15	-6	2	1	10.57	10.50	0	3	5	6.62	6.86
-12	0	2	4.09	4.36	1	1	2	9.91	10.02	-7	2	1	5.95	5.52	1	3	5	2.63	1.74
-11	0	2	6.10	5.69	-1	1	2	42.84	43.24	-8	2	1	5.50	5.96	3	3	5	3.19	2.77
-10	0	2	10.07	9.95	-2	1	2	3.35	3.33	-9	2	1	7.71	7.41	5	3	5	4.16	2.81
-8	0	2	4.97	4.63	-3	1	2	27.28	27.37	-10	2	1	3.64	3.96	6	3	5	3.76	2.82
-7	0	2	2.83	2.39	-4	1	2	14.44	14.41	-11	2	1	4.07	3.76	7	3	5	3.47	1.97
-5	0	2	14.06	13.77	-5	1	2	20.16	20.18	-11	2	2	5.35	5.75	9	3	5	4.35	2.72
-4	0	2	8.88	8.85	-6	1	2	2.95	3.09	-10	2	2	3.46	3.25	11	3	4	3.64	.06
-3	0	2	36.60	37.46	-7	1	2	5.95	5.92	-9	2	2	3.23	2.35	9	3	4	3.75	2.39
-2	0	2	2.96	2.97	-8	1	2	11.65	11.15	-8	2	2	15.21	15.68	8	3	4	5.23	3.95
-1	0	2	48.28	49.26	-9	1	2	8.35	8.49	-7	2	2	3.24	2.19	7	3	4	3.77	2.41
0	0	2	36.26	35.75	-10	1	2	20.33	20.69	-6	2	2	8.20	8.04	6	3	4	5.45	4.63
1	0	2	137.53	142.17	-11	1	2	4.63	5.17	-5	2	2	23.05	23.45	5	3	4	3.66	3.66
2	0	2	10.95	11.09	-12	1	2	3.77	3.08	-4	2	2	25.64	25.54	3	3	4	5.53	5.71
3	0	2	14.28	14.54	-11	1	1	3.66	3.61	-3	2	2	4.31	3.75	0	3	4	14.10	13.84
5	0	2	24.78	25.00	-10	1	1	7.89	7.80	-2	2	2	3.91	4.16	-1	3	4	5.65	5.04
6	0	2	2.20	2.17	-9	1	1	12.16	12.23	-1	2	2	12.96	12.99	-3	3	4	3.71	3.76
8	0	2	3.09	2.46	-7	1	1	8.23	7.84	0	2	2	2.76	2.58	-4	3	4	11.49	11.00
-15	0	4	6.61	4.83	-5	1	1	28.92	28.35	1	2	2	36.27	35.15	-6	3	4	3.35	3.28
-13	0	4	10.01	8.54	-4	1	1	15.72	15.91	2	2	2	16.97	16.86	-7	3	4	7.61	7.81
-11	0	4	8.87	8.56	-3	1	1	4.95	5.37	3	2	2	5.37	5.42	-9	3	4	6.48	5.69
-10	0	4	4.79	4.47	-2	1	1	10.91	11.25	5	2	2	4.09	3.79	-15	3	4	4.63	3.94
-9	0	4	13.23	13.13	-1	1	1	27.65	28.43	6	2	2	8.20	7.87	-12	3	3	3.91	1.37
-7	0	4	2.64	2.88	0	1	1	34.90	34.37	7	2	2	7.05	7.03	-9	3	3	7.12	7.28
-6	0	4	3.83	3.19	1	1	1	35.92	35.56	9	2	2	4.05	3.42	-7	3	3	3.86	4.03
-5	0	4	2.12	1.46	2	1	1	15.25	15.57	10	2	2	5.53	5.58	-6	3	3	10.99	10.66
-4	0	4	6.85	7.22	3	1	1	5.04	4.84	11	2	3	4.25	3.66	-5	3	3	8.03	8.04
-3	0	4	5.65	5.62	4	1	1	5.03	5.14	7	2	3	6.01	5.98	-4	3	3	3.21	3.46
-2	0	4	16.03	16.41	5	1	1	13.57	13.58	6	2	3	2.50	2.20	-3	3	3	7.83	7.87
-1	0	4	2.31	1.98	6	1	1	16.05	15.71	5	2	3	3.30	3.88	-2	3	3	13.73	13.07
0	0	4	23.63	24.00	7	1	1	3.95	3.57	4	2	3	4.04	3.79	-1	3	3	16.96	16.27
1	0	4	23.86	24.36	8	1	1	2.88	2.67	2	2	3	13.94	14.34	1	3	3	2.54	3.58
2	0	4	46.46	47.27	10	1	1	7.58	7.52	1	2	3	11.82	11.85	2	3	3	4.31	4.19
3	0	4	6.85	6.83	11	1	1	3.67	3.10	0	2	3	5.74	5.88	3	3	3	3.32	3.71
4	0	4	3.45	2.94	15	1	0	3.99	2.16	-1	2	3	2.41	3.08	4	3	3	8.72	8.13
5	0	4	2.40	2.63	12	1	0	4.43	4.68	-2	2	3	2.57	2.98	5	3	3	7.43	7.09
6	0	4	10.20	10.29	11	1	0	11.65	11.85	-3	2	3	4.54	4.77	6	3	3	4.30	4.49
-14	0	6	6.05	4.50	10	1	0	8.61	8.69	-4	2	3	16.00	16.07	8	3	3	7.52	6.09
-12	0	6	7.21	6.19	9	1	0	8.69	8.85	-5	2	3	13.07	13.06	10	3	2	2.54	1.21
-10	0	6	9.20	9.04	6	1	0	17.05	16.96	-6	2	3	6.64	6.17	9	3	2	3.65	3.07
-8	0	6	12.10	11.76	5	1	0	6.60	6.49	-7	2	3	6.05	6.31	8	3	2	4.30	4.20
-5	0	6	2.43	1.81	4	1	0	33.35	32.77	-8	2	3	5.99	5.99	7	3	2	10.43	9.66
-4	0	6	2.79	.95	3	1	0	5.14	5.39	-9	2	3	5.66	5.06	5	3	2	10.13	9.76
-2	0	6	3.76	3.48	2	1	0	38.72	39.28	-16	2	3	4.69	2.96	4	3	2	12.68	11.67
-1	0	6	4.64	4.54	1	1	0	10.37	10.04	-13	2	4	3.36	1.44	3	3	2	10.37	9.45
0	0	6	3.99	3.67	0	2	0	68.90	54.24	-11	2	4	4.75	4.97	2	3	2	10.68	9.86
1	0	6	8.45	8.88	1	2	0	14.63	15.01	-10	2	4	4.80	5.85	0	3	2	5.83	5.47
2	0	6	10.93	11.37	2	2	0	12.57	12.97	-9	2	4	3.47	2.20	-1	3	2	26.42	24.23
3	0	6	12.82	13.27	3	2	0	4.54	4.79	-7	2	4	10.85	11.39	-2	3	2	16.94	16.18
4	0	6	3.07	3.44	4	2	0	6.07	5.28	-6	2	4	4.05	4.12	-3	3	2	4.69	4.22
7	0	6	4.51	3.61	5	2	0	19.07	18.51	-5	2	4	11.54	11.41	-4	3	2	7.23	6.22
-13	0	8	4.61	2.78	6	2	0	18.75	18.75	-4	2	4	13.24	13.44	-5	3	2	18.86	17.88
-9	0	8	6.62	5.98	9	2	0	11.49	11.74	-3	2	4	19.39	18.23	-6	3	2	3.59	4.17
-7	0	8	7.55	7.23	10	2	0	3.90	2.89	-2	2	4	2.08	.99	-7	3	2	4.45	4.90
-5	0	8	3.34	.93	11	2	0	3.73	2.80	0	2	4	5.96	6.08	-8	3	2	7.17	8.00
3	0	8	4.36	4.40	12	2	0	4.54	3.55	1	2	4	3.22	2.66	-10	3	2	5.47	4.83
4	0	8	3.74	3.36	10	2	1	6.73	6.15	2	2	4	11.36	11.56	-11	3	1	3.43	1.73
-7	1	10	4.05	1.35	8	2	1	4.14	3.36	3	2	4	7.99	8.22	-10	3	1	3.85	4.36
-6	1	9	4.34	3.17	6	1	4	4.39	4.61	7	2	4	2.91	2.80	-8	3	1	4.82	5.14
-2	1	9	3.53	1.79	4	1	4	3.03	3.11	8	2	5	3.49	1.77	-7	3	1	10.43	9.94
-2	1	8	3.03	2.29	2	1	4	7.01	6.94	6	2	5	3.22	1.67	-6	3	1	11.67	11.68
-7	1	8	6.96	6.01	1	1	4	4.66	4.38	3	2	5	5.60	5.47	-4	3	1	12.17	11.83
-11	1	8	3.95	.20	0	1	4	22.00	22.51	2	2	5	4.02	3.71	-3	3	1	19.05	18.54
-7	1	7	7.09	6.97	-2	1	4	9.46	9.21	-1	2	5	2.31	1.05	-2	3	1	25.02	23.72
-6	1	7	3.47	2.82	-3	1	4	9.38	9.60	-2	2	5	4.40	4.15	-1	3	1	7.79	7.04
-4	1	7	4.13	3.71	-4	1	4	12.28	12.39	-3	2	5	4.72	5.50	0	3	1	6.65	6.06
-3	1	7	3.97	3.32	-5	1	4	2.07	2.32	-4	2	5	8.33	8.39	1	3	1	6.36	6.01
-2	1	7	5.32	5.71	-6	1	4	4.76	4.48	-5	2	5	4.61	4.32	2	3	1	8.31	8.20
2	1	7	5.38	4.96	-7	1	4	8.67	8.86	-6	2	5	3.81	3.68	3	3	1	17.60	18.04
2	1	6	2.91	3.01	-9	1	4	3.36	3.63	-7	2	5	3.71	3.39	4	3	1	14.05	14.50
1	1	6	7.69	7.89	-9	1	4	21.54	22.19	-8	2	5	4.15	3.96	5	3	1	8.55	8.86
0	1	6	2.90	2.68	-11	1	4	4.07	4.71	-11	2	5	3.91	4.57	7	3	1	10.46	10.21
-2	1	6	3.16	2.14	-13	1	4	3.14	2.23	-15	2	5	3.77	2.63	8	3	1	5.36	5.30
-3	1	6	5.42	5.35	-10	1	3	4.02	4.31	-11	2	6	3.38	1.01	9	3	1	3.58	3.78
-4	1	6	2.71	.95	-9	1	3	11.90	12.08	-10	2	6	5.02	4.74	9	3	0	3.19	4.47
-6	1	6	5.07	4.93	-8	1	3	11.82	12.50	-9	2	6	3.17	3.65	8	3	0	3.89	4.82
-8	1	6	14.23	14.30	-6	1	3	10.59	10.49	-6	2	6	4.44	4.19	7	3	0	5.48	5.43
-10	1	6	4.35	4.28	-5	1	3	2.65	2.52	-4	2	6	7.54	7.56	6	3	0	16.23	16.78
-14	1	6	3.92	1.62	-4	1	3	27.03	26.98	-3	2	6	4.10	3.79	5	3	0	2.47	2.56
-10	1	5	4.62	4.29	-3	1	3	8.36	8.32	-2	2	6	8.46	7.91	4	3	0	10.82	11.29
-9	1	5	3.23	3.20	-1	1	3	7.03	6.67	1	2	6	3.16	1.61	3	3	0	19.42	20.30
-8	1	5	11.09	11.29	0	1	3	21.76	22.17	4	2	6	3.47	2.59	2	3	0	21.32	22.05
-7	1	5	7.86	7.51	1	1	3	13.63	14.17	-3	2	7	3.54	3.61	1	3	0	10.65	10.67
-5	1	5	7.41	7.54	2	1	3	16.49	17.22	-4	2	7	2.81	2.34	0	4	0	8.23	8.14
-4	1	5	4.13	4.41	3	1	3	5.19	5.11	-5	2	7	3.72	1.20	1	4	0	2.55	2.53
-3	1	5	14.94	14.55	5	1	3	2.77	2.83	-5	2	10	3.99	.31	3	4	0	9.88	9.59
1	1	5	10.93	11.46	6	1	3	7.37	7.26	-8	3	9	4.36	.87	4	4	0	3.29	3.08
2	1	5	4.85	4.06	7	1	3	5.69	5.84	-4	3	9	4.01	.60	5	4	0	7.72	8.33
3	1	5	6.44	6.85	7	2	1	3.26	3.49	-7	3	7	3.76	3.64	6	4	0	8.24	8.26
7	1	5	3.16	3.32	6	2	1	14.72	14.61	-4	3	7	3.91	2.93	7	4	0	10.92	11.26

Table 2. Continued.

8	4	0	8.86	10.08	-4	4	3	5.68	5.54	-2	5	5	7.12	6.71	5	5	0	5.24	4.95
9	4	0	7.31	7.32	-5	4	3	13.55	14.52	0	5	5	5.43	5.17	4	5	0	3.04	1.45
11	4	1	3.51	2.89	-6	4	3	9.61	9.95	4	5	5	5.07	4.68	3	5	0	17.16	18.07
8	4	1	5.56	4.66	-8	4	3	4.16	3.44	5	5	4	5.36	4.67	1	6	0	9.49	9.30
7	4	1	3.79	9.07	-9	4	3	3.11	3.37	-1	5	4	8.11	8.57	3	6	0	6.63	6.56
6	4	1	6.34	5.96	-8	4	4	4.23	5.05	-2	5	4	4.50	5.07	0	6	1	3.47	2.61
5	4	1	6.60	6.49	-7	4	4	4.65	4.84	-3	5	4	4.58	4.46	-1	6	1	3.31	.90
4	4	1	7.00	6.79	-6	4	4	15.43	16.20	-10	5	4	3.53	3.13	-6	6	2	3.54	3.44
0	4	1	2.32	3.30	-5	4	4	3.26	3.57	-7	5	3	3.75	3.26	-2	6	2	6.09	5.28
-3	4	1	8.88	8.79	-4	4	4	5.03	4.98	-5	5	3	2.33	3.20	0	6	2	6.02	5.96
-4	4	1	9.79	10.22	-3	4	4	10.03	9.94	-3	5	3	10.71	10.58	2	6	2	8.19	8.00
-5	4	1	7.77	7.96	-2	4	4	7.33	7.20	-2	5	3	4.95	4.95	3	6	2	3.64	.54
-6	4	1	13.15	14.13	-1	4	4	7.81	7.50	-1	5	3	9.66	9.16	4	6	2	5.75	5.31
-7	4	1	8.18	8.60	0	4	4	2.80	1.44	3	5	3	7.57	7.21	-7	6	3	3.53	2.06
-9	4	1	3.30	3.00	5	4	4	3.45	3.14	4	5	3	5.41	5.07	-1	6	4	3.70	2.84
-10	4	1	3.79	3.66	-1	4	5	4.62	3.91	5	5	3	5.94	6.43	3	6	4	4.84	4.46
-11	4	1	3.49	3.11	-2	4	5	8.05	7.84	9	5	2	3.41	.71	0	6	5	3.69	1.72
-11	4	2	3.39	3.05	-4	4	5	9.79	9.85	7	5	2	3.77	.52	-1	7	2	3.86	2.83
-8	4	2	7.68	8.25	-5	4	5	6.99	7.69	4	5	2	11.35	11.40	-2	7	2	4.01	4.14
-7	4	2	15.20	16.68	-7	4	5	3.14	3.09	3	5	2	3.58	2.70	-2	7	1	3.89	3.44
-6	4	2	8.60	9.38	-9	4	5	3.57	3.28	-2	5	2	16.06	16.47	2	7	1	3.98	.91
-5	4	2	6.93	8.95	-7	4	6	4.48	4.56	-3	5	2	5.37	4.79	3	7	1	3.47	3.20
-4	4	2	12.60	12.66	-6	4	6	3.81	.84	-4	5	2	6.19	6.01					
-3	4	2	6.29	6.47	-5	4	6	10.53	9.77	-8	5	1	3.40	2.55					
-2	4	2	9.90	10.57	-3	4	6	3.35	1.19	-6	5	1	2.80	3.32					
0	4	2	2.26	.49	-2	4	6	5.70	4.69	-4	5	1	10.27	11.04					
1	4	2	5.34	5.81	-1	4	6	5.85	5.08	-3	5	1	8.62	9.08					
4	4	2	5.90	6.09	0	4	6	3.48	3.62	-2	5	1	11.95	11.46					
7	4	2	4.63	4.16	3	4	6	3.44	.70	-1	5	1	5.48	5.21					
8	4	2	7.36	7.85	-1	4	7	5.28	4.16	1	5	1	3.10	3.22					
10	4	2	4.00	3.92	-3	4	7	4.59	4.90	2	5	1	6.31	7.60					
7	4	3	3.58	2.87	-4	4	7	4.63	4.46	3	5	1	9.48	9.36					
5	4	3	3.63	3.59	-5	5	6	3.66	1.77	4	5	1	9.90	9.52					
-2	4	3	7.36	7.04	-7	5	5	3.24	2.60	5	5	1	6.96	7.47					
-3	4	3	10.84	10.93	-6	5	5	3.48	2.92	7	5	1	3.23	2.11					

Table 3. The principal axes of the thermal vibration ellipsoids given by the components of a unit vector in fractional coordinates e_x, e_y, e_z; the corresponding r.m.s. amplitudes and the B-values.

Atoms	e_x	e_y	e_z	$(\overline{u^2})^{\frac{1}{2}}$ (Å)	B (Å^2)
C2	0.052	0.134	0.046	0.238	4.48
	0.039	−0.079	0.124	0.217	3.73
	−0.066	0.060	0.059	0.197	3.07
C4	0.032	0.149	0.051	0.264	5.48
	0.020	−0.060	0.135	0.243	4.68
	−0.085	0.043	0.011	0.178	2.51
C5	0.057	−0.088	0.104	0.250	4.95
	−0.009	0.115	0.097	0.230	4.33
	0.073	0.082	−0.023	0.176	2.46
C6	0.073	−0.044	0.107	0.246	4.77
	−0.048	0.035	0.097	0.226	4.03
	0.031	0.156	0.008	0.193	2.93
N1	0.051	0.005	0.137	0.243	4.65
	0.040	0.142	−0.028	0.215	3.66
	−0.067	0.087	0.037	0.174	2.39
N3	0.045	0.018	0.139	0.280	6.20
	0.026	−0.160	0.005	0.214	3.61
	0.077	0.043	−0.040	0.195	3.01
O2	0.047	−0.007	0.139	0.327	8.45
	−0.050	0.128	0.030	0.239	4.49
	0.063	0.106	−0.028	0.165	2.16
F5	0.026	0.031	0.142	0.318	7.98
	0.059	−0.129	0.018	0.300	7.10
	0.067	0.101	−0.021	0.198	3.11

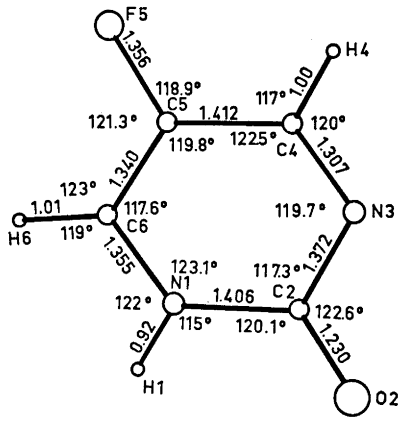


Fig. 1. Bond lengths (Å) and bond angles (°) (corrected values).

Table 4. Bond length (Å) and angles (°). (a) This investigation, uncorrected values. (b) Estimated standard deviations. (c) This investigation, libration corrected values. (d) Pyrimidine-2-one, libration corrected values. (e) Pyrimidine-2-one, estimated standard deviations.

	(a)	(b)	(c)	(d)	(e)
N1–C2	1.394	0.005	1.406	1.384	0.003
C2–N3	1.363	0.004	1.372	1.367	0.003
N3–C4	1.299	0.005	1.307	1.320	0.003
C4–C5	1.399	0.005	1.412	1.403	0.004
C5–C6	1.330	0.005	1.340	1.355	0.004
C6–N1	1.348	0.005	1.355	1.353	0.003
C2–O2	1.227	0.004	1.230	1.244	0.003
C5–F5	1.352	0.004	1.356		
N1–H1	0.92	0.03		0.90	0.02
C4–H4	1.00	0.03		1.00	0.03
C6–H6	1.01	0.05		1.00	0.03
N1···O2	2.738	0.004	2.718	2.796	0.003
C6–N1–C2	123.1	0.3	123.1	123.0	0.3
N1–C2–N3	117.2	0.3	117.3	118.3	0.2
C2–N3–C4	119.8	0.4	119.7	118.1	0.2
N3–C4–C5	122.5	0.4	122.5	124.7	0.3
C4–C5–C6	119.7	0.4	119.8	116.9	0.3
C5–C6–N1	117.7	0.4	117.6	119.1	0.3
N1–C2–O2	120.2	0.4	120.1	119.8	0.2
N3–C2–O2	122.6	0.4	122.6	121.9	0.2
C4–C5–F5	118.9	0.4	118.9		
C6–C5–F5	121.4	0.4	121.3		
C6–N1–H1	122	2		118	1
C2–N1–H1	115	2		119	1
N3–C4–H4	121	2		114	1
C5–C4–H4	117	2		122	1
C5–C6–H6	123	2		124	1
N1–C6–H6	119	2		117	1
N1–H1···O2	175	3	176		

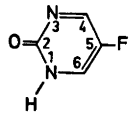
Table 5. Distances from the least-squares plane defined by the first eight atoms.

Atom	Deviation, Å	Atom	Deviation, Å
C2	0.002	O2	0.019
C4	−0.005	F5	0.010
C5	0.002	H1	−0.09
C6	0.000	H4	−0.01
N1	−0.020	H6	−0.02
N3	−0.015		

other, giving the molecule a slightly curved shape, similar to that observed in crystals of pyrimidine-2-one[3] and certain other pyrimidines.

The value of 1.356 Å for the C−F bond length is in agreement with that found in 1-methyl-5-fluorocytosine[11] (1.342 Å, $\delta = 0.009$ Å) and in 5-fluorouracil[12] (1.344 Å, $\sigma < 0.01$ Å), specially when taken into account that these values are not corrected for thermal effects.

The effects of fluorine substitution. For comparison the bond lengths and angles (corrected for libration) derived by X-ray analysis of the parent compound pyrimidine-2-one are also given in Table 4. It is seen that substitution of hydrogen by fluorine causes small changes in the bond lengths in the ring system. None of these are clearly significant, the largest one being 4σ. However, when they all are considered together they indicate a definite pattern of electron redistribution. Fluorine substitution has lengthened N1−C2 by about 0.02 Å and C4−C5 by 0.01 Å, whereas C2−O2, N3−C4, and C5−C6 have become shorter by about 0.015 Å. Qualitatively the changes may be described in terms of an increased contribution to the electronic structure from the pairing scheme:



The double bonds have become shorter, the single bonds longer, but the sum of bond lengths remains the same. These observations may be explained by assuming the fluorine atom to donate electron density to the π-electron system and to withdraw a similar amount of electron density from the σ-system. This picture corresponds to the one generally used to interpret the effects of fluorine substitution, fluorine having a strong inductive effect, as well as a high resonance effect.[1]

Another consequence of fluorine substitution is the highly significant increase of the bond angle at C5 from 116.9° to 119.8°. Similar changes have been observed for a number of other substituents.

Some structural information on the effect of fluorine substitution in pyrimidines may also be derived from a comparison of the structures of 1-methyl cytosine and its 5-fluoro-derivative, whose complexes with 9-ethylguanine

have been studied by X-ray method.[11] The changes near atom C5 are qualitatively the same as in the present case, the angle at C5 becoming larger by 2.1°, the bond C5–C6 shorter by 0.01 Å and C5–C4 longer by 0.03 Å. These analyses are, however, less precise ($\sigma = 0.007 - 0.009$ Å) and the effects are at a lower significance level.

Intermolecular forces. The molecules are linked together to nearly planar zig-zag chains by hydrogen bonds N1–H1···O2 of length 2.718 Å (Fig. 2). This is considerably shorter than the "normal" length of N–H···O bonds in pyrimidines, which appears to be about 2.85 Å. The bond is nearly linear, the angle at H1 being 175°. The corresponding bond in pyrimidine-2-one is found to be 2.796 Å. The shortening is presumably at least in part related to the

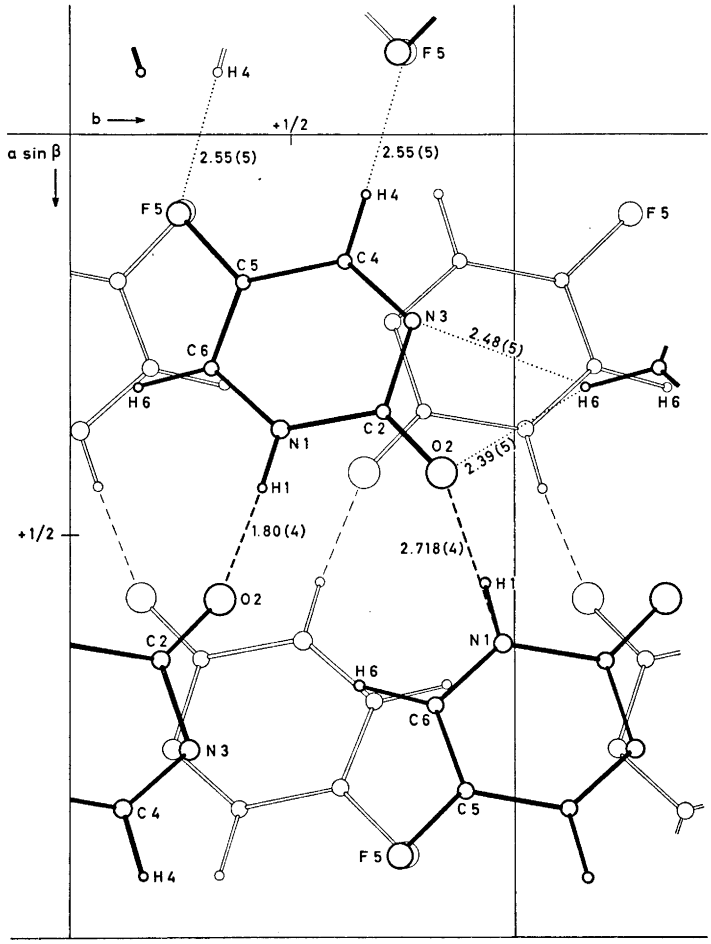


Fig. 2. The *c*-projection of the structure. Broken lines, hydrogen bonds; dotted lines, short intermolecular contacts.

introduction of the electronegative fluorine atom on C5, but may also be caused by crystal forces. Studies of base-pairs have indicated that halogen substitution may modify the hydrogen bonding properties of the bases.[14,15]

The hydrogen bond chains run in the *b* direction. The average interplanar distance between them is about 3.1 Å, the shortest interatomic distance, 3.24 Å, being between O2 and C2. The distances from H6 to O2 and N3 in a neighbouring molecule are 2.39 Å and 2.48 Å, respectively, slightly shorter than normal van der Waals separations. The fluorine atoms do not take part in hydrogen bonding, the nearest hydrogen atom being 2.55 Å apart.

The authors wish to thank *Norges Almenvitenskapelige Forskningsråd* for financial support, and Professor Laland and Dr. Undheim for placing samples of the compound at their disposal.

REFERENCES

1. Sheppard, W. and Sharts, A. *Organic Fluorine Chemistry*, Benjamin, New York 1969.
2. Clark, D. T., Murrel, J. N. and Tedder, J. M. *J. Chem. Soc.* **1963** 1250.
3. Furberg, S. and Solbakk, J. *Acta Chem. Scand.* **24** (1970) 3230.
4. Heidelberger, C. *Progr. Nucl. Acid Res. Mol. Biol.* **4** (1965) 1.
5. Sartorelli, A. C. and Creasey, W. A. *Cancer Res.* **27** (1967) 2201.
6. Helgeland, L. and Laland, S. *Biochim. Biophys. Acta* **87** (1964) 353.
7. Undheim, K. and Gacek, M. *Acta Chem. Scand.* **23** (1969) 294.
8. Hanson, H. R., Hermann, F., Lea, J. D. and Skillman, S. *Acta Cryst.* **17** (1964) 1040.
9. Stewart, R. F., Davidson, E. R. and Simpson, W. T. *J. Chem. Phys.* **42** (1965) 3175.
10. Dahl, T., Gram, F., Groth, P., Klewe, B. and Rømming, C. *Acta Chem. Scand.* **24** (1970) 2232.
11. O'Brien, E. J. *Acta Cryst.* **23** (1967) 92.
12. Kim, S. H. and Rich, A. *J. Mol. Biol.* **42** (1969) 87.
13. Sahore, T. D., Tavale, S. S. and Sobell, H. M. *J. Mol. Biol.* **43** (1969) 361.
14. Mazza, F., Sobell, H. M. and Kartha, G. *J. Mol. Biol.* **43** (1969) 407.

Received May 3, 1971.