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A Neutron Diffraction Study of Potassium Sulphamate, KSO_3NH_2

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A single-crystal neutron diffraction investigation of potassium sulphamate has been made in which the intensities of 501 reflexions were measured. The structure was refined by a least-squares technique with individual anisotropic temperature factors. The non-hydrogen atom positions obtained agree well with those of Jeffrey & Stadler (*J. Chem. Soc.* 1951, p. 1467). The hydrogen atom positions differ substantially from those postulated from the X-ray work and the nitrogen atom is in sp^3 configuration. The sulphamate ions are packed one above the other with hydrogen bonds linking them in infinite chains parallel to the c axis.

Introduction

The crystal structure of potassium sulphamate has been studied by Brown & Cox (1940) and by Jeffrey & Stadler (1951) by X-ray methods. In both cases the authors suggest that the nitrogen valency directions are coplanar and that the hydrogen atoms lie in the mirror plane of symmetry of the molecule.

Experimental procedure

Crystals of potassium sulphamate were grown by slow evaporation from a solution of pure sulphamic acid neutralized with pure potassium hydroxide. The crystal data (from Jeffrey & Stadler) are given in Table 1. Large crystals can be grown easily and a specimen of size 4 × 3 × 3 mm was cut and mounted on a two-circle goniometer set so that the c axis of the crystal was along the φ axis of the goniometer and the scattering vector remained in the χ plane for all reflexions. The intensity data were collected on a neutron diffractometer on the Australian Atomic Energy Commission's reactor HIFAR. The beam current at the specimen was approximately 6×10^6 neutrons cm^{-2}sec^{-1}, at a wavelength of 1·09 Å. The integrated intensities of 501 reflexions with $\sin\theta/\lambda < 0{\cdot}65$ were measured. Of these, 81 were recorded as unobserved. There was no evidence of severe extinction effects. The crystal angles were set by hand and the intensity data recorded by step scanning through the peak in the $\theta-2\theta$ mode. The scan was made in steps of 0·03° of 2θ under monitor control.

Table 1. *Crystal data*

Crystal system: Orthorhombic
Space group: *Pbcm* (D_{2h}^{11}) (no. 57)
Cell parameters $a=5{\cdot}907$, $b=8{\cdot}333$, $c=8{\cdot}302$ Å
$Z=4$ molecules per unit cell
$D_x=2{\cdot}2$ g.cm^{-3}
Mass = 32·5 mg
Linear absorption coefficient, $\mu=0{\cdot}702$ cm^{-1}

Dimensions of crystal

Miller indices of face	Perpendicular distance of face from an origin inside the crystal mm
0 0 1	1·70
0 0 −1	1·70
−1 0 0	1·14
0 1 0	1·49
1 2 0	1·04
1 1 0	0·97
1 0 0	1·14
1 −2 0	1·68
0 −1 0	1·75
−1 −1 0	0·69

Volume calculated from dimensions, 15·85 mm^3
Volume calculated from mass, 14·77 mm^3

Analysis of data

The data were corrected for absorption and reduced to F_o and $\sigma(F_o)$ by the program CDRABS written by one of us (G.W.C.). The absorption cross sections were taken as the sum of the cross section due to true absorption and that due to incoherent scattering. The

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value used for the incoherent scattering cross section for hydrogen was 34 barns, which is the value found by Melkonian (1949) for hydrogen in water for 0·069 eV neutrons. An estimated standard deviation was assigned to every observed intensity according to expressions $\sigma^2(P) = \sigma_1^2(P)+\sigma_2^2(P)$, $\sigma_1(P) = (P+2B)^{\frac{1}{2}}$ where P is the total intensity in the peak less the background intensity B, $\sigma_2(P)=\alpha+\beta P$ and where α and β are constants chosen to allow for errors in crystal setting and background determination. Experience has shown that, for data collected under the conditions of this experiment, appropriate values are $\alpha=200$, $\beta=0{\cdot}02$. The unobserved reflexions were assigned an intensity of $P_{\min}/2$ and a standard deviation of $P_{\min}/2$, where $P_{\min}$ is the intensity of the weakest observed reflexion.

Before initial parameters were selected for the least-squares refinement, structure factors were calculated with the non-hydrogen atom positions found by Jeffrey & Stadler (whose notation is used throughout this work) and the hydrogen atoms in the S–N–O(1) mirror plane.

Comparison with the observed structure factors showed immediately that these positions were incorrect, so an intermolecular interaction N–H···O(2′) was assumed. Jeffrey & Stadler remark that this distance is shorter than that usually associated with molecular packing in crystals but attribute the shortening to an electrostatic attraction between N^+ and O^-.

On this basis the initial hydrogen coordinates were chosen as (0·279, 0·396, 0·152) and the parameters refined by full-matrix least-squares based on F, using the ORFLS program (Busing, Martin & Levy, 1962*a*) weighting each reflexion as $1/\sigma^2(F)$. The scattering lengths of each atom were fixed at the values given by Bacon (1962) and the overall scale factor, positional and anistropic thermal parameters of each atom were varied. After two cycles it was evident that this model was correct (with hydrogen atoms out of plane), but the observed F values for reflexions 004, 006, 200, 355 and 423 were much lower than calculated. These were strong reflexions and it was assumed they were affected by extinction or setting errors. They were dis-

Table 2. *Observed and calculated structure amplitudes with the estimated standard deviation of F_o* (× 100)

Unobserved reflexions are marked with an asterisk.

H = 0, K = 0			
2	291	353	4
8	587	676	9
10	78	111	20
H = 0, K = 2			
0	175	-180	4
1	435	-471	6
2	313	290	5
3	335	-339	6
4	691	-673	9
5	221	193	7
6	71	-75	15
7	245	215	7
8	186	-195	9
9	49	35	28
10	266	287	8
H = 0, K = 4			
0	63	11	12
1	484	-456	7
2	378	363	6
3	197	-181	7
4	363	-334	7
5	89	-111	13
6	573	534	8
7	439	433	3
7	438	433	4
8	67	-49	20
9*	37	34	37
10	147	141	11
H = 0, K = 6			
0	138	130	9
1	361	349	7
2	726	-712	10
3	474	-477	8
4	567	539	8
5	178	182	9
6	233	-230	8
7	41	-37	33
8	120	126	13
H = 0, K = 8			
0	469	-487	8
1	40	-44	32
2	243	209	8
3	106	114	13
4	263	276	8
5	84	-61	18
6	347	344	8
7	99	96	16
H = 0, K = 10			
0	349	-341	8
1	257	-241	8
2*	38	4	38
3	431	421	8
4*	38	-34	38
H = 1, K = 0			
0	52	54	6
2	241	-228	5
4	125	110	8
6	197	-175	8
8*	36	18	36
10	133	-122	13
H = 1, K = 1			
0	169	-191	4
1	258	-284	4
2	356	329	5
3	542	-550	7
4	189	-192	7
5	329	294	7
6	560	596	8
7	205	186	8
8	157	-156	11
9	129	159	13
10	110	91	15
H = 1, K = 2			
0	33	29	15
1	304	-306	5
2	95	84	7
3	332	315	6
4	78	72	12
5	263	-258	7
6	84	72	14
7	181	185	9
8*	36	35	36
9	158	-165	11
10*	38	33	38
H = 1, K = 3			
0	225	-262	5
1	304	-288	6
2	384	-348	6
3	248	244	6
4	143	127	8
5	375	-380	7
6	237	255	8
7	366	359	8
8	158	-158	11
9	80	-99	19
10	385	-423	8
H = 1, K = 4			
0	220	-228	6
1	256	237	6
2	101	103	9
3	201	-188	7
4	232	-222	7
5	191	176	8
6	88	78	15
7	196	-185	9
8	151	-155	11
9	133	124	13
H = 1, K = 5			
0	179	-153	7
1	564	553	8
2	160	-171	8
3	97	-102	12
4	704	665	10
5	139	157	10
6	72	83	19
7	298	-298	8
8*	37	57	37
9	161	147	11
H = 1, K = 6			
0	181	178	8
1	100	92	12
2*	33	-29	33
3	55	-62	22
4	112	109	12
5	55	51	24
6*	36	-19	36
7	62	-53	23
8	109	101	14
H = 1, K = 7			
0	456	-555	8
1	85	68	15
2	204	184	8
3	312	288	8
4	116	-141	13
5*	36	3	36
6	79	60	19
7	195	-181	10
8	311	-303	8
H = 1, K = 8			
0	88	93	16
1	161	-176	10
2	189	-171	9
3	145	155	11
4	80	51	19
5	142	-151	12
6	170	-156	10
7	121	125	13
H = 1, K = 9			
0	373	384	8
1	195	-172	9
2	54	9	27
3	434	415	8
4*	37	41	37
5	117	-152	14
H = 1, K = 10			
0	107	-108	15
1*	38	38	38
2	189	190	10
3	59	-58	26
H = 2, K = 0			
2	58	-31	12
4	129	-129	8
6	574	573	8
8	315	-315	8
10	223	-246	9
H = 2, K = 1			
0	156	148	5
1*	24	-19	24
2	378	-337	6
3	95	86	9
4	62	64	16
5	61	-51	19
6	271	-268	7
7*	36	-22	36
8	75	60	20
9*	38	-33	38
10	153	-167	12
H = 2, K = 2			
0	48	-51	15
1	85	88	9
2	192	-182	6
3	606	621	8
4	469	424	7
5	451	-441	8
6	122	126	11
7*	36	19	36
8	50	45	29
9	166	-201	11
10	240	-240	9
H = 2, K = 3			
0	155	129	7
1	117	107	8
2	175	161	7
3	66	-80	15
4*	32	-5	32
5	71	74	17
6	150	135	10
7	93	-85	16
8	79	71	19
9	90	89	17
H = 2, K = 4			
0	252	-226	7
1	586	600	8
2*	31	-4	31
3*	32	-2	32
4	120	115	11
5	250	253	8
6	225	-228	8
7	532	-512	8
8	77	-72	20
9	69	54	22
H = 2, K = 5			
0	205	-209	7
1	92	-89	12
2	55	46	20
3	59	51	20
4	288	-261	7
5	91	-83	15
6*	36	-0	36
7	95	100	16
8	122	-124	13
9	53	-55	29
H = 2, K = 6			
0	101	109	13
1	144	-135	10
2	353	326	7
3	270	267	8
4	309	-297	8
5*	36	-22	36
6*	37	-41	37
7	104	-92	15
8*	38	2	38
H = 2, K = 7			
0	284	296	8
1*	35	13	35
2	114	-117	13
3	82	-69	17
4	287	279	8
5	55	49	26
6	101	-97	15
7*	38	25	38
H = 2, K = 8			
0	466	523	8
1	211	-188	9
2	197	-176	9
3	97	114	15
4	207	-178	9
5	116	-130	14
6	311	-302	8
H = 2, K = 9			
0	207	-216	9
1*	37	-12	37
2*	37	28	37
3*	38	-38	38
4	150	-152	11
5*	38	34	38
H = 2, K = 10			
0	140	98	12
1	206	211	9
2	122	129	13
H = 3, K = 0			
0	365	412	6
2	78	-59	12
4	195	193	7
6	82	-42	16
8	269	253	8
H = 3, K = 1			
0	338	393	6
1	398	371	7
2	303	-291	6
3	368	328	7
4	360	353	7
5	132	-121	10
6	488	-484	8
7	266	-247	8
8	278	260	8
9*	38	-74	38
H = 3, K = 2			
0	220	-216	7
1	209	213	7
2	72	31	14
3	269	-276	7
4	338	-300	7
5	203	203	8
6*	35	4	35
7	103	-105	14
8	158	-156	11
9	146	147	12
H = 3, K = 3			
0	173	179	7
1*	31	-10	31
2	134	142	9
3*	32	36	32
4	170	-157	9
5	91	106	15
6	328	-332	8
7	133	-138	12
8	77	77	20
9*	38	-44	38
H = 3, K = 4			
0	88	109	13
1	253	-249	7
2	112	91	8
3	140	147	7
4	166	152	6
5	164	-161	7
6	38	64	36
7	239	238	8
8	122	118	9
9	144	-142	12
H = 3, K = 5			
0	86	72	14
1	384	-356	7
2	370	374	7
3*	35	-4	24
4	555	-586	8
6	111	100	9
7	186	184	7
8	49	-52	30
H = 3, K = 6			
0*	35	-6	35
1*	35	-2	35
2	265	-267	8
3	86	-57	16
4	105	110	14
5	75	56	20
6	203	-199	9
7*	38	-13	38
H = 3, K = 7			
0	403	425	8
1*	36	46	36
2	282	-275	6
3	344	-341	6
4	88	82	17
5	73	71	21
6	161	-156	11
7	94	88	17
H = 3, K = 8			
0	183	-199	10
1	34	77	40
2	307	319	8
3	98	-51	25
4	94	-98	16
5	89	84	17
H = 3, K = 9			
0	173	-161	10
1*	38	0	38
2*	38	-23	38
3	223	-215	9
4	114	100	14
H = 4, K = 0			
0	183	167	8
2*	32	-3	32
4	112	-91	12
6	425	-453	8
8	81	81	19
H = 4, K = 1			
0	48	43	22
1	262	254	7
2	107	93	11
3	351	-343	7
4	153	127	10
5	257	259	8
6	90	89	16
7	108	-110	14
8*	38	38	38
9	155	155	11
H = 4, K = 2			
0	193	189	8
1	110	-108	11
2	226	206	7
4	184	-184	8
5	253	280	8
6*	36	-43	36
7*	37	24	37
8	77	73	20
H = 4, K = 3			
0	69	-33	17
1	538	-528	8
2	253	-249	7
3	477	460	8
4	159	154	10
5	425	-402	8
6	193	-193	9
7	366	365	8
8*	38	-7	38
H = 4, K = 4			
0	87	91	15
1	374	-355	7
2	115	-122	12
3	108	-97	13
4	157	-148	10
5	108	-120	14
6*	37	51	37
7	326	321	8
8*	38	9	38
H = 4, K = 5			
0	98	-99	14
1	188	177	9
2	187	188	9
3	139	-117	11
4*	36	35	36
5	158	156	10
6	190	182	9
7	183	-181	10
H = 4, K = 6			
0*	36	-34	36
1	43	16	31
2	112	-118	13
3	139	-130	11
4	267	269	8
5*	37	-47	37
H = 4, K = 7			
0	218	-236	8
1	229	231	8
2	90	97	16
3	94	-123	16
4	238	-232	9
5	121	126	13
H = 4, K = 8			
0	446	-459	8
1	113	117	14
2*	37	39	37
3	70	-72	21
4	93	69	16
H = 4, K = 9			
0	369	403	8
1	135	-157	12
2	225	-220	9
H = 5, K = 0			
0	408	-447	8
2	249	233	8
4	194	-191	9
6	199	192	9
8	255	-266	9
H = 5, K = 1			
0*	34	19	34
1	56	-66	22
2	266	-256	8
3	427	-398	8
4*	36	21	36
5	228	216	8
6*	37	-32	37
7	58	58	26
8*	38	-7	38
H = 5, K = 2			
0	146	160	10
1	164	-152	9
2	144	-141	10
3	248	234	8
4	270	266	8
5	162	-161	10
6	84	-93	18
7	66	54	23
H = 5, K = 3			
0*	35	30	35
1	259	-247	8
2	97	-97	14
3	212	200	9
4	277	262	8
5	269	-266	8
6	235	239	9
7	250	257	9
H = 5, K = 4			
0	63	36	21
1	265	241	8
2	84	-83	16
3	114	-119	13
4*	37	-25	37
5	145	146	11
6*	38	-53	38
7	236	-239	9
H = 5, K = 5			
0	437	-481	8
1	166	160	10
2*	37	9	37
3	84	73	18
4*	37	18	37
5*	37	-23	37
6	141	143	12
H = 5, K = 6			
0	98	-112	15
1*	37	-44	37
2	280	265	8
3	128	107	13
4	250	-238	8
5	88	-106	17
H = 5, K = 7			
0	115	-75	14
1	232	236	9
2	98	108	16
3*	37	-7	37
4	143	137	12
H = 5, K = 8			
0	226	253	9
1*	38	-41	38
H = 6, K = 0			
0	84	-73	17
2	71	46	20
4	106	115	14
6	297	311	8
H = 6, K = 1			
0	302	310	8
1*	36	-34	36
2	245	-238	8
3	145	139	11
4	201	190	9
5	75	-81	20
6	199	-192	10
H = 6, K = 2			
0	180	-186	10
1	204	204	9
2	175	-158	10
3	122	127	13
4*	37	56	37
5*	37	-44	37
6*	38	11	38
H = 6, K = 3			
0	62	43	16
1	175	182	7
2*	37	48	26
3	136	-139	12
4	155	-143	11
5	113	120	14
H = 6, K = 4			
0	54	29	26
1	63	62	23
2	84	82	18
3	208	216	9
4	173	157	10
5*	37	-47	37
H = 6, K = 5			
0	69	-95	21
1	134	-150	12
2	159	174	11
3	85	93	18
4	172	-198	10
H = 6, K = 6			
0	55	-27	27
1*	37	39	37
2*	37	46	37
3*	37	46	37
H = 7, K = 0			
0	108	99	14
2	91	-83	17
4	95	-79	16
H = 7, K = 1			
0*	38	-21	38
1	96	99	16
2	171	177	10
3	148	168	11
4*	38	-35	38
H = 7, K = 2			
0	54	30	27
1	238	245	9
2	125	110	13
3	299	-305	8
H = 7, K = 3			
3*	37	22	37
H = 7, K = 4			
0*	37	-5	37
0*	38	10	38
1*	38	6	38
2*	38	24	38
1	291	-285	8

carded and the reliability factor converged to values of 0·079, 0·067 and 0·073 for all reflexions, excluding unobserved reflexions, and for weighted structure amplitudes respectively. The observed and calculated structure amplitudes are given in Table 2. The final positional parameters and their standard deviations are listed in Table 4. The coordinates of non-hydrogen atoms agree well with those reported from X-ray studies. A Fourier section of the nuclear density at $z=0{\cdot}25$ is shown in Fig. 1, from which it is clear that the hydrogen atoms are not in the mirror plane.

Interatomic distances and bond angles were calculated from the parameters listed in Table 1, using the program ORFFE (Busing, Martin & Levy, 1962*b*). These values are given in Table 3, together with the values for sulphamic acid reported by Sass (1960).

Table 3. *Bond lengths and bond angles*

Standard deviations are shown in brackets.

Bond lengths	Potassium sulphamate	Sulphamic acid
S -N	1·666 (0·006) Å	1·764 (0·02) Å
S -O(1)	1·459 (0·007)	1·421 (0·02)
S -O(2)	1·454 (0·004)	1·452 (0·02)
N-H	1·007 (0·006)	1·024 (0·02) (average)
O(2)···H	2·147 (0·006)	
N-H···O(2)	3·080 (0·006)	

Bond angles	Potassium sulphamate	Sulphamic acid
H-N-H	110·1 (0·7)°	107·6° (average)
H-N-S	110·2 (0·4)	111·3 (average)
N-S -O(1)	108·5 (0·4)	103·2 (average)
N-S -O(2)	103·9 (0·3)	
O(1)-S -O(2)	112·1 (0·3)	115·1 (average)
O(2)-S -O(2′)	115·5 (0·5)	
S—N-O(2)	105·2 (0·1)	
N-H-O(2)	153·2 (0·5)	

Discussion

The nitrogen atom configuration

This investigation shows conclusively that the two hydrogen atoms do not lie in the plane containing the S, N and O(1) atoms. The bond angles around the nitrogen atom are S-N-H 110·2° and H-N-H 110·1°. These are so close to the ideal tetrahedral angle of 109·5° that it must be assumed the nitrogen atom has an sp^3 configuration with a lone pair of electrons in the fourth tetrahedral position. This conclusion is in disagreement with the expected relationship between bond length and bond order for the S-N bond. The theoretical single and double bond lengths are 1·74 and 1·54 Å from the covalent radii given by Pauling (1945). A single bond is associated with a tetrahedral configuration and Sass has found that in sulphamic acid the bond length is 1·764 Å and the nitrogen has an sp^3 configuration. In most other substances (see review by Trueblood & Mayer, 1956) a shorter bond has been observed and attributed to the availability of p electrons from the nitrogen to form π bonds with sulphur d-orbitals (Sass & Donohue, 1958). The nitrogen is then expected to be trigonally bonded with sp^2 hybridization. Recently, O'Connor & Maslen (1965) have found the S-N bond to be 1·61 Å in β-sulphanilamide and the configuration sp^2 while Alléaume & Decap

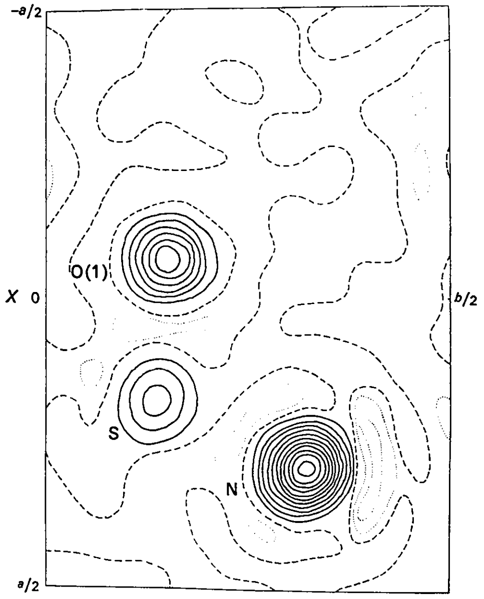

Fig. 1. Fourier section of neutron scattering density at $z=0{\cdot}25$. The full, broken and dotted lines represent positive, zero and negative densities respectively. The negative densities are plotted with half the contour interval of the positive ones.

Table 4. *Atomic parameters and their estimated standard deviations*

Positional parameters are expressed as fractions of the lattice parameters.
Thermal parameters are in the form $\exp[-(\beta_{11}h^2+\beta_{22}k^2+\beta_{33}l^2+\beta_{12}hk+\beta_{13}hl+\beta_{23}kl)]$.
All parameters are given $\times 10^4$.

	$x, \sigma(x)$	$y, \sigma(y)$	$z, \sigma(z)$	$\beta_{11}, \sigma(\beta_{11})$	$\beta_{22}, \sigma(\beta_{22})$	$\beta_{33}, \sigma(\beta_{33})$	$\beta_{12}, \sigma(\beta_{12})$	$\beta_{13}, \sigma(\beta_{13})$	$\beta_{23}, \sigma(\beta_{23})$
S	1775 (10)	1370 (7)	2500	86 (17)	22 (7)	59 (9)	−9 (9)	0	0
N	2914 (4)	3198 (3)	2500	141 (6)	39 (3)	59 (3)	−10 (4)	0	0
O(1)	−684 (6)	1532 (5)	2500	92 (10)	76 (6)	91 (6)	1 (6)	0	0
O(2)	2611 (5)	650 (3)	3981 (3)	201 (8)	67 (3)	43 (3)	10 (4)	−26 (4)	17 (3)
K	6644 (10)	2500	0	136 (19)	51 (6)	44 (7)	0	0	8 (6)
H	2438 (10)	3803 (7)	1506 (7)	285 (20)	131 (7)	119 (9)	−23 (10)	−35 (10)	57 (7)

All parameter changes in the last cycle of least-squares refinement were less than 1×10^{-4}.

(1965) have made a similar observation for γ-sulphanilamide in which they have found an S–N bond of 1·67 Å. Sabine & Cox (1967) have found the S–N bond in $S_4N_4H_4$ to be 1·65 Å and a trigonal nitrogen configuration.

In potassium sulphamate the S–N bond is not significantly longer but the configuration is sp^3. The sulphamate ion configuration is the same as that of the sulphamic acid molecule except for the absence of one of the hydrogen atoms from the nitrogen atom.

Hydrogen bonding

The intermolecular O···H distance of 2·15 Å is significantly less than the van der Waals contact distance of 2·8 Å and constitutes a weak hydrogen bond joining the suphamate molecules in infinite chains parallel to the *c* axis. The N–H bonds are staggered from the S–O bonds with respect to rotation about the S–N bond with a dihedral angle of 60·8° between the SNO(1) and SNH planes.

The potassium ion environment

The potassium ions are located between the chains of sulphamate molecules. Each potassium ion is surrounded by six oxygen atoms, two at each of the distances 2·729 (O(1)], 2·729 [O(2)] and 2·961 Å [O(2)]. The average S–O distance of 1·455 Å is close to the value 1·439 Å for sulphamic acid found by Sass.

Thermal vibrations

A detailed analysis of the thermal vibration parameters was not made; however, inspection of Table 4 shows that the maximum vibration is along **a**, which is normal to the direction of hydrogen bonding.

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The Crystal and Molecular Structure of a Dimethyl Sulfoxide Complex of Iron(III) Chloride

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A three-dimensional X-ray structure determination of the dimethyl sulfoxide (DMSO) compound of empirical formula $FeCl_3(DMSO)_2$ has shown it to be composed of *trans*-$[FeCl_2(DMSO)_4]^+$ and $FeCl_4^-$ ions. It crystallizes in the space group $I4_1/a$ of the tetragonal system with unit-cell dimensions $a=11\cdot60\pm0\cdot01$, $c=20\cdot33\pm0\cdot01$ Å. There are four of the true (ionic) formula units in each cell, with all iron atoms occupying positions of $\bar{4}$ symmetry. The DMSO molecules are coordinated through their oxygen atoms. The S–O distance ($1\cdot541\pm0\cdot006$ Å) is slightly but significantly greater than that in DMSO itself.

Introduction

The pronounced ability of dimethyl sulfoxide (hereafter abbreviated DMSO) to function as a donor or Lewis base toward a wide variety of acceptors or Lewis acids was clearly demonstrated by the isolation of a large number of complexes several years ago (Cotton & Francis, 1960). Subsequent studies showed that other sulfoxides possess similar bonding capacities (Francis & Cotton, 1961; Francis, 1964) but not to the same degree as DMSO.