

The Crystal and Molecular Structure of the Alkaloid Cassipourine

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The structure of one possible enantiomorph of the alkaloid cassipourine ($C_{14}H_{22}N_2S_4$) has been determined from three-dimensional photographically recorded and visually measured X-ray data. The final R value is 0.13 after full-matrix anisotropic least-squares refinement. The molecule is found to consist of two pyrrolizidine units bonded by two S-S linkages and to possess a non-crystallographic twofold axis. The four sulphur and four carbon atoms in the central part of the molecule form a 1,2,5,6-tetra-thiocyclo-octane ring system. The pyrrolizidine units comprise two pyrrolidine rings which can be brought into coincidence by rotation of one by 123° about their common C-N bond. The absolute configuration has been deduced by comparison of the conformation of parts of the pyrrolizidine units with those in two other alkaloids.

Introduction

The alkaloid cassipourine ($C_{14}H_{22}N_2S_4$) (CP) was isolated and studied chemically by Cooks, Warren & Williams (1967). They established that the molecule consisted of two pyrrolizidine groupings bonded by two S-S bridges and suggested the three possible molecular structures given in Fig. 1. Of these, the most probable structure was considered to be either (a) or (b) (Warren, 1964). The crystallographic investigation was undertaken to establish the structure and stereochemistry of the molecule.

Experimental

Crystals of the alkaloid and its dimethiodide were made available for structure analysis by Professor F. L. Warren. The quantities of both types were so small that recrystallization was precluded. The alkaloid crystals were needles of good quality but were exceedingly thin (diameter ~ 0.05 mm). Crystals of the alkaloid-dimethiodide were of much poorer quality and in the form of short needles. The cell constants were measured for both types of crystal from oscillation and Weissenberg photographs. The results obtained were as follows:

Alkaloid

$a = 13.40 \pm 0.05$, $b = 12.18 \pm 0.05$,
(needle axis) $c = 5.06 \pm 0.04$ Å; $\beta = 100 \pm 1^\circ$.
Space group: $P2_1$; $Z = 2$; $\rho = 1.42$ g.cm $^{-3}$.
Calculated formula weight: 348.0,
actual formula weight: 346.6.

Alkaloid-dimethiodide

$d_{100} = 10.48 \pm 0.05$, $b = 14.74 \pm 0.05$,
(needle axis) $c = 7.28 \pm 0.05$ Å.
Space group: $P2_1$; $Z = 2$; $\rho = 1.85$ g.cm $^{-3}$.
Calculated formula weight: 626.8
actual formula weight: 628.5

Densities were measured by flotation in aqueous potassium mercuric iodide. The experimentally derived molecular weights of 348.0 and 344.9 (the latter from the alkaloid-dimethiodide after correction for the presence of the dimethiodide group) agree to within experimental error with the molecular weight of 346.6 calculated for $C_{14}H_{22}N_2S_4$.

Because of the superior quality of the unsubstituted alkaloid crystals and the fact that $\frac{\sum f_H^2}{H} / \frac{\sum f_L^2}{L} = 1.64$, these, rather than the alkaloid-dimethiodide crystals, were used for the structure analysis.

Intensities were recorded with the equi-inclination Weissenberg multiple-film technique and nickel-filtered copper radiation. With the c axis (needle axis) as rotation axis 1261 (h, k, l) reflexions with $0 \leq l \leq 4$ were recorded and their intensities measured visually. Of these, 207 had intensities below the detection limit, notwithstanding five day exposures, and the beam-stop obscured twelve small- θ reflexions. Lorentz and polarization and spot-shape corrections were applied to the intensities. Absorption corrections were obviated by the small crystal diameter (0.05 mm) and low absorption coefficient, which gave the μR value of 0.13. The

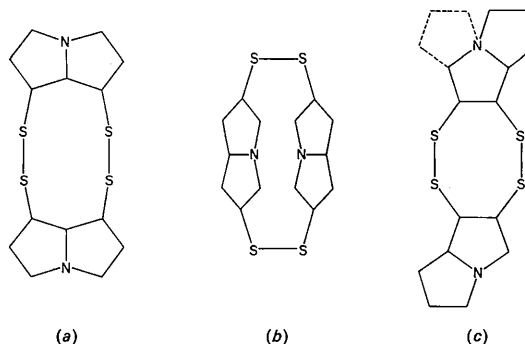


Fig. 1. Proposed structures for cassipourine.

Table 1. Final fractional coordinates and thermal vibration parameters and their e.s.d.'s

The numbering scheme is shown in Fig. (3).

	Fractional coordinates			Thermal vibration parameters					
	x/a	y/b	z/c	U ₁₁	U ₂₂	U ₃₃	U ₁₂	U ₁₃	U ₂₃
S(1)	0.0583 (4)	0.15	0.0780 (12)	0.068 (3)	0.078 (4)	0.070 (4)	0.005 (3)	-0.014 (3)	-0.021 (3)
S(2)	0.1013 (5)	0.3053 (8)	0.1662 (12)	0.068 (4)	0.080 (4)	0.082 (4)	0.007 (3)	-0.001 (3)	-0.026 (3)
S(3)	0.3534 (4)	0.1987 (8)	0.3856 (12)	0.071 (4)	0.090 (4)	0.080 (4)	-0.003 (4)	-0.013 (3)	0.017 (3)
S(4)	0.3203 (5)	0.0772 (7)	0.1108 (14)	0.090 (4)	0.072 (4)	0.091 (5)	0.009 (4)	0.030 (4)	0.002 (3)
N(1)	0.3269 (14)	0.4441 (17)	-0.1537 (33)	0.079 (13)	0.084 (14)	0.042 (11)	-0.004 (11)	-0.004 (9)	-0.006 (9)
N(2)	0.1581 (16)	0.1050 (19)	0.5623 (40)	0.089 (14)	0.083 (14)	0.078 (14)	-0.014 (12)	0.011 (11)	-0.030 (11)
C(1)	0.2113 (17)	0.3221 (22)	0.0199 (43)	0.085 (15)	0.085 (17)	0.059 (14)	0.016 (14)	-0.032 (11)	-0.008 (12)
C(2)	0.2219 (22)	0.4350 (21)	0.1251 (41)	0.128 (23)	0.061 (14)	0.047 (14)	0.018 (15)	-0.004 (13)	0.015 (10)
C(3)	0.3669 (21)	0.5540 (25)	-0.1063 (51)	0.114 (21)	0.094 (21)	0.079 (19)	-0.039 (18)	0.002 (15)	0.012 (15)
C(4)	0.4252 (26)	0.5556 (29)	0.1633 (64)	0.144 (28)	0.091 (24)	0.115 (26)	-0.039 (22)	-0.008 (21)	-0.014 (20)
C(5)	0.4703 (19)	0.4385 (29)	0.1820 (65)	0.073 (17)	0.122 (26)	0.133 (25)	-0.036 (19)	0.008 (16)	0.026 (22)
C(6)	0.3860 (19)	0.3715 (21)	0.0318 (39)	0.104 (18)	0.088 (17)	0.027 (14)	-0.016 (14)	0.011 (12)	-0.014 (11)
C(7)	0.3145 (16)	0.3182 (20)	0.2060 (39)	0.073 (13)	0.075 (15)	0.048 (13)	0.004 (20)	-0.014 (9)	-0.028 (11)
C(8)	0.2189 (17)	-0.0025 (21)	0.2166 (42)	0.076 (15)	0.081 (17)	0.063 (15)	0.004 (13)	-0.003 (11)	-0.015 (12)
C(9)	0.2503 (18)	-0.0819 (23)	0.4475 (46)	0.074 (15)	0.092 (19)	0.067 (16)	-0.009 (14)	-0.008 (13)	0.018 (13)
C(10)	0.2891 (22)	-0.1957 (25)	0.3561 (53)	0.126 (22)	0.080 (19)	0.085 (18)	-0.013 (19)	-0.002 (15)	-0.017 (16)
C(11)	0.1898 (23)	-0.2579 (23)	0.3107 (59)	0.133 (26)	0.062 (16)	0.108 (23)	-0.003 (16)	0.007 (18)	-0.033 (15)
C(12)	0.1367 (24)	-0.2172 (23)	0.5109 (63)	0.126 (22)	0.080 (18)	0.085 (18)	-0.013 (19)	-0.002 (15)	-0.017 (16)
C(13)	0.0779 (19)	-0.0270 (24)	0.4507 (58)	0.077 (16)	0.081 (19)	0.118 (21)	-0.039 (15)	0.020 (14)	-0.017 (16)
C(14)	0.1321 (17)	0.0679 (21)	0.3266 (38)	0.099 (16)	0.081 (15)	0.035 (13)	-0.012 (14)	0.009 (10)	-0.028 (11)

five layer lines were scaled from common intensities on a 20° oscillation photograph.

Structure determination

The three-dimensional Patterson function was computed and interpretation initiated by use of the $(u, \frac{1}{2}, w)$ Harker section (Fig. 2) which contains vectors of the type $(2x, \frac{1}{2}, 2z)$. The b cell constant is relatively small and the molecule would thus be expected to lie nearly parallel to (010). The double S-S bridge should approximate to a twisted rectangle with dimensions of 2 by at least 3.5 Å and which should also lie nearly parallel to (010). Eight of the ten strong peaks can be grouped into two such symmetry related sets, one of which is drawn into Fig. 2. When the y coordinates of these atoms are derived from non-Harker peaks in the Patterson map, the expected double S-S bridge geometry is confirmed. These trial sulphur coordinates were used to initiate the cyclic Fourier process which led to the structure of the whole molecule. Differentiation between carbon and nitrogen atoms was achieved after refinement of the B factors in a least-squares cycle in which all non-sulphur atoms were entered as carbon. The B factors of two of the atoms became negative on refinement, indicating that these were nitrogen.

Structure refinement

The positional and anisotropic thermal motion parameters and scale factors were refined by the full matrix least-squares program *ORXLS* of Busing & Levy which minimizes $\sum w(F_o - F_c)^2$, on an IBM computer. Equal weighting was used and refinement considered complete when all parameter changes were less than 0.2σ . Refinement of the layer line scale factors was alternated with appropriate thermal motion parameter refinement so as to optimize both while maintaining the experimentally established scale factor trend. The atomic scattering factors used were those of Hanson, Herman, Lea & Skillman (1964). Final atomic parameters and their estimated standard deviations are given in Table 1 with the U_{ij} 's from the expression

$$\exp [-2\pi^2(h^2a^*2U_{11} + k^2b^*2U_{22} + l^2c^*2U_{33} + 2hk a^*b^*U_{12} + 2kl b^*c^*U_{23} + 2hl a^*c^*U_{13})].$$

Inclusion of hydrogen atoms in the refinement in positions deduced from the geometry of the rest of the molecule led to no significant reduction in the final R value of 0.13. Calculated and observed structure factors are compared in Table 2.

Molecular geometry

This analysis has shown that CP possesses the conformation shown in Fig. 1(c) with the terminal pyrrolidine ring as drawn in stippled lines. Its chemical name is thus $1\alpha, 1'\beta:2\beta, 2'\alpha$ -(bisdithiodi-8 α -pyrrolizidine).

Table 2. Observed and calculated structure factors on $10 \times$ absolute scale.

Unobserved reflexions are denoted by * and those obscured by the beamstop by -.

H	F _o	F _c	H	F _o	F _c	H	F _o	F _c	H	F _o	F _c	H	F _o	F _c	H	F _o	F _c	H	F _o	F _c
K=0, L=0		2 262	259	9 125	130	3 69	57	-10 65	85	13 24*	27	K=13, L=2	-7 30*	28	3 153	140				
0 - 3240		3 116	127	10 145	160	4 67	51	K=7, L=1	14 22*	23	0 54	76	-8 30*	31	4 51	44				
1 - 145	4 19*	27	11 89	104	5 31	38	-1 49	43	15 19*	46	K=0, L=2	-9 59	66	5 67	54					
2 460	513	5 251	237	12 78	101	K=13, L=1	-2 111	127	-2 111	127	K=3, L=2	-1 34	63	-10 59	67					
3 341	325	6 96	103	13 49	53	0 45	44	-3 209	239	0 270	248	K=9, L=2	-3 351	329	8 70	66				
4 511	498	7 23*	21	K=4, L=1	1 65	71	-4 136	142	1 402	339	-4 94	80	-2 30*	20	9 64	49				
5 328	389	8 66	66	0 467	440	K=0, L=1	-5 120	135	2 421	351	-5 237	257	-3 84	90	10 64	52				
6 104	71	9 67	56	1 487	462	-1 -	685	-6 171	188	3 324	353	-6 202	175	-4 59	19	11 26	20			
7 339	323	K=8, L=0	2 352	323	-2 194	214	-7 24*	19	4 240	274	-7 22*	30	-5 105	113	12 34	32				
8 150	123	0 341	323	3 216	180	-3 583	594	-8 49	69	5 46	74	-9 27*	28	-7 59	36	13 12	22			
9 127	123	1 172	178	4 318	364	-4 367	357	-9 118	125	6 92	98	-9 259	254	-7 73	66	14 17	173			
10 44	48	2 145	147	5 116	77	-5 13*	38	-10 51	51	7 105	135	-8 30*	20	11 12	22	K=6, L=3				
11 46	31	3 162	159	6 240	267	-6 194	187	-11 49	45	8 113	118	K=1, L=2	-8 30*	20	1 81	76				
K=1, L=0		4 112	114	7 127	140	-7 127	140	-12 33	28	9 111	147	-1 -	261	-9 57	57	2 199	176			
1 393	589	5 162	161	8 120	133	-8 341	359	K=8, L=1	10 59	77	-2 367	281	-10 57	52	3 73	66				
2 493	429	6 119	106	9 223	236	-9 22*	7	-1 116	111	11 73	78	-3 146	115	K=10, L=2	4 115	98				
3 557	472	7 23*	25	10 59	77	-10 125	115	-2 176	211	K=4, L=2	-4 162	144	-1 30*	52	5 17*	23				
4 684	656	8 25*	24	11 51	15	-11 82	72	-3 73	93	0 237	240	-5 321	295	-2 59	46	6 49	34			
5 44	59	9 137	138	12 49	41	-12 24*	14	-4 85	88	1 488	462	-6 493	409	-3 30*	46	7 66	48			
6 139	144	K=9, L=0	13 65	65	-13 51	35	-13 51	35	-5 147	147	2 159	131	-7 140	138	-4 62	34	8 72	76		
7 112	110	1 154	171	14 58	39	-14 67	49	-6 111	114	3 146	134	-8 205	184	-5 32*	39	9 31	19			
8 293	276	2 42	53	K=5, L=1	0 157	186	-1 -	595	-7 114	125	4 138	134	-9 27*	28	-6 32*	13	10 28	23		
9 46	28	3 23*	47	1 134	314	-2 492	442	-9 51	61	6 102	139	-10 138	114	-7 59	36	11 12	22			
10 23*	26	4 64*	87	2 118	87	-3 441	405	-10 78	63	7 97	130	-11 70	47	K=11, L=2	12 23	17				
11 114	95	5 121	133	3 231	221	-4 534	499	-11 36	25	8 116	175	K=2, L=2	-1 143	110	-1 59	61	K=7, L=3			
12 62	55	6 25*	36	4 142	149	-5 452	424	-12 24*	30	9 30*	44	-2 396	331	-3 30*	24	1 72	54			
K=2, L=0		7 25*	15	5 249	292	-6 114	125	K=9, L=1	10 30*	53	10 30*	53	-3 111	77	2 132	19				
0 177	133	8 123	121	6 247	92	-7 298	314	-7 29*	43	11 76	30*	-4 280	250	-5 30*	29	3 126	109			
1 353	130	9 23*	52	7 105	103	-8 100	91	-2 47	63	12 67	77	-5 213	196	-6 57	59	4 60	51			
2 281	283	0 23*	21	8 125	141	-9 167	207	-3 87	105	K=5, L=2	-6 57	44	-6 57	44	5 34	17				
3 541	495	1 23*	51	9 49	42	-10 85	84	-4 111	119	0 391	375	-7 191	176	-1 57	68	6 93	79			
4 324	265	2 66	62	10 85	101	-11 76	59	-5 49	54	1 227	204	-8 59	42	-2 30*	35	7 55	40			
5 75	73	3 23*	57	11 27*	25	-12 91	85	-6 129	139	2 170	177	-9 89	79	-3 30*	25	8 32	13			
6 116	110	4 94	94	12 47*	47	-13 27*	33	-7 24*	43	3 462	90	-10 81	77	-5 77	67	9 69	37			
7 137*	144*	5 25*	43	13 22*	47	-14 33	32	-8 27*	39	4 251	280	-11 70	58	-5 54	50	10 31	32			
8 146	152	6 25*	43	14 38	49	K=2, L=1	-1 881	786	-9 85	89	5 86	94	-12 97	85	K=13, L=2	11 24	28			
9 64	65	7 23*	12	K=6, L=1	0 165	152	-2 231	227	-1 69	82	6 100	130	K=3, L=2	-1 27*	21	K=8, L=3				
10 172	140	8 23*	55	1 138	182	-3 229	201	-2 49	57	7 30*	68	-1 151	153	-2 51	42	0 87	66			
11 129	102	9 62	48	2 183	198	-4 345	347	-3 91	92	8 30*	48	-2 86	105	K=0, L=3	0 156	173				
12 33*	22	K=11, L=0	3 200	214	-5 347	308	-4 49	67	10 43	45	-4 132	98	1 155	163	3 69	60				
13 79	62	1 25	51	4 100	99	-6 252	221	-5 69	63	11 40	62	-5 100	101	2 87	90	4 34	32			
K=3, L=0		2 94	102	5 102	106	-7 224	112	-6 24*	35	K=6, L=2	-6 105	122	-3 118	120	5 161	134				
1 218	194	3 25*	45	6 176	197	-8 247	152	-7 27*	17	0 46	69	-7 65	72	4 217	222	6 41	28			
2 312	313	4 25*	44	7 47	54	-9 111	110	-8 45	60	1 129	110	-8 129	110	-6 17*	16	7 24	26			
3 220	210	5 23*	45	8 49	48	-10 47	34	-9 49	35	2 89	95	-9 127	125	6 58	53	8 60	59			
4 179	170	6 25*	45	9 69	80	-11 145	144	-10 65	61	3 183	214	-10 102	103	7 64	66	9 37	35			
5 50	24	7 69	55	K=12, L=0	-12 69	71	K=11, L=1	-1 49	57	4 51	35	-11 84	59	8 72	61	10 37	37			
6 125	159	8 81	85	0 114	104	K=3, L=1	-1 300	323	-2 49	57	5 94	98	K=4, L=2	-1 305	279	9 89	93			
7 324	298	1 66	64	1 214	264	-2 196	209	-3 49	57	6 24	117	-2 332	295	K=1, L=3	0 265	314				
8 108	92	2 46	38	2 258	285	-3 89	32	-4 27*	26	7 30*	28	-2 245	232	K=0, L=3	1 34	37				
9 160	153	0 -	397	3 229	249	-4 176	162	-5 51	62	8 10*	56	-3 97	90	1 47	46	3 35	24			
10 110	102	1 -	792	4 71	87	5 85	100	-5 165	176	9 73	70	-4 307	279	2 61	46	4 93	68			
11 129	122	2 85	94	5 85	100	-6 85	83	-6 85	83	K=7, L=2	0 73	86	-5 73	68	3 254	269	4 93	68		
12 114	102	3 91	58	6 73	83	-7 136	122	-7 136	122	K=12, L=1	0 73	86	-6 57	77	4 201	193	5 40	25		
13 91	70	4 200	190	7 76	82	-8 102	87	-8 49	68	1 100	108	-7 24*	61	5 116	113	6 86	77			
14 77	52	5 69	85	8 49	48	-9 78	94	-3 49	43	2 119	162	-8 183	168	6 173	160	7 24	26			
K=4, L=0		6 62	59	9 36	46	-10 122	85	K=0, L=2	4 27*	53	3 94	98	-9 67	55	7 145	129	8 32	34		
0 173	178	7 138	155	0 71	78	-11 85	71	0 -	114	4 27*	53	-10 100	90	8 86	77	9 51	61			
1 10*	64	8 40	34	1 109	125	-12 69	53	1 178	133	5 57	31	-11 30*	47	9 43	39	K=10, L=3				
2 127	151	9 65	60	2 224	24	-13 24*	40	2 310	260	6 78	94	-12 32*	43	10 87	93	0 57	42			
3 139	143	10 27	79	3 105	121	-14 49	52	3 167	178	7 30*	35	-13 40	54	11 31	29	1 86	69			
4 185	182	11 91	101	4 71	76	-15 42	43	4 121	110	8 59	58	K=5, L=2	-1 70	62	K=2, L=3	2 89	71			
5 224	216	12 19	119	5 82	81	-16 114	129	5 117	114	9 30*	32	-1 70	62	0 179	204	3 78	78			
6 44	30	13 49	25	6 114	129	-1 142	137	6 84	75	10 57	75	-2 54	65	1 201	211	4 58	51			
7 204	213	14 29	141	7 47	54	-2 96	74	7 116	113	K=8, L=1	0 51	40	-3 394	375	2 58	62	5 64	57		
8 69	52	15 13	139	8 49	48	-3 289	279	8 65	50	1 100	108	-4 92	94	3 141	177	6 28	21			
9 135	146	16 19	165	9 36	47	-4 89	84	9 57	44	1 54	69	-5 197	207	4 242	233	7 24	26			
10 193	195	17 30	200	K=9, L=1	-5 129	96	-5 129	96	10 73	93	2 121	122	-6 129	126	5 149	145	8 21	17		
11 81	67	18 45	219	0 136	134	-6 180	162	11 43	51	3 108	113	-7 105	113	6 83	66	9 20	24			
12 25*	8	19 58	236	1 47	50	-7 111	128	12 57	65	4 57	52	-8 38	65	7 181	159	K=11, L=3				
13 23*	10	20 73	255	2 24*	24	-8 40	30	13 38	47	5 30*	28	-9 94	77	8 58	41	0 32	29			
14 58	50	21 86	273	3 82	84	-9 22*	34	14 24*	23	6 78	94	-10 30*	11	9 70	65	1 52	30			
15 44	37	22 99	292	4 118	111	-10 138	140	15 30	53	7 32*	11	-11 40	31	10 34	30	2 78	59			
16 104	112	23 112	311	5 69	90	-11 91	94	K=1, L=2	8 70*	86	8 70*	86	-12 40	39	11 51	65	3 67	59		
17 112	112	24 125	329	6 49	48	-12 51	46	0 313	280	9 70*	86	-12 121	148	12 121	148	4 28	25			
18 127	127	25 138	347	7 24*	44	-13 24*	40	1 294	245	K=9, L=2	0 30*	26	-2 332	2						

Table 2 (cont.)

H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c	H F ₀ P _c
-13 17* 18	-8 95 113	-6 115 99	-6 24 15	-3 21 26	K=5, L=4	K=0, L=4	-7 47 46	-10 26* 22	
-14 29 20	-9 17* 14	-7 66 66	-7 34 28	-4 26 20	0 24* 21	-1 71 58	-8 60 54	-11 44 44	
-15 18* 6	-10 63 67	-8 17* 20	-8 46 30	-5 20 25	1 86 98	-2 64	-9 26* 25	K=7, L=4	
-16 14* 6	-11 58 59	-9 67 45	-9 31 24	K=0, L=4	2 94 92	-3 133 118	-10 52 50	-1 26* 47	
K=1, L=3	-12 55 41	-10 83 78	-10 15* 10	0 180 194	3 58 73	-4 73 90	-11 26* 24	-2 68 66	
-1 66 82	-11 49 34	-11 40 36	-11 31 27	1 26 10	4 26* 12	-5 50 63	-12 34 28	-3 68 60	
-2 90 107	-14 28 31	-12 31 27	-12 11* 12	2 21* 16	5 26* 8	-6 21* 39	K=4, L=4	-4 26* 7	
-3 130 151	-15 12* 2	-13 28 20	-13 12 26	3 123 157	6 60 80	-7 94 116	-1 52 47	-5 60 63	
-4 41 29	-16 14 18	-14 11* 9	K=10, L=3	4 47 74	K=6, L=4	-8 99 104	-2 61 67	-6 26* 31	
-5 96 97	K=4, L=3	-15 12 14	-1 64 49	5 60 61	0 50 35	-9 26* 50	-3 94 95	-7 63 62	
-6 77 92	-1 83 72	K=7, L=3	-2 93 76	K=1, L=4	1 34 22	-10 26* 20	-4 31 40	-8 37 36	
-7 84 107	-2 77 74	-1 198 166	-3 24 20	0 89 62	2 50 38	-11 26* 7	-5 63 64	-9 26* 16	
-8 77 95	-3 196 193	-2 150 137	-4 24 13	1 92 72	3 37 33	-12 60 53	-6 24* 32	-10 44 52	
-9 78 96	-4 100 84	-3 51 31	-5 34 23	2 120 105	4 52 58	K=1, L=4	-7 50 43	K=8, L=4	
-10 51 40	-5 96 107	-4 52 45	-6 23 30	3 44 55	5 37 44	-1 112 104	-8 37 38	-1 26* 25	
-11 41 45	-6 73 79	-5 17* 26	-7 31 18	4 78 90	6 26* 33	-2 29 23	-9 37 22	-2 26* 30	
-12 24 11	-7 72 82	-6 136 113	-8 37 32	5 84 99	7 31 44	-3 107 95	-10 37 26	-3 86 83	
-13 40 34	-8 32 27	-7 69 66	-9 38 26	6 50 58	K=7, L=4	-4 102 116	-11 26* 16	-4 50 47	
-14 21 19	-9 86 93	-8 64 59	-10 12* 15	K=2, L=4	0 37 17	-5 65 94	-12 31 23	-5 26* 17	
-15 12* 8	-10 34 35	-9 63 61	-11 11* 1	0 128 112	1 37 19	-6 29 22	-13 29 15	-6 52 64	
-16 18 21	-11 18* 16	-10 34 27	-12 12 26	1 21* 21	2 52 52	-7 84 75	K=5, L=4	-7 34 43	
K=2, L=3	-12 52 48	-11 38 36	K=11, L=3	2 81 86	3 50 54	-8 63 74	-1 58 37	-8 24* 5	
-1 220 249	-13 47 41	-12 14* 7	-1 69 60	3 118 135	4 52 61	-9 37 27	-2 99 86	-9 31 40	
-2 133 150	-14 32 19	-13 12* 7	-2 55 47	4 89 101	5 50 67	-10 26* 11	-3 44 52	K=9, L=4	
-3 122 134	-15 21 18	-14 18 19	-3 17* 9	5 92 121	K=8, L=4	-11 52 50	-4 31 22	-1 26* 22	
-4 93 95	K=5, L=3	K=8, L=3	-4 31 19	6 50 53	0 86 85	-12 34 23	-5 86 84	-2 71 71	
-5 122 142	-1 135 131	-1 92 83	-5 52 55	7 37 51	1 52 57	K=2, L=4	-6 26* 34	-3 26* 8	
-6 122 170	-2 176 182	-2 83 58	-6 29 25	K=3, L=4	2 52 48	-1 105 87	-7 60 68	-4 50 35	
-7 121 152	-3 78 73	-3 83 62	-7 35 39	0 199 180	3 26* 2	-2 99 102	-8 26* 9	-5 26* 23	
-8 75 91	-4 210 226	-4 46 30	-8 34 32	1 60 38	4 60 76	-3 50 59	-9 26* 43	-6 24* 20	
-9 63 57	-5 64 51	-5 87 65	-9 12* 8	2 115 129	K=9, L=4	-4 131 149	-10 37 41	-7 24* 16	
-10 51 59	-6 141 153	-6 44 38	-10 12 14	3 102 109	0 50 54	-5 78 84	-11 24* 11	-8 29 20	
-11 17* 28	-7 112 105	-7 18* 11	K=12, L=3	4 81 91	1 50 54	-6 110 118	K=10, L=4	-9 34 43	
-12 43 40	-8 66 72	-8 18* 11	-1 35 35	5 86 97	2 24* 12	-7 44 56	-12 21* 20	-1 47 55	
-13 32 26	-9 43 33	-9 41 37	-2 28 29	6 89 122	3 47 53	-8 34 16	-13 26 22	-2 24* 27	
-14 15* 11	-10 41 32	-10 38 28	-3 20 14	7 50 87	4 24* 27	-9 26* 18	K=6, L=4	-3 31 44	
-15 35 31	-11 44 37	-11 15* 15	-4 46 46	K=4, L=4	5 50 69	-10 26* 34	-1 105 84	-4 24* 24	
K=3, L=3	-12 32 29	-12 12* 9	-5 43 42	0 63 30	K=10, L=4	-11 52 47	-2 107 104	-5 24* 12	
-1 24 29	-13 35 26	-13 20 12	-6 38 33	1 112 106	0 24* 17	K=3, L=4	-3 50 46	-6 29 41	
-2 122 115	K=6, L=3	K=9, L=3	-7 11* 12	2 31 41	1 44 47	-1 220 207	-4 60 51	K=11, L=4	
-3 63 55	-1 118 118	-1 64 57	-8 9* 2	3 118 118	2 42 36	-2 86 69	-5 60 61	-1 21* 41	
-4 100 125	-2 132 118	-2 49 25	-9 12 20	4 84 85	3 21* 30	-3 21* 11	-6 102 114	-2 29 46	
-5 87 90	-3 175 179	-3 87 67	K=13, L=3	5 50 69	4 37 54	-4 21* 16	-7 26* 33	-3 21* 14	
-6 90 75	-4 107 94	-4 24 16	-1 38 39	6 26* 54	K=11, L=4	-5 99 89	-8 26* 34	-4 18* 24	
-7 121 148	-5 135 128	-5 24 25	-2 12* 15	7 50 52	0 39 49	-6 55 66	-9 37 47	-5 26 35	

Table 3. Intercomparison of mean bond lengths

Type of bond	Present analysis	Literature value	Reference
S-S	2.02 (1) Å	2.04 (1)	Tables of Interatomic Distances (1958)
S-C	1.78 (3)	1.81 (1)	International Tables (1962)
C-C	1.53 (5)	1.54 (3)	International Tables (1962)
C-N	1.45 (3)	1.47 (1)	International Tables (1962)

The bond lengths and their e.s.d.'s and the atomic nomenclature are given in Fig. 3(a). Bond angles and their e.s.d.'s are given in Fig. 3(b) together with the distances between the atoms and the plane chosen to pass through the centres of the S-S bonds in such a way that the sum of these distances is zero. Averaged equivalent bond lengths are also given in Table 3.

Relatively large (0.05 Å) root-mean-square deviations from the mean have been found for equivalent C-C bonds in the present work. The results for two other pyrrolizidine alkaloids, designated thelepogine methiodide (TM) (Fridrichsons & Mathieson, 1963) and

jacobine bromhydrin (JB) (Fridrichsons, Mathieson & Sutor, 1963) which were analysed at -150°C also contain unexpectedly large deviations. These are 0.03 Å for TM and 0.025 and 0.04 Å for the two independent molecules of JB. Intercomparison of bond-lengths and angles in the pyrrolizidine units of CP, TM and JB is, however, not warranted as those in the latter two have one C=C bond each and TM has a quaternary nitrogen atom. By contrast, the pyrrolizidine units in CP are saturated and have ternary nitrogen atoms.

The molecule possesses a non-crystallographic twofold axis which runs through the centres of the two S-S bonds. This follows from the equality of corresponding out-of-plane displacements (to 0.06 Å) and bond angles (to 4°), as shown in Fig. 3(b), and bond lengths (to 0.09 Å) as shown in Fig. 3(a). These differences from exact twofold symmetry are clearly mainly a result of experimental inaccuracies rather than packing forces and are not statistically significant. The four sulphur and four carbon atoms in the central part of the molecule form a 1,2,4,6-tetrathiooctane ring system. This is the first determination of the structure of such a ring system.

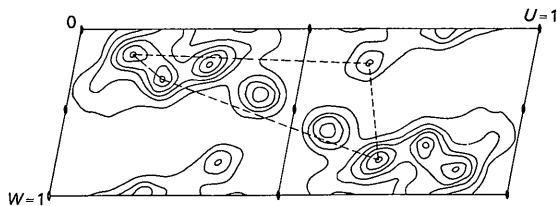


Fig. 2. [010] Patterson projection.

The geometry of the pyrrolizidine units is best described as two pyrrolidine rings which come into coincidence when one is rotated about its common C-N bond by $123 \pm 1^\circ$. Each pyrrolidine ring consists of four essentially planar atoms, *e.g.* N(1), C(6), C(7), and C(2) with the fifth displaced by $0.59 \pm 0.04 \text{ \AA}$ from the plane. The mean out-of-plane displacement of the sets of four nearly planar atoms is $0.03 \pm 0.02 \text{ \AA}$. The senses of these displacements are as follows: C(1) and C(11) below and C(4) and C(14) above the planes of the pyrrolizidine rings.

The stereochemistry of one possible enantiomorph of CP is given in Fig. 4. Its absolute configuration has not been determined experimentally, but by comparison with models made of the corresponding pyrrolizidine rings in the pyrrolizidine units in TM and JB whose absolute configurations have been determined, it can be deduced that the naturally occurring enantiomorph is very probably the mirror image of that given here.

Analysis of the rigid-body thermal motion has not been undertaken as the low accuracy of the data seemed not to warrant further processing.

Molecular packing

The molecules are arranged as shown in Fig. 5 with each stack having its axis parallel to *c* and surrounded by six other stacks. Contact between molecules is exclusively by van der Waals interactions as evidenced by the distances listed in Table 4.

Table 4. Intermolecular distances $< 4 \text{ \AA}$ with their *e.s.d.*'s. (bracketed) in 0.01 \AA

The Roman numerals represent the symmetry operators relevant to the atoms listed second.

Atom in parent molecule	Atom in symmetry related molecule	Symmetry operator index	Interatomic distance (\AA)
S(1)	C(11)	III	3.73 (3)
S(1)	C(12)	III	3.95 (3)
S(1)	C(12)	IV	3.96 (4)
S(1)	C(13)	II	3.88 (3)
S(2)	C(2)	I	3.99 (3)
S(2)	C(12)	IV	3.84 (4)
S(2)	C(13)	IV	3.91 (3)
S(3)	C(4)	VI	3.83 (3)
S(3)	C(6)	I	3.85 (2)
S(3)	N(1)	I	3.85 (2)
S(4)	C(4)	V	3.91 (4)
S(4)	C(5)	V	3.79 (3)
S(4)	C(9)	II	3.85 (3)
S(4)	N(2)	II	3.91 (2)
C(3)	C(4)	II	3.91 (5)
C(4)	C(10)	VII	3.75 (5)
C(7)	N(1)	I	3.56 (3)
C(8)	N(2)	II	3.50 (3)
C(9)	C(5)	VI	3.89 (4)
C(10)	C(5)	VI	3.99 (4)

Index	Symmetry operator
I	(<i>x</i> , <i>y</i> , $1+z$)
II	(<i>x</i> , <i>y</i> , $-1+z$)

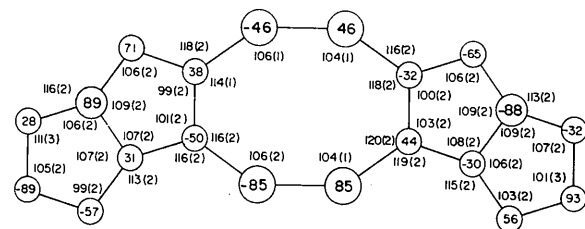
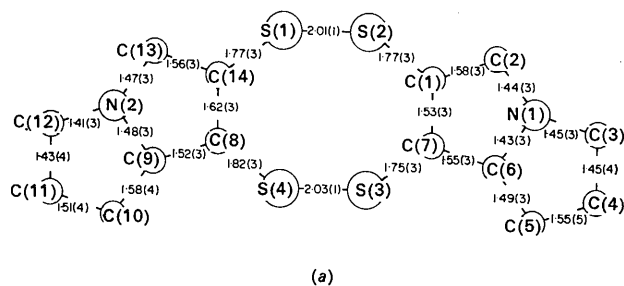


Fig. 3. (a) Atomic nomenclature and bond lengths, in \AA , with their *e.s.d.*'s (bracketed) in 0.01 \AA . (b) Bond angles and their *e.s.d.*'s (bracketed), in degrees, together with normal distances from the mean plane in 0.01 \AA .

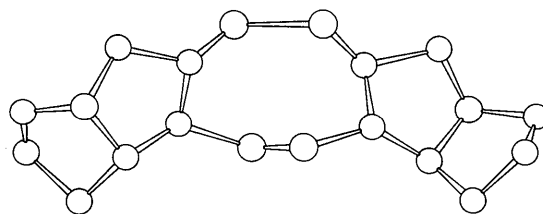


Fig. 4. Perspective view of cassipourine.

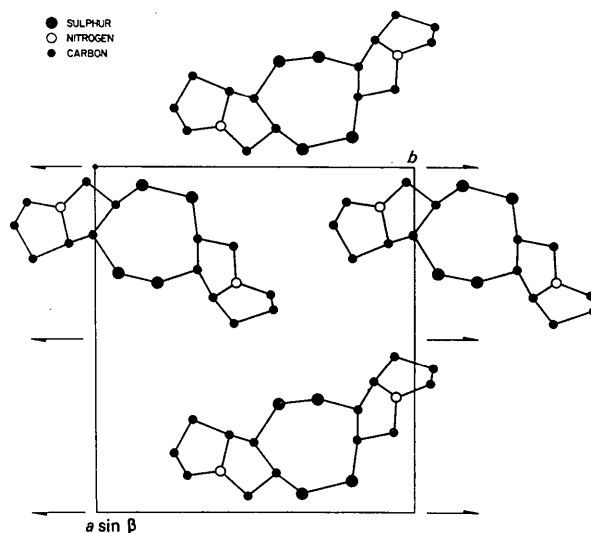


Fig. 5. Packing of molecules in $[001]$ projection.

Table 4 (cont.)

Index	Symmetry operator			
III	($-x,$	$\frac{1}{2}+y,$	$-z)$
IV	($-x,$	$\frac{1}{2}+y,$	$1-z)$
V	($1-x,$	$-\frac{1}{2}+y,$	$-z)$
VI	($1-x,$	$-\frac{1}{2}+y,$	$1-z)$
VII	($x,$	$1+y,$	$z)$

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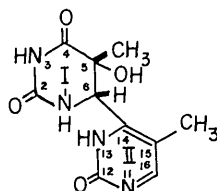
Crystal Structure of a Thymine-Thymine Adduct from Irradiated Thymine

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Thymine irradiated in a frozen aqueous solution with ultraviolet light produces not only dimers which are cyclobutane derivatives but also a racemic thymine-thymine adduct,



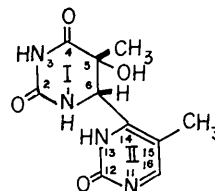
5 α -hydroxy-6 α -4'-[5'-methylpyrimidin-2'-one]-dihydrothymine (one of the antipodes). The material crystallizes with one molecule of H₂O in the triclinic space group *P* $\bar{1}$, with *Z* = 2 and *a* = 9.44 ± 0.02, *b* = 8.29 ± 0.02, *c* = 7.57 ± 0.02 Å; α = 99.0 ± 0.25°, β = 91.5 ± 0.25° and γ = 89.8 ± 0.25°. The structure was solved by obtaining phases directly from the structure factor magnitudes with the use of the symbolic addition procedure. Ring I has the half-chair conformation while ring II is planar. The CH₃ group on C(5) and ring II are both axial to ring I while the OH group on C(5) and the H atom on C(6) are equatorial. The dihedral angle between the planes of rings I and II is ~96°. An extensive system of hydrogen bonding between the three C=O groups, the OH, two of the NH groups and the H₂O molecule binds the molecules together in the crystal.

Introduction

Ultraviolet irradiation of frozen aqueous solutions of thymine and of deoxyribonucleic acid (DNA) has yielded cyclobutane-type dimers of thymine (Wang, 1960, 1961; Beukers, IJlstra & Berends, 1960). Of the four possible cyclobutane-type dimers (Wulff & Fraenkel, 1961; Weinblum & Johns, 1966), detailed crystal structure analyses have been performed for the *syn* 5,5:6,6 type (Camerman & Camerman, 1968; Wei & Einstein, 1968; Adman, Gordon & Jensen, 1968), for the *syn* 5,6:5,6 type (Camerman, Weinblum & Nyburg, 1968) and the *anti* 5,6:5,6 type (Camerman, Nyburg & Weinblum, 1967; Einstein, Hosszu, Longworth, Rahn & Wei, 1967).

A different kind of thymine-thymine product has been isolated from an ultraviolet-irradiated frozen so-

lution of thymine (Varghese & Wang, 1968). Spectroscopic evidence supported the adduct structure:



The X-ray diffraction analysis confirmed the structural formula with the possibility that an H atom exists on N(13) rather than N(11), and established the stereo-configuration of the molecule. This type of photoreaction may be of considerable significance in the photobiology of nucleic acids. A preliminary account of the