STRUCTURE OF LEHMANNINE N-OXIDE

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The molecular and crystal structure of lehmannine in its monohydrate has been studied by x-ray structural analysis. Rings A, B, and C have the chair form and ring D the half-chair form in which the deviations of the atoms from their mean-square plane does not exceed 0.06 Å.

Lehmannine N-oxide was first isolated from the plant *Ammonthamnus lehmannii* Bge. and has the composition $C_{15}H_{22}O_2N_2$, mp 136°C (acetone—ethanol). On reduction with sodium hydrosulfite, it is converted into lehmannine.

The alkaloid lehmannine itself $C_{15}H_{22}ON_2$ was also isolated from the same plant, and, on the basis of spectral characteristics and chemical transformations, the most probable structure of 12,13-dehydromatrine has been suggested for it [1]. Lehmannine is still the only representative of the matrine alkaloids where the double bond is located at C(12)—C(13). For a definitive proof of the structure of lehmannine N-oxide we have used the method of x-ray structural analysis.

The molecule of lehmannine N-oxide (Fig. 1) differs from that matrine N-oxide [2] only by the appearance of a double bond between the C(12) and C(13) atoms in ring D. This determines the similarity of the conformations of these molecules — the forms of rings A, B, and C and their linkages are the same as in matrine N-oxide: A/B-trans, A/C-cis, B/C-cis. The six-membered ring D is planar, in contrast to the half-chair conformation that it possesses in all the other compounds of the matrine series that have been studied [2-4], the maximum deviations of the atoms from the mean-square plane being ±0.05 Å (Table 1). The deviations of the C(2) and C(5) atoms in the chair of ring A are 0.73 and 0.61 Å, the first of these values being the "ideal" value [5]. Judging from the departures of the atoms from the plane of the "basis" atoms of the rings, rings B and C are less "ideal"; the C(7) and N(16) atoms deviate by 0.66 Å and the C(10) and C(6) by 0.70 and 0.60 Å, respectively, from the plane of rings B and C. The planes of rings A and B are parallel, the angle between them being 0.9°, while the plane of ring C is almost normal to the planes of rings A and B: the angles amount to 87.9 and 87.2°, respectively. These angles agree well with the angles found in matrine N-oxide. The angle of inclination of the plane of ring D relative to the plane of ring C is 57.2°. The degrees of deformation of rings A, B, and C in lehmannine and matrine N-oxides are of the same order of magnitude, as is confirmed by the values of the torsional angles (Fig. 1a). The greatest deviations from the ideal value of ±60° [6] are observed in ring C, while in rings A and B the corresponding deviations are somewhat less and are practically the same. The symmetrical (relative to the A, B, C fragment) shortening of the distance between the non-valence-bound atoms and the symmetrical distribution of the torsional angles indicate that, in contrast to matrine N-oxide, the deformation in the rings of the lehmannine N-oxide molecule is distributed uniformly. The O(2)—C(11) and O(2)—C(17) distances are equal to one another, amounting to 2.96 Å.

The mean values of the lengths of the $C(sp^3)$—$C(sp^3)$ and N(1)—$C(sp^3)$ bonds are 1.53 Å each and agree with the values in the other alkaloids of the matrine [2-4] and sparteine series [7]. The C(12)—C(13) double bond, with a length of 1.29 Å, and the C(13)—C(14) $C(sp^3)$—$C(sp^2)$ bond, with a length of 1.45 Å, are shortened in comparison with the "standard" values [8]. It follows from Table 2 that the greatest thermal vibrations are possessed by the peripheral atoms, particularly the C(12) and C(13) atoms. The marked shortening of the

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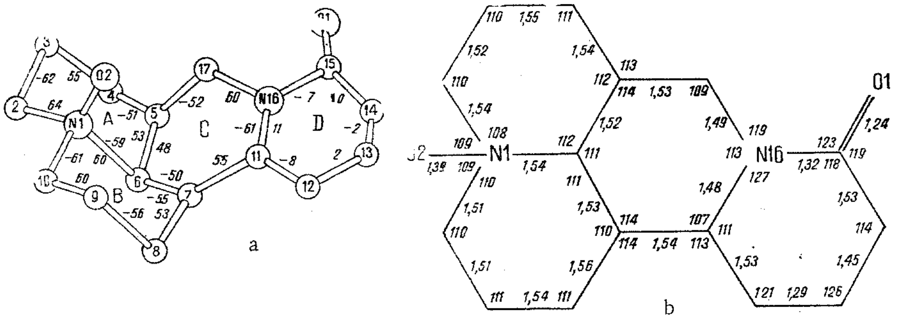

Fig. 1. Lehmannine N-oxide molecule: a) conformation in the crystal, giving the torsional angles; b) bond lengths and values of the valence angles.

TABLE 1. Coefficients of the Equations of the Planes and the Deviations of the Atoms δ from these Planes in the Structure of Lehmannine N-Oxide

Plane	Atom	Coefficients of the equations of the planes				δ, Å
		A	B	C	D	
I (ring *A*)	N(1)	7,20	−3,47	−10,14	−1,25	−0,019
	C(3)					0,019
	C(4)					−0,019
	C(6)					0,019
	C(2)*					0,729
	C(5)*					−0,610
II (ring *B*)	N(1)	7,20	−3,37	−10,34	−1,20	−0,010
	C(6)					0,010
	C(8)					−0,010
	C(9)					0,010
	C(7)*					−0,656
	C(10)*					0,700
III (ring *C*)	C(5)	4,72	−1,48	16,44	3,60	−0,003
	C(7)					0,003
	C(11)					−0,003
	C(17)					0,003
	N(16)*					0,662
	C(6)*					−0,606
IV (ring *D*)	C(11)	8,32	−4,29	1,02	−1,27	0,057
	C(12)					−0,021
	C(13)					−0,023
	C(14)					0,040
	C(15)					0,007
	N(16)					−0,052

*Atoms not included in the calculation of the equations of the planes.

C(12)—C(13) and C(13)—C(14) bonds apparently takes place because of the large thermal vibrations of these atoms. The length of the C(15)—O(1) bond is 1.24 Å, which coincides with the values found in the two molecules of sophoridine N-oxide present in its elementary cell [9].

The valence angles at the tetrahedral carbon atoms are close to the usual values, with the exception of all the exocyclic angles and the angles in ring C at the C(5) and C(7) atoms, which are increased to 113-114°. The equality of the C(6) C(5) C(17) and C(6) C(7) C(11) angles shows that the steric hindrance in the molecule is partially resolved through identical Bayer increases in these angles. The distribution of the angles at C(15) and N(16) atoms is precisely the same as in matrine. The valence angles in ring D are close to 120°, the greatest deviations from this magnitude being observed about the C(11) atom (Fig. 1b).

In the crystal structure of lehmannine N-oxide (Fig. 2), the molecule of water of crystallization unite the molecules of the N-oxide into helices parallel to [001]. The O(W). . . O(1) and O(W). . .O(2) hydrogen bonds have lengths of 2.88 and 2.71 Å, respectively. The helices are connected with one another by van der Waals contacts which have the normal lengths.

TABLE 2. Ellipsoids of the Thermal Vibrations of the Nonhydrogen Atoms and Their Orientation Relative to the Crystallographic Axes in the Structure of Lehmannine N-Oxide (the lengths of the semiaxes of the ETVs are multiplied by 10^3)

Atom	Semi-axes of the ETV, Å	Angle, degrees			Atom	Semi-axes of the ETV Å	Angle, degrees		
		a, j	*b, j*	*c, j*			*a, j*	*b, j*	*c, j*
N(1)	381	136	125	66	C(11)	460	28	116	80
	315	127	37	87		360	86	60	30
	298	70	78	24		364	118	139	62
	396	53	140	77		818	32	122	85
C(2)	371	55	52	57	C(12)	444	77	60	33
	333	124	101	36		262	119	134	58
	480	147	61	75		893	45	135	89
C(3)	352	57	47	61	C(13)	445	56	55	53
	328	94	123	33		356	116	115	37
	444	32	122	84		451	15	84	77
C(4)	386	101	96	12	C(14)	428	99	15	78
	319	60	32	79		352	101	103	18
	416	138	81	50		443	38	52	88
C(5)	335	74	144	59	C(15)	340	85	99	11
	300	53	56	56		330	127	39	79
	382	134	96	44		461	24	113	83
C(6)	326	78	23	70	N(16)	327	106	112	28
	273	46	112	52		291	73	33	63
	471	137	87	47		416	13	102	84
C(7)	342	51	111	46	C(17)	345	98	100	13
	282	74	21	77		295	80	16	78
	494	144	102	57		576	161	71	89
C(8)	409	54	103	39	O(1)	434	106	146	60
	297	92	18	73		319	80	62	30
	480	141	73	56		394	61	38	67
C(9)	369	78	137	50	O(2)	334	105	108	23
	319	53	52	59		283	33	133	87
	440	115	133	53		141	100	137	49
C(10)	395	26	102	67	O(W)	386	68	558	43
	300	98	46	45		3[illegible]0	155	67	80

The numerical values of the ETVs are to be read on three lines.

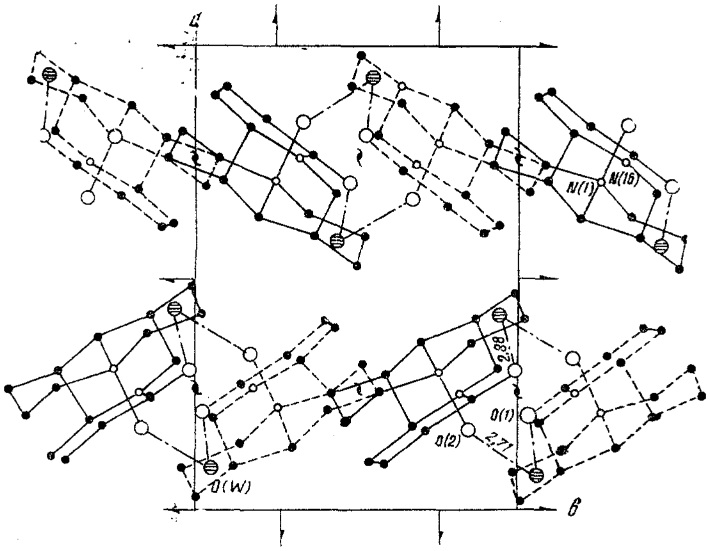

Fig. 2. Packing of the lehmannine N-oxide molecules.

EXPERIMENTAL

Single crystals of lehmannine N-oxide were grown from solution in acetone and had a prismatic habitus. The parameters of the rhombic elementary cell were measured and refined

TABLE 3. Coordinates and Parameters of the Anisotropic Thermal Vibrations of the Nonhydrogen Atoms in the Structure of Lehmannine N-Oxide (all values have been multiplied by 10^4; the standard deviations are given in parentheses)

Atom	x/a	y/b	z/c	B (11)	B (22)	B (33)	B (12)	B (23)	B (13)
N (1)	2883 (4)	7474 (5)	736 (2)	91 (5)	167 (8)	23 (1)	39 (12)	−4 (6)	−13 (4)
C (2)	3771 (5)	8575 (7)	252 (3)	114 (6)	214 (12)	31 (2)	−29 (18)	9 (8)	11 (6)
C (3)	4103 (6)	274 (7)	606 (3)	124 (7)	199 (12)	28 (2)	−27 (17)	11 (8)	4 (6)
C (4)	4871 (5)	9263 (7)	1295 (3)	134 (7)	197 (12)	33 (19)	−92 (13)	−11 (6)	−2 (5)
C (5)	4129 (7)	8699 (6)	1781 (3)	117 (7)	133 (10)	33 (2)	−47 (15)	−5 (7)	−21 (6)
C (6)	3671 (5)	7057 (6)	1402 (2)	94 (6)	165 (10)	26 (2)	35 (14)	−1 (7)	−19 (5)
C (7)	2884 (6)	5854 (7)	1889 (3)	148 (8)	137 (10)	36 (2)	−28 (16)	1 ([illegible])	−53 (7)
C (8)	2441 (6)	4191 (7)	1499 (3)	173 (8)	144 (11)	44 (2)	11 (17)	−30 (9)	−31 (8)
C (9)	1702 (6)	4645 (7)	817 (3)	151 (8)	177 (11)	38 (19)	−45 (18)	−17 (7)	−32 (7)
C (10)	2539 (5)	5798 (7)	357 (2)	122 (7)	203 (11)	32 (2)	37 (14)	−55 (7)	−3 (7)
C (11)	1772 (6)	6805 (7)	2290 (2)	159 (7)	172 (10)	30 (2)	−97 (17)	8 (9)	18 (6)
C (12)	1011 (9)	5629 (9)	2796 (3)	464 (16)	387 (17)	32 (2)	−550 (16)	31 (8)	58 (6)
C (13)	1039 (10)	5844 (14)	3448 (4)	485 (16)	787 (26)	34 (3)	−911 (18)	35 (6)	36 (7)
C (14)	1756 (6)	1797 (8)	3826 (3)	169 (8)	275 (13)	29 (2)	−1 (12)	15 (7)	14 (3)
C (15)	2462 (5)	8507 (7)	3342 (2)	139 (7)	191 (11)	30 (2)	91 (19)	1 (6)	2 (3)
N (16)	2364 (5)	8294 (6)	2658 (2)	175 (6)	161 (9)	23 (1)	−84 (15)	12 (6)	5 (5)
C (17)	3008 (6)	9590 (7)	2189 (3)	153 (8)	141 (11)	28 (2)	−42 (16)	−4 (7)	6 (7)
O (1)	3083 (5)	9736 (6)	3612 (2)	263 (8)	279 (10)	30 (1)	−124 (17)	−49 (6)	−7 (5)
O (2)	1722 (3)	8386 (4)	875 (1)	80 (4)	186 (7)	27 (1)	66 (10)	16 (5)	4 (3)
O (W)	4305 (4)	9336 (5)	4832 (2)	113 (4)	236 (9)	39 (1)	17 (12)	−28 (6)	2 (4)

TABLE 4. Coordinates and Isotropic Thermal Parameters of the Hydrogen Atoms in the Structure of Lehmannine N-Oxide (the values of the coordinates are multiplied by 10^3)

Atom	x/a	y/b	z/c	B_j	Atom	x/a	y,b	z,c	B_j
H_2(1)	469	784	15	3,83	H_9(2)	8'	549	91	4 63
H_2(2)	316	889	—14	3 83	H_{10}(1)	134	354	51	4,63
H_3(1)	484	1118	19	4,14	H_{10}(2)	81	549	91	4.63
H_3(2)	324	1095	65	4,14	H_{11}	109	758	188	4,63
H_4(1)	594	933	114	4,41	H_{12}	48	485	253	8,48
H_4(2)	491	1114	160	4 41	H_{13}	77	497	371	10,78
H_5	504	370	269	3,69	H_{14}(1)	139	815	438	5,25
H_6	437	641	119	2,98	H_{14}(2)	253	650	423	5,25
H_7	349	564	225	4,51	H_{17}(1)	338	1068	244	4,09
H_8(1)	176	314	175	4 75	H_{17}(2)	242	1021	181	4,09
H_8(2)	321	352	135	4,75					
H_9(1)	133	353	51	4,63					

on a Syntex-$P2_1$ diffractometer. The main crystallographic characteristics of the crystals were as follows: a = 10.067(2) Å, b = 6.653(1) Å; c = 19.061(4) Å; ρ_{calc} = 1.28 g/cm³; space group $P2_12_12_1$; Z = 4.

A set of reflections was obtained on the above-mentioned diffractometer by the θ/2θ-scanning method using CuK_α radiation monochromatized by refraction from a graphite single crystal up to θ = 52°, 1095 reflections were obtained, of which 909 reflections with $I \geqslant 2\sigma$ were used in the calculations.

A model of the structure was found by the direct method using the Rentgen-75 complex of programms [10]. A total of 1024 sets of phases of the structural amplitudes was calculated, anf E-syntheses were constructed for the 15 best according to statistical estimates. The third in order of the E-syntheses had the minimum R factor of 0.211. All the 18 nonhydrogen atoms were included among the 19 strongest peaks of this synthesis.

The structure was refined by the method of least squares by the programs [11] of the Kristall complex [12]. After a series of isotropic and anisotropic refinements (R = 0.103) of the positions of the nonhydrogen atoms, the positions of the hydrogen atoms were calculated.

The subsequent refinement of the structure was carried out with allowance for the H atoms, for which the positional and isotropic thermal parameters were refined. In the process, as the initial B_j values we took the isotropic thermal parameters of the carbon atoms to which the H atoms were attached.

Table 3 gives the coordinates and anisotropic thermal parameters of the nonhydrogen atoms, and Table 4 the coordinates and isotropic thermal parameters of the hydrogen atoms of the structure at a final R factor of 0.063.

SUMMARY

The molecular and crystal structures of lehmannine N-oxide in its monohydrate have been investigated. Rings A, B, and C have the chair form and ring D the half-chair form in which the deviations of the atoms from their mean-square planes does not exceed 0.06 Å.

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A STUDY OF COMPLEX MIXTURES OF NATURAL SUBSTANCES BY THE DEFOCUSING AND DADI METHODS.

III. COMPONENTS OF THE PROTECTIVE SECRETION OF THE BEETLE *Coccinella septempunctata*

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The composition of the protective secretion of the seven-spot ladybug *Coccinella septempunctata* L. (Coleoptera, Coccinellidae) has been studied by the methods of high- and low-resolution mass spectrometry. By determining the complete genetic link between the ions of a sample of the secretion by the methods of metastable defocussing and the direct analysis of daughter ions (DADI) the presence of the molecular ions of eight substances contained in the secretion has been shown. These components of the secretion have been identified as squalene, cholesterol, cholesta-3,5-diene, palmitic acid, and the alkaloids coccinellin, precoccinellin, and propylein, and a probable structure has been proposed for a base $C_{13}H_{16}N$.

The carnivorous beetle *Coccinella septempunctata* L. (Coleoptera, Coccinellidae, seven-spotted ladybug) is a useful insect in the fight against aphids, coccids, scale insects, and phytophagous mites. The beetle can consume every day, 68 adult lice or 175 larvae, and the larvae of the entomophage even more — 98 and 270, respectively [1].

Ladybugs are protected from their own enemies by an orange-colored lymphatic liquid of extremely pungent smell and with highly repellant properties for certain species of flies [2]. The alkaloids coccinellin and precoccinellin have been obtained previously by the extraction of a large number of seven-spot ladybugs [3-5]. The methodological procedures used in these investigations are specific only for the isolation of substances with a basic nature. Consequently, there is no information on the nature of the other components of the secretion. Continuing a series of scientific investigations [6], we have studied the composition of the protective secretion of this beetle in the native form.

The pattern of the low-resolution mass spectrum depends greatly on the temperature of recording the spectra of the sample, which is connected with the different volatilities of the components making up the composition of the secretion. Figure 1a-c gives mass spectra obtained at 50, 100, and 150°C, respectively. The determination of the complete genetic link between the ions with the aid of the methods of metastable defocussing and the direct analysis of daughter ions (DADI) [7, 8] showed the presence in the spectra of the peaks of the molecular ions of eight substances with m/z 410 (I), 386 (II), 368 (III), 256 (IV), 209 (V), 193 (VI), 191 (VII), and 189 (VIII) which had independent fragmentation pathways. The accurate m/z values of the peaks, determined by high-resolution mass spectrometry, and the elementary compositions of the molecular and some characteristic ions of substances (I-VIII) are given in Table 1.

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