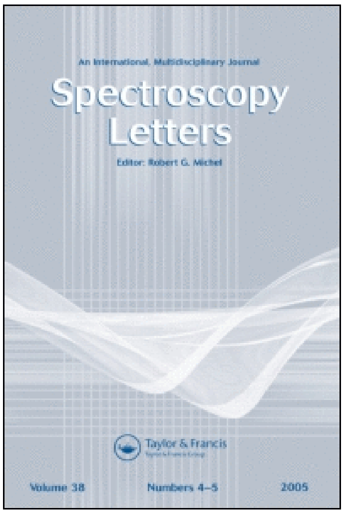

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Comparison Between the IR Spectra and the Structure of the Two Conformations of a Diazabicyclanol

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COMPARISON BETWEEN THE IR SPECTRA AND THE STRUCTURE OF THE TWO CONFORMATIONS OF A DIAZABICYCLANOL

KEY WORDS: Vibrational frequencies, diazabicyclanol, Infrared spectra, scaling frequencies, AM1

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ABSTRACT

In the two stable conformations of the diazabicyclanol 3,7-dimethyl-3,7-diazabicyclo[3.3.1]nonan-9-ol, *chair-chair* (**Va**) and *chair-boat* (**Vb**), the infrared spectra (200 - 4000 cm^{-1}) were recorded, compared and their vibrations analysed. Using the AM1 semiempirical method, the geometry was fully optimized in both forms, and the theoretical Infrared spectra were calculated and compared. In the (**Vb**) conformation, the IR spectra were recorded in CCl_3D, CCl_4 and S_2C solvents. Some correlations were established.

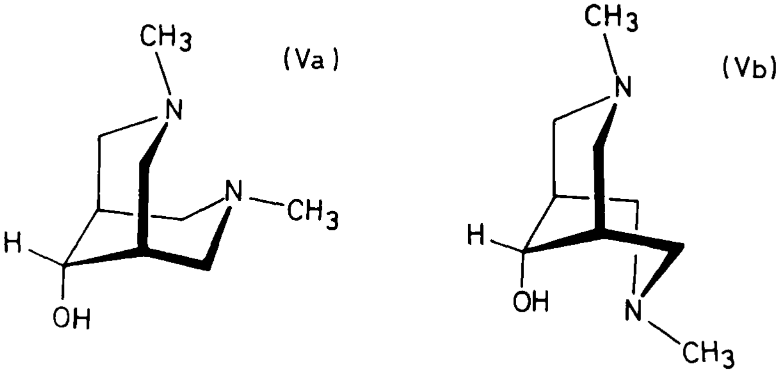
INTRODUCTION

The bicyclo[3.3.1]nonane skeleton may be viewed as two cyclohexane rings fused together, with three ring carbon atoms in common. The conformation of compounds having the bicyclo[3.3.1]nonane carbocyclic ring structure has been relatively well-established, and their *chair-chair* form was found experimentally[1,2] and theoretically[2,3] to be the most stable conformer. Conformations of the 3,7-diaza analogues have been, in contrast, less well studied[4]. They offer additional facets to consider, namely, (i) the possibility of *exo* and *endo* disposition of the N-alkyl substituents, (ii) possible dipole-dipole repulsion of the heteroatoms in the *chair-chair* conformation, and (iii) possible direct overlap of the nitrogen lone-pair orbitals, also in the *chair-chair* conformation[5].

As part of a research program related to the structures and vibrational pattern of pharmacologically active compounds, several aza-bicyclo-nonane systems were examined in previous papers[6-8]. A representative example of diazabicyclanols, 3,7-dimethyl-3,7-diazabicyclo[3.3.1]nonan-9-ol, in its *chair-chair* (**Va**) and *chair-boat* (**Vb**) conformations is examined (Fig. 1) in the present paper. This kind of compounds, with the two nitrogen atoms in close proximity and with an alcoholic group, have a remarkable potential anticholinergic action. The aim of this work is to investigate the vibrational spectra and the structure of the **Vb** form, and to compare with the **Va** conformation. To assist in the interpretation of the spectroscopic data, theoretical methods were used.

EXPERIMENTAL

The synthesis and purification of **Va** and **Vb** have been previously reported[9]. Infrared spectra were recorded on a Perkin Elmer 599 B spectrophotometer. Indene and polystyrene were used for instrument calibration. Spectra of **Va** were recorded in KBr pellets and Nujol, while spectra of **Vb** were registered in deuterated chloroform, carbon tetrachloride and carbon disulfide solvents with spectroscopic purity. The infrared frequencies are accurate to ± 1 cm^{-1}.



(Va) (Vb)

chair-chair (exo,exo) *chair-boat (exo,endo)*

Fig. 1 Drawing of the two preferred conformations of 3,7-dimethyl-3,7-diazabicyclo [3.3.1] nonan-9-ol.

COMPUTATIONAL METHODS

Two quantum mechanic approaches were employed: semiempirical and ab initio. The semiempirical approach used was the improved semiempirical molecular orbital method developed by Dewar et al.[10,11], i.e. AM1. This method has shown reasonable reproduction of the geometric parameters (bond lengths, bond angles, and torsional angles)[10-14], the vibrational spectrum[15,16], and a remarkable promise in a wide variety of applications[16-18], including studies of chemical reactions of various kinds. The calculations with AM1 were carried out with the AMPAC program package[11,19] using the PRECISE keyword, and with the GAUSSIAN 90 program package[20] using the OPT keyword. Geometries were completely optimized without fixing any parameters, thus bringing all geometric variables to their equilibrium values. Force-constant, vibrational frequency and intensity calculations were performed.

For the ab initio calculations, the minimal basis STO-3G in the GAUSSIAN 90 package was selected due to the large size of the molecule.

The DRAW program[21] was also used several times to evaluate graphically the correctness of starting geometries prior to calculation, to review the resulting optimized geometries after the calculation, and to help in the identification of all the normal vibration modes computed by AM1. The drawings were observed in high-resolution graphics computer terminals, Tektronic 4105 model.

RESULTS AND DISCUSSION

Geometry optimization

Figure 2 shows a view of the molecule of **Va** and the labeling of the atoms plotted with the BALL and STICK program[22]. The final bond lengths, bond angles and torsional angles calculated by AM1 and sto-3G methods in **Va** are shown in the z-matrix of Table 1, while the optimum geometric data of **Vb** are listed in Table 2. In columns 3 and 8 of these Tables appear the bond lengths in Å; in columns 5 and 10 the bond angles in degrees, and in columns 7 and 12 the torsional angles also in degrees. The other columns: 2, 4 and 6 with sto-3G, and 2, 9 and 11 with AM1, show the connectivity of the atom considered (1st column). The computed values correspond to a single molecule, without the environment of the crystal structure. Two molecules **A** and **B** were experimentally determined by X-ray diffraction[9] in the crystal of **Va**.

According to the values of Tables 1 and 2, in **Vb** a larger **r** N5···N9 interatomic distance together with shorter **r** N5···O12 and **r** N5···H30 distances than in **Va** are identified. The latter distance is relatively short; this fact is attributed to the existence of intramolecular O-H···N bonding when passing from structure **Va** to **Vb**. Examples of compounds displaying O-H···X bonding are somewhat rare owing to unfavorable energy differences usually existing between *boat* and *chair* conformers. However, a

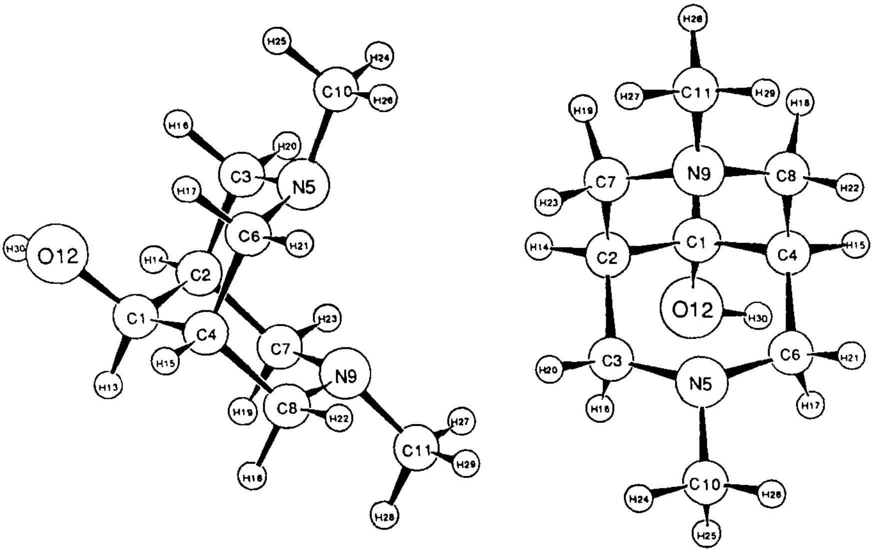


Fig. 2 Two viewpoints of the optimized geometry and labelling of the atoms in the *chair-chair* conformation **Va** of 3,7-Dimethyl-3,7-diazabicyclo [3.3.1] nonan-9-ol.

number of examples in mono- and bicyclic systems have been reported[23,24].

The ∠ N5-C3-C2, ∠ N5-C6-C4 bond angles in **Vb** structure are larger by about 4° than in **Va**, and the torsional angles on C3 and C6 differ remarkably.

Concerning the hydroxylic group, in **Va** the H30 hydrogen in the *gauche* position by AM1 (*cis* with sto-3G) relative to H13 (see Fig 3), changes to *trans* in **Vb**, in accordance with a shorter H30···N5 distance, corresponding to the presence of an intramolecular hydrogen bond on H30. Thus different values of the ∠ H13-C1-O12-H30, ∠ C2-C1-O12-H30 and ∠ C4-C1-O12-H30 torsional angles are obtained. These features are in agreement with the absence of intramolecular bonds in the crystal[9] of **Va**.

Table 1. Z-Matrix with the optimum geometric values obtained by AM1 and by sto-3G ab initio level in the **Va** conformation.

		sto-3G					**AM1**				
C1											
C2	1	1.5521					1.5301				
C3	2	1.5483	1	109.22			1.5310	1	110.00		
C4	1	1.5472	2	106.25	3	-61.61	1.5302	2	106.77	3	-60.38
N5	3	1.4870	2	111.99	1	58.95	1.4554	2	114.54	1	53.50
C6	4	1.5482	1	109.28	2	61.60	1.5313	1	109.88	2	60.62
C7	2	1.5489	1	108.56	4	62.84	1.5317	1	108.37	4	63.40
C8	4	1.5490	1	108.68	2	-62.83	1.5317	1	108.66	2	-63.16
N9	8	1.4867	4	112.08	1	58.94	1.4532	4	114.82	1	53.12
C10	5	1.4824	3	110.28	2	-177.28	1.4455	3	112.03	2	-174.09
C11	9	1.4818	8	110.54	4	-177.24	1.4444	8	112.24	4	-173.04
O12	1	1.4346	2	113.27	3	57.63	1.4196	2	108.10	3	61.57
H13	1	1.0979	2	109.02	3	180.81	1.1270	2	110.34	3	180.13
H14	2	1.0906	1	109.67	4	180.34	1.1230	1	109.68	4	181.43
H15	4	1.0896	1	109.20	2	179.45	1.1236	1	110.13	2	178.98
H16	3	1.0962	2	108.10	1	-64.31	1.1315	2	107.09	1	-70.49
H17	6	1.0956	4	108.05	1	64.35	1.1324	4	107.08	1	69.94
H18	8	1.0968	4	108.32	1	-64.55	1.1324	4	107.47	1	-71.39
H19	7	1.0970	2	108.25	1	64.53	1.1321	2	107.61	1	70.80
H20	3	1.0907	2	109.65	1	178.70	1.1267	2	108.71	1	172.93
H21	6	1.0906	4	109.58	1	-178.59	1.1266	4	108.78	1	-173.66
H22	8	1.0905	4	109.63	1	178.58	1.1272	4	108.57	1	172.52
H23	7	1.0906	2	109.65	1	-178.66	1.1272	2	108.47	1	-173.07
H24	10	1.0886	5	109.30	3	-58.87	1.1213	5	108.72	3	-55.52
H25	10	1.0942	5	113.02	3	61.90	1.1256	5	113.48	3	65.28
H26	10	1.0886	5	109.26	3	-177.36	1.1213	5	108.80	3	-173.84
H27	11	1.0886	9	109.29	8	-176.89	1.1213	9	108.77	8	-173.16
H28	11	1.0944	9	113.03	8	62.35	1.1258	9	113.43	8	66.04
H29	11	1.0885	9	109.27	8	-58.38	1.1214	9	108.82	8	-54.79
H30	12	0.9908	1	104.07	2	62.94	0.9644	1	106.73	2	-166.78

Table 2. Z-Matrix with the optimum geometric values obtained by AM1 in Vb.

C1							H16	3	1.1299	2	108.29	1	138.02
C2	1	1.5292					H17	6	1.1294	4	108.31	1	-139.87
C3	2	1.5365	1	112.91			H18	8	1.1310	4	107.82	1	-67.74
C4	1	1.5286	2	106.45	3	-56.38	H19	7	1.1306	2	107.88	1	67.12
N5	3	1.4472	2	118.50	1	17.66	H20	3	1.1292	2	107.43	1	-106.71
C6	4	1.5351	1	112.87	2	57.39	H21	6	1.1297	4	107.43	1	104.79
C7	2	1.5371	1	107.05	4	65.78	H22	8	1.1266	4	108.92	1	175.87
C8	4	1.5375	1	107.07	2	-65.46	H23	7	1.1264	2	109.03	1	-176.45
N9	8	1.4561	4	113.70	1	56.52	H24	10	1.1253	5	114.66	3	68.84
C10	5	1.4409	3	114.80	2	-117.26	H25	10	1.1221	5	109.00	3	-169.89
C11	9	1.4450	8	112.25	4	-176.91	H26	10	1.1226	5	108.68	3	-52.04
O12	1	1.4109	2	113.98	3	70.23	H27	11	1.1215	9	108.78	8	-174.05
H13	1	1.1303	2	109.75	3	-175.09	H28	11	1.1255	9	113.37	8	65.15
H14	2	1.1223	1	109.51	4	-177.37	H29	11	1.1210	9	108.86	8	-55.66
H15	4	1.1229	1	109.46	2	178.04	H30	12	0.9627	1	108.35	2	-63.04

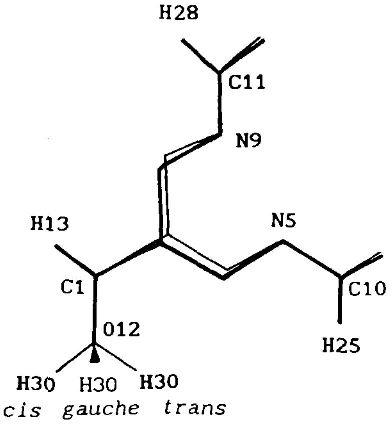


Fig. 3 Definition of the positions in H30.

The ∠ C2-C1-O12 and ∠ C4-C1-O12 angles have nearly the same value in **Vb**, with a slight variation of 0.07°. This means a symmetric position of O12 with respect to C2 and C4, in contrast to those computed for **Va** (108.10 and 113.09°, respectively), corresponding to a *gauche* conformation of H30. This conformation of the H30 atom in **Va** impedes the formation of an intramolecular bond with N5; hence H30 is not aligned in this way, being asymmetric with C2 and C4. Similar values for C1-C2 and C1-C4 bond lengths calculated for **Vb** corroborate this fact.

The preferred conformation of 3,7-dimethyl-3,7-diazabicyclo [3.3.1] nonan-9-ol, as the diazabicyclanols in general, depends on the phase and on the polarity of the solvent[9]. Thus in solid and dimethylsulfoxide (dipole moment $\mu D \simeq 4.5$ Debye), the compound adopts a distorted *chair-chair* conformation **Va** (the computed μD by AM1 is 1.58 D) with H30 in *gauche*, whereas in CCl_4 ($\mu D = 0.28$ D), $CDCl_3$ ($\mu D = 1.16$ D) and S_2C ($\mu D \simeq 0.45$ D) solutions with low dipole moment, an intramolecular hydrogen bond stabilizes the *chair-boat* conformation **Vb** with lower dipole moment (0.76 D) than **Va**, and with H30 in *trans* to form this intramolecular bond.

Scarse in the bibliography are examples of bicyclic systems where the *boat* conformation is stable and exists experimentally[2,25]. Several of them, however, are shown in Fig. 4a. The *exo/endo* notation is explained in Fig. 4b.

The *chair-boat* conformation seems to be stable and in some cases the preferred form in the bicyclo[3.3.1]nonane system if there is a heteroatom at 3-position (*endo*) as well as a substituent at 7-(*endo*), while a 3-*exo*/7-*exo* stabilizes the *chair-chair* form[4,26]. Substituents at these positions therefore govern the conformation of the bicyclo[3.3.1]nonane system and *chair-boat* forms must play a predominant role in the conformational equilibrium. Moreover, the *chair-boat* form would not be possible unless either a very bulky substituent or an intramolecular hydrogen bonding or both are present. The effects of substituents at 2 and 4 positions are less well understood.

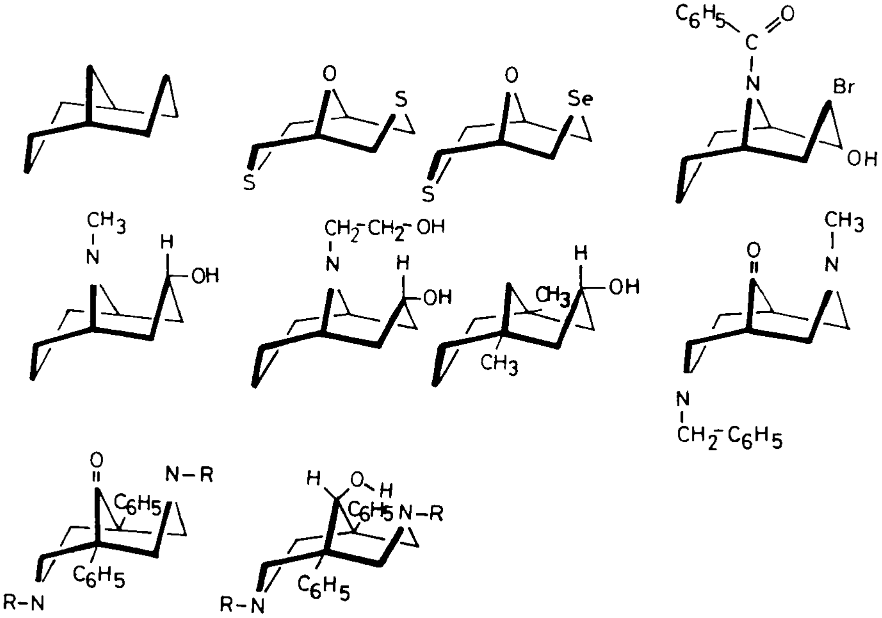
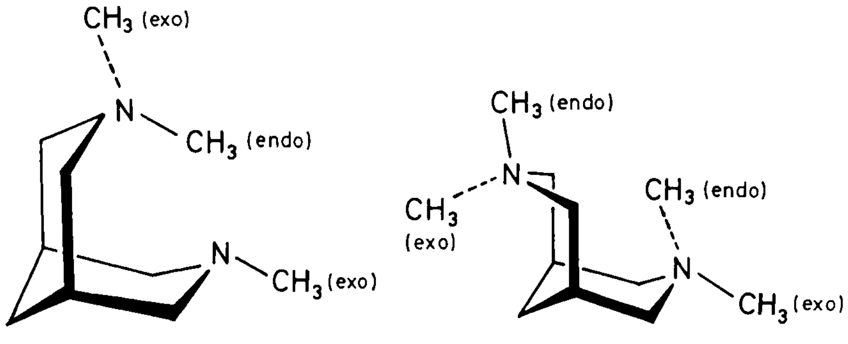


Fig. 4a Several stable experimentally *chair-boat* conformations in the bicyclo[3.3.1]nonane system.



Chair-Chair (endo, exo) Chair-boat (endo, exo)

Fig. 4b The *exo/endo* notation refers to the disposition of the N-methyl groups.

Table 3. Calculated and experimental vibrational frequencies of 3,7-dimethyl-3,7-diazabicyclo[3.3.1]nonan-9-ol (**Vb**).

No.	Freq. (cm^{-1})	Int.[a] (%)	μ[b] (AMU)	Freq. scaled	error[c] (%)	Spectra[e] (cm^{-1})			Characterization
						CCl_3D	CCl_4	S_2C	
1	64	12	72.9	62					τ(C-H) in CH_3 + Γ(C-H)* in C^3H_2
2	88	17	0	85					τ(C-H) in $C^{10}H_3$ + τ(O-H)*
3	116	16	0	112					Γ(C-H) in C^6H_2, CH^{27} + Γ(C-H)* in C^8H_2
4	128	14	0	123					τ(C-H) in $C^{10}H_3$ + Γ(C-H)* in C^3H_2, C^7H_2
5	152	2	0	146					τ(C-H) in $C^{11}H_3$
6	202	56	1.6	193					τ(O-H)
7	233	29	33.0	223					Γ(HO-CH)
8	282	45	0	270					τ(O-H) + Γ(C-H) in C^7H_2, C^8H_2, $CH^{25}H^{26}$
9	319	51	0	305					γ(structure) in N^5, N^9 + γ(C^{10}-N) + Γ(C-H) in $C^{10}H_3$
10	343	16	3.3	328					Γ(C-H) in $C^{11}H_3$ + γ(C-O) + Γ(C-H)* in C^7H_2, C^8H_2, $C^{10}H_3$
11	352	20	0	336					γ(structure) in N^5, N^9 + Γ(C-H) in CH_2
12	393	19	0	375					γ(C-N) in N^9 + Γ(C-H) in C^7H_2, C^8H_2, $C^{11}H_3$
13	400	27	0	382					Γ(C-H) in C^7H_2, C^8H_2 + Γ(C-H)* in C^3H_2, C^6H_2
14	460	6	0	439	1.8[d]		452 vw		γ(C-C-O) + Γ(C^{11}-N)
15	487	8	0	465	0.8[d]		491 m 502 m		Γ(C-N^5) + Γ(C-H) in CH_2
16	542	9	0	517	0.4[d]		521 m 544 m		γ(structure) + Γ(C-H) in CH^{14}, CH^{15} + Γ(C-H)* in $C^{11}H_3$
17	566	31	0	540	0.7[d]		570 m 585 w		γ(C-O) + δ(C-N^5) + γ(CC^1C) + Γ(C-H)* in $CH^{25}H^{26}$
18	666	6	0	635	1.2	643 w 667 vw			Γ(C-H) in CH_2 + γ(structure) + γ(C-H)* in CH
19	747	9	0	712	2.2	728 vb			δ(structure) + γ(C-H) in CH^{18-21}, CH^{28} + γ(O-H)

						815,846 vw		
20	840	25	0	801	1.9^d	856 m	776 mb	δ(CC^1C) + Γ(C-H) in C^3H_2, C^6H_2 + γ(C-H)* in CH
21	944	4	0	900				Γ(C-H) in C^7H_2, C^8H_2 + Γ(C-H)* in C^3H_2, C^6H_2
22	947	29	0	903	1.3	915 vb	909 w	γ(O-H) + δ(structure) + γ(C-H) in CH^{13}, CH^{20-23}
23-	972	6	0	927				γ(C-H) in CH_2 + γ(structure)* + γ(C-H)* in CH_3
25	1016	8	0	969	1.9		951 vw	γ(C-H) in CH^{14}, CH^{15} + δ(structure)
26	1030	3	0	982	1.3	995 vw		γ(C-H) in CH^{13}, C^3H_2, C^6H_2 + δ(C^4-C^6) + γ(C-H)* in CH_2
27	1037	22	0	989	2.3^d	1014 m		γ(C-H) in CH^{14}, CH^{15}, C^3H_2, C^6H_2 + δ(structure)
28	1068	16	0	1019	1.6	1036 s		γ(C-H) in CH^{14}, CH^{15} + γ(C-H)* in CH_2
29	1075	8	0.5	1025				Γ(C-H) in CH_3 + δ(C-H) in CH
30	1108	14	1.2	1057	0.3	1054 vs		Γ(C-H) in CH_3 + δ(C-H)* in CH^{18}, CH^{19}
31	1115	24	0.8	1063	0.6	1069 vs		Γ(C-H) in CH_3
32	1123	27	0.6	1071	1.6	1089 vs		Γ(C-H) in $C^{10}H_3$ + δ(C-H)* in CH, CH^{20-23}
33	1140	5	0.8	1087				δ(C-H) in CH + Γ(C-H) in $C^{11}H_3$
34	1157	3	0.5	1103				τ(C-H) in C^7H_2, C^8H_2 + δ(C-H)* in CH
35	1185	7	0.4	1130	1.3	1145 sh		τ(C-H) in CH_2 + δ(C-H)* in CH^{14}, CH^{15}
36	1196	19	0.4	1141	0.3	1138 m		δ(C-H) in CH^{14}, CH^{15} + τ(C-H)* in CH_2
37	1201	5	0.4	1145	1.5	1162 w		δ(C-H) in CH^{14}, CH^{15} + τ(C-H) in C^3H_2, C^6H_2
38	1206	47	0.8	1150	3.0	1127 s		τ(C-H) in C^7H_2, C^8H_2 + τ(C-H)* in C^3H_2, C^6H_2
39	1229	1	0.5	1172	1.3	1187 w		δ(C-H) in CH + τ(C-H) in C^3H_2, C^6H_2
40	1264	9	0.5	1205	0.9	1216 vw		δ(C-H) in CH^{14}, CH^{15} + τ(C-H)* in CH_2
41	1295	34	1.0	1235	0	1235 m		δ(C-H) in CH^{13} + δ(O-H) + δ(C-H)* in CH^{14}, CH^{15}

(continued)

Table 3. (continued)

42	1307	12	0.6	1246	0.8	1256 s			δ(C-H) in CH + τ(C-H)* in CH_2
43	1320	1	1.2	1259					δ(C-H) in CH^{14}, CH^{15} + Δ_s(C-H) in CH_2
44	1338	5	0.3	1276					ν(CC^1C) + τ(C-H)* in CH_2
45	1358	8	1.2	1295	3.1	1256 s			Δ_s(C-H) in C^7H_2, C^8H_2 + δ_s(C-H)* in $C^{11}H_3$ + ν(C-N^9)*
46	1363	4	0.4	1300					ν(C-C) in C^2C^3, C^4C^6
47	1372	8	0.6	1308					δ_s(C-H) in $C^{10}H_3$
48-	1376	12	0.8	1312					δ_s(C-H) in $C^{11}H_3$
50	1379	34	1.0	1315	3.1	1276 vs			Δ_s(C-H) in C^3H_2, C^6H_2 + δ_s(C-H) in $C^{10}H_3$
51	1383	16	0.7	1319	1.2	1303 w			Δ_s(C-H) in C^7H_2, C^8H_2 + Δ_s(C-H)* in C^3H_2
52-	1387	14	0.6	1323					δ_s(C-H) in $C^{10}H_3$ + Δ_s(C-H) in CH_2
54	1396	12	0.6	1331					Δ_s(C-H) in CH_2 + δ_{as}(C-H)* in $C^{10}H_3$
55-	1398	12	0.7	1333	1.0	1347 vw			Δ_s(C-H) in CH_2 + ν(CC^1C)*
57	1404	15	0.5	1335					Δ_s(C-H) in CH_2
58	1431	24	0.6	1361	0.7			1352 m	Δ_s(C-H) in C^3H_2, C^6H_2 + Δ_s(C-H)* in C^7H_2, C^8H_2
59	1458	60	1.5	1387	1.5	1367 s			ν(CC^1C) + ν(C-O) + δ(O-H) + δ_{as}(C-H)* in CH_3
60	1469	22	1.7	1398	1.1	1383 m		1390 vs	δ_{as}(C-H) in $C^{11}H_3$ + Δ_s(C-H)* in C^7H_2, C^8H_2
61	1480	7	1.2	1408	2.0	1437 sh	1432 sh		δ_{as}(C-H) in $C^{10}H_3$ + Δ_s(C-H)* in C^3H_2, C^6H_2
62	1495	84	0.2	1423	0.1		1421 vs		ν_s(C-N) in N^9 + ν(C-C) in C^2C^7, C^4C^8
63	1514	100	1.8	1441	0.6	1450 s	1444 vs		ν_{as}(C-N) in N^9 + Δ_s(C-H) in C^7H_2, C^8H_2
64	1534	90	0.1	1460	0.5	1468 vs	1468 vs		ν_s(C-N) in N^5 + ν(C-C)* in C^2C^3
65	1540	79	0.5	1466	1.2		1484 vs		ν_{as}(C-N) in N^5 + δ(O-H)
						1584 vw	1584 vw		
66	1554	57	1.1		3.1[d]	1604 m		1675 mb	δ(O-H) + δ(C-H) in CH^{13}

						2238 w	2238 m	2683 m	Combination bands
						2704 w	2704 m	2701 m	Combination bands
67	2949	16	0.7	2821	1.2				ν_s(C-H) in C^8H_2 mainly in H^{18}
68	2952	18	0.7	2823	1.2	2788 vs	2783 vs	2763 vs	ν_s(C-H) in C^7H_2 mainly in H^{19}
69-	2954	9	0.7	2825					ν_s(C-H) in C^3H_2, C^6H_2
71	2979	28	0.7	2849	1.4	2810 s	2810 s		ν_s(C-H) in $C^{10}H_3$ mainly in H^{24}
72	2985	21	0.7	2855	0.2	2848 s	2848 s	2837 vs	ν_s(C-H) in $C^{11}H_3$ mainly in H^{28}
73	3018	7	0.7	2887					ν_s(C-H) in $CH^{25,26}$
74	3027	8	0.7	2896	0.1				ν_s(C-H) in $CH^{27,29}$
75-	3027	8	0.6	2896		2892 s	2892 s	2883 vs	ν_{as}(C-H) in C^3H_2, C^6H_2
77	3035	9	0.6	2903					ν_{as}(C-H) in C^8H_2 mainly in H^{22}
78	3037	8	0.6	2905					ν_{as}(C-H) in C^7H_2 mainly in H^{23}
79	3042	16	0.6	2910					ν(C-H) in CH^{13}
80	3051	19	0.6	2919	0.7	2941 vs	2940 vs	2930 vs	ν(C-H) in CH^{15}
81	3055	18	0.6	2922					ν(C-H) in CH^{14}
82	3101	13	0.6	2967	0.1	2972 m	2972 s	2962 s	ν_{as}(C-H) in $C^{10}H_3$
83	3106	9	0.6	2971					ν_{as}(C-H) in $C^{11}H_3$
84	3518	47	0.7	3368	0.2	3360 sb	3350 sb	3347 sb	ν(O-H)
						3605 m		3603 w	ν(O-H) in free groups
						3620,3670 w	3620 w		ν(O-H) in free groups

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[a] Intensities relative to line 63. [b] μ, reduced masses. [c] $100 \cdot |\nu_{exp.} - \nu_{scaled}|/\nu_{exp.}$, $\nu_{exp.}$ is from the CCl_3D spectrum, when it is identified. [d] With the non-scaled frequency. [e] Note: vs, very strong; s, strong; m, medium; w, weak; vw, very weak; sh, shoulder; sb, strong and very broad; mb, medium and broad. *, very weak contribution of this mode.

To the best of our knowledge the *boat-boat* conformation has not been proposed with certainty for any molecule having the bicyclo[3.3.1]nonane skeleton.

Vibrational frequencies

Compound **Vb** crystallizes without water. This fact is reflected in a different IR spectra, especially in the O-H modes, with respect to **Va** which crystallizes with water and alcohol molecules binding through the hydroxylic group, because in **Va** the lone nitrogen electrons pairs in both rings of the bicyclic structure are involved in the bonding with either of these water or alcohol molecules[9].

In Table 3 are shown for **Vb** the assignment of the observed IR bands in CCl_3D, CCl_4 and S_2C solvents, and the computed and scaled frequencies by AM1 with their intensities. Fig. 5 records the IR spectrum of **Vb** in CCl_3D. In CCl_4 the spectrum was registered only in the 450-1000 cm^{-1} and 1300-4000 cm^{-1} ranges, and in S_2C in the 1300-4000 cm^{-1} region. The relative IR intensities of the third column were calculated by dividing the value of the computed intensity by the intensity of the strongest line obtained (in the study, line number 63). The characterization of the bands is shown in the last column. To correct the deficiency of the AM1 method, a scaling equation[27] was used:

$$\nu_{scaled}(cm^{-1}) = 0.7 + 0.9528\ \nu_{AM1}(cm^{-1})$$

However with frequencies higher than 1400 cm^{-1}, a lower error is obtained using another scaling equation[27]:

$$\nu_{scaled}(cm^{-1}) = -14.8 + 0.9614\ \nu_{AM1}(cm^{-1})$$

The scaled frequencies obtained are listed in the fifth column. The theoretical spectrum computed with these new frequencies is shown in Fig. 6. The % error values determined in this way with

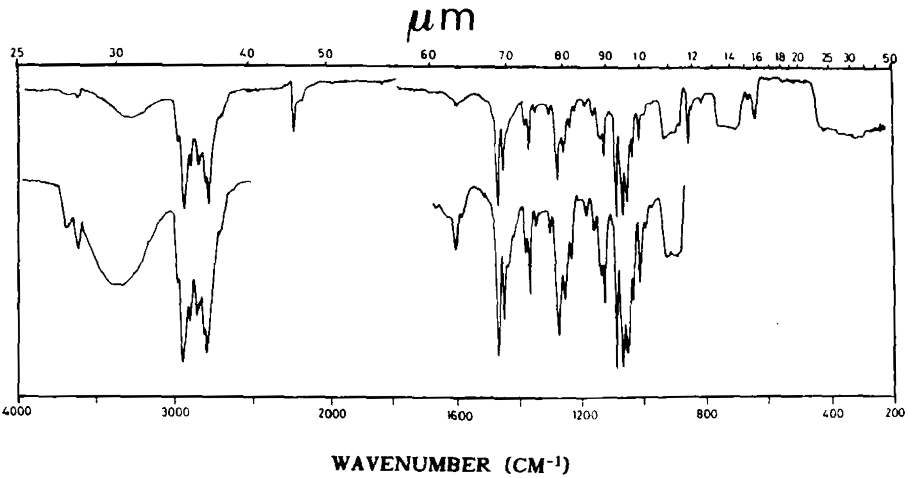


Fig. 5 Infrared spectrum of **Vb** in CCl_3D.

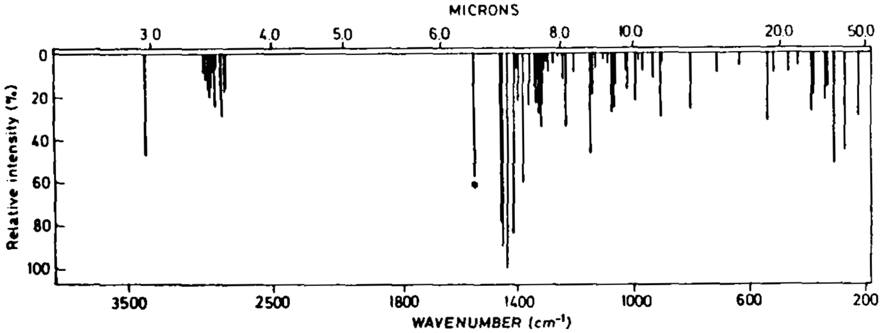


Fig. 6 Theoretical spectrum of **Vb** calculated by AM1 with the scaled frequencies. (*) Non-scaled frequency.

respect to the experimental data in CCl_3D are collected in the sixth column. In general, a good concordance between the observed and calculated frequencies is obtained, with errors lower than 3%. The modes undetected in the IR spectra are those with the lowest calculated IR intensities. In the low frequency range (< 900 cm^{-1}), with modes characteristic of the bicyclic structure, the possibility of the use of scaling equations is, in general, reduced due to the specificity of the structure, and they normally give unsatisfactory results. However in this case the use of the non-scaled frequencies computed by AM1 gives good concordance with the experimental.

In Table 4 are collected several selected calculated and experimental frequencies in **Va**, especially in the O-H and C-N groups, while in Fig. 7 is registered its theoretical spectrum with the scaled frequencies and the IR spectrum in KBr pellets.

The characteristics of the spectra are discussed in the following sections:

O-H vibrations. The IR spectra of **Vb** in very dilute CCl_4 solution show a strong O-H band at ca. 3350 cm^{-1}, corresponding to a stretching O-H vibration. The position of the maximum is unaltered in solution of CCl_3D indicating the existence of an intramolecular O-H···N bond. This fact is corroborate by the AM1 predictions. Thus a strong O-H band is computed at 3368 cm^{-1} (scaled), with a very small error, only 0.2%. A weak band at 3620 cm^{-1} is also observed in CCl_4. This band indicates a small proportion of free O-H groups of *chair-chair* forms in **Vb**.

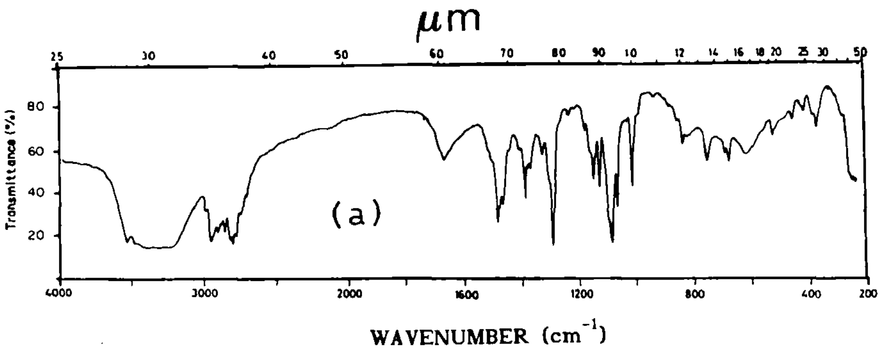
In the IR spectra of **Va** in KBr pellets and in Nujol, a broad absorption at 3200-3400 cm^{-1} is identified corresponding to O-H groups, which are bonded with water and alcohol molecules. A broad absorption band in the 3100-3600 cm^{-1} range with bands at 3480 and 3520 cm^{-1} attributed to water of crystallization[9], is also observed.

The IR spectrum of **Vb** in CCl_3D solution shows a strong and broad band centered at 3360 cm^{-1}, which suggests the coexistence

Table 4. Several selected calculated by AM1 and experimental vibrational frequencies of Va.

No.	Freq. (cm^{-1})	Int.[a] (%)	Freq. scaled	error[b] (%)	Spectra[c] in KBr	Characterization
6	188	79	180			τ(O-H)
7	204	17	195		238 m	Γ(O-H)
8	294	19	281	1.1	284 vw	$\Gamma(CH_2)$ + τ(O-H)
9	330	47	315	3.3	305 vw	γ(C-N) in N^9
16	527	17	503	0.2	502 w	γ(structure)
17	569	20	543	4.4[d]	595 m-b	γ(C-O) + δ(ring) + γ(C-H) in $C^{10}H_3$
26	1015	34	968	2.7	995 s	γ(C-H) in CH^{14}, CH^{15} + δ(ring)
28	1067	19	1017	2.9	1047 s	γ(C-H) in CH^{14} and CH^{15}
31-	1112	26	1060	0.5	1065 vs	Γ(C-H) in CH_3 and CH^{13}
41	1265	25	1206	0.7	1214 vw	δ(O-H) + δ(C-H) in CH
44	1345	38	1282	0.9	1270 vs	ν(C-C) in C^4C^8 +δ(C-H) in $CH^{15,18,21}$
51-	1378	19	1314	0.3	1310 m	δ_s(C-H) in CH_3
57	1397	11	1331	1.5	1352 m	ν(C-C) in C^4C^6 + δ(C-H)
59	1443	85	1373	0.2	1370 s	ν_s(OCC) + δ(C-H)
60	1468	25	1397	0.5	1390 w	δ_{as}(C-H) in CH_3
62	1504	97	1431	1.3	1450 s	ν_s(C-N) in N^5 + δ(C-H) in CH^{14}, CH^{15}
63	1508	65	1435	1.0		ν_s(C-N) in N^9 + δ(C-H) in CH^{14}, CH^{15}
64	1513	100	1440	1.7	1465 vs	ν_{as}(C-N) + δ_{as}(C-H) in CH_2
65	1519	67	1446	1.3		ν_{as}(C-N) + δ_{as}(C-H) in CH_2
66	1543	40	-	-	1655 mb	δ(O-H)
72	2984	22	2854	1.6	2808 s	ν_s(C-H) in $C^{10}H_3$, mainly in H^{25}
73-	3026	8	2895			ν_s(C-H) in CH_3
79	3034	5	2902			ν_{as}(C-H) in C^3H_2
82-	3105	10	2971	0.3	2980 w	ν_{as}(C-H) in CH_3
84	3498	47	3348		3300 vs-b	ν(O-H)

[a] Intensities relative to line 64. [b] $100 \cdot |\nu_{exp.} - \nu_{scaled}| / \nu_{exp.}$ [c] Note: vs, very strong; s, strong; m, medium; w, weak; vw, very weak; m-b, medium and broad; vs-b, very strong and broad. [d] With the non-scaled frequency.



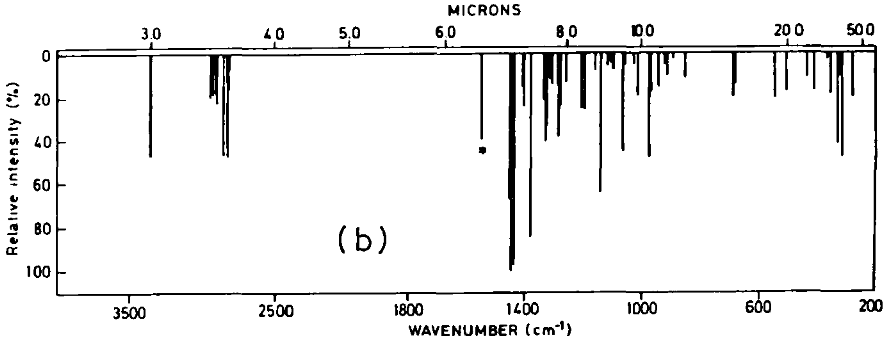


Fig. 7 (a) Infrared spectrum of **Va** in KBr pellets and (b) theoretical spectrum with the scaled frequencies by AM1.

of intramolecularly-bonded and solvent-bonded molecules, probably in *chair-boat* conformations. Moreover, a weak band at 3605 cm^{-1} indicates the presence of free O-H groups of *chair-chair* conformations as in polar solvent solutions. Results with **Vb** in CS_2 are similar. Thus in the O-H region a broad absorption with a maximum at ca. 3347 cm^{-1} is observed.

The δ(O-H) mode is predicted with strong intensity at 1554 cm^{-1} in **Vb** and 1543 cm^{-1} in **Va** , which corresponds to the medium intensity IR band at 1604 cm^{-1} in **Vb** (in CCl_3D) and at 1655 cm^{-1}

in **Va**. Because AM1 computes a hydroxy group without intermolecular hydrogen bonds with the environment, the calculated frequencies are far from the experimental, especially in the **Va** molecule. The strong bands in **Vb** at 1540, 1458 and 1295 cm^{-1} are also computed with a slight contribution of the mode δ(O-H).

The out-of-plane bending γ(O-H) is determined in **Vb** at 903 cm^{-1} (scaled), in good agreement with the very broad IR band at 915 cm^{-1} in CCl_3D and the weak absorption at 909 cm^{-1} in CCl_4. The torsional mode τ(O-H) is predicted in the far-infrared range, at 202 cm^{-1} in **Vb** and at 188 cm^{-1} in **Va**.

Other vibrations: The C-O stretching is predicted as a very strong band at 1387 cm^{-1} *(scaled)* in **Vb** *and* at 1373 cm^{-1} (scaled) in **Va**, which corresponds to the strong IR absorption at 1367 cm^{-1} (in CCl_3D) and at 1370 cm^{-1} (in KBr pellets) respectively, with slight errors. The out-of-plane bendings γ(C-O) also show close values between the **Va** and **Vb** forms. They are calculated as strong bands at 566 cm^{-1} (**Vb**) and at 569 cm^{-1} (**Va**), and at 460, 455 cm^{-1} in **Vb** and **Va** respectively.

The C-H stretchings appear in the 2700-3000 cm^{-1} range of the IR spectra as very strong Bohlmann bands. They are well predicted by AM1 with errors, in general, lower than 1.5%. The frequencies do not change appreciably from **Va** to **Vb** form.

The most intense computed bands are due to the ν(C-N) stretching vibration. The frequencies corresponding to N9 are very close between the **Va** and **Vb** conformations, but they differ about 25-30 cm^{-1} in N5 due to the *boat* form of **Vb**. Thus the antisymmetric mode is determined and scaled in N9 at 1446 cm^{-1} (**Va**) close to the value at 1441 cm^{-1} (**Vb**); while in N5 it is computed at 1440 cm^{-1} (**Va**) far from the value at 1466 cm^{-1} in **Vb**. A similar result is obtained with the symmetric mode with a scaled frequency in N5 and **Vb** at 1460 cm^{-1} that differs from the other ν_s(C-N) vibrations, about 30-40 cm^{-1}. The strong-very strong IR bands observed in **Vb** at 1450 and 1468 cm^{-1} in CCl_3D and at 1421, 1444, 1468 and 1484 cm^{-1} in CCl_4 are assigned to this ν(C-N) stretching mode.

CONCLUSIONS

The molecular geometry of the diazabicyclanol studied is accurately determined by the AM1 theoretical method in its two stable conformations, **Va** (*chair-chair*) and **Vb** (*chair-boat*), the differences being in the standard deviation of this method. The discrepancias with the x-ray study of **Va** are attributed to the fact that, in the crystal, the molecules through their nitrogen atoms, are implicated in bonding with either water or alcohol molecules.

The conformer **Va** is slightly more stable than **Vb**, and **Va** is the conformer that predominates in the solid state. In solution in nonpolar solvents, the conformer **Vb** with lower dipole moment (0.75 D by AM1) is stabilized and it is the only form present; while in polar solvents the **Va** form with higher dipole moment (1.58 D by AM1) is adopted. In the transformation from **Va** to **Vb**, a simultaneous change in the position of the hydrogen of the hydroxylic group from *gauche* to *trans* is produced to form an intramolecular hydrogen bond with N5 which stabilizes this *boat-chair* structure.

The frequencies corresponding to N9 are very close between the **Va** and **Vb** conformations, but differ about 25-30 cm^{-1} in N5 due to the *boat* form of **Vb**.

Good reproduction of the experimental frequencies is obtained with AM1. Thus the % error obtained with the use of a scaling equation is very small, in the majority of cases less than 3.5%. Concerning the intensity of the vibrations, it is noted that, in general, the modes not detected in the spectra are those having the lowest calculated intensities. In general the coincidence grade is satisfactory between the different spectra.

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