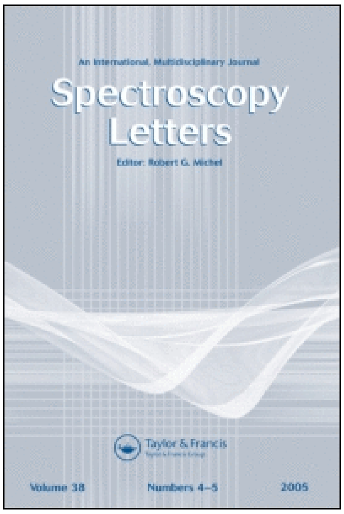

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Infrared and Raman Study of Benzocaine Hydrochloride

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INFRARED AND RAMAN STUDY OF BENZOCAINE HYDROCHLORIDE

KEY WORDS: Benzocaine hydrochloride, IR spectra, Raman spectra, Local anesthetic, vibrational frequencies

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ABSTRACT

The infrared and laser Raman spectra (100-4000 cm^{-1}) of benzocaine hydrochloride were recorded and its vibrations analysed. A theoretical spectrum with the AM1 semiempirical method was calculated. An infrared study with the temperature was also made. From the experimental data, the torsion and inversion barriers of amine group were calculated.

INTRODUCTION

Local anesthetics are drugs which possess the capacity to block the conduction of nerve action potentials by inhibiting changes in membranes. They have a number of additional effects on membrane structures and functions. These drugs can associate with both the lipids and proteins of cellular membranes[1], inhibit membrane transport[2] and alter surface mobility[3]. The infrared and Raman spectra of these local anesthetics have been the subject of considerable attention in recent years[4-8] and there is now an almost complete understanding of the vibrational spectra of some of them[6,8]. In these studies, the amino group was indicated to play an important role in the reactivity of these molecules, and for this reason an analysis of the $-NH_2$ torsional and wagging bands was carried out. Benzocaine hydrochloride (BEN-HCL), molecule studied in the present work, shows the amino group as NH_3^+, under the interaction of the Cl^- ions of the hydrochloride. The assignments of its vibrational modes are of considerable interest for a correct interpretation of the physicochemical behavior leading to potential applicability of local anesthetics in pharmacy.

On the IR and Raman assignments of the NH_2 torsional and wagging bands, there are very few data in the literature[9-11], especially in local anesthetics, regardless of their phase, although this could be attributable to the low intensity of these bands in the spectra. The aim of this paper is to make a systematic investigation in order to clarify the matter. In the amino group of BEN-HCL, the IR and Raman bands of the torsion and wagging modes were tentatively assigned. The spectra in other regions were also studied and assignments have been proposed.

MATERIALS AND METHODS

Samples of BEN-HCL from Merck were used without further purification. The deuteration was carried out by simple dissolution with D_2O and the sample was dried in a vacuum oven.

The infrared spectra in solid phase with KBr pellets were recorded in a Perkin-Elmer 599 B spectrophotometer. For the study with temperature, the

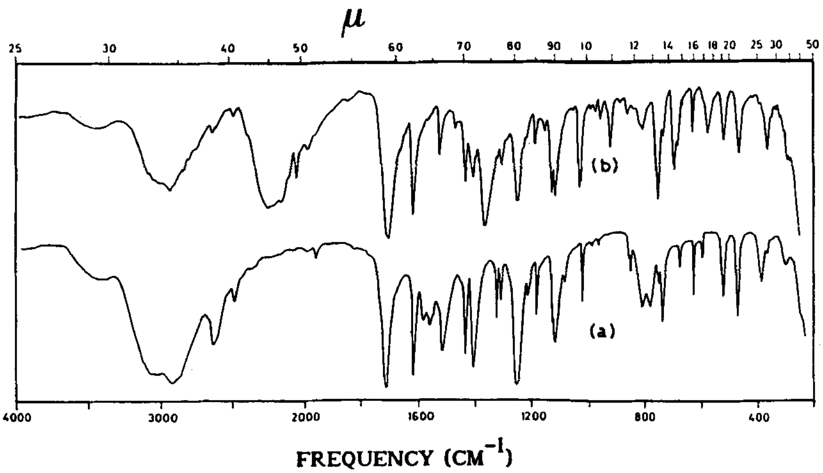

Fig. 1. Infrared spectra of solid BEN-HCL, a) non-deuterated, b) deuterated.

samples were warmed in an aluminium cell with external windows of KBr, using the automatic temperature controller CTC-250 (Beckman). The scale employed ranged from room temperature to 200°C and was monitored with a thermocouple.

Raman spectra of samples were recorded with a Jobin-Yvon Model Ramanor U-1000 laser-Raman double monochromator equipped with holographic gratings. Photon counting was used for signal detection and the source was a Spectra-Physics Model 165 2ω Argon ion laser. The laser power employed was in the range 100-400 mω.

RESULTS AND DISCUSSION

INFRARED SPECTRA

Fig. 1a shows the IR spectrum of BEN-HCL in the solid state in the 200-4000 cm^{-1} range using KBr pellets. To help in the identification of the amino

Table 1. Frequencies in cm^{-1} and tentative assignments of the bands in the Infrared and Raman spectra of deuterated and non-deuterated solid benzocaine hydrochloride.

Raman	I.R.			Assignment
$-NH_2$	$-NH_2$	$-ND_2$	sol(200^{o}C)	
3077.5 m	3000 vs 2910 vs	3080 vs	3000 2900 bd	ν_{as}(N-H) in NH_3^+
3060 vw		-		ν_s(N-H) in NH_3^+
3049 m		-		ν_s(N-H) in NH_3^+
3014.5 w		-		ν(N-H···)inter.
2984.5 vw		-		ν(C-H)ring, ν(C-H)sat.
2955 vw		-		
-	-	3010 s	-	ν(N-H) in NDH_2^+
-	-	2912 s	-	ν(N-H) in ND_2H^+
-	2600 s	2630 w	2580 s	Combination band or ν(N-H···)inter.
-	2480 w	2480 w	2470 w	Combination band
-	2460 w	-	-	Combination band
-	-	-	2320 m	
-	-	2240 vs 2210 vs 2150 s	-	ν(N-D) in NDH_2^+, ND_2H^+ and ND_3^+
-	-	2040 m	-	ν(N-D···)inter. ?
-	1947 w	-	-	$\beta_s(NH_3^+)$ + δ(C-H) ?
1697 s	1700 vs	1700 vs	1705 vs	ν(C=O)
1654 vw	-	-	-	$\beta_s(NH_3^+)$?
-	1610 vs	1612 vs	1605 s	ν(C=C) 8a
1580 vs	1572 w	-	-	ν(C=C) 8b
-	1550 m	-	1558 m	$\beta_s(NH_3^+)$

Table 1. (continued)

1519 w	1505 m	1515 m	1492 s	ν(C=C) 19a, ν(COC) ?
-	-	1460 vw	-	$\beta_s(NH_2D^+ + NHD_2^+)$?
1427 w	1423 s	1423 s	1423 s	ν(C=C) 19b ?
1397 m	1393 m	1397 m	1385 m	δ_{as}(C-H)sat.
1319 w	1318 m	1315 w	1318 m	ν(C=C) 14, δ(C-H) in CH_2
1298 m	1303 w	1300 w	1300 vw	δ(C-H) in CH_3
1274 w	-	-	-	δ(C-H) 18a coupled with 19a
1240 s	1245 vs	1245 s	1230 vs	ν(COC), δ(C-H), ν(C-N)?
1213 m	1209 vw	1213 vw	-	$\delta(NH_3^+)$
1194 m	-	-	-	δ(C-H)ring.
1175 s	1180 m	1182 m	1180 m	δ(C-H) in CH_2, ν(C-C)
-	-	1148 w	-	$\beta_s(ND_3^+)$
1117 s	1120 s	1124 s	1120 sh	δ(C-H) in CH_2
-	1110 s	1112 s	1110 m	δ(C-H) 18b
1092 vw	1080 w	-	-	$\Gamma(NH_3^+)$
1076 w	-	-	-	δ(C-H) in CH_2
1050 vw	-	-	-	δ(C-H) 18a coupled with 19a
-	-	1029 s	-	δ_{as}(C-D) ?
1035 w	1020 m	1022 s	1018 w	δ(C-H) in CH_3, δ(C-H) 7a
1001 m	-	-	-	γ(C-H)
986 w	990 vw	990 vw	-	γ(C-H) 17a
970 m	964 vw	972 vw	-	γ(C-H) in CH_3 ?
-	-	958 w	-	δ(C-D)
939 w	-	-	-	γ(C-H) 5

(continued)

Table 1. (continued)

927 w	-	-	-	γ(C-H) 5
-	-	921 m	-	$\Gamma(NH_2D^+) + \Gamma(NHD_2^+)$
-	-	888 vw	-	δ(C-D)
-	860 w	862 w	-	γ(C-H) 17b
837 s	852 w	-	850 vw	δ(CCC), δ(COO)
824 s	-	-	-	δ(C-H), δ(CCC)
-	-	812 sh	-	δ(C-D)
772 vw	810 w	810 vw	-	$\gamma(NH_3^+)$ wagging, δ(CCC)
-	-	758 m	-	$\Gamma(ND_3^+)$
755.5 w	753 w	-	-	γ(COO) ?
742 w 722.5 w	740 m	738 w	740 m	γ(C-H)
-	-	698 s 686 m	-	$\gamma(NH_2D^+) + \gamma(NHD_2^+)$ wagging
682.5 w	680 w	-	680 vw	γ(CCC) 4, γ(COO)
666.5 s	-	-	-	γ(C-H)
632 s	632 m	635 m	632 w	δ(CCC) 6b ?
585.5 vw	602 w	-	600 vw	$\gamma(NH_3^+)$ wagging
-	-	580 m	-	$\gamma(ND_3^+)$ wagging
529 m	525 m	525 m	520 m	γ(CCC)
471 w	478 s	480 s	475 m	γ(CCC) 16b
-	-	438 vw	-	$\gamma(ND_3^+)$ wagging
424 vw	390 m	395 vw	-	$\tau(NH_3^+)$ torsion
-	-	370 m	-	
369.5 m	366 w	355 vw	-	δ(C-N) in NH_3^+
313 w	300 w	300 w		γ(C-R) 10b ?

Table 1. (continued)

-	-	290 vw	$\tau(ND_3^+)$ torsion
247.5 m			τ(structure) ?
234.5 vw			$\gamma(NH_3^+)$ wagging, δ(structure)
150 vs			$\tau(-CH_2-CH_3)$, γ(C-O)
116 s			$\tau(CH_3)$

Abbreviations used: vs, very strong; s, strong; m, medium; w, weak; vw, very weak; sh, shoulder; bd, broad; inter, intermolecular; sat., saturated chain.

torsional and wagging bands, the spectra of the deuterated compound was recorded (Fig 1b). The frequencies of the observed bands, their estimated intensities and assignments are listed in Table 1, in the second and third columns for the non-deuterated and deuterated compounds respectively. The frequencies assigned with vibration number in Wilson's notation refer to the aromatic ring. A theoretical study by AM1 was carried out[12] and its spectrum calculated, Fig. 2. The different modes of these spectra were studied as follows:

Amino group vibrations : A very broad band observed at high frequency with two maxima at 3000 and 2910 cm^{-1} was assigned to the NH_3^+ group. There were also contributions to the intensity of this band from C-H stretchings of the ring and of the saturated chain. In Benzocaine of free basis (BEN)[8] the amino group (NH_2) stretching bands appear narrow and at higher frequencies. In BEN-HCL the hydrochloride is linked to the amino group because the hydrogen of the HCl group is situated where the BEN molecule presents the most basicity which correspond to the proximities of this group[13]. The geometry of the $-NH_2$ group is very strongly changed by the new hydrogen introduced and has strong

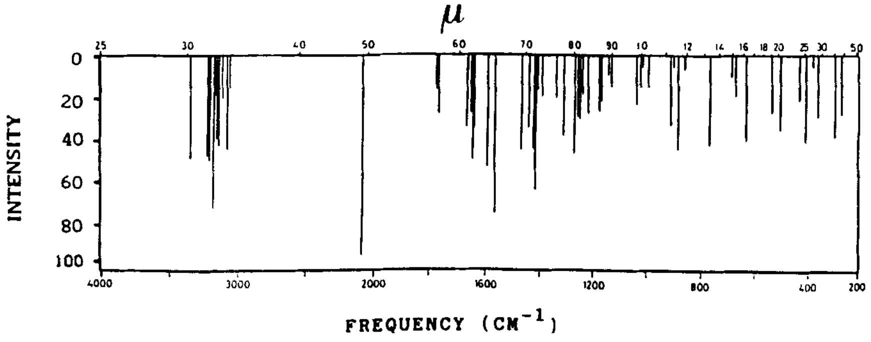

Fig. 2. Theoretical spectrum of BEN-HCL by the AM1 semiempirical method.

interactions with the Cl^- ions of the hydrochloride. The broadening of the bands in BEN-HCL can be attributed to hydrogen bonding.

With deuteration, the intensity of this broad band decreased, strong new absorptions appearing at 2240, 2210 and 2150 cm^{-1} which because of their form and position were assigned to N-D stretchings in amino groups totally and partially deuterated. The N-H stretching in these mixed forms were assigned to the new bands at 3010 and 2912 cm^{-1}. The N-H/N-D ratio in these vibrations was according to the harmonic approximation[8].

The bands corresponding to intermolecular hydrogen bonds were difficult to assign, because they were hidden by broad and strong absorptions in the 2500-3100 cm^{-1} range. Interactions of the *p*-amino group with Cl^- ions possibly constitute intermolecular bond type N-H···Cl and not N-H···O as in BEN[6].

The scissoring $\beta_s(NH_3^+)$ mode was observed at 1550 cm^{-1}, lower than for the NH_2 group (around 1630 cm^{-1}) in aniline derivatives. With isotopic substitution, the band disappeared completely, this mode appearing at 1148 cm^{-1} corresponding to the ND_3^+ group. The decrease of ca. 425 cm^{-1} by deuteration of the amino group finds support from that reported for the $[C_6H_5NH_3]^+$ cation[14]. The absorption observed at 1460 cm^{-1} with very weak intensity could be due to β_s in partially deuterated groups NH_2D^+ and NHD_2^+.

The rocking mode $\Gamma(NH_3^+)$ was detected with weak intensity at 1080 cm^{-1} and disappeared with isotopic substitution. The new bands on deuteration at 921 and 758 cm^{-1} were tentatively assigned because of their form and position as rocking modes in partially deuterated groups NH_2D^+, NHD_2^+ and in the ND_3^+ group respectively.

In the low frequency range, the bands at 810 and 602 cm^{-1} decreased in intensity with the deuteration, new bands appearing at 580 and 438 cm^{-1}. The ratio between 810 and 580 cm^{-1} was 1.396 and between 602 and 438 cm^{-1} was 1.374, in accordance with the harmonic approximation with similar value in BEN[6]; Hence these bands were assigned to the out-of-plane $\gamma(NH_3^+)$ and $\gamma(ND_3^+)$ wagging. These absorptions, however, appeared at frequencies ca. 150 cm^{-1} higher than in related molecules[9-11,15,16]. This fact was attributed to an appreciable increase in the inversion barrier height, owing to different geometric parameters in the amino group with less motion of the hydrogens, and in good agreement with the strong decrease in the frequency of their N-H stretching modes. The new bands situated at 698 and 686 cm^{-1} in the IR spectrum of the deuterated compound were identified as the wagging mode in NH_2D^+ and NHD_2^+ groups.

The very weak band at 290 cm^{-1} was designated as $\tau(ND_3^+)$ mode, while in the non-deuterated analogue it was assigned to the medium intensity band at 390 cm^{-1}. The ratio between both frequencies was in good agreement with that reported in related compounds[6,9-11,17].

A slight contribution of the ν(C-N) stretching vibration to the strong band at 1245 cm^{-1} is expected. The decrease ca. 40 cm^{-1} with regard to BEN was in agreement with the decrease in electronic density at the C-N bond, due to the new hydrogen of the amino group. According to other hydrochloride compounds[18], this new hydrogen was more strongly bonded to nitrogen than were the other two hydrogens. Thus both hydrogens have a lower force constant for their N-H bonds and higher $H\hat{N}H$ and inversion angles, in agreement with the strong decrease in the frequency of the N-H stretching bands and the increase in frequency of the wagging vibrations. The observation in the spectrum of the deuterated compound of many mixed species of H and D, in all the bands of the amino group, corroborated this fact. The C-N bending mode was recorded at 366 cm^{-1}, in the range of other aniline derivatives[19,20].

Ester group vibrations: The stretching band of the carboxylic group C=O appears at 1700 cm^{-1} being responsible for the most intense IR band. When BEN is in solution[8], the intermolecular bond type N-H···O, does not exist, and this ν(C=O) mode is observed at 1700 cm^{-1} the same frequency as in our case. Hence in BEN-HCL in the solid state, the carboxylic group was free and not involved in interactions with the atoms of the hydrochloride moiety, nor in the crystalline lattice through that moiety. These features corroborated that the band registered in the spectra tentatively assigned as intermolecular hydrogen bonds, corresponded to type N-H···Cl.

The C=O out-of-plane bending was observed with weak intensity at 680 cm^{-1}. Another band corresponding to this mode was characterized[12] by AM1 at 753 cm^{-1}. The C-O-C stretching vibration was tentatively assigned at 1245 cm^{-1}, as in methyl p-hydroxybenzoate[20]. A slight contribution to this mode was computed[12] by AM1 for the band at 1505 cm^{-1}.

Ethyl group vibrations: The frequencies of C-H stretching mode were hidden by the broad and very strong band established in the 2700-3100 cm^{-1} range of the spectrum. The bands at 1393, 1303, 1120 and 964 cm^{-1} were assigned to C-H in-plane bending of CH_3 and CH_2 groups. Slight contributions of this moiety were calculated[12] in the absorptions at 1318, 1180 and 1020 cm^{-1}.

Normal vibrations of the ring: The bands with prominent intensities at 1610, 1572, 1505 and 1423 cm^{-1}, lying in the 1400-1630 cm^{-1} range, were assigned to C=C stretching frequencies, in particular to modes 8a, 8b, 19a and 19b following Wilson's notation. These assignments are supported by the data reported on benzene derivatives[20]. The vibration mode 14, kekule vibration, slightly changes with substitution of the ring and therefore identified at 1318 cm^{-1}. Mode 18b, regarded as C-H in-plane bending vibration, was observed with strong intensity at 1110 cm^{-1}.

In the radial vibrations, only a slight contribution of mode 7a was clearly recognized at 1020 cm^{-1}, the band at 632 cm^{-1} tentatively assigned to mode 6b. The C-H stretching modes of vibrations, 2, 20a and 20b, were not distinguished in the broad band above 2700 cm^{-1}.

The C-H out-of-plane bending vibrations are characterized in *p*-benzene derivatives by normal modes 17, 10a and 5; in our case only mode 17b at 860 cm^{-1} and 17a at 990 cm^{-1} were identified. With the C-R out-of-plane bending vibrations, denoted by normal modes 10b and 11, the band at 300 cm^{-1} was tentatively assigned to mode 10b, while mode 11 appears in the range of 115-215 cm^{-1} out of the IR spectra recorded. Another normal vibration of the ring, but corresponding to C-C-C out-of-plane bending, was assigned to mode 16b at 478 cm^{-1} with strong intensity. A slight contribution of mode 4 was also computed for the band at 680 cm^{-1}. These assignments are supported by those reported in *p*-amino benzoic acid[19].

TEMPERATURE EFFECT

The temperature influence on the IR spectrum in the solid state was studied in the 25-200°C range. In Fig. 3 the IR spectra are only registered at the temperatures 25, 100, 150 and 200°C. In the fourth column of Table 1 are shown the results obtained only at the highest temperature registered, 200°C.

The most important changes observed in the spectra as the temperature rose were as follows: The bands at low temperatures had little or no displacement, but when the temperature was high (>100°C) a slight decrease in the frequencies was observed. The frequency of the ν(C-N) and ν(COC) modes decreased ca. 15 cm^{-1}, while the ν(C=O) mode remained unchanged. With heating of the sample, the bands at 1572, 1080, 990 and 860 cm^{-1} corresponding to ν(C=C) 8b, $\Gamma(NH_3^+)$, γ(C-H) 17a and γ(C-H) 17b modes respectively, and the

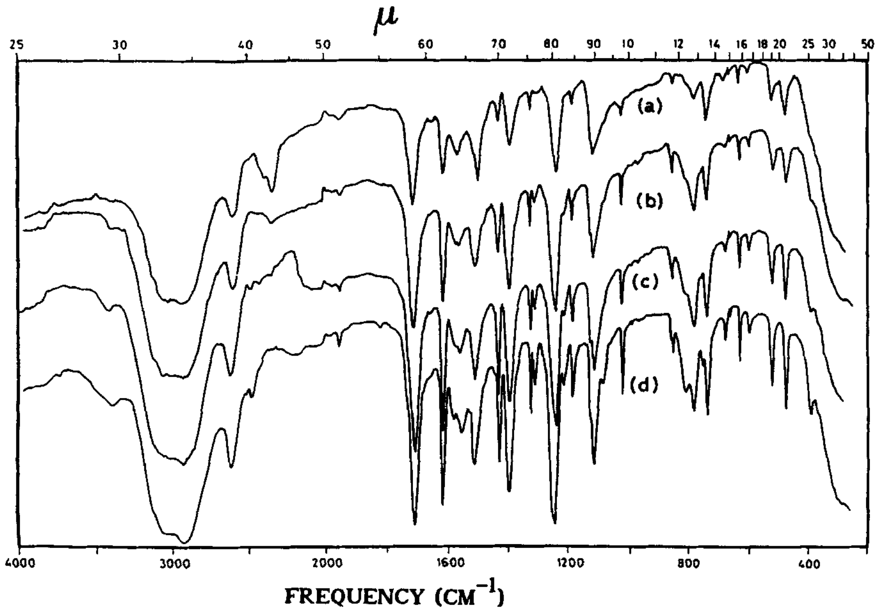

Fig. 3. IR spectra spectra of solid BEN-HCL at different temperatures, a) 200°C, b) 150°C, c) 100°C and d) 25°C.

bands at 964 and 753 cm^{-1}, disappeared. The torsion and wagging modes of the amine group decreased in intensity and disappeared because of their sensitivity to temperature. The overtones and combinations bands also diminished in intensity as the temperature rose.

The band at 2600 cm^{-1} remained unchanged until nearly 200°C, appearing then at 2580 cm^{-1}. The great width of this band, if ascribed as an intermolecular hydrogen bond, should be attributed to a polymeric intermolecular association through the amino group, which would be strong because it does not change in intensity when the temperature increases.

At 150°C a new band appeared at 2320 cm^{-1} which increased in intensity as the temperature rose, possibly due to the presence of a new association.

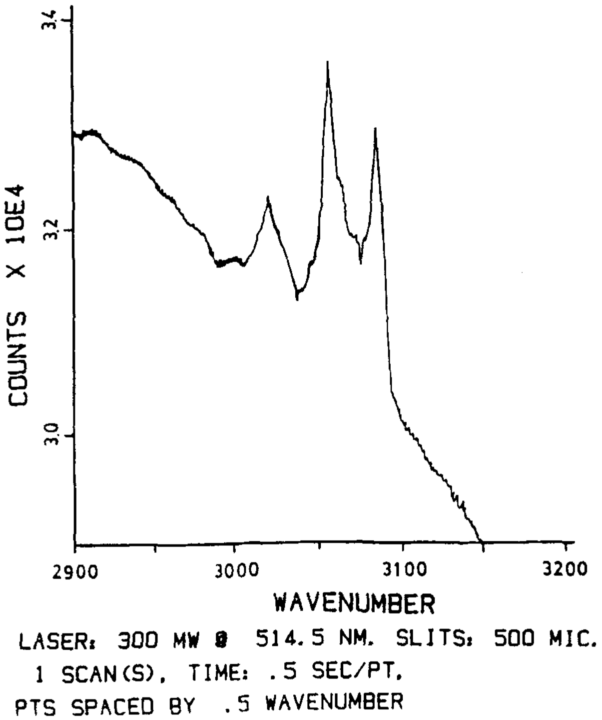

Fig. 4. Raman spectrum of solid BEN-HCL between 3200 and 2900 cm^{-1}.

RAMAN SPECTRA

In Figs. 4-6 are shown the Raman spectra of BEN-HCL in the solid state. The assignments for the observed Raman lines are listed in the fifth column of Table 1. The analysis of the fundamental vibrations was carried out as follows:

Amino group vibrations: In the Raman spectrum, Fig. 4, it was possible to identify the symmetric and asymmetric stretching vibrations of the NH_3^+ group at 3049, 3060 cm^{-1} and at 3077.5 cm^{-1} respectively. These assignments are supported by the data on $[C_6H_5NH_3]^+$ cation and on monomethyl ammonium ion[14,21].

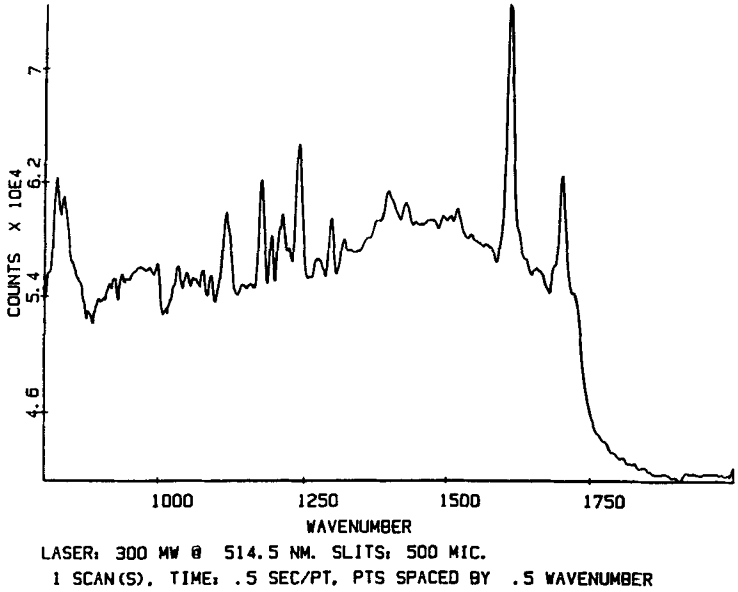

Fig. 5. Raman spectrum of solid BEN-HCL between 2000 and 750 cm^{-1}.

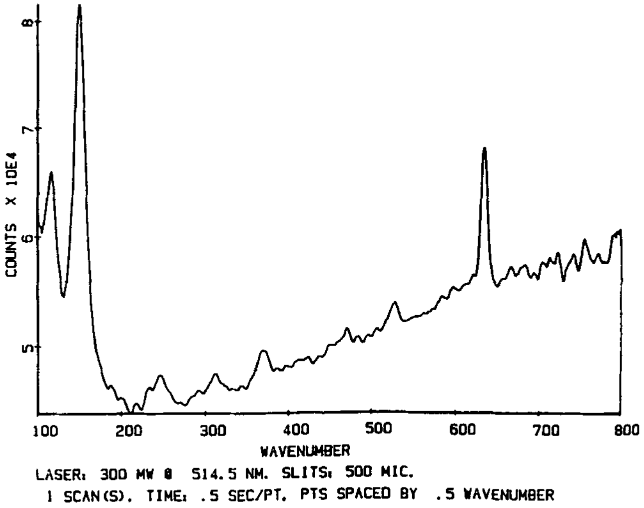

Fig. 6. Raman spectrum of solid BEN-HCL between 800 and 100 cm^{-1}.

The scissoring $\beta_s(NH_3^+)$ and rocking $\Gamma(NH_3^+)$ modes were in general very difficult to observe in the Raman spectra[17], non-appearing or with very weak intensity. Thus a very weak band at 1654 cm^{-1} tentatively assigned to $\beta_s(NH_3^+)$ mode and a band at 1092 cm^{-1} assigned to $\Gamma(NH_3^+)$ were recognized.

The bands at 772 and 585.5 cm^{-1} were identified as the wagging mode, while the vibration at 424 cm^{-1} was assigned to the torsion mode of the NH_3^+ group. A decrease compared to IR in the wagging frequencies and related increment in the torsional mode was observed.

Normal vibrations of the ring: The frequencies of tangential skeletal vibrations were close to those found in IR In the intensity, modes 19 and 14 appeared weak in disagreement with IR while mode 18b was not detected. New bands at 1274 and 1050 cm^{-1} were assigned to mode 18a coupled strongly, according to Scherer[22], with vibration 19a.

A slight contribution of radial vibration 7a was assigned[20] to the weak band at 1035 cm^{-1}. An increase ca. 15 cm^{-1} respect to IR was observed.

The out-of-plane skeletal vibration 16b appeared, also with weak intensity, at 471 cm^{-1}, while mode 4 was identified at 682.5 cm^{-1}. Among the C-R out-of-plane vibrations was registered only the normal mode 10b at 313 cm^{-1}, because of the low frequency of mode 11, and possibly because this mode was hidden by the strong bands at 150 and 116 cm^{-1}. C-H out-of-plane vibrations are the normal modes 5, 10a, 17a and 17b. The weak bands at 939 and 927 cm^{-1} were assigned to mode 5. Mode 10a generally gives a weak or very weak band in IR and Raman spectra of benzene derivatives[20], which reasonably explains why this vibration was not detected in our spectra. Mode 17a appeared at 986 cm^{-1} while the IR band corresponding to vibration 17b was not recorded in Raman.

Other vibrations: The frequencies of *ester* and ethyl groups were generally characterized close to IR. New bands at 1076, 1001, 824 and 666.5 cm^{-1} were observed and tentatively assigned to C-H bending in saturated chain. The strong bands at 150 and 116 cm^{-1}, Fig. 6, were assigned to torsional mode in ethyl and $-CH_3$ groups respectively. Bending and torsion of the complete molecular structure[12] were determined for the bands at 234.5 and 247.5 cm^{-1} respectively.

The overtones and combinations bands were not observed in the Raman spectra.

ROTATION OF THE AMINO GROUP

The rotational barrier V_2 corresponding to the torsional mode in the amino group was calculated, for a rotation potential function[23]:

$$V(\alpha) = 1/2 \; V_2 \; (1 - \cos 2\alpha) \qquad (1)$$

where α is the rotation angle.

In order to determine the value of V_2 several authors[24] have used the harmonic approximation, which in our case provided the data of the fourth column in Table 2. In the second column are shown the experimental torsional frequencies and in the third column are computed the rotation constants, B_o in cm^{-1}, calculated through the optimized parameters of the amino group (Table 3). A more rigorous optimization procedure[6,17] was used, solving the rotation Hamiltonian[25,26], and computing the values of the rotation barrier V_2, fifth column, Table 2, in which all the values were higher than those obtained by the harmonic approximation. The difference between both methods increases as the torsional frequency rises. However, the differences were relatively slight, therefore the procedure based on the harmonic approximation to fit the potential function from the frequency measurements in the spectra is appropriate in this kind of compounds.

INVERSION OF THE AMINO GROUP

The possible inversion transitions of the amino group in several substituted anilines in gas phase have been reported. In the solid state however, the

Table 2. Experimental frequencies and optimized values of the torsional barriers V_2 in cm^{-1}.

Amino group	τ^{exp}	B_o	Barrier height V_2	
			Harm. approx.	Hamilt. calc.
Deuterated	290 (IR)	3.28	6410	6600
Non-deuterated	424 (R)	5.60	8026	8243
	390 (IR)		6790	6974

(IR) and (R) values obtained by IR and Raman spectroscopy, respectively.

Table 3. Bond lengths and bond angles of the amine group in BEN-HCl calculated by semiempirical methods.

Parameters	CNDO/2		AM1	
	Bond lengths (Å)	Bond angles (°)	Bond lengths	Bond angles
C - N	1.46		1.4648	
N - H	1.085		1.0264	
N - H^+	1.04		1.0274	
$H\hat{N}H$		108		109.25
$H\hat{N}C$		109		109.97
H_2N - aromatic ring plane (ωo)		56.5		53.88
H^+ N - aromatic ring plane		64.0		70.56

Table 4. Optimized values in the amino group of the inversion angle ω_o in degrees, the barrier height $\hat{V}_i$ in cm^{-1} and the associated frequencies ($\nu_1 \rightarrow \nu_4$) in cm^{-1}, computed for the first four energy levels with a torsional hamiltonian (T.H.) and a vibration harmonic approximation (H.A.V.)

Method	Freq.	ω_o(°)	V_1^i	V_2^i	$\hat{V}_i$	ν_1	ν_2	ν_4	ν_6
T.H.	IR	20.1	450000	-119796	444	208	810*	602*	465
	R	20.2	415000	-110550	418	186.5	772*	585.5*	430
H.A.V.	IR	8.6	-	-	650	208	810*	602*	378
	R	9.8	-	-	680	186.5	772*	585.5*	378
T.H.	IR (deut.)	13.8	192000	-49427	410	142	580*	438*	380
H.A.V.	R (deut.)	13.5	-	-	670	142	580*	438*	250

IR and R, Infrared and Raman respectively; (deut.), deuterated compound;

* frequencies obtained experimentally.

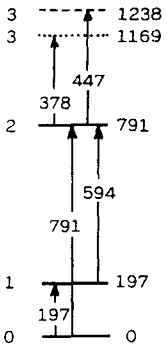

Fig. 7. Inversion energy levels and comparison of both methods, torsional Hamiltonian (- - -) and vibration harmonic approximation (. . .).

search of these experimental wagging frequencies is more complicated because these bands appear broad and with weak intensity[27,28]. Thus in our study of BEN-HCL, as in other local anesthetics studied, only two wagging bands were clearly identified. With these two wagging bands and with the transition scheme[29] of the six different possible modes in which the inversion transitions can be realized for the first four energy levels, two distinct methods were used in our study.

In Table 4, the results obtained with a torsional Hamiltonian (T.H.) and an harmonic approximation of vibration (H.A.V.) are shown. The inversion angle ω_o and the inversion barrier $\hat{V}_i$ in the amino group appear in the third and sixth columns respectively. The parameters V_1^i and V_2^i of the fourth and fifth columns are from the eqns. reported by Larsen[30]. In the seventh to tenth columns are listed the frequencies of inversion energy transitions through the two wagging bands observed in the spectra (eighth and ninth columns). The transitions produced, according to the same model selected in other local anesthetics[29], were: $\Psi_o^s \to \Psi_o^{as}$, $\Psi_o^s \to \Psi_1^s$, $\Psi_o^{as} \to \Psi_1^s$ and $\Psi_1^s \to \Psi_1^{as}$.

Table 4 shows that the H.A.V. computes excessively low values for ω_o and higher $\hat{V}_i$ than those calculated by T.H. Nevertheless, the data providedby both procedures for ω_o were lower than the theoretical value obtained by semiempirical methods, Table 3. Similar results were reported and explained using related molecules[31,32]. In Fig. 7 the inversion transitions calculated for both methods are illustrated. The frequency values in this figure are the average between the IR and Raman data. These results are supported by the data calculated in other local anesthetics[29].

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