Conformational Study of Taurine in the Gas Phase[†]

Vanessa Cortijo, M. Eugenia Sanz, Juan C. López, and José L. Alonso*

Grupo de Espectroscopia Molecular (GEM), Departamento de Química Física, Facultad de Ciencias, Universidad de Valladolid, 47005 Valladolid, Spain

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The conformational preferences of the amino sulfonic acid taurine ($NH_2-CH_2-CH_2-SO_3H$) have been investigated in the gas phase by laser ablation molecular beam Fourier transform microwave spectroscopy (LA-MB-FTMW) in the 6−14 GHz frequency range. One conformer has been observed, and its rotational, centrifugal distortion, and hyperfine quadrupole coupling constants have been determined from the analysis of its rotational spectrum. Comparison of the experimental constants with those calculated theoretically identifies the detected conformer unambiguously. The observed conformer of taurine is stabilized by an intramolecular hydrogen bond O−H···N between the hydrogen of the sulfonic acid group and the nitrogen atom of the amino group.

Taurine, also known as 2-amino-ethanesulfonic acid ($NH_2-CH_2-CH_2-SO_3H$), is a relevant biomolecule in a variety of physiological processes such as the development of the brain and tissues,[1] calcium modulation, and osmoregulation.[2] Taurine also acts as a neurotransmitter in the central nervous system activating some of the same receptors as γ-aminobutyric acid (GABA).[3,4] The biological activity of taurine depends on its molecular shape. Knowledge of the intramolecular and intermolecular forces is necessary to understand the way in which taurine interacts with other molecules. This knowledge can only be achieved in the gas phase, where it is possible to discriminate between inherent and external properties and where the interaction of an isolated molecule with others can be precisely controlled. To date, the structure of taurine has only been determined in crystals,[5] where it is stabilized as a zwitterion ($NH_3^+-CH_2-CH_2-SO_3^-$). The lack of studies on taurine in the gas phase, where it adopts a neutral form, is most likely due to the fact that it is a solid at room temperature with a high melting point. In this Letter, we present the investigation of the shape of taurine in the gas phase. We have vaporized taurine by laser ablation (LA), seeded it in a molecular beam (MB), and used rotational spectroscopy in the time domain (FTMW) to probe its conformations. The 355 nm light of a pulsed Nd:YAG laser is used to transfer solid taurine (mp 328 °C) to the gas phase. The vaporized molecules are dragged by a Ne flow (stagnation pressure 20 bar) into a Fabry−Pérot resonator at very low pressures, where they form a molecular beam. A very short microwave radiation pulse (0.3 μs) is then applied to macroscopically polarize taurine. Once the exciting radiation ceases, the molecular decay signals are collected in the time domain and converted to the frequency domain by Fourier transform. LA-MB-FTMW[6,7] spectroscopy provides the high resolution and sensitivity needed to distinguish unambigously between the different conformational structures and provide accurate structural information directly comparable to the in vacuo theoretical predictions.

Taurine is a flexible molecule that can adopt a number of conformations by rotation around its single bonds (see Table 1). To guide the spectroscopic assignments a conformational search was performed using the computationally inexpensive semiempirical method AM1[8] without imposing any restrictions on the torsions of the dihedral angles. Twenty different conformers were found, whose geometries were subsequently fully optimized[9] using the B3LYP density functional and the 6-311++G(d,p) basis set. The seven lowest-energy structures were then reoptimized again using the frozen core Moller−Plesset (MP) second-order perturbation method and the same basis set. The resulting geometries (see Table 1) show intramolecular hydrogen bonds established between the amino and the sulfonic groups: N−H···O=S (type I), O−H···N (type II), and N−H···O−H (type III), and they have been labeled following the nomenclature employed in aliphatic α-amino acids for the amino−carboxylic interactions.[6] The derived theoretical spectroscopic constants and dipole moment components collected in Table 1 have been used to predict the spectral positions and intensities of rotational transitions. On this basis, it was relatively straightforward to recognize the rotational spectra of one rotamer. All observed transitions were split in several components. Taurine bears a ^{14}N atom with nonzero quadrupole moment ($I = 1$) which interacts with the electric field gradient at the site of the nucleus and causes the coupling of the nuclear spin to the overall rotational momentum. The coupling results in hyperfine splitting patterns (see Figure 1) for all transitions. After many trials the patterns of nine ^aR-, three ^bR-, and three ^cR-branch transitions were assigned. A total of 43 hyperfine transitions were fitted (see Supporting Information)[10] using a Watson's S-reduced semirigid rotor Hamiltonian in the I^r representation,[11] $H_R^{(S)}$, supplemented with a term that accounts for the nuclear quadrupole coupling interaction, H_Q.[12] The spectroscopic constants determined from the fit are given in Table 2.

The experimental rotational constants are consistent with those predicted for conformers IIa and IIb (see Tables 1 and 2). However, the quadrupole coupling constants of the detected species only match those predicted for conformer IIa and thus allow the unambiguous identification of the observed species as taurine IIa. Furthermore, the predicted values of the electric dipole moment components for conformer IIa (see Table 1) are in good agreement with the microwave power needed for

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* Corresponding author: e-mail, jlalonso@qf.uva.es; fax, +34-983-423204.

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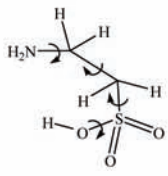
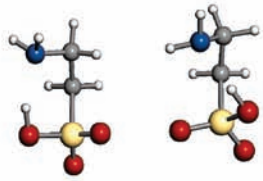
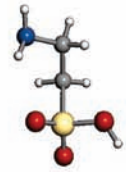
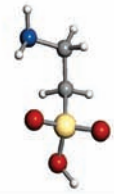
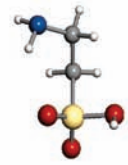
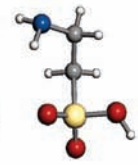
TABLE 1: Predicted Spectroscopic Parameters for the Lowest-Energy Conformers of Taurine at the MP2/6-311G(d,p) Level

	Type II (O–H···N)		Type I (N–H···O)				Type III (N–H···O–H)
	IIa	IIb	Ia	Ib	Ic	Id	IIIa
A/ MHz	3939	3878	4004	4036	3896	3986	3883
B/ MHz	1726	1776	1581	1553	1576	1572	1621
C/ MHz	1634	1679	1517	1497	1525	1509	1537
χ_{aa}/ MHz	-2.23	-1.00	2.02	2.01	-2.20	-2.14	2.05
χ_{bb}/ MHz	0.59	1.40	2.49	2.67	2.73	2.66	2.54
χ_{cc}/ MHz	1.64	-0.40	-4.50	-4.69	-0.54	-0.52	-4.59
μ_a/D	-7.2	6.7	1.5	0.7	-1.6	0.5	-3.2
μ_b/D	1.2	-1.8	3.6	2.4	1.8	3.1	0.0
μ_c/D	1.6	0.6	-0.7	0.8	0.0	1.2	1.5
μ_{total}/D	7.5	6.9	3.9	2.6	2.4	3.3	3.5
ΔE/ cm^{-1}	0	1151	1874	2034	2043	2093	1887
							

optimal polarization of the *a*-, *b*-, and *c*-type transitions. Additional searches in several frequency regions were carefully carried out to look for other taurine conformers, but no further transitions were detected. Considering that other conformers are predicted to lie above 1000 cm^{-1} of conformer IIa, they might not be populated enough in our molecular beam for their transitions to be above noise level.

The conformational landscape of taurine is dominated by a single conformer that is stabilized by an intramolecular O−H···N hydrogen bond established between the amino and sulfonic groups. The observed conformer is predicted as the global minimum, being approximately 1000 cm^{-1} more stable than the second most stable form, which also presents a O−H···N hydrogen bond. However, conformer IIb is destabilized by a more folded arrangement of the amino and sulfonic groups (the dihedral angle ∠NCCS is −37° in IIb while in IIa it is −60°). Interestingly, conformers displaying a N−H···O hydrogen bond are predicted to be considerably higher in energy, and their energies are similar to those conformers with a N−H···O−H intramolecular interaction. All this implies that the hydrogen atom of the oxygen in the sulfonic group is much more electrophilic than the amino group hydrogens. Besides, the nucleophile character of the oxygen in the sulfonic acid group does not seem to change much upon having a hydrogen atom bound to it since the energies for the type I and type III conformers are alike.

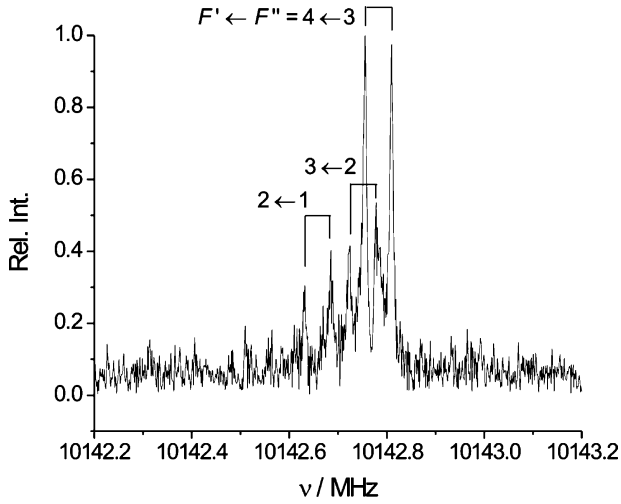
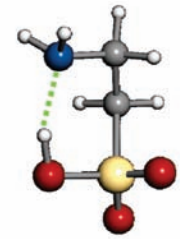


Figure 1. The $3_{0,3} \leftarrow 2_{0,2}$ rotational transition of the taurine conformer IIa showing the nuclear quadrupole hyperfine structure. In our setup the molecular beam and the microwave radiation travel parallel to each other, which causes each rotational transition to appear as a doublet due to the Doppler effect. The molecular frequency is the arithmetic mean of the frequencies of the Doppler components.

TABLE 2: Experimental Spectroscopic Constants of the Observed Conformer of Taurine

A^a /MHz	4028.96103 (98)^b
B /MHz	1739.75877(36)
C /MHz	1645.00253(37)
Δ_J / kHz	0.229(12)
χ_{aa} /MHz	-2.0181(45)
χ_{bb}/MHz	0.5483(61)
χ_{cc} /MHz	1.4742(61)
N^c	43
σ /kHz	3.5



[a] *A*, *B*, and *C* are the rotational constants; Δ_J is a quartic centrifugal distortion constant; χ_{aa}, χ_{bb}, and χ_{cc} are the diagonal elements of the ^{14}N nuclear quadrupole coupling tensor. [b] Standard error in parentheses in units of the last digit. [c] Number of fitted transitions. [d] Root mean square of the fit.

The conformational preferences of taurine can be compared with those of related β-alanine, a β-amino acid where a carboxylic group replaces the sulfonic group. In β-alanine four conformers have been detected.[13] The most populated conformer (global minimum) bears a N−H···O hydrogen bond between the amino and carboxylic groups, as it does the second most populated conformer. The third most populated conformer, very close in population to the second one, is stabilized by a O−H···N hydrogen bond. The very different conformational behavior of β-alanine and taurine can be attributed to the different polar groups involved in the intramolecular interactions. The carboxylic group is affected by its *cis*/*trans* conformational equilibrium that favors the forms with N−H···O bond and a

cis-COOH configuration. In addition the sulfonic group has a stronger acidic (electrophilic) character than the carboxylic group (see their gas phase acidities in refs 14 and15). These factors clearly change the balance of forces toward the conformation stabilized by a O−H···N hydrogen bond in taurine.

In this work, we have studied the conformational landscape of taurine and characterized the intramolecular interactions at play in this molecule. Knowing the molecular shape can assist us in understanding biological phenomena, where molecular recognition certainly plays a crucial role. Further steps in this direction imply the study of biomolecules in a media with more resemblance to the biological environment, and in this respect investigations of complexes with water will be carried out using LA-MB-FTMW spectroscopy.

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Supporting Information Available: Tables of the rotational frequencies of the detected conformer of taurine. This material is available free of charge via the Internet at http://pubs.acs.org.

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