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International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.3, pp 1403-1416, 2015

FTIR, FT-Raman and Density functional theory studies on Ofloxacin

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Abstract: FTIR and FT-Raman spectra of Ofloxacin were recorded in the regions 4000-450 cm^{-1} and 4000-50 cm^{-1} respectively. The structure, conformational stability, geometry optimization and vibrational frequencies have also been investigated. Satisfactory vibrational assignments were made for the stable conformer of the molecule using density functional theory DFT-B3LYP methods with the 6-31++G(d,p) basis set. Observed fundamental vibrational wave numbers of the molecule and calculated results by DFT method indicates that B3LYP is superior for molecular vibrational problems. The most stable conformer was optimized and the structural and vibrational parameters were determined based on this. The complete assignments were performed based on the Potential Energy Distribution (PED) of the vibrational modes, calculated using Vibrational Energy Distribution Analysis (VEDA) 4 program. The Mulliken atomic charges and thermodynamic functions of the title molecule were also performed using the DFT method.

Keywords: Ofloxacin, FTIR, FT-Raman, DFT.

1. Introduction

Ofloxacin is a synthetic antibiotic of the fluoroquinolone drug class considered to be a second-generation fluoroquinolone [1-2]. Ofloxacin was first patented in 1982 (European Patent Daiichi) and received approval from the U.S. Food and Drug Administration (FDA) on December 28, 1990. Ofloxacin is sold under a wide variety of brand names as well as generic drug equivalents, for oral and intravenous administration. Ofloxacin is also available for topical use, as eye drops and ear drops (marketed as Ocuflox and Floxin Otic respectively in the United States and marketed as Optiflox, eylox respectively in Jordan and Saudi Arabia. Ofloxacin is a racemic mixture, which consists of 50% levofloxacin (the biologically active component) and 50% of its "mirror image" or enantiomer dextrofloxacin. Connecting with our previous studies in the trend of fluoroquinolones metal complexes [3, 4], we are reporting in the present article, the isolation and characterization of some new metal complexes formed from the interaction of ofloxacin. Density functional theory (DFT) is used to compute the cation type influence on theoretical parameters of the Zr(IV) and V(IV) complexes of ofloxacin and shows if the two oxygen atoms (Opyr and Ocarboxilic) of ofloxacin lie at trans or at cis positions so the two diastereoisomers of the studied complexes are going to be calculated. Such computational characterization reduces time consuming experiments for biomedical and pharmaceutical studies of the drugs and its complexes analyses techniques.

To our knowledge, theoretical density functional theory (DFT) calculations or detailed vibrational infrared (IR) and Raman analysis have not been performed on the Ofloxacin molecule. A detailed quantum chemical investigation will aid in understanding the vibrational modes of Ofloxacin and thus clarifying the experimental data available for this molecule. DFT calculations are known to provide excellent vibrational wavenumbers scaled to compensate for the approximate treatment of electron correlation, for basis set deficiencies and anharmonicity effects [5–10]. In this work, by using the DFT-B3LYP methods, we calculated the vibrational wavenumbers of Ofloxacin and molecular geometric parameters. These calculations are valuable for providing insight into the vibrational spectrum and molecular parameters.

2. Experimental

The spectroscopic pure sample of Ofloxacin was procured from a reputed pharmaceutical firm in Chennai, India and used as such without any further purification. The solid phase FTIR spectrum was recorded in the region 4000-450 cm^{-1} in evacuation mode on Nexus 670 DTGS using KBr pellet technique with 4.0 cm^{-1} resolution. FT- Raman spectrum of the powder sample was recorded using 1064 nm line Nd:YAG laser as the excitation wavelength in the region 4000-50 cm^{-1} using Bruker RFS 27 spectrometer with 8 scans at a resolution of 2 cm^{-1}. Spectral measurements were carried out at Sophisticated Analytical Instrument Facility, IIT Madras, India.

3. Computational Method

The theoretical computations were performed at DFT-B3LYP levels on a Pentium IV/1.6 GHz personal computer using the Gaussian 03W program package[12]. DFT employed the B3LYP keyword, which invokes Becke’s three-parameter hybrid method[11] using the correlation function of Lee et al[13]. The optimized geometry was used in the vibrational frequency calculations at the DFT level to characterize all stationary points as minima. Finally, calculated normal-mode vibrational frequencies provide thermodynamic properties by way of statistical mechanics.

4. Results and discussion

4.1 Molecular geometry

The optimized structural parameters calculated by DFT-B3LYP level with the 6-31++G(d,p) basis set in accordance with the atom numbering scheme as given in Fig. 1 are listed in Table 1. From the theoretical values, it is found that some of the calculated values slightly deviate from the experimental values, due to the fact that the theoretical calculations are performed in a gaseous state and the experimental values are achieved in the solid state. By allowing the relaxation of all parameters, the calculations converge to optimized geometries, which correspond to true energy minima. The C-H bond lengths in the ring structure are in good agreement with the available data [14]. Further the result of our calculation shows that C=O bonds give typical double bond characteristics. The C-C bond lengths are found to be high compared to other bond length values. The bond angle of C-C-H in the ring lies between 107^0 to 113^0.The bond angle between C-C-O has higher value then all other bond angles. The bond angle of C-C-O in the ring structure is found to be higher than the C-C-O bond angle in the methylene molecule. The dihedral angle between C11-C14-O16-H32 by B3LYP method is 0.0754°.

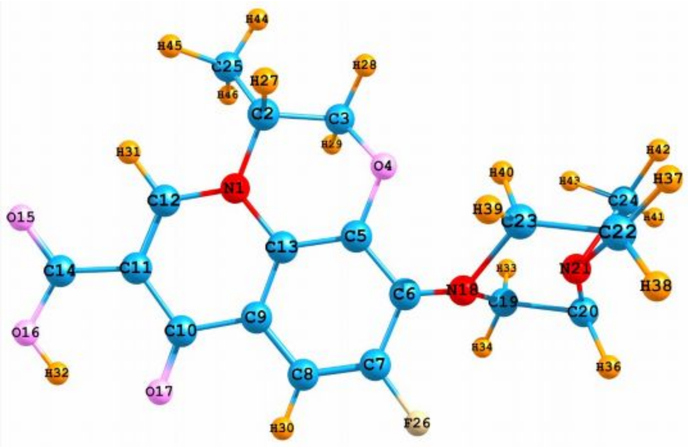

Fig. 1 Atom numbering scheme of Ofloxacin

Table 1. Structural parameters of Ofloxacin

BOND LENGTH	B3LYP	BOND ANGLE	B3LYP	BOND ANGLE	B3LYP	DIHEDRAL ANGLE	B3LYP	DIHEDRAL ANGLE	B3LYP	DIHEDRAL ANGLE	B3LYP
R(1,2)	1.462	A(2,1,12)	121.9267	A(18,19,33)	110.596	D(12,1,2,3)	-153.905	D(7,6,18,19)	65.1238	D(34,19,20,35)	67.6778
R(1,12)	1.3648	A(2,1,13)	118.4418	A(18,19,34)	109.091	D(12,1,2,25)	-31.1155	D(7,6,18,23)	-152.852	D(34,19,20,36)	-49.5093
R(1,13)	1.4081	A(12,1,13)	119.6257	A(20,19,33)	108.973	D(12,1,2,27)	89.2081	D(6,7,8,9)	-1.2417	D(19,20,21,22)	48.0998
R(2,3)	1.5412	A(1,2,3)	110.3984	A(20,19,34)	108.204	D(13,1,2,3)	26.9792	D(6,7,8,30)	179.5681	D(19,20,21,24)	-81.4499
R(2,25)	1.5249	A(1,2,25)	114.6336	A(33,19,34)	108.195	D(13,1,2,25)	149.7684	D(26,7,8,9)	178.8278	D(35,20,21,22)	169.8808
R(2,27)	1.134	A(1,2,27)	106.5266	A(19,20,21)	115.463	D(13,1,2,27)	-89.9081	D(26,7,8,30)	-0.3623	D(35,20,21,24)	40.3311
R(3,4)	1.4253	A(3,2,25)	108.4281	A(19,20,35)	107.63	D(2,1,12,11)	-179.123	D(7,8,9,10)	-179.2632	D(36,20,21,22)	-72.9051
R(3,28)	1.1222	A(3,2,27)	107.8917	A(19,20,36)	108.739	D(2,1,12,31)	0.4991	D(7,8,9,13)	0.3587	D(36,20,21,24)	157.5451
R(3,29)	1.1207	A(25,2,27)	108.748	A(21,20,35)	109.689	D(13,1,12,11)	-0.0175	D(30,8,9,10)	-0.0652	D(20,21,22,23)	-49.2089
R(4,5)	1.3925	A(2,3,4)	111.1739	A(21,20,36)	106.769	D(13,1,12,31)	179.6051	D(30,8,9,13)	179.5566	D(20,21,22,37)	-170.6695
R(4,39)	2.4874	A(2,3,28)	110.0287	A(35,20,36)	108.365	D(2,1,13,5)	-1.7691	D(8,9,10,11)	179.2204	D(20,21,22,38)	72.0382
R(5,6)	1.4144	A(2,3,29)	111.0634	A(20,21,22)	110.88	D(2,1,13,9)	179.1376	D(8,9,10,17)	-0.7881	D(24,21,22,23)	80.3432
R(5,13)	1.4209	A(4,3,28)	103.8228	A(20,21,24)	113.686	D(12,1,13,5)	179.0939	D(13,9,10,11)	-0.3938	D(24,21,22,37)	-41.1174
R(6,7)	1.4376	A(4,3,29)	109.9577	A(22,21,24)	113.681	D(12,1,13,9)	0.0005	D(13,9,10,17)	179.5978	D(24,21,22,38)	-158.4097
R(6,18)	1.4061	A(28,3,29)	110.5753	A(21,22,23)	114.944	D(1,2,3,4)	-53.8121	D(8,9,13,1)	-179.3975	D(20,21,24,41)	-57.0925
R(7,8)	1.3956	A(3,4,5)	113.5678	A(21,22,37)	109.681	D(1,2,3,28)	-168.263	D(8,9,13,5)	1.4925	D(20,21,24,42)	-175.1836
R(7,26)	1.3559	A(4,5,6)	117.4458	A(21,22,38)	106.895	D(1,2,3,29)	68.9688	D(10,9,13,1)	0.2173	D(20,21,24,43)	63.848
R(8,9)	1.3969	A(4,5,13)	119.9352	A(23,22,37)	107.671	D(25,2,3,4)	179.843	D(10,9,13,5)	-178.8928	D(22,21,24,41)	174.7837
R(8,30)	1.1051	A(6,5,13)	122.544	A(23,22,38)	109.116	D(25,2,3,28)	65.3921	D(9,10,11,12)	0.3742	D(22,21,24,42)	56.6926
R(9,10)	1.4754	A(5,6,7)	116.2015	A(37,22,38)	108.375	D(25,2,3,29)	-57.376	D(9,10,11,14)	-179.6776	D(22,21,24,43)	-64.2757
R(9,13)	1.4125	A(5,6,18)	124.468	A(18,23,22)	111.278	D(27,2,3,4)	62.2258	D(17,10,11,12)	-179.6172	D(21,22,23,18)	51.7268
R(10,11)	1.4554	A(7,6,18)	119.2146	A(18,23,39)	108.588	D(27,2,3,28)	-52.2252	D(17,10,11,14)	0.3311	D(21,22,23,39)	171.4567
R(10,17)	1.2453	A(6,7,8)	121.3389	A(18,23,40)	111.377	D(27,2,3,29)	-174.993	D(10,11,12,1)	-0.1852	D(21,22,23,40)	-71.0611
R(11,12)	1.3801	A(6,7,26)	120.4969	A(22,23,39)	109.003	D(1,2,25,44)	-170.31	D(10,11,12,31)	-179.7987	D(37,22,23,18)	174.2743
R(11,14)	1.469	A(8,7,26)	118.1641	A(22,23,40)	108.374	D(1,2,25,45)	71.0753	D(14,11,12,1)	179.8631	D(37,22,23,39)	-65.9958
R(12,31)	1.1131	A(7,8,9)	121.3962	A(39,23,40)	108.146	D(1,2,25,46)	-50.7086	D(14,11,12,31)	0.2496	D(37,22,23,40)	51.4864
R(14,15)	1.2399	A(7,8,30)	119.7957	A(21,24,41)	108.779	D(3,2,25,44)	-46.4649	D(10,11,14,15)	-179.2052	D(38,22,23,18)	-68.3014
R(14,16)	1.3566	A(9,8,30)	118.8032	A(21,24,42)	108.805	D(3,2,25,45)	-165.079	D(10,11,14,16)	0.762	D(38,22,23,39)	51.4285
R(16,32)	0.9707	A(8,9,10)	119.4494	A(21,24,43)	113.623	D(3,2,25,46)	73.137	D(12,11,14,15)	0.745	D(38,22,23,40)	168.9108

R(18,19)	1.4548	A(8,9,13)	119.285	A(41,24,42)	108.557	D(27,2,25,44)	70.6041	D(12,11,14,16)	-179.2878		
R(18,23)	1.4514	A(10,9,13)	121.2645	A(41,24,43)	108.481	D(27,2,25,45)	-48.0101	D(11,14,16,32)	0.0754		
R(19,20)	1.5467	A(9,10,11)	115.1562	A(42,24,43)	108.488	D(27,2,25,46)	-169.794	D(15,14,16,32)	-179.9541		
R(19,33)	1.129	A(9,10,17)	121.2092	A(2,25,44)	108.506	D(2,3,4,5)	55.3471	D(6,18,19,20)	-165.2332		
R(19,34)	1.1249	A(11,10,17)	123.6346	A(2,25,45)	111.127	D(28,3,4,5)	173.6119	D(6,18,19,33)	73.217		
R(20,21)	1.454	A(10,11,12)	120.393	A(2,25,46)	111.607	D(29,3,4,5)	-68.0684	D(6,18,19,34)	-45.6678		
R(20,35)	1.1242	A(10,11,14)	123.2589	A(44,25,45)	108.012	D(3,4,5,6)	153.5512	D(23,18,19,20)	50.8128		
R(20,36)	1.1267	A(12,11,14)	116.3481	A(44,25,46)	108.58	D(3,4,5,13)	-29.5186	D(23,18,19,33)	-70.737		
R(21,22)	1.4545	A(1,12,11)	123.7804	A(45,25,46)	108.909	D(4,5,6,7)	178.5325	D(23,18,19,34)	170.3782		
R(21,24)	1.4459	A(1,12,31)	116.8453			D(4,5,6,18)	2.49	D(6,18,23,22)	164.9016		
R(22,23)	1.5471	A(11,12,31)	119.3733			D(13,5,6,7)	1.6883	D(6,18,23,39)	44.9258		
R(22,37)	1.124	A(1,13,5)	121.0271			D(13,5,6,18)	-174.354	D(6,18,23,40)	-74.054		
R(22,38)	1.1263	A(1,13,9)	119.7791			D(4,5,13,1)	1.5563	D(19,18,23,22)	-51.9257		
R(23,39)	1.1241	A(5,13,9)	119.1877			D(4,5,13,9)	-179.345	D(19,18,23,39)	-171.9015		
R(23,40)	1.1296	A(11,14,15)	124.0792			D(6,5,13,1)	178.3245	D(19,18,23,40)	69.1187		
R(24,41)	1.1217	A(11,14,16)	122.8015			D(6,5,13,9)	-2.5769	D(18,19,20,21)	-49.3551		
R(24,42)	1.1216	A(15,14,16)	113.1192			D(5,6,7,8)	0.2198	D(18,19,20,35)	-172.2353		
R(24,43)	1.1245	A(14,16,32)	111.8514			D(5,6,7,26)	-179.851	D(18,19,20,36)	70.5777		
R(25,44)	1.1178	A(6,18,19)	116.7716			D(18,6,7,8)	176.4819	D(33,19,20,21)	73.1282		
R(25,45)	1.1168	A(6,18,23)	118.7807			D(18,6,7,26)	-3.5892	D(33,19,20,35)	-49.7519		
R(25,46)	1.1165	A(19,18,23)	113.5763			D(5,6,18,19)	-118.945	D(33,19,20,36)	-166.939		
R(26,34)	2.2931	A(18,19,20)	111.6879			D(5,6,18,23)	23.0794	D(34,19,20,21)	-169.4421		

4.2 Mulliken atomic charges

The calculation of effective atomic charges plays an important role in the application of quantum mechanical calculations to molecular systems. Our interest here to describe the electron distribution in Ofloxacin as broadly as possible, and to assess the sensitivity of the calculated charges to change the choice of quantum chemical method. The calculated natural atomic charge values from the Mulliken population analysis (MPA) procedures using the DFT method are listed in Table 2. The atomic charges of ofloxacin as shown in Fig. 2.

The MPA of Ofloxacin shows that the presence of two oxygen's atoms [O15 = -0.475363; O16 = -0.423305] imposes positive charges on the carbon atom [C14 = 0.178585]. Similarly, the carbon atoms C6 and C19 possess negative charges, resulting in the positive charges on the nitrogen atom N18. Moreover, there is no difference in charge distribution observed on all hydrogen atoms except from H27 to H32 hydrogen atom. The large positive charge on H32 is due to the large negative charge accumulated on the O16 atom.

Table 2 Mulliken atomic charges of Ofloxacin

Atoms	B3LYP	Atoms	B3LYP	Atoms	B3LYP
N_1	0.065492	O_{17}	-0.617972	H_{32}	0.414330
C_2	0.345489	N_{18}	0.177919	H_{33}	0.155896
C_3	-0.164682	C_{19}	-0.072528	H_{34}	0.145818
O_4	-0.299932	C_{20}	-0.242675	H_{35}	0.125351
C_5	-0.413352	N_{21}	-0.083827	H_{36}	0.172188
C_6	-0.506364	C_{22}	-0.570056	H_{37}	0.124321
C_7	0.213336	C_{23}	0.227387	H_{38}	0.162791
C_8	-0.259035	C_{24}	-0.393667	H_{39}	0.131355
C_9	0.357687	C_{25}	-0.592893	H_{40}	0.183182
C_{10}	-0.001997	F_{26}	-0.340183	H_{41}	0.148701
C_{11}	0.588969	H_{27}	0.201236	H_{42}	0.148907
C_{12}	-0.148827	H_{28}	0.152899	H_{43}	0.118012
C_{13}	-0.077214	H_{29}	0.187538	H_{44}	0.163703
C_{14}	0.178585	H_{30}	0.193553	H_{45}	0.146519
O_{15}	-0.475363	H_{31}	0.256940	H_{46}	0.195767
O_{16}	-0.423305	-	-	-	-

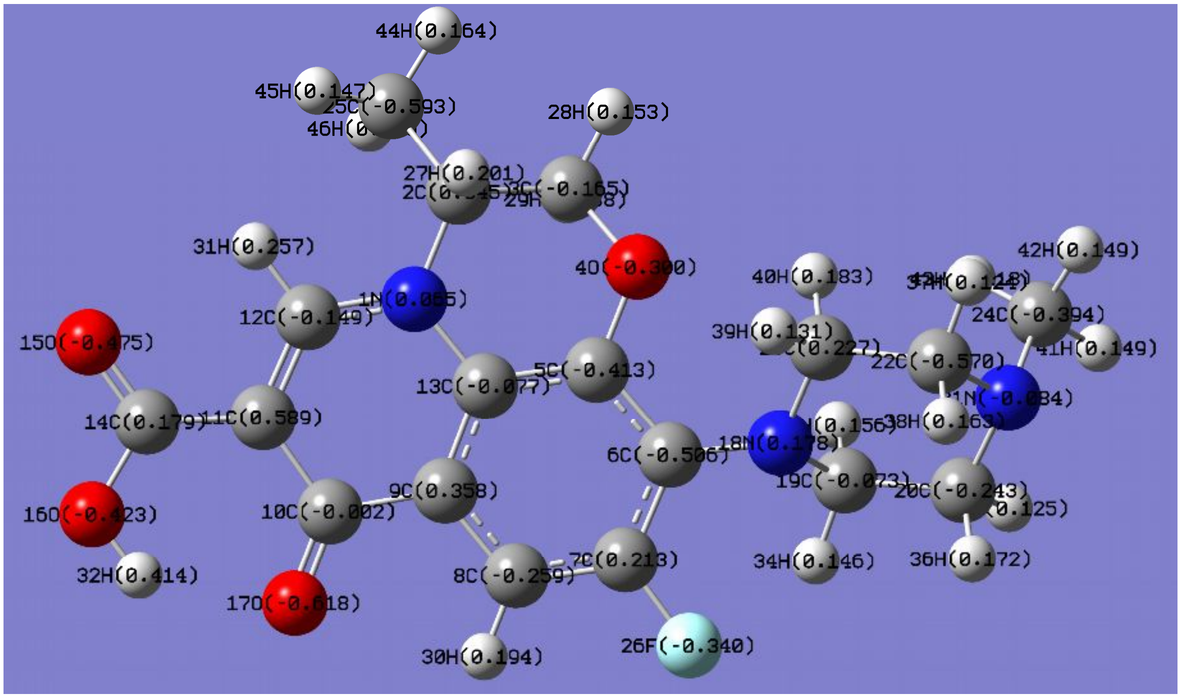

Fig. 2 Atomic charges of Ofloxacin

4.3 Vibrational analysis

The observed and calculated frequencies using B3LYP/6-31++G(d,p) method and their IR intensities and assignments are listed in Table 3. Experimental & theoretical IR, and FT-Raman spectra of Ofloxacin are shown in Figs. 3, 4 respectively. The description of band assignments is as follows.

4.3.1 O-H and C-H Vibrations

The stretching vibrations of the free hydroxyl group are mainly found within the region 3600-3550 cm^{-1}. Hydroxyl group shows a large variation in wavenumber, intensity and bandwidth of the spectral vibrations due to presence of inter or intra molecular hydrogen bonding in the molecules [15]. The B3LYP wavenumber 3406 cm^{-1} corresponds to O-H stretching vibration with PED contribution of 100% is fairly agrees with FTIR 3419 cm^{-1}.

The aromatic C-H stretching vibrations lie in the range 3100-3000 cm^{-1} [16]. C-H stretching vibration is assigned to 3043, 2998, 2968, 2936, 2922 cm^{-1} in FTIR and 2979, 2930, 2861, 2838, 2801 and 3044, 3000, 2986, 2969, 2949 cm^{-1} in FT-Raman spectra. The corresponding B3LYP values are 3045, 2997, 2962, 2961, 2960 cm^{-1}. The DFT values are in good agreement with experimental values. The PED contribution is above 84%. Latha et al [17] have observed C-H stretching vibrations at 2930, 2869 cm^{-1} in FTIR and at 2934, 2871 cm^{-1} in FT-Raman spectra.

4.3.2 C=O and C=C stretching vibrations

The C=O stretching is assigned at 2004 cm^{-1} in the DFT method, meanwhile in the FT-IR spectra, the assignment goes to 1935 cm^{-1}. The bands observed at 1712 and 1717 cm^{-1} in the FTIR spectrum and the Raman spectrum are ascribed to the C=C stretching mode. These vibrations are predicted at 1721 cm^{-1} by DFT calculations for Ofloxacin, which agree well with the experimental values.

4.3.3 C-N vibration

C-N stretching vibration occurs in the region 1300-800 cm^{-1} [16]. The wavenumbers 1145, 1131, 1116, 979, 890 cm^{-1} in FTIR and 1141, 890 cm^{-1} in FT-Raman are attributed to C-N stretching vibration. The corresponding B3LYP wavenumber are 1164, 1125, 1120, 982, 872 cm^{-1}. There is a decrease in frequency because of C-N vibration mixing up with the other bending vibration. Muthu et al [18] have observed C-N stretching vibration at 976, 876 cm^{-1} in FTIR spectrum.

Table 3. Vibrational Assignments of Ofloxacin

EXPERIMENTAL		THEORETICAL (B3LYP)		ASSIGNMENT
FT-IR	FT RAMAN	FREQUENCY	INTENSITY	
3419		3406	140.89	υ OH(100)
		3155	5.04	υ CH(99)
		3153	98.99	υ CH (100)
		3106	18.65	υ CH (99)
		3105	2.22	υ CH(99)
		3080	90.97	υ CH(100)
		3066	11.68	υ CH(91)
		3061	3.79	υ CH(98)
		3059	4.33	υ CH(98)
		3058	7.05	υ CH(96)
		3053	8.55	υ CH(98)
		3052	4.44	υ CH(99)
3043	3044	3045	6.62	υ CH(99)
		3023	1.22	υ CH(98)
		2999	5.96	υ CH(85)
2998	3000	2997	0.78	υ CH(84)
	2986	2990	5.92	υ CH(81)
2968	2969	2962	4.46	υ CH(87)
2936		2961	1.95	υ CH(88)
2922	2949	2960	7.82	υ CH(98)
		2031	401.85	υ OC(78)
1935		2004	405.7	υ OC(91)
		1781	33.07	υ CC(75)
		1776	791.6	υ CC(40)+υ NC(30)
1712	1717	1721	291.93	υ CC(50)
		1714	69.74	υ CC(19)+υ NC(30)
		1688	470.25	υ NC(11)+υ FC(22)
		1641	88.25	υ CC(21)+υ NC(11)
1622	1619	1632	64.83	υ CC(27)+υ OC(16)+υ FC(14)
		1606	429.94	υ OC(16)+υ CC(33)
1549	1542	1561	20.01	υ NC(12)+υ OC(25)
1523	1518	1522	39.31	υ NC(20)
		1517	51.5	υ NC(39)+δ CNC(10)
1458	1453	1489	231.48	υ CC(10)+δ HOC(55)
		1486	14.3	υ NC(70)
		1472	47.62	υ NC(72)
		1469	15.09	δ HOC(11)+δ HCH(17)
		1464	31.59	υ OC(16)+δ HOC(14)
		1439	35.81	δ HCH(76)
		1431	4.38	δ HCH(17)

		1417	1.61	δ HCH(43)
1407		1406	10.05	τ HCNC(64)
		1401	2.46	δ HCH(53)
1397	1396	1399	4.49	δ HCH(57)
		1391	5.49	δ HCH(61)
		1389	9.28	υ CC(41)
		1384	8.12	δ HCH(70)
		1382	1.72	δ HCH(59)
		1378	7.86	δ HCH(81)
		1377	16	δ HCH(35)
		1375	0.71	δ HCH(84)
1370	1371	1369	55.86	υ OC(34)
		1365	18.66	δ HCH(26)+τ HCNC(39)
1351	1349	1356	13.26	τ HCNC(43)
		1343	17.02	υ CC(16)+δ HCH(11)+τ HCOC(12)
		1338	4.84	τ HCNC(57)
1306	1322	1323	2.53	δ OCC(10)+τ HCNC(16)
		1297	3.3	δ HCC(16)+τ HCOC(14)
1289	1288	1295	10.13	δ HCC(60)
1254	1253	1261	4.61	δ HCO(25)+δ HCC(10)
1241	1240	1238	16.42	δ HCC (17)
1224	1225	1231	8.84	δ HCC(50)
1199	1198	1205	22.76	δ HCC(26)+δ HCN(20)+τ HCNC(10)
		1193	3.11	δ HCO(22)+TROS HCNC(12)
		1188	7.78	δ HCC(36)+τ HCNC(21)
		1184	2.23	υ CC(26)+τ HCNC(22)
		1180	3.07	δ HCN(15)
		1172	12.86	δ HCN(15)
1145	1141	1164	5.12	υ NC(12)+υ CC(17)+δ HCC(14)
		1143	34.07	υ CC(11)+δ HCN(11)
1131		1125	0.79	τ HCNC(53)
1116		1120	17.05	υ NC(33)
		1116	6.28	δ HCC(13)+τ HCNC(22)
1093		1092	5.09	δ HCN(14)+γ CCCN(11)
		1091	3.31	δ HCN(11)
1072	1054	1071	17.06	δ HCN(11)
1055	1038	1035	0.95	τ HCNC(12)+τ NCCN(10)
1010		1016	0.5	τ HCCC(37)
		1005	0.78	υ CC(12)+δ COC(14)
		988	5.51	τ HCCC(18)
979		982	2.39	δ CNC(16)
955		955	4.1	τ HCCC(66)+τ CCCN(10)
		953	4.63	τ HCCC(77)
931		952	0.77	τ HCCC(77)
890	890	872	0.46	τ HCNC(22)
851		838	114.19	γ OCCC(51)
804		807	2.97	δ OCC(17)

782	782	790	12.74	υ OC(12)
765		774	1.31	γ NCCC(12)
745	747	751	10.14	γ NCCC(15)
		723	7.26	γ OCOC(36)+γ NCCC(14)
710		708	21.22	δ CNC(14)
		691	3.01	δ OCO(27)
669	664	670	2.33	γ OCOC(31)
631		643	6.48	γ OCOC(31)
		617	1.19	δ CCC(17)+δ CNC(15)+δ NOC(10)
592	598	588	4.48	δ OCO(12)+γ CCNC(22)
568		568	4.62	δ CCC(13)
		563	1.14	τ HCCC(16)+τ CCCC(10)+γ FCCC(26)+γ OCCC(17)
542	547	550	2.23	δ CNC(11)+δ NCC(32)+δ CCN(12)
494	504	499	19.31	δ CCN(10)+δ OCC(12)
	492	483	14.44	TROS CCNC(10)
		477	4.64	δ CNC(35)
		465	9.36	δ CNC(21)+τ CCNC(13)
		453	2.77	δ OCC(25)+γ CCCN(12)
	435	440	2.44	γ CCCN(15)
		418	47.59	τ HOCC(37)
		411	51.56	τ HOCC(41)
	396	405	1.07	τ HOCC(41)
		385	1.68	δ CCC(17)+δ OCC(12)
		375	28.42	δ NCC(19)+δ FCC(14)
	350	344	1.11	τ CCCC(15)+γ OCCC(10)
	323	333	3.65	δ FCC(12)+δ CCC(12)
	284	307	7.83	δ CNC(10)+δ FCC(13)+δ CCC(19)
	271	271	1.26	δ CNC(11)
	257	244	8.57	γ CCCC(11)
	227	238	10.71	γ CCCC(11)
	204	208	9.18	τ NCCN(13)
		205	5.06	τ NCCN(13)
	175	186	2.93	τ HCCC(55)
		172	3.58	δ CCC(30)
		167	2.19	δ CCC(10)+τ CCCC(11)
	144	153	0.7	τ HCNC(39)
		147	1.28	δ CNC(11)+τ HCNC(28)
	112	119	0.96	τ CNCC(19)+γ CCCN(21)+δ NCC(12)
	97	98.4	1.74	TROS CNCC(15)+τ CCCC(12)+γ CCCN(26)
	67	68.9	1.23	τ CCCC(13)+τ CNCC(20)+τ CCNC(18)
		55.9	1.96	τ CCCC(22)+ τ CCNC(14)+γ CCCN(10)
		52.2	1.6	τ CCCC(11)+ τ OCCC(33)+τ OCCN(14)
		38.8	3.04	τ CCNC(25)+τ OCCC(34)+τ CNCC(10)
		35.9	1.04	τ OCCC(15)+τ CNCC(40)+τ CCCC(13)
		23	1.29	τ CCCC(30)+τ CNCC(30)

τ – Torsion, γ -wagging, δ- bending, υ-stretching

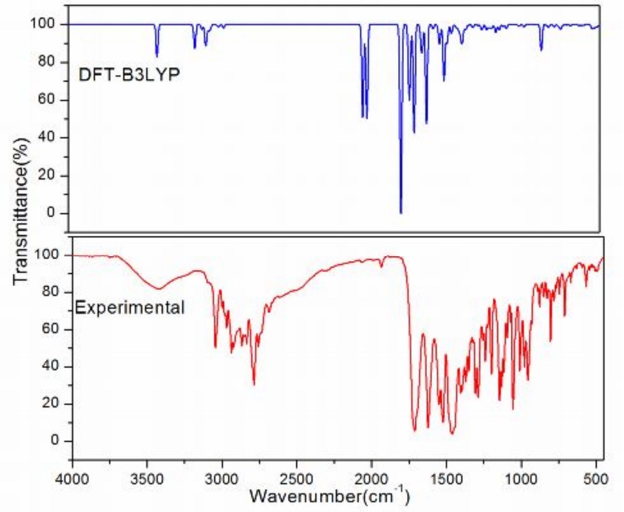

Fig. 3 Experimental and theoretical IR spectrum of Ofloxacin

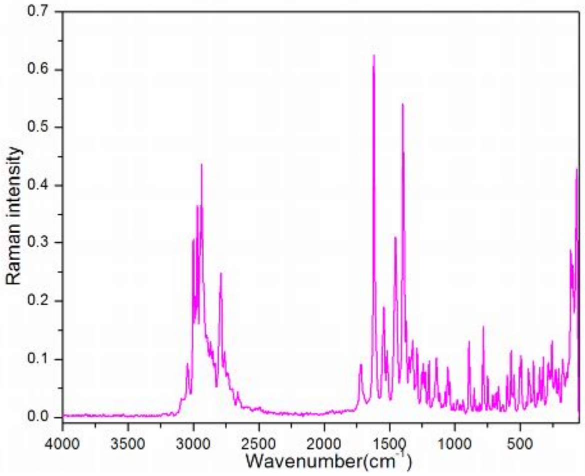

Fig. 4 Experimental FT-Raman spectrum of Ofloxacin

4.4 Thermodynamic properties

Using the DFT/B3LYP with 6-31++G(d,p) as the basis set, several thermodynamic properties like zero point energy, rotational constants, rotational temperatures, molar capacity, energy and entropy of Ofloxacin have been calculated and shown in Table 4. The statistical thermo chemical analysis of Ofloxacin was performed considering the molecule to be at room temperature 298.15K and one atmospheric pressure. All the thermodynamic data supply helpful information for further study of the title molecule. They can be used to compute the other thermo-dynamic energies according to relationships of thermodynamic functions and estimate directions of chemical reactions according to the second law of thermodynamical field [19].

The thermodynamic quantities such as heat capacity at constant pressure (C^0_{pm}), entropy (S^0_m), enthalpy (ΔH^0_m), for various ranges (100-1000k) of temperatures are determined on the basis of vibrational analysis at DFT-B3LYP level and presented in Table 5. All the thermodynamic data were provide supportive information on the Ofloxacin molecular structure for the further more additional study. From Table 5, it can be observed that the thermodynamic parameters are increasing with temperature ranging from 100 to 1000k, due to the fact that the vibrational intensities of molecule with temperature [20,21]. The following quadratic equations are used to predict approximately the values of heat capacity at constant pressure, entropy and enthalpy changes with temperature. The correlation graphics of those parameters shows in Fig.5,

$$C^0_{p.m}=13.43465+1.33939T-5.01014E-4T^2 \ (R^2=0.99932)$$

$$S^0_m=269.47518+1.40354T-2.80732E-4T^2 \ (R^2=0.99997)$$

$$\Delta H^0_m=-13.26085+0.13785T+3.98117E-4T^2 \ (R^2=0.99953)$$

All the thermodynamic data’s can be used to compute the other thermodynamic energies according to relationship of thermodynamic functions and estimate directions of chemical reactions according to the second law of thermodynamics in thermo chemical field .

The total energy of a molecule is the sum of translational, rotational, vibrational and electronic energies, i.e., $E=E_t+E_r+E_v+E_e$. The statistical thermo chemical analysis of Ofloxacin is carried out considering the molecule to be at room temperature and one atmospheric pressure. Thermodynamic parameters such as zero point vibrational energy (ZPVE), thermal energy, specific heat capacity, rotational constants; rotational temperature and entropy of the molecule calculated by DFT method (B3LYP level) is presented in Table 4.

The electronic energy levels are generally very widely separated in energy compared to the thermal energy kT at room temperature. In each electronic level, there are several vibrational levels and for each vibrational level, there are several rotational states. This is a simplified and useful model to start with. The total energy is a sum of all these energies and is given by

$$E_{total}=E_{el}+E_{vib}+E_{trans}+E_{others}$$

The term E others includes nuclear spin energy levels and may also be use later to include the interactions between the first four. Assuming the first three to be independent and neglecting the last term, the molecular partition function (i.e., a sum over the molecular energy states) is given by

$$q =\sum e^{-(E_{ele}+E_{vib}+E_{rot}+E_{trans})/Kt} = \sum e^{-\beta E_{el}} \; \sum e^{-\beta E_{vib}} \; \sum e^{-\beta E_{rot}} \; \sum e^{-\beta Et}{}_{rans}$$

Here, the summation is over the electronic, vibrational and rotational states can be done separately since they are assumed to be independent. Therefore,

$$q= q_{el}*q_{vib}*q_{rot}*q_{trans}$$

The molecular partition q function is written as the product of electronic, vibrational, rotational and partition functions.

The value of zero point energy of Ofloxacin is 238.555 Kcal/mol obtained B3LYP. The dipole moment of the molecule was also calculated by B3LYP method with two basis sets. Dipole moment reflects the molecular charge distribution and is given as a vector in three dimensions. Therefore, it can be used as descriptor to depict the charge movement across the molecule depending upon the centers of positive and negative charges. For charged systems, dipole moment value depends on the choice of origin and molecular orientation.

Table 4. Thermodynamic parameters of Ofloxacin

Parameter	**B3LYP**
Zero point vibrational energy(Kcal/Mol)	238.555
Rotational constant (GHz)	0.4400
	0.1109
	0.0912
Rotational temperatures (Kelvin)	0.0211
	0.0023
	0.0044
Entropy (Cal/Mol-Kelvin)	
Total	158.699
Translational	43.546
Rotational	35.534
Vibrational	79.62
Molar capacity at constant volume	
(Cal/Mol-Kelvin)	
Total	84.205
Translational	2.981
Rotational	2.981
Vibrational	78.244

Energy (KCal/Mol)	
Total	252.344
Translational	0.889
Rotational	0.889
Vibrational	250.567
Dipole moment	8.7418 (Debye)

Table 5 Thermodynamic properties at different temperatures for the Ofloxacin

Temperature (K)	S^{0}m (cal mol^{-1} K^{-1})	C$^0_{p.m}$ (cal mo^{-1} K^{-1})	ΔH^0_m (K cal mol^{-1})
100	403.98	152.09	9.33
200	542.2	257.55	29.87
298.15	664.11	360.63	60.17
300	666.34	362.61	60.84
400	785.19	467.71	102.41
500	899.99	562.45	154.03
600	1009.84	642.64	214.4
700	1114.07	709.25	282.1
800	1212.5	764.62	355.88
900	1305.31	810.9	434.72
1000	1392.83	849.85	517.82

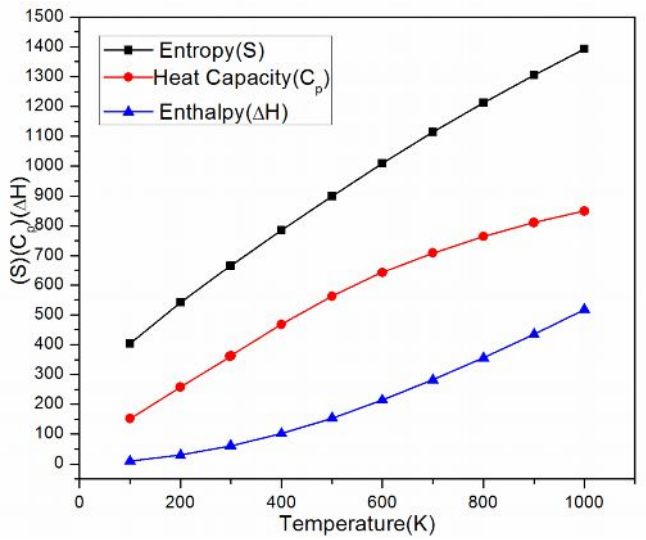

Fig. 5 Thermodynamic properties of Ofloxacin

5. Conclusion

We present results on the structural and vibrational properties of Ofloxacin using IR and Raman spectra. The theoretically calculated values of both bond lengths and bond angles of the structures of the minimum energy were then compared with available data. The data obtained during the course of present investigation show that a better agreement between the experimental and theoretical data is obtained using the DFT-B3LYP method with the basis set 6-31++G(d,p). This study predicts that the vibrational frequencies of Ofloxacin could be successfully elucidated by the DFT-B3LYP method using Gaussian program. This study confirms that the theoretical calculation of the vibrational frequencies for Ofloxacin is quite useful for determining the vibrational assignment and for predicting new vibrational frequencies. The atomic charges of the title molecule have been studied by DFT methods. The calculated normal-mode vibrational frequencies provide thermodynamic properties by way of statistical mechanics.

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