Molecular Structure investigation Towards Pharmacodynamic Activity of Sulfamethoxazole using Experimental and Computational Tools

Sathya A[1], Prabhu T[2] and Ramalingam S[3]

[1]Research Scholar, Department of Physics, A.V.C.College (Autonomous), Mayiladuthurai, Tamilnadu, India.

[1] Department of Physics, A.V.C.College of Engineering, Mayiladuthurai, Tamilnadu, India.

[2] PG and Research Department of Physics, A.V.C. College, Mayiladuthurai, Tamilnadu, India.

Abstract

Fourier transform infrared (FTIR) and FT-Raman spectra have been recorded and extensive spectroscopic investigations have been carried out on Sulfamethoxazole (SMX). The structural and spectroscopic data of the molecule in the ground state were calculated by using Density Functional Theory (DFT) using 6-31G(d,p) basis set. The vibrational frequencies were calculated and scaled values were compared with experimental FT-IR and FT-Raman spectra. In order to explore the molecular dynamic activity for describing root cause of obtained molecular chemical property, the FT-IR and FT-Raman experimental spectra investigated along with the computational results. The observed and calculated frequencies are found to be in good agreement. The theoretically constructed FT-IR and FT-Raman spectra exactly coincide with experimental one. The first order hyperpolarizability of this novel molecular system and related properties of CFA are calculated using B3LYP/6-311++G(d,p) and HF/6-311++G(d,p) methods on the finite-field approach.

Keywords: Density Functional Theory, Nonlinear optical effects (NLO), Mulliken charge distribution, Sulfamethoxazole, UV-Visible.

1. Introduction

Sulfamethoxazole (**SMZ** or **SMX**) is an antibiotic. It is used for bacterial infection. It was introduced to the United States in 1961(Chemla DC and Zyss J et al. 1987) [1]. To the best of our knowledge, neither quantum chemical calculation, nor the vibrational spectra sulfamethoxazole have been reported. Therefore, the present investigation was undertaken to study the vibrational spectra of this molecule completely and to identify the various modes with greater wavenumber accuracy. Density Functional Theory (DFT) and Hartree Fock (HF) (French MJ, Inc., 2009) [2] calculations have been performed to support our wavenumber assignments. Hence, in the present work, a detailed vibrational analysis, chemical shifts, HOMO–LUMO, Mulliken atomic charge, thermodynamic studies, NMR spectral analysis and UV-Visible spectral analysis has been attempted using DFT/B3LYP and HF methods at 6-311++G(d,p) basis set by recording FT-IR and FT-Raman spectra of the compound.

2. Experimental Details

Fourier transform infrared spectra of the title compound is measured at the room temperature in the region 4000–400 cm^{-1} using a BRUKER IFS-66 V FTIR spectrometer (Aiping F, Dongmei,and Zhengyu Z, 2000) [3] at a resolution of ± 1 cm^{-1} equipped with a MCT detector, a KBr beam splitter and globar source. The FT-Raman spectrum of 2,4-BDA was recorded on a BRUKER IFS – 66 V model interferometer equipped with

FRA-106 FT-Raman accessory in the 3500–100 cm^{-1}. Stokes region using the 1064 nm line of a Nd:YAG laser for excitation operating at 200 mW power. The reported wave numbers are believed to be accurate within ±1 cm^{-1}. The UV–visible absorption spectrum of the sample was recorded using a Varion Cary 5E UV–VIS, NIR spectrophotometer in the range 200–400 nm with high resolution (Moorthy N., et al. 2016)[4].

3. Computational Details

Calculations of the title compound were carried out with Gaussian09 program using the HF/6-31G (2d,p), B3LYP/6-31G (d,p) and B3LYP/6-311++G(d,p) levels of theory to predict the molecular structure and vibrational wave numbers. Molecular geometry Fig.1 was fully optimized by Berny's optimization algorithm using redundant internal coordinates (Beck AD, Rev., 1988)[5]. Harmonic vibrational wave numbers were calculated using the analytic second derivatives to confirm the convergence to minima of the potential surface. The wave number values computed contain known systematic errors and hence, we have used scaling factors 0.8929 and 0.9613 for HF and DFT methods.

The absence of imaginary wave numbers of the calculated vibrational spectrum confirms that the structure deduced corresponds to minimum energy. The assignments of the calculated wave numbers are aided by the animation option of GAUSSVIEW program, which gives a visual presentation of the vibrational modes. The potential energy distribution (PED) is calculated with the help of GAR2PED software package. The optimized geometrical parameters (B3LYP/6-11++G(d,p) are given in Table 1.

4. Results and Discussion

Molecular geometry

The geometrical structure along with numbering of atoms of Sulfamethoxazole is obtained from Gaussian 03W and GAUSSVIEW programs are shown in Fig.1. The optimized geometrical parameters of DPA obtained by DFT–B3LYP/6-311++G (d,p) and HF/6-311++G(d,p) levels are listed in Table 1. From the structural data given in Table 3, it is observed that the various bond lengths are found to be almost same at HF and B3LYP levels.
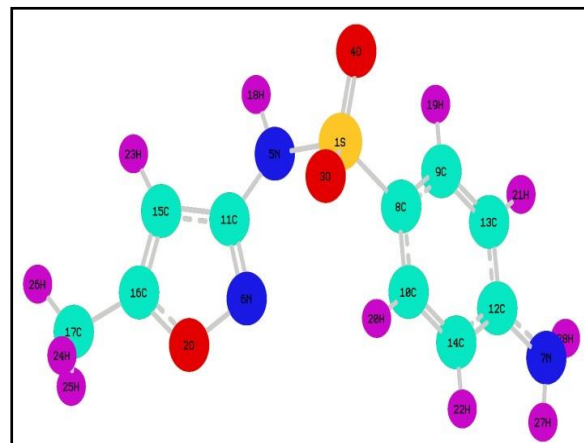

Fig. 1 Optimized geometric structure of Sulfamethoxazole.

However, the B3LYP/6-31++G (d,p) level of theory, in general slightly over estimates bond lengths but it yields bond angles in excellent agreement with the HF method (Zhao Y, et al.2006)[6]. The calculated geometric parameters can be used as origin to calculate the other parameters for the compound. The calculated C–C bond lengths of the ring vary from 1.37 to 1.48 Å. In this study the C-H bond lengths were studied as 1.08 Å. The density functional calculation gives almost same bond angles in tested molecule. The dihedral angles of our title molecule show that our tested molecule was planar. In generally the optimized bond length and bond angles are slightly smaller than the experimental values. This is due to the fact that all the theoretical calculations belongs to isolated molecule (Krishnamoorthy. V and Balachandran V, 2006) [7] were done in gaseous state and the experimental results were belongs to molecule is in solid state. . The CN single bond length calculated at 1.279 Å, 1.3799 Å and double bond length at 1.317 Å which exactly correlates with experimental values at 1.380 Å, 1.401 Å and 1.292 Å respectively. The calculated S-O bond lengths are 1.4184 Å and 1.426 Å which show moderate agreement with the experimental one at 1.435 and 1.416 Å respectively. The O3-S1-C8-C9 bond angle observed at 157°.

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Table 1: Optimized geometrical parameters for Sulfamethoxazole computed at HF/DFT (B3LYP&B3PW91) with 6-31++G(d,p) & 6-311++G(d, p) basis sets.

Geometrical Parameter	Methods			
	HF	B3LYP		B3PW91
	6-311+G	6-31+G	6-311++G(d,p)	6-31+G
Bond length(Å)				
S1-O3	1.4184	1.4627	1.4558	1.4574
S1-O4	1.426	1.4692	1.4622	1.4642
S1-N5	1.6623	1.7256	1.7244	1.7108
S1-C8	1.75	1.776	1.776	1.7662
O2-N6	1.3683	1.4068	1.4033	1.3923
O2-C16	1.3178	1.3502	1.3467	1.3451
N5-C11	1.3829	1.3938	1.3929	1.3883
N5-H18	0.996	1.0142	1.0121	1.0128
N6-C11	1.279	1.3161	1.3113	1.3143
N7-C12	1.3799	1.3848	1.3836	1.3793
N7-H27	0.9943	1.0094	1.0079	1.0081
N7-H28	0.9943	1.0093	1.0079	1.008
C8-C9	1.3884	1.3991	1.3956	1.3968
C8-C10	1.387	1.3984	1.3949	1.3961
C9-C13	1.376	1.3887	1.3852	1.3862
C9-H19	1.0739	1.0845	1.0827	1.0853
C10-C14	1.3775	1.3887	1.3852	1.3862
C10-H20	1.0725	1.0835	1.0816	1.0843
C11-C15	1.4315	1.4301	1.4286	1.4264
C12-C13	1.398	1.4104	1.4072	1.4085
C12-C14	1.3956	1.4096	1.4064	1.4076
C13-H21	1.0755	1.0866	1.0848	1.087
C14-H22	1.0754	1.0866	1.0847	1.0869
C15-C16	1.3429	1.3628	1.3592	1.3618
C15-H23	1.0685	1.0796	1.0773	1.0798
C16-C17	1.4883	1.4891	1.4869	1.4847
C17-H24	1.0845	1.0951	1.0932	1.0948
C17-H25	1.0845	1.0951	1.0934	1.0948
C17-H26	1.082	1.0919	1.0901	1.0916
Bond angle(°)				
O3-S1-04	120.7207	121.6602	121.6153	121.7554
03-S1-N5	109.3934	109.4697	109.4348	109.4858
03-S1-C8	108.717	108.9087	108.845	108.8182
O4-S1-N5	101.7462	101.3168	101.5161	101.337
O4-S1-C8	109.221	109.2395	109.2243	109.1765
N5-S1-C8	105.993	104.8451	104.8219	104.8714
N6-O2-C16	110.0545	109.6901	109.6317	109.9133
S1-N5-C11	126.3223	124.3141	124.2041	124.6443
S1-N5-C8	111.3147	108.7284	108.8559	109.2961
C11-N5-H18	116.9872	115.8597	115.8355	116.3311
O2-N6-C11	105.5969	104.7342	104.8753	104.9236
C12-N7-H27	116.429	117.5588	117.4264	117.6061

C12-N7-H28	116.5054	117.6467	117.5136	117.6909
H27-N7-H28	113.2229	114.1	114.0234	114.2332
S1-C8-C9	119.6276	119.3214	119.3606	119.3657
S1-C8-C10	120.0842	119.8359	119.769	119.8223
C9-C8-C10	120.2851	120.8404	120.8689	120.8104
C8-C9-C13	119.986	119.5597	119.5364	119.5854
C8-C9-H19	119.9632	119.9077	119.9282	119.8206
C13-C9-H19	120.0439	120.5274	120.5283	120.5879
C8-C10-C14	119.8088	119.4238	119.4116	119.4499
C8-C10-H20	119.8586	119.9203	119.9279	119.7992
C14-C10-H20	120.3319	120.6525	120.6576	120.7478
N5-C11-N6	122.9524	121.8241	121.7309	121.865
N5-C11-C15	125.1668	125.8401	126.0522	125.9247
N6-C11-C15	111.8546	112.2926	112.186	112.1713
N7-C12-C13	120.3344	120.5042	120.5125	120.5147
N7-C12-C14	120.4609	120.5442	120.5587	120.5702
C13-C12-C14	119.1582	118.9047	118.8777	118.8674
C9-C13-C12	120.2809	120.5494	120.5719	120.5569
C9-C13-H21	119.8867	119.752	119.7359	119.7337
C12-C13-H21	119.8253	119.6939	119.6877	119.7044
C10-C14-C12	120.4793	120.7216	120.7327	120.7292
C10-C14-H22	119.7203	119.6158	119.6301	119.5995
C12-C14-H22	119.8	119.6625	119.6372	119.6711
C11-C15-C16	102.4776	103.6878	103.6837	103.4347
C11-C15-H23	128.6925	128.2285	128.252	128.4682
C16-C15-H23	128.8256	128.0792	128.0593	128.0929
O2-C16-C15	110.0131	109.5898	109.6165	109.5519
O2-C6-C17	117.0425	116.8021	116.8788	116.8399
C15-C16-C17	132.9434	133.6055	133.5026	133.6061
C16-C17-H24	109.9663	110.7068	110.6324	110.7156
C16-C17-H25	110.0383	110.78	110.7059	110.7841
C16-C17-H26	110.3139	110.1914	110.2404	110.188
H24-C17-H25	108.2062	107.7665	107.7791	107.7807
H24-C17-H26	109.1318	108.6517	108.7025	108.6417
H25-C17-H26	109.144	108.668	108.7072	108.6541
Dihedral angles(°)				
O3-S1-N5-C11	-39.4497	-32.6575	-32.3125	3.3942
O3-S1-N5-H18	113.604	109.4342	109.7739	11.0127
O4-S1-N5-C11	-168.232	-162.3377	-162.0446	63.2101
O4-S1-N5-H18	-15.1783	-20.246	-19.9581	18.8032
C8-S1-N5-C11	77.6016	84.0404	84.2826	83.2201
C8-S1-N5-H18	-129.3447	-133.8679	-133.631	32.373
O3-S1-C8-C9	-157.4072	-155.1317	155.2463	55.1915
O3-S1-C8-C10	21.9627	24.3153	24.3045	24.3456
O4-S1-C8-C9	-23.8288	-20.1248	-20.3655	0.1843
O4-S1-C8-C10	155.5411	159.3223	159.1853	159.3529
N5-S1-C8-C9	85.0884	87.7854	87.7533	87.7359
N5-S1-C8-C10	-95.5417	-92.7676	-92.696	-92.7269
C16-O2-N6-C11	0.5242	0.7562	0.843	0.7216
N6-O2-C16-C15	-0.2622	-0.5423	-0.6368	-0.5092

N6-O2-C16-C17	-179.9498	179.9647	179.8141	179.9467
S1-N5-C11-N6	-27.5894	-38.0701	-39.8954	-35.1672
S1-N5-C11-C15	154.4257	144.508	142.2892	147.2855
H18-N5-C11-N6	-179.3117	-177.7831	-179.6493	-177.3661
18H-N5-C11-C15	2.7034	4.7951	2.5352	5.0866
O2-N6-C11-N5	-178.8057	-178.4349	-178.8328	178.5244
O2-N6-C11-C15	-0.5804	-0.6935	-0.7401	-0.669
H27-N7-C12-C13	-160.4146	-162.7425	-162.4996	-162.9173
H27-N7-C12-C14	22.0876	19.7777	20.1281	19.6209
H28-N7-C12-C13	-22.69	-20.245	-20.5518	-20.0226
H28-N7-C12-C14	159.8122	162.2752	162.0759	162.5156
S1-C8-C9-C13	179.7137	179.6169	179.6796	179.7231
S1-C8-C9-H19	0.676	0.4466	0.6453	0.6234
C10-C8-C9-C13	0.3451	0.1755	0.1339	0.1906
C10-C8-C9-H19	-178.6926	-178.9948	-178.9004	-178.9091
S1-C8-C10-C14	-179.5799	-179.5748	-179.6245	-179.6976
S1-C8-C10-H20	0.7012	1.0879	0.9984	0.9382
C9-C8-C10-C14	-0.2142	-0.1363	-0.0806	-0.1672
C9-C8-C10-H20	-179.933	-179.4737	-179.4577	-179.5314
C8-C9-C13-C12	-0.0947	-0.0181	0.048	0.021
C8-C9-C13-H21	-179.1277	-179.2273	-179.1819	-179.1706
H19-C9-C13-C12	178.9422	179.147	179.0764	179.1136
H19-C9-C13-H21	-0.0908	-0.0622	-0.1536	-0.078
C8-C10-C14-C12	-0.1665	-0.0604	-0.1549	-0.0677
C8-C10-C14-H22	179.5969	179.8432	179.7716	179.8072
H20-C10-C14-C12	179.551	179.272	179.2175	179.2904
H20-C10-C14-C16	-0.6855	-0.8244	-0.856	-0.8348
N5-C11-C15-C16	178.6068	178.019	178.3715	178.1294
N5-C11-C15-H23	-2.0986	-2.7188	-2.3966	-2.5714
N6-C11-C15-C16	0.4285	0.3863	0.378	0.3787
N6-C11-C15-H23	179.7231	179.6486	179.6098	179.6779
N7-C12-C13-C9	-177.8101	-177.6938	-177.6924	-177.7535
N7-C12-C13-H21	1.2235	1.5158	1.538	1.4383
C14-C12-C13-C9	-0.2799	-0.1731	-0.2765	-0.249
C14-C12-C13-H21	178.7536	179.0365	178.9539	178.9428
N7-C12-C14-H20	177.9386	177.7327	177.7455	177.776
N7-C12-C14-H22	-1.8247	-2.1709	-2.181	-2.0988
C13-C12-C14-C10	0.4116	0.213	0.3308	0.2729
C13-C12-C14-H22	-179.3517	-179.6906	-179.5957	-179.6019
C11-C15-C16-O2	-0.081	0.1146	0.1775	0.0955
C11-C15-C16-C17	179.5389	179.4897	179.623	179.5338
H23-C15-C16-O2	-179.3743	-179.1492	-179.0564	-179.2072
H23-C15-C16-C17	0.2456	0.2259	0.3892	0.231
O2-C16-C17-H24	59.5118	59.6676	59.1673	59.558
O2-C16-C17-H25	-59.5888	-59.8274	-60.2472	-59.963
O2-C16-C17-H26	179.9307	179.8863	179.4334	179.7676
C15-C16-C17-H24	-120.0871	-119.6728	-120.2472	-119.8487
C15-C16-C17-H25	120.8122	120.8322	120.3383	120.6302
C15-C16-C17-H26	0.3317	0.5458	0.0189	0.3609

Table 2: Observed and HF and DFT (B3LYP & B3PW91) with 6-31++G(d,p) & 6-311++G (d,p) level calculated vibrational frequencies of Sulfamethoxazole.

Symmetry Species C_S	Observed frequency (cm^{-1})		Methods				Vibrational Assignments
			HF	B3LYP		B3PW91	
	FT-IR	FT-Raman	6-311++G (d,p)	6-311++G (d,p)	6-311++G (d,p)	6-31++G (d,p)	
A$'$	-	3800 w	3828	3848	3843	3987	(N-H) υ
A$'$	-	3790 vs	3759	3733	3736	3870	(N-H) υ
A$'$	-	3720 vs	3724	3730	3735	3861	(N-H) υ
A$'$	-	3610 vs	3552	3557	3640	3511	(N-H) υ
A$'$	--	3620 vs	3518	3512	3591	3460	(N-H) υ
A$'$	-	3502 s	3497	3497	3576	3445	(N-H) υ
A$'$	-	3450 s	3462	3457	3430	3410	(N-H) υ
A$'$	-	3402 vs	3459	3453	3405	3408	(N-H) υ
A$'$	3360 m	-	3403	3414	3366	3379	(N-H) υ
A$'$	3336 w	-	3375	3375	3326	3341	(N-H) υ
A$'$	-	3302 vs	3311	3311	3290	3266	(N-H) υ
A$'$	3298 vs	-	3312	3308	3211	3314	(N-H) υ
A$'$	-	3202 w	3207	3195	3194	3189	(C-H) υ
A$'$	-	3147 s	3142	3161	3159	3149	(C-H) υ
A$'$	3096 vs	-	3108	3115	3082	3111	(C-H) υ
A$'$	-	3050 vs	3052	3060	3072	3088	(C-H) υ
A$'$	306 vs	-	3037	3044	3041	3049	(C-H) υ
A$'$	-	3020 s	3030	2983	3038	3005	(C-H) γ
A$'$	295 vs	-	2931	2943	2933	2930	(C-H) γ
A$''$	2939 vs	-	2913	2929	2917	2917	(C-H) γ
A$''$	2924 vs	-	2885	2914	2897	2911	(C-H) υ
A$''$	-	2920 w	2895	2905	2896	2906	(C-H) υ
A$''$	2872 vs	-	2886	2836	2800	2871	(C-H) υ
A$'$	-	2720 vw	2743	2622	2723	2716	(C-H) υ
A$'$	-	2600 vs	2577	2567	2572	2645	(C-H) γ
A$'$	-	2520 s	2495	2549	2547	2355	(C-H) γ
A$'$	-	2446 vs	2538	2515	2516	2470	(C-H) γ
A$'$	-	2400 vs	2435	2444	2445	2540	(C-H) γ
A$''$	-	2208 vs	2445	2474	2467	2460	(C-H) δ
A$''$	-	2199 s	2421	2386	2373	2313	(C-H) δ
A$''$	-	2198 vs	2206	2219	2198	2277	(C-H) δ
A$''$	-	2110 vs	2152	2171	2170	2199	(C-H) δ
A$''$	-	2099 vs	2114	2074	2127	2110	(C-H) δ
A$''$	-	2005 s	2095	2057	2117	2131	(C-H) δ
A$''$	-	1940 vs	1988	1972	1969	2005	(N-H) δ
A$''$	-	1920 vs	1906	1963	1953	1981	(N-H) υ
A$''$	-	1880 vs	1929	1909	1906	1921	(C-H) υ

A″	-	1820 s	1887	1889	1892	1899	(C-H) υ
A″	-	1799 vs	1814	1820	1813	1801	(N-H) υ
A″	-	1726 vs	1682	1714	1704	1720	(C-H) υ
A″	1611 s	-	1658	1609	1606	1576	(C=C) γ
A″	1596 vs	-	1613	1595	1601	1564	(C-H) γ
A″	1492 vs	-	1464	1484	1473	1503	(C-C) γ
A″	1410 vs	-	1424	1391	1416	1366	(C-H) δ
A″	1364 vs	-	1396	1370	1366	1363	(C-N) δ
A″	1326 vw	-	1379	1368	1363	1341	(C-H) δ
A″	1319 vw	-	1349	1321	1324	1305	(C-N) δ
A″	1299 vs	-	1321	1300	1301	1372	(S=O) δ
A″	1278 vs	-	1305	1266	1279	1271	(N-H) δ
A″	1187 vs	-	1204	1185	1184	1181	(C-H) δ
A″	1162 vw	-	1124	1161	1153	1176	(C=C) υ
A″	1129 vs	-	1101	1134	1130	1172	(C-H) υ
A″	-	1090 m	1064	1136	1080	1137	(C-H) υ
A″	1085 s	-	1049	1085	1082	1098	(N-H) υ
A″	1034 m	-	1048	1036	1041	1047	(C-H) υ
A″	-	1010 s	998	988	991	999	(C-H) υ
A″	-	1001 vs	1001	930	999	935	(N-O) υ
A″	-	970 vs	975	995	980	999	(C-H) υ
A″	961 vs	-	970	986	967	972	(C-H) υ
A″	-	940 vs	1110	943	919	943	(C=C) υ
A″	936 m	-	1098	939	912	938	(C-H) γ
A″	-	915 vs	985	967	951	837	(C-C) γ
A″	-	905 vs	961	915	900	828	(C-H) γ
A″	899 s	-	922	910	897	815	(S-H) γ
A″	845 s	-	830	880	868	799	(C-H) γ
A″	822 s	-	816	825	816	741	(S-H) δ
A″	-	820 s	804	833	818	836	(C-H) δ
A″	809 vs	-	758	825	807	824	(C-H) δ
A″	782 vs	-	690	822	792	812	(C-S) δ
A″	-	780 s	782	782	610	618	(C-H) δ
A″	765 vs	-	775	786	758	791	(C-H) δ
A″	734 vs	-	738	749	767	754	(N-H) δ
A″	-	-	734	734	732	727	(N-H) γ
A″	-	700 vs	700	700	690	689	(C-H) γ
A″	685 m	-	685	685	680	667	(C-H) γ
A″	-	630 s	630	630	612	630	(C-H) γ
A″	597 m	-	597	597	596	597	(C-H) γ
A″	554 w	-	554	554	550	554	(N-H) γ

vs –very strong; **s** – strong; **m**- medium; **w** – weak; A″ - asymmetric; A′– symmetric;

υ – Stretching; **α** –deformation; **δ** - In plane bending; **γ**-out plane bending; **τ** – Twisting.
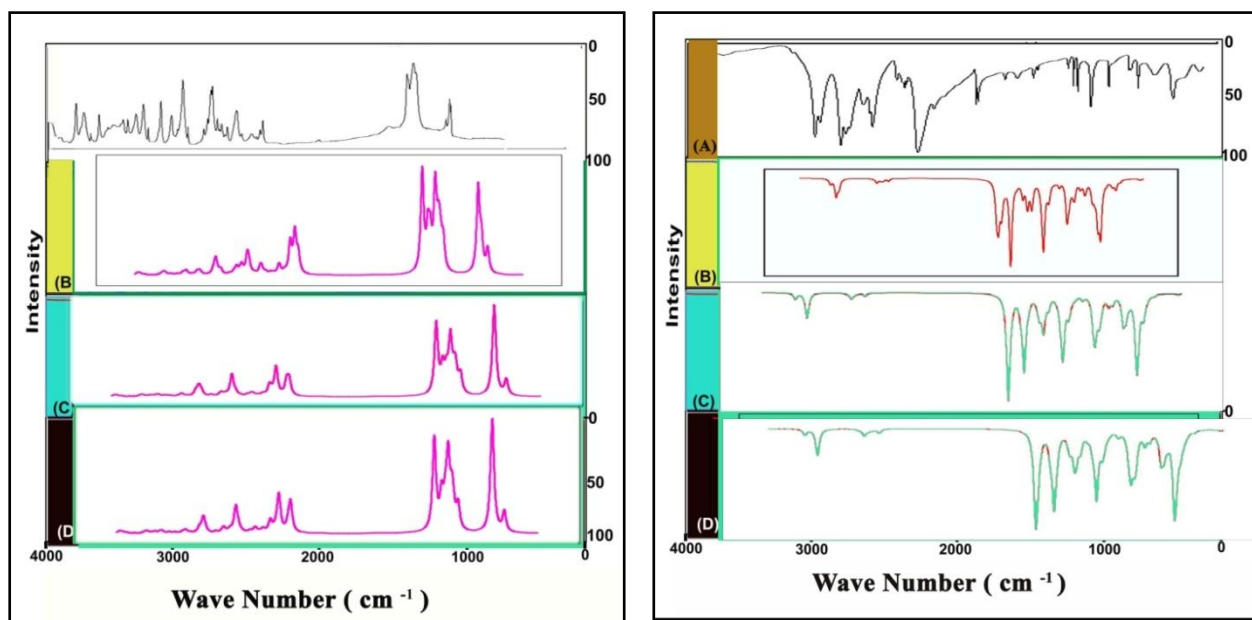
Fig. 2& 3 Experimental and Theoretical Spectra of FT-Raman and FT-IR.

4. Vibrational assignments

4.1 Carbon & Hydrogen (C-H) Vibrations

The existence of one or more aromatic rings in a structure is readily determined from the C-H and C=C-C ring related vibrations. The C-H stretching occurs above 3000 cm^{-1} and is typically exhibited as a multiplicity of weak to moderate bands compared with the aliphatic C-H stretch (Saxena R, et al. 2002)[8]. In this region the bands are not affected appreciably by the nature of substituent. From Table 2 the observed FT-IR and FT-Raman spectral wavenumbers are assigned to the C-H stretching modes of aromatic group of sulfamethoxazole. The very strong bands in FT-IR at 3096 and 2872 cm^{-1} in FT-Raman spectra are assigned to C-H stretching vibrations in the out of lane vibrations are observed. The observed the same vibrations which also correlated with the experimental values.

4.2 Carbon & Carbon (C-C) Vibrations

This vibrations are appears to be mixed mode as evident from the Table 2 with participation of C-C stretching vibrations. The experimental value for these modes in FT-IR and FT-Raman spectrum indicate an excellent agreement with our calculations.

4.3 S-H & N-H Vibrations

The S-H vibrations are appeared in the frequency range 922,816 in plane bending N-H vibrations are appeared in the frequency range 734, 554 out of plane bending.

5. Frontier molecular orbital analysis

The Highest Occupied Molecular orbital (HOMO) and the Lowest-lying Unoccupied Molecular Orbital (LUMO) are named as Frontier Molecular Orbitals (FMO) (Silverstein R.M and Webster F.X, et al. 2003) [9]. The FMO is an important role in the optical and electric properties, as well as in quantum chemistry and UV–Visible spectrum. The HOMO represents the ability to donate an electron, LUMO as an electron acceptor represents the ability to obtain an electron. The electronic absorption corresponds to the transition from the ground to the first excited state and is mainly described by one electron excitation from the HOMO to the LUMO. Chemical hardness (g) and softness (s) can be used as harmonizing tools to describe the thermodynamic aspects of chemical reactivity. The Frontier orbital gap helps to characterize the chemical reactivity kinetic stability, chemical reactivity, optical polarizability, chemical hardness, softness of a molecule. The investigations of FT-IR, FT-Raman, UV-Visible, FT-NMR Spectra and Quantum Chemical Computations of Sulfamethoxazole Molecule calculated HOMO and LUMO energy and the energy values of the frontier orbitals by B3LYP/6-311++G (d,p) are presented in Table 3. The

ionization potential (I.P) values suggest how tightly an electron is bound within the nuclear attractive field of the systems. It is linearly related with the chemical hardness (g). By using HOMO and LUMO energy values for a molecule, the Ionization potential and chemical hardness of the molecule were calculated using Koopmans' theorem (Perdew J.P et al. 1983) [10] and are given by

$$\Delta_{xc} = \{IP - EA\} - \{\varepsilon_{n+1}(n) - \varepsilon_n(n)\}$$

Where IP and EA are the ionization potential and electron affinity, respectively, and ε_{n+1} indicates the mth orbital energy of the n-electron system. Perdew and Levy and Casida verified in different ways that HOMO energy is identical to the minus IP, $\varepsilon_n(n) = -IP$. On the basis of above equation, this implies that LUMO energy corresponds to the minus EA, $\varepsilon_{n+1}(n) = -EA$. The hardness has been associated with the stability of chemical system. Considering the chemical hardness, large HOMO–LUMO gap means a hard molecule and small HOMO–LUMO gap means a soft molecule. One can also relate the stability of molecule to hardness, which means that the molecule with least HOMO–LUMO gap means, it is more reactive. The hard molecules are not more polarizable than soft ones because they need big energy to excitation 3D plots of the HOMO, LUMO, orbitals computed at the B3LYP/6-311++G (d,p) level. The electron affinity can be used in combination with ionization energy to give electronic chemical potential (Krishnakumar V & John Xavier R, 2003) [11].

$$\mu = \frac{1}{2}(\varepsilon LUMO + \varepsilon HOMO)$$

Chemical softness(S) = 1/η describes the capacity of an atom or group of atoms to receive electrons and is the inverse of the global hardness. The soft molecules are more polarizable than the hard ones because they need small energy to excitation. A molecule with a low energy gap is more polarizable and is generally associated with the high chemical activity and low kinetic stability and is termed soft molecule8. A hard molecule has a large energy gap and a soft molecule has a small energy gap It is shown from the calculations that Sulfamethoxazole

has the least value of global hardness (2.632835ev) and the highest value of global softness (10.53134eV) is expected to have the highest inhibition efficiency.

The global electrophilicity index (ω) has been defined by Parr et al. (1999)[12] as

$$\omega = \frac{\mu^2}{2\eta}$$

From this μ ≈ -(I+A)/2 and η ≈ (I-A)/2 are the electronic chemical potential and the chemical hardness respectively, approximated in terms of the vertical ionization potential (I) and electron affinity (A). The electrophilicity is a descriptor of reactivity that allows a quantitative classification of the global electrophilic nature of a molecule with in a relative scale and effectively is the power of a system to 'soak up' electron.

The global electrophilicity index of Sulfamethoxazole is also calculated from the B3LYP 6311++G(d,p) and UV-visible, there values are listed in Table 3.

6. NLO Properties

Non-Linear Optical (NLO) (Keresztury G, et al.2002)[13] effects arise from the interactions of electromagnetic fields in various media to produce new fields altered in phase, frequency, amplitude or other propagation characteristics from the incident fields. The first hyper polarizability of this novel molecular system and related properties of Sulfamethoxazole are calculated using DFT/B3LYP method at 6-311G++ (d,p) basis set based on the finite field approach. NLO is at the forefront of current research because of its importance in providing the key functions of frequency shifting, optical modulation, optical switching, optical logic, and optical memory for the emerging technologies in areas such as telecommunications, signal processing, and optical inter connections.

Table 3: Calculated energies, Chemical hardness, Electro negativity, Chemical potential, Electrophilicity index of Sulfamethoxazole in UV-Visible.

Parameter	B3LYP 6311++G (d,p)	UV-Visible	Electrophilicity Charge Transfer (ECT) $(\Delta N_{max})_A$-$(\Delta N_{max})_B$
E_{total} (Hartree)	-623.7	-623.8	
E_{HOMO} (eV)	6.23929	6.720666	
E_{LUMO} (eV)	0.97362	1.70370	
$\Delta E_{HOMO-LUMO\ gap}$ (eV)	5.26567	5.016966	
E_{HOMO-1} (eV)	5.23929	5.72066	4.2482
E_{LUMO+1} (eV)	1.97362	2.7037	
$\Delta E_{HOMO-1-LUMO+1\ gap}$ (eV)	3.26567	3.01696	
Chemical hardness (η)	2.632835	2.50848	
Electronegativity (χ)	3.606455	4.21218	
Chemical potential (μ)	3.606455	4.21218	
Chemical softness(S)	10.53134	10.03393	
Electrophilicity index (ω)	7.393030	9.00291	
Dipole moment	5.9161	5.9161	

In the presence of an applied electric field, the energy of a system is a function of the electric field. First order hyper polarizability is a third rank tensor that can be described by 3 x 3 x 3 matrices. The 27 components of the 3D matrix can be reduced to 10 components due to the Kleinman symmetry. It can be given in the lower tetrahedral format. It is obvious that the lower part of the 3 x 3 x 3 matrices is a tetrahedral. The components of β are defined as the coefficients in the Taylor series expansion of the energy in the external electric field.

When the external electric field is weak and homogeneous, this expansion becomes: $E=E_0-\mu\alpha F\alpha-1/2\alpha\alpha\beta F\alpha F\beta- 1/6\beta\alpha\beta\gamma F\alpha F\beta F\gamma+....$ Where E_0 is the energy of the unperturbed molecules, $F\alpha$ is the field at the origin, $\mu\alpha$, $\alpha\alpha\beta$ and $\beta\alpha\beta\gamma$ are the components of dipole moment, polarizability and the first order hyperpolarizabilities, respectively. DFT has been extensively used as an effective method to investigate the organic NLO materials.

Polarizability is the property of a species and it is minimum for most stable species and is maximum for least stable species like transition state.The α and β values of the Gaussian 05 output are in atomic units (a.u) and these calculated values converted into electrostatic unit (e.s.u) (α: 1 a.u = 0.1482×10^{-24}esu; for β: 1 a.u =8.639×10^{-33} esu;) and these above polarizability values of Sulfamethoxazole are listed in Table 4. The total

dipole moment (Mohan.J ed al.2001)[14] can be calculated using the following equation.

$$\mu = \surd(\mu x^2 + \mu y^2 + \mu z^2)$$

Table 4: The Electronic Dipole moment (Debye), Polarizability and first hyperpolarizability of Sulfamethoxazole

Parameter	a.u	Parameter	a.u
α_{xx}	-70.7525	β_{xxx}	-63.7329
α_{xy}	-12.4315	β_{xxy}	-64.4482
α_{yy}	-108.5586	β_{xyy}	17.6783
α_{xz}	-0.4007	β_{yyy}	-56.6573
α_{yz}	-5.4278	β_{xxz}	-55.0667
α_{zz}	-107.1550	β_{xyz}	8.0731
α_{tot}	220.635	β_{yyz}	-6.3909
$\Delta\alpha$	283.635	β_{xzz}	7.9455
μ_x	-0.4932	β_{yzz}	-4.3115
μ_y	-4.2713	β_{zzz}	-5.4213
μ_z	-3.9574	βtot	215.2758
μ_{tot}	5.8437		

7. Conclusion

The FTIR, FT-Raman, UV–Vis spectral measurements have been made for the Sulfamethoxazole molecule. The complete vibrational analysis and first order hyperpolarizability, HOMO and LUMO analysis and thermodynamic properties of the title compound was performed on the basis of DFT and HF calculations at the 6-311++G(d,p) basis set. The consistency between the calculated and experimental FTIR and FT-Raman data indicates that the B3LYP and HF methods can generate reliable geometry and related properties of the title compound. The difference between the observed and scaled wave number values of most of the fundamentals is very small. The Mulliken atomic charges and the natural atomic charges obtained are tabulated that gives a proper understanding of the atomic theory. The calculated dipole moment and first order hyperpolarizability results indicate that the title compound is a good candidate of NLO material. The calculated normal-mode vibrational frequencies provide thermodynamic properties by the way of statistical mechanics.

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