Research Article

Structural, Electronic, and Vibrational Properties of Isoniazid and Its Derivative N-Cyclopentylidenepyridine-4-carbohydrazide: A Quantum Chemical Study

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Isoniazid (Laniazid, Nydrazid), also known as isonicotinylhydrazine (INH), is an organic compound that is the first-line medication in prevention and treatment of tuberculosis. The optimized geometry of the isoniazid and its derivative N-cyclopentylidenepyridine-4-carbohydrazide molecule has been determined by the method of density functional theory (DFT). For both geometry and total energy, it has been combined with B3LYP functionals having LANL2DZ and 6-311 G (d, p) as the basis sets. Using this optimized structure, we have calculated the infrared wavenumbers and compared them with the experimental data. The calculated wavenumbers by LANL2DZ are in an excellent agreement with the experimental values. On the basis of fully optimized ground-state structure, TDDFT//B3LYP/LANL2DZ calculations have been used to determine the low-lying excited states of isoniazid and its derivative. Based on these results, we have discussed the correlation between the vibrational modes and the crystalline structure of isoniazid and its derivative. A complete assignment is provided for the observed FTIR spectra. The molecular HOMO, LUMO composition, their respective energy gaps, and MESP contours/surfaces have also been drawn to explain the activity of isoniazid and its derivative.

1. Introduction

Tuberculosis remains a major worldwide health problem with at least 10 million new cases and 3 million deaths estimated to occur annually. Isoniazid (Laniazid, Nydrazid), also known as isonicotinylhydrazine (INH), is an organic compound that is the first-line medication in prevention and treatment of tuberculosis. The compound was first synthesized in the early 20th century [1] but its activity against tuberculosis was first reported in the early 1950s, and three pharmaceutical companies attempted unsuccessfully to simultaneously patent the drug [2]. With the introduction of isoniazid, a cure for tuberculosis was first considered reasonable. Isoniazid is available in tablet, syrup, and injectable forms (given intramuscularly or intravenously). It is available worldwide, is inexpensive,

and is generally well tolerated. It is manufactured from isonicotinic acid, which is produced from 4-methylpyridine [3].

A previous investigation was done on determination of microquantities of isoniazid (INH), either in pure form or in pharmaceutical formulations by calorimetric method [4]. In another work, studies on the 4-benzoylpyridine-3-carboxamide entity as a fragment model of the isoniazid-NAD adduct were carried out [5]. A previous work on vibrational analysis of isoniazid was done by Gunasekaran et al. [6] by Wilson G.F. method which is a classical method, so it is necessary to work again with quantum chemical method to reduce the inaccuracy in previous work. The title compound, N-cyclopentylidenepyridine-4-carbohydrazide, $C_{11}H_{13}N_3O$, is a derivative of the antituberculosis drug isoniazid. The

TABLE 1: Optimized geometrical parameters of isoniazid and N-cyclopentylidenepyridine-4-carbohydrazide (CPPC) by (B3LYP)/ 6-311 G (d, p) and (B3LYP)/LANL2DZ methods.

Isoniazid				N-Cyclopentylidenepyridine-4-carbohydrazide parameters			
Parameters	Bond lengths			Parameters	Bond lengths		
	LANL2DZ	Calculated 6-311 G (d, p)	Wilson GF (literature)		LANL2DZ	Calculated 6-311 G (d, p)	Exp.
R(1, 2)	1.4036	1.3933	(1.470)	R(1, 2)	1.4054	1.3905	(1.3801)
R(1, 6)	1.3599	1.3355	(1.358)	R(1, 6)	1.3596	1.3381	(1.3309)
R(1, 7)	1.0866	1.0866	(1.100)	R(1, 7)	1.0865	1.0862	(0.95)
R(2, 3)	1.4146	1.3965	(1.420)	R(2, 3)	1.4100	1.3954	(1.3836)
R(2, 8)	1.0845	1.0788	(1.100)	R(2, 8)	1.0850	1.0824	(0.95)
R(3, 4)	1.4124	1.3972	(1.420)	R(3, 4)	1.4119	1.397	(1.3904)
R(3, 11)	1.5098	1.5067	(1.517)	R(3, 11)	1.5114	1.5098	(1.4973)
R(4, 5)	1.4088	1.3903	(1.420)	R(4, 5)	1.4079	1.3937	(1.3768)
R(4, 9)	1.0806	1.0822	(1.100)	R(4, 9)	1.0868	1.084	(0.95)
R(5, 6)	1.3563	1.3373	(1.358)	R(5, 6)	1.3564	1.3346	(1.3360)
R(5, 10)	1.0872	1.0864	(1.100)	R(5, 10)	1.0870	1.0866	(0.95)
R(11, 12)	1.2625	1.2198	(1.208)	R(11, 12)	1.2496	1.2106	(1.2249)
R(11, 13)	1.3903	1.377	(1.369)	R(11, 13)	1.3920	1.3825	(1.3484)
R(13, 16)	1.0203	1.0161	(1.012)	R(13, 14)	1.3977	1.369	(1.3961)
R(13, 17)	1.4052	1.402	(1.352)	R(13, 15)	1.0175	1.0129	(0.889)
R(14, 17)	1.0170	1.0152	(—)	R(14, 16)	1.2980	1.275	(1.2759)
R(15, 17)	1.0170	1.0142	(—)	R(16, 17)	1.5220	1.5146	(1.5076)
—	—	—	—	R(16, 20)	1.5329	1.5238	(1.5035)
—	—	—	—	R(17, 18)	1.5495	1.5388	(1.5243)
—	—	—	—	R(17, 21)	1.1002	1.0975	(0.99)
—	—	—	—	R(17, 22)	1.0942	1.0904	(0.99)
—	—	—	—	R(18, 19)	1.5529	1.5413	(1.5227)
—	—	—	—	R(18, 23)	1.0985	1.0952	(0.99)
—	—	—	—	R(18, 24)	1.0955	1.0915	(0.99)
—	—	—	—	R(19, 20)	1.5537	1.5438	(1.5333)
—	—	—	—	R(19, 25)	1.0955	1.0915	(0.99)
—	—	—	—	R(19, 26)	1.0983	1.0946	(0.99)
—	—	—	—	R(20, 27)	1.1020	1.0983	(0.99)
—	—	—	—	R(20, 28)	1.1001	1.0955	(0.99)
Bond angles							
Parameters	LANL2DZ	6-311 G (d, p)	Wilson GF	Parameters	LANL2DZ	6-311 G (d, p)	Exp.
A(2, 1, 6)	123.156	124.085	(128.1)	A(2, 1, 6)	123.207	123.7612	(124.11)
A(2, 1, 7)	120.854	119.882	(115.9)	A(2, 1, 7)	120.864	120.2359	(117.9)
A(6, 1, 7)	115.989	116.031	(115.9)	A(6, 1, 7)	115.927	116.0026	(117.9)
A(1, 2, 3)	119.423	118.609	(113.4)	A(1, 2, 3)	119.086	118.8914	(118.76)
A(1, 2, 8)	121.333	121.238	(123.3)	A(1, 2, 8)	121.357	121.5728	(120.6)
A(3, 2, 8)	119.243	120.148	(123.3)	A(3, 2, 8)	119.553	119.5347	(120.6)
A(2, 3, 4)	117.688	117.644	(120.0)	A(2, 3, 4)	118.003	117.7332	(118.04)
A(2, 3, 11)	115.580	116.359	(119.9)	A(2, 3, 11)	117.887	117.7499	(119.94)
A(4, 3, 11)	126.731	125.851	(119.9)	A(4, 3, 1)	124.079	124.4757	(121.87)

TABLE I: Continued.

A(3, 4, 5)	118.793	116.359	(120.0)	A(3, 4, 5)	118.940	118.7973	(118.51)
A(3, 4, 9)	120.388	119.095	(119.90)	A(3, 4, 9)	122.012	121.7783	(120.7)
A(5, 4, 9)	120.818	119.585	(119.9)	A(5, 4, 9)	119.000	119.3816	(120.7)
A(4, 5, 6)	123.709	121.315	(123.5)	A(4, 5, 6)	123.267	123.7549	(124.23)
A(4, 5, 10)	120.395	120.222	(118.2)	A(4, 5, 1)	120.733	120.095	(117.9)
A(6, 5, 10)	115.895	116.119	(118.2)	A(6, 5, 1)	115.997	116.1492	(117.9)
A(1, 6, 5)	117.229	116.890	(115.9)	A(1, 6, 5)	117.480	117.0429	(116.34)
A(3, 11, 12)	120.109	120.608	(123.5)	A(3, 11, 12)	121.407	121.7922	(121.01)
A(3, 11, 13)	123.160	120.465	(113.2)	A(3, 11, 13)	114.386	113.8995	(115.24)
A(12, 11, 13)	116.730	116.119	(123.10)	A(12, 11, 13)	124.194	124.3057	(123.71)
A(11, 13, 16)	112.897	110.815	(118.3)	A(11, 13, 14)	120.222	120.4885	(117.90)
A(11, 13, 17)	127.415	123.657	(120.9)	A(11, 13, 15)	119.204	118.6787	(120.9)
A(16, 13, 17)	119.687	120.608	(120.9)	A(14, 13, 15)	120.413	120.0841	(121.2)
A(13, 17, 14)	113.970	112.315	(—)	A(13, 14, 16)	117.618	117.4204	(116.39)
A(13, 17, 15)	113.972	109.553	(—)	A(14, 16, 17)	120.864	121.3315	(120.59)
A(14, 17, 15)	115.002	109.146	(—)	A(14, 16, 20)	129.064	128.9664	(129.82)
—	—	—	—	A(17, 16, 20)	110.061	109.6831	(109.59)
—	—	—	—	A(16, 17, 18)	103.828	103.7083	(103.49)
—	—	—	—	A(16, 17, 21)	109.558	109.1963	(111.1)
—	—	—	—	A(16, 17, 22)	111.559	111.673	(111.1)
—	—	—	—	A(18, 17, 21)	110.424	110.1309	(111.1)
—	—	—	—	A(18, 17, 22)	114.254	114.7737	(111.1)
—	—	—	—	A(21, 17, 22)	107.188	107.2821	(109)
—	—	—	—	A(17, 18, 19)	103.849	103.6438	(103.09)
—	—	—	—	A(17, 18, 23)	110.096	109.8783	(111.1)
—	—	—	—	A(17, 18, 24)	112.690	113.1144	(111.1)
—	—	—	—	A(19, 18, 23)	110.044	109.8696	(111.1)
—	—	—	—	A(19, 18, 24)	112.485	112.7897	(111.1)
—	—	—	—	A(23, 18, 24)	107.663	107.5175	(109.1)
—	—	—	—	A(18, 19, 20)	104.367	104.3214	(103.63)
—	—	—	—	A(18, 19, 25)	112.900	113.1836	(111)
—	—	—	—	A(18, 19, 26)	109.818	109.665	(111)
—	—	—	—	A(20, 19, 25)	112.372	112.7006	(111)
—	—	—	—	A(20, 19, 26)	109.763	109.5735	(111)
—	—	—	—	A(25, 19, 26)	107.597	107.3627	(109)
—	—	—	—	A(16, 20, 19)	104.150	104.3483	(103.78)
—	—	—	—	A(16, 20, 27)	109.9266	109.6136	(111)
—	—	—	—	A(16, 20, 28)	112.6795	112.4489	(111)
—	—	—	—	A(19, 20, 27)	110.6596	110.8512	(111)
—	—	—	—	A(19, 20, 28)	112.2491	112.6471	(111)
—	—	—	—	A(27, 20, 28)	107.209	106.9667	(109)

XRD analysis of this compound was done recently by Lemmerer et al. [7]. It is a derivative of such an important biological isoniazid molecule so comparative study of these two compounds is necessary for discovery of new drugs.

In the present communication, the molecular structure of well-known drug isoniazid and its derivative has been analyzed using the density functional theory. The equilibrium

geometry, harmonic vibrational frequencies, and HOMO-LUMO gap have been calculated by the density functional B3LYP method employing LANL2DZ and 6-311 G (d, p) as the basis sets. The detailed interpretation of the infrared spectra of isoniazid and its derivative in terms of the normal mode analysis has been reported. The main objective of the present study is to investigate in detail the vibrational

TABLE 2: Comparison of the observed and calculated vibrational spectra of isoniazid with (B3LYP)/6-311 G (d, p) and B3LYP/LANL2DZ.

LANL2DZ	B3LYP		IR (Int.)	FTIR (exp.)	FT Raman (exp.)	Vibrational assignments
	IR (Int.)	6-311 G (d, p)				
27	4.4893	39	2.1136	—	—	Whole molecule twists from joint
136	0.1522	121	3.0144	—	—	Twist NH ₂
163	0.0223	134	2.9603	—	—	Rock NH ₂
200	2.6928	198	2.2873	—	—	Whole molecule bends from joint
281	9.3909	261	15.6415	—	—	β (C-N-N)
343	64.239	306	54.4552	—	—	Twist NH ₂
380	4.8231	370	2.1727	—	—	τ (C-C-C=O)
385	3.0767	377	0.0835	—	—	γ (C-C-C) + γ (C-C-H)
457	3.736	452	5.6374	504	504	γ (C-C-C) + γ (C-C-H)
528	2.5885	544	17.1188	—	—	Rock NH ₂ + β (C-C=O)
578	142.03	588	52.8091	—	—	Rock NH ₂
658	23.445	636	26.3687	660	666	τ (C-C-C-C) + τ (C-N-C-C)
659	28.530	659	0.79	—	—	Twist NH ₂
668	162.33	702	45.9836	674	682	Rock NH ₂
701	110.45	720	3.2826	—	—	γ (C-N-H)
710	0.1352	745	774.0493	—	—	β (C-N-C) + β (C-C-C)
758	29.601	836	13.6245	745	750	γ (C-C-C) + γ (C-C-H)
854	37.843	865	0.5422	845	849	γ (C-C-H)
904	0.0237	874	143.4664	—	—	γ (C-C-H)
953	4.925	956	0.4745	—	—	Ring breathing
998	2.1689	970	3.0528	—	—	γ (C-C-H)
1005	2.381	977	3.1906	1020	1002	γ (C-C-H)
1046	9.4117	1052	17.7683	—	—	β (C-C-H) + β (C-C=O)
1049	20.656	1060	5.0938	1061	1057	β (C-N-C) + β (C-C-C)
1072	1.5593	1071	3.1435	—	—	β (C-C-H)
1170	69.756	1154	50.7026	—	—	β (C-C-C) + β (C-C-H)
1200	1.2477	1198	1.8033	1200	1187	β (C-C-H)
1223	0.006	1227	3.1093	—	—	Twist NH ₂
1249	5.3368	1268	3.7348	—	—	ν (C-N) + ν (C-C)
1305	3.9465	1301	3.2532	—	—	β (C-C-H)
1353	177.39	1334	194.7891	1334	1331	β (O=C-N) + β (C-C-H)
1383	56.249	1386	31.6275	—	—	β (C-C-H)
1416	48.473	1427	19.6455	1412	1410	β (C-N-H)
1448	2.1058	1465	1.3185	—	—	β (C-C-H)
1517	56.958	1535	28.9279	1472	—	ν (C-C)
1560	11.455	1574	9.7845	—	—	ν (C-C)
1577	87.192	1634	30.7552	1556	1551	ν (C=O)
1642	55.629	1684	235.7803	1635	1642	S(NH ₂)
3079	32.086	3030	34.8746	3050	3065	ν (C-H)
3085	9.0201	3035	14.6458	—	—	ν (C-H)
3121	4.9876	3089	2.9337	—	—	ν (C-H)
3153	8.4279	3119	3.3617	—	—	ν (C-H)
3381	1.8185	3341	1.8712	—	—	ν (N-H)
3389	17.234	3387	16.6022	3303	3300	ν (N-H)
3509	9.0098	3426	4.449	—	—	ν (N-H)

ν : stretching; β : in plane bending; γ : out of plane bending; S: scissoring; w: wagging; τ : torsion.

TABLE 3: Comparison of calculated vibrational spectra of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC) with (B3LYP)/6-311 G (d, p) and B3LYP/LANL2DZ.

LANL2DZ	B3LYP		IR (Int.)	Vibrational assignments
	IR (Int.)	6-311 G (d, p)		
29	0.189	29	0.0368	Whole molecule twists from middle
44	0.0329	43	0.0041	Whole molecule twists from middle
55	1.0643	56	0.5335	Ring B bends from middle
65	2.6343	64	1.7946	Twisting in ring B
115	1.2256	113	0.2943	Twisting in ring B
155	9.5443	152	8.6203	Both rings twist from middle
189	11.479	187	10.7292	Bending in whole molecule
221	0.5418	226	0.7907	γ (C-C-C) ring B
239	1.4716	243	1.22	τ (C-C-N-N)
284	4.2682	285	4.0485	τ (N-N-C=O)
324	4.6942	325	0.6016	Twist CH ₂ ring B
376	0.124	374	0.0949	Out of plane bending in ring A as a whole
395	2.2666	382	7.9387	τ (C-C-C=O)
453	8.0728	443	26.6387	ω (N-H)
466	11.181	464	11.8231	Out of plane bending in whole molecule
542	4.2055	492	20.6542	Whole molecule bends from middle
554	52.148	546	8.846	Twist CH ₂ ring B
573	25.912	559	0.4785	Twist CH ₂ ring B
588	7.2812	593	9.2922	β (C-C=N)
654	1.136	657	0.8099	Ring A deformation
660	43.182	663	50.3605	Ring A breathing
690	28.825	696	16.6761	γ (C-C-C) ring A
739	0.3987	736	0.1654	Twist in ring B
750	13.234	746	10.518	γ (C-C-C) ring A
811	0.675	806	0.01	γ (CH ₂) ring B
835	12.940	825	13.797	γ (C-C-C) ring B
837	25.375	830	1.1714	γ (C-C-C) ring A
873	2.6331	866	2.3196	γ (C-C-C) ring B
885	25.947	867	0.4876	β (N-C=O) joint to both rings
887	3.846	889	4.1429	γ (C-C-H) ring A
906	5.1907	907	22.5923	Twist CH ₂ ring B
947	5.0577	933	2.7875	γ (C-C-H) ring B
951	5.9695	951	0.2745	Ring A breathing
966	2.0181	973	4.7925	γ (C-C-C) ring A
986	18.651	974	0.9688	γ (C-C-C) ring A
990	12.259	985	0.3854	γ (C-C-C) ring A
1002	2.3552	995	0.0806	Twist CH ₂ ring B
1027	5.8621	1021	12.9074	γ (C-C-C) ring B
1048	14.225	1050	17.0033	β (C-C-H) ring A
1072	17.410	1067	8.9467	β (C-C-H) ring A
1104	73.216	1105	114.2174	β (C-C-H) ring A
1127	0.6851	1118	0.8245	Twist CH ₂ ring B
1144	9.5501	1144	23.861	γ (C-C-H) ring B
1184	15.684	1174	13.5043	β (C-C=N) ring A + β (C-C-C) ring B
1196	6.0684	1188	9.5816	γ (C-C-H) ring B

TABLE 3: Continued.

LANL2DZ	B3LYP		IR (Int.)	Vibrational assignments
	IR (Int.)	6-311 G (d, p)		
1203	3.3536	1195	23.0436	β (C–C–H) ring A
1222	62.461	1209	146.2051	Twist CH ₂ ring B
1237	163.03	1217	51.1901	β (C–C–C) ring A + twist CH ₂ ring B
1249	10.424	1232	34.5492	Ring A deformation
1266	9.0924	1256	4.27	Twist CH ₂ ring B
1283	2.845	1279	0.3718	Rock CH ₂ ring B
1305	0.2089	1295	0.4946	Twist CH ₂ ring B
1306	0.0683	1297	1.5912	Twist CH ₂ ring B
1312	0.6944	1301	0.9643	β (C–C–H) ring A
1381	13.894	1385	14.4629	β (C–C–H) ring A
1436	34.372	1416	17.0927	S(CH ₂) ring B
1441	13.808	1420	7.2964	S(CH ₂) ring B
1447	11.264	1442	5.421	β (C–C–H) ring A
1461	9.7004	1456	3.4055	S(CH ₂) ring B
1469	1.2504	1463	17.0394	S(CH ₂) ring B
1487	313.60	1489	318.044	β (C–N–H)
1529	37.617	1538	23.3689	Ring A deformation
1563	7.4055	1573	17.1708	ν (C–C) ring A
1604	227.40	1654	22.9328	ν (C=O)
1623	2.596	1715	302.3136	ν (C=N) joint ring B
2902	18.706	2890	12.407	ν (C–H) ring B
2925	15.584	2900	12.3498	ν (C–H) ring B
2938	21.950	2917	25.4822	ν (C–H) ring B
2939	41.648	2923	12.8395	ν (C–H) ring B
2954	38.945	2934	41.6752	ν (C–H) ring B
3001	42.309	2975	40.8297	ν (C–H) ring B
3009	30.010	2981	39.1011	ν (C–H) ring B
3017	50.383	2990	14.2807	ν (C–H) ring B
3072	8.0634	3031	21.1113	ν (C–H) ring A
3086	26.263	3038	23.6222	ν (C–H) ring A
3095	16.702	3061	12.3221	ν (C–H) ring A
3118	4.5408	3088	3.1852	ν (C–H) ring A
3416	17.207	3412	13.2313	ν (N–H)

ν : stretching; β : in plane bending; γ : out of plane bending; S: scissoring; ω : wagging; τ : torsion.

spectra of important biological molecules (isoniazid and its derivative) by DFT [8] method, which can presumably help in understanding its dynamical behavior. To the best of our knowledge no detailed DFT calculations have been performed on isoniazid and its derivative so far in the literature. Here we have discussed only results from LANL2DZ because these results are closer to experimental data than 6-311 G (d, p). So, here LANL2DZ shows supremacy over 6-311 G (d, p) basis set.

2. Experimental and Computational Methods

2.1. Structure and Spectra. The molecular structures of the title compounds isoniazid and its derivative are made by molecular modeling. The model molecular structures of the compounds are given in Figures 1 and 2. Fourier transform

infrared spectrum was recorded with FTIR Perkin Elmer spectrometer in KBr dispersion in the range of 400 to 4000 cm⁻¹ for the title molecule. Fourier transform Raman spectrum was recorded in the range of 50 to 3500 cm⁻¹ for isoniazid [6].

2.2. Computational Methods. Initial geometry was generated from standard geometrical parameters and was minimized without any constraint in the potential energy surface. The gradient corrected density functional theory (DFT) with the three-parameter hybrid functional (B3) [9] for the exchange part and the Lee-Yang-Parr (LYP) correlation function [10] has been employed for the computation of molecular structure, vibrational frequencies, HOMO-LUMO, and energies of the optimized structures, using GAUSSIAN 09 [11]. The calculated vibrational frequencies have also been scaled

TABLE 4: Calculated parameters for isoniazid and CPPC using TDDFT//B3LYP/LANL2DZ.

Excitation	CI coefficient	Expansion wave length (nm) calculated	Oscillator strength	Energy (eV)
<i>Isoniazid</i>				
Excited state 1				
31 $\rightarrow$ 37	0.63973	214.82	0.1780	5.7714
34 $\rightarrow$ 38	0.27134			
Excited state 2				
34 $\rightarrow$ 38	0.50322	180.83	0.5155	6.8565
31 $\rightarrow$ 38	-0.13282			
Excited state 3				
34 $\rightarrow$ 39	0.53619	159.44	0.2444	7.7762
29 $\rightarrow$ 38	-0.11809			
<i>CPPC</i>				
Excited state 1				
49 $\rightarrow$ 55	0.45328	214.82	0.3239	5.7716
53 $\rightarrow$ 57	0.10859			
52 $\rightarrow$ 57	0.10042			
Excited state 2				
47 $\rightarrow$ 55	0.26652	185.18	0.2676	6.6955
50 $\rightarrow$ 56	0.50556			
53 $\rightarrow$ 58	0.22945			
Excited state 3				
49 $\rightarrow$ 56	0.45774	175.46	0.1706	7.0662
50 $\rightarrow$ 57	0.41085			

TABLE 5: Lowest energy, HOMO-LUMO gap (frontier orbital energy gap) and dipole moment of isoniazid and N-cyclopentylidenepyridine-4-carbohydrazide (CPPC) by (B3LYP)/6-311 G (d, p) and (B3LYP)/LANL2DZ methods.

Parameters	Isoniazid		N-Cyclopentylidenepyridine-4-carbohydrazide	
	LANL2DZ	6-311 G (d, p)	LANL2DZ	6-311 G (d, p)
Energy (in au)	-472.2226	-472.4245	-666.3336	-666.6202
Dipole moment (in Debye)	5.49	4.94	6.25	5.37
HOMO	-6.8353	-6.8852	-6.7673	-6.7821
LUMO	-1.8800	-1.9129	-1.9815	-1.9875
Frontier orbital energy gap (eV)	4.9552	4.9723	4.7857	4.7946

by a factor of 0.963 [12]. By combining the results of GaussView's program [13] with symmetry considerations, vibrational frequency assignments were made with a high degree of accuracy. We used this approach for the prediction of IR frequencies of title compound and found it to be very straightforward. Density functional theory calculations are reported to provide excellent vibrational frequencies of organic compound if the calculated frequencies are scaled to compensate for the approximate treatment of electron correlation, for basis set deficiencies and for anharmonicity. A number of studies have been carried out regarding calculations of vibrational spectra by using B3LYP methods with LANL2DZ and 6-311 G (d, p) basis sets. The scaling factor was applied successfully for B3LYP method and was found to be easily transferable in a number of molecules. Thus, vibrational frequencies calculated by using the B3LYP functional with LANL2DZ as basis set can be utilized to

eliminate the uncertainties in the fundamental assignment in the IR spectra.

3. Results and Discussion

3.1. Molecular Structure. In the case of isoniazid, the molecule has only one pyridine ring. The optimized bond length of C-C in six membered pyridine ring ranges between 1.403 Å and 1.414 Å. The optimized bond length of C-C outside the ring is 1.509 Å. The optimized bond lengths of C-N in ring range between 1.356 Å and 1.359 Å. The optimized bond length of C-N outside the ring is found to be 1.390 Å. The optimized C-H bond lengths attached to the ring are found to be 1.080 Å -1.087 Å. The optimized C=O bond length adjacent to ring is found to be 1.262 Å. The optimized N-H bond lengths adjacent to ring are found to be 1.016 Å-1.020 Å.

TABLE 6: Calculated ϵ_{HOMO} , ϵ_{LUMO} , energy band gap ($\epsilon_{\text{L}} - \epsilon_{\text{H}}$), chemical potential (μ), electronegativity (χ), global hardness (η), global softness (S), and global electrophilicity index (ω) for isoniazid and CPPC at B3LYP/LANL2DZ level.

Molecules	ϵ_{H}	ϵ_{L}	$\epsilon_{\text{L}} - \epsilon_{\text{H}}$	χ	μ	η	S	ω
CPPC 2	-6.7673	-1.9815	4.7857	4.3744	-4.3744	2.3929	0.2090	3.9984
ISO 2	-6.8353	-1.8800	4.9552	4.3577	-4.3577	2.4776	0.2018	3.8322

TABLE 7: Fukui functions (f_k^+ , f_k^-), local softness (s_k^+ , s_k^-), and local electrophilicity indices (ω_k^+ , ω_k^-) for selected atomic sites of CPPC, using Mulliken population analysis at B3LYP/LANL2DZ level.

CPPC	f_k^+	f_k^-	s_k^+	s_k^-	ω_k^+	ω_k^-
N6	0.063725	0.047259	0.013319	0.009877	0.254798	0.18896
C11	0.088784	0.050459	0.018556	0.010546	0.354994	0.201755
N13	0.016223	0.049147	0.003391	0.010272	0.064866	0.196509
N14	0.023381	0.043409	0.004887	0.009072	0.093487	0.173567
H15	0.018967	0.032456	0.003964	0.006783	0.075838	0.129772
CPPC (full)	f_k^+	f_k^-	s_k^+	s_k^-	ω_k^+	ω_k^-
C1	0.037085	0.053511	0.007751	0.011184	0.148281	0.213956
C2	0.079194	0.038498	0.016552	0.008046	0.316649	0.15393
C3	0.037105	0.018265	0.007755	0.003817	0.148361	0.073031
C4	0.056432	0.033863	0.011794	0.007077	0.225638	0.135398
C5	0.046093	0.054106	0.009633	0.011308	0.184298	0.216337
N6	0.063725	0.047259	0.013319	0.009877	0.254798	0.18896
H7	0.05017	0.048264	0.010486	0.010087	0.2006	0.192979
H8	0.024605	0.022564	0.005142	0.004716	0.098381	0.09022
H9	0.025706	0.012418	0.005373	0.002595	0.102783	0.049652
H10	0.048308	0.046734	0.010096	0.009767	0.193155	0.186861
C11	0.088784	0.050459	0.018556	0.010546	0.354994	0.201755
O12	0.10292	0.103102	0.02151	0.021548	0.411515	0.412243
N13	0.016223	0.049147	0.003391	0.010272	0.064866	0.196509
N14	0.023381	0.043409	0.004887	0.009072	0.093487	0.173567
H15	0.018967	0.032456	0.003964	0.006783	0.075838	0.129772
C16	0.07141	0.083266	0.014925	0.017403	0.285526	0.332931
C17	-0.01717	-0.0153	-0.00359	-0.0032	-0.06865	-0.06118
C18	0.000227	-0.00052	4.74E - 05	-0.00011	0.000908	-0.00206
C19	0.000575	0.001021	0.00012	0.000213	0.002299	0.004082
C20	-0.02038	-0.0215	-0.00426	-0.00449	-0.08147	-0.08597
H21	0.03456	0.04074	0.007223	0.008515	0.138185	0.162895
H22	0.039332	0.053361	0.00822	0.011152	0.157265	0.213359
H23	0.02873	0.033782	0.006005	0.00706	0.114874	0.135074
H24	0.028555	0.033136	0.005968	0.006925	0.114174	0.132491
H25	0.029499	0.033406	0.006165	0.006982	0.117949	0.133571
H26	0.025818	0.029323	0.005396	0.006129	0.103231	0.117245
H27	0.034231	0.046674	0.007154	0.009755	0.136869	0.186621
H28	0.025909	0.028557	0.005415	0.005968	0.103595	0.114182

When a five-membered carbon ring is also attached to isoniazid, it becomes N-cyclopentylidenepyridine-4-carbohydrazide. For N-cyclopentylidenepyridine-4-carbohydrazide, it has one six-membered pyridine ring (A) and one five-membered carbon ring. The optimized bond length of C-C in six-membered pyridine ring A ranges between 1.405 Å and 1.411 Å, while for another ring B it ranges between 1.521 Å and 1.553 Å. The optimized bond lengths of C-N in pyridine ring A range between 1.356 Å

and 1.359 Å. The optimized bond length of C-N in between both rings is found to be 1.392 Å. The optimized C-H bond lengths attached to the ring A are found to be 1.084 Å–1.086 Å while for ring B it ranges between 1.094 Å and 1.101 Å. The optimized C=O bond length in between both rings is found to be 1.249 Å. The optimized N-H bond length in between the rings is found to be 1.017 Å. All the optimized bond lengths are in good agreement with the experimental values given in the literature and summarized in Table 1 [7]. This

TABLE 8: Fukui functions (f_k^+ , f_k^-), local softness (s_k^+ , s_k^-), and local electrophilicity indices (ω_k^+ , ω_k^-) for selected atomic sites of isoniazid, using Mulliken population analysis at B3LYP/LANL2DZ level.

ISO	f_k^+	f_k^-	s_k^+	s_k^-	ω_k^+	ω_k^-
N6	0.087184	0.075685	0.017594	0.015273	0.334107	0.29004
C11	0.045066	0.105331	0.009094	0.021256	0.172702	0.403649
O12	0.125455	0.097778	0.025317	0.019732	0.480769	0.374705
N13	0.104399	-0.09059	0.021068	-0.01828	0.400078	-0.34714
H14	0.07228	0.027223	0.014586	0.005494	0.276991	0.104324
H15	0.045876	0.053631	0.009258	0.010823	0.175806	0.205525
H16	0.066534	0.058946	0.013427	0.011895	0.254972	0.225893
N17	-0.07824	0.12441	-0.01579	0.025106	-0.29982	0.476764
ISO (full)	f_k^+	f_k^-	s_k^+	s_k^-	ω_k^+	ω_k^-
C1	0.070332	0.074531	0.014193	0.01504	0.269526	0.285618
C2	0.086439	0.065308	0.017443	0.013179	0.331252	0.250273
C3	0.098962	-0.00059	0.019971	-0.00012	0.379242	-0.00226
C4	0.068608	0.080752	0.013845	0.016296	0.26292	0.309458
C5	0.061734	0.096349	0.012458	0.019443	0.236577	0.369229
N6	0.087184	0.075685	0.017594	0.015273	0.334107	0.29004
H7	0.068036	0.06207	0.01373	0.012526	0.260728	0.237865
H8	0.03037	0.040116	0.006129	0.008095	0.116384	0.153733
H9	-0.02115	0.070626	-0.00427	0.014252	-0.08104	0.270653
H10	0.068106	0.05842	0.013744	0.011789	0.260996	0.223877
C11	0.045066	0.105331	0.009094	0.021256	0.172702	0.403649
O12	0.125455	0.097778	0.025317	0.019732	0.480769	0.374705
N13	0.104399	-0.09059	0.021068	-0.01828	0.400078	-0.34714
H14	0.07228	0.027223	0.014586	0.005494	0.276991	0.104324
H15	0.045876	0.053631	0.009258	0.010823	0.175806	0.205525
H16	0.066534	0.058946	0.013427	0.011895	0.254972	0.225893
N17	-0.07824	0.12441	-0.01579	0.025106	-0.29982	0.476764

FIGURE 1: Model molecular structure of isoniazid.

FIGURE 2: Model molecular structure of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC).

difference in the bond lengths is attributed to the difference in bond strength. The length of a chemical bond is the result of equilibrium of attractive and repulsive forces between the atoms which are bonded. In fact, the distance between the atoms of a bond is not constant since the atoms are

always vibrating in molecules; the measured bond distance is, therefore, an average value. Although the measurements may vary in accuracy, still similar bonds have fairly constant

TABLE 9: Polarizability and hyper polarizability of isoniazid and N-cyclopentylidenepyridine-4-carbohydrazide (CPPC) by (B3LYP)/LANL2DZ methods.

	Isoniazid		N-Cyclopentylidenepyridine-4-carbohydrazide	
	LANL2DZ	6-311 G (d, p)	LANL2DZ	6-311 G (d, p)
Polarizability				
α_{xx}	-54.4243	-53.1504	-87.0159	-86.5468
α_{xy}	-13.9175	-11.3119	8.2530	6.5995
α_{yy}	-57.0302	-56.9567	-96.2129	-95.0135
α_{yz}	0.0007	2.9339	4.6341	4.0900
α_{zz}	-58.4664	-57.4167	-88.0328	-87.9161
α_{zx}	0.0006	2.8602	1.0289	0.8897
α	56.6403	55.8412	90.4205	89.8254
Hyper polarizability				
β_{xxx}	104.6160	92.6426	-133.3584	-99.8131
β_{xxy}	-9.7260	-11.3252	50.4571	40.4792
β_{xyy}	-5.2048	-2.4771	-9.9876	-5.2677
β_{yyy}	-28.2262	-20.4938	-30.0106	-21.2944
β_{zzz}	0.0026	4.0365	-0.0107	-0.6537
β_{xxz}	0.0029	8.9620	6.7905	5.7162
β_{xzz}	13.6068	11.5672	-9.3808	-4.2219
β_{yzz}	-3.0727	-2.3332	1.3678	2.3214
β_{yyz}	-0.0001	2.6541	1.3952	0.9832
β_{xyz}	-0.0020	-3.8704	12.4376	10.8998
β total	120.2335	115.5787	154.1308	111.5623

TABLE 10: Calculated thermodynamic properties of isoniazid and N-cyclopentylidenepyridine-4-carbohydrazide (CPPC) by (B3LYP)/LANL2DZ and 6-311 G (d, p) methods.

	E (thermal) (k cal mol ⁻¹)		CV (cal K ⁻¹ mol ⁻¹)		S (cal K ⁻¹ mol ⁻¹)	
	Iso	CPPC	Iso	CPPC	Iso	CPPC
Total	89.150 (88.749)	152.971 (151.836)	32.161 (32.206)	49.600 (50.109)	92.375 (92.452)	116.973 (117.377)
Translational	0.889 (0.889)	0.889 (0.889)	2.981 (2.981)	2.981 (2.981)	40.658 (40.658)	41.830 (41.830)
Rotational	0.889 (0.889)	0.889 (0.889)	2.981 (2.981)	2.981 (2.981)	29.577 (29.490)	32.607 (32.545)
Vibrational	87.373 (86.972)	151.194 (150.059)	26.199 (26.244)	43.638 (44.147)	22.141 (22.304)	42.537 (43.002)

lengths in different molecules, variation generally being much less.

3.2. Vibrational Assignments. The molecules isoniazid and its derivative (CPPC) contain 17 and 28 atoms and they have 45 and 78 normal modes of vibration, respectively. All the fundamental vibrations are active IR. The harmonic vibrational frequencies are calculated for both the molecules at B3LYP/LANL2DZ and 6-311 G (d, p) level and experimental frequencies (FTIR) have been compared in Tables 2 and 3 for isoniazid and its derivative (CPPC), respectively. Tables 2 and 3 also include the vibrational assignments of the normal modes. Vibrational assignments are based on the observation of the animated modes in GaussView and assignments reported in the literature.

In isoniazid, the N-H functional group is present at 3389 cm⁻¹ in calculated spectra which is in good agreement with the experimental data. The C-H functional group is present at a number of positions. The stretching vibration, $\nu(\text{C-H})$, is expected to occur in the region 2800–3200 cm⁻¹. The $\nu(\text{C-H})$ functional group is present at 3079 cm⁻¹ in calculated spectra which is in good agreement with the experimental data, that is, 3050 cm⁻¹. The calculated values of the $\nu(\text{C-H})$ vibration lie within this spectral range. The calculated (scaled) and experimental frequencies are deviated by a large amount, which may be explained by the presence of hydrogen bonding in the solid sample. The theoretical calculations have been done on gas-phase molecule.

The -NH₂ functional group is important constituents of isoniazid and vibrations corresponding to these groups are

present in a number of modes. The stretching modes corresponding to these groups are of two types: symmetric and asymmetric stretching. In the symmetric stretching vibration, both the arms of the functional group are stretching in-phase with each other, whereas, in the asymmetric stretching mode, the atomic hydrogen motions are out-of-phase. The twisting and rocking vibrations for both the functional groups are present mixed with other vibrations in middle region. As expected, the ring torsion modes along with wagging modes appear in the low frequency range. An intense band due to torsion of C-C-C-C is at 658 cm^{-1} in calculated spectrum which matches well with the experimental one, that is, 560 cm^{-1} . There are some frequencies in lower region having appreciable IR intensity. Furthermore, the study of low frequency vibrations is of great significance, because it gives information on weak intermolecular interactions, which take place in enzyme reactions [14]. Knowledge of low frequency mode is also essential for the interpretation of the effect of electromagnetic radiation on biological systems [15].

In CPPC, the N-H functional group is present at 3416 cm^{-1} in calculated spectra having appreciable IR intensity. The C-H functional group is present at a number of positions. The $\nu(\text{C-H})$ functional group is present at 2939, 2954, and 3001 cm^{-1} in calculated spectra having substantial IR intensity. The region $1600\text{--}2000\text{ cm}^{-1}$ is generally considered as the double bond stretching region for C=O, C=C, and C=N bonds [16–19]. The C=O stretching vibration, $\nu(\text{C=O})$, appears as a prominent mode in the calculated spectra at 1604 cm^{-1} .

The $-\text{CH}_2$ functional groups are important constituents of CPPC and vibrations corresponding to these groups are present in a number of modes. Due to twist $-\text{CH}_2$ mode an intense peak is present at 554 cm^{-1} in calculated spectra as a prominent mode. The twisting and rocking vibrations for the functional group are present mixed with other vibrations in middle region. Here, we are discussing only most IR active modes present in calculated spectra for both the molecules. The aim of this section is to obtain direct information on lower and higher frequency vibrations of such biologically active molecules. No experimental FTIR spectrum is available for comparison so it will be a suitable path for experimental researchers.

3.3. Electronic Spectra and Electronic Properties. On the basis of fully optimized ground-state structure, TDDFT//B3LYP/LANL2DZ calculations have been used to determine the low-lying excited states of isoniazid and CPPC. The calculated results involving the vertical excitation energies, oscillator strength (f), and wavelength are carried out using the Gaussian 09W program. Experimental wavelengths are not available so these calculated data can help the experimental researchers. Electronic transitions determined from excited state calculations are listed in Table 4 for the three lowest energy transitions of the molecule. For isoniazid, TD-DFT calculation predicts three intense electronic transitions at 5.7714 eV (214.82 nm), 6.8565 eV (180.83 nm), and 6.7948 eV (159.44 nm) with oscillator strengths of 0.1780, 0.5155, and 0.2444, respectively.

FIGURE 3: Calculated UV spectrum of CPPC.

FIGURE 4: Calculated UV spectrum of isoniazid.

For CPPC and TD-DFT calculation predicts three intense electronic transitions at 5.7716 eV (214.82 nm), 6.6955 eV (185.18 nm), and 7.0662 eV (175.46 nm) with oscillator strengths of 0.3239, 0.2676, and 0.1706, respectively. The calculated UV spectrum of isoniazid and its derivative CPPC are shown in Figures 3 and 4.

The frontier orbitals, HOMO and LUMO, determine the way the molecule interacts with other species. The frontier orbital gap helps to characterize the chemical reactivity and kinetic stability of the molecule. A molecule which has a larger orbital gap is more polarized having more reactive part as far as reaction is concerned [20]. According to the present calculations, the frontier orbital gap in case of the given molecules is 4.9531 and 4.7835 eV, respectively, for isoniazid and CPPC given in Table 5. So we can say that CPPC is more reactive than isoniazid. The plots of the HOMO, LUMO, and electrostatic potential for both the molecules are shown in Figures 5–10. For isoniazid, HOMO (Figure 5) is located over the whole molecule. LUMO is located (Figure 6) at the same place as HOMO excluding hydrogen atoms. For

FIGURE 5: HOMO picture of isoniazid.

FIGURE 6: LUMO picture of isoniazid.

CPPC, HOMO (Figure 7) is located nearby and on ring B. LUMO is located (Figure 8) nearby and on ring A. The importance of MESP lies in the fact that it simultaneously displays molecular size, shape, and positive, negative, and neutral electrostatic potential regions in terms of colour grading (shown in Figures 9 and 10) and is very useful in investigation of molecular structure with its physiochemical property relationship [21–25]. We have also plotted 3D MESP structures of the title compound as shown in Figures 11 and 12. For isoniazid and CPPC, the electronegative region is outside of the molecule near the oxygen atoms. The energy equal to the shielded potential energy surface is required for any substitution reaction near oxygen. The electronegative lines (in between -0.08 a.u. and -0.02 a.u.) form a closed contour which clearly indicates that total flux passing in between these curves are not equal to zero. For any nucleophilic substitution reaction near oxygen (closed contour area), an amount of energy equal to shielded potential energy surface is required; however, the remaining part of the molecule is suitable for electrophilic substitution reaction. Thus, it can be asserted that MESP values have been shown to be well related to biological properties. [26–28].

FIGURE 7: HOMO picture of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC).

FIGURE 8: LUMO picture of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC).

3.4. Reactivity Descriptors

3.4.1. Global Reactivity Descriptors. The energies of frontier molecular orbitals (ϵ^{HOMO} , ϵ^{LUMO}), energy band gap ($\epsilon^{\text{LUMO}} - \epsilon^{\text{HOMO}}$), electronegativity ($\chi = -(1/2)(\epsilon^{\text{LUMO}} + \epsilon^{\text{HOMO}})$), chemical potential ($\mu = -\chi$), global hardness ($\eta = (1/2)(\epsilon^{\text{LUMO}} - \epsilon^{\text{HOMO}})$), global softness ($S = 1/2\eta$), and global electrophilicity index ($\omega = \mu^2/2\eta$) [29–32] of isoniazid and CPPC have been listed in Table 6. It is found that the gap between HOMO and LUMO is smaller in CPPC than isoniazid.

3.4.2. Local Reactivity Descriptors. Fukui function (FF) of a molecule provides information of the local site reactivity within the molecule and as such it provides a method for understanding and categorizing chemical reactions. These values represent the qualitative descriptors of reactivity of different atoms in the molecule. Ayers and Parr [33] have elucidated that molecules tend to react where the FF is the largest when attacked by soft reagents and in places where the FF is smaller when attacked by hard reagents. The use of Fukui functions for the site selectivity of isoniazid and CPPC molecules for nucleophilic and electrophilic attacks has been made with special emphasis on the dependence of Fukui values on the basis of B3LYP/6-311G(d,p) level of theory. Using Mulliken atomic charges of cationic and anionic states

FIGURE 9: MESP picture of isoniazid.

FIGURE 10: MESP picture of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC).

FIGURE 11: Contour plot of isoniazid.

FIGURE 12: Contour plot of N-cyclopentylidenepyridine-4-carbohydrazide (CPPC).

of isoniazid and CPPC, local Fukui functions (fk^+ , fk^-), local softness (sk^+ , sk^-), and local electrophilicity indices (ωk^+ , ωk^-) [30, 31] have been calculated using the following equation:

$$\begin{aligned}fk^+ &= [q(N+1) - q(N)] \quad \text{for nucleophilic attack,} \\fk^- &= [q(N) - q(N-1)] \quad \text{for electrophilic attack,} \\fk^0 &= \frac{1}{2} [q(N+1) + q(N-1)] \quad \text{for radical attack.}\end{aligned}\quad (1)$$

Local softness and electrophilicity indices are calculated using the following equation:

$$\begin{aligned}sk^+ &= Sfk^+, & sk^- &= Sfk^-, \\ \omega k^+ &= \omega fk^+, & \omega k^- &= \omega fk^-, \end{aligned}\quad (2)$$

where + and - signs show nucleophilic and electrophilic attacks, respectively.

Fukui functions, local softness, and local electrophilicity indices for selected atomic sites in isoniazid and CPPC have been listed in Tables 7 and 8. For CPPC, the maximum values for local nucleophilic reactivity descriptors (fk^- , sk^- , ωk^-) at N13 and N14 indicate that these two sites are more prone to electrophilic attack. But on comparison with N17 of isoniazid it is found that the N14 of CPPC has lower affinity towards electrophile. This situation changes because the nitrogen of CPPC is bonded through a double bond to the C16 of a pentagonal ring; hence, the charge density around N14 decreases.

3.5. Dipole Moment, Polarizability, Hyper Polarizability, and Thermodynamic Properties. Dipole moment (μ), polarizability (α), and total first static hyper polarizability β [31, 32] are also calculated in Tables 5 and 9 by using density functional

theory. They can be expressed in terms of x , y , z components and are given by the following equation:

$$\begin{aligned}\mu &= (\mu_x^2 + \mu_y^2 + \mu_z^2)^{1/2}, \\ \langle \alpha \rangle &= \frac{1}{3} [\alpha_{xx} + \alpha_{yy} + \alpha_{zz}], \\ \beta_{\text{Total}} &= (\beta_x^2 + \beta_y^2 + \beta_z^2)^{1/2} \\ &= \left[(\beta_{xxx} + \beta_{xyy} + \beta_{xzz})^2 + (\beta_{yyy} + \beta_{yxx} + \beta_{yzz})^2 \right. \\ &\quad \left. + (\beta_{zzz} + \beta_{zxx} + \beta_{zyy})^2 \right]^{1/2}.\end{aligned}\quad (3)$$

The β components of Gaussian output are reported in atomic units, where 1 a.u. = 8.3693×10^{-33} e.s.u. For isoniazid and CPPC, the calculated dipole moment values are 5.49 and 6.25 Debye. Having higher dipole moment than water (2.16 Debye), isoniazid and CPPC both can be used as better solvents. For isoniazid, we see a greater contribution of α_{zz} in molecule which shows that molecule is elongated more towards Z direction and more contracted to X direction. Perpendicular part contributes less part of polarizability of molecule. β_{xxx} , β_{yyy} contribute a larger part in hyper polarizability. This shows that molecule is more optical active in X -axis and Y -axis directions. For CPPC, we see a greater contribution of α_{yy} in molecule which shows that molecule is elongated more towards Y direction and more contracted to X direction. Perpendicular part contributes less part of polarizability of molecule.

β_{xxx} , β_{xyy} contribute a larger part in hyper polarizability. This shows that molecule is more optical active in X -axis and XY -plane directions. The connection between the electric dipole moments of an organic molecule having donor-acceptor substituent and first order hyper polarizability is widely recognized in the literature. Standard thermodynamic functions such as free energy, constant volume heat capacity CV , and entropy S have also been calculated for both the molecules and are given in Table 10. These functions can provide helpful information for further study of the title compounds.

4. Conclusion

This paper reports a comprehensive computational structural study on antituberculosis drug isoniazid and its new derivative N -cyclopentylidenepyridine-4-carbohydrazide. The frequency assignments for isoniazid and its derivative N -cyclopentylidenepyridine-4-carbohydrazide have been done for the first time by employing density functional theory (DFT) with LANL2DZ and 6-311 G (d, p) as the basis sets. Normal modes analysis provides detailed description of the vibrational spectra of the molecules in question. Reactivity reflects the susceptibility of a substance towards a specific chemical reaction and plays a key role in, for example, the design of new molecules and understanding biological

systems and material science. The lower value of frontier orbital energy gap and a higher dipole moment in case of CPPC suggest a more reactive nature as compared to isoniazid. Hyper polarizability is mainly controlled by the planarity of the molecules, the donor and acceptor strength, and bond length alteration. The values of hyper polarizability indicate a possible use of these compounds in electrooptical applications.

We have also discussed global and local reactivity descriptors sites for both molecules during electrophilic, nucleophilic, and radical attacks. These values represent the qualitative descriptors of reactivity of different atoms in the molecule. The present work might encourage the need for an extensive study by the experimentalists interested in the vibrational spectra and the structure of these compounds. The results reported in the present paper can help in the experimental investigations on the origin of the biological activity of these molecules.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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