

## DENSITY FUNCTIONAL THEORY CALCULATION ON DOPAMINE

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## ABSTRACT

Vibrational spectroscopy has significant contributions towards the studies of structure and physicochemical properties of crystals and molecular systems. The vibrational analysis of chosen compound Dopamine has been made using FTIR and FTRaman spectroscopy. A satisfactory assignment of the fundamental vibrations has been made according to the position, shape, nature and relative intensity. The molecular geometry, calculated frequency and thermodynamical parameters have been analyzed using density functional theory.

**KEY WORDS:** Dopamine, FTIR, FTRaman spectroscopy and DFT.

## 1. INTRODUCTION

Dopamine is a hormone and neurotransmitter occurring in a wide variety of animals, including both vertebrates and invertebrates. In the brain, this phenethylamine functions as a neurotransmitter, activating the five types of dopamine receptors - D1, D2, D3, D4 and D5, and their variants. Dopamine is produced in several areas of the brain, including the substantia nigra and the ventral tegmental area (www.encyclopedia). Dopamine is also a neurohormone released by the hypothalamus. Its main function as a hormone is to inhibit the release of prolactin from the anterior lobe of the pituitary.

Dopamine can be supplied as a medication that acts on the sympathetic nervous system, producing effects such as increased heart rate and blood pressure. However, because dopamine cannot cross the blood-brain barrier, dopamine given as a drug does not directly affect the central nervous system. Dopamine has the chemical formula  $C_6H_3(OH)_2-CH_2-CH_2-NH_2$ . Its chemical name is "4-(2-aminoethyl)benzene-1,2-diol" and its abbreviation is "DA." As a member of the catecholamine family, dopamine is a precursor to norepinephrine (noradrenaline) and then epinephrine (adrenaline) in the biosynthetic pathways for these neurotransmitters.

The crystal structure of Dopamine Hydrochloride has been studied by (Bergin and Carlstrom, 1968). An extensive work has been carried out using FTIR, Raman and UV-Visible spectroscopic methods on dopamine by earlier workers (Barreto, 1998; Singh, 2000; Arulmozhichelvan, 1997). (Sun-Kyung Park, 2000) have studied the vibrational analysis of Dopamine Neutral Base based on density functional force field at B3LYP/6-31G (d,p) level. Recently the vibrational and normal coordinate analysis of Dopamine has been carried out by (Gunasekaran, 2007). Application of density functional theory (DFT) to study the molecular structure of any compound has received much attention recently because of a faster convergence in time than the traditional quantum mechanical correlation methods in part, and improvements in the prediction of vibrational frequencies, infrared intensity, reduced masses and force constant. So in the present investigation the structural elucidation of dopamine has been carried out using density functional theory for the first time by comparing three basis sets.

**Density functional theory:** Density functional theory (DFT) is a quantum mechanical theory used in physics and chemistry to investigate the electronic structure (principally the ground state) of many-body systems, in particular atoms, molecules and the condensed phases. DFT is among the most popular and versatile methods available in condensed matter physics, computational physics, and computational chemistry. It is widely used in the design of new drugs and materials. Examples of such properties are structure (i.e. the expected positions of the constituent atoms), absolute and relative (interaction) energies, electronic charge distributions, dipoles and higher multipole moments, vibrational frequencies, reactivity or other spectroscopic quantities, and cross sections for collision with other particles.

Ab initio methods are based entirely on theory from first principles. Other (typically less accurate) methods are called empirical or semi-empirical because they employ experimental results, often from acceptable models of atoms or related molecules, to approximate some elements of the underlying theory. Both ab initio and semi-empirical approaches involve approximations. In principle, ab initio methods eventually converge to the exact solution of the underlying equations as the number of approximations is reduced. In practice, however, it is impossible to eliminate all approximations, and residual error inevitably remains. The goal of computational chemistry is to minimize this residual error while keeping the calculations tractable.

Density functional theory (DFT) methods are often considered to be *ab initio* methods for determining the molecular electronic structure, even though many of the most common functionals use parameters derived from empirical data, or from more complex calculations. In DFT, the total energy is expressed in terms of the total one-electron density rather than the wave function. In this type of calculation, there is an approximate Hamiltonian and an approximate expression for the total electron density. DFT methods can be very accurate for little computational cost.

Some methods combine the density functional exchange functional with the Hartree-Fock exchange term and are known as hybrid functional methods.

In modern computational chemistry, quantum chemical calculations are typically performed within a finite set of basis functions. In these cases, the wavefunctions under consideration are all represented as vectors, the components of which correspond to coefficients in a linear combination of the basis functions in the basis set used. The most common minimal basis set is STO-nG, where  $n$  is an integer. This  $n$  value represents the number of Gaussian primitive functions comprising a single basis function (Dreizler and Gross, 1995). Commonly used minimal basis sets of this type are: STO-3G, STO-4G, STO-6G, STO-3G\* - Polarized version of STO-3G. Here is a list of commonly used split-valence basis sets of this type:

- 3-21g, 3-21g\* - Polarized, 3-21+g - Diffuse functions, 6-31g

Therefore in the present investigation DFT is used to study the complete vibrational spectra of the title compound.

## 2. EXPERIMENTAL

Spectroscopic grade pure sample of Dopamine HCl has been procured from Sigma Aldrich Company, USA and used as such without further purification. The FTIR spectra of the samples are recorded in the region 4000-400  $\text{cm}^{-1}$  on Perkin-Elmer Spectrum One Spectrometer using KBr pellet technique. The FT-Raman spectra are recorded using 1064 nm line of Nd: YAG laser operating at 200 mW on Bruker FRA106/ Bruker RSS 100 spectrometer in the region 3500-50  $\text{cm}^{-1}$  at Sophisticated Analytical Instrumentation Facility, IIT, Chennai. The molecular structure of Dopamine is presented in Fig.1 and the experimental FTIR and FT-Raman spectra of Dopamine are presented in Fig.2.

**Computational method:** The DFT calculations were performed using Gaussian 03W (Frisch, 2003) program package, invoking gradient geometry optimization (Schlegel, 1982). The optimized structural parameters were used in the vibrational frequencies calculations at B3LYP, BLYP and B3PW91 levels using 6-31G(d,p) basis set. It has been utilized the gradient corrected density functional theory (Hohenberg and Kohn, 1964) with three-parameter hybrid functional for exchange part and the Lee-Yang-Parr correlation function (Lee, 1988) for the computation of vibrational frequencies and energies of optimized structure.

## 3. RESULTS AND DISCUSSION

**Molecular geometry:** In the present investigation, the optimized structure parameters of Dopamine calculated by DFT-B3LYP, BLYP and B3PW91 levels with the 6-31G (d,p) basis set and are listed in Table 3. The Table compares the calculated bond lengths and angles of Dopamine with those experimentally available from X-ray diffraction data (Bergin and Carlstrom, 1968). The numbering of atoms for the chosen compound has been performed using (www.chemcraft) and is presented in Fig.3.

**Vibrational analysis:** The Dopamine has 45 normal modes of vibration which are distributed as  $\Gamma_{\text{vib}} = 31 A' + 14 A''$ . Here all the modes are active both in infrared and Raman. The band assignments have been made by assuming  $C_s$  point group symmetry. The computed IR spectra of Dopamine for B3LYP/6-31G (d,p), BLYP/6-31G (d,p) and B3PW91/6-31G (d,p) are presented in Fig 4. The calculated vibrational wavenumber, IR intensities, reduced mass and force constants for Dopamine are summarized in Tables 1 for B3LYP/6-31G levels. The vibrational assignments are summarized in the Table 2. The vibrational frequency assignments of Dopamine have been made on the basis of magnitude and relative intensities of the observed bands in analogy with the related compounds and are discussed as follows.

**C-NH<sub>2</sub> vibrations:** A strong band appears in the region 1250-1340  $\text{cm}^{-1}$  in nearly at the primary aromatic amines. The intensity of the band appears to be rather variable and probably it is associated with some substitution or other structural features (Mohan and Illangovan, 1994). In the present investigation the IR bands observed at 1321 and 1261  $\text{cm}^{-1}$  have been assigned the C-NH<sub>2</sub> asymmetric and symmetric stretching vibrations respectively. The calculated values at B3LYP/6-31G (d,p), BLYP/6-31G (d,p) and B3PW91/6-31G (d,p) levels are nearly in good agreement with the observed values.

**C-H vibrations:** The C-H stretching vibrations of a heterocyclic aromatic compound fall in the region 3100-3000  $\text{cm}^{-1}$ . In this region the bands are not much affected by the nature and position of substituents (Nakkeeran, 1997). Hence in the present work the IR bands observed at 3004-3146 have been assigned to aromatic C-H stretching vibrations. The calculated frequencies at 3020, 3044, 3059, 3091, 3148  $\text{cm}^{-1}$  by B3LYP/6-31G (d,p) level and 3032, 3054, 3076, 3106 and 3160  $\text{cm}^{-1}$  by B3PW91/6-31G (d,p) level are assigned to C-H stretching vibrations which are good in agreement with the experimental values.

**C-C-C in plane and out of plane bending vibrations:** Benzene exhibits two in-plane carbon bending vibrations at 1010  $\text{cm}^{-1}$  ( $B_{1u}$ ) which is non-degenerate and at 606  $\text{cm}^{-1}$  ( $E_{2g}$ ) which is degenerate (15). The carbon out-of-plane bending vibrations are defined with reference to the non-degenerate  $B_{2g}$  (703  $\text{cm}^{-1}$ ) and degenerate  $E_{2u}$  (404  $\text{cm}^{-1}$ ) modes of benzene (Marshall and Gunasekaran, 1996). Based on this, in the present work the FTIR bands observed at 460  $\text{cm}^{-1}$ , 475  $\text{cm}^{-1}$ , 718  $\text{cm}^{-1}$ , 725  $\text{cm}^{-1}$  are assigned to C-C-C out of plane bending vibrations and 599  $\text{cm}^{-1}$ , 669  $\text{cm}^{-1}$  are assigned

to C-C-C in plane bending vibrations. These are in good agreement with literature value (Gunasekaran, 2007). The calculated frequencies are also shows an excellent agreement with the experimental values.

**C-H in plane and out of plane bending vibrations:** The bands due to C-H in plane ring bending vibrations, interact somewhat with C-C stretching vibrations are observed as a number of m-w intensity sharp bands in the region 1300-1000  $\text{cm}^{-1}$ . The C-H out of plane bending vibrations are strongly coupled vibrations (strong coupling between adjacent hydrogens and much weaker coupling between hydrogen separated by other substituting groups) and occur in the region 900-667  $\text{cm}^{-1}$ . These extremely intense absorptions are used to assign the position of substituents on the aromatic ring (Jag Mohan, 2001). (Singh, 2002) have assigned the C-H out of plane bending vibration at 920  $\text{cm}^{-1}$  and C-H in plane bending vibration at 1111  $\text{cm}^{-1}$  in 3,4-dihydroxybenzaldehydes. Hence in the present case both the observed and calculated frequencies are in the same region. Similarly the other stretching and bending vibrations are calculated and assigned in the characteristic region.

Any discrepancy noted between the observed and calculated frequency may be due to the fact that the calculations have been done on single molecule in the gaseous state contrary to the experimental values recorded in the presence of intermolecular interactions. The force constant values are computed at three basis sets and are in good agreement with the related compounds.

**Thermodynamical parameters:** On the basis of vibrational analysis at B3LYP/6-31G (d,p), BLYP/6-31G (d,p) and B3PW91/6-31G (d,p) levels several thermodynamic parameters are calculated and are presented in Table 3. The zero point vibration energies (ZPVE), rotational constants, thermal energy, heat capacity and the entropy  $S_{\text{vib}}(T)$  are calculated to the extent of accuracy and the variation in ZPVEs to be insignificant.

#### 4.CONCLUSION

An attempt has been made in the present investigation for the proper frequency assignment for the compound Dopamine from the FTIR and FTRaman spectra. The optimized structural parameters, vibrational wavenumbers, IR intensities, reduced mass, force constants, zero point energy, rotational constants, thermal energy, heat capacity and entropy were calculated and analysed by density functional theory at B3LYP/6-31G (d,p), BLYP/6-31G (d,p) and B3PW91/6-31G (d,p) levels. From the theoretical values shows slight variation with the experimental values due to the theoretical calculations belonging to isolated molecules in gaseous phase and the experimental results belong to molecules in the solid phase.

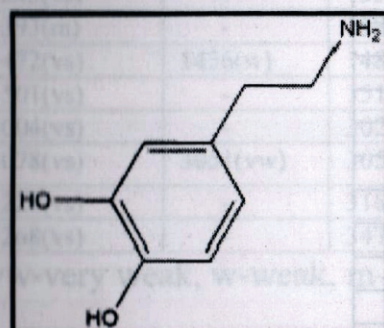


Fig.1 Molecular structure of Dopamine

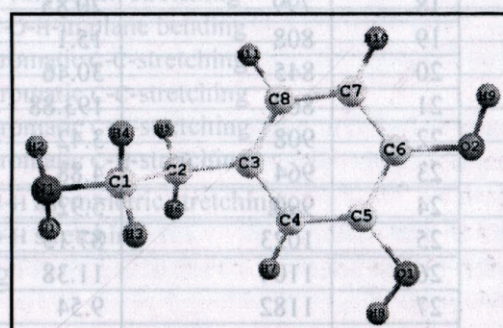
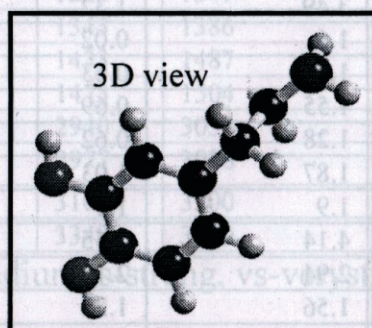


Fig.3 The atom numbering for Dopamine

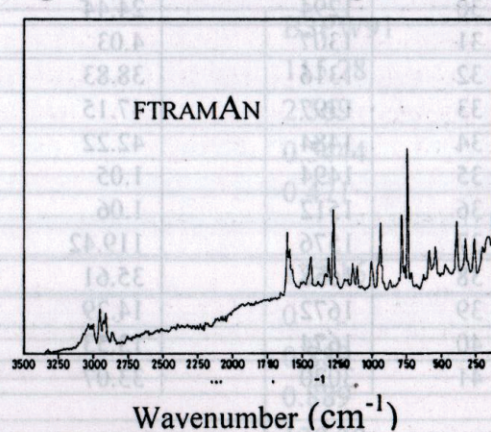
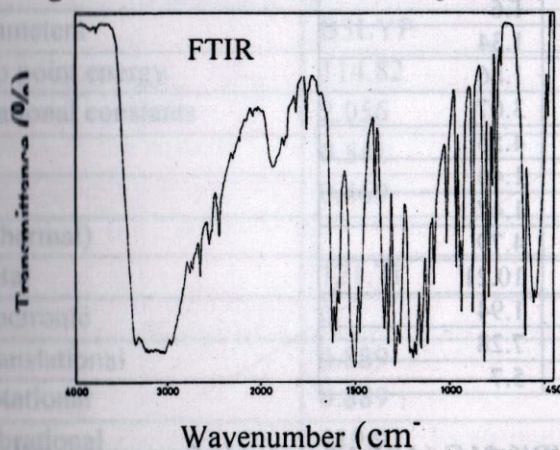


Fig.2 Vibrational spectra of Dopamine

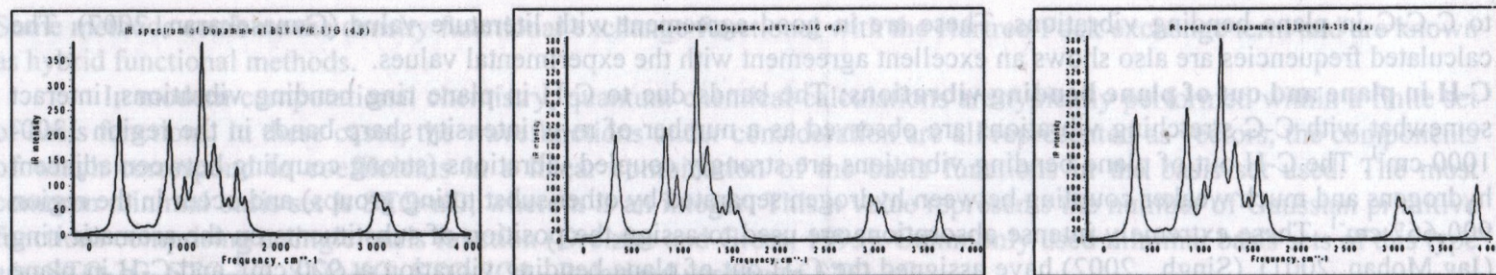


Fig.4. Computed IR spectra of Dopamine

No.	Wavenumber	IR Intensity	Reduced mass	Force constant
1	177	0.46	5.23	0.09
2	254	10.9	4.09	0.15
3	292	3.42	2.6	0.13
4	309	35.79	2.03	0.11
5	317	17.26	1.72	0.1
6	319	12.98	4	0.24
7	324	28.03	1.1	0.07
8	335	161.94	1.18	0.08
9	395	31.13	4.49	0.41
10	461	0.43	3.27	0.41
11	476	2.91	3.93	0.52
12	550	3.4	4.38	0.78
13	591	4.91	6.01	1.24
14	639	7.16	4.63	1.12
15	705	0.51	5.06	1.49
16	759	7.06	2.38	0.81
17	767	5.97	1.46	0.51
18	799	20.85	3.49	1.32
19	808	15.1	1.6	0.02
20	845	30.46	1.49	0.63
21	867	193.88	1.55	0.69
22	908	3.42	1.28	0.62
23	964	4.88	1.87	1.03
24	990	5.92	1.9	1.1
25	1023	87.15	4.14	2.55
26	1104	11.38	2.94	2.12
27	1182	9.54	1.56	1.28
28	1201	96.88	1.23	1.05
29	1206	259.06	1.51	1.3
30	1294	24.44	1.62	1.6
31	1307	4.03	1.32	1.34
32	1316	38.83	1.82	1.86
33	1397	47.15	2.67	3.07
34	1484	42.22	3.5	4.55
35	1494	1.05	1.09	1.44
36	1512	1.06	1.09	1.47
37	1576	119.42	3.27	4.79
38	1658	35.61	6.3	10.21
39	1672	14.29	1.17	1.94
40	1674	13.53	4.4	7.28
41	3020	33.07	1.05	5.7

Table-1: Vibrational wavenumbers obtained for Dopamine at B3LYP/6-31G(d,p) [harmonic frequency  $\text{cm}^{-1}$ , IR intensities ( $\text{Km mol}^{-1}$ ), reduced masses (amu) and force constants ( $\text{mdyneA}^{-1}$ )]

Table-2: Experimental FTIR and FTRaman frequencies and vibrational assignments of Dopamine

FTIR( $\text{cm}^{-1}$ )	FTRaman ( $\text{cm}^{-1}$ )	B3LYP ( $\text{cm}^{-1}$ )	BLYP ( $\text{cm}^{-1}$ )	B3PW91( $\text{cm}^{-1}$ )	Vibrational assignments
460(vw)	-	461	444	460	C-C-C-out of plane bending
475(w)	-	476	460	475	C-C-C-out of plane bending
548(vs)	-	550	532	550	C-C-O-in plane bending
599(vs)	603(w)	591	572	591	C-C-C-in plane bending
-	-	639	615	639	C-C-C-in plane bending
694(vw)	-	705	674	708	C-C-C-out of plane bending
751(s)	756(m)	759	735	758	C-C-C-out of plane bending
773(m)	-	767	747	765	C-N-H-out of plane bending
791(vs)	-	799	768	802	C-H-out of plane bending
815(vs)	801(w)	808	774	808	C-H-out of plane bending
-	-	845	807	844	C-H-out of plane bending
877(vs)	-	867	850	863	C-H-out of plane bending
-	-	908	866	908	C-H-in plane bending
963(s)	-	964	935	964	C-H-in plane bending
-	-	990	961	991	C-H-in plane bending
1014(s)	1020(w)	1023	970	1036	C-C-C-trigonal bending
1107(m)	-	1113	1080	1121	C-H-in plane bending
1146(vs)	1153(w)	1139	1104	1139	NH <sub>2</sub> twisting
1176(vs)	-	1182	1147	1185	C-S stretching
1191(vs)	-	1201	1169	1201	C-O stretching
1214(vs)	-	1206	1173	1210	C-N stretching
1261(vs)	-	1294	1253	1291	C-NH <sub>2</sub> sym. stretching
1287(vs)	1292(m)	1307	1271	1303	C-NH <sub>2</sub> sym. stretching
1321(vs)	1327(w)	1316	1273	1320	C-NH <sub>2</sub> asym. stretching
1343(vs)	-	1338	1288	1349	C-NH <sub>2</sub> asym. stretching
1393(m)	-	1389	1343	1386	C-O-H-in plane bending
1472(vs)	1456(w)	1484	1433	1487	aromatic C-C-stretching
1501(vs)	-	1512	1473	1504	aromatic C-C-stretching
3004(vs)	-	3020	2940	3032	aromatic C-H-stretching
3078(vs)	3051(vw)	3059	2977	3076	aromatic C-H-stretching
3220(vs)	-	3188	3105	3200	N-H asymmetric stretching
3268(vs)	-	3478	3349	3509	O-H stretching

vw-very weak, w-weak, m-medium, s-strong, vs-verystrong

Table-3: Zero point energy (Kcal mol<sup>-1</sup>), Rotational constants (GHz), Thermal Energy (Kcalmol<sup>-1</sup>, Heat Capacity (Cal mol<sup>-1</sup>), Kelvin Entropy (Cal mol<sup>-1</sup>-Kelvin) for Dopamine.

Parameters	B3LYP	BLYP	B3PW91
Zero point energy	114.82	111.2	115.28
Rotational constants	2.056	2.521	2.569
	0.541	0.532	0.5444
	0.469	0.022	0.471
E(Thermal)			
Total	121.71	118.24	122.16
Electronic	0	0	0
Translational	0.889	0.889	0.889
Rotational	0.889	0.889	0.889
Vibrational	119.93	116.46	120.38
Heat capacity	41.732	42.91	41.681
Entropy	103.19	104.17	103.16

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