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Computational Study of Doping in Dopamine with Halogens to Increase Its Efficiency for Curing Disease

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Abstract

In this work a comprehensive study of dopamine was conducted using theoretical first principal method due to its crucial importance as hormone for neurotransmission process in the animal body. Many basis set and functional were used for the optimization of the compound to attain stability and find the suitable energy point for the overall calculations. Then the compound is doped with first three members of the halogens (fluorine, chlorine and bromine) to analyze the effect of their presence in terms of change in their electronic properties such as bandgap, density of states and other spectroscopic parameters such as NMR and FT-IR.

Keywords: Dopamine, DFT, Hatree-Fock, bandgap, Humo-Lumo energy, Spectroscopy

1. Introduction

One of the main functions of dopamine in animals especially human beings is the neuro transmitting process which is the ability to send signals from brain to nerves cells and vice versa [1, 2]. Some researchers suggested that dopamine serve as a memory storage in the brain, control incoming noise to the body and regulate human character [3]. Majority of the diseases associated with the brain and nervous system is related to the malfunction of dopamine in the body. Such diseases include Parkinson disease (PD) resulted from improper or insufficient release of dopamine in the brain and Schizophrenia disease (SD) which is resulted from the change in the level of dopamine the body system of the body [4-7].

Decreasing in the activity of dopamine in the human and animal body result in a disease called attention deficit hyperactivity disorders (ADHD) [8]. Nowadays majority of the researches of dopamine molecule is moving towards the direction of developing sensitive method to analyze dopamine for curing many related diseases [9-11] and that is why it is important to understand the reactivity, structure and stability of the dopamine molecule [12]. The cumulative nuclear magnetic resonance and DFT give details about electrochemical properties and its activity as a neurotransmitter [14].

In this work, dopamine molecule was doped with the first three members of the halogen's family (fluorine, chlorine and bromine) to analyze their effect of some spectroscopic properties and electronic properties such as NMR, FT-IR, bandgap energy, potential energy map and density of states. The theoretical work is compared with literature and there is agreement.

2. Computational procedure

The dopamine figure was drawn using gauss view 9.0 and two methods were applied to optimized the structure (DFT and Hatree-Fock) using eight basis set and functionals to achieve convergence and stability of the molecule [7]. The method was implemented by different papers to describe geometries and energies of a noncovalent systems. The ground state geometry optimization of dopamine was done with DFT using hybrid functional B3LYP at various basis set; STO-3G, 3-21G, 6-31G, 6-31G*, 6-311G, LanL2MB, LanL2DZ, SDD. The frequency calculation was determined using the optimized structure to obtain the minimum on the potential energy surface [7]. Furthermore, the UV is also determined using the optimized structure. The plotting of the three-dimensional mapping of the molecular orbitals is done by the B3LYP/6-311G basis set [8-9]. At the B3LYP/6-311G basis sets, the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) energies are calculated. All calculations in this paper are performed using the Gaussian 09 program [12-14]. During the stability check there is appearance of resonance in the benzene ring instead of conjugated cyclic double bond. This indicate that there is a strong bond between the atoms of the molecule after optimization.

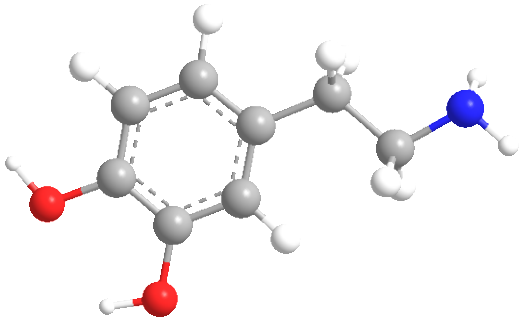

Figure 1. Optimized molecular structure of dopamine

3. Result and discussion

The dopamine figure was drawn using gauss view 9.0 and two methods were applied to optimized the structure (DFT and Hatree-Fock) using eight basis set and functionals to achieve convergence and stability of the molecule. During the stability check there is appearance of resonance in the benzene ring instead of conjugated cyclic double bond. This indicate that there is a strong bond between the atoms of the molecule after optimization.

Table 1 The comparison of different methods during convergence of dopamine molecule

Basis set	Hatree-Fock (eV)	DFT (eV)
STO-3G	1.32466069	0.57389264
3-21G	3.53859646	5.06679992
6-31G	4.43385810	5.49783166
6-31G*	4.43385810	5.49783166
6-311G	4.80910607	5.69865327
LanL2DZ	5.07360282	5.53102982
LanL2MB	0.89961550	0.57443688
SDD	5.08067784	5.53211828

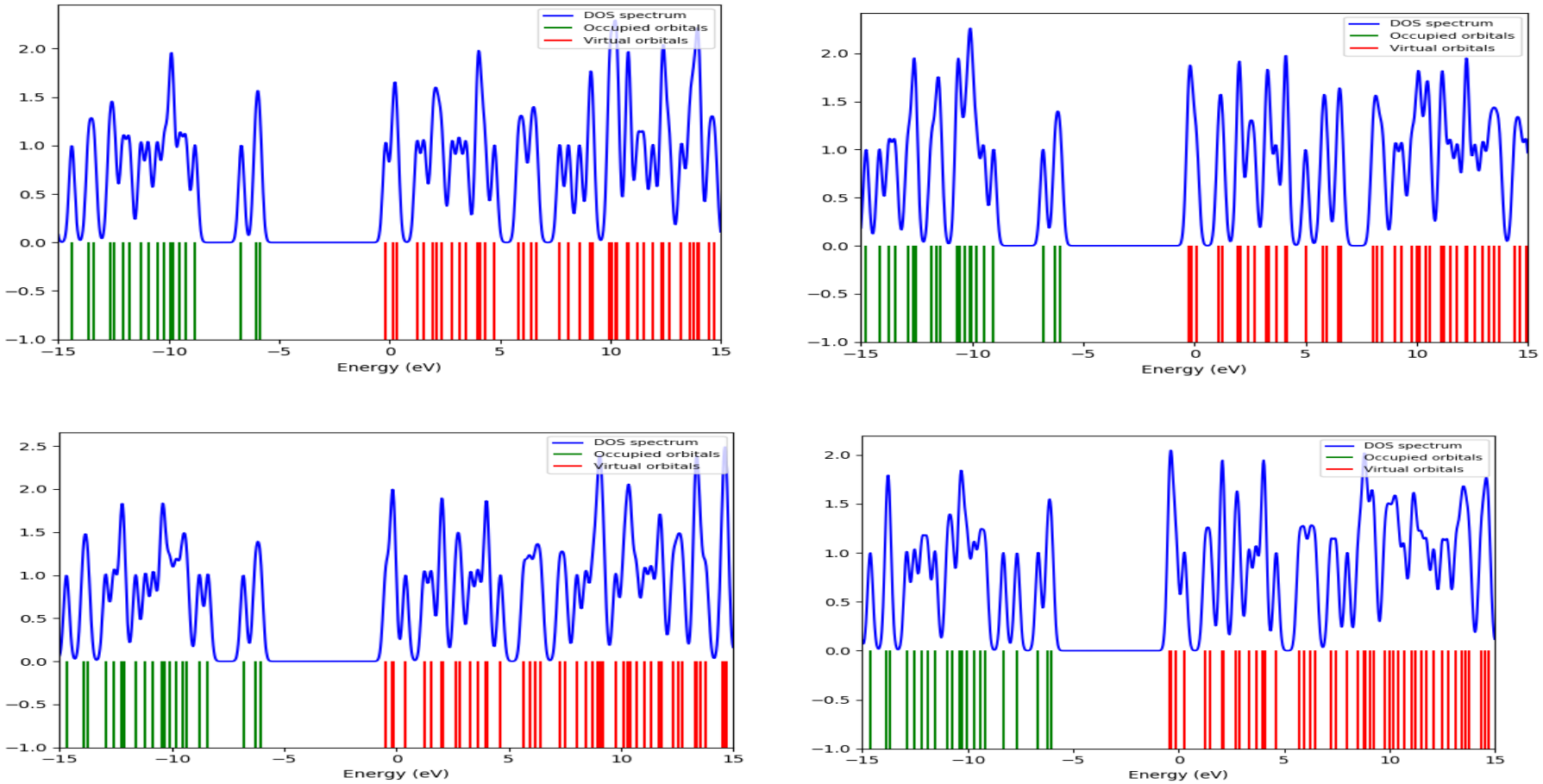

Figure 2. The density of states of (a) dopamine (b) dopamine doped with fluorine (c) dopamine doped with chlorine (d) dopamine with bromine.

3.1 The molecular orbital

This calculation proves that dopamine molecule has 42 molecular orbitals that are already occupied by the electrons. The highest occupied molecular orbital (HOMO) is localized on the benzene ring while the lowest unoccupied molecular orbital is not localized on the benzene ring but close to it. As seen from Figure 3 both HOMO-1 and LUMO+1 is delocalized on the nitrogen atom. The HUMO-LUMO energy values of dopamine and dopamine doped with the three first members of halogens are shown in Figure 3. In the attempt to create a close relationship between the biochemical system and chemical reactions, the bandgap energy of HOMO-LUMO is always used as factor (i.e. quantum chemical descriptor) [16]. The wide difference in energy bandgap indicates the high stability for the complex compound under investigation. There is another property that is associated with bandgap energy, that property is polarizability. Soft molecules are less polarizable than hard molecules. The difference in HOMO-LUMO bandgap energy in normal dopamine in gas phase is 5.698 eV.

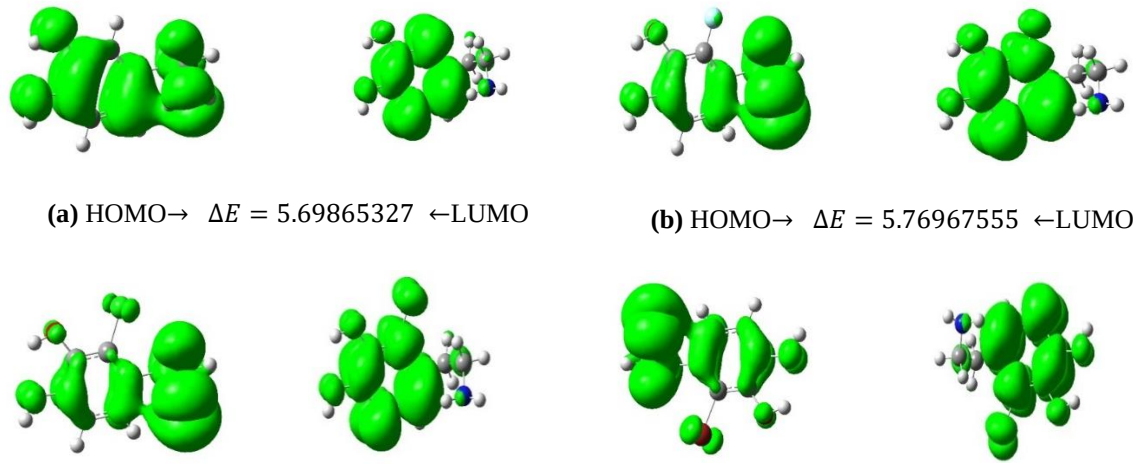

Figure 3. Frontier molecular orbital of dopamine and the doped dopamine with halogens of (a) dopamine (b) dopamine doped with fluorine (c) dopamine doped with chlorine (d) dopamine with bromine

Table 2 The comparison of the bandgap of dopamine doped with the first three members of halogens group

S/N	Atom doped with dopamine	Energy of 6-311G basis set (eV)
1	Flourine	5.76967555
2	Chlorine	5.59307226
3	Bromine	5.59606554

3.2. The electronic and optical study of dopamine and then doped with the first three members of halogen group

The vibrational frequencies of the dopamine molecule in this work were analysed using DFT/B3LYP along with 6-311G basis set. Gauss-view molecular visualization software was initially use to plot the infrared then Origin graphing and analysis software is used to plot the Fourier transform infrared spectroscopy vibrational band. The comparison between the normal dopamine and then doped with members of halogen group can be observe from figure 4.

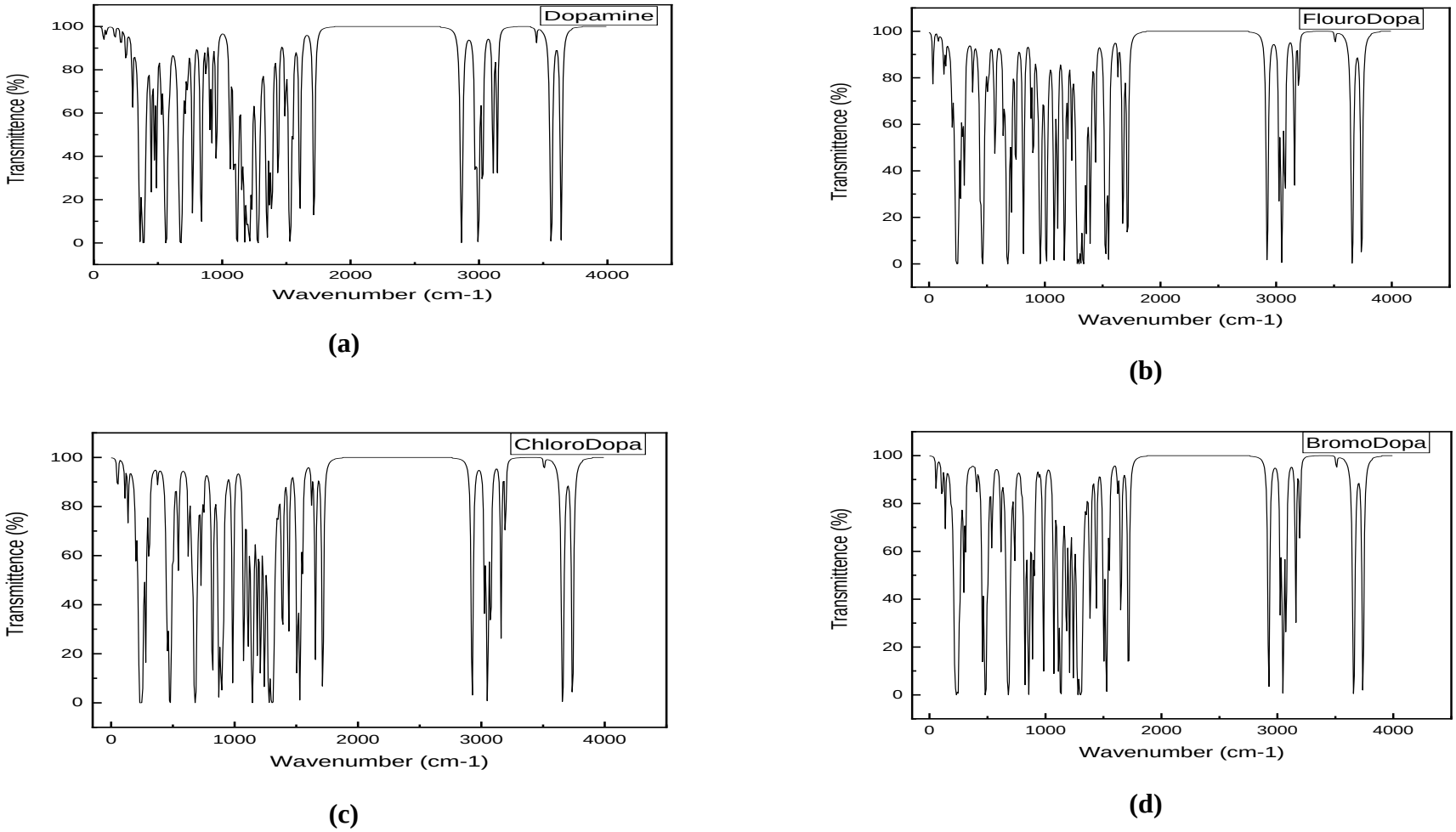

Figure 4. The FT-IR absorbance spectra of comparison between dopamine and then doped with the first three member of the halogens group of (a) dopamine (b) dopamine doped with fluorine (c) dopamine doped with chlorine (d) dopamine with bromine

The benzene ring present in the dopamine molecule can be investigated from the bonds of C-H, C-C and C=C ring vibrational modes. The C-H stretching vibrations of dopamine occurs about 3000 cm^{-1} and there is also a present of weak to moderate bands (multiplicity) when compared with normal C-H stretching [17-19]. In this work, the vibrational modes were calculated theoretically in the range 3065-3124 cm^{-1}. This shows an excellent and precise agreement with experimental results.

The normal aliphatic C-H stretching was detected theoretically at about 2867-2973 cm^{-1} [20]. In the work, C-H stretching in ascorbic acid was calculated at 2979-3046 cm^{-1} for B3LYP while 1259, 1193 and 1147 cm^{-1} bands are for C-H in-plane bending vibration in the dopamine molecule. The theoretical results obtained from the B3LYP model are close to the true value which is the indication of the accuracy of the model.

The C-C stretching vibration in the ring has different values due to the nature of the ring but in most cases, it ranges from 1600-1350 cm^{-1} [18]. The value has little increase due to the DFT methods approximation in this work and was found to at 1680, 1444 and 1365 cm^{-1}.

3.3 Ultraviolet spectroscopy

Ultraviolet spectroscopic (UV-Vis) analysis and technique is one of the important methods for measuring the absorption of a molecule. From Fig 4 the fluorine has the highest intensity at 39263.7831 with wavelength of 188.50 cm. At the lowest intensity is the bromine with absorption at 15801.00 and wavelength of 195.00 cm. The intermediate in the absorption is the chlorine with intensity at 35723.9772 and wavelength at 195.00 cm. All these variations in the wavelengths and intensities of the dopamine doped with the first three members of the halogen group are attributed to the electronegativity of the halogens as arranged in the periodic table. The fluorine is the most electronegative element followed by chlorine then bromine. The increasing negativity of the group started from the top member down to the lowest members.

Table 3 The comparison of the uv-vis of dopamine doped with the first three members of halogens group

S/N	Molecule (12 states)	Intensity	Wavelength (cm)
1	Dopamine	34140.6548	188.50
2	With flourine	39263.7831	188.50
3	With Chlorine	35723.9772	195.00
4	With bromine	15801.00	201.00

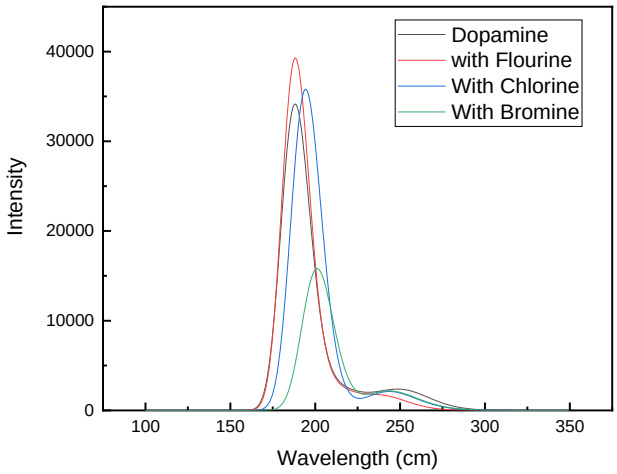

Figure 5. The UV-Visible absorbance spectra of comparison between dopamine and halogen doped dopamine with the first three member of the halogens group

3.4 Nuclear magnetic resonance (NMR)

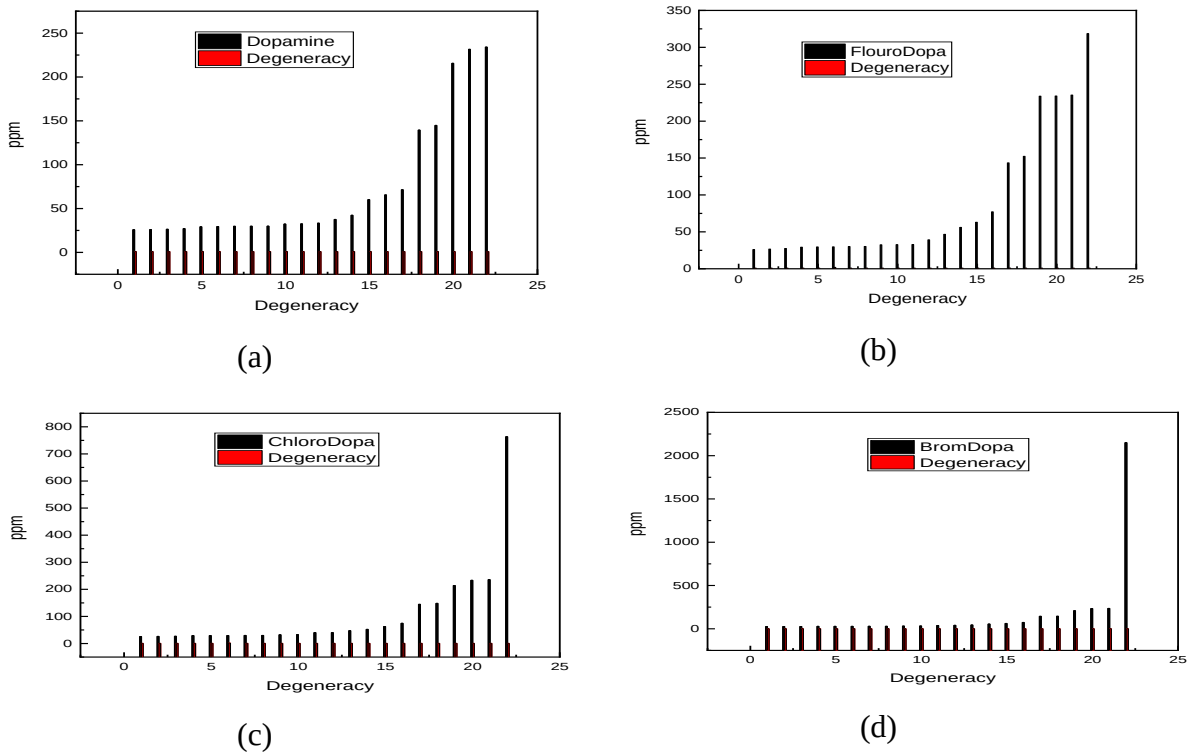

Figure 6. NMR data of comparison between dopamine and then doped with the first three member of the halogens group (a) dopamine (b) dopamine doped with fluorine (c) dopamine doped with chlorine (d) dopamine doped with bromine

Figure 6 explains the theoretical H-NMR and C-NMR structure of dopamine and then doped with the first members of the hydrogen group respectively. Gaussian 09 software package was used to calculate the NMR and then Origin software package was used to plot the figures. The figures show that the shielding for the normal ascorbic acid is 0 to 250 ppm. There was a shift in ppm when fluorine was introduced to the compound from 0 to 350 ppm. The changes in ppm also continued when fluorine is replaced with chlorine from 0 to 800 ppm. The changes in ppm were intense when bromine was introduced from 0 to

2500 ppm. This is a clear indication that the shielding range increase with an increase in the electronegativity of the halogen's family.

Table 4 The comparison of the nuclear magnetic resonance of dopamine doped with the first three members of halogens group

S/N	Doping atom	NMR (ppm)
1	Flourine	318.6160
2	Chlorine	783.5461
3	Bromine	2150.7061

Fig 5 shows the normal NMR peaks of the dopamine molecule with more carbon at the upfield and less carbon at downfield. The whole orientaion of the molecules has changed when flourine is introduced. There is an appearance of sharp medium peak of flourine at 318.6168 ppm and also the carbons and the hydrogens changed their chemical enviroment due to inductive and neighbouring effect. The same trends happened when flourine is replaced with chlorine and later bromine, they have paeaks at 783.5461 and 2150.7061 ppm respectively. This proves that NMR peaks generated by the halogens family in ascorbic acid has a close linear relationship with their electronegativity. Table 3 give a precise individual position of the halogen members in terms of ppm.

3.5 Potential energy map (PES)

The potential energy map is playing a very important and crucial role in determining the concentration of electrons in a particular molecule. It can also be used to in understanding electrical and optical properties o the molecule as well. The electron in the undoped dopamine molecule are concentrated towards the two hydroxyl groups attached to the benzene ring (the blue portion) due to electronegativity of the oxygen atom. When one of the hydrogen of the benzene is replaced with flourine atom, the orientation of the molecule was completely change due to the presence of more electronegative element. As a result of that some electrons have migrated from the oxygen to the flourine part of the molecule. The same happened with chlorine and bromine (Figure 5) but the migration depends on the electron affirnity of the incoming molecule.

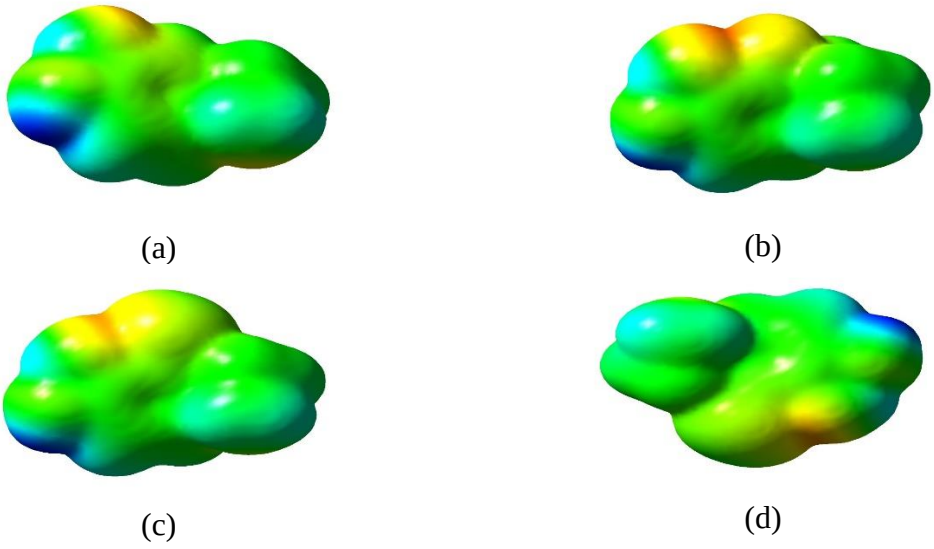

Figure 5. The potential energy map of comparison between dopamine and then doped with the first three member of the halogens group of (a) dopamine (b) dopamine doped with fluorine (c) dopamine doped with chlorine (d) dopamine with bromine

Conclusion

This work analyses the basic properties of dopamine (including bandgap, density of states and spectroscopic properties) and it is then doped with the first three members of halogen group to compare the change in electronic and other spectroscopic parameters. Different basis set in DFT and Hatree-Fock were used in the optimization process to determine the lowest energy and suitable basis set for the whole calculation of the ascorbic acid, then later the compound was doped with the first three halogens' members separately. Spectroscopic properties were determined such as UV-vis and NMR for both the doped and the undoped dopamine. Finally, the FTIR spectra of the dopamine with different doping with halogens group was investigated by theoretical method. It was found that the bandgap is sensitive to the doping as we moved down the group members (the bandgap depends on the electronegativity of the halogens members).

Author Contribution

Authors contributed equally.

Conflict of Interests

The authors declare that there is no conflict of interest.

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