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Molecular Investigation and Characterization of 5-(3-bromo-4-fluorobenzylidene)pyrimidine-2,4,6(1H,3H,5H)-trione: A Molecular Orbital Approach

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Abstract: 5-(3-Bromo-4-Fluorobenzylidine)pyrimidine-2,4,6(1H,3H,5H)-trione(BFPT) was synthesized and investigated by experimental and theoretical methodologies. The spectral characterization was made using FT-IR, FT-Raman and density functional calculation with B3LYP/6-31G(d,p) level of theory. The optimization of predicted molecule has been studied using the same level of basis set. To study the vibrational behaviour, the FT-IR and FT-Raman spectra were recorded in the region between 400-4000 cm^{-1} and 50-4000 cm^{-1} respectively. Both experimental and theoretical results were compared and analysed the characteristics of the title compound. Non-linear optical activity was investigated and found that BFPT compound is a good non-linear material. The natural bond orbital analysis, molecular electrostatic potential and band gap energies were analysed and the reactive path of the BFPT molecule were also studied.

Keywords: Molecular Orbital; Density Functional Theory; FT-IR; Raman; Non-linear Optical Activity

1. INTRODUCTION

Barbituric acid is an important compound with a heterocyclic structure and possibility of existing in several tautomeric forms because of mobility of the hydrogen atoms in its molecules. Some experimental investigations of barbituric acid and its derivatives mainly tuned to its application in medicine and as dye in chemical industry [1,2]. Barbituric acid derivatives possess a rather broad spectrum of therapeutic activity. Substituted heterocyclic/substituted aryl systematic variation at the 5^{th}-position of barbituric [3-5] or thiobarbituric [6-8] acids nucleus remarkably increases the antiepileptic activity. In particular, pyrimidine-derived biomolecules have received much attention from spectroscopists, drug, clinical and industrial researchers because of their therapeutic importance [9–17]. Barbiturates are a class of central nervous system depressants [18] utilized as sedatives, sleeping agents,

hypnotics, anxiolytics, anticonvulsants, and anaesthetics [19]. In addition, they have additional pharmacological activities as antioxidant anxiolitics, analeptics, anti-AIDA, immune modulator, anticancer agents and in other psychiatric disorders and possess effects on motor and sensory functions [20–25]. New pharmacological properties of barbituric acid derivatives established in recent years significantly expanded the application range of barbiturates [26].

The biological significance of the pyrimidine derivatives has promoted us to synthesize a new substituted barbituric acid and to evaluate them for their anti-microbial activity. In this present investigation, a new pyrimidine derivative was synthesized by condensation of 3-bromo-4-fluourobenzaldehyde with barbituric acid. Attention has been focused on structural activity relationship. Vibrational analysis by Density Functional Theory (DFT) approaches are the powerful tool for the determination of various molecular properties and molecular geometry of the molecule. Thermodynamic data such as enthalpy of formation are often helpful in the understanding of the structural conformational and reactivity trends exhibited by molecules. The data are needed to estimate the amount of energy released or adsorbed in a chemical reaction, in calculating other thermodynamics functions, and more importantly in assessing the relative stability of molecules. One of the purposes of thermochemistry is to derive the enthalpy of formation of compound from their elements and to relate the energy to structure and chemical binding [27].

The main objective of this investigation is to calculate the molecular geometry and energy of the title compound by DFT method by using B3LYP/6-31G(d,p) level of theory. However, literature survey reveals that to the best of our knowledge, the quantum chemical calculations for BFPT have not been reported so far. Therefore, the present investigation using DFT method of calculations along with experimental characterization of FT-IR, FT-Raman spectra were undertaken to study the vibrational spectra and various normal modes with greater wavenumber accuracy. HOMO-LUMO analysis have been carried out to elucidate the information regarding energy gap and charge transfer within the molecule, also its NLO property, molecular electrostatic potential (MEP) and thermodynamic property of the title compound.

2. COMPUTATIONAL AND EXPERIMENTAL METHODS

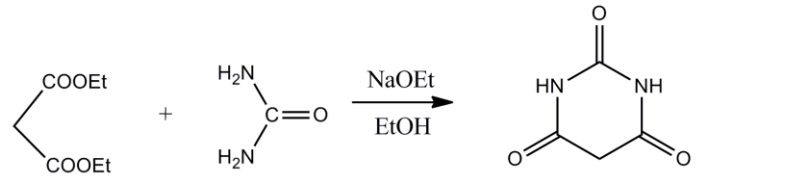
Computational Details

Gaussian 03 quantum chemical software was used in all calculations. Optimized structural parameters and vibrational wavenumbers for the BFPT molecule were calculated by using B3LYP functional with 6-31G(d,p) basis set. The vibrational modes were assigned on the basis of PED analysis using VEDA4 program [28]. The calculated harmonic vibrational wavenumbers were scaled down uniformly by a factor of 0.9608 for B3LYP/6-31G(d,p) level of theory, which accounts for systematic errors caused by basis set incompleteness, neglect of electron correlation and vibrational anhormonicity [29,30].

Experimental

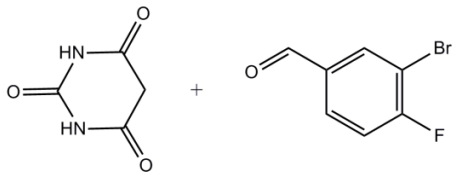
Synthesis of barbituric acid (Stage-I)

In a round-bottomed flask fitted with a reflux condenser, 2.3 g (0.1 mol) of finely cut sodium is dissolved in 50 ml of absolute alcohol. To this solution 16.01g (0.1 mol) of ethyl malonate followed by 6.006g (0.1mol) of dry urea dissolved in 50 ml of hot (70°) absolute alcohol are added. After being well shaken the mixture is refluxed for seven hours on an oil bath heated to 110°C. A white solid separates rapidly. After the reaction is completed100 ml of hot (50°) water is added and then enough hydrochloric acid to make the solution acidic. The resulting clear solution is filtered and cooled in an ice bath overnight. The white product is collected on a Buchner funnel, washed with 50 cc. of cold water and then dried in an oven at 105-110°C for three to four hours and recrystallized from ethanol. The yield of barbituric acid is 75%.

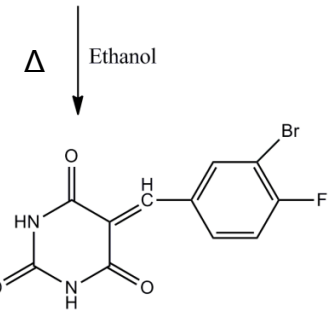


Diethylmalonate Urea Pyrimidine-2,4,6(1H,3H,5H)-trione

(Barbituric acid)



Barbituric acid 3-Bromo-4-Fluoro benzaldehyde



5-(3-bromo-4-fluorobenzylidene)pyrimidine-2,4,6(1*H*,3*H*,5*H*)-trione

3. RESULTS AND DISCUSSION

3.1 Structural determination by NMR spectra

5-(3-bromo-4-fluorobenzylidene)pyrimidine-2,4,6(1H,3H,5H)-trione:

^{1}H-NMR (400 MHz, DMSOd_6): δ = 7.48-7.44 (m, 1H), 7.98-7.95 (m,1H), 8.15-8.13 (m,1H), 9.0 (s,1H, =CH).;^{13}C-NMR (100 MHz, DMSOd_6): δ= 109.5, 116.7, 117.47, 126.78, 131.5, 136.1, 161.4, 163.9, 170.2.; IR (KBr) νcm^{-1}, 3444, 3221 (NH), 3115 (Aromatic C–H), 1691 (C=O), 1593 (C=C).

The newly synthesized compound BFPT was confirmed by FT-IR and NMR spectral analysis. The appearance of totally four signals in the ^{1}H-NMR and ten signals in ^{13}C-NMR spectrum confirm the formation of required product. The observed ^{1}H-NMR signal at 7.4, 7.9 and 8.1ppm are corresponding to the three aromatic protons which evident that the compound containing only one aromatic ring. The strong peaks observed at 1691 cm^{-1} in FT-IR and the characteristic peak at 163 and 161 ppm in ^{13}C NMR is clearly indicates the presence of carbonyl groups in this compound. Further, the FT-IR signal at 1593 cm^{-1} confirms C=C linkage.

3.2 Molecular investigation of 5-(3-bromo-4-fluorobenzylidene)pyrimidine-2,4,6(1H,3H,5H)-trione

3.2.1 Molecular geometry

The optimized molecular structure along with the numbering scheme for BFPT is shown in Fig.1. The optimized geometrical parameters are calculated using B3LYP/6-31G(d,p) level of theory and also listed in the Table1. There is no exact crystal data available for this compound. Hence, the optimized geometrical parameters are compared with available crystal data of analogous molecule from the literature.

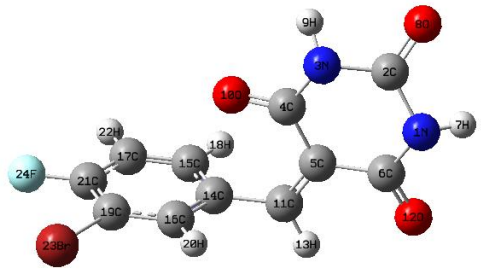


Figure 1. Optimized structure of BFPT.

The bond length of phenyl ring C_{14}–C_{11}, C_{14}–C_{15}, C_{16}–C_{19} and C_{17}–C_{21} are 1.452, 1.413, 1.385 and 1.319 Å respectively. In which the bond length of C_{16}–C_{19} and C_{17}–C_{21} are slightly lower due to the presence of electronegative atoms. The bond distance of C=C lies in the range of 1.368-1.416 Å and the bond length for C_2–N_1, C_6–N_1, C_2–N_3 and C_4–N_3 are calculated about 1.386, 1.390, 1.387 and 1.394 Å, respectively. These values are in agreement with X–ray diffraction data [31]. Similarly C=C and C=O groups bond length are calculated about 1.01 and 1.22 Å at B3LYP/6-31G(d,p) respectively, which also shows satisfactory agreement with the above crystal data.

In our study, the C–N–C angle in pyrimidine ring differs nearly by 1º and their magnitude found to be similar to the crystal data [33]. The bond angle of C_5–C_4–N_3 and C_5–C_6–N_1 are 115.33 and 116.05º respectively. The four outer angles of pyrimidine ring C_2–N_1–H_7, C_6–N_1–H_7, C_2–N_3–H_9, C_4–N_3–H_9 are found to almost same for uracil [32]. The angle of C_4–C_5–C_6 in pyrimidine ring is 118.62º, also C_7–C_8–O_7 and C_7–C_{10}–O_5 angles are 124.34 and 126.52º respectively. These bond angles are in agreement with literature [33].

The bond angles C_6–C_5–C_{11}, C_{11}–C_5–C_4 and C_4–C_5–C_6 in the centre of C_5 atom and their bond angles are 113.48, 127.89 and 118.62º respectively. The sum of these angles 359.99 indicating that the C_5 atom is of sp^2 hybridization type. In addition, the bond angles C_5–C_{11}–H_{13}, C_{14}–C_{11}–H_{13} and C_5–C_{11}–C_{14} in the centre of C_{11} are 109.97, 112.10 and 137.91º. The total sum to 359.98º which shows that C_{11} atom is also of sp^2 hybridization. So the title compound has good conjugation. The bond angles of C–C–C in phenyl ring lies in the range of 118–120º signifying all the carbon atoms are sp^2 hybridized which are in agreement with the literature value [34].

Table 1. Bond parameters of BFPT

Bond length	(Å)	Bond angle	(º)	Bond angle	(º)
C_{11}-H_{13}	1.089	C_5-C_{11}-H_{13}	109.979	C_{14}-C_{15}-C_{17}	120.429
C_{15}-H_{18}	1.080	H_{13}-C_{11}-C_{14}	112.10	C_{17}-C_{15}-H_{18}	120.472
C_{16}-H_{20}	1.084	N_1-C_2-N_3	113.5273	C_{15}-C_{17}-C_{21}	120.078
C_{17}-H_{22}	1.084	C_6-C_5-C_{11}	113.484	C_{17}-C_{21}-C_{19}	120.942
C_4-C_5	1.479	C_{11}-C_{14}-C_{16}	114.707	C_{14}-C_{16}-C_{19}	121.381
C_5-C_6	1.500	C_2-N_1-H_7	115.960	C_{15}-C_{17}-H_{22}	121.312
C_{11}-C_{14}	1.452	C_2-N_3-H_9	115.558	C_{16}-C_{19}-Br_{23}	121.178
C_{14}-C_{15}	1.413	C_4-N_3-H_9	115.673	N_1-C_2-O_8	123.373
C_{16}-C_{19}	1.385	N_3-C_4-C_5	115.336	N_3-C_2-O_8	123.098
N_1-C_2	1.38	C_6-N_1-H_7	116.347	C_5-C_6-O_{12}	124.345
N_1-C_6	1.390	N_1-C_6-C_5	116.055	C_5-C_4-O_{10}	126.524
N_3-C_4	1.394	N_3-C_4-O_{10}	118.139	C_{11}-C_{14}-C_{15}	127.169
C_4-O_{10}	1.224	C_4-C_5-C_6	118.620	C_2-N_1-C_6	127.692
C_6-O_{12}	1.221	C_{15}-C_{14}-C_{16}	118.123	C_4-C_5-C_{11}	127.895
C_5-C_{11}	1.368	C_{19}-C_{16}-H_{20}	118.794	C_2-N_3-C_4	128.768
C_{14}-C_{16}	1.416	C_{21}-C_{17}-H_{22}	118.609	C_5-C_{11}-C_{14}	137.919
C_{15}-C_{17}	1.388	N_1-C_6-O_{12}	119.599	C_{21}-C_{19}-Br_{23}	119.776
C_{19}-C_{21}	1.396	C_{14}-C_{15}-H_{18}	119.097	C_{17}-C_{21}-F_{24}	119.243
C_{19}-Br_{23}	1.897	C_{14}-C_{16}-H_{20}	119.824	C_{19}-C_{21}-F_{24}	119.814

3.2.2 Vibrational assignment

The molecule BFPT contains phenyl ring, carbonyl groups and halogens. It consists 24 atoms, hence can have 66 normal modes of vibrations. The harmonic wavenumber calculations were performed with B3LYP/6-31G(d,p) level of theory. The title molecule belongs to C_1 point group symmetry. The

recorded FT-IR, FT-Raman, calculated wavenumbers, intensities, force constant and reduced masses are given in Table S1. The comparison of experimental and theoretical vibrational spectra of BFPT is shown in Figs. 2 & 3. The potential energy distributions for all fundamental vibrations were calculated using VEDA4 program.

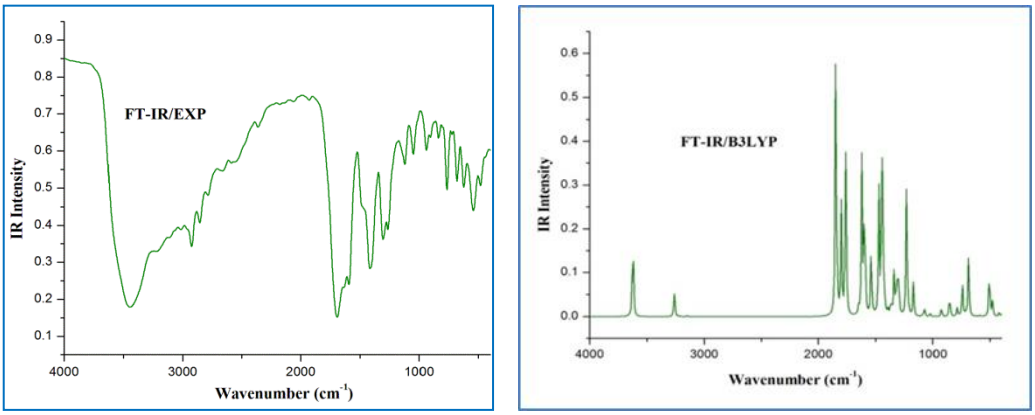


Figure 2. The recorded and theoretical FT-IR spectra of BFPT

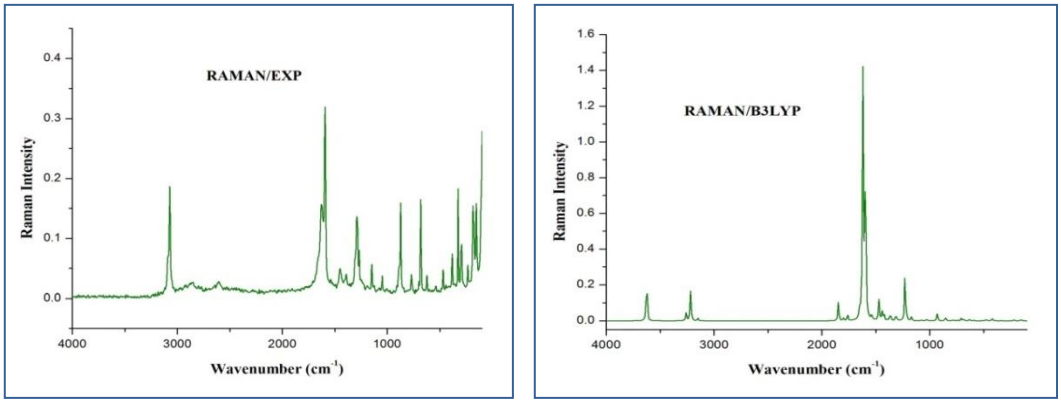


Figure 3. The recorded and theoretical FT-Raman spectra of BFPT

3.2.2.1 C-H vibrations

Aromatic compounds commonly exhibit multiple weak bands in the region 3100-3000 cm^{-1}[35,36] due to aromatic C−H stretching vibration. Accordingly, in the present study the C–H vibrations of the BFPT molecule are observed at 3115cm^{-1} in the FT-IR and 3074 cm^{-1} in FT-Raman spectrum are in good agreement with theoretical wavenumbers at 3133 $cm^{-1}$and 3088 cm^{-1} respectively. The aromatic C-H in-plane-bending and out-of-plane bending vibrations observed at 1300-1000 cm^{-1} and 900-690 cm^{-1} respectively [37, 38]. The peak observed at 1120 cm^{-1} in FT-IR spectrum is assigned for C–H in-plane-bending vibration. The infrared band observed at 941 cm^{-1} is assigned to C–H out-of-plane bending vibration which is coincide with calculated value found at 967 cm^{-1}.

It is well known that the aliphatic C−H stretching vibrations are observed at lower wavenumber than the ring C−H stretching vibrations. The C_{11}−H_{13} stretching vibration has been observed at 3012 cm^{-1} in FT-IR and is lesser than the aromatic C−H stretching vibrations and this value has good agreement with theoretical wavenumber at 3027 cm^{-1}.

3.2.2.2 Ring Vibrations

The aromatic ring carbon–carbon stretching vibrations occur in the region 1650-1430 cm^{-1}[39]. The actual position of these modes are determined not so much by the nature of the substituents but by the form of substitution around the ring [40], although heavy halogens cause the frequency to diminish undoubtedly [41]. As predicted in the earlier reference, in the present work the strong C=C aromatic stretching is observed at 1593 cm^{-1} in FT-IR and 1593cm^{-1}, 1538 cm^{-1} in FT-Raman spectrum, respectively. These values show well agreement with calculated values at 1584 cm^{-1} and 1533 cm^{-1}. The linkage formed between pyrimidine ring and phenyl ring at the position of C_{11}–C_5 observed at 1413 cm^{-1} and it show good accordance with calculated value at 1413 cm^{-1} and also in consistent with literature values [42].

The C–C stretching in phenyl ring is calculated at 1311 and 1364 cm^{-1}. These vibrations are in line with experimental value at 1303 cm^{-1} in FT-IR spectrum. The stretching vibration of C_6–C_5 bond in pyrimidine ring observed at 1049 and 1047 cm^{-1} in FT-IR and FT-Raman spectra. These values show good agreement with the calculated wavenumber at 1041 cm^{-1}.

3.2.2.3 C=O vibrations

The carbonyl C=O stretching vibration is expected to occur in the region 1715-1680 cm^{-1}[43, 44]. In the present investigation, carbonyl vibrations observed at 1691 cm^{-1} in FT-IR spectrum and this wavenumber coincides well with theoretically calculated wavenumber at 1692 cm^{-1} in B3LYP method and also find support from the literature [45]. Furthermore, the observed bands at 765cm^{-1}(FT-IR) and 769 cm^{-1}(FT-Raman) have been assigned to the C=O out-of-plane bending vibrations. Similar vibration has been observed at721cm^{-1}(FT–IR)/721cm^{-1}(FT–Raman) for C=O out-of-plane bending vibration of tetrahydropyrimidine [46].

3.2.2.5 C–X Vibrations

The bromo and fluoro substituted aromatic compounds absorbs strongly in the region of 690-515 cm^{-1} and 1250-1120 cm^{-1} respectively for stretching vibrations. The C–Br stretching vibration is assigned at 682 and 683 cm^{-1} in FT-IR and FT-Raman respectively. This value consistent with computed value (681cm^{-1}) at mode no. 40 and supported by the literature at 656 cm^{-1}[50]. A weak band at 1263 cm^{-1}in FT-IR and 1267 cm^{-1} in FT-Raman spectra are due to the strong coupling between stretching vibrations of fluorine and skeletal vibrations. These values are coinciding with calculated wavenumber at 1262 cm^{-1}.

3.3 Molecular electrostatic potential

Molecular electrostatic potential (MEP) represents a point in the space around the molecule to provide an indication of net electrostatic effect produced at that point by total charge distribution

(electron + nuclei) of the molecule and correlated with dipole moments, chemical reactivity, electronegativity, partial charges [51]. The importance of MEP lies in the fact that it simultaneously displays molecular size, shape as well as positive, negative and neutral electrostatic potential region in terms of colour grading also very useful in research of molecular structure with its physiochemical property.

The different values of the electrostatic potential on the surface of the molecule are represented by different colours. The red colour represents most negative electrostatic potential (electrophilic region) and the positive region which preferred site for nucleophilic attack symptoms as blue colour and green represents regions close to zero potential or neutral site [52,53]. The red region refers to the areas which favour interaction between lone pair oxygen and adjacent hydrogen atom. The MEP of BFPT shown in Fig. 4. The negative potential shows the acceptor nature refers to carbonyl groups of pyrimidine ring. Whereas the positive potential or donor nature is around N–H group of pyrimidine ring and the neutral region (green colour) refers to phenyl ring.

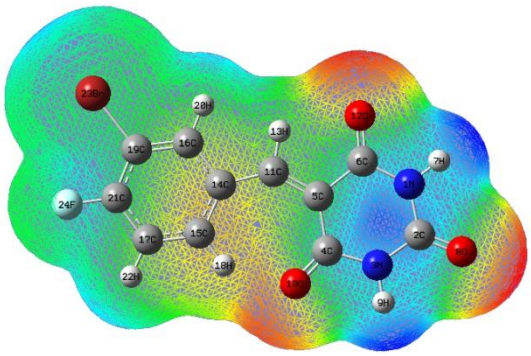


Figure 4. Molecular electrostatic potential map of BFPT.

3.4 Mulliken population analysis

The calculation of atomic charges has an important role in the application of quantum chemical calculation to molecular system [54]. Because, the atomic charges affect many properties such as dipole moment, electronic structure and polarizability [55]. The atomic charge of individual atom and its total value of the investigated compound have been obtained by mulliken population analysis are depicted in Table S2 and the graphical plot shown in Fig. 5. From the table S2, we can observe that the atomic charge of the BFPT molecule in the range from –0.609 to 0.603. The highest positive value 0.745 is exhibited by C_2 atom while the negative value –0.609 is exhibited by N_1 atom. It could be observed that entire oxygen atom possessed the negative value.

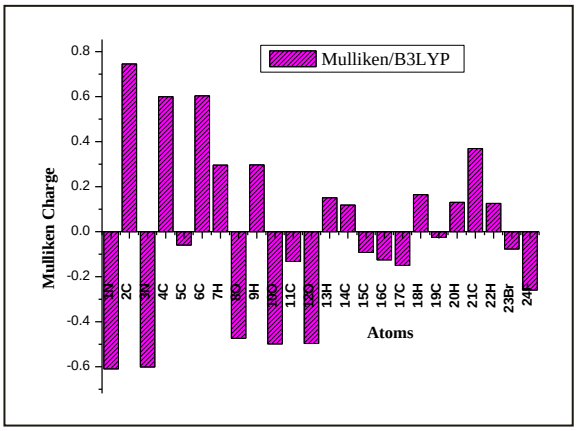


Figure 5. Mulliken atomic charges of BFPT

3.5 Frontier molecular orbital analysis

The π electron cloud moment from donor to acceptor can make the molecule highly polarized through the single-double path when it changes from the ground state to the excited state. Both the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) are the main orbitals taking part in chemical stability. The HOMO represents the ability to donate an electron, LUMO as an electron acceptor represents the ability to obtain an electron [56]. The LUMO and HOMO energies have been calculated by B3LYP/6-31G(d,p) level of theory (Fig. 6).

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 the molecule to hardness, which means that molecule with least HOMO-LUMO gap means it is more reactive and the soft molecules are more polarizable than the hard ones because they need small energy to excitation [57]. The frontier molecules orbital (HOMO and LUMO) and frontier orbital energy gap helping to exemplify the reactivity and kinetic stability of molecules are important parameters in the electronic studies [58,59]. The analysis of the wave function indicates that the electron absorption corresponding to the transition from the ground state to the first excited state is mainly defined by one electron excitation from the highest occupied orbital (HOMO) to the lowest unoccupied orbital (LUMO) [60].

The calculated HOMO-LUMO energy gap of the BFPT molecule is 3.9955eV. Meanwhile, the lowering of the energy gap describes that chemical activity and the eventual charge transfer takes place within the molecule, which influences the biological activity of the molecule. The positive phase is represented in red colour and the negative phase is represented in green colour. The HOMO-LUMO plot of BFPT molecule is given in Fig.6 and their orbital values are shown in Table 2.

As seen from the Fig. 6, the HOMO is located on the phenyl ring and bromine atom. The LUMO is located on entire molecule. Associated within the framework of molecular orbital theory, the ionization energy and electron affinity can be expressed by HOMO and LUMO orbital energies as $I = -E_{HOMO}$ and $A = -E_{LUMO}$. The global hardness, $\eta = 1/2(E_{LUMO} - E_{HOMO})$. The electron affinity can be used in combination

with ionization energy to give electronic chemical potential, $\mu = 1/2(E_{LUMO} + E_{HOMO})$. The global electrophilicity index, $\Psi = \mu^2 / 2\eta$ [61,62]. These parameters have been calculated and tabulated in Table 3. The value of η of the BFPT molecule is 1.9977eV. Hence we concluded that the title compound belongs to hard material and have higher stability.

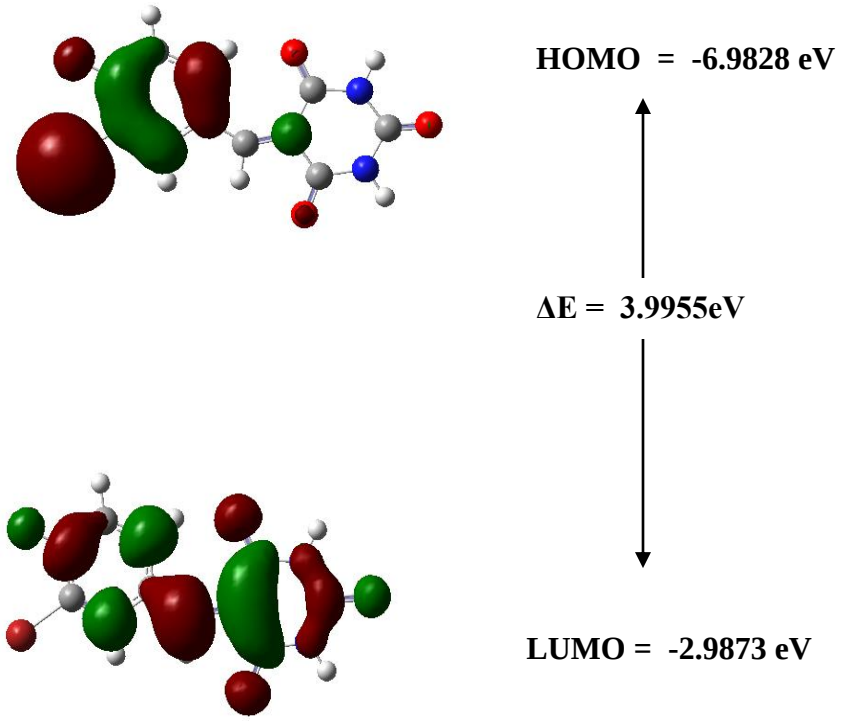


Figure 6. The frontier molecular orbitals of BFPT

DOS spectrum represents the number of energy level on the energy axis that the section has width dE and the spectrum is convoluted with Gaussian curves of heights equal to the calculated contributions for each orbital. The most important application of the DOS plot is to demonstrate MO (Molecular orbital) compositions and their contribution to chemical bonding [63]. DOS spectrum of BFPT is shown in Fig. S1.

3.6 Electronic absorption spectra analysis

Electronic transitions are usually classified according to the orbitals engaged or to specific parts of the molecule involved. Common types of electronic transition in organic compounds are π-π*, n-π*[64]. In order to understand the electronic transitions of BFPT, theoretical calculations on electronic absorption spectrum, capable of describing the spectra features of the molecule, were performed by TD-

DFT method. The theoretical calculation of UV spectral analysis of BFPT have been investigated in gas phase and the calculated excitation energies, oscillator strength (f) and wavelength (λ) and spectral assignment are given in Table S3.

Table 2. The Frontier molecular orbital of BFPT

Orbitals	Orbital energies (a.u)	Orbital energies (eV)
O_{73}	-0.3039	-8.2699
O_{74}	-0.3002	-8.1711
O_{75}	-0.2732	-7.4361
O_{76}	-0.2719	-7.4002
O_{77}	-0.2566	-6.9828
V_{78}	-0.1097	-2.9873
V_{79}	-0.0383	-1.0446
V_{80}	-0.0190	-0.5189
V_{81}	-0.0153	-0.4179
V_{82}	-0.0094	-0.2563

O-Occupied orbital; V-Virtual orbital

Table 3. Global reactivity descriptors of BFPT

Global reactivity descriptors	**Values**
HOMO	-6.9824
LUMO	-2.9871
HOMO–LUMO energy gap (ΔE)	-3.9953
Global hardness (η)	1.9976
Global softness (s)	0.5006
Chemical potential (μ)	-4.9847
global electrophilicity index (Ψ)	6.2192

The theoretical absorption wavelengths are compared with experimental wavelengths are shown in Table S3. TD-DFT calculations predict three transitions in UV-Vis region. The transition at 3.4116 eV(363 nm) and at 3.6350eV (341 nm) with oscillator strength 0.1618 and strong transition at 4.0301eV (307 nm) with higher oscillator strength 0.5655 in gasphase. The band at 272 nm in experimental spectrum corresponding to the calculated wavenumber at 307 nm with red shift of 35 nm and are assigned for π-π* transition. The calculated and visible absorption maxima of the title molecule corresponded to

the electronic transition between frontier orbitals, such as transition from HOMO-2 to LUMO, HOMO to LUMO, HOMO to LUMO +1. The theoretical and experimental UV-Vis spectrum is shown in Fig.S2.

3.7 Non–linear optics

The first hyperpolarizability (β) of this molecular system and related properties (α, β, Δα) of the title compound were calculated using B3LYP/6-31G(d,p) level of theory, based on finite field approach. In the presence of an applied electric field, the energy of system is a function of the electric field. Polarizability and hyperpolarizability characterize the response of a system in an applied electric field [65]. They determine not only the strength of molecular interaction and collision process but also the non-linear optical properties (N.L.O) of the system [66,67]. First order hyperpolarizability is a third rank tensor that can be described by 3×3×3 matrix. The 27 components of the 3D matrix can be reduced to 10 components due to the Kleinman symmetry [68]. It can be given in the lower tetrahedral format. It is obvious that the lower part of the 3×3×3 matrixes 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:

$$E = E_0 - \mu_\alpha F_\alpha - 1/2\alpha_{\alpha\beta}F_\alpha F_\beta - 1/6\beta_{\alpha\beta\gamma}F_\alpha F_\beta F_\gamma \quad (2)$$

Where E^0 is the energy of the unperturbed molecules, F_α the field at the origin μ_α, $\alpha_{\alpha\beta}$, and $\beta_{\alpha\beta}{}^{\gamma}$ are the components of dipole moment, polarizability and the first hyperpolarizabilities respectively. The total static dipole moment (μ), The mean polarizability (α_0), The anisotropy of polarizability (Δα) and mean first hyperpolarizability (β_0) using x,y,z components. They are defined as...

$$\mu = \sqrt{\left(\mu_x^2 + \mu_y^2 + \mu_z^2\right)} \quad (3)$$

$$\alpha = \frac{\alpha_{xx} + \alpha_{xy} + \alpha_{xz}}{3} \quad (4)$$

$$\beta_0 = \left(\beta_x^2 + \beta_y^2 + \beta_z^2\right)^{1/2} \quad \text{and} \quad (5)$$

$$\beta_x = \beta_{XXX} + \beta_{XYY} + \beta_{XZZ}$$

$$\beta_Y = \beta_{YYY} + \beta_{XXY} + \beta_{YYZ}$$

$$\beta_Z = \beta_{ZZZ} + \beta_{XXZ} + \beta_{YYZ}$$

In the present study, the calculated dipole moment (μ), polarizability (α) and first hyperpolarizability (β_0) of the BFPT compound are 1.2977 Debye, $3.6998 \times 10^{-30} esu$ and

$14.56 \times 10^{-30} esu$ respectively and the values are shown in Table 4. The β_0 value of the title compound is 39 times greater than that of urea. These results indicate that the BFPT molecule is a good candidate of NLO material. Urea is one of the Prototypical molecular used in the study of the NLO properties of molecular systems. Therefore it was used frequently as a threshold value for comparative purposes.

To understand this phenomenon in the context of molecular orbital theory, we examined the molecular HOMO and LUMO of the title compound. When we see the first hyperpolarizability value, there is an inverse relationship between the first hyperpolarizability and HOMO-LUMO gap, allowing the molecular orbital's to overlap to have a proper electronic communication conjugation, which is a marker of the intramolecular charge transfer from the electron donating group through π-conjugation system to the electron accepting group [69,70].

Table 4. The molecular electric dipole moments μ (Debye), Polarizability (α_0) and Hyperpolarizability (β_0) values of BFPT

Parameters	B3LYP/6-31G(d,p)
μ	1.2977 Debye
α	3.6998 x10^{-30}*esu*
Hyperpolarizability (β_0)	x10^{-30}*esu*
β_{xxx}	-1140.35
β_{xxy}	482.60
β_{xyy}	-227.36
β_{yyy}	94.56
β_{xxz}	-283.46
β_{xyz}	190.48
β_{yyz}	-59.86
β_{xzz}	-195.69
β_{yzz}	1.46
β_{zzz}	92.10
β_0	14.56 x10^{-30}*esu*

*Standard value for urea (**μ**=1.3732 Debye, β_0=0.3728x10^{-30}esu): **esu**-electrostatic unit

3.8 NBO analysis

NBO analysis provides the most accurate possible 'natural Lewis structure' because all orbital details are mathematically chosen to include the highest possible percentage of the electron density. A useful aspect of the NBO method is that it gives information about interactions in both filled and virtual orbital spaces that could enhance the analysis of intra-and intermolecular interactions. The second order Fock matrix was carried out to evaluate the donor-acceptor interactions in the NBO analysis [71]. The interactions result is a loss of occupancy from the localized NBO of the idealized Lewis structure into an empty non-Lewis orbital. For each donor (i) and acceptor (j), the stabilization energy $E^{(2)}$ associated with the delocalization $i \rightarrow j$ is estimated as

$$E^{(2)}=\Delta E_{ij}=q_i\frac{F(i,j)^2}{\varepsilon_j-\varepsilon_i} \qquad (7)$$

where q_i is the donor orbital occupancy, are ε_i and ε_j diagonal elements and F(i, j) is the off diagonal NBO Fock matrix element. Natural bond orbital analysis provides an efficient method for studying intra and intermolecular bonding and interaction among bonds, and also provides a convenient basis for investigating charge transfer or conjugative interaction in molecular systems. Some electron donor orbital, acceptor orbital and the interacting stabilization energy resulted from the second-order micro-disturbance theory are reported [72]. The larger the $E^{(2)}$ value, the more intensive is the interaction between electron donors and electron acceptors, i.e. the more donating tendency from electron donors to electron acceptors and the greater the extent of conjugation of the whole system. Delocalization of electron density between occupied Lewis-type (bond or lone pair) NBO orbitals and formally unoccupied (anti-bond or Rydgberg) non-Lewis NBO orbitals correspond to a stabilizing donor–acceptor interaction. NBO analysis has beenperformed on the molecule at the DFT/B3LYP/6-31G(d,p) level of theory in order to elucidate the intramolecular, re-hybridization and delocalization of electron density within the molecule are shown in Table 5.

In the present study, the electron densities of the σ bonds are higher than π bonds. The lowering of the electron densities is due to transfer of lone pair electron from donor to acceptor (anti-bonding) orbital. This is evident from the table that the electron densities of σ N–C, N–H, C–C, C–H and C–X are higher in the range of 1.968-1.995 and their corresponding anti bonding orbital have weaker electron densities with lesser hyper conjugative energy. On the other hand, the occupancy of π C_5–C_{11}, C_{14}–C_{16}, C_{15}–C_{17}, C_{19}–C_{21} decreased by increasing electron densities of their corresponding anti-bonding orbitals with maximum stabilization energy.

Table 5. Second order perturbation theory analysis of Fock matrix in NBO basis of BFPT

Type	Donor (i)	ED/e	Acceptor (j)	ED/ e	[a]$E^{(2)}$ kJ/mol	[b]F(i,j) (a.u)	[c]E(j)-E(i) (a.u)
σ–σ*	N_1–H_7	1.9812	C_2–N_3	0.0855	17.91	1.09	0.062
			C_5–C_6	0.0728	15.44	1.08	0.057
π–π*	C_2–O_8	1.9845	C_2–O_8	0.3251	7.03	0.38	0.024
σ–σ*	N_3–C_4	1.9885	C_2–O_8	0.0102	10.84	1.43	0.054
			C_5–C_{11}	0.0164	8.12	1.44	0.047
π–π*	C_4–O_{10}	1.9778	C_5–C_{11}	0.1744	17.24	0.4	0.038
π–π*	C_5–C_{11}	1.7726	C_4–O_{10}	0.2942	103.64	0.28	0.075
			C_5–C_{11}	0.1744	8.41	0.3	0.022
			C_6–O_{12}	0.2852	101.59	0.28	0.075
			C_{14}–C_{16}	0.3990	38.62	0.29	0.048
π–π*	C_6–O_{12}	1.9838	C_5–C_{11}	0.1744	11.72	0.4	0.031
σ–σ*	C_{11}–H_{13}	1.9689	C_4–C_5	0.0677	34.73	0.95	0.08
			C_5–C_{11}	0.0164	5.36	1.13	0.034
			C_{14}–C_{15}	0.0251	23.97	1.06	0.07
π -π*	C_{14}–C_{16}	1.5995	C_5 –C_{11}	0.1744	98.07	0.28	0.077
			C_{15}–C_{17}	0.2779	84.56	0.28	0.07
			C_{19}–C_{21}	0.4318	78.87	0.25	0.062
π–π*	C_{15}–C_{17}	1.6630	C_{14}–C_{16}	0.3990	69.91	0.27	0.061
			C_{19}–C_{21}	0.4318	115.56	0.25	0.076
n–π*	N_1	1.6568	C_2–O_8	0.3251	244.05	0.28	0.114
			C_6–O_{12}	0.2852	229.37	0.28	0.112
n–π*	N_3	1.6576	C_2–O_8	0.3251	241.67	0.28	0.114
			C_4–O_{10}	0.2942	231.42	0.27	0.111
n–σ*	O_8	1.8436	N_1–C_2	0.0845	113.97	0.67	0.123
			C_2–N_3	0.0855	114.64	0.67	0.123
n–σ*	O_{10}	1.8642	N_3–C_4	0.0788	112.09	0.68	0.122
			C_4–C_5	0.0677	74.73	0.7	0.101
			C_{15}–H_{18}	0.0272	19.41	0.79	0.055
n–σ*	O_{12}	1.8556	N_1–C_6	0.0789	112.59	0.68	0.123
			C_5–C_6	0.0728	83.89	0.66	0.105
			C_{11}–H_{13}	0.0210	8.16	0.72	0.034
n–π*	Br_{23}	1.9348	C_{19}–C_{21}	0.4318	42.59	0.28	0.053
n–π*	F_{24}	1.9013	C_{19}–C_{21}	0.4318	97.74	0.41	0.095
π*–π*	C_4–O_{10}	0.2942	C_5–C_{11}	0.1744	285.73	0.02	0.076
π*–π*	C_6 –O_{12}	0.2852	C_5–C_{11}	0.1744	297.78	0.02	0.068
π*–π*	C_{14}–C_{16}	0.3990	C_5–C_{11}	0.1744	685.55	0.01	0.07
			C_{15}–C_{17}	0.2779	805.8	0.01	0.08
π*–π*	C_{19}–C_{21}	0.4318	C_{14}–C_{16}	0.3990	673.46	0.02	0.08
			C_{15}–C_{17}	0.2779	366.73	0.04	0.083

[a] E(2) means energy of hyper conjugative interaction (stabilization energy).
[b] F(i,j) is the fork matrix element between i and j NBO orbitals.
[c] Energy difference between donor(i) and acceptor(j) NBO orbitals.

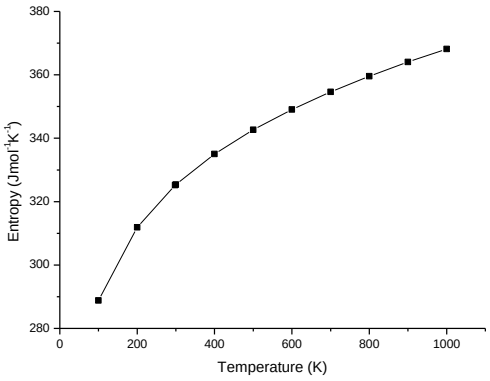


Figure 7. Correlation graph between Temperature Vs Entropy of BFPT

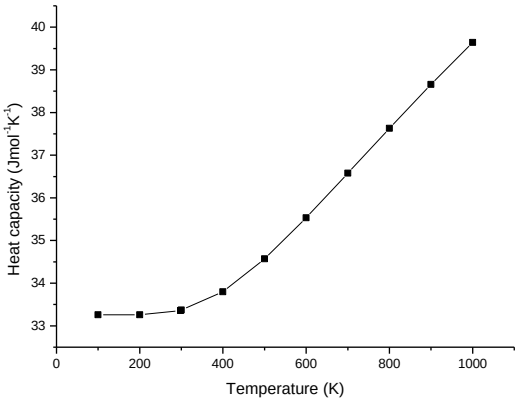


Figure 8. Correlation graph between Temperature Vs Heat capacity of BFPT

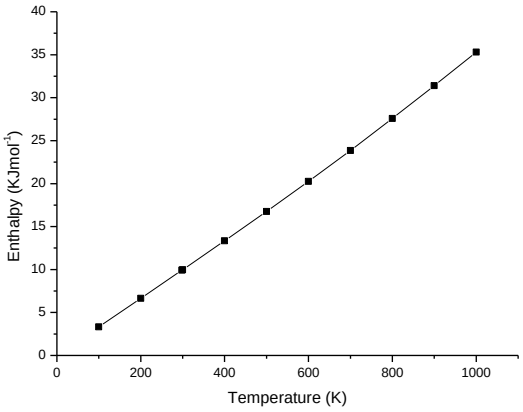


Figure 9. Correlation graph between Temperature Vs Enthalpy of BFPT

The hyper conjugative interactions are observed in benzene and pyrimidine ring for donor and acceptor orbitals of $\pi(C_{14}–C_{16})\rightarrow \pi^*(C_5–C_{11}, C_{15}–C_{17}, C_{19}–C_{21})$, $\pi(C_{15}–C_{17})\rightarrow\pi^*(C_{14}–C_{16}, C_{19}–C_{21})$,

$\pi(C_{19}–C_{21})\rightarrow\pi^*(C_{14}–C_{19})$ and $\pi(C_5–C_{11})\rightarrow\pi^*(C_4–O_{10}$, $C_6–O_{12}$, $C_{14}–C_{16})$ are shows maximum hyperconjugative energy, in which pyrimidine ring have higher stabilization energy. The π–π* interaction of BFPT molecule reveals that intra molecular charge transfer occur in pyrimidine ring with maximum stabilization energy.

It is evident from the table, the n–π* interaction for LPN1$\rightarrow\pi^*(C_2–O_8$, $C_6–O_{12})$, LPN3$\rightarrow\pi^*(C_2–O_8$, $C_4–O_{10})$ have higher hyperconjugative energy leading stabilization of 244.05 & 229. 37 and 241.67 & 231.42 KJ/mol respectively, during the n– π* interaction more energy delocalization takes place. The n–σ^* transitions for O_8, O_{10}, O_{12}, Br_{23} and F_{24} have lesser stabilization energy then n–π* interaction.

Table 6. Thermodynamic parameters of BFPT

T (K)	S(J/mol.K)	Cp(J/mol.K)	ddH (kJ/mol)
100.00	288.84	33.26	3.33
200.00	311.89	33.26	6.65
298.15	325.18	33.36	9.92
300.00	325.39	33.37	9.98
400.00	335.04	33.80	13.34
500.00	342.66	34.57	16.75
600.00	349.05	35.53	20.26
700.00	354.60	36.58	23.86
800.00	359.56	37.63	27.57
900.00	364.05	38.66	31.39
1000.00	368.17	39.64	35.30

3.9 Thermodynamic properties

The total energy of a molecule is the sum of translational, rotational, vibrational and electronic energies, i.e., $E = E_t + E_r + E_v + E_e$. The statistical thermo chemical analysis of BFPT is carried out considering the molecule to be at room temperature of 298.15 K and one atmospheric pressure.

The thermodynamic parameters, like rotational constant, zero point vibrational energy (ZPVE) of the molecule by DFT method with B3LYP are presented in Table S4. On the basis of vibrational analysis and statistical thermodynamics, the standard thermodynamic functions: heat capacity (Cp), entropy (S), and enthalpy (ΔH) were obtained and listed in Table 6.

As is evident from Table 7, all the values of Cp, S, and ΔH increases with the increase of temperature from 100K to1000K, which is attributed to the enhancement of the molecular vibration while the temperature increases because at a constant pressure (db = 1 atm) values of Cp, S, and ΔH are equal to the quantity of temperature [73]. The correlations between these thermodynamic properties and temperatures T are shown in Fig. 7-9.

4. CONCLUSION

The calculated vibrational frequencies obtained by DFT calculations are in good agreement with the experimental values obtained for the investigated molecule. The energies of important molecular orbital's absorption wavelength (λ_{max}), oscillator strength and excitation energies of the compound were also determined from TD-DFT method and compared with experimental values. The FMO analysis of BFPT molecule explains eventual charge transfer interaction taking place within the molecule. The MEP map shows that the negative potential sites are on the electronegative atoms while the positive potential sites are around the hydrogen atom. The predicted NLO properties of the title compound much greater than urea. Therefore the compound is a good candidate as a second order non-linear optical material. The thermodynamic properties of the title compound at different temperatures have been calculated. It is seen that the heat capacities, entropies and enthalpies increase with the increasing temperature owing to the intensities of the molecular vibrations increase with increasing temperature.

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The authors declare no conflict of interest

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