

BIBECHANA

A Multidisciplinary Journal of Science, Technology and Mathematics

ISSN 2091-0762 (Print), 2382-5340 (Online)

Journal homepage: <http://nepjol.info/index.php/BIBECHANA>

Publisher: Research Council of Science and Technology, Biratnagar, Nepal

NBO, nonlinear optical and thermodynamic properties of 10-Acetyl-10H-phenothiazine 5-oxide

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Article history: Received 11 October, 2017; 11 December, 2017

DOI: <http://dx.doi.org/10.3126/bibechana.v15i0.18385>

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Abstract

In this paper, natural bond orbital (NBO) analysis, nonlinear optical and the thermodynamic properties of 10-Acetyl-10H-phenothiazine 5-oxide have been analyzed by employing density functional theory level employing 6-311++G(d,p) basis set. NBO analysis reveals that the intra-intermolecular charge transfer occurs within the molecule leading to the stabilization. The predicted nonlinear optical properties (NLO) like; polarizability and first hyperpolarizability support that the molecule could attract the interests for future investigation.

Keywords: APTZ; DFT; NBO, Nonlinear optical and thermodynamic properties.

1. Introduction

The heterocyclic organic compounds in which sulphur and nitrogen are incorporated in the tricyclic system; exhibit a wide range of pharmacological / biological activities [1-5]. Different derivatives of phenothiazene are known for their clinical activities. Antihistamines, diuretics, analgesics, neuroleptics, antileukemic, antimutagenic, antileishmanial etc. are some of their main potential applications [2-7] of the drugs that containing phenothiazenes. Pallafox *et. al.* [6] studied the infrared, Raman and ¹³C-NMR spectroscopic studies of *N*-Methyl Phenothiazine. Sharma *et. al.* [7] reported various remarkable biological activities of thiazolidines. Previously, we have revealed vibrational analysis of 10-Acetyl-10H-phenothiazine5-oxide [APTZ] using quantum chemical calculations [8]. The aim of the present study is to communicate some additional investigations on structure activity relation of the molecule on the APTZ molecule. In this study, we have presented the nonlinear optical and thermodynamic properties together with the natural bond orbital (NBO) analysis of the title compound by employing density functional theory [DFT] [9] 6-311++G(d,p) basis set [10] using Gaussian 09 program package [11].

2. Materials and methods

2.1. Theoretical method

Using the data available in PubChem data base [12] geometry optimization has been performed

without using any constraints. The optimized ground state structure of the molecule obtained by DFT method visualized in Gauss View program [13] is shown in Figure 1. We have utilized the DFT based on Becke's three-parameter (local, non-local, HF) hybrid exchange functional with Lee–Yang–Parr correlation functional (B3LYP) [10].

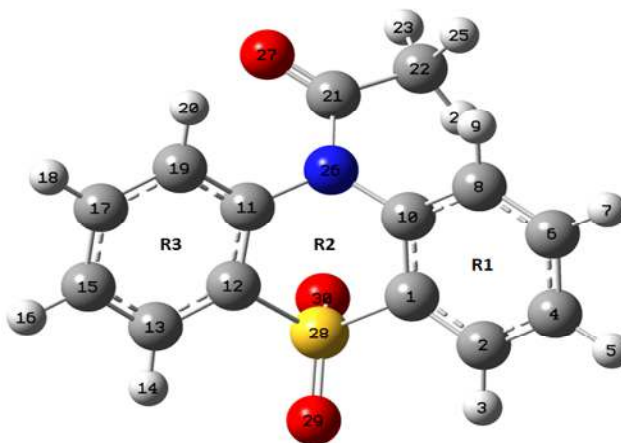


Fig. 1: Optimized structure of APTZ molecule (sulphur: yellow, nitrogen: blue, oxygen: red, carbon: gray and hydrogen: white in colours).

The basis set 6-311++G(d,p) augmented by ‘d’ polarization functions on heavy atoms (nitrogen, sulphur etc.) and ‘p’ polarization functions on hydrogen atoms as well as diffuse functions for both hydrogen and heavy atoms.

3. Results and Discussion

3.1. Natural bond orbital (NBO) analysis

NBO analysis is one of the efficient methods for studying hybridization, conjugative interactions, covalence effects and charge transfer in polyatomic wave functions into localized form, corresponding to one center (lone pairs) and two centers (bonds) of Lewis structure picture [14]. Here, by utilizing the second-order micro-disturbance theory analysis we have reported some of the electron donor orbital, acceptor orbital and the interacting stabilization energy. The intensity of the interaction between electron donors and electron acceptors, i.e. the more donating tendency from electron donors to electron acceptors depends on the $E^{(2)}$ value. The hyperconjugative interaction energy was deduced from the second-order perturbation approach [15, 16].

$$E^{(2)} = -n_{\sigma}[\langle\sigma|F|\sigma\rangle^2/E_{\sigma^*} - E_{\sigma}] = -n_{\sigma}[F_{ij}^2/\Delta E]$$

where F_{ij}^2 is the Fock matrix element between i and j NBO orbital, E_{σ} and E_{σ^*} are the energies of σ and σ^* NBO's, and n_{σ} is the population of the donor orbital. The larger the $E^{(2)}$ value the more intensive is interaction between electron donors and electron acceptors, the greater the extent of conjugation of the whole system [14]. Hyperconjugation is a stabilizing effect that arises from overlap between an occupied orbital with another neighboring electron deficient orbital when these orbitals are properly oriented. The most important interaction between “filled” (donor) Lewis type NBOs and “empty” (acceptor) non-Lewis NBOs are reported in Table 1.

A strong intramolecular hyperconjugative interaction of π electrons occurs from C1-C10 to the $\pi^*(C2 - C4)$ and $\pi^*(C6 - C8)$ bonds of the ring R1 which increase the electron densities (EDs) (0.31e and 0.32e) leading to the stabilizations of 20.07 and 16.82 kcal/mol, respectively. Another intermolecular

hyperconjugative interaction of π electrons occurs from C17-C19 to the $\pi^*(C11 - C12)$ and $\pi^*(C13 - C15)$ bonds of the ring R3 which increase the EDs (0.43e and 0.31e) leading to the stabilizations 23.89 kcal/mol and 18.92 kcal/mol, respectively. The enhanced interaction

Table 1. Second order perturbation theory analysis of Fock matrix in NBO Basis.

Donor NBO (i)	ED/e	Acceptor NBO (j)	ED/e	E(2) kcal/mol	E(j)-E(i) a.u.	F(i,j)a.u.
$\sigma(C13-H14)$	1.97771	$\sigma^*(C11-C12)$	0.03212	5.08	1.06	0.065
$\sigma(C19-H20)$	1.97695	$\sigma^*(C11-C12)$	0.03212	5.03	1.05	40.065
$\sigma^*(S28-O29)$	0.13706	$\sigma^*(S28-O30)$	0.15311	58.58	0.01	0.069
$\pi(C1-C10)$	1.67702	$\pi^*(C2-C4)$	0.30670	20.07	0.30	0.070
		$\pi^*(C6-C8)$	0.32028	16.82	0.30	0.063
$\pi(C2-C4)$	1.64157	$\pi^*(C1-C10)$	0.43019	20.47	0.26	0.067
		$\pi^*(C6-C8)$	0.32028	21.67	0.28	0.070
$\pi(C6-C8)$	1.65806	$\pi^*(C1-C10)$	0.43019	23.09	0.27	0.072
		$\pi^*(C2-C4)$	0.30670	18.10	0.29	0.065
$\pi(C11-C12)$	1.68646	$\pi^*(C13-C15)$	0.30962	20.12	0.30	0.070
		$\pi^*(C17-C19)$	0.30712	16.33	0.31	0.063
$\pi(C13-C15)$	1.64879	$\pi^*(C11-C12)$	0.43279	20.21	0.26	0.066
		$\pi^*(C17-C19)$	0.30712	20.51	0.29	0.069
$\pi(C17-C19)$	1.64130	$\pi^*(C11-C12)$	0.43279	23.89	0.26	0.072
		$\pi^*(C13-C15)$	0.30962	18.92	0.28	0.066
LP(1)N26	1.68652	$\pi^*(C1-C10)$	0.43019	14.67	0.27	0.058
		$\pi^*(C11-C12)$	0.43279	14.63	0.27	0.058
		$\pi^*(C21-O27)$	0.01587	41.57	0.30	0.102
LP(2)O27	1.85623	$\sigma^*(C21-C22)$	0.05125	18.85	0.62	0.099
		$\sigma^*(C21-N26)$	0.10121	30.04	0.64	0.126
LP(2)O29	1.80719	$\sigma^*(C1-S28)$	0.20940	12.01	0.45	0.066
		$\sigma^*(C12-S28)$	0.20601	17.58	0.45	0.079
LP(3)O29	1.79804	$\sigma^*(S28-O30)$	0.15311	21.15	0.57	0.100
LP(2)O30	1.81031	$\sigma^*(C1-S28)$	0.20940	14.23	0.44	0.071
		$\sigma^*(C12-S28)$	0.20601	14.70	0.44	0.072
LP(3)O30	1.77862	$\sigma^*(S28-O29)$	0.13706	21.63	0.55	0.100
$\pi^*(C1-C10)$	0.43019	$\pi^*(C2-C4)$	0.30670	149.22	0.02	0.081
		$\pi^*(C6-C8)$	0.32028	195.11	0.02	0.083
$\pi^*(C11-C12)$	0.43279	$\pi^*(C13-C15)$	0.30962	138.07	0.02	0.080
		$\pi^*(C17-C19)$	0.30712	135.91	0.02	0.084

$E^{(2)}$ means energy of hyper conjugative interaction (stabilization energy).

E(i)-E(j) is the energy difference between donor (i) and acceptor (j) NBO orbitals.

F(i,j) is the Fock matrix element between i and j NBO orbitals.

$\pi^*(C1-C10)$ further conjugate with the NBOs $\pi^*(C2-C4)$ and $\pi^*(C6-C8)$ resulting to high stabilizations 149.22 and 195.11 kcal/mol. Similarly, the enhanced interaction $\pi^*(C11-C12)$ further conjugates with the NBOs $\pi^*(C13-C15)$ and $\pi^*(C17-C19)$ leading to the high stabilizations 138.07 and 135.91 kcal/mole, respectively. Further, the other significant hyperconjugative interactions of π electrons in the molecular system are from $\pi(C2-C4)$ to $\pi^*(C1-C10)$ / $\pi^*(C6-C8)$ leading energies 20.47 / 21.67 kcal/mol, and from $\pi(C13-C15)$ to $\pi^*(C11-C12)$ / $\pi^*(C17-C19)$ leading energies 20.21 / 20.51 kcal/mol, respectively. Delocalization of lone pair electron is otherwise related to the resonance interaction in a molecular system. In this molecule, the main lone pair electron donation are from LP(1) N26 to the antibonding acceptor $\pi^*(C21-O27)$ (41.57 kcal/mol), from LP(2)O27 to the antibonding acceptor $\sigma^*(C21-N26)$ (30.04 kcal/mol). Similarly, another lone pair electron donations are from LP(3) O29 to the antibonding acceptors $\sigma^*(S28-O30)$ with stabilization energy 21.15 kcal/mol and from LP(3)O30 to the antibonding acceptor $\sigma^*(S28-O29)$ with stabilization 21.63 kcal/mol. The interactions mainly include within the rings R1 and R3, and the nitrogen and sulphur atoms of the ring R2.

The NBO analysis also describes the bonding in terms of the natural hybrid orbital LP(2) O27, which occupy a higher energy orbital (-0.27030 a.u.) with considerable p-character (99.92%) and low

occupation number (1.85623) and the other LP(1)O27 occupy a lower energy orbital (-0.70715 a.u.) with p-character (41.40%) and high occupation number (1.98474). Another natural hybrid orbital LP(2) O29, which occupy a higher energy orbital (-0.30236a.u.) with considerable p-character (99.91%) and low occupation number (1.80719) and the other LP(1)O29 occupy a lower energy orbital (-0.29619 a.u.) with p-character (24.15%) and high occupation number (1.98263). Similarly, the other NBO analysis describes in terms of the natural hybrid orbital LP(2)O2, which occupy a higher energy orbital (- 0.29619 a.u.) with p-character (99.92%) and low energy occupation (1.81031) and other LP(1)O30 occupy a lower energy orbital (-0.81342 a.u.) with p-character (23.45%) and high occupation number (1.98110). Thus, pure p-type lone pair orbital participates in the electron donation interactions in the compound. The results are tabulated in Table 2.

Table 2. Selected Lewis orbitals (occupied bond or lone pair) with the valence hybrids corresponding to the various interactions in (3): A-donor, B-acceptor and(ED)-Electron density.

Bond(A-B)	ED _{A-B}	ED _A (%)	ED _B (%)	NBO Hybrid orbitals	s (%)	p (%)
σ (C1-S28)	1.96350	54.34	45.66	0.7372(sp ^{3.21}) _{C+}	23.73	76.23
	-0.69894	-	-	0.6757(sp ^{3.34}) _S	22.74	75.92
σ (C10-N26)	1.97989	38.37	61.63	0.6194(sp ^{2.69}) _{C+}	27.04	72.86
	-0.80968	-	-	0.7850(sp ^{1.98}) _N	33.54	66.42
σ (C11-N26)	1.97750	37.98	62.02	0.6163(sp ^{2.74}) _{C+}	26.70	73.20
	-0.79572	-	-	0.7875(sp ^{2.06}) _N	32.64	67.32
σ (C12-S28)	1.96303	53.74	46.26	0.7330(sp ^{3.24}) _{C+}	23.59	76.36
	-0.69859	-	-	0.6802(sp ^{3.26}) _S	23.17	75.52
σ (C21-N26)	1.98018	35.37	64.63	0.5947(sp ^{2.39}) _{C+}	29.50	70.37
	-0.81385	-	-	0.8039(sp ^{1.98}) _N	33.50	66.47
σ (C21-O27)	1.99417	35.16	64.84	0.5930(sp ^{2.08}) _{C+}	32.42	67.40
	-1.09153	-	-	0.8052(sp ^{1.44}) _O	40.97	58.92
σ (S21-O29)	1.98590	35.28	64.72	0.5939(sp ^{2.61}) _{S+}	27.25	71.24
	-0.98985	-	-	0.8045(sp ^{3.15}) _O	24.08	75.80
σ (S21-O30)	1.98233	35.24	64.76	0.5937(sp ^{2.62}) _{S+}	27.22	71.24
	-0.97802	-	-	0.8047(sp ^{3.25}) _O	23.48	76.41
LP(1)N26	1.68652	-	-	(sp ^{99.99})	0.30	99.69
	-0.28427	-	-	-	-	-
LP(1) O27	1.97547	-	-	(sp ^{0.71})	58.58	41.40
	-0.70715	-	-	-	-	-
LP(2) O27	1.85623	-	-	P	-	99.92
	-0.27030	-	-	-	-	-
LP(1) O29	1.98263	-	-	(sp ^{0.32})	75.84	24.15
	-0.81174	-	-	-	-	-
LP(2) O29	1.80719	-	-	P	-	99.91
	-0.30236	-	-	-	-	-
LP(3) O29	1.79804	-	-	(sp ^{99.99})	0.12	99.79
	-0.29967	-	-	-	-	-
LP(1) O30	1.98110	-	-	(sp ^{0.31})	76.54	23.45
	-0.81342	-	-	-	-	-
LP(2) O30	1.81031	-	-	P	-	99.92
	-0.29619	-	-	-	-	-
LP(3) O30	1.77862	-	-	(sp ^{99.99})	0.04	99.87
	-0.29196	-	-	-	-	-

The Mulliken charges provide partial atomic charges. They are explicitly sensitive to the choice of basis set used for theoretical calculation. They give qualitative results of the charge distribution to the related atoms. The NBO charges operate the electron density and are more reliable. Localized natural atomic orbitals can be used to describe electron density. The polarization bonds are considered in this method while no polarization is considered in the Mulliken system. The Mulliken and NBO charges obtained by B3LYP/6-311++G(d,p) basis have been listed in the Table 3. Their graphical comparison is shown in the Figure 2.

Table 3. Comparison of NBO and Mulliken charges by B3LYP/6-311++G(d,p) basis.

Atom no.	Mulliken charges (esu)	NBO charges (esu)	Atom no.	Mulliken charges (esu)	NBO charges (esu)
1 C	-0.801065	-0.32909	16 H	0.072371	0.24827
2 C	0.338536	-0.18010	17 C	0.065647	-0.20784
3 H	0.138707	0.27189	18 H	0.077403	0.24719
4 C	-0.174436	-0.23767	19 C	-0.128778	-0.21207
5 H	0.073405	0.25036	20 H	0.109145	0.26802
6 C	0.018242	-0.20909	21 C	0.159322	0.70133
7 H	0.090411	0.24828	22 C	-0.308930	-0.74808
8 C	0.056851	-0.23514	23 H	0.163485	0.27063
9 H	0.065658	0.25055	24 H	0.141922	0.25093
10 C	-0.394878	0.16009	25 H	0.146591	0.24921
11 C	-0.003160	0.16753	26 N	0.352297	-0.49404
12 C	-0.554110	-0.32425	27 O	-0.278885	-0.57932
13 C	0.203503	-0.20626	28 S	0.861219	2.17709
14 H	0.133208	0.26962	29 O	-0.340694	-0.92582
15 C	-0.033144	-0.23002	30 O	-0.249846	-0.91217

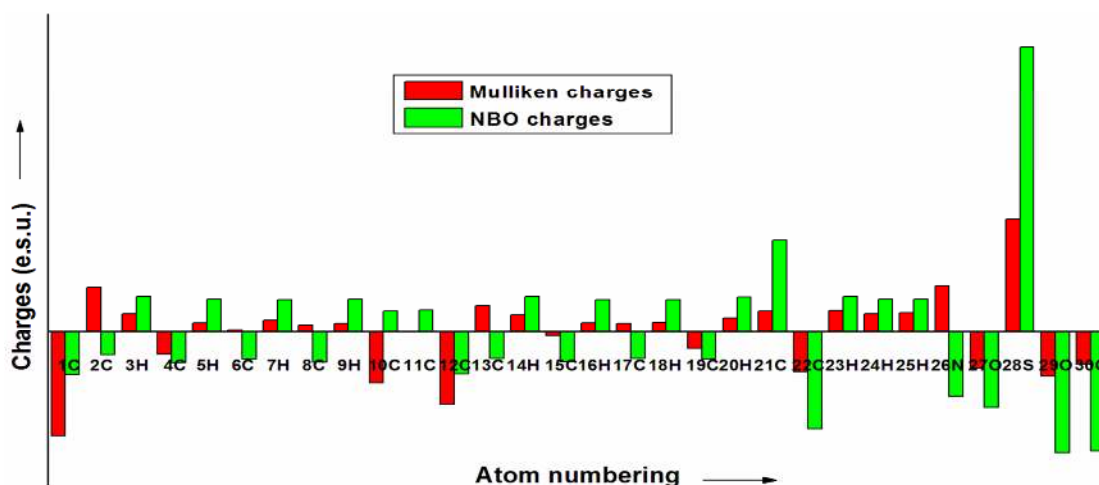


Fig. 2: Graphical representation of Mulliken and NBO charges.

3.2. Nonlinear optical (NLO) properties

NLO phenomena have attractive attention because of their potential applications in optical communication, optical sensing, data storage, computing etc. [17, 18]. The first hyperpolarizability (β_0) of the molecular system, and the related properties; mean polarizability (α_0) and anisotropy of polarizability ($\Delta\alpha$) have been calculated using B3LYP/6-311++G(d,p) basis set. First order hyperpolarizability is a third rank tensor that can be described by 3x3x3 matrix. The 27 components of 3d-matrix can be reduced to 10 components by Kleinman symmetry [19]. It can be given in the lower tetrahedral format. Energy of a system during weak and homogeneous electric field can be given as:

$$E = E_0 - \sum_i \mu_i F^i - \frac{1}{2} \sum_{ij} \alpha_{ij} F^i F^j - \frac{1}{6} \sum_{ijk} \beta_{ijk} F^i F^j F^k \dots$$

Where E_0 is the energy of unperturbed molecule, F^i is the field at the origin μ_i , α_{ij} and β_{ijk} are the components of dipole moment, polarizability and first hyperpolarizability, respectively. The components of hyperpolarizability tensor are listed in the Table 4.

Table 4. Dipole moment (μ ; Debye), polarizability ($\alpha \times 10^{-24}$ esu) and first hyperpolarizability ($\beta_0 \times 10^{-31}$ esu) by B3LYP/6-311++ G(d,p) method.

Dipole moment		Polarizability		Hyperpolarizability	
μ_x	-2.5505	α_{xx}	-95.1487	β_{xxx}	6.4396
μ_y	1.8587	α_{yy}	-125.1014	β_{yyy}	9.9021
μ_z	-4.6646	α_{zz}	-124.3313	β_{zzz}	4.3677
μ_0	5.6319	α_{xy}	-6.6784	β_{xyy}	-28.9734
	4.2 (Urea)	α_{xz}	-2.1461	β_{xxy}	-19.6156
		α_{yz}	0.6211	β_{xxz}	-36.0926
		α_0	17.0223	β_{xzz}	-5.6695
		$\Delta\alpha$	35.0921	β_{yzz}	16.7140
				β_{yyz}	-15.6364
				β_{xyz}	-10.6509
				β_0	4.8308
					1.947 (Urea)

The total static dipole moment (μ_0), mean polarizability ($\Delta\alpha$), anisotropy of polarizability ($|\alpha_0|$) and first hyperpolarizability (β_0) can be expressed as [20]:

$$\mu_0 = (\mu_x^2 + \mu_y^2 + \mu_z^2)^{1/2} |\alpha_0| = \frac{1}{3} (\alpha_{xx} + \alpha_{yy} + \alpha_{zz})$$

$$\Delta\alpha = \frac{1}{2} [(\alpha_{xx} - \alpha_{yy})^2 + (\alpha_{yy} - \alpha_{zz})^2 + (\alpha_{zz} - \alpha_{xx})^2 + 6\alpha_{xx}^2]^{1/2}$$

$$\beta_0 = [(\beta_{xxx} + \beta_{xyy} + \beta_{xzz})^2 + (\beta_{yyy} + \beta_{xxy} + \beta_{yzz})^2 + (\beta_{zzz} + \beta_{xxz} + \beta_{yyz})^2]^{1/2}$$

The dipole moment, mean polarizability, anisotropy of polarizability and first hyperpolarizability of the title compound have been calculated and listed in the Table 4. These values are found to be higher than that of the standard NLO material urea [21]. In this study the first hyperpolarizability has been calculated nearly 2 times that of urea. Hence, the higher value of β_0 shows that the investigated compound has good nonlinear property.

3.3 Thermodynamic properties

Computation of thermodynamic properties of molecules is important for both thermochemistry and chemical equilibrium. Statistical thermodynamics with the two key ideas, Boltzmann distribution and the partition function leads to the derivation of the equations utilized for computing thermochemical data in Gaussian programs. The total energy, zero-point energy, heat capacity (C_m^0), entropy ($S_{p,m}^0$), enthalpy (H_m^0), dipole moment and the rotational constants of the molecular system were obtained directly from the output of Gaussian calculation employing B3LYP/6-311G(d,p) basis set and are listed in the Tables 5 (a & b).

Table 5(a). Variation of different thermodynamic parameters with temperature.

Temp (K)	Enthalpy (kcal/mol)	Specific heat (cal/mol-K)	Entropy (cal/mol-K)
100	141.533	23.442	79.872
200	144.808	42.245	103.205
300	150.005	61.648	124.810
400	157.087	79.568	145.639
500	165.817	94.504	165.501
600	175.887	106.439	184.190
700	187.024	115.953	201.647
800	198.963	123.673	218.447

The correlation between temperature and these thermodynamic properties are given in Figure3. The correlation equations are as follows:

$$H_m^o = 138.660893 + 0.01732 T + 7.32786 \times 10^{-5} T^2 (R^2 = 0.99966)$$

$$S_m^o = 55.97127 + 0.24566 T - 5.33423 \times 10^{-5} T^2 (R^2 = 0.9999)$$

$$C_{p,m}^o = -1.05686 + 0.24515 T - 1.11082 \times 10^{-4} T^2 (R^2 = 0.9995)$$

Table 5(b). Different thermodynamic parameters at room temperature.

Parameters	DFT/6-311++G(d,p)
Total energy (Hartree)	-1218.8951192
Zero-point vibrational energy (kcal/mol)	140.14841
Rotational constants (GHz)	0.48096 0.37617 0.27138
Enthalpy (kcal/mol)	149.891
Specific heat (cal/mol-K)	61.295
Entropy (cal/mol-K)	124.424

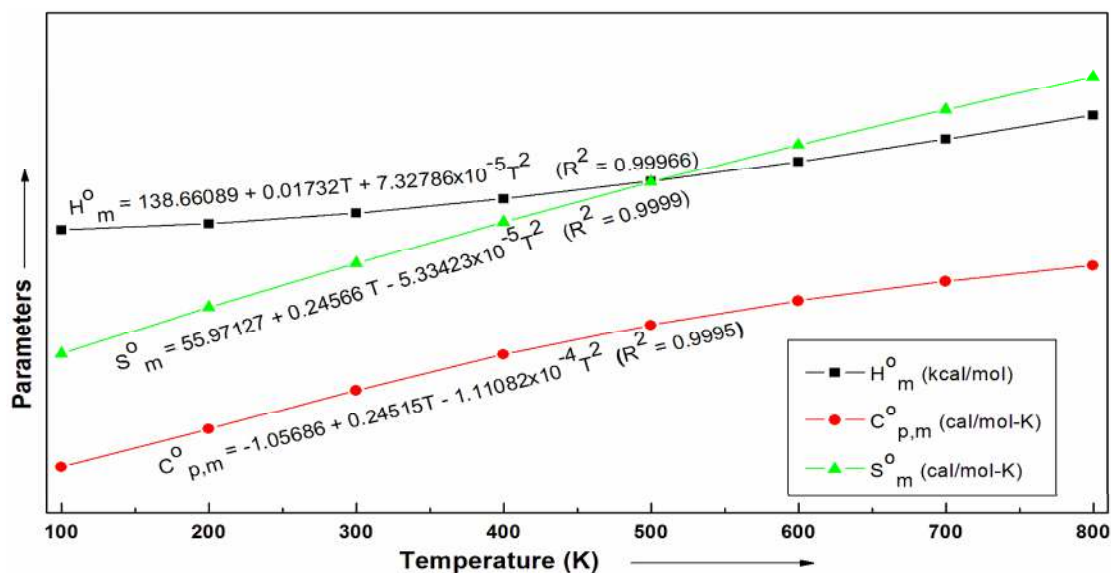


Fig. 3: Correlation between different thermodynamic properties with the temperature.

It is observed that the parameters increase from 100 to 800 K due to the increase in the molecular vibrational intensities with the temperature.

4. Conclusion

Using NBO studies stability of the molecule arising from hyperconjugative interaction and charge delocalization has been predicted by B3LYP/6-311++G(d,p) method. The $\pi \rightarrow \pi^*$ interactions are responsible for the conjugation of respective π -bonds within aromatic rings R1 and R3 with maximum energy ~ 195 , and 135 kcal/mol, respectively. The calculated data suggest an extended π -electron delocalization in the system is responsible for the nonlinearity of the title compound. Due to increase in vibrational frequencies the thermodynamic properties also vary with the temperature.

Acknowledgements

Thanks are to the Brazilian National Council for Scientific and Technological Development (CNPq) and TWAS, the academy of sciences for the developing world (CNPq-TWAS/Post-Doc fellowship).

References

- [1] Y.R. Dixit, N. Gautam and D.C. Gautam, Synthesis of bioactive fluorinated 10H-phenothiazines and their sulfone derivatives, *E-J. Chem.* 5(S1) (2008) 1063. <http://www.e-journals.net>, ISSN: 0973-4945; CODEN ECJHAO.
- [2] I.K. Pajeva, M. Wiese, H.P. Cordes and J.K. Seydel, Membrane interactions of some catamphiphilic drugs and relation to their multidrug-resistance-reversing ability, *J. Cancer Res. Clin. Oncol.* 122(1) (1996) 27. doi.org/10.1007/BF01203070.
- [3] M.A. Wuonola, M.G. Palfreyman, N. Motohashi, M. Kawase, S. Gabay, R.R. Gupta and J. Molnár, The primary in vitro anticancer activity of "half-mustard type" phenothiazines in NCI's revised anticancer screening paradigm., *Anticancer Res.* 18(1A) (1998) 337. <http://europepmc.org/abstract/med/9568100>.
- [4] C.H. Chan, Yin, J. Garforth, J.H. McKie, R. Jaouhari, P. Speers, K.T. Douglas, P.J. Rock, V. Yardley, S.L. Croft and A.H. Fairlamb, Phenothiazine Inhibitors of Trypanothione Reductase as Potential Antitrypanosomal and Antileishmanial Drugs, *J. Med. Chem.* 41(2) (1998) 148. [doi: 10.1021/jm960814j](https://doi.org/10.1021/jm960814j).
- [5] J.A. Molnár, Hevér, I. Fakla, J. Fischer, I. Ocsovaki and A. Aszalós, Inhibition of the transport function of membrane proteins by some substituted phenothiazines in *E. coli* and multidrug resistant tumor cells, *Anticancer Res.* 17(1A) (1997) 481. <https://www.ncbi.nlm.nih.gov/pubmed/9066699>.
- [6] M.A. Palafox, M. Gil, J.L. Núñez and G. Tardajos, Study of phenothiazine and N-methyl phenothiazine by infrared, raman, ¹H-, and ¹³C-NMR spectroscopies *Int. J. Quant. Chem.* 89(3) (2002) 147. [doi/10.1002/qua.10314](https://doi.org/10.1002/qua.10314).
- [7] R. Sharma, P. Samadhiya, S.D. Srivastava and S.K. Srivastava, Synthesis and biological activity of 4-thiazolidinone derivatives of phenothiazine, *J. Serb. Chem. Soc.* 77(1) (2012) 17. [doi: 10.2298/JSCI00924152S](https://doi.org/10.2298/JSCI00924152S).
- [8] B.D. Joshi, P. Tandon and S. Jain, NBO, chemical reactivity, thermodynamic properties and hyperpolarizability analysis of aristolochic acid II, *BIBECHANA* 9 (2013) 38. doi.org/10.3126/bibechana.v14i0.15892.
- [9] P. Hohenberg and W. Kohn, Inhomogeneous Electron Gas, *Phys. Rev. B* 136 (1964) 864. dx.doi.org/10.1103/PhysRev.136.B864.
- [10] A.D. Becke, Density-functional thermochemistry. III. The role of exact exchange, *J. Chem. Phys.* 98 (1993) 5648. <http://dx.doi.org/10.1063/1.464913>.
- [11] M. Frisch, G.W. Trucks, H.B. Schlegel, G.E. Scuseria, J.R. Cheeseman, M.A. Robb, G. Scalmani, V. Barone, B. Mennucci, G.A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H.P. Hratchian, A.F. Izmaylov, J. Bloino, G. Zheng, J.L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Ishida, M. Hasegawa, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J.A. Montgomery, Jr., J.E. Peralta, F. Ogliaro, M. Bearpark, J.J. Heyd, E. Brothers, K.N. Kudin, V.N. Staroverov, R. Kobayashi, J. Normand, A. Raghavachari, A. Rendell, J.C. Burant, S.S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J.M. Millan, M. Klene, J.E. Knox, J.B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R.E. Stratmann, O. Yazyev, A.J. Austin, R. Cammi, C. Pomelli, J.W. Ochterski, R.L. Martin, K. Morokuma, V.G. Zakrzewski, G.A. Voth, P. Salvador, J.J. Dannenberg, S. Dapprich, A.D. Daniels, J. Farkas, B. Foresman, J.V. Ortiz, J. Cioslowski and D.J. Fox, (2009) GAUSSIAN 09, Revision, Gaussian, Inc., Wallingford CT.
- [12] <https://pubchem.ncbi.nlm.nih.gov> structure search data base.
- [13] A. Frisch, A.B. Nielson and A.J. Holder, Gauss View User Manual, Gaussian Inc, Pittsburgh, P.A., 2000.
- [14] R. Mishra, A. Srivastava, P. Tandon and S. Jain, Spectroscopic and quantum chemical analysis of a natural product–Hayatin hydrochloride *J. Mol. Struct.* 1093 (2015) 101. doi.org/10.1016/j.molstruc.2015.03.032.
- [15] M.W. Wong, Vibrational frequency prediction using density functional theory, *Chem. Phys. Lett.* 256 (1996) 391. [doi.org/10.1016/0009-2614\(96\)00483-6](https://doi.org/10.1016/0009-2614(96)00483-6).
- [16] A.P. Scott and L. Radom, Harmonic Vibrational Frequencies: An Evaluation of Hartree–Fock, Møller–Plesset, Quadratic Configuration Interaction, Density Functional Theory, and Semiempirical Scale Factors, *J. Phys. Chem.* 100(41) (1996) 16502. doi.org/10.1021/jp960976r.

- [17] C. Zhang, Y.L. Song and X. Wang, Correlations between molecular structures and third-order non-linear optical functions of heterothiometallic clusters: a comparative study, *Chem. Reviews* 251(1-2) (2007) 111. <https://doi.org/10.1016/j.ccr.2006.06.007>.
- [18] T.M. Kolev, D.Y. Yancheva, B.A. Stamboliyska, M.D. Dimitrov and R. Wortmann, Nonlinear optical properties of pyridinium-betaines of squaric acid: Experimental and theoretical study *Chem. Phys.* 348 (2008) 45. doi.org/10.1016/j.chemphys.2008.02.018.
- [19] D.A. Kleinman, Nonlinear Dielectric Polarization in Optical Media, *Phys. Rev.*126 (1962) 1977. doi.org/10.1103/PhysRev.126.1977.
- [20] S.P. Karna, P.N. Prasad and M. Dupuis, Nonlinear optical properties of p-nitroaniline: An ab initio time-dependent coupled perturbed Hartree-Fock study, *J. Chem. Phys.* 94(2) (1991) 1171. doi.org/10.1063/1.460024
- [21] C.Y. Panicker, H.T. Varghese, P.S. Manjula, B.K. Sarojini, B. Narayana, J.A. War, S.K. Srivastava, C. Van Alsenoy and A.A. Al-Saadi, FT-IR, HOMO-LUMO, NBO, MEP analysis and molecular docking study of 3-Methyl-4- {(E)-[4-(methylsulfanyl)-benzylidene]amino} 1H-1,2,4-triazole-5(4H)-thione, *Spectrochim. Acta A* 151 (2015) 198. doi.org/10.1016/j.saa.2015.06.076.