Application of Reactivity Descriptors to the Benzenesulfonamide Derivatives

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Abstract The present work has been carried out a theoretical study on molecular structures, frontier molecular orbitals and NBO analysis of benzenesulfonamide derivatives 1-4 using DFT/B3LYP method and 6-31G (d,p) basis set. The calculated geometric parameters are obtained by same method. The active sites are determined by molecular electrostatic potential and results show that the regions exhibiting the negative sites are localized on sulfamide function, amid function and nitrile group; while the regions presenting the positive sites are localized around the hydrogen atoms. The frontier orbitals energies gap and related properties of the title molecules illustrates the high reactivity of compound 4 and the charge transfer occurs within the molecules. Mulliken population analysis on atomic charges is also computed. Stability of the molecules arising from hyper conjugative interactions, charge delocalization has been analyzed using natural bond analysis. The results show that charge in electron density (ED) in the π^* anti-bonding orbitals and E(2) energies confirms the occurrence of ICT within the molecules. The predictive first hyperpolarizability also shows that the molecules 1-4 might have good nonlinear optical (NLO) activities.

Keywords sulfamide; density functional theory; computational chemistry; quantum chemical calculations

1. Introduction

The derivatives of sulfonamide are very important because of their varied structures and biological activities [1]. Moreover, numerous sulfonamide derivatives have been reported as carbonic anhydrase inhibitors [2-4], anti-cancer [5] and anti-inflammatory agents [6]. Among the large derivatives of sulfonamide we have the benzene sulfonamides which are the first efficient chemotherapeutic agents used for several years to heal or avoid systemic bacterial infections. They play a vital role as key constituent in number of biologically active molecules. The application of DFT to chemical systems has received much attention because of faster convergence in time than traditional quantum mechanical correlation methods [7,8]. The B3LYP hybrid functional has been shown to successfully predict a wide range of molecular properties.

In this study we report the quantum chemical computation by using density functional theory (DFT) combined with the B3LYP/6-31G(d,p) level of benzenesulfonamide derivatives **1-4** illustrate in literature [9]. The calculations of optimized geometric parameters, molecular electrostatic potential surface, FMOs analysis, hyperpolarizability, inter and intra molecular charge transfer, Mulliken population analysis and biological activity of the molecules based on its electrophilicity index have been carried out.

2. Materials and Methods

All calculations were performed using the 3-parameter hybrid functional (B3) for exchange part and the Lee-Yang-Parr (LYP) correlation function [10,11], with 6-31G(d,p) as the basis set using the DFT method and Gaussian 09 suite of program [12].

3. Results and Discussion
3.1. Molecular Geometry

The optimized geometric parameters such as bond lengths, bond angles and dihedral angles of the title molecules are given in Tables 1-4 using the B3LYP with 6-31G (d,p) basis set. Figure 1 shows the molecular scheme and atom numbering of benzenesulfonamide derivatives **1-4**.
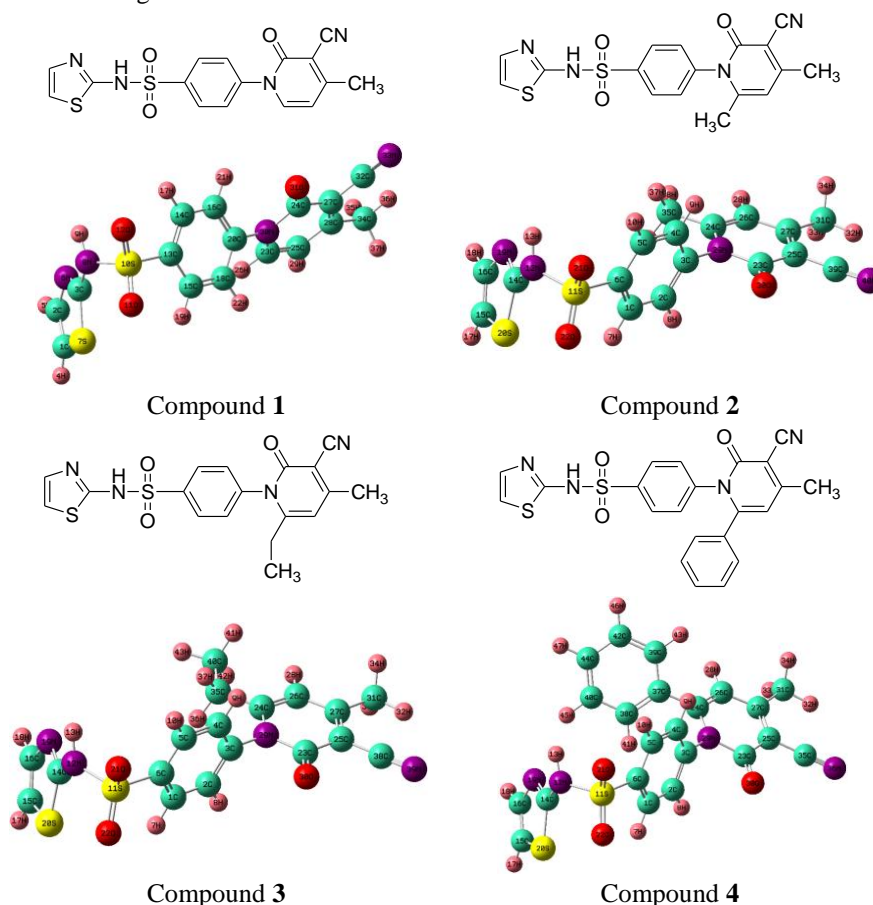

Compound **1**   Compound **2**

Compound **3**   Compound **4**

*Figure 1: Optimized molecular structure of benzenesulfonamide derivatives **1-4***

Table 1: Optimized geometric parameters of compound **1**

Bond Length(Å)		Bond Angles (°)		Dihedral Angles (°)	
R(1,2)	1.362	A(1,2,6)	116.186	D(23,25,28,34)	179.809
R(1,7)	1.742	A(6,3,7)	115.441	D(3,8,10,12)	179.739
R(3,6)	1.303	A(6,3,8)	121.477	D(24,27,28,34)	179.643
R(3,7)	1.760	A(7,3,8)	122.825	D(31,24,30,23)	178.927
R(3,8)	1.396	A(1,7,3)	87.913	D(10,13,15,18)	178.574
R(8,9)	1.017	A(3,8,9)	112.418	D(14,16,20,30)	177.888
R(8,10)	1.707	A(3,8,10)	124.251	D(4,1,7,3)	177.738
R(10,11)	1.461	A(8,10,11)	105.635	D(13,15,18,22)	177.700
R(10,13)	1.794	A(8,10,13)	106.465	D(21,16,20,18)	177.680
R(20,30)	1.437	A(11,10,12)	123.591	D(14,13,15,19)	177.282
R(24,27)	1.465	A(27,24,31)	124.850	D(27,24,30,20)	176.398
R(24,30)	1.434	A(30,24,31)	121.019	D(8,3,7,1)	174.895
R(24,31)	1.221	A(20,30,24)	119.114	D(9,8,10,11)	169.800
R(27,32)	1.430	A(23,30,24)	121.848	D(12,10,13,15)	156.701
R(32,33)	1.164	A(28,34,36)	112.212	D(27,28,34,37)	121.830

Table 2: Optimized geometric parameters of compound **2**

Bond Length(Å)		Bond Angles (°)		Dihedral Angles (°)	
R(3,29)	1.445	A(1,2,3)	119.813	D(29,24,26,28)	179.996
R(6,11)	1.796	A(2,3,29)	119.586	D(30,23,29,24)	179.963
R(11,12)	1.707	A(21,11,22)	123.640	D(35,24,26,27)	179.943
R(11,21)	1.459	A(11,12,13)	112.422	D(25,23,29,3)	179.894
R(11,22)	1.460	A(11,12,14)	124.151	D(29,24,35,38)	179.890
R(12,13)	1.017	A(13,12,14)	112.447	D(23,25,27,31)	179.863
R(12,14)	1.396	A(12,14,19)	121.534	D(21,11,12,14)	179.366
R(14,19)	1.303	A(12,14,20)	122.761	D(29,3,4,5)	179.182
R(14,20)	1.760	A(19,14,20)	115.458	D(6,1,2,8)	179.020
R(23,29)	1.432	A(14,19,16)	110.255	D(2,1,6,11)	177.876
R(23,30)	1.221	A(14,20,15)	87.921	D(17,15,20,14)	177.708
R(24,29)	1.379	A(25,23,29)	114.321	D(2,3,4,9)	177.538
R(24,35)	1.503	A(29,23,30)	119.896	D(12,14,20,15)	174.978
R(25,39)	1.429	A(29,24,35)	118.573	D(22,11,12,13)	169.663
R(39,40)	1.164	A(3,29,24)	121.140	D(1,6,11,21)	158.491

Table 3: Optimized geometric parameters of compound **3**

Bond Length(Å)		Bond Angles (°)		Dihedral Angles (°)	
R(1,6)	1.396	A(2,1,6)	118.934	D(29,24,35,40)	179.998
R(3,4)	1.396	A(1,6,11)	119.385	D(30,23,25,27)	179.981
R(6,11)	1.796	A(6,11,12)	106.311	D(30,23,29,24)	179.977
R(11,12)	1.707	A(6,11,21)	108.150	D(24,26,27,31)	179.929
R(11,21)	1.459	A(11,12,13)	112.503	D(25,23,29,3)	179.868
R(11,22)	1.460	A(11,12,14)	124.296	D(29,3,4,5)	179.375
R(12,13)	1.017	A(13,12,14)	112.497	D(6,1,2,8)	179.046
R(12,14)	1.396	A(12,14,19)	121.491	D(2,1,6,11)	177.779
R(14,19)	1.303	A(12,14,20)	122.792	D(17,15,20,14)	177.664
R(14,20)	1.760	A(19,14,20)	115.452	D(36,35,40,41)	176.508
R(15,20)	1.742	A(14,19,16)	110.255	D(12,14,20,15)	174.771
R(23,29)	1.431	A(29,23,30)	119.914	D(22,11,12,13)	170.214
R(23,30)	1.221	A(3,29,23)	114.700	D(1,6,11,21)	160.115
R(24,26)	1.370	A(3,29,24)	121.414	D(26,24,35,36)	123.430
R(24,29)	1.382	A(23,29,24)	123.886	D(25,27,31,33)	121.003

Table 4: Optimized geometric parameters of compound **4**

Bond Length(Å)		Bond Angles (°)		Dihedral Angles (°)	
R(3,29)	1.442	A(2,1,6)	119.052	D(18,16,19,14)	180.000
R(6,11)	1.791	A(1,6,11)	119.320	D(9,4,5,6)	179.578
R(11,12)	1.715	A(6,11,12)	105.131	D(29,23,25,35)	179.059
R(11,21)	1.459	A(6,11,21)	108.511	D(29,24,26,28)	177.629
R(11,22)	1.460	A(12,11,21)	103.985	D(17,15,20,14)	177.523
R(12,13)	1.017	A(21,11,22)	123.517	D(37,24,29,23)	176.661
R(12,14)	1.396	A(11,12,14)	123.451	D(29,3,4,5)	174.916
R(14,19)	1.306	A(12,14,20)	122.352	D(12,14,20,15)	174.558
R(14,20)	1.759	A(19,14,20)	115.325	D(26,24,29,3)	174.331
R(15,20)	1.740	A(14,19,16)	110.255	D(22,11,12,13)	173.564
R(16,19)	1.378	A(25,23,29)	114.817	D(2,1,6,11)	172.787
R(23,29)	1.437	A(25,23,30)	124.976	D(1,6,11,21)	163.596
R(23,30)	1.221	A(29,23,30)	120.200	D(26,24,37,38)	129.721
R(24,29)	1.386	A(29,24,37)	120.795	D(2,3,29,24)	119.001
R(35,36)	1.164	A(2,1,6)	119.052	D(4,3,29,23)	116.260

3.2. Molecular Electrostatic Potential (MEP)

Molecular electrostatic potential has been found to be a very useful tool in the investigation of the correlation between molecular structures with its physiochemical property relationship, including biomolecules and drugs

[13, 14]. The MEP is a useful property to study reactivity given that an approaching electrophile will be attracted to negative regions (where the electron distribution effect is dominant). The different electrostatic potential values of the surface are represented by different colors, the maximum negative region, which preferred site for electrophilic reactive as a show red and yellow region. The molecular electrostatic potentials of the benzenesulfonamide derivatives **1-4**were evaluated using the B3LYP/6-31G (d,p) method and the projection of MEP surface is given in Figure 2.
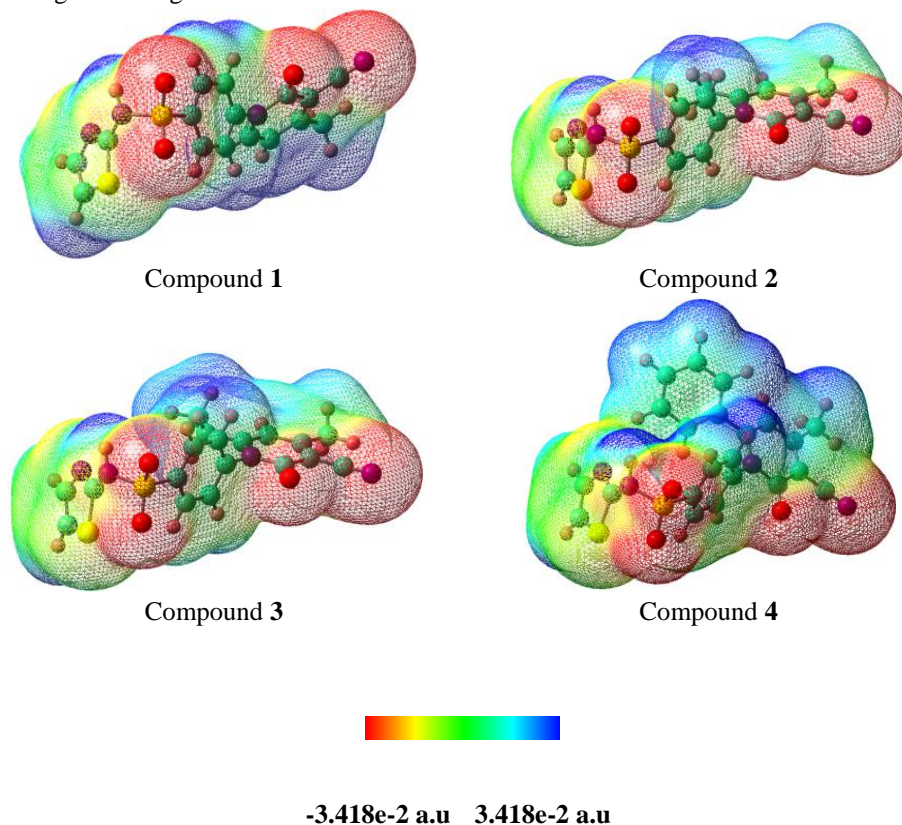

Compound **1**   Compound **2**

Compound **3**   Compound **4**

-3.418e-2 a.u   3.418e-2 a.u

*Figure 2: Molecular electrostatic potential surface of benzenesulfonamide derivatives **1-4***

In all molecules, the regions exhibiting the negative electrostatic potential are localized on sulfamide function, amid function and nitrile group; while the regions presenting the positive potential are localized vicinity of the hydrogen atoms.

3.3. Basin Analysis

The concept of basin was first introduced by Bader in his atom in molecular (AIM) theory, after that, this concept was transplant to the analysis of ELF by Savin and Silvi. In fact, basin can be defined for any real space function, such as molecular orbital, electron density difference, electrostatic potential and even Fukui function.

A real space function in general has one or more maxima, which are referred to as attractors or (3,-3) critical points. Each basin is a subspace of the whole space, and uniquely contains an attractor. The basins are separated with each other by interbasin surfaces(IBS), which are essentially the zero-flux surface of the real space functions; mathematically, such surfaces consist of all of the points **r** satisfying $\nabla f(r). n(r) = 0$, where n(r) stands for the unit normal vector of the surface at position r.

Interbasin surfaces (IBS) dissect the whole molecular space into individual basins, each IBS actually is a bunch of gradient paths derived from a (3,-1) critical points (CP). The interbasin surfaces of compounds **1-4** generated by (3,-1) critical points are illustrated below.
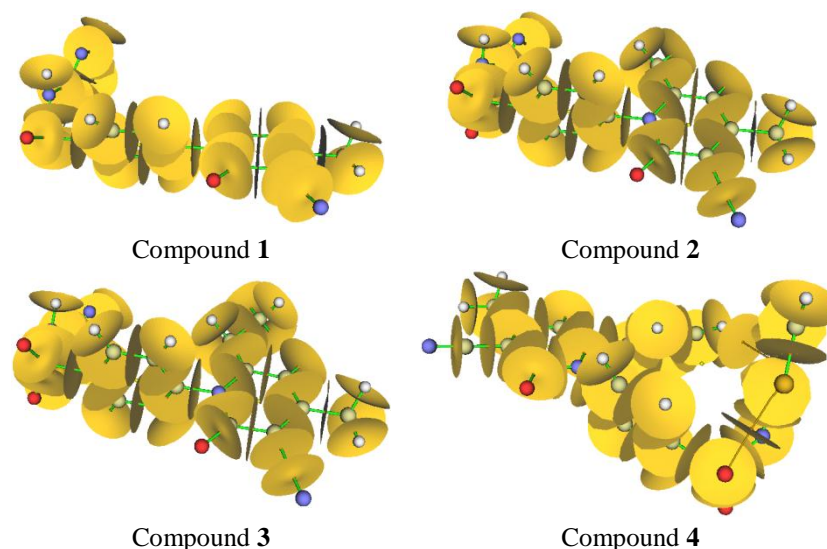
Compound **1**   Compound **2**

Compound **3**   Compound **4**

*Figure 3: Plots of the interbasin surfaces of compounds **1-4***

The number of interbasin surfaces is 40, 43, 46 and 52 for compounds **1-4** respectively.

3.4. Frontier Molecular Orbitals (FMOs)

HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital) are the very important parameters for quantum chemistry. The eigen values of HOMO and LUMO and their energy gap reflect the biological activity of the molecule. A molecule having a small frontier orbital gap is more polarisable and is generally associated with a high chemicalreactivity and low kinetic stability [15-17]. The HOMO and LUMO orbitals and their transition state were obtained using DFT/B3LYP method and 6-31G (d,p) basis set and shown in Figure 4 for compound **4** which is the most reactive.
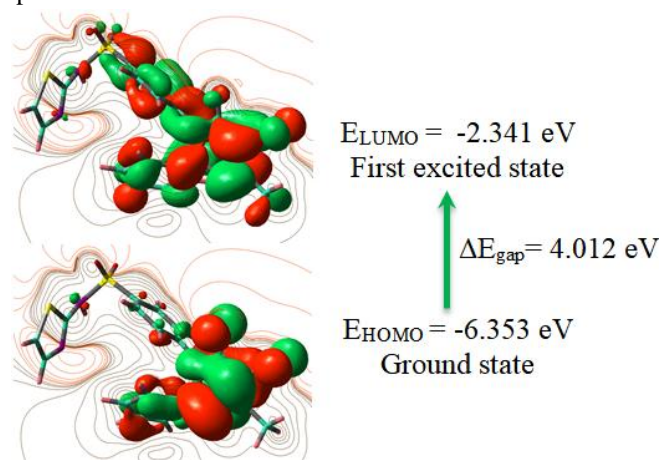

$E_{LUMO} = -2.341$ eV
First excited state

$\Delta E_{gap} = 4.012$ eV

$E_{HOMO} = -6.353$ eV
Ground state

*Figure 4: HOMO-LUMO Structure with the energy level diagram of compound **4***

HOMO is confined over the 4-(3-Cyano-4-methyl-2-oxo-6-phenylpyridin-1(2H)-yl) group, while LUMO is confined over the benzensulfamide and 4-(3-Cyano-4-methyl-2-oxo-6-phenylpyridin-1(2H)-yl) group for compound **4** which gives charge transfer process in the molecular system.

3.5. Global Reactivity Descriptors

DFT based reactivity descriptors have been extensively used for rationalization and interpretation of diverse aspects of chemical bonding, reaction mechanism, and reactive centers. These quantum chemical descriptors are related to electronic structure of compounds and to the mechanism that is involved in the covalent bond formation as a result of reaction between the nucleophiles and the electrophiles. The chemical reactivity and site selectivity of the molecular systems have been determined on the basis of Koopman's theorem [18]. The energies (E_{HOMO}, E_{LUMO}) of frontier molecular orbitals, have been used to calculate global reactivity descriptors

such as, electronegativity (χ), chemical potential (μ),Global hardness (η), global softness (*S*), and electrophilicity index(ω) using DFT/B3LYP with 6-31G(d,p) basis set and the results were given in Table 5.

Table 5: Quantum chemical descriptors of benzenesulfonamide derivatives **1-4**

Parameters	Compound 1	Compound 2	Compound 3	Compound 4
E_{HOMO}(eV)	-6.532	-6.394	-6.368	-6.353
E_{LUMO}(eV)	-2.399	-1.981	-1.941	-2.341
ΔE_{gap} (eV)	4.133	4.413	4.427	4.012
I (eV)	6.532	6.394	6.368	6.353
A (eV)	2.399	1.981	1.941	2.341
μ (eV)	-4.465	-4.188	-4.155	-4.347
χ (eV)	4.465	4.188	4.155	4.347
η (eV)	2.066	2.207	2.214	2.006
S (eV)	0.242	0.227	0.226	0.249
ω (eV)	4.825	3.973	3.899	4.710

The compound which has the lowest energy gap is the compound **4** (ΔE_{gap} = 4.012 eV). This lower gap allows it to be the softest molecule. The compound that has the highest energy gap is the compound **3** (ΔE_{gap} = 4.427 eV). The compound that has the highest HOMO energy is the compound **4** (E_{HOMO} = -6.353 eV). This higher energy allows it to be the best electron donor. The compound that has the lowest LUMO energy is the compound **1** (E_{LUMO} = -2.399 eV) which signifies that it can be the best electron acceptor. The two properties like *I* (potential ionization) and *A* (affinity) are so important, the determination of these two properties allows us to calculate the absolute electronegativity (χ) and the absolute hardness (η). These two parameters are related to the one-electron orbital energies of the HOMO and LUMO respectively. Compound **4** has the lowest value of the potential ionization (*I* = 6.353 eV), so that will be the better electron donor. Compound **1** has the largest value of the affinity (*A* = 2.399 eV), so it is the better electron acceptor. The chemical reactivity varies with the structure of molecules. Chemical hardness (softness) value of compound **4** (η = 2.006 eV, **S** = 0.249 eV) is lesser (greater) among all the molecules. Thus, compound **4** is found to be more reactive than all the compounds. Compound **1** possesses higher electronegativity value (χ = 4.465 eV) than all compounds so; it is the best electron acceptor. The value of ω for compound **1** (ω = 4.825 eV) indicates that it is the stronger electrophiles than all compounds. Compound **4** has the smaller frontier orbital gap so, it is more polarizable and is associated with a high chemical reactivity, low kinetic stability and is also termed as soft molecule.

3.6. Mulliken Analysis

The calculation of atomic charges plays an important role in the application of quantum mechanical calculations to molecular systems [19]. Mulliken charges are calculated by determining the electron population of each atom as defined in the basis function. The charge distribution of donor and acceptor pairs involving the charge transfer molecule. These charges are expected to influence the properties like dipole moment, electronic parameters, polarizability and refractivity [20]. The Mulliken population analysis of compound **4** which is the most reactive was performed in B3LYP/6-31G(d,p) level to obtain the values of the atomic charges and are detailed in a Mulliken's plot as visualized in Figure 5.
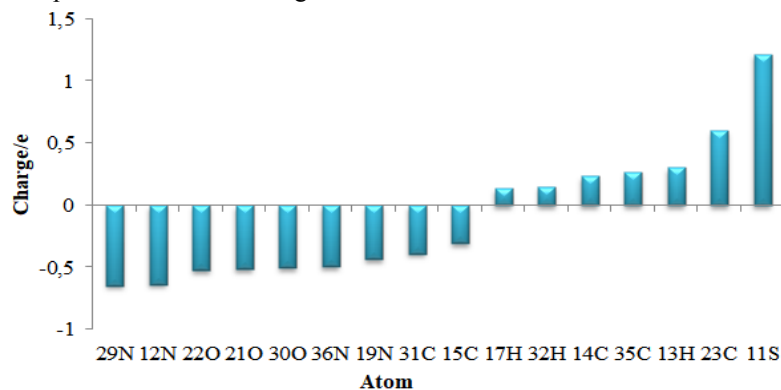

Figure 5. Mulliken's plot of compound **4**

The atom 29N shows more negative (-0.648742e) charge and 11S more positive (1.218491e) charge, which suggests extensive charge delocalization in the entire molecule. The charge noticed on the 12N, 36N and 19N is smaller and equal to -0.634899e, -0.493322e and -0.434278e respectively. This can be explained by the high degree of conjugation, with a strong push-pull effect. Negatively charged oxygen (22O, 21O and 30O) atoms shows that charge is transferred from sulfur to oxygen and from carbon to oxygen. Carbon atoms 31C and 15C are more negatively charged which indicate that the charge transfer from thiazole ring to 4-(3-Cyano-4-methyl-2-oxo-6-phenylpyridin-1(2H)-yl) group through benzene sulfamide. The maximum atomic charge of carbons is obtained for 14C, 35C and 23C. This is due to the attachment of negatively charged azote. The positive charges are localized on the hydrogen atoms. Very similar values of positive charges are observed for the hydrogen atoms (17H, 32H and 13H (0.137923, 0.150730 and 0.307336e) respectively) bonded to the negative atoms (15C, 31C and 12N) respectively.

3.7. Natural Bond Orbital Analysis (NBO)

NBO analysis helps in identifying individual bonds and the energies associated with lone-pair electrons that play a vital role in the chemical processes [21]. The NBO theory also provide an efficient method for analyzing intra and intermolecular bonding and interaction among bond and also act as a convenient basis for investigation charge transfer or conjugative interaction in molecular systems [22]. Some electron donor orbital, acceptor orbital and in the interaction stabilization energy resulted from the second order micro disturbance theory are reported [23,24]. The stabilization energy E (2) values of the benzenesulfonamide derivatives **1-4** were calculated on the basis of second-order Fock matrix perturbation theory using B3LYP/6-31G (d,p) basis set. The larger E (2) values were listed in Tables 6-9.

Table 6: Second order perturbation theory analysis of Fock matrix on NBO of compound **1**

Donor(i)	ED/e	Acceptor(j)	ED/e	E(2) Kcal/mol	E(j)-E(i) a.u	F(i.j) a.u
LP (1) N30	1.56611	π*(C24-O31)	0.34234	43.96	0.29	0.103
LP (1) N30	1.56611	π*(C23-C25)	0.23968	41.96	0.29	0.104
LP (2) O31	1.84298	σ*(C24-N30)	0.11084	32.67	0.61	0.127
LP (2) S7	1.64027	π*(C3-N6)	0.39703	29.20	0.24	0.076
π (C27-C28)	1.74415	π*(C24-O31)	0.34234	26.56	0.28	0.079
π (C18-C20)	1.66007	π*(C13-C15)	0.38225	22.5	0.28	0.072
LP (1) N8	1.81529	π*(C3-N6)	0.39703	22.36	0.31	0.079
π (C14-C16)	1.63942	π*(C18-C20)	0.36337	22.34	0.27	0.070
π (C23-C25)	1.79391	π*(C27-C28)	0.27246	20.56	0.31	0.073
π (C13-C15)	1.68219	π*(C14-C16)	0.28146	19.91	0.30	0.070
π (C14-C16)	1.63942	π*(C13-C15)	0.38225	19.68	0.27	0.065
LP (2) O31	1.84298	σ*(C24-C27)	0.06601	19.47	0.70	0.106
π (C27-C28)	1.74415	π*(C32-N33)	0.07995	19.16	0.39	0.081
LP (2) S7	1.64027	π*(C1-C2)	0.26042	19.07	0.27	0.066
LP (3) O12	1.77125	σ*(S10-O11)	0.15430	18.64	0.57	0.094
LP (2) O12	1.81141	σ*(S10-C13)	0.20995	18.59	0.45	0.082
π (C3-N6)	1.87888	π*(C1-C2)	0.26042	18.49	0.35	0.074
LP (3) O11	1.76856	σ*(S10-O12)	0.14596	18.45	0.57	0.094
LP (2) O11	1.81620	σ*(S10-C13)	0.20995	18.23	0.45	0.081
LP (3) O11	1.76856	σ*(N8-S10)	0.27852	17.72	0.40	0.076

Table 7: Second order perturbation theory analysis of Fock matrix on NBO of compound **2**

Donor(i)	ED/e	Acceptor(j)	ED/e	E(2) Kcal/mol	E(j)-E(i) a.u	F(i.j) a.u
LP (1) N29	1.59470	π*(C23-O30)	0.34203	44.87	0.29	0.103
LP (1) N29	1.59470	π*(C24-C26)	0.26218	44.84	0.29	0.106
LP (2) O30	1.84547	σ*(C23-N29)	0.11027	33.00	0.61	0.128
LP (2) S20	1.63826	π*(C14-N19)	0.39799	29.35	0.24	0.076
π (C25-C27)	1.74387	π*(C23-O30)	0.34203	27.26	0.29	0.081
π (C24-C26)	1.76675	π*(C25-C27)	0.28260	22.84	0.31	0.076

Donor(i)	ED/e	Acceptor(j)	ED/e	E(2) Kcal/mol	E(j)-E(i) a.u	F(i,j) a.u
π (C2-C3)	1.65272	π*(C1-C6)	0.37923	22.70	0.27	0.071
LP (1) N12	1.81633	π*(C14-N19)	0.39799	22.01	0.31	0.079
π (C4-C5)	1.63943	π*(C2-C3)	0.34067	21.95	0.28	0.070
π (C1-C6)	1.67641	π*(C4-C5)	0.29497	20.54	0.30	0.070
π (C25-C27)	1.74387	π*(C39-N40)	0.08352	19.63	0.39	0.082
π (C4-C5)	1.63943	π*(C1-C6)	0.37923	19.47	0.27	0.065
LP (2) O30	1.84547	σ*(C23-C25)	0.06648	19.47	0.70	0.107
LP (2) S20	1.63826	π*(C15-C16)	0.26053	19.14	0.27	0.066
π (C2-C3)	1.65272	π*(C4-C5)	0.29497	18.91	0.29	0.067
LP (2) O21	1.81120	σ*(C6-S11)	0.21086	18.67	0.45	0.082
LP (3) O21	1.77206	σ*(S11-O22)	0.15393	18.50	0.57	0.093
LP (3) O22	1.76735	σ*(S11-O21)	0.14599	18.44	0.57	0.094
π (C14-N19)	1.87909	π*(C15-C16)	0.26053	18.43	0.35	0.074
LP (2) O22	1.81506	σ*(C6-S11)	0.21086	18.38	0.45	0.081

Table 8: Second order perturbation theory analysis of Fock matrix on NBO of compound **3**

Donor(i)	ED/e	Acceptor(j)	ED/e	E(2) Kcal/mol	E(j)-E(i) a.u	F(i,j) a.u
LP (1) N29	1.59748	π*(C23-O30)	0.34282	45.24	0.29	0.104
LP (1) N29	1.59748	π*(C24-C26)	0.26012	44.14	0.29	0.105
LP (2) O30	1.84579	σ*(C23-N29)	0.10980	32.90	0.61	0.128
LP (2) S20	1.63829	π*(C14-N19)	0.39819	29.34	0.24	0.076
π (C25-C27)	1.74483	π*(C23-O30)	0.34282	27.27	0.29	0.081
π (C2-C3)	1.65096	π*(C1-C6)	0.38081	22.83	0.27	0.071
π (C24-C26)	1.76850	π*(C25-C27)	0.28113	22.79	0.31	0.076
LP (1) N12	1.81565	π*(C14-N19)	0.39819	22.21	0.31	0.079
π (C4-C5)	1.63901	π*(C2-C3)	0.34081	21.96	0.28	0.070
π (C1-C6)	1.67623	π*(C4-C5)	0.29600	20.59	0.30	0.070
π (C25-C27)	1.74483	π*(C38-N39)	0.08349	19.63	0.39	0.082
π (C4-C5)	1.63901	π*(C1-C6)	0.38081	19.48	0.27	0.065
LP (2) O30	1.84579	σ*(C23-C25)	0.06631	19.39	0.70	0.107
LP (2) S20	1.63829	π*(C15-C16)	0.26066	19.16	0.27	0.066
π (C2-C3)	1.65096	π*(C4-C5)	0.29600	18.90	0.29	0.067
LP (2) O21	1.81157	σ*(C6-S11)	0.21054	18.64	0.45	0.082
LP (3) O21	1.77197	σ*(S11-O22)	0.15396	18.47	0.57	0.093
LP (3) O22	1.76739	σ*(S11-O21)	0.14608	18.46	0.57	0.094
π (C14-N19)	1.87901	π*(C15-C16)	0.26066	18.43	0.35	0.074
LP (2) O22	1.81504	σ*(C6-S11	0.21054	18.36	0.45	0.081

Table 9: Second order perturbation theory analysis of Fock matrix on NBO of compound **4**

Donor(i)	ED/e	Acceptor(j)	ED/e	E(2) Kcal/mol	E(j)-E(i) a.u	F(i,j) a.u
LP (1) N29	1.58634	π*(C23-O30)	0.34231	43.69	0.29	0.102
LP (1) N29	1.58634	π*(C24-C26)	0.27266	42.85	0.29	0.104
LP (2) O30	1.84317	σ*(C23-N29)	0.11058	32.91	0.60	0.127
LP (2) S20	1.63104	π*(C14-N19)	0.40311	29.79	0.24	0.076
π (C25-C27)	1.73823	π*(C23-O30)	0.34231	27.33	0.29	0.081
π (C3-C4)	1.64954	π*(C5-C6)	0.38623	22.92	0.27	0.071
π (C24-C26)	1.75638	π*(C25-C27)	0.28564	22.60	0.31	0.075
π (C42-C44)	1.64943	π*(C37-C39)	0.37626	21.72	0.27	0.069
π (C1-C2)	1.63885	π*(C3-C4)	0.34866	21.54	0.28	0.069
LP (1) N12	1.82137	π*(C14-N19)	0.40311	20.40	0.31	0.076
π (C38-C40)	1.65826	π*(C42-C44)	0.31992	20.25	0.28	0.068
π (C38 -C40)	1.65826	π*(C37-C39)	0.37626	20.17	0.27	0.067
π (C5-C6)	1.68440	π*(C1-C2)	0.28876	19.75	0.30	0.069
π (C1-C2)	1.63885	π*(C5-C6)	0.38623	19.74	0.27	0.065
π (C42-C44)	1.64943	π*(C38-C40)	0.30358	19.52	0.28	0.067

π (C25-C27)	1.73823	π*(C35-N36)	0.08317	19.49	0.39	0.082
LP (2) S20	1.63104	π*(C15-C16)	0.26264	19.46	0.27	0.066
LP (2) O30	1.84317	σ*(C23-C25)	0.06511	19.12	0.70	0.106
π (C37-C39)	1.65981	π*(C42-C44)	0.31992	19.10	0.29	0.066
π (C37-C39)	1.65981	π*(C38-C40)	0.30358	19.03	0.29	0.067

The intra molecular interaction for the title compounds is formed by the orbital overlap between: π (C27-C28) and π*(C24-O31) for compound **1**, π (C25-C27) and π*(C23-O30) for compound **2**, π (C25-C27) and π*(C23-O30) for compound **3** and π (C25-C27) and π*(C23-O30) for compound **4** respectively, which result into intermolecular charge transfer (ICT) causing stabilization of the system. The intra molecular hyper conjugative interactions of π (C27-C28) to π*(C24-O31) for compound **1**, π (C25-C27) to π*(C23-O30) for compound **2**, π (C25-C27) to π*(C23-O30) for compound **3** and π (C25-C27) to π*(C23-O30) for compound **4** lead to highest stabilization of 26.56, 27.26, 27.27 and 27.33 kJ mol^{-1} respectively. In case of LP (1) N30 orbital to the π*(C24-O31) for compound **1**, LP (1) N29 orbital to π*(C23-O30) for compound **2**, LP (1) N29 orbital to π*(C23-O30) for compound **3**, LP (1) N29 orbital to π*(C23-O30) for compound **4** respectively, show the stabilization energy of 43.96, 44.87, 45.24 and 43.69 kJ mol^{-1} respectively.

3.8. Nonlinear Optical Properties (NLO)

Hyperpolarizabilities are very sensitive to the basis sets and level of theoretical approach employed [25] that the electron correlation can change the value of hyperpolarizability. The nonlinear properties have an important role in the design of materials used in signal processing, communication technology and optical memory devices. The nonlinear optical properties are associated with the delocalized π-electrons of a molecule. The increase ofthe conjugation in the molecule results in a change in the NLO properties where the NLO properties of a molecule are related to the energy gap between HOMO and LUMO. Theoretically calculated values of first order hyperpolarizability, dipole moments, total polarizability and anisotropy of the polarizability of benzenesulfonamide derivatives **1-4** are calculated at the DFT method with B3LYP/6-31G (d,p) basis set and collected in Table 10.

Table 10: Nonlinear optical properties of benzenesulfonamide derivatives**1-4**

Parameters	Compound 1	Compound 2	Compound 3	Compound 4
β_{xxx}	-230.0045	-186.1605	-154.3984	73.0615
β_{yyy}	81.8253	77.1865	87.1588	113.2137
β_{zzz}	1.8797	6.6301	5.2358	35.2778
β_{xyy}	-25.8230	-26.3635	-42.9643	94.0958
β_{xxy}	266.6517	248.2191	258.3370	237.9229
β_{xxz}	-6.9118	73.0063	46.7259	27.9672
β_{xzz}	-3.4086	-29.5927	-32.6204	30.0152
β_{yzz}	-9.0005	5.1674	9.2081	18.9344
β_{yyz}	1.5909	3.8592	2.6995	-26.4531
β_{xyz}	17.7699	-3.9189	-11.7807	-36.4486
β_{tot}(esu)x10^{-33}	431.6102	391.2765	392.1366	430.7056
μ_x	-0.7539	-1.0883	-0.7682	0.0092
μ_y	9.7628	10.0933	10.5935	9.9875
μ_z	0.5135	2.9409	2.0212	1.4250
μ(D)	9.8054	10.5692	10.8119	10.0887
α_{xx}	-191.1267	-195.0254	-199.5566	-213.4084
α_{yy}	-156.4602	-169.0706	-180.7509	-207.4153
α_{zz}	-153.1847	-156.5771	-161.6355	-180.6645
α_{xy}	18.0198	16.4959	18.2320	-23.9600
α_{xz}	-4.1536	17.5398	16.8383	21.9981
α_{yz}	-7.2433	-9.1002	-8.7403	-4.2780
α(esu)x10^{-24}	50.0933	56.0511	56.1739	64.3486
$\Delta\alpha$(esu)x10^{-24}	7.4238	8.3068	8.3250	9.5365

Since the values of the polarizabilities ($\Delta\alpha$) and the hyperpolarizabilities (β_{tot}) of the GAUSSIAN 09 output are obtained in atomic units (a.u.), the calculated values have been converted into electrostatic units (e.s.u.) (for α; 1 a.u = 0.1482 x 10^{-24} e.s.u., for β; 1 a.u = 8.6393 x 10^{-33} e.s.u.). The calculated values of dipole moment (μ) for the title compounds were found to be 9.8054, 10.5692, 10.8119 and 10.0887 D respectively, which are approximately nine and ten times than to the value for urea (μ = 1.3732 D). Urea is one of the prototypical molecules used in the study of the NLO properties of molecular systems. Therefore, it has been used frequently as a threshold value for comparative purposes. The calculated values of polarizability are 50.0933 x 10^{-24}, 56.0511 x 10^{-24}, 56.1739 x 10^{-24} and 64.3486 x 10^{-24} esu respectively; the values of anisotropy of the polarizability are 7.4238, 8.3068, 8.3250 and 9.5365 esu, respectively. The magnitude of the molecular hyperpolarizability (β_{tot}) is one of the important key factors in a NLO system. The DFT/6-31G (d,p) calculated first hyperpolarizability value (β_{tot}) of benzenesulfonamide derivatives compounds are equal to 431.6102 x 10^{-33}, 391.2765 x 10^{-33}, 392.1366 x 10^{-33} and 430.7056 x 10^{-33} esu. The first hyperpolarizability of title molecules is approximately 1.26, 1.14, 1.14 and 1.25 times than those of urea (β of urea is 343.272 x10^{-33} esu obtained by B3LYP/6-311G (d,p) method). The above results show that the title compounds might have the NLO applications.

4. Conclusion

A complete theoretical study of benzenesulfonamide derivatives **1-4** was performed using Density functional theory calculation with B3LYP/6-31G (d,p) basis set. The molecular structures of the titled compounds have been optimized using the DFT method. The reactivity sites are identified by mapping the molecular electrostatic potential (MESP) surface and the obtained results show that the negative electrostatic potential regions are localized over the sulfamide function, amid function and nitrile group; while the regions presenting the positive sites are localized around the hydrogen atoms. The calculated frontier orbital energies show that charge transfer occurs within these molecules. The structure-chemical reactivity relations of the compounds **1-4** were determined through chemical potential, global hardness, global softness, electronegativity and electrophilicity by conceptual DFT methods and results show that compound **4** has a high chemical reactivity. Further, Mulliken population analyses on atomic charges were also determined and interpreted.NBO analysis was carried out to explain the stability of molecules. The calculated first hyperpolarizability shows that the molecules are attractive molecules for future applications in non-linear optics.

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