

Theoretical Analysis and Molecular Orbital studies of Sulfonamides Products with N-Alkylation and O-alkylation

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Abstract— In this comprehensive study, theoretical investigation was carried out on sulfonamides products with N-alkylation and O-alkylation **1-4** using DFT/B3LYP method with 6-31G (d,p) basis set. The optimized geometrical parameters were calculated by means of density functional theory. Information about size, shape, charge density distribution and site of chemical reactivity of the molecules **1-4** has been obtained by mapping electron density iso-surface with electrostatic potential surface. The lowering in the HOMO and LUMO energy gap for compound **3** explains the eventual charge transfer interactions that take place within the molecule. The chemical reactivity parameters (chemical hardness and softness, electronegativity, chemical potential and electrophilicity index) were discussed clearly and results show that compound **3** is the most reactive. Mulliken population analysis of atomic charges is also computed and interpreted. A detailed molecular picture of the title compounds and their interactions were obtained from NBO analysis. Nonlinear optical NLO behavior of the examined molecule was investigated by the determination of the electric dipole moment μ , the polarizability α and the hyperpolarizability β .

Keywords— Sulfamide; Density functional theory; Computational chemistry; Quantum chemical calculations.

I. INTRODUCTION

Sulfonamides constitute an important class of antimicrobial agents in the world owing to their low cost, low toxicity and excellent activity against bacterial diseases. Their significance appeared when sulfanilamide, an important analogue of sulfonamide, was reported [1] to be the first metabolite of an antibacterial drug. Many sulfonamide derivatives were synthesized, characterized

and tested for antibacterial [2], anti-tumor [3,4] anti-carbonic anhydrase [5,6], diuretic [7,8], hypoglycemic properties [9], antithyroid [10], anti-inflammatory [11], and other biological activities [3,4].

DFT method has extensively used in chemical reaction for the interpretation and prediction of complex system behavior at an atomic scale. Furthermore the DFT calculations are powerful and very reliable tool for calculating various molecular properties. Accordingly, it is necessary to underline that the theoretical approaches deduced from DFT/B3LYP calculation level are more effective and reliable as compared to those inferred from the other methods¹¹.

In this perspective, the geometrical parameters, molecular electrostatic potential (MEP), frontier orbitals, global reactivity descriptors, Mulliken charges, NBO analysis and nonlinear optical properties (NLO) of the sulfonamides products with N-alkylation and O-alkylation **1-4** described in literature [12] have been calculated by using DFT (B3LYP) method with 6-31G (d,p) basis set to predict their reactivity and applications.

II. MATERIALS AND METHODS

The density functional (DFT/B3LYP) at the 6-31G (d,p) basis set level was adopted to calculate the properties of the title molecules in this work. All the calculations were performed using Gaussian 09W program package [13].

III. RESULTS AND DISCUSSION

3.1. Molecular Geometry:

The optimized geometrical parameters of sulfonamides products with N-alkylation and O-alkylation **1-4** obtained through DFT/B3LYP method using 6-31G (d,p) basis set are listed in Tables 1-4. The molecular structures of these compounds **1-4** are depicted in Fig 1.

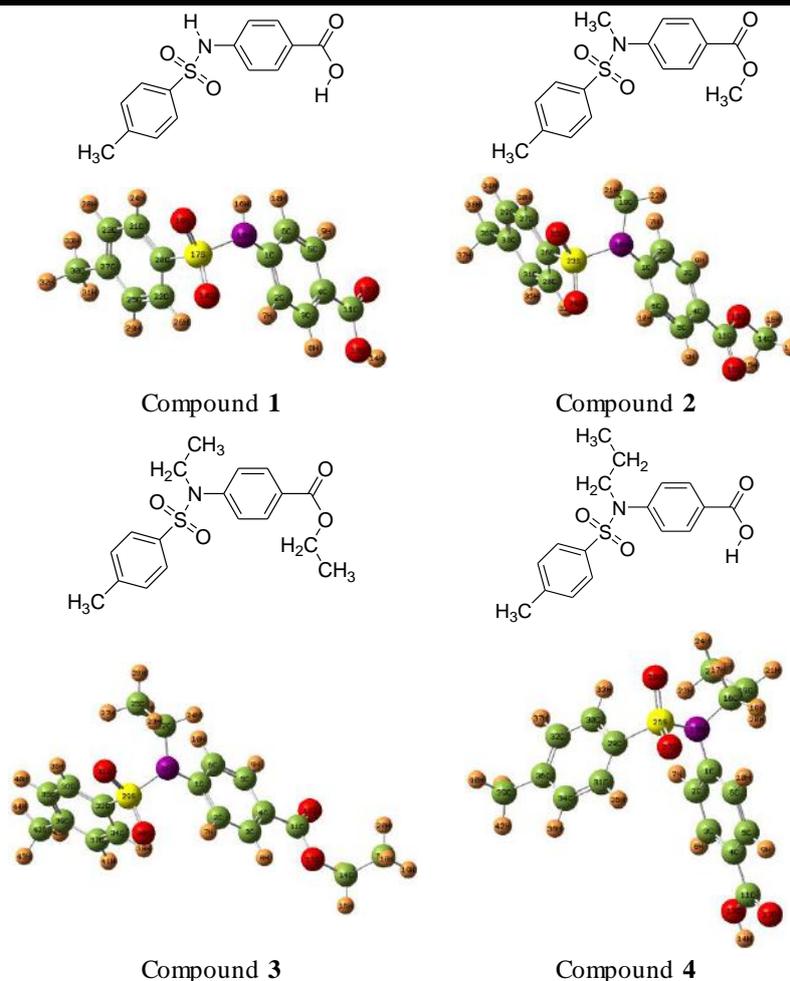


Fig.1: Optimized molecular structure of sulfonamides products with N-alkylation and O-alkylation 1-4

Table.1: Optimized geometric parameters of compound 1

Bond Length (Å)	Bond Angles (°)		Dihedral Angles (°)		
R(1,2)	1.405	A(2,1,6)	119.607	D(3,4,5,9)	179.919
R(1,15)	1.412	A(2,1,15)	121.621	D(2,1,6,10)	179.894
R(2,7)	1.083	A(4,11,13)	113.108	D(20,21,23,28)	179.639
R(11,12)	1.216	A(12,11,13)	121.912	D(2,3,4,11)	179.456
R(11,13)	1.358	A(11,13,14)	105.616	D(11,4,5,6)	179.441
R(13,14)	0.971	A(1,15,16)	115.463	D(26,22,25,27)	178.776
R(15,16)	1.015	A(1,15,17)	125.515	D(17,20,21,23)	178.720
R(15,17)	1.705	A(16,15,17)	109.369	D(21,23,27,30)	178.591
R(17,18)	1.462	A(15,17,18)	107.298	D(22,20,21,24)	178.567
R(17,19)	1.462	A(15,17,20)	106.557	D(6,1,2,7)	178.132
R(17,20)	1.792	A(18,17,19)	122.683	D(15,1,6,5)	177.284
R(20,21)	1.397	A(18,17,20)	107.842	D(2,1,15,16)	172.147
R(21,23)	1.392	A(21,23,27)	121.186	D(18,17,20,21)	155.434
R(21,24)	1.085	A(21,23,28)	119.340	D(23,27,30,31)	152.733
R(30,31)	1.094	A(27,30,31)	111.492	D(6,1,15,17)	137.111

Table 2: Optimized geometric parameters of compound 2

Bond Length (Å)	Bond Angles (°)		Dihedral Angles (°)		
R(1,18)	1.429	A(6,1,18)	119.905	D(4,11,13,14)	179.914
R(4,11)	1.488	A(3,4,11)	122.679	D(6,1,2,7)	179.908
R(11,12)	1.216	A(4,5,6)	120.847	D(9,5,6,1)	179.901
R(11,13)	1.355	A(4,11,13)	112.473	D(2,3,4,11)	179.831
R(13,14)	1.436	A(12,11,13)	122.934	D(27,29,33,36)	179.553
R(14,15)	1.093	A(11,13,14)	115.088	D(26,27,29,34)	179.421
R(18,19)	1.470	A(13,14,15)	110.675	D(35,31,33,29)	179.401
R(18,23)	1.719	A(1,18,19)	118.214	D(11,4,5,6)	179.166
R(19,20)	1.099	A(1,18,23)	118.645	D(2,1,6,10)	178.933
R(23,24)	1.462	A(18,19,20)	113.433	D(32,28,31,33)	178.728
R(23,25)	1.464	A(18,23,24)	107.209	D(23,26,27,29)	178.515
R(23,26)	1.793	A(18,23,26)	105.650	D(28,26,27,30)	178.258
R(26,27)	1.395	A(24,23,25)	121.794	D(18,1,2,3)	177.289
R(27,30)	1.084	A(23,26,28)	119.519	D(1,18,23,25)	174.729
R(36,38)	1.093	A(33,36,37)	111.048	D(23,18,19,22)	166.611

Table 3: Optimized geometric parameters of compound 3

Bond Length (Å)	Bond Angles (°)		Dihedral Angles (°)		
R(1,21)	1.426	A(2,1,6)	118.837	D(29,32,33,35)	179.984
R(4,5)	1.400	A(2,1,21)	121.110	D(5,4,11,13)	179.907
R(4,11)	1.488	A(3,4,11)	122.897	D(2,1,6,10)	179.770
R(11,12)	1.217	A(4,11,12)	124.135	D(32,33,35,40)	179.686
R(11,13)	1.354	A(12,11,13)	123.575	D(11,4,5,6)	179.481
R(13,14)	1.447	A(11,13,14)	116.503	D(16,14,17,20)	178.977
R(14,17)	1.521	A(13,14,17)	111.410	D(33,35,39,42)	178.936
R(17,20)	1.093	A(14,17,18)	110.891	D(15,14,17,18)	177.525
R(21,22)	1.483	A(1,21,22)	120.241	D(21,1,6,5)	177.333
R(21,29)	1.703	A(1,21,29)	121.202	D(13,14,17,19)	175.674
R(22,25)	1.530	A(22,25,27)	111.069	D(1,21,29,31)	174.601
R(29,30)	1.464	A(21,29,32)	106.348	D(29,21,22,24)	164.211
R(29,31)	1.465	A(30,29,31)	121.283	D(30,29,32,33)	140.557
R(29,32)	1.796	A(37,39,42)	120.577	D(2,1,21,22)	139.697
R(39,42)	1.509	A(39,42,44)	111.518	D(6,1,21,29)	137.965

Table 4: Optimized geometric parameters of compound 4

Bond Length (Å)	Bond Angles (°)		Dihedral Angles (°)		
R(1,15)	1.442	A(2,1,6)	119.807	D(4,11,13,14)	179.945
R(4,11)	1.487	A(4,11,12)	124.878	D(16,19,22,25)	179.853
R(11,12)	1.215	A(4,11,13)	113.066	D(29,31,34,38)	179.829
R(11,13)	1.357	A(12,11,13)	122.056	D(11,4,5,6)	179.794
R(13,14)	0.972	A(11,13,14)	105.681	D(38,34,36,32)	179.764
R(15,16)	1.487	A(1,15,16)	115.883	D(3,4,11,12)	179.754
R(15,26)	1.719	A(1,15,26)	115.381	D(5,4,11,13)	179.684
R(16,17)	1.092	A(16,15,26)	115.802	D(6,1,2,7)	179.481
R(26,27)	1.470	A(15,16,18)	110.213	D(31,29,30,33)	178.474
R(26,28)	1.467	A(15,16,19)	111.614	D(1,15,26,28)	175.760
R(26,29)	1.791	A(16,19,22)	113.837	D(27,26,29,30)	163.950
R(29,31)	1.394	A(15,26,29)	101.965	D(16,15,26,29)	149.351
R(31,35)	1.084	A(27,26,28)	120.237	D(2,1,15,26)	108.120
R(36,39)	1.509	A(27,26,29)	107.606	D(15,26,29,31)	102.605

3.2. Molecular Electrostatic Potential (MEP):

The molecular electrostatic potential is related to the electronic density and a very useful descriptor for determining sites for electrophilic attack and nucleophilic reactions as well as hydrogen-bonding interactions [14-16]. MEP surface diagram is used to understand the reactive behavior of a molecule, in that negative regions

can be regarded as potential electrophilic sites, whereas the positive regions are nucleophilic centers. In Fig 2, using the DFT/B3LYP method and 6-31G (d,p) basis set, the electrophilic site was presented by negative (red) regions and nucleophilic center was shown by the positive (blue) regions of MEP of the compounds 1-4.

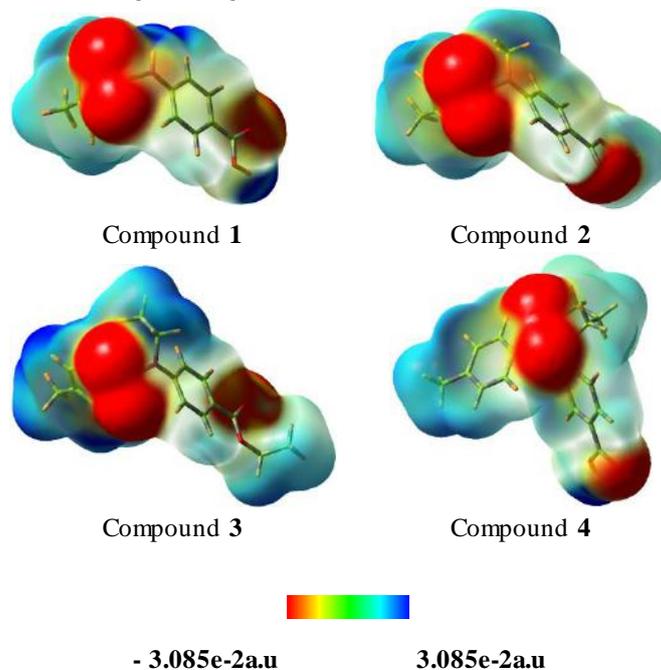


Fig 2: Molecular electrostatic potential surface of sulfonamides products with N-alkylation and O-alkylation 1-4

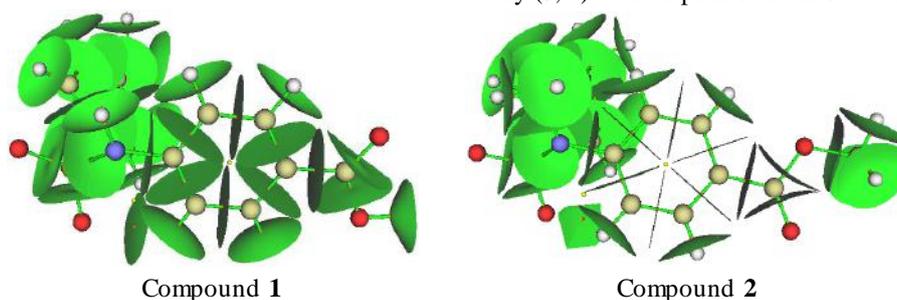
In all molecules, the regions exhibiting the negative electrostatic potential are localized on sulfamide function and on acid function for compound 1 and compound 4 and on ester function for compound 2 and compound 3; while the regions presenting the positive potential are localized vicinity of the hydrogen atoms.

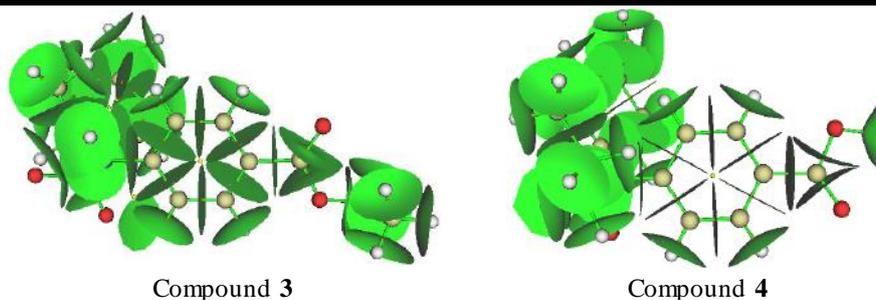
3.3. Basin Analysis:

The concept of basin was first introduced by Bader in his atom in molecular (AIM) theory, after that, this concept was transplanted 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 \mathbf{r} satisfying $\nabla f(\mathbf{r}) \cdot \mathbf{n}(\mathbf{r}) = 0$, where $\mathbf{n}(\mathbf{r})$ stands for the unit normal vector of the surface at position \mathbf{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 3

Compound 4

Fig.3: Plots of the interbasin surfaces of compounds 1-4

The number of interbasin surfaces is 35, 41, 49 and 44 for compounds 1-4 respectively.

3.4. Frontier Molecular Orbitals (FMOs):

The frontier orbitals, HOMO and LUMO determine the way the molecule interacts with other species and the gap between them helps in characterizing the chemical reactivity as well as kinetic stability of the molecule. The HOMO illustrates the ability to donate an electron, LUMO as an electron acceptor represents the ability to

obtain an electron. The electronic absorption corresponds to the transition from the ground to the first excited state and is mainly described by one electron excitation from the HOMO to the LUMO, the smaller the energy gap of the LUMO and HOMO, the easier it is for the electrons of HOMO to be excited. Fig 4 described the distributions and energy levels of the HOMO-1, HOMO, LUMO and LUMO+1 orbitals computed at the B3LYP/6-31G (d,p) level for the compound 3 which is the most reactive.

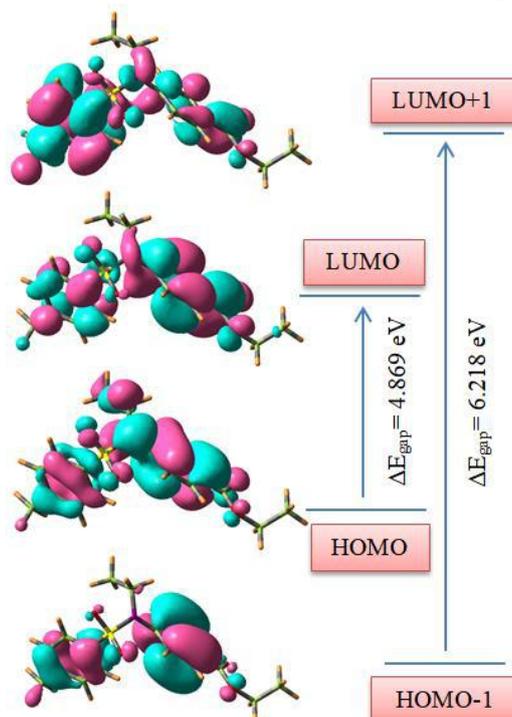


Fig.4: HOMO-LUMO Structure with the energy level diagram of compound 3

HOMO-1, HOMO, LUMO and LUMO+1 orbitals are almost confined over the whole molecule for compound 3 which gives charge transfer process in the molecular system.

3.5. Global Reactivity Descriptors:

The estimation of the reactivity of chemical species is one of the main purposes of theoretical chemistry and a lot of work has been carried out in the same line. Density functional theory has been successful in giving theoretical

background of accepted qualitative chemical concepts. In this framework, several reactivity descriptors have been projected and used to analyze chemical reactivity and site selectivity. Hardness, global softness, electro negativity, potential ionization and affinity are the global reactivity descriptors widely used to understand the global nature of molecules in terms of their stability and it is possible to obtain knowledge about the reactivity of molecules. The global reactivity properties such as; E_{HOMO} , E_{LUMO} , ΔE_{gap} , the ionization potential (I), the electron affinity (A), the

absolute electronegativity (χ), the absolute hardness (η) and softness (S) for the sulfonamides products with N-alkylation and O-alkylation **1-4** have been calculated at

B3LYP/6-31G (d,p) basis set and the result are given in Table 5.

Table.5: Quantum chemical descriptors of sulfonamides products with N-alkylation and O-alkylation 1-4

Parameters	Compound 1	Compound 2	Compound 3	Compound 4
E_{HOMO} (eV)	-6.503	-6.383	-6.244	-6.725
E_{LUMO} (eV)	-1.503	-1.430	-1.374	-1.611
ΔE_{gap} (eV)	5.000	4.953	4.869	5.114
I (eV)	6.503	6.383	6.244	6.725
A (eV)	1.503	1.430	1.374	1.611
μ (eV)	-4.003	-3.906	-3.809	-4.168
χ (eV)	4.003	3.906	3.809	4.168
η (eV)	2.500	2.476	2.435	2.557
S (eV)	0.200	0.202	0.205	0.196
ω (eV)	3.205	3.081	2.980	3.398

The compound which has the lowest energy gap is the compound **3** ($\Delta E_{\text{gap}} = 4.869$ eV). This lower gap allows it to be the softest molecule. The compound that has the highest energy gap is the compound **4** ($\Delta E_{\text{gap}} = 5.114$ eV). The compound that has the highest HOMO energy is the compound **3** ($E_{\text{HOMO}} = -6.244$ eV). This higher energy allows it to be the best electron donor. The compound that has the lowest LUMO energy is the compound **4** ($E_{\text{LUMO}} = -1.611$ 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 **3** has the lowest value of the potential ionization ($I = 6.244$ eV), so that will be the better electron donor. Compound **4** has the largest value of the affinity ($A = 1.611$ eV), so it is the better electron acceptor. The chemical reactivity varies with the structure of molecules. Chemical hardness (softness) value of compound **3** ($\eta = 2.435$ eV, $S = 0.205$ eV) is lesser (greater) among all the molecules. Thus, compound **3** is

found to be more reactive than all the compounds. Compound **4** possesses higher electronegativity value ($\chi = 4.168$ eV) than all compounds so; it is the best electron acceptor. The value of ω for compound **4** ($\omega = 3.398$ eV) indicates that it is the stronger electrophiles than all compounds. Compound **3** 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:

Atomic charges for molecule can be derived in multiple ways with a high level of convergence to the same values and only then, knowing the remaining uncertainty, are suited for molecular simulations. Mulliken charges arise from the mulliken population analysis [17,18] and provide a means of estimating partial atomic charges from calculations carried out by the methods of computational chemistry. The Mulliken atomic charges of compound **3** which is the most reactive are calculated by DFT/B3LYP method and 6-31G (d,p) basis set and detailed in a Mulliken's plot as visualized in Fig 5.

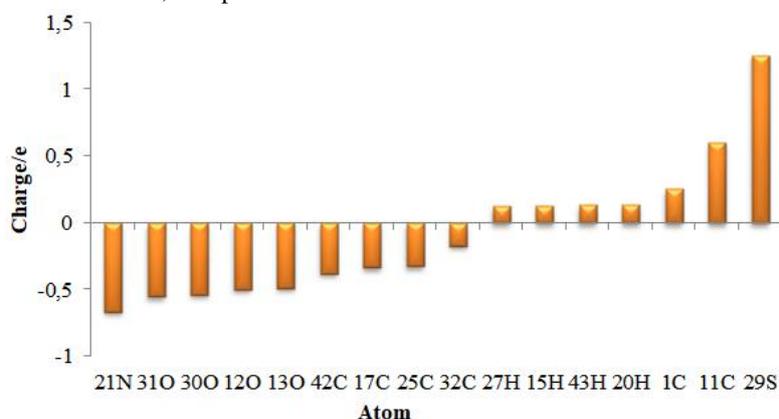


Fig.5: Mulliken's plot of compound 3

The atom 21N shows more negative (-0.665192e) charge and 29S more positive (1.257995e) charge, which suggests extensive charge delocalization in the entire molecule. Negatively charged oxygen (31O, 30O, 12O and 13O) atoms shows that charge is transferred from sulfur to oxygen and from carbon to oxygen. Carbon atoms 42C, 17C, 25C and 32C are more negatively charged which indicate that the charge transfer on the whole molecule. The maximum atomic charge of carbons is obtained for 1C and 11C. This is due to the attachment of negatively charged 21N and (12O, 13O) respectively. The positive charges are localized on the hydrogen atoms. Very similar values of positive charges are observed for the hydrogen atoms (27H, 15H, 43H and 20H (0.129123, 0.130262, 0.136093 and 0.136652e) respectively) bonded to the negative atoms (25C, 14C, 42C and 17C) respectively.

3.7. Natural Bond Orbital Analysis (NBO):

The importance of the NBO method is originated from it gives information about the intra- and intermolecular bonding and interactions among bonds. Furthermore, it provides a convenient basis for investigating the interactions in both filled and virtual orbital spaces along with charge transfer and conjugative interactions in molecular system [19]. The delocalization effects are treated as the intramolecular charge transfer (ICT) from the highest occupied bonding orbitals into unoccupied anti-bonding orbitals and their importance can be more quantitatively characterized through a second-order perturbative treatment. The stabilization energy $E(2)$ values of the titles compounds were calculated on the basis of second-order Fock matrix perturbation theory using DFT/B3LYP method with 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 (2) O13	1.82543	$\pi^*(C11-O12)$	0.26186	45.75	0.34	0.114
LP (2) O12	1.84573	$\sigma^*(C11-O13)$	0.09933	33.73	0.61	0.129
π (C25-C27)	1.62459	$\pi^*(C20-C22)$	0.39527	26.13	0.26	0.074
π (C3-C4)	1.63486	$\pi^*(C11-O12)$	0.26186	23.86	0.26	0.073
π (C1-C2)	1.62238	$\pi^*(C3-C4)$	0.38416	23.82	0.29	0.074
π (C3-C4)	1.63486	$\pi^*(C5-C6)$	0.38416	22.63	0.28	0.072
π (C5-C6)	1.68415	$\pi^*(C1-C2)$	0.38364	22.45	0.28	0.072
π (C21-C23)	1.66157	$\pi^*(C25-C27)$	0.32651	21.67	0.29	0.071
π (C20-C22)	1.68588	$\pi^*(C21-C23)$	0.30315	21.27	0.30	0.071
LP (1) N15	1.82113	$\pi^*(C1-C2)$	0.38364	19.27	0.33	0.076
LP (3) O18	1.77022	$\sigma^*(S17-O19)$	0.14523	18.87	0.57	0.095
LP (3) O19	1.78101	$\sigma^*(S17-O18)$	0.15524	18.85	0.57	0.094
LP (2) O12	1.84573	$\sigma^*(C4-C11)$	0.06673	18.47	0.69	0.103
π (C21-C23)	1.66157	$\pi^*(C20-C22)$	0.39527	18.25	0.27	0.063
π (C3-C4)	1.63486	$\pi^*(C1-C2)$	0.38364	18.23	0.27	0.063
π (C25-C27)	1.62459	$\pi^*(C21-C23)$	0.30315	18.14	0.28	0.064
LP (2) O19	1.81478	$\sigma^*(S17-C20)$	0.20616	18.00	0.45	0.081
LP (2) O18	1.81877	$\sigma^*(S17-C20)$	0.20616	17.56	0.45	0.080
LP (3) O18	1.77022	$\sigma^*(N15-S17)$	0.27308	16.83	0.40	0.074
LP (3) O19	1.78101	$\sigma^*(N15-S17)$	0.27308	16.29	0.40	0.073

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 (2) O13	1.79647	$\pi^*(C11-O12)$	0.26278	47.60	0.33	0.114
LP (2) O12	1.84587	$\sigma^*(C11-O13)$	0.10298	34.02	0.62	0.132
π (C29-C33)	1.63559	$\pi^*(C26-C27)$	0.38941	25.47	0.26	0.074
π (C3-C4)	1.64155	$\pi^*(C11-O12)$	0.26278	22.49	0.26	0.071
π (C5-C6)	1.65673	$\pi^*(C1-C2)$	0.38815	22.26	0.27	0.070
π (C1-C2)	1.65042	$\pi^*(C3-C4)$	0.37422	21.84	0.29	0.072
π (C28-C31)	1.66447	$\pi^*(C29-C33)$	0.32434	21.71	0.29	0.071

π (C26-C27)	1.69323	π^* (C28-C31)	0.29325	20.60	0.30	0.070
π (C3-C4)	1.64155	π^* (C5-C6)	0.27771	20.11	0.29	0.070
π (C3-C4)	1.64155	π^* (C1-C2)	0.38815	19.18	0.27	0.065
π (C5-C6)	1.65673	π^* (C3-C4)	0.37422	18.72	0.28	0.065
LP (3) O24	1.77279	σ^* (N18-S23)	0.28903	18.72	0.39	0.078
LP (3) O25	1.78112	σ^* (N18-S23)	0.28903	18.69	0.39	0.078
LP (2) O25	1.81373	σ^* (S23-C26)	0.20849	18.58	0.45	0.082
LP (2) O24	1.81500	σ^* (S23-C26)	0.20849	18.35	0.45	0.082
π (C28-C31)	1.66447	π^* (C26-C27)	0.38941	18.29	0.27	0.063
LP (2) O12	1.84587	σ^* (C4-C11)	0.06466	18.14	0.69	0.102
π (C29-C33)	1.63559	π^* (C28-C31)	0.29325	17.84	0.28	0.064
LP (3) O24	1.77279	σ^* (S23-O25)	0.14628	17.79	0.57	0.092
LP (3) O25	1.78112	σ^* (S23-O24)	0.14828	17.27	0.57	0.090

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 (2) O13	1.79164	π^* (C11-O12)	0.26966	48.63	0.33	0.115
LP (2) O12	1.84618	σ^* (C11-O13)	0.10153	33.25	0.63	0.131
π (C35-C39)	1.63420	π^* (C32-C33)	0.38818	25.41	0.27	0.074
π (C3-C4)	1.63275	π^* (C11-O12)	0.26966	22.81	0.26	0.071
π (C1-C2)	1.62838	π^* (C3-C4)	0.38015	22.46	0.29	0.072
π (C3-C4)	1.63275	π^* (C5-C6)	0.30204	21.91	0.28	0.071
π (C34-C37)	1.66451	π^* (C35-C39)	0.32671	21.65	0.29	0.071
π (C5-C6)	1.67420	π^* (C1-C2)	0.37485	21.23	0.28	0.069
π (C32-C33)	1.69074	π^* (C34-C37)	0.29810	20.71	0.30	0.070
π (C3-C4)	1.63275	π^* (C1-C2)	0.37485	19.61	0.27	0.065
LP (3) O30	1.76709	σ^* (S29-O31)	0.14477	18.84	0.56	0.094
LP (2) O31	1.81299	σ^* (S29-C32)	0.20689	18.38	0.45	0.082
π (C34-C37)	1.66451	π^* (C32-C33)	0.38818	18.31	0.27	0.064
LP (3) O31	1.78844	σ^* (S29-O30)	0.15764	18.13	0.57	0.092
π (C35-C39)	1.63420	π^* (C34-C37)	0.29810	18.05	0.28	0.065
LP (2) O12	1.84618	σ^* (C4-C11)	0.06459	18.05	0.69	0.102
LP (2) O30	1.81920	σ^* (S29-C32)	0.20689	17.46	0.45	0.080
π (C1-C2)	1.62838	π^* (C5-C6)	0.30204	17.33	0.29	0.064
π (C5-C6)	1.67420	π^* (C3-C4)	0.38015	17.31	0.29	0.064
LP (3) O31	1.78844	σ^* (N21-S29)	0.27749	17.30	0.41	0.076

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 (2) O13	1.82352	π^* (C11-O12)	0.25212	46.11	0.34	0.114
LP (2) O12	1.84545	σ^* (C11-O13)	0.09927	33.80	0.61	0.130
π (C34-C36)	1.63617	π^* (C29-C31)	0.37927	25.45	0.27	0.074
π (C3-C4)	1.63974	π^* (C11-O12)	0.25212	22.30	0.26	0.070
LP (3) O28	1.79291	σ^* (N15-S26)	0.28669	21.91	0.40	0.085
π (C5-C6)	1.64359	π^* (C1-C2)	0.35205	21.83	0.27	0.069
π (C30-C32)	1.66734	π^* (C34-C36)	0.32322	21.71	0.29	0.071
π (C1-C2)	1.65107	π^* (C3-C4)	0.36671	21.03	0.29	0.070
π (C29-C31)	1.69031	π^* (C30-C32)	0.29539	21.01	0.30	0.071
π (C3-C4)	1.63974	π^* (C1-C2)	0.35205	19.84	0.28	0.066
π (C3-C4)	1.63974	π^* (C5-C6)	0.27958	19.69	0.29	0.069

π (C5-C6)	1.64359	π^* (C3-C4)	0.36671	19.66	0.28	0.066
LP (3) O27	1.77819	σ^* (N15-S26)	0.28669	19.32	0.39	0.079
LP (2) O12	1.84545	σ^* (C4-C11)	0.06778	18.73	0.69	0.104
LP (2) O28	1.80545	σ^* (S26-C29)	0.19763	18.69	0.45	0.082
LP (2) O27	1.80864	σ^* (S26-C29)	0.19763	18.38	0.45	0.081
π (C30-C32)	1.66734	π^* (C29-C31)	0.37927	17.99	0.27	0.063
π (C1-C2)	1.65107	π^* (C5-C6)	0.27958	17.89	0.29	0.066
π (C34-C36)	1.63617	π^* (C30-C32)	0.29539	17.79	0.28	0.064
LP (3) O27	1.77819	σ^* (S26-O28)	0.14346	17.71	0.56	0.091

The intra molecular interaction for the title compounds is formed by the orbital overlap between: π (C25-C27) and π^* (C20-C22) for compound **1**, π (C29-C33) and π^* (C26-C27) for compound **2**, π (C35-C39) and π^* (C32-C33) for compound **3** and π (C34-C36) and π^* (C29-C31) for compound **4** respectively, which result into intermolecular charge transfer (ICT) causing stabilization of the system. The intra molecular hyper conjugative interactions of π (C25-C27) to π^* (C20-C22) for compound **1**, π (C29-C33) to π^* (C26-C27) for compound **2**, π (C35-C39) to π^* (C32-C33) for compound **3** and π (C34-C36) to π^* (C29-C31) for compound **4** lead to highest stabilization of 26.13, 25.47, 25.41 and 25.45 kJ mol⁻¹ respectively. In case of LP (2) O13 orbital to the π^* (C11-O12) for compound **1**, LP (2) O13 orbital to π^* (C11-O12) for compound **2**, LP (2) O13 orbital to π^* (C11-O12) for compound **3**, LP (2) O13 orbital to π^* (C11-O12) for compound **4** respectively,

show the stabilization energy of 45.75, 47.60, 48.63 and 46.11 kJ mol⁻¹ respectively.

3.8. Nonlinear Optical Properties (NLO):

The non-linear optical properties of the organic molecules are associated to the delocalized π electrons that move along molecule. The increase of the conjugation on molecule gives rise to an increase in its non-linear optical properties. One another way to increase non-linear optical properties is to add donor and acceptor groups. If the donor and acceptor groups are powerful, delocalization of π electron cloud on organic molecules increases and as a result of this the polarizability and first hyperpolarizability of organic molecules increase [20]. The dipole moment (μ), polarizability (α), anisotropy of polarizability ($\Delta\alpha$) and first hyperpolarizability (β_0) of sulfonamides products with N-alkylation and O-alkylation **1-4** were calculated using DFT/B3LYP method with 6-31G (d,p) basis set and illustrated in Table 10.

Table.10: Nonlinear optical properties of sulfonamides products with N-alkylation and O-alkylation 1-4

Parameters	Compound 1	Compound 2	Compound 3	Compound 4
β_{xxx}	10.1879	42.8963	72.7392	-13.1469
β_{yyy}	53.0159	47.2709	28.4891	30.4972
β_{zzz}	11.3645	13.7123	7.8813	11.9986
β_{xyy}	5.8714	24.2109	-8.0498	18.5791
β_{xxy}	45.8341	98.8568	59.0868	63.8974
β_{xxz}	-47.1180	67.3212	-27.2668	70.7141
β_{xzz}	4.1576	-4.3122	8.2628	11.4853
β_{yzz}	-1.8291	-3.0512	-6.6454	9.1439
β_{yyz}	-5.5542	2.6668	10.3103	9.6574
β_{xyz}	-17.5447	13.5678	-1.0398	23.0215
β_0 (esu)x10 ⁻³³	112.8079	177.2564	109.3349	139.7808
μ_x	-1.1682	-0.3538	-0.2435	-0.2088
μ_y	4.4313	5.4070	2.7319	2.9856
μ_z	0.9318	4.1778	2.1331	4.4819
μ (D)	4.6765	6.8422	3.4746	5.3894
α_{xx}	-121.2508	-131.4657	-134.6974	-144.8960
α_{yy}	-126.6992	-129.8462	-140.2193	-125.6791
α_{zz}	-115.6411	-133.1144	-152.0142	-145.2273
α_{xy}	-16.3967	-7.5930	-12.6363	-9.2442
α_{xz}	-13.1709	0.8616	-19.8395	-2.2152
α_{yz}	-8.7559	-5.5399	-9.9334	-1.2229

$\alpha(\text{esu})\times 10^{-24}$	40.6040	16.5913	46.8039	25.5213
$\Delta\alpha(\text{esu})\times 10^{-24}$	6.0175	2.4588	6.9363	3.7823

Since the values of the polarizabilities ($\Delta\alpha$) and the hyperpolarizabilities (β_0) 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. = 0.1482×10^{-24} e.s.u., for β ; 1 a.u. = 8.6393×10^{-33} e.s.u.). The calculated values of dipole moment (μ) for the title compounds were found to be 4.6765, 6.8422, 3.4746 and 5.3894 D respectively, which are approximately four, six and three times respectively than to the value for urea ($\mu = 1.3732$ 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 40.6040×10^{-24} , 16.5913×10^{-24} , 46.8039×10^{-24} and 25.5213×10^{-24} esu respectively; the values of anisotropy of the polarizability are 6.0175, 2.4588, 6.9363 and 3.7823 esu, respectively. The magnitude of the molecular hyperpolarizability (β_0) is one of the important key factors in a NLO system. The DFT/6-31G (d,p) calculated first hyperpolarizability value (β_0) of sulfonamides products with N-alkylation and O-alkylation are equal to 112.8079×10^{-33} , 177.2564×10^{-33} , 109.3349×10^{-33} and 139.7808×10^{-33} esu. The first hyperpolarizability of title molecules is approximately 0.32, 0.34, 0.31 and 0.40 times than those of urea (β of urea is 343.272×10^{-33} esu obtained by B3LYP/6-311G (d,p) method). The above results show that all studied compounds **1-4** might have not the NLO applications.

IV. CONCLUSION

We have reported in this review, a complete computational study of sulfonamides products with N-alkylation and O-alkylation **1-4** by DFT/B3LYP method and 6-31G (d,p) basis set. The optimized molecular structures were obtained by same method. In addition, a molecular electrostatic potential map (MEP) of the title compounds has been analyzed for predicting the reactive sites and from the MEP contour map we note that the negative electrostatic potential are localized on sulfamide function and on acid function for compound **1** and compound **4** and on ester function for compound **2** and compound **3**. The HOMO-LUMO energy gap of the compound **3** is low and hence we conclude, according to the global reactivity properties analysis that it is the more reactive compared to other compounds. Mulliken's net charges have been calculated and results show that 21N is the more negative and 29S is the more positive charge, which Indicates extensive charge delocalization in the entire molecule. Natural bond orbital analysis has been carried out to analysis the stability of the molecules

arising from hyper-conjugative interactions and charge delocalization. The nonlinear optical properties are also addressed theoretically. The title compounds may be not a potential applicant in the development of NLO materials.

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