Current Chemistry Letters 14 (2025) 31–40

Contents lists available at GrowingScience

Current Chemistry Letters

homepage: www.GrowingScience.com

Structural, electronic, and spectroscopic properties of oxadiazole isomers in the light of DFT computational study

Oumaima Oulhaj[a*], Lamya Oubenmoussa[a], Hicham Essassaoui[a], Mohamed Bouha[a] and Mohamed Mbarki[a]

[a]*Laboratory of Engineering in Chemistry and Physics of Matter, Department of Chemistry and Environment, Faculty of Science and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco*

C H R O N I C L E

Article history:
Received July 18, 2024
Received in revised form
August 15, 2024
Accepted October 7, 2024
Available online
October 7, 2024

Keywords:
Oxadiazoles
Isomers
DFT
Structural properties
Electronic properties
Spectroscopic properties

A B S T R A C T

Oxadiazoles, a class of nitrogen-containing heterocycles, exhibit diverse applications in pharmaceuticals, industry, and other fields. This study employs Density Functional Theory (DFT) to investigate the structural, electronic, and spectroscopic properties of four oxadiazole isomers. The B3LYP functional and the 6-311G(d,p) basis set were used for calculations. Frontier orbital energies, energy gap, chemical reactivity descriptors, dipole moment, and thermodynamic properties were computed. Additionally, IR and UV spectra were analyzed. The results indicate significant variations in electronic and thermodynamic properties among the isomers. Isomer 4 demonstrated the highest stability and electrophilicity. The calculated IR and UV spectra were compared with available experimental and theoretical data. The study provides valuable insights into the structural and reactivity trends within the oxadiazole family, contributing to a deeper understanding of their potential applications.

1. Introduction

Heterocyclic compounds, featuring one or more heteroatoms (like nitrogen, oxygen, or sulfur) within their ring structures, are ubiquitous in chemistry. Among them, nitrogen-containing heterocycles hold particular interest due to their prevalence in pharmaceuticals. A review by Njardarson's group at the University of Arizona [1, 2] revealed that a staggering 59% of unique small-molecule drugs approved by the FDA contain a nitrogen heterocycle. This highlights the significance of nitrogen heterocycles, such as oxadiazoles, triazoles, thiadiazoles, and imidazoles, in driving advancements within the chemical industry due to their diverse and valuable properties. Oxadiazoles, a specific class of nitrogen-containing heterocycles, have garnered significant attention across various fields, including pharmaceuticals, industrial applications, cosmetics, and agriculture. Their versatility extends across scientific disciplines, ranging from medicinal chemistry to optoelectronics. This study delves into oxadiazoles using the density functional theory (DFT) method. We will explore the four isomeric forms of the oxadiazole ring: 1,2,3-oxadiazole; 1,2,4-oxadiazole; 1,2,5-oxadiazole; and 1,3,4-oxadiazole. By comparing these isomers, we aim to elucidate the similarities and differences between them. Additionally, we will investigate aspects of their reactivity and analyze their infrared (IR) and ultraviolet (UV) spectroscopic properties.

2. Materials and Methods

All calculations were carried out using Gaussian 09 software employing the Density Functional Theory (DFT) approach. The B3LYP functional, incorporating the non-local exchange function with three Becke parameters and the Lee–Yang–Parr correlation function [3,4], was chosen with the Pople 6-311G (d,p) basis set.[5] Four oxadiazole isomers were analyzed using DFT: 1,2,3-oxadiazole (isomer 1), 1,2,4-oxadiazole (isomer 2), 1,2,5-oxadiazole (isomer 3), and 1,3,4-oxadiazole (isomer

* Corresponding author
E-mail address Oumaimaoulhaj72@gmail.com (O. Oulhaj)

doi: 10.5267/j.ccl.2024.10.004

4). DFT calculations were performed with Gaussian 09W, while GaussView 6.0 was used for visualization and generating graphs. DFT offers a well-balanced approach between accuracy and computational cost, making it suitable for studying medium to large molecules. Several recent studies have demonstrated the effectiveness of density functional theory (DFT) in analyzing similar molecular systems, including azole derivatives. These works have successfully employed the B3LYP functional and the 6-311G basis set, supporting their selection in this study.[6-9] The B3LYP functional and the 6-311G basis set were chosen for the simulations. We evaluated various electronic and thermodynamic properties of the isomers, including frontier orbital energies (HOMO and LUMO), the energy gap (E_{GAP}), electronic chemical potential (μ), chemical hardness (η), softness (S), global electrophilicity index (ω), global nucleophilicity index (N), and electron affinity. Additionally, infrared (IR) and ultraviolet (UV) spectra were analyzed to explore the spectroscopic properties of the isomers.

3. Results and Discussion

3.1. Electronic Properties

Based on the calculations, the energies of the frontier orbitals were determined. **Table 1** presents the energies: HOMO, LUMO, and the HOMO-LUMO gap (E_{GAP}) for the four isomers studied. The HOMO and LUMO are the most important orbitals influencing the molecule's chemical stability:

- ✓ The HOMO reflects the electron-donating character of the molecule. The higher the energy of this molecular orbital (MO), the more readily the molecule will donate electrons.
- ✓ The LUMO reflects the electron-accepting character of the molecule. The lower the energy of this MO, the more readily the molecule will accept electrons.
- ✓ The HOMO-LUMO gap (E_{GAP}) specifies the molecule's kinetic stability, chemical reactivity, optical properties, polarizability, and chemical hardness and softness.

Table 1. Frontier Orbital Energies (eV) for the Different Isomers

Oxadiazole Isomers	1	2	3	4
HOMO (eV)	-0.29	-0.31	-0.33	-0.29
LUMO (eV)	-0.05	-0.04	-0.06	-0.02
E_{GAP} (eV)	0.23	0.27	0.26	0.26

Fig. 1 presents the HOMO-LUMO Gap (E_{GAP}) energies of the studied isomers. It is well known that the lowest E_{GAP} indicates strong charge transfer interactions occurring within the molecule.[10] When the HOMO and LUMO energy levels are close, a small change in the environment can excite the molecule. This leads to high reactivity and low stability. As observed in **Fig. 1**, isomer 1 has the lowest E_{GAP} and is therefore the least stable. Isomers 2, 3, and 4 are more stable.

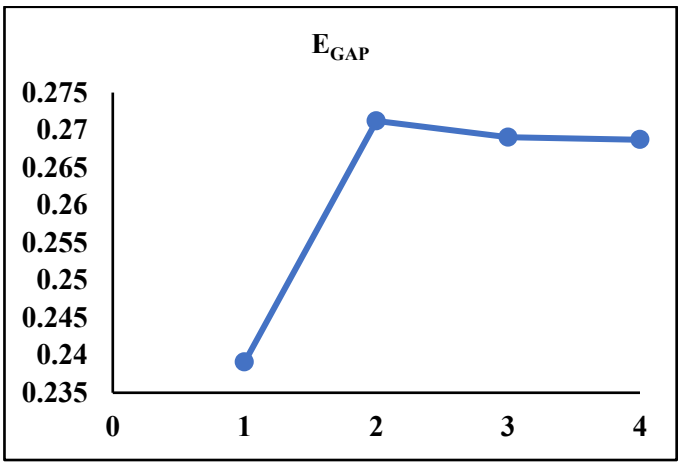


Fig. 1. HOMO-LUMO Gap (E_{GAP}) Energies of Oxadiazole Isomers

The theoretically predicted low stability of isomer 1 is consistent with experimental findings. Experiments have shown that this isomer is unstable in its cyclic form. Due to valence tautomerism, it converts to diazoacetaldehyde.[11-13] Valence tautomerism can be defined as the interconversion of isomeric forms without any rearrangement or proton transfer.[12] In contrast, isomers 2, 3, and 4 exhibit a large energy gap between the HOMO and LUMO orbitals. This can be attributed to the limited conjugation of pi electrons within their heterocyclic rings.[14] Furthermore, it is noteworthy that a theoretical study employing the same method (TD-DFT/B3LYP/6-311++G) was conducted on isomer 4 by A. Faeez and S.F. Al-saidi.[15]

The values obtained for E_{HO}, E_{BV}, and E_{GAP} differ from those reported in the literature (**Fig. 2**). This difference is likely due to the solvent employed. In our study, the theoretical calculations were performed in a vacuum, whereas the other study

[15] utilized either gas or water. Solvents can significantly impact the calculated properties of molecules, such as their frontier orbital energies (E_{HO} and E_{BV}) and band gaps (E_{GAP}). This is because solvents interact with the molecules, stabilizing them to varying degrees. Generally, polar solvents provide greater stabilization compared to non-polar solvents. In the case of the oxadiazole isomers, it is probable that the gas phase or aqueous environment used in the previous study stabilized the molecules more than the vacuum used in our study. This would lead to lower values of E_{HO} and E_{BV}, and a smaller band gap (E_{GAP}).

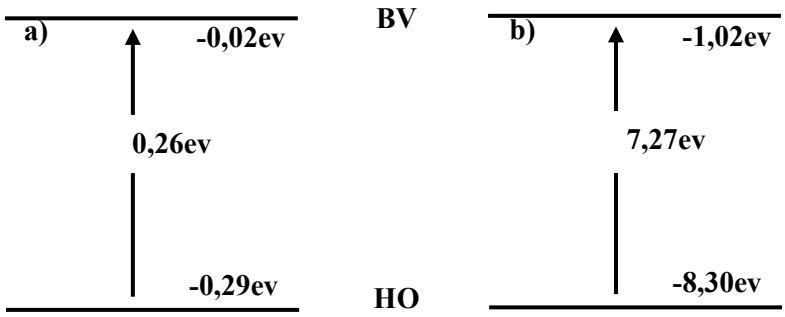


Fig. 2. E_{HO}, E_{BV}, and E_{GAP} values for isomer 4 obtained using the DFT method in the present study (a) and study [15] (b).

For isomer 4 (OD), a comparison of its frontier orbital energies (E_{HO}), lowest unoccupied molecular orbital energies (E_{BV}), and band gaps (E_{GAP}) with its amine (ODA) and diamine (ODDA) derivatives was conducted by A. Faeez and S.F. Al-saidi.[11] Their study found that the calculated EGAP values for OD, ODA, and ODDA increase in the following order: ODDA < ODA < OD. Lower EGAP values indicate more reactive and less stable molecules. This suggests that the substitution of one or two electron-donating groups (-NH_2) in the oxadiazole ring of isomer 4 disrupts the HOMO and LUMO energy levels, leading to a decrease in the energy gap and consequently, destabilization of the derivatives of isomer 4 and an increase in their reactivity.[15] This finding highlights the fact that oxadiazoles themselves are not commonly used in organic chemistry; rather, it is their derivatives that hold greater significance. In addition, the study of the overall reactivity of molecules is also based on the calculation of other indices derived from electronic properties. **Table 2** summarizes the values of ionization potential (I), electron affinity (A), electrochemical potential (μ), absolute electronegativity (χ), chemical hardness (η), softness (S), global electrophilicity index (ω), and global nucleophilicity index (N) for the oxadiazole isomers: 1, 2, 3, and 4.

Table 2. Geometrical Properties of the Isomers

Oxadia-zoles	1	2	3	4
Ionization potential (I)	0.29	0.31	0.33	0.29
Electron affinity (A)	0.05	0.04	0.06	0.02
Chemical hardness (η)	-0.11	-0.13	-0.13	-0.13
Softness (S)	-4.18	-3.68	-3.71	-3.72
Electronic chemical potential (μ)	-0.17	-0.17	-0.19	-0.16
Electronegativity (χ)	0.17	0.17	0.19	0.16
Electrophilicity (ω)	-0.12	-0.11	-0.14	-0.09
Nucleophilicity (N	-9.66	-9.68	-9.69	-9.66

The electrochemical potential determines the direction of electron transfer during a condensation reaction between two molecules. **Fig. 3** represents the electrochemical potential of the four isomers. According to the figure, isomer 4 has a higher electrochemical potential than the other isomers, implying that electron transfer will occur towards isomer 4.

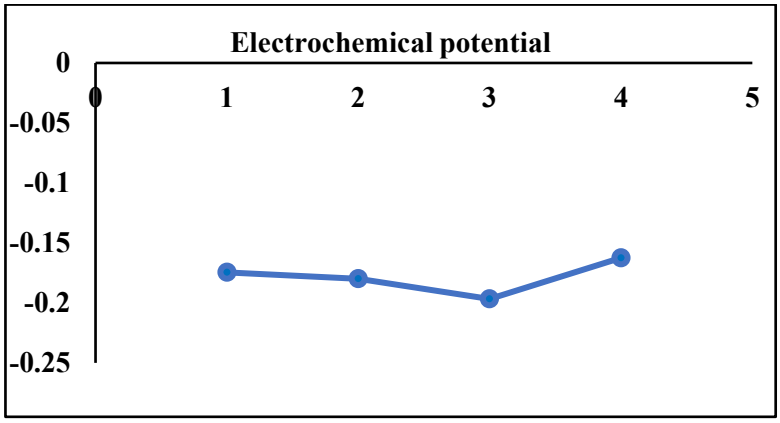


Fig. 3. Electrochemical Potential of the Isomers

Hardness provides information about the relative duration for a molecule to retain electrons within its vicinity. According to **Fig. 4**, isomer 1 exhibits high hardness compared to the other isomers. Consequently, it holds more electrons in its surrounding environment compared to the other isomers. Conversely, softness is the propensity of a cationic molecule (A^+) to accept electrons or an anionic molecule (A^-) to lose electrons. The difficulty for oxadiazole 1 to receive or lose electrons is greater than for the other isomers.

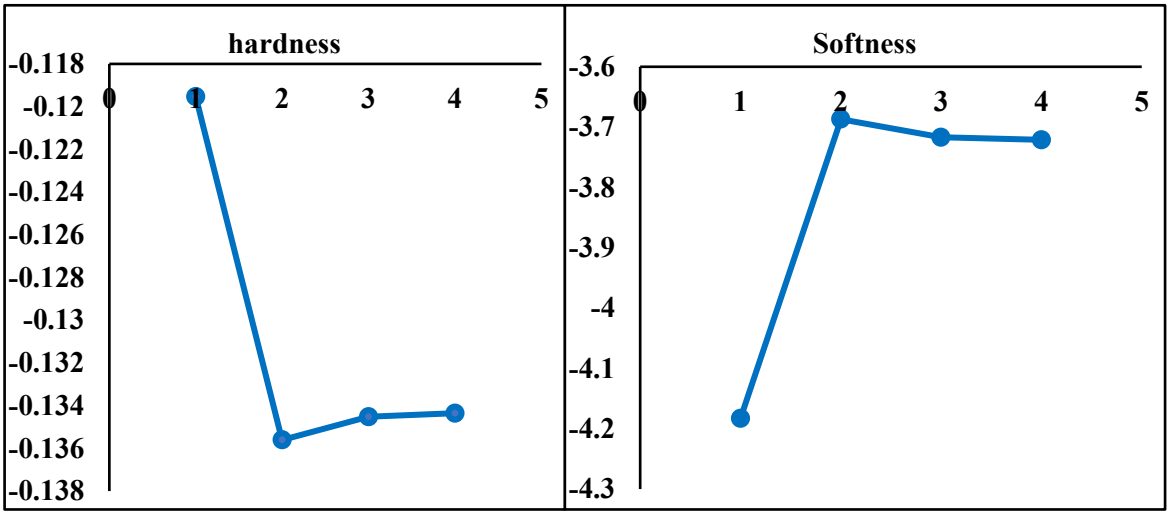


Fig. 4. Hardness and Softness

Fig. 5 presents the global nucleophilicity index (N) and global electrophilicity index (ω) for the four isomers. Oxadiazole 3 exhibits the lowest nucleophilicity index among the isomers, implying that its reactivity towards electrophilic attack is the weakest. Isomer 4, on the other hand, has the highest electrophilicity index, indicating that its reactivity towards nucleophilic attack is the strongest. However, an experimental study [16] reported that derivatives of isomer 2 are more electrophilic than those of isomer 4. The same study showed that isomer 4 derivatives do not react under the same reaction conditions due to their significantly lower electrophilicity. This could be attributed to the aromaticity of isomer 4's ring, which favors substitution over addition reactions.[16] It is evident that this study considers isomer 4 derivatives to be less electrophilic than those of isomer 2. Our study, in contrast, demonstrates that isomer 4's oxadiazole ring is more electrophilic than that of isomer 2. This discrepancy can be explained by the fact that heterocyclic rings react differently from their derivatives.

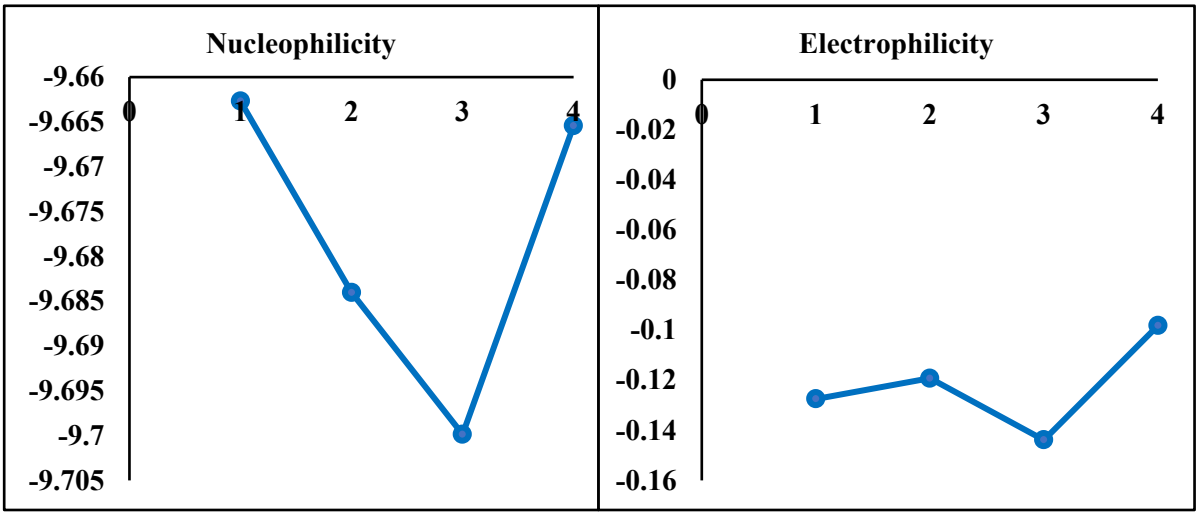


Figure 5. Comparison of Global Nucleophilicity and Electrophilicity Indices

Furthermore, it is important to mention that a theoretical study (DFT in the gas phase) [11] has examined the molecular electrostatic potential of isomer 4 (**Fig. 6**). The molecular electrostatic potential (MEP) map highlights the size of the molecule and the regions of negative, positive, and neutral electrostatic potential, represented by a color scale. This MEP map allows us to understand the electrophilic attraction towards a negative region where the partial negative electron charge is dominant. The red color indicates the maximum negative potential, favoring an electrophilic attack. While the blue color indicates a positive region, favoring a nucleophilic attack. The figure shows a negative potential on the nitrogen atoms

(electronegative atoms each possessing a lone pair), and a positive potential on the carbon and hydrogen atoms. It is clear that electrophilic substitutions in the oxadiazole ring are extremely difficult at the carbon level due to its relatively low electron density. In addition, considering the aromaticity of the core of isomer 4 as a 6π electronic system, the two nitrogen atoms each have a fully available free electron pair for hydrogen bonding.

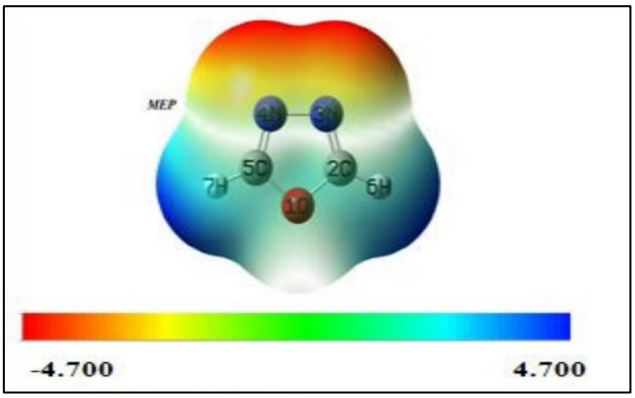


Fig. 6. Molecular electrostatic potential for isomer 4 (DFT in gas phase) [11]

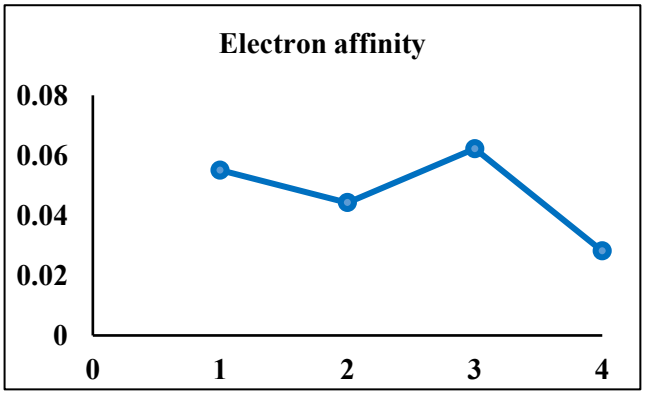


Fig. 7. Electron affinity of the isomers

Electron affinity refers to the ability of a neutral atom or molecule to capture an additional electron. The results are presented in **Fig. 7**. This figure shows that isomer 4 has a lower electron affinity than the other isomers, which implies that it is the most stable isomer. Indeed, the unsubstituted isomer 4 is the most stable isomeric structure among all isomeric oxadiazoles.[17] **Table 3** summarizes the dipole moment in the x, y, and z directions, as well as the total dipole moment of the isomers.

Table 3. Dipole moments of the isomers

Oxadiazole isomers	Dipole moment x	Dipole moment y	Dipole moment z	Total dipole moment
1	-2.99	-1.88	0.00	3.53
2	-0.82	0.83	-0.00	1.17
3	0	3.44	0.00	3.44
4	0	-3.14	-0.00	3.14

Based on the findings presented in **Fig. 8**, the overall dipole moment value of isomer 2 is lower than that of the other isomers. Consequently, isomer 2 is less stable than the other isomers. This result contradicts the E_{GAP} findings, which indicated that isomer 2 was among the most stable isomers, while isomer 1 was the least stable. As previously mentioned, isomer 1's low stability was attributed to its valence tautomerism.

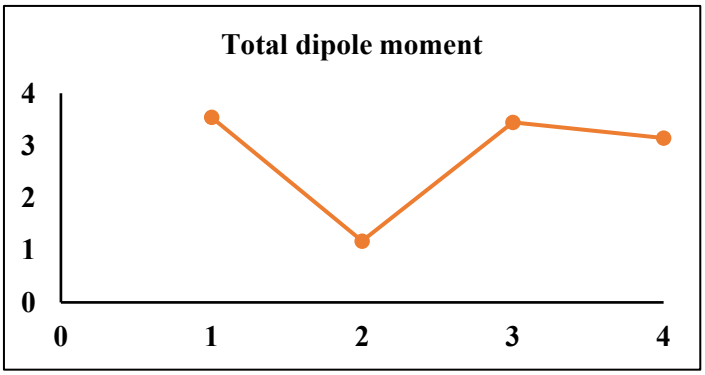


Figure 8. Global Dipole Moment of Isomers

3.2. Thermodynamic properties

For each isomer, the enthalpy (H), entropy (S), and Gibbs free energy (G) were determined. Enthalpy (H) is the sum of a system's internal energy and the product of its pressure and volume. Entropy (S) characterizes the degree of disorder or unpredictability of the information content of a system. Gibbs free energy (G) is given by the relationship G = H - T × S. In this analysis, only relative energies between the isomers are reported. The reference isomer is 1,3,4-oxadiazole,

which has the lowest free energy and is considered the most thermodynamically stable. Table 4 presents the relative thermodynamic parameters compared to this reference isomer. **Table 4** presents the results of these thermodynamic quantities.

Table 4. Thermodynamic Parameters

	ΔH (Kcal/mol)	**S (cal/mol.K)**	ΔG (Kcal/mol)
1.2.3-oxadiazole	19.6	64.8	19.4
1.2.4-oxadiazole	5.7	64.1	5.7
1.2.5-oxadiazole	30.8	64.3	30.7
1.3.4-oxadiazole	0	64.1	0

The variation of free energy is presented in **Fig. 9**. It is observed that isomer 4 exhibits the lowest free energy, making it the most thermodynamically stable isomer. The thermodynamic stability of isomer 4 has been mentioned in several studies.[15,18] This theoretical result is also consistent with another experimental study, [17,18] which compared the stability of oxadiazole 4 with that of oxadiazole 2. It has been demonstrated that the reactivity of oxadiazole 4 is lower than that of oxadiazole 2. Indeed, an increase in the aromaticity of a molecule is generally associated with a decrease in its reactivity. Studies have shown that oxadiazole 4 is more aromatic than oxadiazole 2.[16,20] Furthermore, the latter is considered only a simple conjugated diene.[16,20] Therefore, oxadiazole 4, being more aromatic, is less reactive and consequently more stable, as also demonstrated by the current theoretical study. Additionally, it should be noted that compared to other isomeric oxadiazoles, the derivatives of oxadiazole 4 also exhibit better metabolic stability, better water solubility, and lower lipophilicity.[21]

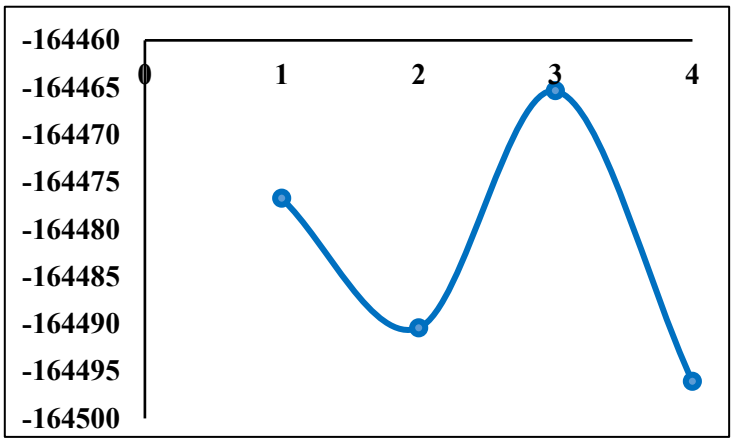
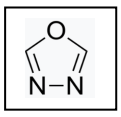


Fig. 9. Free Enthalpy of Isomers

3.3. Theoretical IR and UV spectroscopy

The calculated IR spectra are shown in **Fig. 10**. Regarding isomer 4, the calculated frequency values in our study are compared to those of other theoretical and experimental methods (**Table 5**).

Table 5. Theoretical IR Frequencies of Isomer 4 Compared to Other Theoretical and Experimental Data



Oxadiazole 4

		Frequency (cm^{-1}) DFT 6-31G Present Study	**Frequency (cm^{-1}) DFT 6-31G Other Study [15]**	**Frequency (cm^{-1}) Ab initio [22]**	**Frequency (cm^{-1}) Experience [23]**
C-H Elongation mode	**symmetry**	---	3291	3180	3169
	Asymmetry	3280	3285	3147	3167
C-H vibrational mode	**symmetry**	867	872	849	852
	Asymmetry	---	841	823	825
N-N streching		975	974	952	951
C=N	**symmetry**	1540	1558	1529	1534
	Asymmetry	1561	1534	1500	1541
C-O-C symmetry and Asymmetry	**symmetry**	1108	1104	1093	1090
In-plane C-H bending vibration	**Asymmetry**	1082	1083	1081	1078
N-N bond with C-O-C chain stretching and ring deformation	**symmetry**	975	974	952	951
	Asymmetry	950	946	923	920
H-C-O-C-H		645	644	633	625

According to the table, it is observed that the frequency values found by the DFT method are the same for the two theoretical studies.[11] On the other hand, it is observed that the values found by the ab initio method are closer to the experimental values. It can be deduced that for IR spectra, it is better to predict them by the ab initio method.

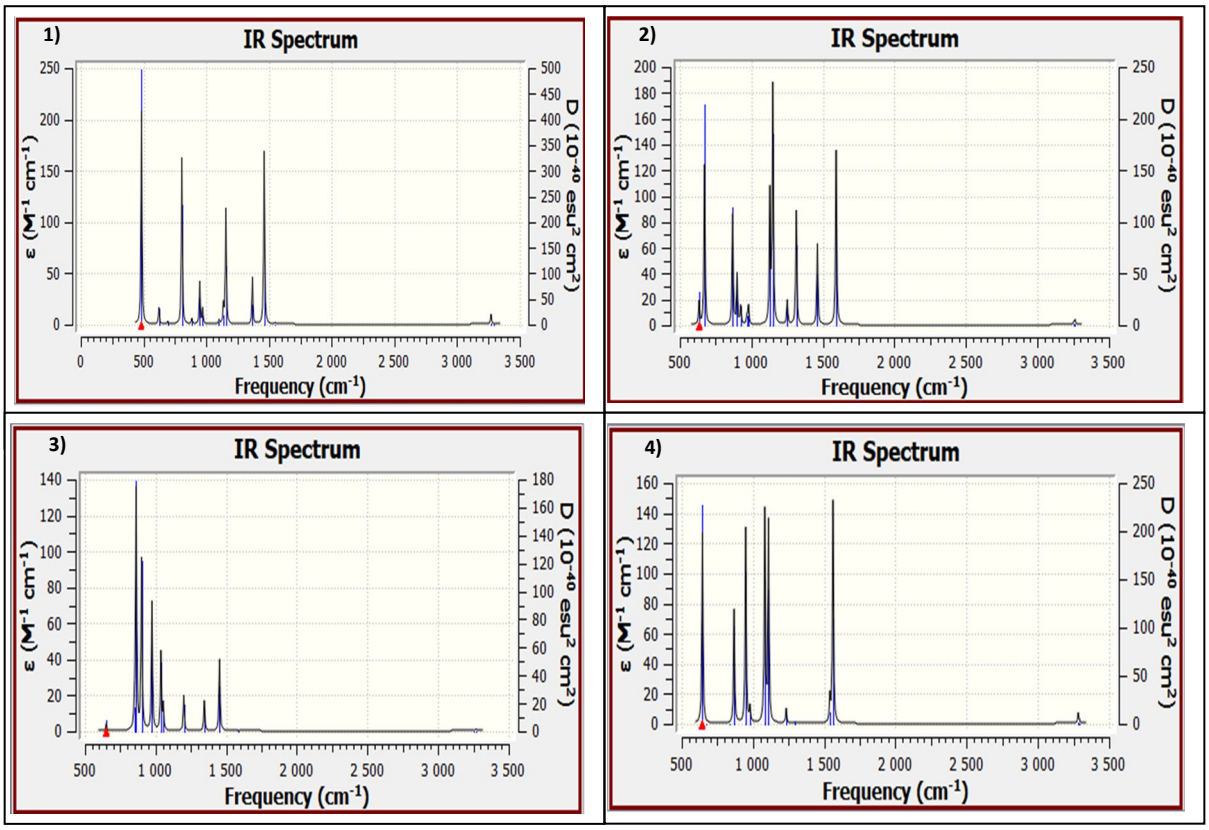


Fig. 10. IR Spectra Determined by the DFT Method of Isomers 1, 2, 3, and 4

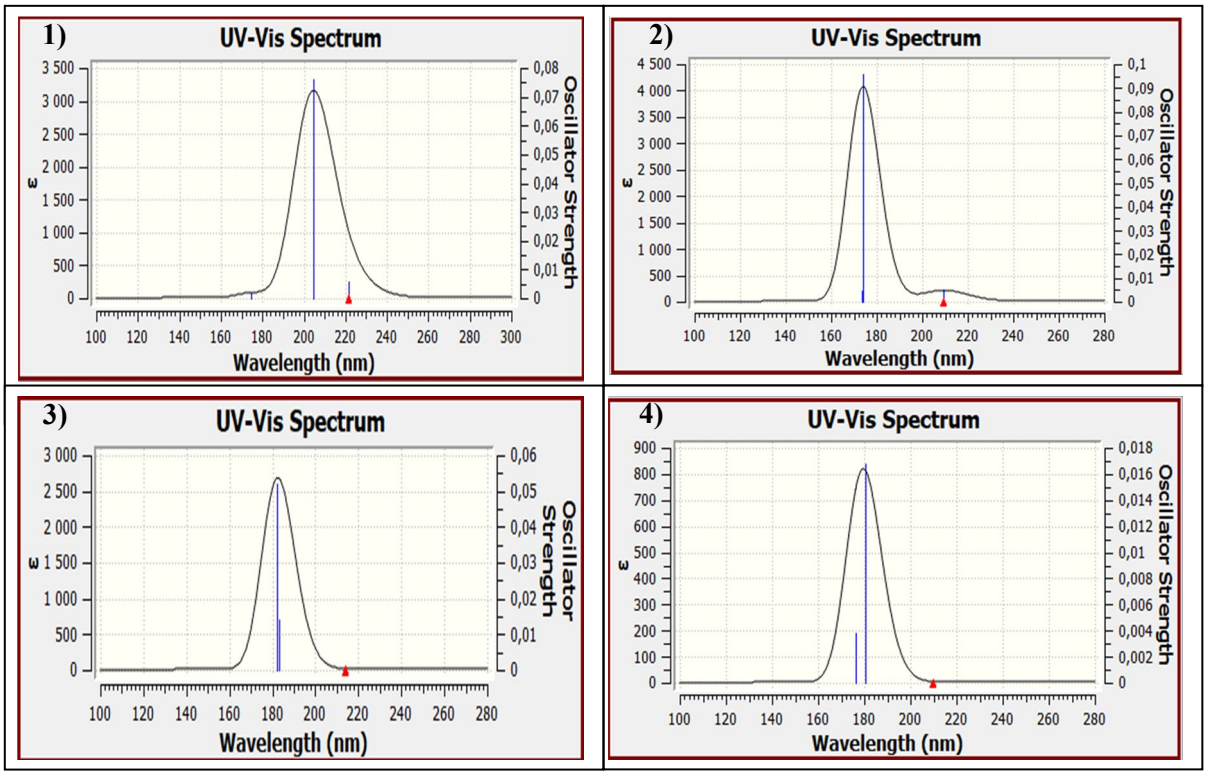


Fig. 11. UV spectra determined by the DFT method of isomers 1, 2, 3, and 4.

The UV spectrum of each isomer typically exhibits a main absorption maximum wavelength (λmax) (**Fig. 11**).

Table 6 presents the IR spectral assignments for the main bands of the isomers.

Table 6. IR Spectral Assignments of Isomers 1, 2, and 3

Isomer 1	C=C band at 1460 cm^{-1} N-O band at 1340 cm^{-1} C-N band at 1140 cm^{-1} C=O band at 950 cm^{-1}
Isomer 2	C=N band at 1600 cm^{-1} N-O band at 1300 cm^{-1} C-N band at 1150 cm^{-1} C-O band at 1125 cm^{-1}
Isomer 3	C-N band at 1450 cm^{-1} N-O band at 1340 cm^{-1} C-C band at 1050 cm^{-1}

Table 7 summarizes the main λmax bands of the 4 isomers studied. It is noteworthy that the calculated λmax values for the four isomers suggest a π-π transition, indicating the presence of a conjugated system. Based on the table, we observe that the λmax values of isomers 2, 3, and 4 are close to each other and differ from that of isomer 1, which is slightly higher. Furthermore, when comparing the λmax values of isomers 2 and 4, we see that λmax(4) is greater than λmax(2). It is well-known that increasing conjugation in a molecule leads to a bathochromic shift in the wavelength, thereby decreasing the energy required for the $\pi \rightarrow \pi^*$ transition.

Table 7. The main UV absorption bands of the studied isomers.

Oxadiazole isomers	**λ_{max} (nm)**
1	204
2	174
3	183
4	180

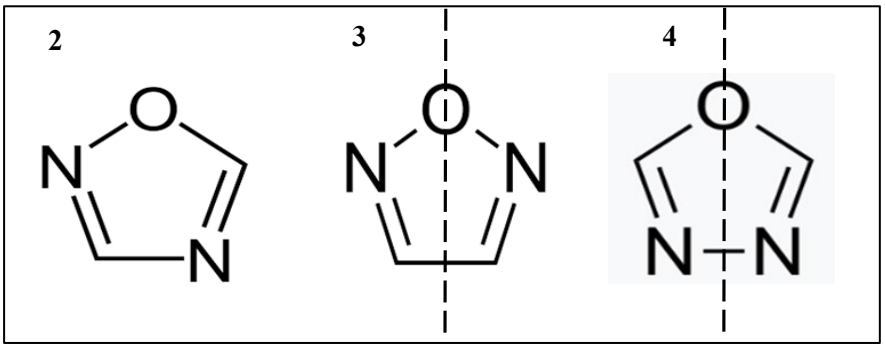


Fig. 12. Symmetry of isomers 3 and 4 relative to isomer 2

The theoretically obtained UV result (λmax(4) > λmax(2)) indicates that isomer 4 exhibits greater conjugation compared to isomer 2, implying a higher degree of aromaticity. This corroborates the findings presented earlier (paragraph: Thermodynamic Properties) and aligns with the experimental results reported in [16,20], which demonstrate that isomer 4 is more aromatic than isomer 2, the latter being merely considered a conjugated diene. The enhanced aromaticity of isomer 4 can be attributed to its symmetry. This symmetry could also explain the higher λmax value of isomer 3 relatives to isomer 2 (**Fig. 12**). Furthermore, the results indicate that isomer 1 exhibits a λmax that deviates slightly from those of the other three isomers. This is likely attributed to the presence of N=N and C=C double bonds. These double bonds are absent in the other isomers, which solely contain the C=N double bond. Furthermore, regarding isomer 4, an attempt was made to compare the obtained results with other bibliographic data (**Table 8**). The λmax values calculated in our study and that of [15] are close. However, only one band was detected in our case. This can be explained by the influence of the chosen solvent: in our calculations, the vacuum was chosen as the solvent while in study [15] gas or water was used as the solvent. On the other hand, the λmax value found by KAKITANI et al [23] is 203 nm. It is known that the HMO method is less accurate than the DFT, but the λmax value remains close to the result found by the DFT method.

Table 8. UV Absorption Wavelengths of Isomer 4 Compared to Other Theoretical and Experimental Data

DFT 6-31G (vacuum) Our study	**DFT 6-31G (gas) Other study [15]**	**DFT 6-31G (water) Other study [15]**	**HMO Other study [23]**
--------	210	199	203
180	181	178	-------

4. Conclusion

This DFT study provides a comprehensive exploration of the structural, electronic, and spectroscopic properties of four oxadiazole isomers. Our findings underscore significant disparities in their electronic and thermodynamic characteristics, with profound implications for their stability, reactivity, and potential applications. Among the isomers, isomer 4 emerged as the most stable and electrophilic, aligning with experimental observations regarding its derivatives. The calculated infrared (IR) and ultraviolet (UV) spectra offer valuable insights into the vibrational and electronic transitions within the oxadiazole framework. The pronounced IR absorption peaks associated with key molecular vibrations confirm the relevance of these isomers in chemical synthesis and characterization. However, the influence of solvent effects on UV spectra highlights the necessity for further investigations in diverse media to fully comprehend the environmental impacts on the electronic properties of these compounds.

Future research should prioritize the synthesis of these isomers under varying conditions to validate the computational predictions and assess their practical applications. Additionally, exploring the effects of substituents and functional groups on the electronic and thermodynamic properties of these isomers could provide valuable insights for tailoring their properties to specific needs. In conclusion, this study contributes significantly to our understanding of the oxadiazole family, providing a solid foundation for future research and applications. By elucidating the structural and electronic features of these isomers, we pave the way for the targeted design and optimization of oxadiazole-based compounds with enhanced properties for a wide range of applications.

Disclosure statement

The authors declare that there are no conflicts of interest.

References

1. Vitaku E., Smith D. T., and Njardarson J. T. (**2014**) Analysis of the structural diversity, substitution patterns, and frequency of nitrogen heterocycles among US FDA approved pharmaceuticals: miniperspective. *J. Med. Chem*., 57(24), 10257-10274. doi.org/10.1021/jm501100b
2. Pitasse-Santos P., Sueth-Santiago V., and Lima M. E. (2018) 1, 2, 4-and 1, 3, 4-Oxadiazoles as Scaffolds in the Development of Antiparasitic Agents. *J. Brazil. Chem. Society.*, 29(3), 435-456. doi.org/10.21577/0103-5053.20170208
3. Midoune A., and Messaoudi A. (**2020**) Etude computationnelle DFT/TD-DFT de la molécule tétrathiafulvalène-1, 3-benzothiazole pour mettre en évidence ses propriétés structurelles, électroniques, vibrationnelles et optiques non linéaires. *Comp. Rend. Chimie*., 23(2), 143-158.
4. Becke A. D. (**1992**) Density-functional thermochemistry. I. The effect of the exchange-only gradient correction. *J. Chem. Physics*., 96(3), 2155-2160. doi.org/10.1063/1.462066
5. Hehre W. J., and Stewart R. F., and Pople J. A. (**1969**) Self-consistent molecular-orbital methods. I. Use of Gaussian expansions of Slater-type atomic orbitals. *J. Chem. Physics.*, 51(6), 2657-2664. doi.org/10.1063/1.1672392
6. Virk N., Iqbal J., Aziz-ur-Rehman A., Abbasi M., Siddiqui S., Rasool S., Nisa M. N., Abid M. A., Hira K., Zafar F.,Javaid, H. (2023). In vitro biological assessment of 1, 3, 4-oxadiazole sandwiched by azinane and acetamides supported by molecular docking and BSA binding studies. *Curr. Chem. Letters.*, 12(2), 353-368. doi.org/10.5267/j.ccl.2022.12.004
7. El Hassani I. A., Brandán, S. A., Mortada, S., Arshad, S., Romano, E., Ramli, Y., Mague J. T., and Karrouchi K. (2024). 2-(allylthio)-5-(5-phenyl-1H-pyrazol-3-yl)-1, 3, 4-oxadiazole: Synthesis, single crystal XRD, spectroscopic characterization, antidiabetic activity, DFT and ADMET studies. *J. Mole. Structure*., 1295, 136620. doi.org/10.1016/j.molstruc.2023.136620
8. Oliveira M. S., Santos A. B., Ferraz T. V., Moura G. L., and Falcão, E. H. (2023). Non-symmetrical 1, 3, 4-oxadiazole derivatives: synthesis, characterization, and computational study of their optical properties. *Chem. Physics. Impa*., 6, 100162. doi.org/10.1016/j.chphi.2023.100162
9. Waghchaure R. H., and Adole V. A. (2024). DFT Computational Studies, Spectroscopic (UV–Vis, IR, NMR), In Silico Molecular Docking and ADME Study of 3-(3-Methylpyridin-2-yl)-5-phenyl-1, 2, 4-oxadiazole. *J. Mole. Structure*., 1296, 136724. doi.org/10.1016/j.molstruc.2023.136724
10. Govindarajan M., Karabacak M., Udayakumar V., and Periandy S. (**2012**) FT-IR, FT-Raman and UV spectral investigation: Computed frequency estimation analysis and electronic structure calculations on chlorobenzene using HF and DFT. *Spectrochimica Acta Part A: Mol. Biom. Spectroscopy.*, 85(1), 251-260. doi.org/10.1016/j.saa.2011.10.002
11. Gupta R. R., Kumar M., and Gupta V. (**2013**). Heterocyclic Chemistry: Volume II: Five-Membered Heterocycles. *Springer Science & Business Media*. doi.org/10.1007/978-3-662-07757-3
12. Katritzky A., Ramsden C. A., Joule J., and Zhdankin V. (**2010**) Handbook of heterocyclic chemistry. *3rd Edition - August 24, Oxford: Elsevier,*
13. Katritzky A. R., Ramsden C. A., Scriven E. F., and Taylor R. J. (**2008**) Comprehensive Heterocyclic Chemistry III. Vol. 6, Other Fivemembered Rings with Three or more Heteroatoms, and their Fused Carbocyclic Derivatives. *Amsterdam: Elsevier.,* 1-13718. doi.org/10.1016/C2009-1-28335-3

14. Naik L., Khazi I. A. M., and Malimath G. H. (**2020**) Electronic excitation energy transfer studies in binary mixtures of novel optoelectronically active 1, 3, 4-oxadiazoles and coumarin derivatives. *Chem. Phys. Letters*., 749, 137453. doi.org/10.1016/j.cplett.2020.137453
15. Faeez A., and Al-Saidi S. F. (**2017**) A Theoretical Study on the Vibrational and UV/VIS Spectra for the some 1, 3, 4-oxadiazole Derivatives by Using DFT Approach. *Research. J. Pharm. Biolo. Chem. Sciences*., 8(1), 299-309.
16. Pitasse-Santos P., Sueth-Santiago V., and Lima M. E. (**2018**) 1, 2, 4-and 1, 3, 4-Oxadiazoles as Scaffolds in the Development of Antiparasitic Agents. *J. Brazilian. Chem. Society*., 29(3), 435-456. doi.org/10.21577/0103-5053.20170208
17. Luczynski M., and Kudelko A. (**2022**) Agnieszka. Synthesis and Biological Activity of 1, 3, 4-Oxadiazoles Used in Medicine and Agriculture. *Applied Sciences.*, 12(8), 3756. doi.org/10.3390/app12083756
18. Nadir A., and Yahi C. (**2021**) Synthèse des nouvelles molécules à base de 1, 3, 4 Oxadiazole, évaluation de leurs activités biologiques. *Diss. Universite Mohamed Boudiaf-M'sila*.
19. Salassa G., and Terenzi A. (**2019**) Metal complexes of oxadiazole ligands: An overview. *Inter. J. Mole. Scien*., 20(14), 3483. doi.org/10.3390/ijms20143483
20. Glomb T., Szymankiewicz K., and Świątek, P. (**2018**) Anti-cancer activity of derivatives of 1, 3, 4-oxadiazole. *Molecules.*, 23(12), 3361. doi.org/10.3390/molecules23123361
21. Hegelund F., Larsen R. W., Aitken R. A., Aitken K. M., and Palmer M. H. (**2007**) Aitken. High-resolution infrared and theoretical study of four fundamental bands of gaseous 1, 3, 4-oxadiazole between 800 and 1600 cm^{-1}. *J. Mole. Spectroscopy*., 246(2), 198-212. doi.org/10.1016/j.jms.2007.09.011
22. El-Azhary A. A. (**1996**) Vibrational analysis of the spectra of 1, 3, 4-oxadiazole, 1, 3, 4-thiadiazole, 1, 2, 5-oxadiazole and 1, 2, 5-thiadiazole: comparison between DFT, MP2 and HF force fields. *Spect. Acta Part A: Mole. Biom. Spect*., 52(1), 33-44. doi.org/10.1016/0584-8539(95)01535-3
23. Kakitani T., and Kakitani H. (**1977**) Application of self-consistent HMO theory to heteroconjugated molecules. *Theoretica. Chimica. Acta*., 46, 259-275. doi.org/10.1007/BF00554512