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DFT analysis: correlation of epinephrine HOMO-LUMO, refractive index, optical electronegativity, and electrical conductivity with Substituted Halogens (F, Cl, Br)

R. O. Kareem✉

Physics Department, College of Science, University of Halabja,
Halabja 46018, Iraq

Abstract

Purpose: Epinephrine (EP) may affect lipid and glucose metabolism in addition to haemodynamic parameters, according to a number of studies. This study's primary goal was to provide a theoretical computer analysis of the EP molecule by including halogens like fluorine (F), chlorine (Cl), and bromine (Br): (EP, EP-Br, EP-Cl, and EP-F).

Experimental part: The Gaussian program was used to obtain the optimal shape of the EP compound, and the DFT/6-311G (d,p) basis set and B3LYP level of theory were employed. Quantum chemistry properties were then analyzed, including the energy gap (E_{HOMO}-E_{LUMO}), reduced density gradient (RDG), density of states (DOS), and molecular electrostatic potential (MEP) on surfaces.

Conclusions: The results showed that the larger refractive index of the EP-F molecule was associated with a higher value of EP-F (0.446 eV^{-1}) molecular softness, while the EP molecule exhibited higher hardness (η) (2.296 eV) and a smaller refractive index. On the other hand, a smaller bandgap for EP-F (4.483 eV) indicated reduced chemical stability, increased electron dispersion, a lower work function (2.40682 eV), and improved electrical conductivity (σ = 1.249). According to our Electron Localized Function (ELF) topological analysis data, the group of H atoms had a red patch around them, indicating an abundance of delocalized electrons.

Keywords: Epinephrine, DFT, Refractive Index, Electron Localized Function (ELF), Electrical Conductivity, Optical Electronegativity

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✉ Kareem R. O, e-mail: rebaz.kareem@uoh.edu.iq

1. Introduction

Although both norepinephrine (NEP) and epinephrine (EP) are catecholamines that are chemically similar and play a part in the fight-or-flight response, they are distinct from one another in terms of their receptor selectivity, spectrum of physiological effects, release patterns, and medical uses. Both are organic substances produced by the body's adrenal glands. In healthy individuals, NEP has been demonstrated to have an impact on hemodynamic parameters, lipid and carbohydrate metabolism, and plasma EP increases. On mineral metabolism, EP physiological effects are unknown. There are conflicting reports on how much EP affects blood magnesium levels and large dosages of the hormone have been shown to lower amounts of inorganic phosphorus and calcium [1]. EP is involved in the control of the sympathetic nervous system and the body's response to stress, whereas selenium is more closely linked to enzymatic processes and antioxidant defense [2]. The body releases adrenaline (AD) into the circulation in response to perceived stress or danger. Moreover, it is a component of various emergency medical circumstances, such as cardiac arrest, and is utilized medicinally to treat severe allergic responses. In cases of emergency or rapidly deteriorating circumstances, it can be given by injection [3]. The chemical structure of the powdered form of EP is white to almost white in microcrystalline form, tasteless, and melting point (211–212) °C. The pH of aqueous solutions is somewhat alkaline, numbing, somewhat bitter flavor.

The three -OH and one -NH groups found in the EP molecule are both involved in the formation of hydrogen bonds and are readily exposed to redox processes. The likelihood of an H-bond forming between these four potential bonding places is higher for the –OH group attached to C [5]. Moreover, carboxyl or carbonyl groups might develop as a result of the oxidative sensitivity of the aliphatic OH next to the amino group [6]. It is essential to comprehend the sites of binding and hydrogen bonding interactions of adrenaline [7]. After optimization, all bond lengths that surfaced fall within permissible boundaries [5]. By rotating the three angles from the alcohol groups, –COH, and the dihedral angle H–C–N–H, the potential energy surface (PES), in which the corresponding lowest energy was for the expanded geometry, was derived [6].

The chemical structure of EP includes halogen atoms, specifically one or two halogen atoms. It's important to note that the addition of halogen atoms, such as chlorine, fluorine, and bromine can influence certain properties of a compound, but in the case of epinephrine, the halide atoms mainly contribute to its structural configuration rather than dramatically altering its chemical or physical properties [8]. Energy in a chemical context can refer to various aspects, including the internal energy of the molecule, its potential energy in a certain environment, or its energy of formation. The presence of halides affects the bond energies within the molecule. The energy required to break or form bonds can be quantified, but these values depend on specific conditions [9].

The EP species' chemical stability demonstrates the results of the quantum chemical calculations. Among other electronic properties, the global hardness and chemical potential were computed. Density Functional Theory (DFT) was utilized to determine the molecular structure of the NEP molecule. In addition, the electronic distribution, energy-related to the structures, and distribution of HOMO and LUMO iso-surfaces are provided [6]. More investigation is required to find out more about the conformational stability of these substances [10]. On the other hand, for computing molecular structure, chemical reaction energies, and energy electronic calculations, DFT is a trustworthy and effective technique [11]. The improved molecular geometries [12]. They found that other factors outside the hydrogen bonding interaction are also responsible for the relative stabilities and activity [7]. An extensively employed approach for determining molecular energies and structural characteristics, as well as for accurately and successfully assessing many molecular properties, is the DFT method. Norepinephrine (NEP) and epinephrine (EP) are both catecholamines with similar chemical structures. The main difference between them is that norepinephrine has a hydrogen atom (H) attached to the nitrogen atom, while epinephrine has a methyl group (-CH_3) attached to the nitrogen atom. NEP plays a major role in the fight-or-flight response by increasing heart rate, blood pressure, and blood sugar levels. It not only increases heart rate, but also dilates airways and stimulates glucose release from the liver [13, 14].

The current study is the first theoretical report on the EP molecule, produced by introducing halogens into the ortho position of the benzene ring. Research was conducted mostly with the aim of performing a theoretical and computational analysis of the EP molecule by the inclusion of halogens such fluorine (F), chlorine (Cl), and bromine (Br) to the structure as shown in Fig. 1. Researchers have discovered a number of intriguing correlations between the HOMO-LUMO energy gap, the refractive index (*n*), the dielectric constant (ε), the electrical conductivity (σ), and the optical electronegativity (Δχ*). Additionally, they have discovered the Fermi level energy (*E*f) and the work function (Φ) of four distinct types of EP molecules. These molecules were created by employing substituted halogens with names such as: EP, EP-Br, EP-Cl, and EP-F.

2. Computational studied

The Gaussian 09W software suite was used to look at the structure of the epinephrine (EP) molecule using different halogens, which were named: epinephrine (EP), epinephrine bromine (EP-Br), epinephrine chlorine (EP-Cl), and epinephrine fluorine (EP-F) [15]. A useful way to study molecular structure is through the density-functional theory (DFT). Based on the B3LYP level of theory, and 6-311G(d, p) basis set, the EP molecule was optimized by using the DFT methodology. The following parameters are often recognized as eigenvalues that represent various energy-related properties: E_{HOMO}, E_{LUMO}, the energy band gap (Eg), ionization energy (IE), electron affinity (EA), absolute electronegativity (χ), global hardness (η), global softness (*S*). Also, the reduced density gradient (RDG), the density of state (DOS), and the molecular electrostatic potential (MEP) on surfaces have been investigated. The Multiwfn_3.7 program is used to create contour maps that illustrate the Electron localized function (ELF) for the title compounds [15–21]. For each chemical, we determine its essential optical characteristics, such as the, the Fermi level energy (*E*f), and the work function (Φ) [22, 23], refractive index (*n*), the dielectric constant (ε), electrical conductivity (σ), and the optical electronegativity (Δχ*): Moss relation [24], Ravind relation [25], Herve relation [25], Reddy relation [26], Kumar relation [27], Tripathy relation [27].

3. Result and Discussion

3.1. Geometric optimization and charge distribution

The optimal form was obtained by using the Gaussian software in conjunction with the DFT/

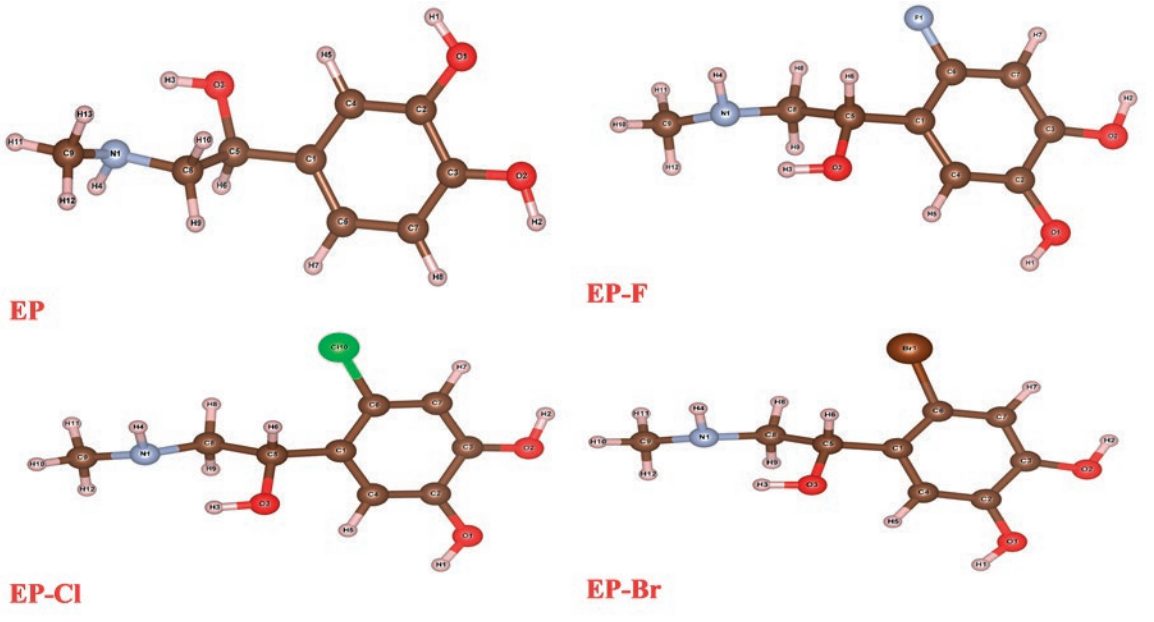

Fig. 1. The title compound's structure

6-311G (d,p) basi sets, which were neutral to the structure of the epinephrine (EP). This is shown in Fig. 1 left hand. The first step of a geometry optimization technique that can be used for this method is to look at the energy that is linked to a certain starting shape of the molecules. There is a clear correlation between the form and type of the molecular orbitals (MOs) of organic chemicals, which are often referred to as HOMO and LUMO, and the chemical and biological functions of these substances [18]. In comparison to other elements such as carbon (C), nitrogen (N), hydrogen (H), halogens like fluorine (F), chlorine (Cl), and bromine (Br), the nitrogen (N) atoms. The N-H groups was investigated to be the most negatively charged: (–0.4299, –0.4342, –0.4336, and –0.4335 e^-) for the EP, EP-Br, EP-Cl, and EP-F molecules. According to the results, the N element with EP has a lower charge (4N = -0.4299 e^-). This is because the electronegativity of the hydrogen or (H = 2.20) is less than Br, Cl, and F elements. As can be seen on the right-hand side of Fig. 2, the physicochemical characteristics and chemical reactions of the compounds EP, EP-F, EP-Cl, and EP- Br are influenced by the electrostatic potential (ESP) maps and the electron charge densities. It was observed that the charge distribution of all molecules was altered by the presence of halogens like fluorine (F), chlorine (Cl), and bromine (Br). Equation (1) provides a quantitative demonstration of the ESP creation surrounding molecules at a location and a point r (in atomic units) [28, 29]:

$$V_{(r)} = \sum_A \frac{Z_A}{\left[R_A - r\right]} - \int \frac{\rho(r)d\dot{r}}{\left[\dot{r} - r\right]}, \tag{1}$$

where $\rho(r)$ is the electronic density and ZA is the nucleus charge at RA. The overall charge distribu-

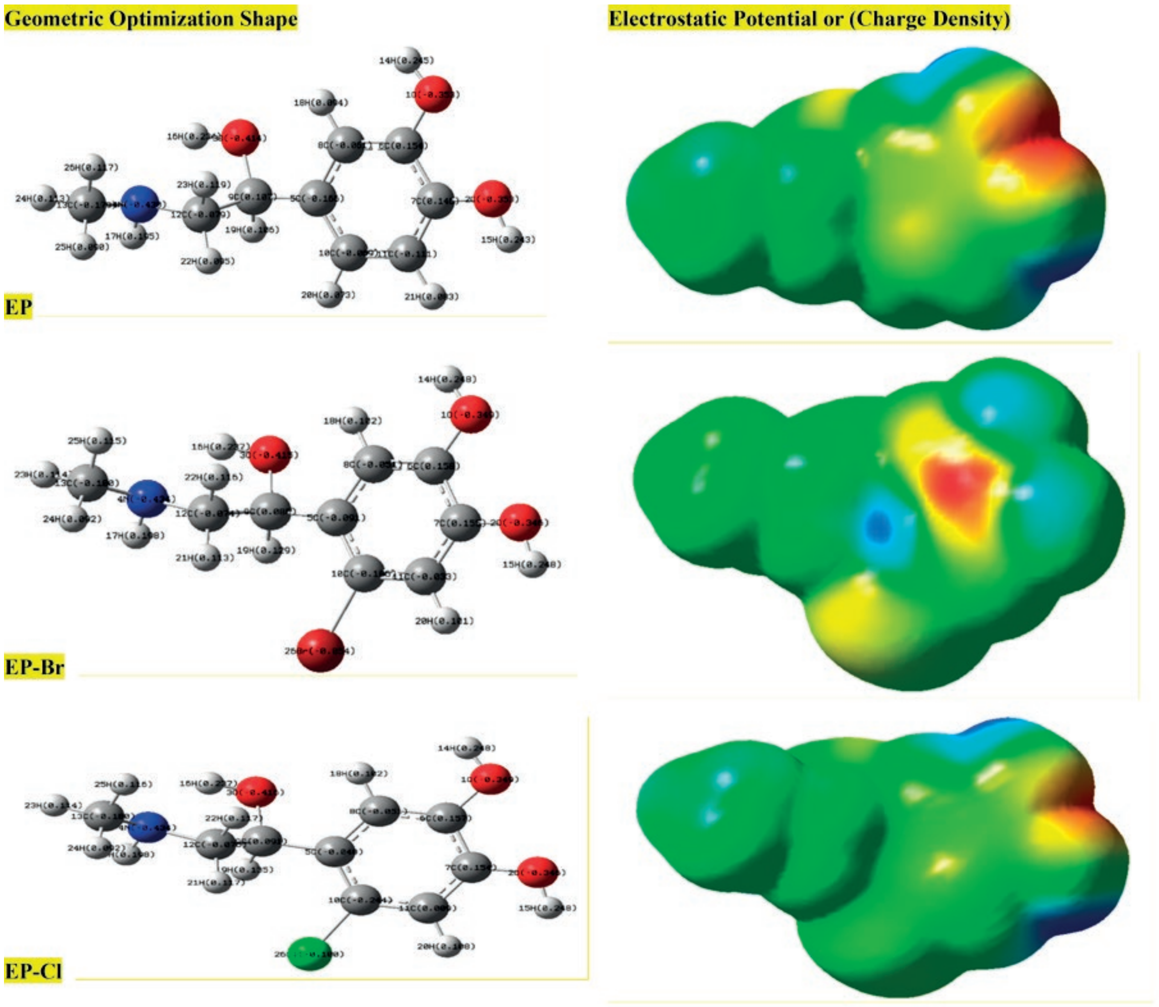

Fig. 2. Left-hand geometry optimization, right hand Electrostatic potential (ESP) surface, DFT approach

tion (electron + nucleus) of the molecule reflects the net electrostatic effect at *r*. The potential (*V*) is a function of distance (*r*). Molecular electrostatic potential (MEP) analysis is a powerful tool for studying the boundary of a molecule's charge concentration. Through the use of MEP analysis, the physicochemical characteristics of the system, including chemical reactivity, dipole moment, and partial charges, are linked to the geometry of the system shape [22]. A number of factors are associated with the ESP, including partial charges, electronegativity, the dipolar moment, and the location of chemical processes within the molecular structure. The various color zones that are connected with each molecule are related with varied electronegativity, which are ordered here: F = 3.98 > Cl = 3.16 > Br = 2.96 > H = 2.20 eV. In an electrostatic potential map, areas with a high electronegativity tend to correlate with redder zones, which indicates a more negative potential. On the other hand, areas with a low electronegativity will seem much more positive (bluer) zones. Fig. 2 shows that, according to the EP picture, C-OH had a higher negative charge density and a red zone than other groups. Blue has more positive charge, smaller electron density, and lower proton affinity. When the colors red, yellow, green, and blue are arranged in this way, the potential is increased. The existence of a broad negative zone (green) range is an indication that the molecular structure of norepinephrine (EP, EP-Br, EP-Cl, and EP-F) is particularly reactive with nucleophilic types. This is shown by the fact that the range of the negative zone is vast [29, 30].

3.2. Global reactivates analyses

As can be seen in Fig. 3, the energy gap (*Eg*) that exists between the highest occupied molecular orbital (HOMO), and the lowest unoccupied molecular orbital (LUMO) is examined in this section. Additionally, the Frontier molecular orbitals (FMOs) of (EP, EP-Br, EP-Cl, and EP-F) compounds are analyzed as well. FMO analysis is crucial because it reveals the optical properties and electronic behavior of the material. In addition, it provides details on the electrical conductivity of the compound, the distribution of electrons, its stability, and its resistance to sensing. The energy gap (*Eg*) values reveal aspects of charge transport and system reactivity. The complex with the lowest energy gap values has a large electronic distribution from donor to acceptor orbitals, resulting in increased electrical conductivity of title compounds. A smaller bandgap (*Eg*) E_{HOMO}-E_{LUMO} is associated with higher electrical conductivity, more electron dispersion, less chemical stability, and more reactivity, according to a review of the literature [12, 17, 22, 31]. The term "E_{HOMO}-E_{LUMO} energy gap" is used in the context of molecular orbitals to refer to the minimum amount of energy that is necessary to transfer a molecular orbital from its occupied state to its unoccupied state. It is necessary to investigate, and evaluate both the HOMO and the LUMO aspects of the system in order to acquire an understanding of the electronic structure of the molecular system as well as the mechanism that is responsible for the transfer of potential energy, and chemical stability- reactivity of molecules.

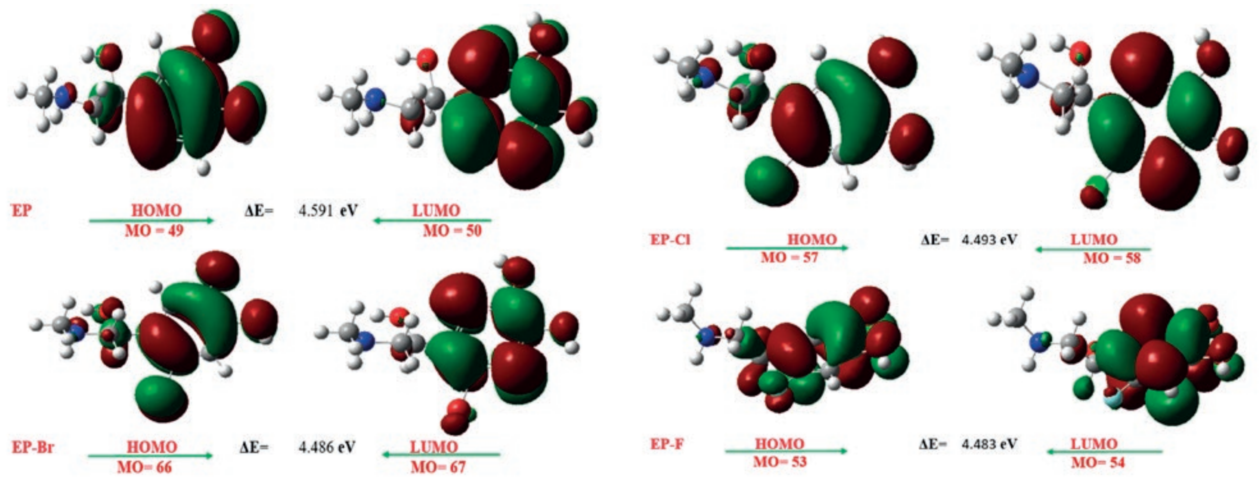

Fig. 3. The Front molecular orbitals (FMOs) diagram according to HOMO-LUMO

An inventory of the HOMO-LUMO energy gap as well as other global reactivities of all compounds can be found in Table 1, which can be seen below. The DFT/ B3LYP level of theory (technique) was used to determine this gap using the basis sets 6-311G (d, p) [16, 17, 32, 33].

Fig. 4a displays the graph illustrating the variety of correlation between the HOMO, and LUMO of the compounds, as well as the energy gap. The EP-F compound with a lower energy gap of 4.483 eV shows characteristics of high electronic distribution, low chemical stability, high electrical conductivity, and high reactivity. In contrast EP, EP-Br, and EP-Cl have higher energy gaps, resulting in less electronic distribution, high stability, low electrical conductivity, and low reactivity. The EP-F values with the lowest energy gap, which are 4.483 eV, have a significant electronic dispersion from the donor orbitals to the acceptor orbitals.

According to the literature assessment, systems with higher chemical hardness and ionization potential values imply less reactivity than systems with lower values. Because they can transmit electrons more easily than hard molecules, soft molecules are more reactive. In Table 1, molecular hardnesses are listed from greatest to lowest: EP > EP-Cl > EP-Br > EP-F while molecular softness EP-F > EP-Br > EP- Cl > EP compounds. The PE-F molecule has a softness of 0.446 eV^{-1}, which indicates that it is very capable of transferring electrons. According to Fig. 4b, based on this, we may deduce that a larger energy band gap indicates a lower molecular softness, and that the reverse is also true: that a higher molecular hardness is correlated with a

Table 1. Calculation of global reactivates parameters DFT/ 6-311 G (d, p)

Parameters Calculation [16, 17, 18, 19, 34, 35, 36]	EP	EP-Br	EP-Cl	EP-F	Recent study DFT/ SSD [17]
HOMO (eV)	−4.57086	−4.76543	−4.76854	−4.64816	−5.698
LUMO (eV)	0.02043	−0.27986	−0.27564	−0.16547	−0.101
IP (eV)	4.571	4.765	4.769	4.648	5.698
EA (eV)	−0.020	0.280	0.276	0.165	0.101
Band gap energy (E_g) (eV)	4.591	4.486	4.493	4.483	5.597
Hardness (η) (eV)	2.296	2.243	2.246	2.241	2.798
Softness (S) (eV^{-1})	0.436	0.445	0.445	0.446	0.357
Electronegativity (χ) (eV)	2.275	2.523	2.522	2.407	2.899
Chemical potential (μ) (eV)	−2.275	−2.523	−2.522	−2.407	–

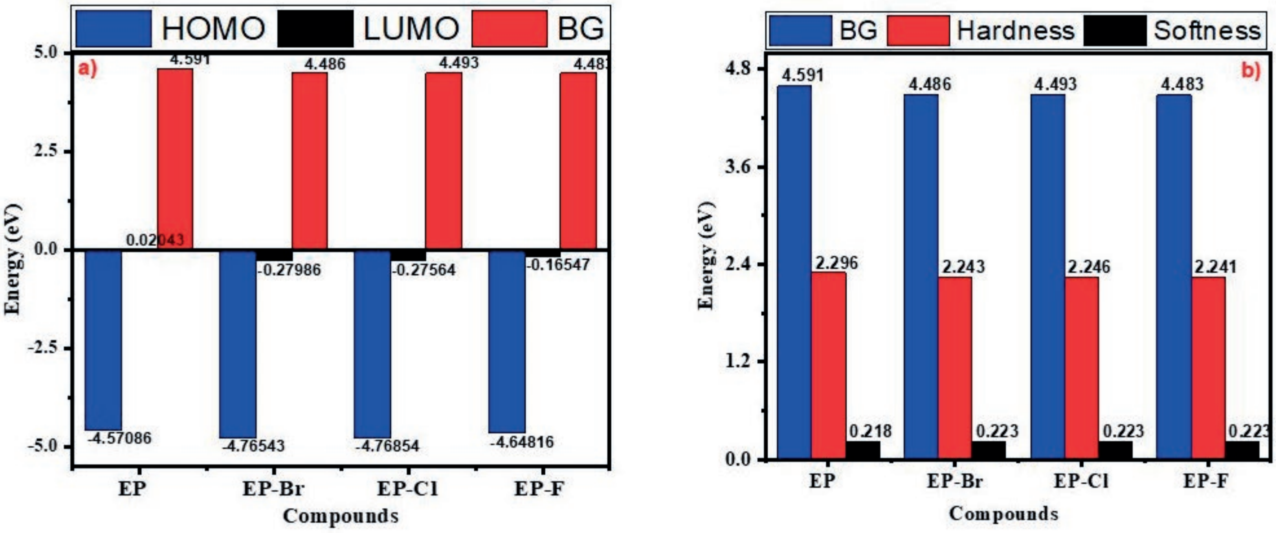

Fig. 4. Displays calculations for Compression HOMO, LUMO, BG, hardness, and softness

lower softness (Fig. 4b). Electronegativity, which is represented by the symbol χ, is a measurement that measures the ability of an atom to take an electron. It is possible that EP-Br attracts electrons with a larger degree of attraction force when its electronegativity is high (2.523 eV), since this indicates that the element has a high electronegativity capacity [17, 30, 37, 38]. Based on the current findings, the literature analysis confirms and agrees with the HOMO and LUMO calculation approaches [17].

3.3. Optical properties

The optical characteristics of norepinephrine, including its refractive index (*n*), dielectric constant (ε), and optical electronegativity (Δχ*), are discussed in this section. The following formula is used to determine the refractive index of the EP, EP-Br, EP-Cl, and EP-F: Moss et al. [24], Ravindra et al. [25], Herve et al. [25], Reddy et al. [26], Kumar et al., and Tripathy et al. [27]. The coefficients of the refractive index that were estimated by using the Moss, Tripathy, Kumar, and Herve equations each have values that are rather close to one another, as can be observed by looking at the information that was collected in Table 2. The association between the refractive index and the energy gap is laid out in Tables 1, 2 are listed from the highest to lowest value: refractive index (EP-F> EP-Br > EP-Cl> EP), while energy gap (EP> EP-Cl> EP-Br> EP-F). From the information shown in Tables 1 and 2, it is clear that the refractive index of EP Derivatives and the HOMO-LUMO energy gap are inversely connected to one another. The high refractive index corresponds with great molecular softness. The big energy gap is connected with a decreased refractive index. As demonstrated in Tables 2 and 3, the dielectric constant (ε) of the EP, EP-Br, EP-Cl, and EP-F increases with increasing optical refractive index values for these elements. According to the data shown in Tables 1, 2, and 3, a higher energy gap is associated with a lower refractive index and a lower dielectric constant [39, 40]. Our findings indicate that high molecular softness (S) correlates with a high refractive index, whereas high hardness (η) correlates with a low refractive index.

3.4. Correlation between Fermi energy, and energy gap

The energy gap (*E*g) values, Fermi level energy (*E*f), and work function (Φ) values obtained in the present study provide electronic distribution, low chemical stability, high electrical conductivity, and high reactivity. The DFT/B3LYP level of theory (technique) was used to determine this Fermi level energy, and work function 6-311G (d, p) basis sets. Equation (2) provides the formula for calculating the Fermi level energy or (Ef), which is the amount of energy that an electron occupies while it is at a temperature of zero degrees Celsius. This energy may be derived from the FMO orbitals. where the work function or (Φ)

Table 2. Refractive indexes of compounds (*n*)

Species	EP	EP-Br	EP-Cl	EP-F
Moss Relation [24]	2.13281938	2.145192	2.144356	2.14555
Ravind Relation [25]	1.23744575	1.302542	1.298202	1.304402
Herve Relation [25]	1.96123086	1.980418	1.979121	1.980974
Reddy Relation [26]	2.45695842	2.472461	2.471413	2.472912
Kumar Relation [27]	2.05995684	2.075377	2.074334	2.075825
Tripathy Relation [27]	2.00701618	2.023146	2.022042	2.02362

Table 3. Dielectric constants of computed (ε)

Species	EP	EP-Br	EP-Cl	NEP-F
Moss Relation [24]	4.548919	4.601847	4.5983	4.6034
Ravind Relation [25]	1.531272	1.696615	1.6853	1.7015
Herve Relation [25]	3.846427	3.922054	3.9169	3.9243
Reddy Relation [26]	6.036645	6.113066	6.1079	6.1153
Kumar Relation [27]	4.243422	4.30719	4.3029	4.3090
Tripathy Relation [27]	4.028114	4.09312	4.0887	4.0950

is the amount of energy that must be expended in order to remove one electron from the Fermi level [41].

$$\text{Fermi level energy } (Ef) = \frac{\text{HOMO} + \text{LUMO}}{2}, \qquad (2)$$

$$\Phi = \text{Vel}(+, \infty) - Ef, \qquad (3)$$

where the electrostatic potential energy of the electron far from the surface of the material is denoted by *V*el (+, ∞), and it is equal to zero. Because of chemical interactions and the transfer of energy levels from the HOMO to the LUMO, substituted halogens such as fluorine (F), chlorine (Cl), and bromine (Br) also impact the *E*f and work function (*F*) values for epinephrine or (EP) compounds. As a result of the fact that the electrostatic potential energy is equal to zero, the work function (Φ) is taken as the negative of the Fermi level energy value. The *E*f is computed by taking the average of the HOMO and LUMO energy values [23]. Using Equation (3), we can determine the relationship that exists between the work function and the Fermi level energy. The variations in the values of the work function also show that there is a transfer of charges between substituted halogens and compounds including epinephrine (EP) [23]. The values of the minimal work function (2.40682) and the Fermi level energy (−2.40682) are experienced by the EP-F compound. According of this, the small energy bandgap (*E*g) indicates better electrical conductivity, greater electron dispersion, less chemical stability, minimal work function, and the Fermi level energy as seen in Table 5, and Fig. 5. As a result of this, the small energy bandgap (*E*g) exhibits characteristics such as improved electrical conductivity, increased electron dispersion, decreased chemical stability, a minimum work function, and the Fermi level energy, as can be shown in Table 5 and Fig. 5.

Table 4. Optical electronegativity ($\Delta\chi^*$)

Compounds Name	6-311G (d, p)
EP	0.058375
EP-Br	1.202248
EP-Cl	1.204124
EP-F	1.201444

Table 5. The work function (Φ), Fermi level energy (*E*f), and energy gap (*E*g) correlation

Compounds Name	Eg (eV)	Ef [23] (eV)	Φ [22, 23] (eV)
EP	4.591	−2.27521	2.27521
EP-Br	4.486	−2.52265	2.52265
EP-Cl	4.493	−2.52209	2.52209
EP-F	4.483	−2.40682	2.40682

3.5. Electrical conductivity

The process by which electrons travel from the valence band (VB) to the conduction band (CB) is referred to as the electrical conductivity of a substance. The varied electronic properties of the complexes are the cause of the variations in the electrical conductivity of the complexes. Equation (4) is the primary factor in determining the electrical conductivity [42]:

$$\sigma = \text{A}\,T^{\frac{3}{2}} \times \text{EXP}^{\left(\frac{-E}{2KT}\right)}. \qquad (4)$$

Where σ is the electrical conductivity, A is the Richardson constant ($\text{A} = 6{\cdot}10^6$, $T = 298.16$), Boltzmann constant ($K = 8.318{\cdot}10^6$ kJ/ mol·k) [43]. The presented equation establishes a connection between the HOMO–LUMO energy gap values and the electrical conductivity of the complexes. As can be seen in Table 6, this data reveals that an increase in the values of the energy gap leads to a decrease in the electrical conductivity of the compounds.

3.6. Electron localized function (ELF) topological analysis

Electron localized function (ELF) topology studies are often used to reveal the structure of atomic shells, categorize chemical bonds, and validate charge-shift bonds on the surface of molecules, as well as electron concentrations such as bonding, nonbonding, and lone pair. ELF employs τ (*r*) to detect the additional kinetic energy density induced by Pauli's repulsion principle [44]. The Multiwfn_3.7 program is used

Table 6. The electrical conductivity (σ), and energy gap (*E*g) correlation

Compounds Name	*E*g (*E*v)	σ
EP	4.591	122
EP-Br	4.486	1.248
EP-Cl	4.493	1.247
EP-F	4.483	1.249

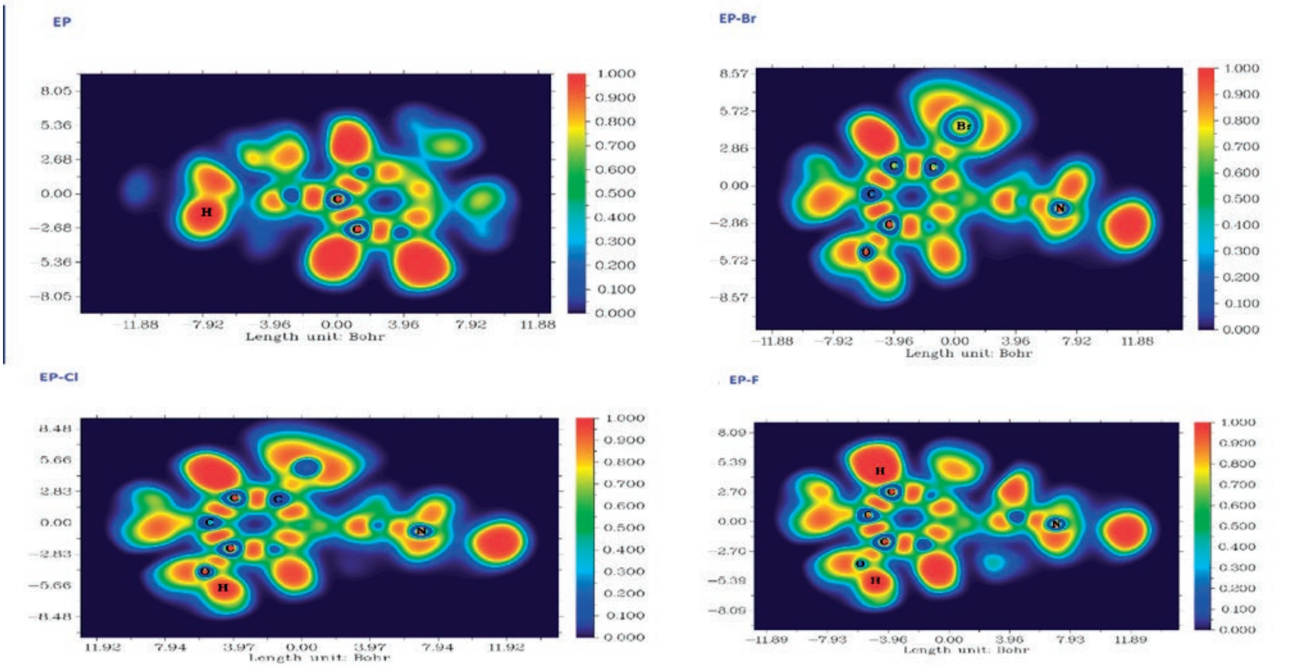

Fig. 5. Electron localized function (ELF) topology

to create contour maps that illustrate the ELF for the title compounds, as seen in Fig. 5 [45].

Fig. 5 depicts ELF color-filled maps ranging from 1.0 to 0.0, illustrated by red and blue colors, respectively. The red color patches surrounding C-C, C-N, and bonds have greater density values, indicating interaction with a confined electron cloud, particularly the hydrogen atoms in terminal carbon. The blue hue area surrounding a few C atoms in compounds indicates delocalized bonding. The group of H atoms has a red area encircling them, which indicates that there are an excessive number of electrons that are considered to be delocalized (Fig. 5) [44, 46].

3.7. RDG analyses

The Multiwfn application was applied in order to accomplish the task of making the colorful RDG scatter plots [45], whereas the VMD program was utilized in order to achieve the goal of delivering a graphical representation of the three-dimensional iso surface [47]. Chemical interactions influence the stability of molecular structures. Analyzing reduced density gradient (RDG) calculations may help identify weak interaction or intermolecular forces attraction. The colorful RDG scatter plots were generated using the Multiwfn free software. For the purpose of determining the RDG values, we applied Equation (5) below according to the electron density $\rho(r)$:

$$\mathrm{RDG}(r) = \frac{1\left|\nabla\rho(r)\right|}{2(3\pi r^2)^{\frac{1}{3}}\rho^{\frac{4}{3}}(r)}. \quad (5)$$

In three-dimensional space, r stands for the position vector. This vector indicates a particular place in space where several criteria – including electron density and its gradient – are assessed. The low-density gradient reveals regions that contain a limited number of electrons, which are the cause of weak interactions. As part of the isosurface plots, RDG is plotted against the second eigenvalue of the electron density Hessian matrix ($\lambda 2$), and the electron density $\rho(r)$. The characteristics of weak interaction may be determined from the isosurface, and these characteristics are dependent on the values of $\lambda 2$. The blue zone, which is characterized by negative values, also known as $\lambda 2\ (\mathrm{r})\ \rho(r) < 0$, is associated with strong interactions, such as hydrogen bonding, and a high electron charge density. As opposed to the green zone, which corresponds to van der Waal interactions that are relatively weak, the red zone, which has positive values $\lambda 2(r)\ \rho(r) > 0$, indicates a strong repulsive interaction and a drop in electron density. The green zone is marked by the sign $\lambda 2(r)\ \rho(r) \approx 0$. The RDG plots that were anticipated for the test compounds EP, EP-Br, EP-Cl, and EP-F are shown in Fig 6.

3.8. Density of state (DOS)

The density of state, often known as DOS, is a crucial metric that provides information on the number of states that exist inside the HOMO-LUMO unit energy interval for a certain chemical system. Its graph is used for the purpose of assessing the type of electron structure in addition to the distribution of molecular orbitals along with the energies linked with their E_{HOMO}, and E_{LUMO} constituents. For the purpose of determining the DOS of the compounds that were investigated, we used the DFT/6-311G (d,p) basis set in this study. Equation (6) allows one to determine the DOS in relation to energy levels [23,48-52]:

$$\mathrm{DOS}(E) = \Sigma\, g(E - \varepsilon_i). \qquad (6)$$

In this formula, *E* represents the total electron energy, '*g*' corresponds to a Gaussian function with a fixed Full Width at Half Maximum (FWHM) of = 0.3, and ε_i signifies the energy associated with the i^th [53]. It was discovered that the variation in the energy gap (*E*g): 0.1687, 0.1648, 0.1651, and 0.1647 a.u for the EP, EP-Br, EP-Cl, and EP-F, respectively in Fig. 7. Therefore, it is possible to draw the conclusion that the highest and lowest DOS values in the *E*g were found for compounds containing EP and EP-F compounds. With the presence of substituted halogens in the epinephrine (EP) molecule, it is possible that the density of states (DOS) of the molecule will be altered, as shown in Fig. 7. This is in addition to the peak shifts that occur in the electronic spectra of the molecule. This may be attributed to a number of factors, including the following: shifts in the energy levels of electronic states and the orbitals of molecules.

4. Conclusion

In conclusion, our extensive investigation employing Gaussian program simulations with DFT/6-31G(d,p) basis set, and substituted halogens in the molecule of epinephrine (EP)

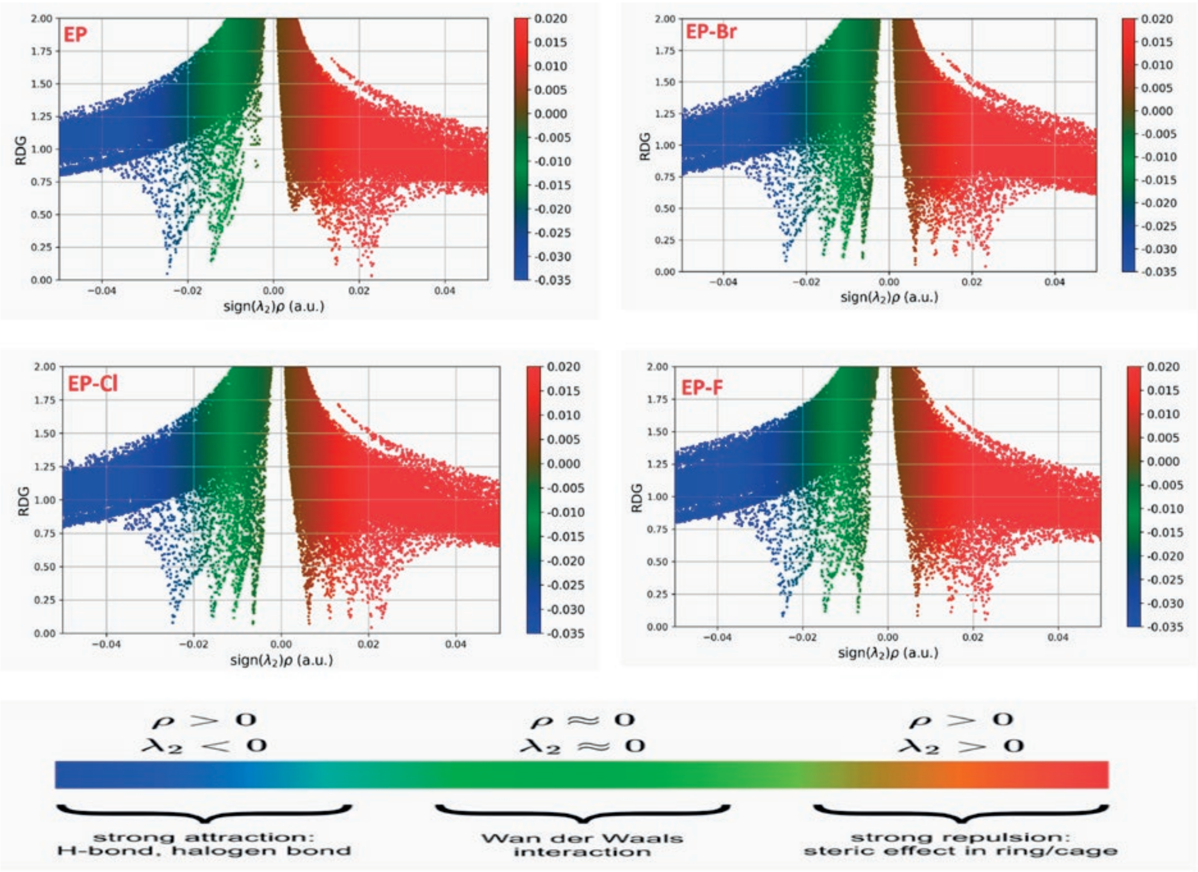

Fig. 6. The RDG scatter

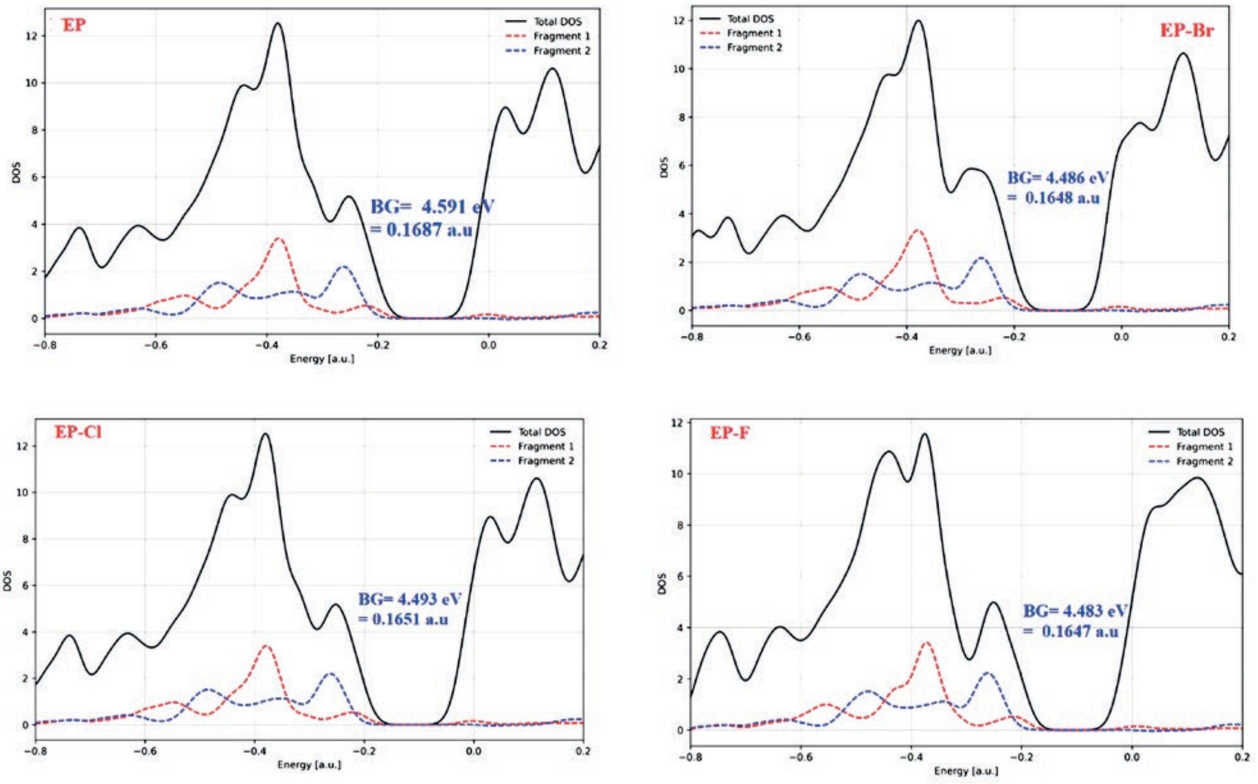

Fig. 7. Total Energy (a.u), the density of state (DOS) using Fragments 1, and 2 DFT/B3LYP/ 6-311G (d,p)

compounds offered crucial insights into their molecular properties. Front molecular orbitals (FMOs), which include HOMO and LUMO as well as other molecular orbitals, provide information about electronic structure, chemical stability, and reactivity. Estimated HOMO-LUMO energy gaps at the B3LYP level of theory (method), The EP-F compound with a smaller energy gap of 4.483 eV has excellent electrical conductivity, reactivity, and electronic distribution, and less chemical stability. Results show that the PE-F molecule has a softness of 0.446 eV^{-1}, which indicates that it is very capable of transferring electrons. The optical characteristics of epinephrine, including its refractive index (*n*), dielectric constant (ε), and optical electronegativity (Δχ*), are discussed in this section. The correlation between refractive index, and energy gap are listed from the highest to lowest value: refractive index (EP-F > EP-Br > EP-Cl > EP), while energy gap (EP > EP-Cl > EP-Br > EP-F). When the refractive index is high, it means that the molecules are relatively soft, while large hardness (η) is related to small refractive index. It is associated with a higher energy gap and is associated with a lower refractive index and a lower dielectric constant. Results from calculations show that a smaller bandgap (*Eg*) implies a higher Fermi level energy, poorer chemical stability, a smaller work function (Φ), and better electrical conductivity. The optical electronegativity (Δχ*) was used to distinguish between different kinds of bonds, and the correlation between lower Δχ* values and higher refractive indices demonstrated its connection to the HOMO-LUMO energy gap. The presence of substituted halogens in the molecule of norepinephrine, often referred to as NEP, has the ability to bring about alterations in the energy levels of electronic states, and the orbitals of molecules. This is because the molecule contains halogens that have been replaced. Modifications in the physicochemical properties of the EP molecule, including its stability and reactivity, are also seen. According to our ELF data, the group of H atoms have a red patch surrounding them, indicating that there are too many delocalized electrons.

The online version contains supplementary material

Conflict of interests

The author declares that he has no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Information about the author

Rebaz Obaid Kareem, M.Sc in General Physics, Lecturer at the Departmet of Physics, Faculty of Science, Physics Department, Halabja University (Kurdistan Region, Iraq).

https://orcid.org/0000-0001-6273-1309

rebaz.kareem@uoh.edi.iq

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