

Original Scientific Paper

Development of Mathematical Methods of DFT by Using the Physical Chemistry Parameters of Quinolines $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$

RAHIM ESMKHANI* AND MOUNES HANAFOROUGH

Department of Chemistry, Khoy Branch, Islamic Azad University, Khoy, Iran

ARTICLE INFO

Article History:

Received: 22 May 2022

Accepted: 15 July 2022

Published online: 30 September 2022

Academic Editor: Adel Reisi-Vanani

Keywords:

Quinolones

 $C_{26}H_{23}ClN_4$ $C_{26}H_{23}FN_4$

DFT

Primitive

Exchange and correlation

Energy

Chemical activity

ABSTRACT

Quinolones are synthetic compounds which are part of the antibiotics family. Quinolines were first obtained in 1834 and isoquinolines were obtained from coal tar in 1885. In this paper, exchange and correlation energies of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are calculated by using the DFT methods with STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets. The optimized structure and electronic properties calculations for the studied molecule have been performed by using Gaussian 09 program. A mathematical equation of second grade was exploited for the correlation and exchange energy with the number of primitives. The chemical reactivity of the $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been investigated at B3LYP/6-31G (d) level of theory. The band gap energy, total energy (E), chemical hardness (η), electronic chemical potential (μ), and global electrophilicity index (ω), ionization potential (IP) and electron affinity (EA) for the $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been calculated for the chemical activity of the above molecules. According to the results, the $C_{26}H_{23}ClN_4$ molecule is more stable and the chemical activity of $C_{26}H_{23}FN_4$ is greater.

© 2022 University of Kashan Press. All rights reserved

1. INTRODUCTION

Quinolines are synthetic compounds which are part of the antibiotics family. Quinolines were first obtained in 1834 and isoquinolines were obtained from coal tar in 1885. Today, studies

*Corresponding Author (Email address: resmkhani@iaukhoy.ac.ir; resmkhani_84@yahoo.com)

DOI: 10.22052/IJMC.2022.246403.1627

on these compounds have shown that these compounds have applications in the pharmaceutical industry, especially in neuroleptics and activities that play a role in the function of Alzheimer's disease and tumor disease. The isoquinoline skeleton is found in a large number of naturally occurring and synthetic biologically active heterocyclic compounds [1–3]. In particular, 1,2-dihydroisoquinoline derivatives are part of delivery systems that transport drugs through the otherwise highly impermeable blood-brain barrier [4]. These compounds also exhibit sedative [5], antidepressant [6,7], antitumor, and antimicrobial activities [8]. Synthesis of 3-(*t*-butylimino or cyclohexylimino)-2-aryl-2,3-dihydropyrrolo[2,1-*a*]isoquinoline-1,1(10b *H*) dicarbonitriles was developed through a one-pot four-component high-yield reaction of malononitrile, an aldehyde, isoquinoline and *t*-butylisocyanide or cyclohexylisocyanide [9].

In this paper, the structural properties of quinolines with the formula of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are calculated by using the DFT methods with STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets. Then mathematical equations for correlation and exchange energies for this molecule have been calculated comparing to primitive numbers. The band gap energy, total energy (E), chemical hardness (η), electronic chemical potential (μ), and global electrophilicity index (ω), ionization potential (IP) and electron affinity (EA) for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been calculated by using B3LYP/6-31g.

2. METHODS

All computations on $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been carried out by using Gaussian 09 program at the restricted LSDA, B3LYP, PBEPBE, MPW1PW91, HF, MP2 levels in STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets. Exchange and correlation energies in the above mentioned basis sets were calculated and the curve for correlation and exchange energies according to the number of primitives were drawn by using Excell 2013 and the mathematical equation between them was obtained.

Energy minimum molecular geometries were located by minimizing energy. The chemical reactivity of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been investigated at B3LYP/6-31G(d) level of theory.

3. RESULTS AND DISCUSSION

3.1. MOLECULAR PROPERTIES

The structure of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are shown in Figures 1 and 2. All computations are carried out by using Gaussian 09 program.

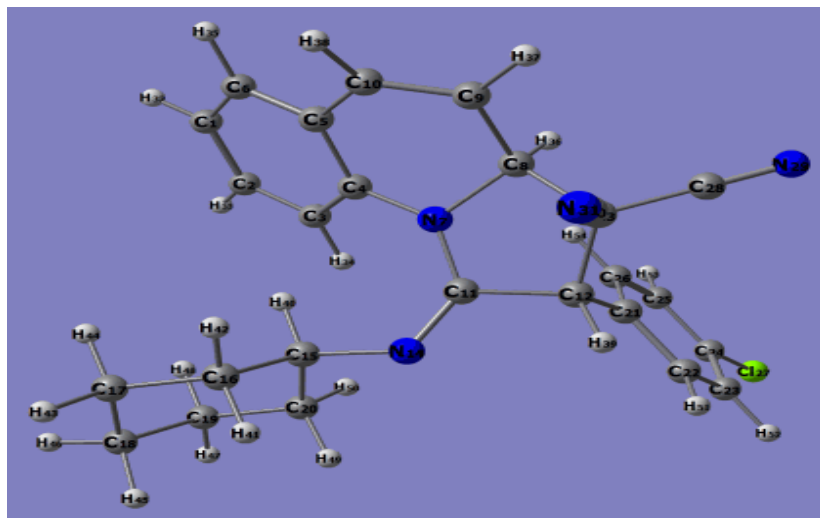


Figure 1. The theoretical optimized possible geometric structure with numbering of $C_{26}H_{23}ClN_4$.

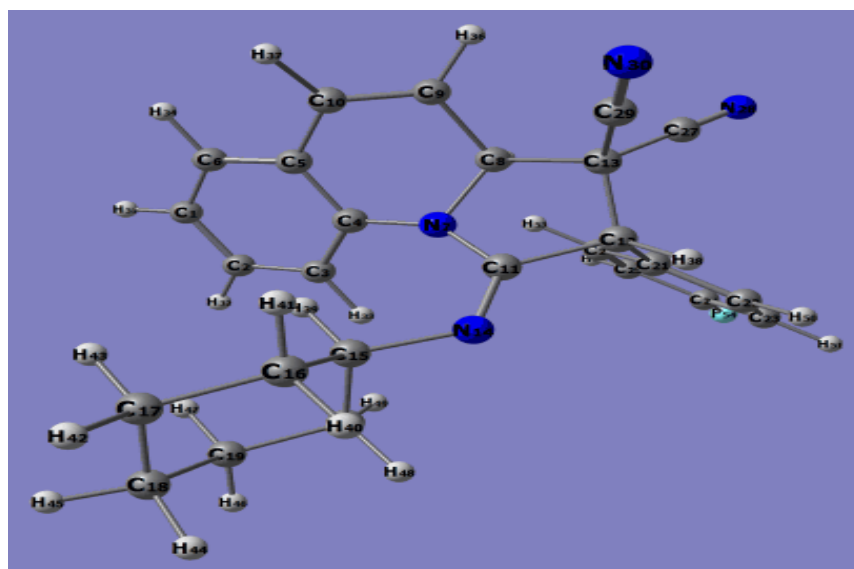


Figure 2. The theoretical optimized possible geometric structure with numbering of $C_{26}H_{23}FN_4$.

3.2. EXCHANGE AND CORRELATION ENERGY CALCULATED

The total optimized energy of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ at the RHF and RMP2 levels in STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets are calculated using Gaussian 09. Correlation energy is calculated with Equation (1). The results of these calculations are shown in Tables 1 and 2 [10].

$$E_{\text{correlation}} = E_{\text{RMP2}} - E_{\text{RHF}} \quad (1)$$

To calculate the exchange energy, total optimized energy of $\text{C}_{26}\text{H}_{23}\text{ClN}_4$ and $\text{C}_{26}\text{H}_{23}\text{FN}_4$ at the restricted LSDA, B3LYP, PBEPBE, MPW1PW91 levels in STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets are calculated. The average of energy differences in different levels is equal to exchange energies in the mentioned levels. The results of the exchange energy are shown in Tables 3 and 4.

The number of the primitives in 3-21G, 6-31G and 6-311G basis sets are 546, 798 and 938, respectively. The correlation and exchange energy diagrams in relation with the primitives number is drawn using Excell 2013 and using fitting method, the mathematical equations are exploited. The results are shown in the Figures 3 to 6 and Tables 5 to 8.

Table 1: The correlation energy calculated for $\text{C}_{26}\text{H}_{23}\text{ClN}_4$ at STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets.

Basis set	$E_{\text{HF}}(\text{au})^a$	$E_{\text{MP2}}(\text{au})$	$E_{\text{corr.}}(\text{au}) = E_{\text{MP2}} - E_{\text{HF}}$
STO-3g	-1655.2388	-1656.9639	-1.7250
3-21g	-1666.0777	-1668.8694	-2.7917
6-31g	-1674.4960	-1677.2902	-2.7942
6-311g	-1674.7433	-1677.7619	-3.0186
6-21g	-1673.6265	-1676.4151	-2.7886

au : atomic unit

Table 2: The correlation energy calculated for $\text{C}_{26}\text{H}_{23}\text{FN}_4$ at STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets.

Basis set	$E_{\text{HF}}(\text{au})^a$	$E_{\text{MP2}}(\text{au})$	$E_{\text{corr.}}(\text{au}) = E_{\text{MP2}} - E_{\text{HF}}$
STO-3g	-1298.5689	-1300.2196	-1.6508
3-21g	-1307.5643	-1310.3836	-2.8193
6-31g	-1314.3213	-1317.1452	-2.8238
6-311g	-1314.5773	-1316.7004	-2.1230
6-21g	-1313.3386	-1316.1564	-2.8178

au : atomic unit

Table 3: The exchange energy is calculated for $C_{26}H_{23}ClN_4$ at STO-3G, 3-21G, 6-31G, 6-311G and 6-21G basis sets.

Method	Total Energy (au)					Energy Difference (au)				
	STO-3g	3-21g	6-31g	6-311g	6-21g	STO-3g	3-21g	6-31g	6-311g	6-21g
LSDA	-1655.4015	-1666.7692	-1675.2229	-1675.5921	-1674.3481	-7.9840	-7.9163	-8.0007	-7.9310	-7.9752
B3LYP	-1663.3854	-1674.6855	-1683.2236	-1683.5231	-1682.3233					
MPW1PW91	-1663.3564	-1674.4348	-1682.9764	-1683.2444	-1682.0709	-0.0290	-0.2507	-0.2472	-0.2787	-0.2524
B3LYP	-1663.3854	-1674.6855	-1683.2236	-1683.5231	-1682.3233					
PBEPBE	-1661.7426	-1672.9558	-1681.5235	-1681.8152	-1680.6052	-1.6428	-1.7297	-1.7001	-1.7079	-1.7181
B3LYP	-1663.3854	-1674.6855	-1683.2236	-1683.5231	-1682.3233					
PBEPBE	-1661.7426	-1672.9558	-1681.5235	-1681.8152	-1680.6052	-1.6138	-1.4790	-1.4529	-1.4292	-1.4657
MPW1PW91	-1663.3564	-1674.4348	-1682.9764	-1683.2444	-1682.0709					
LSDA	-1655.4015	-1666.7692	-1675.2229	-1675.5921	-1674.3481	-7.9549	-7.6656	-7.7535	-7.6523	-7.7228
MPW1PW91	-1663.3564	-1674.4348	-1682.9764	-1683.2444	-1682.0709					
LSDA	-1655.4015	-1666.7692	-1675.2229	-1675.5921	-1674.3481	-6.3411	-6.1866	-6.3006	-6.2231	-6.2571
PBEPBE	-1661.7426	-1672.9558	-1681.5235	-1681.8152	-1680.6052					
Average =Exchange Energy(au)						-4.2609	-4.2047	-4.2425	-4.2037	-4.2319

Table 4: The exchange energy are calculated for $C_{26}H_{23}FN_4$ at STO-3G, 3-21G,6-31G, 6-311G and 6-21G basis sets.

Method	Total Energy (au)					Energy Difference (au)				
	STO-3g	3-21g	6-31g	6-311g	6-21g	STO-3g	3-21g	6-31g	6-311g	6-21g
LSDA	-1299.1966	-1308.6723	-1315.4554	-1315.8242	-1314.4587	-7.2597	-7.2029	-7.2893	-7.2247	-7.2619
B3LYP	-1306.4563	-1315.8752	-1322.7447	-1323.0489	-1321.7206					
MPW1PW91	-1306.3847	-1315.5937	-1322.4642	-1322.7377	-1321.4373	-0.0716	-0.2816	-0.2805	-0.3112	-0.2833
B3LYP	-1306.4563	-1315.8752	-1322.7447	-1323.0489	-1321.7206					
PBEPBE	-1304.9360	-1314.2689	-1321.1649	-1321.4604	-1320.1209	-1.5203	-1.6063	-1.5798	-1.5885	-1.5997
B3LYP	-1306.4563	-1315.8752	-1322.7447	-1323.0489	-1321.7206					
PBEPBE	-1304.9360	-1314.2689	-1321.1649	-1321.4604	-1320.1209	-1.4487	-1.3247	-1.2993	-1.2773	-1.3164
MPW1PW91	-1306.3847	-1315.5937	-1322.4642	-1322.7377	-1321.4373					
LSDA	-1299.1966	-1308.6723	-1315.4554	-1315.8242	-1314.4587	-7.1881	-6.9214	-7.0088	-6.9135	-6.9786
MPW1PW91	-1306.3847	-1315.5937	-1322.4642	-1322.7377	-1321.4373					
LSDA	-1299.1966	-1308.6723	-1315.4554	-1315.8242	-1314.4587	-5.7394	-5.5967	-5.7095	-5.6361	-5.6622
PBEPBE	-1304.9360	-1314.2689	-1321.1649	-1321.4604	-1320.1209					
Average =Exchange Energy(au)						-3.8713	-3.8223	-3.8612	-3.8252	-3.8503

Table 5: The primitive number and correlation energy calculated for $C_{26}H_{23}ClN_4$.

Basis set	Primitive NO.	Ecorr.(au)
3-21g	546	-2.7917
6-31g	798	-2.7942
6-311g	938	-3.0186

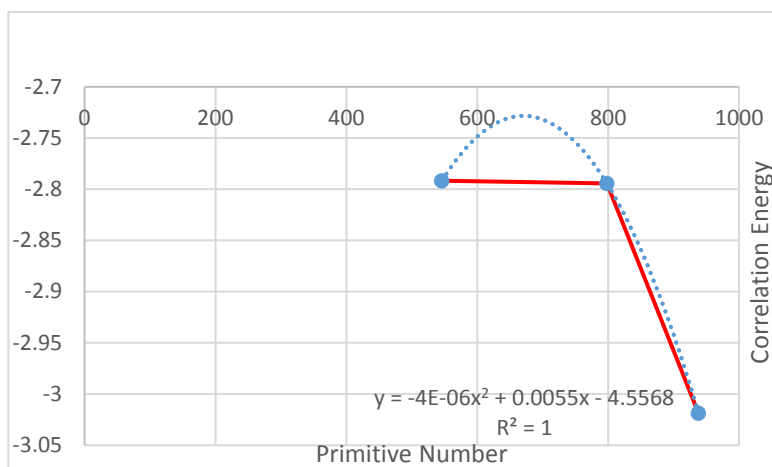


Figure 3: The correlation energy of the $C_{26}H_{23}ClN_4$ system as a primitive number at different levels of theory with 3-21G, 6-31G and 6-311G basis sets (..... Calculated, — data fitted).

Table 6: The primitive number and exchange energy calculated for $C_{26}H_{23}ClN_4$.

Basis set	Primitive NO.	Eexch. (au)
3-21g	546	-4.2047
6-31g	798	-4.2425
6-311g	938	-4.2037

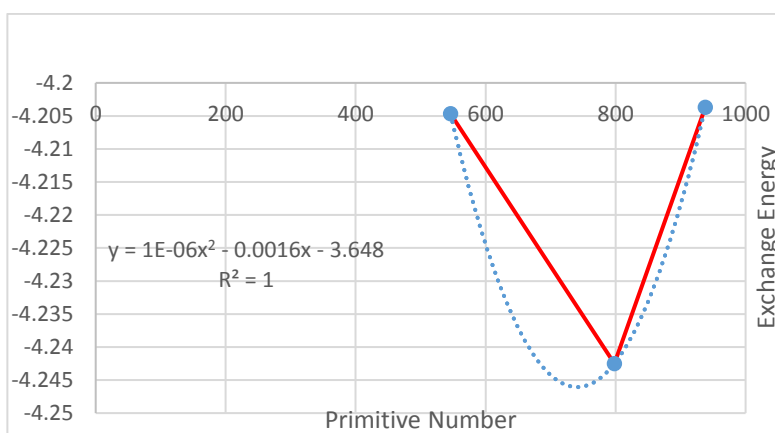
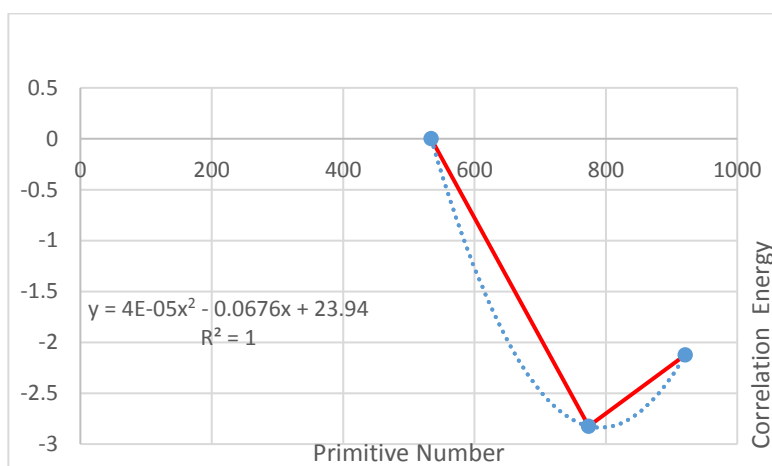


Figure 4: The exchange energy of the $C_{26}H_{23}ClN_4$ system as a primitive number at different levels of theory with 3-21G, 6-31G and 6-311G basis sets (..... Calculated, — data fitted).

Table 7: The primitive number and correlation energy calculated for $C_{26}H_{23}FN_4$.

Basis set	Primitive NO.	Ecorr.(au)
3-21g	534	-2.8193
6-31g	774	-2.8238
6-311g	921	-2.1230

**Figure 5:** The Correlation energy of the $C_{26}H_{23}FN_4$ system as a primitive number at different levels of theory with 3-21G, 6-31G and 6-311G basis sets (..... Calculated, — data fitted).**Table 8:** The primitive number and exchange energy calculated for $C_{26}H_{23}FN_4$.

Basis set	Primitive NO.	Eexch. (au)
3-21g	534	-3.8223
6-31g	774	-3.8612
6-311g	921	-3.8252

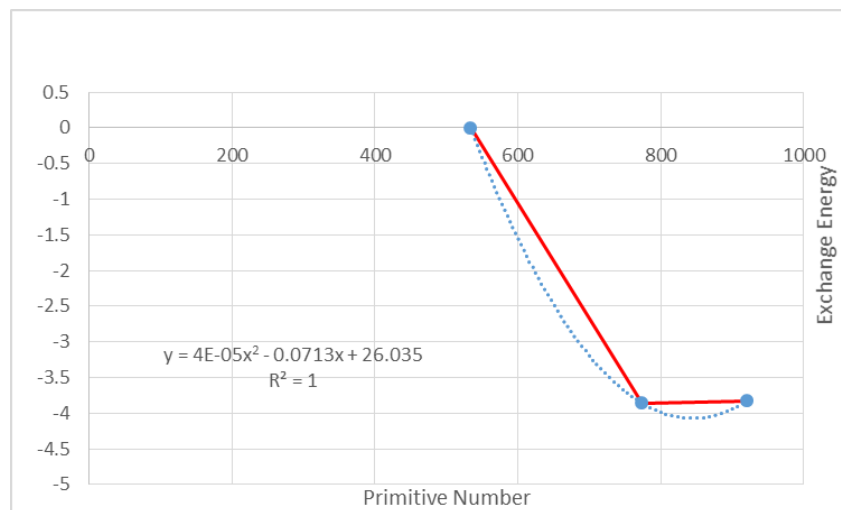


Figure 6: The Exchange energy of the $C_{26}H_{23}FN_4$ system as a primitive number at different levels of theory with 3-21G ,6-31G and 6-311G basis sets (..... Calculated, — data fitted).

3.3. NBO STUDY ON THE STRUCTURE OF $C_{26}H_{23}ClN_4$ AND $C_{26}H_{23}FN_4$

NBO calculation are carried out using Gaussian 09 program at the B3LYP/6-31G level [10–12].

3.3.1. FRONTIER MOLECULAR ORBITAL

Both the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) are the main orbitals taking part in chemical stability. The HOMO represents the ability to donate an electron, LUMO as an electron acceptor represents the ability to obtain an electron. The HOMO and LUMO energy were calculated by B3LYP/ 6-31G method. Energy difference between HOMO and LUMO orbital is called as energy gap that is an important stability for structures. The large LUMO-HOMO gap is often concerned as a molecule stability condition. The HOMO–LUMO energies and energy gap were also calculated at the B3LYP/6-31G and the values are listed in Table 9, respectively.

Table 9: Global chemical reactivity indices for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ at the level of B3LYP/6-31G theory.

	$C_{26}H_{23}ClN_4$	$C_{26}H_{23}FN_4$
E total /hartree	-1683.2236	-1322.7447
E HOMO/ev	-5.846	-5.832
E LUMO/ ev	-1.295	-1.281
E gap / ev	4.551	4.551

3.3.2. CHEMICAL REACTIVITY

The chemical reactivity descriptors calculated by using DFT are total energy (E), chemical hardness (η), electronic chemical potential (μ), and global electrophilicity index (ω) [13,14]. The chemical hardness is associated with the stability and reactivity of a chemical system. In a molecule, it measures the resistance to change in the electron distribution or charge transfer. On the basis of frontier molecular orbitals, chemical hardness corresponds to the gap between the Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO). The chemical hardness is approximated by using Equation (2).

The larger LUMO–HOMO energy gap, the harder and more stable/less reactive the molecule. Table 10 contains the computed chemical hardness value for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$.

$$\eta = (\epsilon_{LUMO} - \epsilon_{HOMO}) / 2. \quad (2)$$

The electronic chemical potential is defined as the negative of electronegativity of a molecule and determined by using Equation (3).

$$\mu = (\epsilon_{HOMO} + \epsilon_{LUMO}) / 2. \quad (3)$$

The parameter μ physically describes the escaping tendency of electrons from an equilibrium system. The values of μ for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are presented in Table 10.

The global electrophilicity index (ω), introduced by Parr, is calculated using the electronic chemical potential and chemical hardness as shown in Equation (4).

$$\omega = \mu^2 / 2\eta. \quad (4)$$

The electrophilicity index measures the propensity or capacity of a species to accept electrons. It is a measure of the stabilization in energy after a system accepts additional amount of electronic charge from the environment [7]. The electrophilicity value (Table 10) for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are 2.801 eV and 2.779 eV.

The HOMO and LUMO orbital energies are related to gas phase ionization potential (IP) and electron affinity (EA) of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ according to the Koopmans' theorem through Equations (5) and (6). The ionization potential (IP) and electron affinity (A) values for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ are presented in Table 10.

$$EA = -\epsilon_{LUMO}, \quad (5)$$

$$IP = -\epsilon_{HOMO}. \quad (6)$$

Table 10: The global chemical reactivity indices for $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ at the level of B3LYP/6-31G theory.

	$C_{26}H_{23}ClN_4$	$C_{26}H_{23}FN_4$
μ / ev	-3.571	-3.557
η / ev	2.276	2.276
ω / ev	2.801	2.779
EA/ev	1.295	1.281
IP/ev	5.846	5.832

4. CONCLUSION

DFT calculations are carried out using Gaussian 09 program. The structures of $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ molecules are totally optimized. A mathematical equation of second grade was exploited for the correlation and exchange energy with the number of primitives.

The electronic properties (E_{gap} , μ , η , ω , EA, IP) are calculated by using B3LYP/6-31g and their values for $C_{26}H_{23}ClN_4$ molecule are 4.551 (ev), -3.571 (ev), 2.276 (ev), 2.801 (ev), 1.295 (ev), 5.846 (ev) and for $C_{26}H_{23}FN_4$ are 4.551 (ev), -3.557 (ev), 2.276 (ev), 2.779 (ev), 1.281 (ev), 5.832 (ev), respectively. The chemical reactivity of the $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been investigated at B3LYP/6-31G(d) level of theory. The band gap energy, total energy (E), chemical hardness (η), electronic chemical potential (μ), and Global electrophilicity index (ω), ionization potential (IP) and electron affinity (EA) for the $C_{26}H_{23}ClN_4$ and $C_{26}H_{23}FN_4$ have been calculated for the chemical activity of the above molecules. According to the results, the $C_{26}H_{23}ClN_4$ molecule is more stable and the chemical activity of $C_{26}H_{23}FN_4$ is greater.

REFERENCES

1. K. W. Bentley, *The Isoquinoline Alkaloids*, Pergamon Press, London, 1965.
2. K. W. Bentley, β -Phenylethylamines and the isoquinolines alkaloids, *Nat. Prod. Rep.* **18** (2001) 148 – 170.
3. J. P. Michael, Quinoline, quinazoline and acridone alkaloids, *Nat. Prod. Rep.* **19** (6) (2002) 742 – 760.
4. E. Pop, W. M. Wu, E. Shek and N. Bodor, Brain-specific chemical delivery systems for β -lactam antibiotics. Synthesis and properties of some dihydropyridine and dihydroisoquinoline derivatives of benzylpenicillin, *J. Med. Chem.* **32** (1989) 1774 – 1781.
5. E. Lukevics, I. Segal, A. Zablotskaya and S. Germane, Synthesis and neurotropic activity of novel quinoline derivatives, *Molecules* **2** (1997) 180 – 185.

6. B. E. Maryanoff, D. F. McComsey, J. F. Gardocki, R. P. Shank, M. J. Costanzo, S. O. Nortey, C. R. Schneider and P. E. Setler, Pyrroloisoquinoline antidepressants. 2. In-depth exploration of structure-activity relationships, *J. Med. Chem.* **30** (1987) 1433 – 1454.
7. K. L. Sorgi, C. A. Maryanoff, D. F. McComsey, D. W. Graden and B. E. Maryanoff, Application to the stereoselective synthesis of pyrroloisoquinoline antidepressants, *J. Am. Chem. Soc.* **112** (1990) 3567 – 3579.
8. H. J. Knjlkcr and S. Agarwal, Total synthesis of the antitumor active pyrrolo[2,1 - a]isoquinoline alkaloid (\pm)crispine A, *Tetrahedron Lett.* **46** (7) (2005) 1173 – 1175.
9. A. Aminkhani, Synthesis of dihydropyrrolo [2,1-a] isoquinolines via isosyanide-based four-component reaction, *Heterocycl. Commun.* **19** (2) (2013) 109 – 112.
10. R. Esmkhani and M. Monajjemi, Electronic structural investigation of boron nitrid nano cage ($B_{30}N_{20}$) in point of exchange and correlation energy, *J. Comput. Theor. Nanosci.* **12** (4) (2015) 652 – 659.
11. A. E. Reed, L. A. Curtiss and F. Weinhold, Intermolecular interactions from a natural bond orbital, donor-acceptor viewpoint, *Chem. Rev.* **88** (6) (1988) 899 – 926.
12. C. James, A. Amal Raj, R. Reghunathan, V. S. Jayakumar and I. Hubert Joe, Structural conformation and vibrational spectroscopic studies of 2,6-bis(*p*-*N,N*-dimethyl benzylidene)cyclohexanone using density functional theory, *J. Raman Spectrosc.* **37** (12) (2006) 1381 – 1392.
13. E. R. Davidson, S. A. Hagstrom, S. J. Chakravorty, V. M. Umar and C. F. Fischer, Ground-state correlation energies for two- to ten-electron atomic ions, *Phys. Rev. A* **44** (1991) 7071 – 7083.
14. S. J. Chakravorty, S. R. Gwaltney, E. R. Davidson, F. A. Parpia and C. F. Fischer, Ground-state correlation energies for atomic ions with 3 to 18 electrons, *Phys. Rev. A* **47** (1993) 3649 – 3670.