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Structural Analysis of Epinephrine by Combination of Density Functional Theory and Hartree-Fock Methods

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Abstract: In this study, we built a model to predict the structure and chemical properties of epinephrine using Density Functional Theory (DFT) and Hartree-Fock (HF) methods, as the methods currently playing a significant role in computational quantum theories. Six basis sets of DFT and HF methods were used to calculate bandgap energies to find the minimum energy bandgap. The basis set 6-311++G was further used to characterize the most stable molecular geometry of epinephrine, as well as the molecular characteristics. Then, the basis set B3LYP/6-31G(d,p) applied on epinephrine to investigate the energy of the highest occupied molecular orbital (E_{HOMO}), the energy of the lowest unoccupied molecular orbital (ELUMO), energy gap ($\Delta E = E_{LUMO} - E_{HOMO}$) and the dipole moment (μ). The fraction of transferred electrons (ΔN) was also calculated, which determined the interaction between the iron surface and the epinephrine compound. Corrosion inhibitor behavior can therefore be predicted from the calculated data without an experimental study. The findings of the calculations show good relation between organic-based corrosion inhibitors and quantum chemical parameters process. The parametrization and stimulation optimized in this study can be used as a model to predict the chemical structure and activity of any compound with the known chemical formula.

Keywords: Adrenaline; structure stimulation, vibration frequency, charge distribution, anti-corrosion activity.

Yoğunluk Fonksiyonel Teorisi ve Hartree-Fock Yöntemlerinin Kombinasyonu ile Epinefrinin Yapısal Analizi

Öz: Bu çalışmada, günümüzde hesaplamalı kuantum teorilerinde önemli bir rol oynayan yöntemler olan Yoğunluk Fonksiyonel Teorisi (DFT) ve Hartree-Fock (HF) yöntemlerini kullanarak epinefrinin yapısını ve kimyasal özelliklerini tahmin etmek için bir model oluşturduk. Minimum enerji bant aralığını bulmak için bant aralığı enerjilerini hesaplamak için altı temel DFT ve HF yöntemi seti kullanıldı. 6-311++G temel seti ayrıca epinefrinin en kararlı moleküler geometrisini ve moleküler özelliklerini karakterize etmek için kullanıldı. Daha sonra, en yüksek dolu moleküler orbitalin (EHOMO) enerjisini, en düşük boş moleküler orbitalin enerjisini (ELUMO), enerji aralığını (ΔE = ELUMO) araştırmak için epinefrine uygulanan temel set B3LYP/6-31G(d,p) - EHOMO) ve dipol momenti (μ). Demir yüzey ile epinefrin bileşiği arasındaki etkileşimi belirleyen transfer edilen elektronların oranı (ΔN) da hesaplandı. Korozyon önleyici davranış bu nedenle deneysel bir çalışma olmaksızın hesaplanan verilerden tahmin edilebilir. Hesaplamaların bulguları, organik bazlı korozyon inhibitörleri ile kuantum kimyasal parametreler süreci arasında iyi bir ilişki olduğunu göstermektedir. Bu çalışmada optimize edilen parametreleştirme ve uyarım, bilinen kimyasal formüle sahip herhangi bir bileşiğin kimyasal yapısını ve aktivitesini tahmin etmek için bir model olarak kullanılabilir.

Anahtar kelimeler: Adrenalin; yapı uyarımı, titreşim frekansı, yük dağılımı, korozyon önleyici aktivite.

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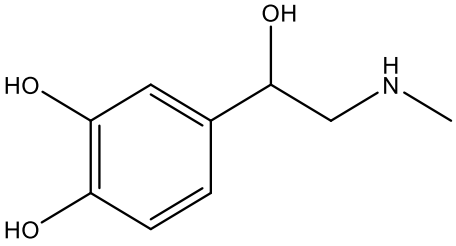
1. Introduction

Recently, using machine-learning approach to predict the structure and chemical properties of a compound increased dramatically, it depends on the atomistic structure and parameters included. Epinephrine (Table 1) also known as adrenaline, is biogenic amine and an important neurotransmitter in the mammalian central nervous system, which is secrets by the medulla of the adrenal gland [1, 2]. It plays an important role in biological systems, controls a wide variety of physiological and behavioral processes, for example controlling the blood pressure, cardiac excitability, respiration and vasodilation, mainly through different receptor types [3-5].

Table 1. Chemical structure and selected properties of epinephrine

CAS no.	51-43-4
Synonyms	Adrenaline
IUPAC name	4-[(1R)-1-hydroxy-2-(methylamino)ethyl]benzene-1,2-diol
Chemical structure	
Molecular formula	$C_9H_{13}NO_3$
Molar mass	183.2 g/mol[a]
Solubility in water (at 20 °C)	180 mg/L[b]
Log K_{OW}	-2.59

a. reference [6] and b reference [7]

The chemical and physical properties of epinephrine have been the focus to investigate the compound activity and biological interaction. The study of energetically and conformational structures of epinephrine help to better understanding hormones functions and activities. Recent theoretical and experimental studies on epinephrine have shown that the conformation of catecholamine neurotransmitters auto regulates the binding of receptors and thus directly influences metabolism levels [8]. Therefore, different approaches and techniques have been developed and used to stimulate epinephrine s properties and activities [9-12].

Modern techniques, in particular spectroscopic have been used to investigate the function, structure, and interaction in biologically active systems [13]. The vibrational spectroscopy deal with the density functional theory in the compound at the molecular level, it has been proved as an important tool to analyze the vibrations, molecular surroundings, bonding nature and interactions. The spectral intensities predicted by the DFT method are crucial for the interpretation of experimental spectra of epinephrine, especially the specific wavenumbers given for every atom [14, 15].

DFT has a good cost-accuracy ratio for large systems, however the calculations are often prohibitive in terms of the necessary computational efforts, and works better for charged systems (e.g., proteins with charged residues), where the self-interaction error can lead to artificial charge-transfer. The limitations of DFT can be alleviated by applying Hartree-Fock (HF) theory together using the same Gaussian basis set. In addition, HF reduces numerical noise in the quadrature of the exchange-correlation energy during frequency calculations or geometry optimizations [16, 17]. In addition, the combination of the DFT and HF methods can fill the gap between existing semi-empirical methods

and DFT in terms of the cost-accuracy ratio with a physically sound approach. Using the combination of DFT and HF have the following advantages: First, elevate the performance of the systems and eliminate self-interaction error and extended charged systems even when treated unscreened are unproblematic. Second, in HF theory, the calculation is performed completely analytical for the computation of gradients to eliminate the problems with numerical noise in geometry optimizations or frequency calculations. Third, HF is inherently able to treat the importance of hydrogen bonding so that there is no need for atom-type dependent H-bond corrections [18, 19].

Thus, the objective of this study was to predict the structure and chemical properties of epinephrine, using basis set of 6-311++G of the DFT and HF methods. For stimulation, DFT was used to predict the geometry and harmonic vibration of epinephrine and HF was operated in parallel to reduce numerical noise during frequency calculations and overcome the limitation of DFT. Details of vibrational frequency, charge distribution, electrostatic potential and spectral analysis were calculated using the model. As far as authors are concerned, this is the first approach to stimulate epinephrine structure in the molecular level using the combination of DFT and HF methods.

2. Experimental Study

The structure of epinephrine was investigated using DFT and HF methods, operating on different bases set. In the present study, we performed the DFT and HF three-parameter hybrid function with the basis sets (3-21G, 3-21+G, 6-31G, 6-31+G, 6-31++G) to predict the chemical properties of the neutralized form of epinephrine. The basis sets were applied to find the bandgap energies and obtain the optimal one, as the approach presented and validated before [20, 21]. The parameters and performance of the 3-21G basis sets are examined with regard to the calculation of equilibrium geometries and vibrational frequencies for a variety of organic and organometallic compounds [21-23]. The basis sets were chosen to provide some special characteristics, which are suitable to determine the chemical structure and physicochemical properties of epinephrine. All computations were performed using the Gaussian software package 09 [24].

The basis set 6-311++G of both DFT and HF methods was the optimal one, therefore was further used to stimulate and optimize the most stable molecular geometry of epinephrine, by orienting the molecule in all directions to find a position where all active sites are reachable. In addition, vibrational assignments of epinephrine were stimulated. Fourier-transform infrared spectroscopy (FT-IR) spectra were stimulated with already optimized bandgap energies and molecular geometry in the region of 4000- 50 cm^{-1}. The chemical shifts in epinephrine of carbon (^{13}C), proton (^{1}H), nitrogen (^{15}N) and oxygen (^{17}O) Nuclear magnetic resonance spectroscopy (NMR) calculated using the basis set 6-311++G of both DFT and HF methods. For calculation and correction of the chemical shifts of ^{13}C and ^{1}H, ^{15}N and ^{17}O NMR, organic solvents of tetramethylsilane, ammonia and water were used as a reference, respectively. In addition, UV-Vis spectra, atomic charges distribution and (MEP) were calculated using both of the methods.

In addition, the parameters related to the electronic structure including the energy of the highest occupied molecular orbital (E_{HOMO}), the energy of the lowest unoccupied molecular orbital (E_{LUMO}), energy gap ($\Delta E = E_{LUMO} - E_{HOMO}$) and the dipole moment (μ) related to the corrosion efficacy, as well as hardness (η), softness (σ), electronegativity (χ), electrophilicity (ω) and nucleophilicity (ε) index, values were computed Gaussian View09, using the following equations [25].

$$I = -E_{HOMO} \quad (1)$$

$$A = -E_{LUMO} \quad (2)$$

$$\Delta E = (E_{LUMO} – E_{HOMO}) \quad (3)$$

$$\eta = (I – A) / 2 \quad (4)$$

$$\sigma = 1/\eta \quad (5)$$

$$\chi = (I + A) / 2 \quad (6)$$

$$Pi = -\chi \quad (7)$$

$$\omega = Pi^2/2\eta \quad (8)$$

$$\varepsilon = Pi * \eta \quad (9)$$

The number of electrons transferred between the inhibitor and the metal [26] calculated using equation (10).

$$\Delta N = \frac{X\text{metal} - X\text{inhibitor}}{2.(\eta\text{metal} - \eta\text{inhibitor})} \quad (10)$$

3. Results and Discussions

Six basis sets of DFT & HF methods were used to calculate the bandgaps energies of epinephrine's molecular structure using Gaussian 09 programs, the result of all basis sets were summarized in Table 2. Overall, the result shows the bandgap energies of both of the methods (DFT & HF) are close to each other, confirming the good performance and accuracy of the methods to complete each other and describe the molecular structure of epinephrine. However, DFT has lower bandgap energies values compare to HF. As the best basis set and for further analysis and simulation, the basis set of 6-311++G was chosen, as the difference of bandgap energies between the methods were lowest, with 2.5 eV different. The difference between bandgap energies of DFT and HF were ranged from 2.57 to 6.56 eV, using the other basis sets.

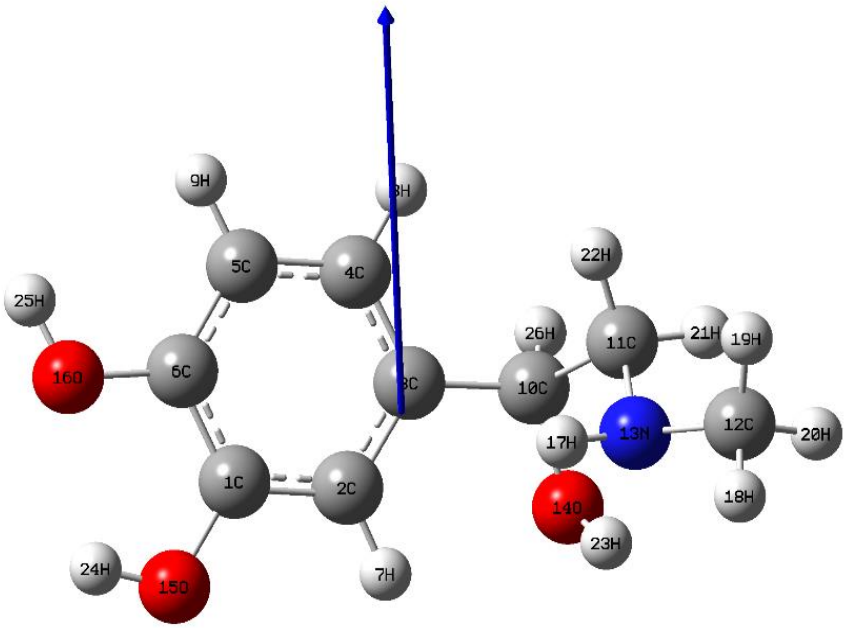
Table 2. The bandgap energies (eV) were obtained for epinephrine using different basis sets of DFT and HF methods.

Basis sets	DFT method	HF method
3-21G	5.84	12.4
3-21+G	6.87	10.3
6-31G	5.84	12.2
6-31+G	6.66	10.1
6-31++G	6.84	9.41
6-311G	6.11	12.1
6-311+G	6.73	10.1
6-311++G	6.89	9.39

3.1 Molecular Geometry

The structure of epinephrine is consisting of twenty-six atoms, which are thirteen hydrogens, nine carbons, three oxygen, and one nitrogen atoms. Further application of a basis set of 6-311++G of DFT and HF methods helped to predict the most stable structure, where the molecule was oriented in all directions to find a position that all active sites are possible to reach and react. DFT and HF methods suggest the same molecular geometry for epinephrine. The geometrical structure of epinephrine was presented as the particular globular structure that all reactive sites efficiently faced out of the molecule. The proposed structure helps to increase the reactivity of epinephrine by increasing the active sites and by devoting some of the active sites to be restricted sites of larger molecules such as enzymes. The optimized structures with numbering atoms were visualized by Gauss View 09 software, presented in Figure 1.

(a)



(b)

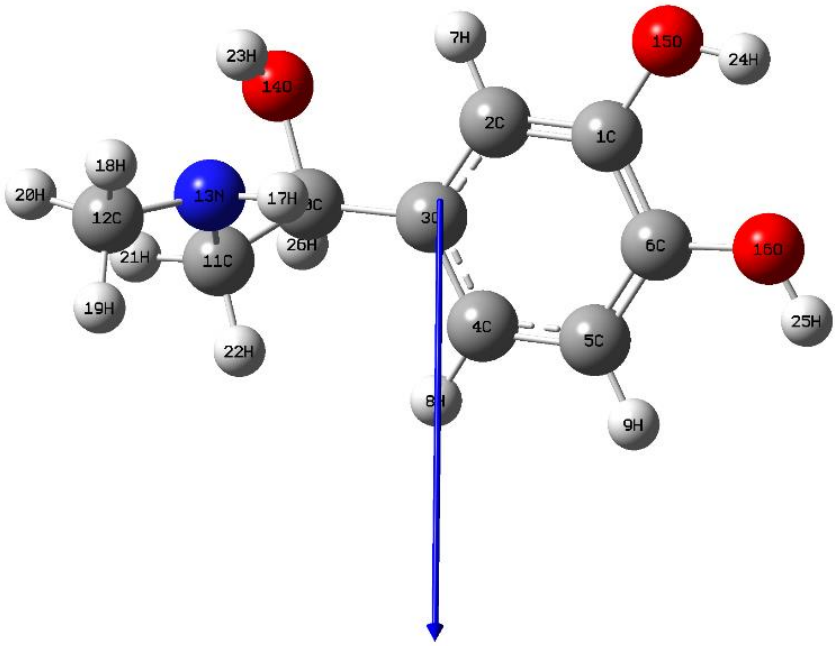


Figure 1. Molecular geometries of epinephrine stimulated by (a) DFT and (b) HF method, using 6-311++G basis set.

The geometrical parameters (bond length and bond angles) of the epinephrine using a basis set of 6-311++G of DFT and HF methods are listed in Table 3. The computed parameters of bond length and bond angle are comparable between the methods, thus the accuracy of the methods are reliable to stimulate the bond length ad bond angles.

3.2 Vibrational Assignments

The basis set 6-311++G of DFT and HF methods was operated to predict and measure the vibrational

frequency of epinephrine. FT-IR spectra of epinephrine of both methods are presented in Figure 2, and all individual vibration of Carbon-Carbon (C-C)/C=C, Carbon-hydrogen (C-H), Oxygen-hydrogen (O-H) and Nitrogen-hydrogen (N-H) are discussed in detail below.

Table 3. Geometrical parameters of epinephrine: bond length and bond angle, using a basis set of 6-311++G of DFT and HF methods.

Bond length(Å)			Bond angle (Å)		
Geometrical position	DFT method	HF method	Geometrical position	DFT method	HF method
C1-C2	1.391	1.391	C1-C2-C3	120.2	120.4
C2-C3	1.399	1.399	C2-C3-C4	119.2	118.8
C3-C4	1.404	1.404	C3-C4-C5	120.7	120.7
C4-C5	1.398	1.398	C4-C5-C6	119.4	119.6
C5-C6	1.390	1.390	C2-C3-C10	121.1	121.4
C3-C10	1.526	1.526	C3-C10-C11	112.5	112.9
C10-C11	1.546	1.546	C10-C11-C12	138.5	140.1
C11-C12	2.497	2.497	C11-C12-N13	31.9	110.1
C12-N13	1.469	1.469	C3-C10-O14	112.2	111.9
C10-O14	1.452	1.452	C2-C1-O15	119.6	119.2
C1-O15	1.389	1.389	C5-C6-O16	125.0	124.4
C6-O16	1.406	1.406			

C-C/C=C Vibrations: The basis set 6-311++G of DFT and HF methods recorded C-C/C=C vibrations. C=C vibrations for aromatic moieties occur in the region of 1420-1625 cm-1, such as for benzene ring, also two or more vibrations occur in the benzene ring with heavy vibration at 1500 cm^{-1}. An additional vibration can occur at 1580 cm^{-1} when the benzene ring is conjugated with other atoms. In epinephrine structure, according to DFT methods, the C=C vibrations were recorded at 1425 to 1699 cm^{-1}, while with HF method were recorded at 1355 to 1808 cm^{-1}. The strong vibration of C=C which conjugated the benzene ring to the other atoms were recorded at 1699 cm^{-1} and1808 cm^{-1} by DFT HF methods, respectively. The C-C vibration of a single bond in a benzene ring was symmetrically vibrated at the range 1353-1425 cm^{-1} for DFT methods, and the vibration was changed to 1355-1390 cm^{-1} by the HF method. The strong C-C vibration for single bond was observed at 1425 cm^{-1} by the DFT method, however the vibration slightly shifted at 1390 cm^{-1} by HF method. The stout C-C single bond vibration out of the plane was vibrated at 1218 cm^{-1} and 1275 cm^{-1} by DFT and HF methods, respectively. At the molecular level, the carbon-carbon vibration usually occurs in the region of 1400-1600 cm^{-1} [27-29].

C-H Vibration: The basis set 6-311++G recorded C-H vibrations out of the plane at 1199 cm^{-1} and 1238 cm^{-1} for DFT and HF methods respectively, and alighted with the previous literature. Moreover, the C-H symmetrical and anti-symmetrical vibration out of the plane recorded at the range of 3034-3050 cm^{-1} and 3136-3248 cm^{-1} by DFT method respectively, however, they are in the range of 3100-3122 cm^{-1} and 3196-3314 cm^{-1} by HF methods, respectively. C-H vibrations in the benzene ring were vibrated at 1308 cm^{-1} by DFT method, and at 1299 cm^{-1} by HF method, previous literature completely agree with the results [30]. The C-H bond vibration is very useful to determine the characterizations of a compound. In general, C-H stretching vibration for aromatic molecules was recorded in the range

3000-3100 cm^{-1}, due to weak interaction between C-H compare to the interaction C-C. The C-H bonding vibration was located in the range of 990-1390 cm^{-1} [31, 32], the vibration of the C-H interactions in the plane occur above 1200 cm^{-1} [33, 34]. The C-H vibration out of the plane is usually observed in the range of 700-1000 cm^{-1} [35-37].

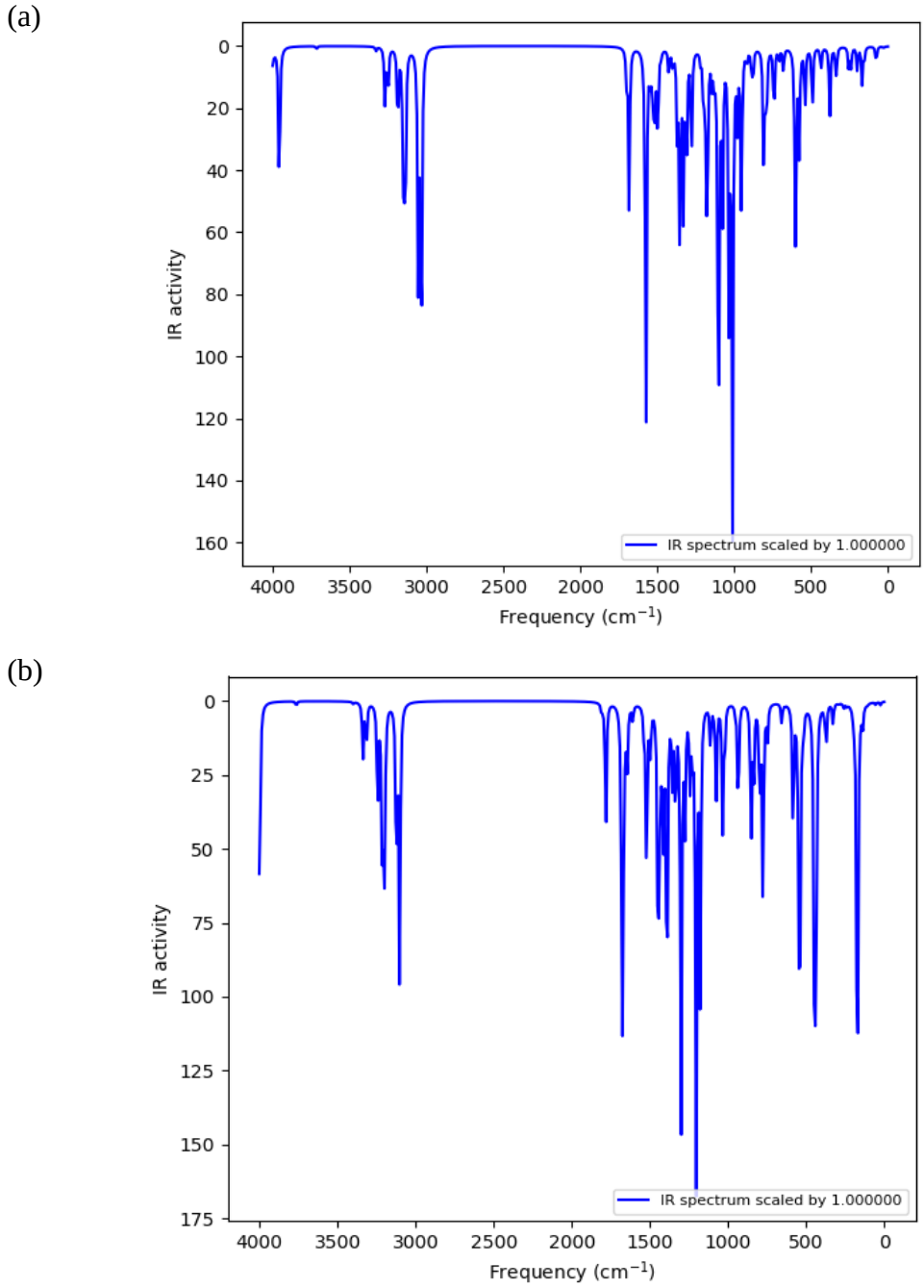


Figure 2. FT-IR spectra of epinephrine using (a) DFT method and (b) HF method on the basis set 6-311++G.

O-H vibrations: The basis set 6-311++G of DFT and HF methods recorded the O-H vibrations for three hydroxyl groups that are present. DFT method recorded O-H symmetrical vibration at 3957, 4021, 4070 cm^{-1} for each O14-H23, O15-H24, O16-H25 vibrations respectively, while HF method recorded the same vibrations at 3997, 4052, 4100 cm^{-1} for h O14-H23, O15-H24, O16-H25, respectively. In the literature, the O-H vibration was reported in the range above of 3500 cm^{-1}, depending on the location of the OH groups in the molecule [38-40], in which all of the stimulated vibrations are aligned within the same range.

Table 5. NMR chemical shift for epinephrine was calculated using the basis set 6-311++G of DFT and HF method.

	Chemical shits (^{13}C, ^{1}H, ^{15}N and ^{17}O NMR)	
Atomic number	DFT	HF
1-C	141.15	131.38
3-C	138.01	130.07
6-C	136.80	124.71
2-C	113.28	107.37
4-C	112.44	105.98
5-C	108.00	101.89
10-C	65.309	43.858
11-C	50.792	31.995
12-C	27.372	12.426
7-H	6.2437	6.4463
8-H	5.1988	5.2107
9-H	5.0991	5.1055
24-H	3.8499	3.4672
26-H	3.5481	3.0501
25-H	1.9916	1.439
23-H	1.7092	1.2525
22-H	1.5887	1.1138
21-H	1.4887	0.9192
18-H	1.3864	0.7913
20-H	1.2111	0.5493
19-H	1.074	0.5377
17-H	-2.249	-2.820
N13	20.085	-3.15
15-O	91.154	55.598
16-O	75.782	43.904
14-O	33.738	7.256

For shits of ^{13}C and ^{1}H, ^{15}N and ^{17}O NMR, organic solvents of tetramethylsilane, ammonia and water were used as a reference, respectively.

N-H vibration: The basis set 6-311++G of DFT and HF methods recorded N-H stretching vibration for the only nitrogen atom in epinephrine structure. The strong N-H vibration of nitrogen atom was recorded at 3714 cm^{-1} by DFT method, but HF method recorded two peaks for N-H stretching vibration at 3763 and 1672 cm^{-1}. The N-H stretching vibration was reported before in the range of 3500-3350 cm^{-1} and 1650 to 1550 cm^{-1} [41, 42].

3.3 NMR Investigation

The basis set 6-311++G of DFT and HF methods were used to predict ^{13}C and ^{1}H NMR spectra of epinephrine, using tetramethylsilane as organic solvents reference. The chemical shifts of epinephrine are listed in Table 5, the chemical shifts of both methods are close to each other, confirming the basis set 6-311++G as a good model. The nine carbons in epinephrine's structure shifted in a different order during ^{13}C NMR chemical shift prediction. Using both methods, the order of ^{13}C NMR chemical shift is very dependent on the molecular position, ordering the chemical shifts (ppm) from high to small is as follows; C1>C3>C6>C2>C4>C5>C10>C11>C12. In addition, the ^{1}H NMR chemical shift of hydrogens were in order of; H7>H8>H9> H24>H26>H25>H23>H22>H21>H18> H20>H19>H17 in both methods.

^{15}N-NMR chemical shits for only nitrogen atom in epinephrine is also predicted using ammonium as an organic solvent reference. However, there is chemical shifts are slightly shifts using DFT and HF methods, as the chemical shift recorded by DFT was 20.0859 ppm while HF gave -3.15 for nitrogen atoms.

^{17}O-NMR chemical shits for oxygen atoms were recorded using water as an organic solvent reference. The chemical shift for the three oxygen atoms by DFT method were calculated at 91.1541, 75.7822, 33.7383 ppm, while HF methods calculated the chemical shifts at 55.5986, 43.9043, 7.256 ppm for O15, O16, O14 atoms, respectively.

3.4 UV- VIS Analysis

UV-Vis spectroscopy is one of the fundamental techniques used to characterize the activity of a compound to form a complex [43, 44]. Thus, the basis set 6-311++G of DFT and HF methods were used to predict UV-Vis spectra of epinephrine. The spectra of epinephrine using DFT and HF methods are presented in Figure 3, both of the spectra are comparable. The maximum wavelength calculated for epinephrine was 245 nm and 208 nm using DFT and HF methods, respectively.

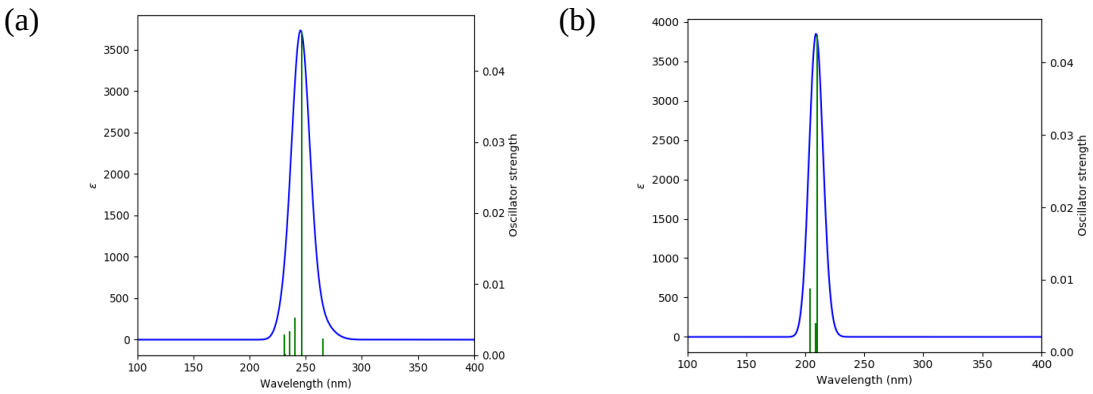


Figure 3. UV-visible spectra of epinephrine using (a) DFT method and (b) HF method on the basis set 6-311++G.

3.5 Atomic Charges Distribution

Identifying the atomic charges is one of the essential parameters to characterize a compound activity [45]. Mulliken charge theory was used to calculate atomic charges, using the basis set 6-311++G of DFT and HF methods, the result listed in Table 6. The data shows that epinephrine had higher atomic

charge by DFT method compare to HF method. In epinephrine molecule, the higher atomic charge distribution on the oxygen suggests that has potential sites for nucleophilic moieties and interact with weak electronic molecules. Whereas, nitrogen atoms reacted more electrophilic like radical species. Epinephrine molecule has three oxygen atoms and one nitrogen atom, therefore, the tendency of nucleophilic compete over electrophilic tendency, therefore it acts as a nucleophilic compound, Figure 4.

Table 6. Atomic charges distribution of epinephrine using Mulliken charge theory, calculated using the basis set 6-311++G of DFT and HF method.

Atom number	Atoms types	Atomic charges distribution	
		DFT	HF
1	C	-0.771	-0.491
2	C	0.048	0.016
3	C	0.843	0.656
4	C	-0.541	-0.460
5	C	0.305	0.232
6	C	-0.018	-0.138
7	H	0.416	0.501
8	H	0.283	0.359
9	H	0.296	0.384
10	C	-0.845	-0.845
11	C	-0.815	-0.783
12	C	-0.611	-0.634
13	N	-0.246	-0.303
14	O	-0.253	-0.320
15	O	-0.487	-0.656
16	O	-0.573	-0.709
17	H	0.350	0.387
18	H	0.220	0.219
19	H	0.213	0.215
20	H	0.231	0.235
21	H	0.284	0.309
22	H	0.228	0.240
23	H	0.365	0.402
24	H	0.376	0.424
25	H	0.375	0.407
26	H	0.326	0.353

3.6 MEP

Electrostatic surface potential illustrates the atomic charges distribution of a molecule and visualizes the charge densities. The charge distribution is the difference in electronegativity, it can determine the polarization of charges [46]. MEP of epinephrine was stimulated by the basis set 6-311++G of DFT and HF methods, presented in Figure 5. MEP demonstrates the electrostatic potential map on epinephrine molecule, and identifies how chemical interactions happen, and where the chemical

bonds possibly formed. The red color scaling indicates the higher electron density and very condensate electrons distribution in the molecule, while the blue color indicates the lower electron density and lower electronegativity. The large electronegativity variation contributes to red fields then toward to blue color. The stimulated models were very close to each other and comparable. The deep red color was found in a position close to oxygen fourteen and nitrogen atom, but the blue color was found in a position oxygen sixteen. The negative range (green) is associated with the reactivity of nucleophilic, and the positive range (blue) is associated with the electrophilic activity. Most parts of the epinephrine molecule were in the negative (green) range, with a few parts that were a positive (blue) color, proving that epinephrine structure is very reactive with nucleophilic species.

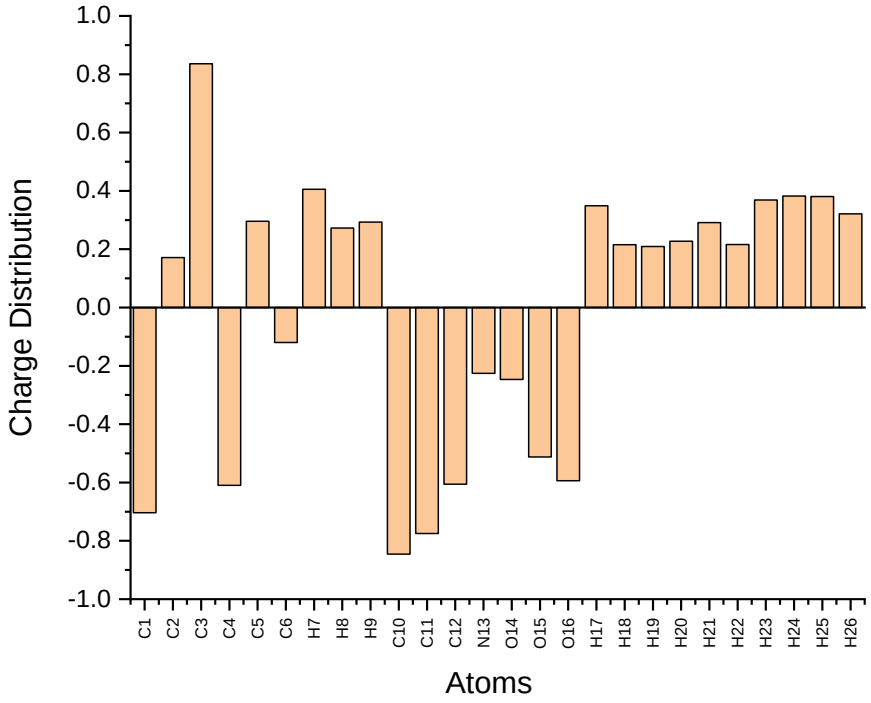


Figure 4. Charge distribution on all induvial atoms of epinephrine.

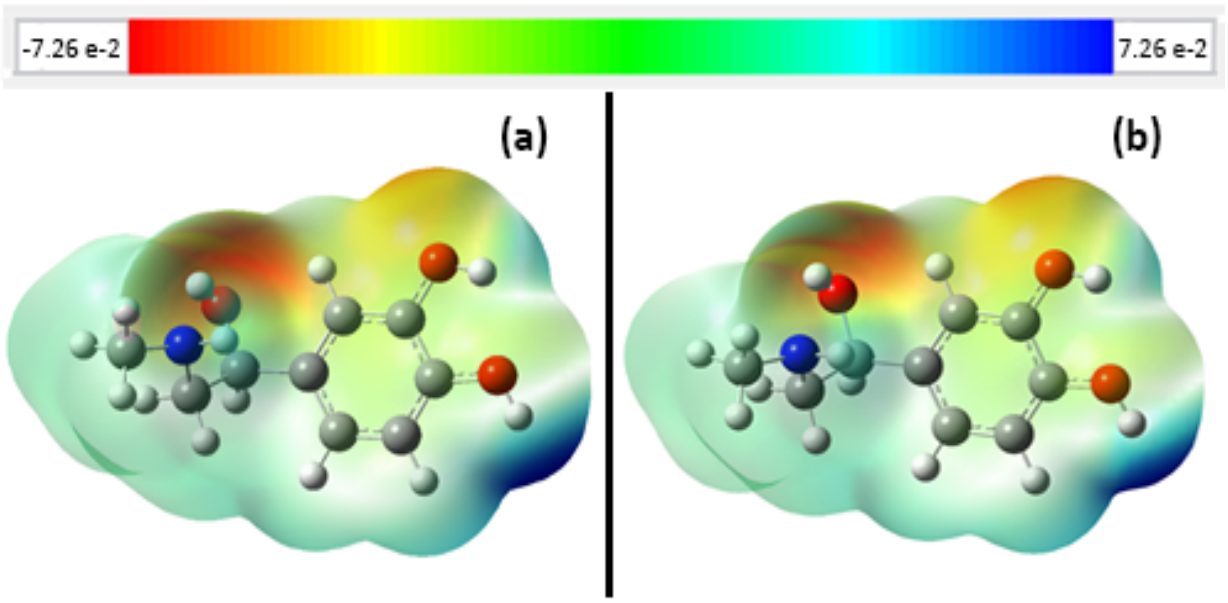


Figure 5. MEP of epinephrine using (a) DFT method and (b) HF method on the basis set 6-311++G.

3.7 Study Inhibitor Activity

The HOMO and LUMO energy levels for epinephrine are equal to -6.163 and -0.727 eV, respectively, Table 7. Since HOMO is related to donating electrons capacity, and therefore essential to study the corrosion of metals. HOMO values increase as the inhibitory effect of inhibitor molecules increases [47-49], the mechanism of charge transfer along the metal surface helps adsorption. Based on the high E_{HOMO} values, epinephrine has higher inhibitory activity. The low level of E_{LUMO} energy values shows that the epinephrine will put an extra negative charge on the surface of the metal, as illustrated in Figure 6. Thus, based on the low and high energy values of E_{LUMO} and E_{HOMO} of epinephrine, respectively, can conclude it has a relatively high corrosion inhibition.

Table 7. Quantum chemical parameters calculation of epinephrine Using DFT/6-311++(d,p).

Parameters	**Equation**	**Results**
Total Energy (a.u)		-631.182
μ (D)		5.303
LUMO (eV)		-0.727
HOMO (eV)		-6.163
I (eV)	$I = -E_{HOMO}$	6.163
A (eV)	$A = -E_{LUMO}$	0.727
ΔE (eV)	$\Delta E = (E_{LUMO} - E_{HOMO})$	5.436
η (eV)	$\eta = (I - A) / 2$	2.718
σ (eV)	$\sigma = I/\eta$	2.267
χ (eV)	$\chi = (I + A) / 2$	3.445
Pi (eV)	$Pi = -\chi$	-3.445
ω (eV)	$\omega = Pi2/\eta2$	1.606
ε (eV)	$\varepsilon = Pi * \eta$	4.366
ΔN	$\Delta N =(\chi metal- \chi inhibitor)/2 (\eta metal- \eta inhibitor)$	0.837

In corrosion inhibitors, the lower value of ΔE relies on E_{HOMO} rather than $E_{LUMO,}$ and the inhibitor derivatives can be used as good anti-corrosion agents with high HOMO energy and low ΔE [25, 47, 50, 51]. Epinephrine has a strong inhibition activity depending on the highest HOMO energy values and ΔE, Figure 7, also the negatively charged oxygen, and carbon atoms in our provided more effective inhibitor activity. The existence of negatively charged heteroatoms helps to improve the ability to adsorb on the metal surface via the donor-acceptor process [52, 53]. The high intensity of negatively charged atoms compare to positively charged atoms in epinephrine has a good anti-corrosion activity. In addition, the values of η and σ of epinephrine compound are close to each other (Table 7), make it a Lewis-based and soft inhibitor, which is more reactive than hard inhibitors [54].

The of χ and Pi provide how coordinated covalent bond happens between the metal and the inhibitor. The calculated χ values of epinephrine were smaller than the experimental χ value of the iron metal, [55, 56]. The high values of dipole moment (μ) enhance inhibition activity, which was 5.303 D, relatively high μ values based on the experimental values [25, 26, 47]. Furthermore, ω and ε demonstrate the ability of an inhibitor to accept and donate electrons respectively. The inhibition activity of epinephrine increases as ε increases, while decreases when ω decreases [57-60].

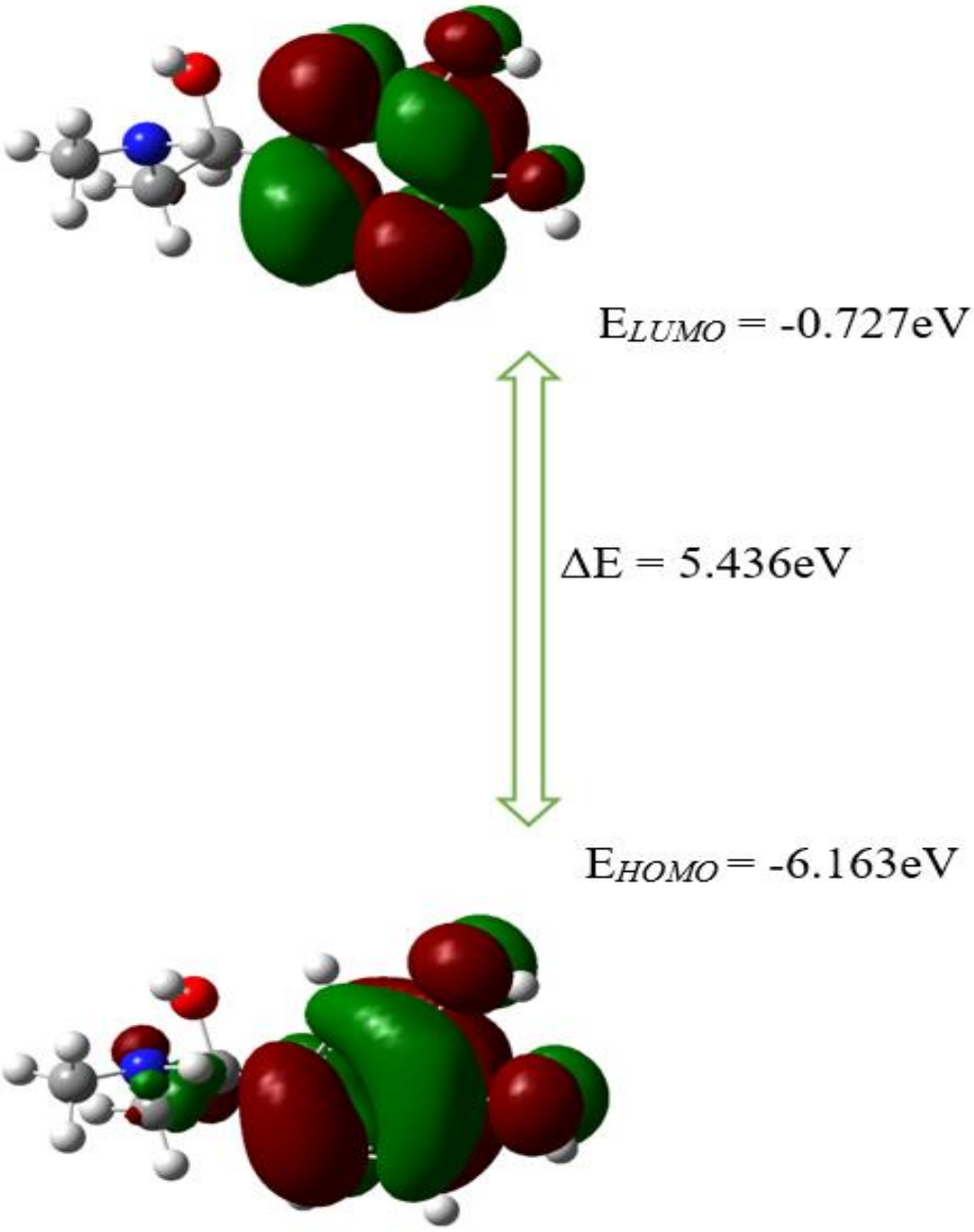


Figure 6. HOMO and LUMO energy levels of epinephrine.

4. Conclusion

In this study, a model was used to predict the chemical structure of epinephrine using DFT and HF methods. Different basis sets were operated to choose the optimal basis set for the model. The basis set of 6-311++G gave the lowest difference between the bandgap energies for DFT and HF methods, chosen as an optimal one. Then the basis set of 6-311++G was further used for both methods to calculate and predict other structural property and energy characterization; including FT-IR, ^{13}C, ^{1}H, ^{15}N and ^{17}O NMR and UV-Vis spectra, also atomic charges distribution and MEP. Overall, the calculation and simulation of DFT and HF method were very close to each, and compared with experimental data from the literature, confirming a good and accuracy of the calculation model for

epinephrine structure. Epinephrine has high E_{HOMO} and low E_{LUMO} values, which make it a donor compound and had high inhibitor activity. Therefore, epinephrine can be used to hide the surface of the metals a low dipole moment and as an anti-corrosion agent. The electronegativity of O and C atoms have a major influence on the inhibitor activity, followed by the other parameters; η, ω, σ, ε, Pi and χ. The model used in this study was capable to calculate and simulate the structure and chemical activities of epinephrine and can be further used to parametrize any compound with known chemical formula with having the least known experimental data.

Author(s) Contributions

Each author's contribution to the study is 25%.

Conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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