DFT STUDIES OF 3-METHYL-2, 6-DIPHENYL-PIPERIDIN-4,5-DIONE

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Abstract:

A density functional theoretical study of 3- methyl – 2,6 –diphenyl- piperidin- 4,5 –dione (MDPPD) is presented in this work. Theoretical calculations based on DFT are gaining importance in computational chemistry.The enriched physicochemical properties of 3- methyl – 2,6 –diphenyl- piperidin –4,5 –dione (MDPPD) have been calculated with the aid of Computational Density Functional Theory. These calculations are performed using the DFT/B3LYP/6-31+G** basis set and compared with the experimental data. The biological activity of the compound is determined from the HOMO-LUMO energy gap. The knowledge about the reactive sites within the molecule and the charge of the atoms are obtained from the Molecular electrostatic potential maps (MEPs).

Key Words: Computational DFT, Vibrational Analysis, NMR & MEP

1. Introduction:

Generally piperidinediones are known to have tumor inhibiting activity and other dione such as quinazolinediones, cyclic and spirodiones are reported to have anti-microbial and herbicidal activities [1-3]. Many of the experimental works both in organic and inorganic chemistry have been amply supported by computational studies. Computational chemistry is the modeling of all aspects of chemistry by computation rather than experimentation. With the aid of high speed computer and softwares, computational calculations have become an important component of theoretical and experimental research and become common tools for everyday chemists like that of IR, UV or NMR spectrometer. Computational calculations provide theoretical predictions which can be compared with experimental results. There are number of commercially available softwares with excellent graphics which allow graphical control (Input) and excellent viewing of three dimensional structures, electron densities, spectrum and spectral data, dipole moment, HOMO, LUMO, polarizability and hyperpolarizability etc. Computer-aided molecular design (CAMD) is one of the applications of computer technology in computational chemistry which helps in predicting theoretically the structure of molecules. Combination of experimental results with theoretical calculations obtained by using density functionalstudies helps in structure determination of organic molecules and to study their properties. A variety of computational chemistry methods use CAMD to obtain structure –reactivity relationship. Theoretical calculations based on DFT are gaining importance in computational chemistry [4-9]. An attempt has been made to compare the theoretical calculations done using Gaussian 09w program package with experimental results reported [10.]**.**

2. Computational Method:

The entire quantum chemical calculation was carried using Gaussian 09w program package [11]. The optimization was performed using DFT method and B3LYP functional in combination with 6-31+G** basis set. The normal modes of vibration were calculated from the optimized structure. The normal modes assignment was got from the visual animation of the GaussView Program [12]. The NMR chemical shifts were calculated using GIAO method implemented in the Gaussian software.The frontier molecular orbital energies, energy gap between various occupied and unoccupied molecular orbitals of title compound were also calculated in the same method with the same basis set. The molecular electrostatic potential (MEP) surface is plotted over the optimized geometry.

3. Results and Discussion:

3.1 Optimized Structure: The MDPPD was optimized at DFT/B3LYP/6-31+G** level and shown in Fig.1.The bond lengths and bond angles were determined from the optimized structure. The C7-O9 and C8-O10 were calculated to be 1.2128 and 1.2082Å respectively. The N11-H12 bond length was predicted to be 1.0181Å. The C=C bond lengths of phenyl rings were found in the range 1.3945 – 1.4026Å. CH$_3$ methyl C-H bonds were in the range 1.0927– 1.0960Å
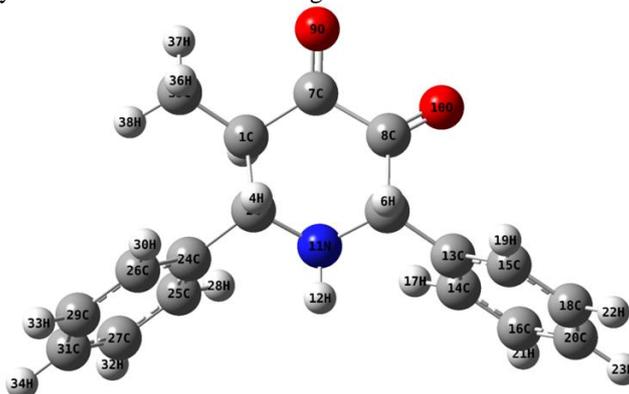

Figure 1: Optimized structure of MDPPD along with atom numbering

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3.2 Vibrational Analysis: According to the calculations, the molecule has 35 atoms and 99 normal modes of vibrations. The assignments of vibrational frequencies were made on the basis of the corresponding PEDs by using VEDA program [13]. The vibrational frequencies obtained from IR spectrum of the compound [10] and based on theoretical DFT studies are tabulated in Table 1.

Table 1: Experimental and Calculated Vibrational frequencies

Group	IR spectral data obtained in cm^{-1}[10]	Calculated values by DFT in cm^{-1}
C=O at 4 and 5	1744.89, 1685.65	1752.83, 1726.34
2° N-H stretch	3252.87	3348.34
CH$_3$ group	2841.44	2878.06
Aromatic C-H stretch	2929.82	2930.97
C=C skeletal	1604.15	1592.76
In plane bending	1179.30	1176.06
Out of plane bending	835.04	831.74

Theoretical values obtained by DFT studies are in good agreement with the IR spectral data obtained.

3.3 UV-VIS Spectral Analysis: Time-dependent density functional theory (TD-DFT) calculation is performed for MDPPD on the basis of fully optimized ground state structure to investigate the electronic absorption properties. The λ_{max} values which are the function of electron availability, electronic excitation energies and oscillator strength are obtained from the UV-Visible spectra, simulated theoretically with B3LYP/6-31+G** basis set and are displayed in Table-2. The calculated absorption maxima values for MDPPD have been found to be 446.71, 329.12 and 301.46nm. The oscillator strength for 329.12nm is of higher in magnitude compared to other transitions. The absorption band of MDPPD at the longer wave length region 446.71nm is caused by the $n - \pi*$ transition. The lower excitation energies evidence the non-linear optical property of the compound.

Table 2: UV-V is Spectral Data

Excited state	Theoretical Wavelength (nm)	Excitation energy(eV)	Oscillator strength(f)	Assignment
S1	446.71	2.7755	0.0002	n→π*
S2	329.12	3.7672	0.0030	n→π*
S3	301.46	4.1128	0.0020	π→π*

3.4 ^{1}H NMR Analysis: The proton NMR chemical shifts were calculated using GIAO method implemented in the Gaussian software. The ^{1}Hchemical shifts of various protons from NMR spectra [10] and theoretical values obtained by DFT studies are tabulated in Table 3.

Table 3: ^{1}H Chemical shifts of MDPPD

Proton	NMR data[10]	DFT data
3Hs of CH$_3$	0.9	0.5, 0.53, 1.23
H of NH	1.2	1.06
C$_2$-H, C$_3$-H, C$_6$-H	2.0-3.0	2.67, 3.54, 4.1
Aryl protons (10Hs)	6.8-7.8	6.65-7.51

3.5 HOMO-LUMO Analysis: The HOMO-LUMO energy gap helps in determining the significant degree of electric excitation and charge transfer. The electron donating ability is characterized by the HOMO energy and electron accepting ability is characterized by LUMO energy. The gap between HOMO and LUMO characterizes the molecular chemical stability [14] and prove the bioactivity from ICT [15, 16]. A molecule with small energy gap is highly polarizable and associated with a high chemical reactivity. The HOMO-LUMO plot is displayed in Fig. 2.

ΔE= 4.24eV

HOMO energy = -6.24eV.
LUMO energy = -2.00eV.

HOMO-LUMO energy gap = 4.24 eV. This value explains the eventual charge transfer within the molecule and the bioactivity of the molecule. Experimentally the compound was found to show moderate activity against Staphylococcus Aureus and Candida Albicans on comparison with the control Ciprofloxacin [10].
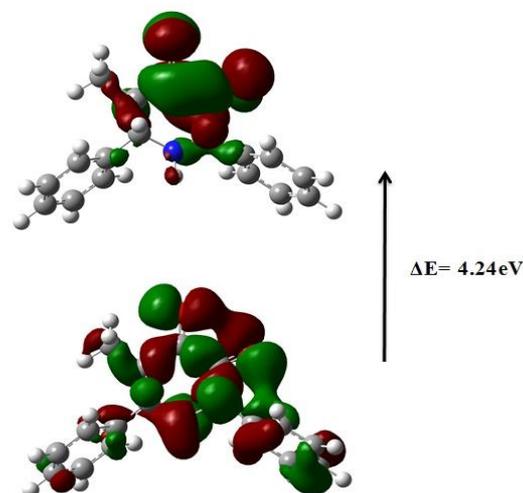
Figure 2: HOMO-LUMO PLOT of MDPPD

3.6 Molecular Electrostatic Potential: The molecular electrostatic potential (MEP) is used primarily for predicting sites and relative reactivities towards electrophilic attack, in studies of biological recognition and hydrogen bonding interactions. The MEP map is shown in Fig. 3. The electrostatic potential increases in the order red<orange<yellow<green<blue. The positive (blue) region of MEP is related to electrophilic reactivity and the negative (red) regions to nucleophilic reactivity. As seen from the Figure the C=O group regions has negative potential and N-H region has positive potential.
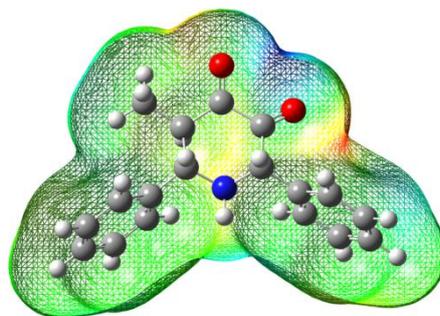

Figure 3: MEP MAP of MDPPD

4. Conclusion:

The optimization of the MDPPD was carried out to determine the exact geometrical parameters. The vibrational frequencies of the functional groups were simulated theoretically which were in fair agreement with the experimental IR data. The UV analysis revealed the optical nature of the synthesized compound. The NMR calculations made were in good agreement with the original ^{1}H NMR. The calculated HOMO-LUMO energy gap revealed high chemical reactivity of the molecule and biological activity which was compared with the experimental results. The inter-molecular interactions were manifested from the MEP map and it shows C=O groups have negative potential and N-H region has positive potential.

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