Antillatoxin (ATX) Time-Resolved Absorption and Resonance FT-IR and Raman Biospectroscopy and Density Functional Theory (DFT) Investigation of Vibronic-Mode Coupling Structure

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To cite this article:

Alireza Heidari, Jennifer Esposito, Angela Caissutti. Antillatoxin (ATX) Time-Resolved Absorption and Resonance FT-IR and Raman Biospectroscopy and Density Functional Theory (DFT) Investigation of Vibronic-Mode Coupling Structure. *American Journal of Optics and Photonics*. Vol. 7, No. 1, 2019, pp. 18-27. doi: 10.11648/j.ajop.20190701.13

Received: April 8, 2019; Accepted: June 3, 2019; Published: June 13, 2019

Abstract: Antillatoxin (ATX) is a potent lipopeptide neurotoxin produced by the marine cyanobacterium *Lyngbya majuscula*. ATX activates voltage-gated sodium channels, which can cause cell depolarisation, NMDA-receptor over activity, excess calcium influx and neuronal necrosis. Parameters such as FT-IR and Raman vibrational wavelengths and intensities for single crystal Antillatoxin are calculated using density functional theory and were compared with empirical results. The investigation about vibrational spectrum of cycle dimers in crystal with carboxyl groups from each molecule of acid was shown that it leads to create Hydrogen bonds for adjacent molecules. The current study aimed to investigate the possibility of simulating the empirical values. Analysis of vibrational spectrum of Antillatoxin is performed based on theoretical simulation and FT-IR empirical spectrum and Raman empirical spectrum using density functional theory in levels of HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG**. Vibration modes of methylene, carboxyl acid and phenyl cycle are separately investigated. The obtained values confirm high accuracy and validity of results obtained from calculations.

Keywords: Vibronic Structure, Vibrational Spectra Analysis, Density Functional Theory (DFT), Antillatoxin, Non-Focal Functions of Becke, Correlation Functions of Lee-Yang-Parr, Time-Resolved Absorption and Resonance, FT-IR and Raman Biospectroscopy

1. Introduction

Antillatoxin (ATX) is a potent lipopeptide neurotoxin produced by the marine cyanobacterium *Lyngbya majuscula*. ATX activates voltage-gated sodium channels, which can cause cell depolarisation, NMDA-receptor over activity, excess calcium influx and neuronal necrosis. Density Functional Theory (DFT) is one of the most powerful calculation methods for electronic structures [5-7]. Numerous results have been previously studied and indicate successful use of these methods [8-10]. The theory is one of the most appropriate methods for simulating the vibrational

wavenumbers, molecular structure as well as total energy. It may be useful to initially consider the calculated results by density functional theory using HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG** approach [11-16]. It should be noted that calculations are performed by considering one degree of quantum interference as well as polarization effects of 2d orbitals in interaction [17-23].

2. Details of Calculations

All calculations of molecular orbital in the base of ab are

performed by Gaussian 09. In calculation process, the structure of Antillatoxin molecule (Figure 1) is optimized and FT-IR and Raman wavenumbers are calculated using HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG** base [24-72]. All optimized structures are adjusted with minimum energy. Harmonic vibrational wavenumbers are calculated using second degree of derivation to adjust convergence on potential surface as good as possible and to evaluate vibrational energies at zero point. In optimized structures considered in the current study, virtual frequency modes are not observed which indicates that the minimum potential energy surface is correctly chosen [73-111]. The optimized geometry is calculated by minimizing the energy relative to all geometrical quantities without forcing any constraint on molecular symmetry. Calculations were performed by Gaussian 09 [112-137]. The current calculation is aimed to maximize structural optimization using density functional theory. The calculations of density functional theory are performed by HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG** function in which non-focal functions of Becke and correlation functions of Lee-Yang-Parr beyond the Franck-Condon approximation are used [138-150]. After completion of optimization process, the second order derivation of energy is calculated as a function of core coordination and is investigated to evaluate whether the structure is accurately minimized. Vibrational frequencies used to simulate spectrums presented in the current study are derived from these second order derivatives. All calculations are performed for room temperature of 327(K).

Figure 1. Different sections of the Antillatoxin [43-93].

3. Vibration Analysis

Analysis of vibrational spectrum of Antillatoxin is performed based on theoretical simulation and FT-IR empirical spectrum and Raman empirical spectrum using density functional theory in levels of HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG**. Vibration modes of methylene, carboxyl acid and phenyl cycle are separately investigated.

C-H stretching vibrations in single replacement of benzene cycles are usually seen in band range of 3200-4200 cm^{-1} . Weak Raman bands are at 3289 cm^{-1} and 3302 cm^{-1} . C-C stretching mode is a strong Raman mode at 1299 cm^{-1} . Raman weak band is seen at 1773 cm^{-1} , too. Bending mode of C-H is emerged as a weak mode at 1498 cm^{-1} and 1297 cm^{-1} and a strong band at 1381 cm^{-1} in Raman spectrum. Raman is considerably active in the range of 1300-1550 cm^{-1} which 1293 cm^{-1} indicates this issue.

C-H skew-symmetric stretching mode of methylene group is expected at 3285 cm^{-1} and its symmetric mode is expected at 3099 cm^{-1} . Skew-symmetric stretching mode of CH_2 in Antillatoxin has a mode in mid-range of Raman spectrum at 3200-3320 cm^{-1} . When this mode is symmetric, it is at 3195 cm^{-1} and is sharp. The calculated wavenumbers of higher modes are at 3163 cm^{-1} and 3193 cm^{-1} for symmetric and skew-symmetric stretching mode of methylene, respectively.

Scissoring vibrations of CH_2 are usually seen at the range of 1627-1681 cm^{-1} which often includes mid-range bands. Weak bands at 1640 cm^{-1} are scissoring modes of CH_2 in Raman spectrum. Moving vibrations of methylene are usually seen at 1569 cm^{-1} . For the investigated chemical in the current study, these vibrations are at 1439 cm^{-1} were calculated using density functional theory. Twisting and rocking vibrations of CH_2 are seen in Raman spectrum at 1015 cm^{-1} and 1289 cm^{-1} , respectively, which are in good accordance with the results at 999 cm^{-1} and 1264 cm^{-1} , respectively.

In a non-ionized carboxyl group (COOH), stretching vibrations of carbonyl [C=O] are mainly observed at the range of 1940-1988 cm^{-1} . If dimer is considered as an intact constituent, two stretching vibrations of carbonyl for symmetric stretching are at 1840-1885 cm^{-1} in Raman spectrum. In the current paper, stretching vibration of carbonyl mode is at 1897 cm^{-1} which is a mid-range value.

Stretching and bending bands of hydroxyl can be identified by width and band intensity which in turn is dependent on bond length of Hydrogen. In dimer form of Hydrogen bond, stretching band of O-H is of a strong Raman peak at 1467 cm^{-1} which is due to in-plane metamorphosis mode. Out-of-plane mode of O-H group is a very strong mode of peak at 1149 cm^{-1} of Raman spectrum. The stretching mode of C-O (H) emerges as a mid-band of Raman spectrum at 1347 cm^{-1} .

Lattice vibrations are usually seen at the range of 0-650 cm^{-1} . These modes are induced by rotary and transferring vibrations of molecules and vibrations and are including Hydrogen bond. Bands with low wavenumbers of Hydrogen

bond vibrations in FT-IR and Raman spectrum (Figure 2) are frequently weak, width and unsymmetrical. Rotary lattice vibrations are frequently stronger than transferring ones. Intra-molecular vibrations with low wavenumbers involving

two-bands O-H ...O dimer at 188 cm^{-1} , 293 cm^{-1} and 349 cm^{-1} are attributed to a rotary moving of two molecules involving in-plane rotation of molecules against each other.

Figure 2. 3D Simulation of (a) FT-IR spectrum and (b) Raman spectrum of Antillatoxin.

4. Results and Discussion

There are many unanswered questions regarding toxins huge polyol and polyether compounds, such as whether this type of compound has any limitations with regard to the molecular weight or length of the carbon chain as well as the need for and physiological roles of these unique metabolites in toxins biosystems. Preliminary studies in our group have shown that unprecedented huge polyol compounds, whose molecular weights are 5,170 and 8,250, may exist in symbiotic nature. Further studies on the conformation, mode of action, and interaction of these unique toxins secondary metabolites with biomacromolecules are essential. Huge polyol and polyether compounds larger than 2,000 mu are

considered to be mid-size molecules that fall between small-size (drug-like) natural products and biopolymers, and further studies on their three-dimensional structures and dynamics in living systems should contribute to the creation of new scientific fields.

5. Conclusion and Summary

Calculations of density functional theory using HF/6-31G*, HF/6-31++G**, MP2/6-31G, MP2/6-31++G**, BLYP/6-31G, BLYP/6-31++G**, B3LYP/6-31G and B3LYP6-31-HEG** levels were used to obtain vibrational wavenumbers and intensities in single crystal of Antillatoxin. Investigation and consideration of vibrational spectrum confirm the formation of dimer cycles in the investigated

crystal with carboxyl groups from each Hydrogen molecule of acid protected from adjacent molecules. The calculated vibrational spectrum which obtains from calculations of density functional theory is in good accordance with recorded empirical values which indicates successful simulation of the problem. The obtained results indicate that the results obtained from theoretical calculations are valid through comparing with empirical recorded results.

Acknowledgements

Authors are supported by an American International Standards Institute (AISI) Future Fellowship Grant FT1201009373496. We acknowledge Ms. Isabelle Villena for instrumental support and Dr. Michael N. Cocchi for constructing graphical abstract figure. We gratefully acknowledge Prof. Dr. Christopher Brown for proof reading the manuscript.

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