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ORIGINAL PAPER

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CHIH-DFT determination of the molecular structure and IR and UV spectra of solanidine

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Abstract Solanidine is the steroidal aglycon of some potato glycoalkaloids and a very important precursor for the synthesis of hormones and some pharmacologically active compounds. In this work, we make use of a new chemistry model within Density Functional Theory, called CHIH-DFT, to calculate the molecular structure of solanidine, as well to predict its infrared and ultraviolet spectra. The calculated values are compared with the experimental data available for this molecule as a means of validation of our proposed chemistry model.

Keywords Solanidine · DFT · Molecular structure · Infrared spectrum · Ultraviolet spectrum

Introduction

The pharmaceutical industry is dedicated to discovering effective methods of making new molecular drugs. Most common drugs were initially discovered by screening natural products. Plants and microorganisms create a remarkably useful array of small molecules, originally created as poisons and toxins for their own protection but then harnessed by us for use in medicine. Of course, once an effective drug is discovered, the mechanisms of action may be studied and improved. Today, nanoscale design adds a new level of control to the discovery and optimization of drugs. Rational design, based on our nanoscale knowledge of the target, is used to enhance existing drugs and to design entirely new medicinal compounds [1].

Glycoalkaloids are potentially toxic secondary plant metabolites found in potatoes, tomatoes, and eggplants. Adverse effects after potato glycoalkaloid ingestion by animals and humans include anticholinesterase activity in the central nervous system, induction of hepatic ornithine decarboxylase, disruption of cell membranes, and possible teratogenicity. The two major potato glycoalkaloids, α-chaconine and α-solanine, are trisaccharides or triosides; i.e., they have three carbohydrate groups attached to the 3-position of the aglycon. The hydrolysis products of these compounds are the so-called β- and γ-chaconines and solanines, with one or two carbohydrates each [2]. Solanidine is the steroidal aglycon of these glycoalkaloids and a very important precursor for the synthesis of hormones and some pharmacologically active compounds [3].

The objective of this work is to report the results of the calculation of the molecular structure of solanidine [(3β)-solanid-5-en-3-ol], as well as to predict its infrared (IR) and ultraviolet (UV–Vis) spectra by using a new chemistry model within Density Functional Theory (DFT) [4] specially tailored to study heterocyclic systems and to validate the calculated results by comparison with the experimental data available for this molecule. Our approach will be limited to the description of molecules in their equilibrium geometry and, in some sense, it can be regarded as a semiempirical DFT. CHIH-DFT has been already validated for the case of antiparasitic drugs, [5–7] flavonoids [8, 9], and organic corrosion inhibitors [10, 11]. Solanidine will be one among the several analogous molecules to be studied in this way.

Theory and computational details

Using a chemistry model, called CHIH-DFT (Density Functional Theory for heterocyclic systems), which is specially designed to study heterocyclic compounds, the megazol molecule was characterized using the Gaussian 03W program [12]. The PBEg functional was used, which is analogous to the PBE0 functional [13]. The difference resides in the g factor, which is a measure of the amount of Hartree–Fock exchange incorporated in the hybrid functional, and whose value depends on the structure of the heterocycle being studied. For the solanidine molecule, it is

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equal to 0.160. The 3–21G* and the CBSB2** basis sets were used, and all these together are called CHIH(small) theory. The original papers give a complete description of the method [5–11].

The calculation of the UV–Vis spectrum of solanidine was performed by solving the time-dependent Kohn–Sham equations according to the method implemented in Gaussian 03W [14–17]. The equations were solved for ten excited states.

The IR and UV–Vis spectra were calculated and visualized using the SWizard program [18].

Results and discussions

The results for the equilibrium conformation of the neutral molecule of solanidine calculated with the CHIH(small) chemistry model are shown in Fig. 1 through the representation of its molecular structure showing the atomic labeling and numbering. To the best of our knowledge, the experimental X-ray structure has never been reported. Some relevant bond distances, angles, and torsional dihedral angles are those that involve the heterocyclic nitrogen, the hydroxyl oxygen, and the double bond. For example, C45-N51 is 1.482 Å , N51-C66 is 1.474 Å, C1-C3 is 1.339 Å, and C10-O23 is 1.471 Å. In the same way, some relevant angles (in degrees) are C1-C3-C20 (124.8), C15-C1-C3 (122.5), C12-C10-O23 (106.0), and C45-N51-C52 (105.3). For the torsional dihedral angles, it is worth mentioning C47-C45-N51-C66 (−164.9), C47-C45-N51-C52 (−41.4), C15-C1-C3-C20 (−3.4), C12-C1-C3-C20 (169.9), and C1-C12-C10-O23 (−71.6).

The molecular dipole moment is perhaps the simplest experimental measure of the charge density in a molecule. The accuracy of the overall distribution of electrons in a molecule is hard to quantify because it involves all the multipoles. From the present calculations, the total energy and the total dipole moment of the ground state with the CHIH(small) chemistry model are −1183.318 au and 1.6211 D, respectively, for the solanidine molecule.

The shape of the total electron density for the solanidine molecule is shown in Fig. 2. The calculated molecular volume is 333.141 cm^3 mol^{-1}.

The IR spectrum for the solanidine molecule calculated with the CHIH(small) chemistry model is shown in Fig. 3. The experimental spectrum was reported recently [3]. The principal unscaled peaks are as follows:

- 400 cm^{-1}: OH bending
- 798 cm^{-1} (719 cm^{-1}): CH2 rocking
- 992 cm^{-1}: CH2 rocking
- 1,087 cm^{-1} (1,032 cm^{-1}): CH2 rocking
- 1,177 cm^{-1}: CH3 wagging
- 1,438 cm^{-1} (1,378 cm^{-1}): CH3 wagging
- 1,546 cm^{-1} (1,463 cm^{-1}): CH3 wagging
- 2,897 cm^{-1}: CH2 asymmetric stretching
- 3,027 cm^{-1} (2,848 cm^{-1}): CH2 asymmetric stretching
- 3,099 cm^{-1} (2,917 cm^{-1}): CH2 asymmetric stretching

The values displayed in parentheses are the experimental wave numbers taken from reference [3], from which an average scaling factor of 0.935 can be derived. There is a good overall agreement with the experimental spectrum, especially considering that it was obtained on the solid phase, while the calculated results are in the gas phase.

The UV–Vis spectra of the solanidine molecule calculated with the CHIH(small) chemistry model is shown in Fig. 4. The wavelength belonging to the HOMO-LUMO transition, and thus the maximum wavelength, is found at 214.6 nm. This can be compared with the experimental UV spectra (taken in ethanol) of solanidine-related compounds [19], which show peaks around 210 nm. As the HOMO-

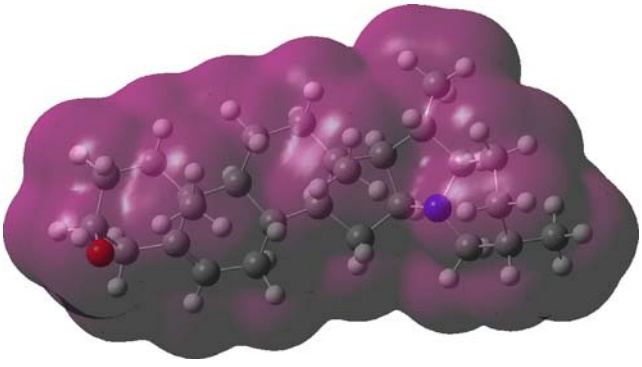

Fig. 2 Total electron density of the solanidine molecule calculated with the CHIH(small) chemistry model

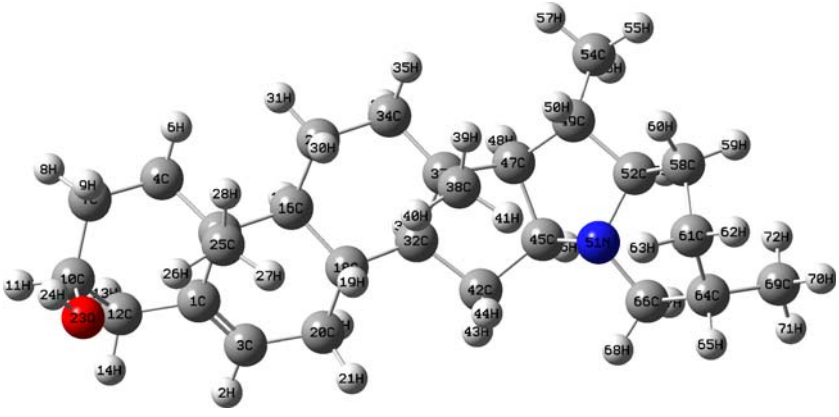

Fig. 1 Molecular structure of solanidine calculated with the CHIH(small) chemistry model

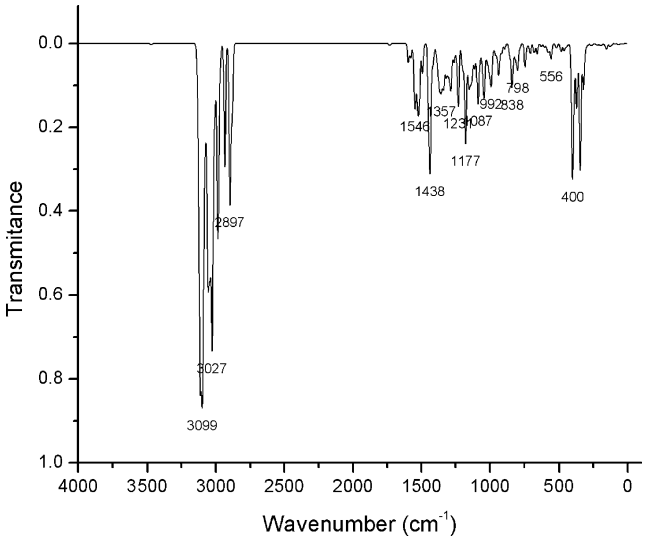

Fig. 3 Infrared (IR) spectrum of the solanidine molecule calculated with the CHIH(small) chemistry model

LUMO transition takes place in the UV region, out of the visible zone, it can be predicted that this molecule will be colorless or slightly colored. It has been reported as a white crystalline powder [3].

Conclusions

In this work, a new chemistry model within DFT (the CHIH chemistry model) has been presented and the methodology been applied to the study of a molecule that is potentially a very important precursor for the synthesis of hormones and some pharmacologically active compounds. The molecular structure for solanidine [(3β)-solanid-5-en-3-ol] has been determined using the CHIH(small) chemistry model.

The shape of the total electronic density of this molecule was shown, as well as some electronic parameters like the total energy and the dipole moment. The calculated molecular volume for the molecule has been also reported.

The IR and UV–Vis spectra for solanidine have been predicted according to the CHIH(small) chemistry model, and an assignment of the principal peaks made. The shape of the UV–Vis spectra and the maximum absorption wavelength belonging to this molecule are shown.

The CHIH chemistry model appears to be a useful tool for the study of the molecular structure and electronic properties of heterocycles, and further applications to several molecular systems are being pursued in our laboratory.

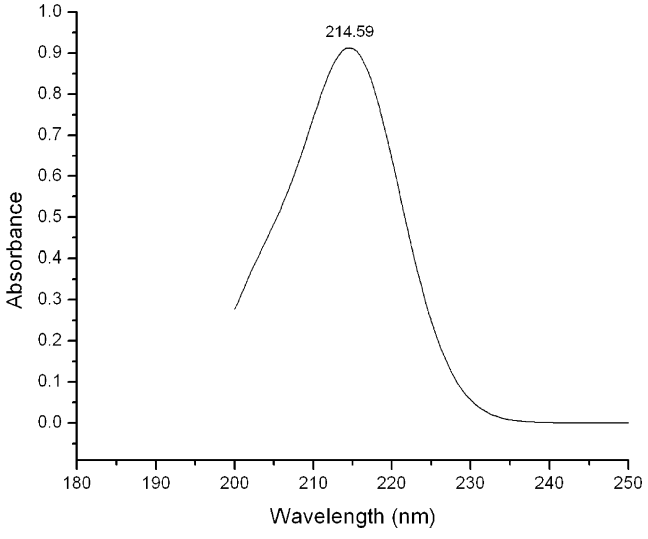

Fig. 4 Ultraviolet (UV–Vis) spectrum of the solanidine molecule calculated with the CHIH(small) chemistry model

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