Vibrational Spectroscopy 86 (2016) 128–133

Contents lists available at ScienceDirect

Vibrational Spectroscopy

journal homepage: www.elsevier.com/locate/vibspec

Vibrational spectroscopic study of some quinoline derivatives

Rafaella F. Fernandes[a], Pedro Henrique F. Stroppa[b], Gilson R. Ferreira[a], Adilson D. da Silva[b], Howell G.M. Edwards[c], Luiz F.C. de Oliveira[a,*]

[a] NEEM – Núcleo de Espectroscopia e Estrutura Molecular, Departamento de Química, Universidade Federal de Juiz de Fora, 36036-330, Juiz de Fora, MG, Brazil
[b] NUPEQ – Núcleo Multifuncional de Pesquisas Químicas, Departamento de Química, Universidade Federal de Juiz de Fora, 36036-330, Juiz de Fora, MG, Brazil
[c] School of Life Sciences, University of Bradford, Bradford, BD7 1DP, West Yorkshire, UK

ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form 9 June 2016
Accepted 10 June 2016
Available online 21 June 2016

Keywords:
Quinolines
Vibrational spectroscopy
Raman spectra
Infrared spectra
DFT calculation

ABSTRACT

This work deals with the successful synthesis, spectroscopic properties (Raman and infrared) and theoretical calculations of some quinoline derivatives, namely 4-azido-7-chloroquinoline and the commercially available 4,7-dichloroquinoline, quinolin-8-ol. The analysis of the Raman and infrared spectra of the quinoline derivatives, supported by DFT calculations, for the first time has afforded the opportunity to characterize unambiguously the main vibrational bands for these important molecules, which are mainly used as anti-malaria compounds. Despite the very similar structures of these quinolines the Raman and infrared spectra exhibit significant wavenumber shifts for several key bands. A characteristic band at *ca.* 1580 cm^{-1} can be assigned involving a δ(OH) mode for quinolin-8-ol (QNO) as well as the band at *ca.* 1090 cm^{-1} attributed to δ(CCl) for 4,7-dichloroquinoline (DCQN). The compound 4-azido-7-chloroquinoline (ACQN) shows a very characteristic marker band at *ca.* 1300 cm^{-1}, which has been assigned to the ν(NN) mode of the azide group.

1. Introduction

Raman spectroscopy has been considered as a powerful analytical tool for biological investigations [1–3] because of the low interference from the spectral scattering of water, but the presence of strong associated fluorescence emission has been a major disadvantage for the recording of weaker Raman bands. The advent of Fourier transform instruments coupled with near infrared excitation has facilitated the Raman spectroscopic studies of biological molecules, in particular those relevant here to studies of malaria [4–10]. Malaria is a life-threatening infectious disease which results in more than 700,000 deaths globally every year [11] and with an estimated 3.4 billion people at risk of infection. In Madagascar malaria was almost eradicated some years ago due to the success of an established control programme achieved by the use of chloroquine at the community level [12,13], but a resistance against the chloroquine [14] has seen a resurgence in the malarial epidemics. Therefore, the development of new and efficient drugs against this disease demands a better understanding of the molecular mode of action of the anti-malarial drugs [15,16].

In addition to the medicinal and therapeutic potential of quinoline derivatives, these compounds have also shown potential applications due to their structural and electronic proprieties. The electronic delocalization and material nonlinear optical properties present in quinoline and its derivatives results in the manifestation of fluorescence effects [17] and important developments in the field of organic light emitting diodes (OLED) [18–20]. Chemically, quinoline compounds consist of an aromatic heterocyclic unit of benzene attached to a pyridine ring fused at two adjacent carbon atoms; the parent member of the quinoline family is quinoline itself with a molecular structure of C_9H_7N.

Raman spectroscopy has been applied successfully hitherto to characterize quinoline derivatives [4,7,21–23], because amino-quinolines in particular have chromophoric groups and highly symmetric molecular structures, which give rise to intense Raman signals [4,5,10,24,25]. The vibrational spectra of several different substituted quinolines which vibrational spectra have been recorded and analyzed using DFT calculations as an auxiliary tool [22,26–28].

It is important to notice that the solid state structure for 4,7-dichloroquinoline has been described previously in literature [29], in which two molecules are present in the quinolone asymmetric unit, where the compound crystallizes in a monoclinic system and

* Corresponding author.
E-mail address: luiz.oliveira@ufjf.edu.br (L.F.C. de Oliveira).

http://dx.doi.org/10.1016/j.vibspec.2016.06.005
0924-2031/

space group $P2_1/n$. However, the vibrational spectra (Raman and infrared) were not reported yet, for this or for any of the other quinolines investigated here.

In this current study, Raman and infrared spectroscopic techniques have been used for the first time to characterize the three quinoline derivatives shown in Fig. 1, namely the commercially available 4,7-dichloroquinoline and quinolin-8-ol, and also the novel compound 4-azido-7-chloroquinoline; the latter compound was synthesized from 4,7-dichloroquinoline (Scheme 1) according to the method described by Pereira et al. [30] and described below. Theoretical DFT calculations were also performed at the B3LYP/6–311++G(d,p) level to correlate the molecular structure of these important biological molecules and their vibrational spectra.

2. Experimental

2.1. Materials

The quinoline derivatives 4,7-dichloroquinoline and quinolin-8-ol were purchased from Sigma-Aldrich (purity 97%); all the solvents (VETEC) used were spectroscopic grade. The new compound, 4-azido-7-chloroquinoline, has been prepared from 4,7-dichloroquinoline (Scheme 1), according to the methodology described by Pereira et al. [30]: to a solution of 4,7-dichloroquinoline in anhydrous DMF containing molecular sieves, sodium azide (20 mmol) was added in one aliquot at room temperature, and the resulting mixture stirred at 85 °C for 8 h. The reaction mixture was then allowed to cool to room temperature and then diluted with CH_2Cl_2, washed with water, dried over anhydrous Na_2SO_4, and evaporated to dryness. The resulting residue was purified by small column chromatography to yield the final pure product as colorless, needle-like crystals.

2.2. Instrumentation

FT-Raman spectra of all quinoline specimens were recorded with a Bruker FT Raman spectrometer (RFS 100) in the macroscopic mode with a spectral resolution of 4 cm^{-1}. The instrument was equipped with a Nd:YAG laser operating at 1064 nm as excitation source and a liquid nitrogen cooled Germanium-detector. Good signal-to-noise ratios were obtained with 200 scans accumulated, using a laser power at the sample of between 150 and 200 mW. All spectra were recorded in triplicate in order to confirm the reproducibility of wavenumber position and intensity of the observed Raman bands.

Infrared (FT-IR) spectra were recorded with a Bruker Alpha FT-IR spectrometer, in the 3500–400 cm^{-1} region with the sample supported in KBr pellet form. A 4 cm^{-1} spectral resolution was used and an average of 64 scans accumulated to enhance the signal-to-noise ratios.

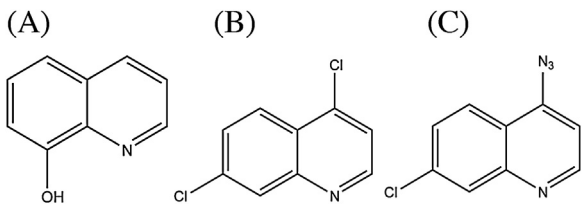
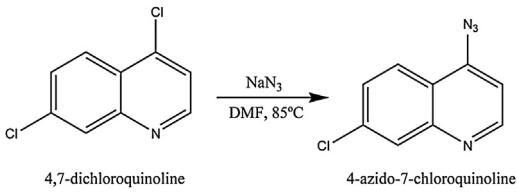


Fig. 1. Chemical structures of the three quinoline derivatives: (A) quinolin-8-ol (QNO); (B) 4,7-dichloroquinoline (DCQN) and (C) 4-azido-7-chloroquinoline (ACQN).



Scheme 1. Synthetic route to obtain the compound 4-azido-7-chloroquinoline.

2.3. Calculations

The structures for the quinoline compounds were fully optimized in the gas phase at the B3LYP [31,32] level using the 6–311++G(d,p) [33] triple-zeta basis-set (hereafter abbreviated as B3LYP/6–311++G(d,p)); the optimized structures are shown in Supplementary materials as Fig. S1. All of the geometries were considered as neutral species. The final geometries were characterized as minima on the potential energy surface (PES) through a harmonic frequencies calculation (all frequencies found were real). The infrared and Raman band intensities were also calculated and the spectra simulated by fitting a Lorentzian type function [34] with parameters set to 10 cm^{-1} for the average width of the bands at half height (FWHM) and 2×10^{-6} mol cm^{-3} for the sample concentration. The spectra for all species were then assigned according to the normal-mode analysis. Frequency scaling was not needed since the theoretically predicted values and the observed experimental spectral profiles were in satisfactory agreement allowing unambiguous band assignments to be made. All calculations were carried out with a Gaussian 09 program [35].

3. Results and discussion

3.1. Theoretical calculations

Molecular modeling based on DFT calculation was used to predict the structures (Fig. S1) and spectroscopic properties of the quinoline derivatives (Figs. 2 and 3). Table 1 reports the predicted structural parameters for QNO, DCQN and ACQN, for which experimental data are not yet available. It should be noted that the dihedral angles of the quinoline derivatives indicate that the structures for isolated molecules are planar (all dihedral angles around the carbon atoms in Table 1 are either 0° or 180°) except for the azide group (in the ACQN molecule) where the dihedral angle C10N11N12N13 is 172.70°. The predicted aromatic bond lengths C5C10, C4N7, C8N7 are respectively 1.41, 1.36 and 1.31 Å which are in accordance with those recorded for analogous systems [36]. The QNO compound has the main bond angles C2C3C4, C3C4C5, C4C5C6, C4C5C10, C4N7C8 and N7C8C9 equal to 119.85°, 119.72°, 119.20°, 116.28°, 118.08° and 123.17°, respectively, and DCQN has very similar analogous bond angles, namely 119.74°, 119.11°, 119.01°, 116.09°, 117.67° and 124.41°.

3.2Spectroscopic analysis.

The infrared and Raman spectra were obtained theoretically for all quinoline derivatives studied here in order to assist in the assignment of the vibrational bands. The experimental and calculated infrared spectra for all structures are given in Fig. 2; despite the very similar skeletal structures of the three compounds studied the Raman and infrared spectra exhibit significant wavenumber displacements for analogous bands. For this reason the vibrational assignments (IR and Raman) were separated for each individual compound in Tables 2–4. The analyses of the infrared spectra based on the correlation curves for each compound, relating the wavenumbers obtained experimentally