# Accepted Manuscript

Vibrational, structural and electronic study of a pyridinium salt assisted by SXRD studies and DFT calculations

Pablo Labra-Vázquez, Miguel Palma-Contreras, Rosa Santillan, Norberto Farfán

PII: S0022-2860(16)31196-6

DOI: 10.1016/j.molstruc.2016.11.033

Reference: MOLSTR 23134

To appear in: Journal of Molecular Structure

- Received Date: 24 August 2016
- Revised Date: 8 November 2016
- Accepted Date: 10 November 2016

Please cite this article as: P. Labra-Vázquez, M. Palma-Contreras, R. Santillan, N. Farfán, Vibrational, structural and electronic study of a pyridinium salt assisted by SXRD studies and DFT calculations, *Journal of Molecular Structure* (2016), doi: 10.1016/j.molstruc.2016.11.033.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.









SXRD



**Reactivity** and **NLO** susceptibility

# Vibrational, structural and electronic study of a pyridinium salt assisted by SXRD studies and DFT calculations.

Pablo Labra-Vázquez,<sup>a</sup> Miguel Palma-Contreras,<sup>a</sup> Rosa Santillan,<sup>b</sup> Norberto

# Farfán.<sup>a</sup>\*

<sup>a</sup> Facultad de Química, Departamento de Química Orgánica, Universidad Nacional Autónoma de México, 04510 México D.F., México. e-mail: norberto.farfan@gmail.com, Fax: +52 55 56223722; Tel: +52 55 56223899 ext. 44443

<sup>b</sup> Departamento de Química, Centro de Investigación y de Estudios Avanzados del IPN, México D.F. Apdo. Postal 14-740, 07000, México

#### Abstract

The molecular structure of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (C<sub>12</sub>H<sub>11</sub>IN<sub>2</sub>O) is discussed using an experimental (FT-IR/ATR, NMR, SXRD) and theoretical (DFT, B3LYP/6-311G<sup>\*\*</sup>) approach. Compound **2** crystallized in the monoclinic  $P2_1/c$  space group with 4 molecules per unit cell and unit cell dimensions a = 7.5629 Å (3), b = 21.5694 Å (7), c = 7.8166 Å (3). The crystal packing is governed by ion-dipole contacts and  $\pi$ - $\pi$  stacking. High electrostatic potential at the ethanone hydrogens was derived from DFT calculations, further explaining the acidity and reactivity of the molecule as a Michael donor.

#### Keywords

Pyridinium salt; Polypyridyl compounds; Non-Linear Optics; DFT; X-Ray Diffraction.

#### **1. Introduction**

Pyridinium salts are heterocycles bearing a quaternary (usually alkylated or acylated) annular nitrogen. The positive charge delocalized within the ring confers these compounds unique chemical and physical properties that have been exploited in diverse areas. Relevant applications include numerous synthetic strategies to obtain and modify a myriad of heterocycles,[1-5] as well as improvements in the development of amphiphilic polymers[6, 7] and advanced organoelectronic[8, 9] and photonic[10] materials.

The reactivity of pyridinium salts has been at the focus of intense research since the earlier 60's. The first investigations by the group of F. Kröhnke, reported that these compounds could be cleaved to yield aromatic amines or enamines, and that the pyridinium group could also be used as a leaving group in  $S_N2$  reactions.[11] Such observations paved the way to the report by Zecher and Kröhnke of their famous pyridine synthesis from pyridinium salts and  $\alpha$ , $\beta$ -unsaturated ketones,[12] that has become one of the most used synthetic methodologies for pyridine-containing organic compounds.

Particularly, 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide has been widely employed as Michael donor in the synthesis of 2,2'-bipyridines (bpy) and 2,2':6',2''-terpyridines (tpy), among other polypyridyl ligands (Scheme 1).[13] However, a common issue in the synthesis of these compounds is the concomitant formation of colored by-products that significantly lower the yields, particularly when the  $\alpha$ , $\beta$ -unsaturated carbonyl counterpart is poorly activated towards 1,4-addition, i.e. when electron donating groups are present. Only few studies dealing with this issue have been published, with kinetic factors usually invoked (stoichiometry or concentration) to explain the formation of such species.[14-16]



**Scheme 1.** Use of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (center) as Michael donor in the synthesis of 2,2'-bipyridine (bpy) and 2,2':6',2''-terpyridine (tpy) ligands.

As part of our ongoing program on devising efficient nitric oxide (NO) photo-releasing Ru(II) tpy complexes,[17-19] we became interested in further unveiling the factors that affect the overall synthetic yields of the tpy ligands *via* the Kröhnke route. To date, this remains poorly described although the reactivity of the Michael donor is expected to play a pivotal role. Thus, herein we report a structural study of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide comprising vibrational, spectral and theoretical approaches.

#### 2. Results and Discussion

#### 2.1 Synthesis and NMR characterization.

Treatment of 2-acetylpyiridine (1) with a solution of iodine in pyridine followed by heating to reflux, yielded the corresponding pyridinium salt (2) in moderate yields *via* an Ortoleva-King reaction (Scheme 2). The identity of the compound was confirmed by high resolution mass spectrometry, showing a peak at m/z 199.0869 for the  $[M-I]^+$  ion.



Scheme 2. Synthesis and numbering of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide(2).

The <sup>1</sup>H-NMR spectrum of **2** is characterized by the signal of the methylene hydrogens (H-4), appearing as a highly deshielded singlet at  $\delta = 6.52$  ppm due to negative inductive effects from both the carbonyl group and the quaternary nitrogen of the pyridinium ring. The COSY (<sup>1</sup>H-<sup>1</sup>H) experiment allowed the distinction of two unique spin systems corresponding to the pyridine (H-7 to H-10) and pyridinium (H-1 to H-3) rings. Given the lack of overlap between the signals from these spin systems and the magnetic equivalence of hydrogens within the pyridinium ring a straightforward and unequivocal assignment of the <sup>1</sup>H-NMR signals was achieved.

In a similar manner, the <sup>13</sup>C-NMR spectrum of **2** showed characteristic signals at  $\delta = 67.18$ and  $\delta = 192.05$  ppm as expected for the methylene (C-4) and the carbonyl group (C-5) resonances, correspondingly. Of particular relevance was the presence of through-bond spin states transmission between hydrogens H-7/H-4 and the carbonyl group (C-5) and between the methylene carbon (C-4) and the *ortho* hydrogens of the pyridinium ring (H-1), both correlations derived from the HMBC (<sup>1</sup>H-<sup>13</sup>C) experiment further confirmed the NMR assignments.

Unambiguous assignment of the <sup>1</sup>H and <sup>13</sup>C chemical shifts of compound **2** was performed with the aid of 2D-NMR techniques, including homonuclear (<sup>1</sup>H-<sup>1</sup>H) COSY/NOESY and



heteronuclear (<sup>1</sup>H-<sup>13</sup>C) HSQC/HMBC experiments. Figure 1 summarizes the most relevant interactions observed.

**Figure 1.** Relevant 2D-NMR interactions observed in the (a) HMBC (<sup>1</sup>H-<sup>13</sup>C) and (b) NOESY (<sup>1</sup>H-<sup>1</sup>H) experiments for 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (2) (CDCl<sub>3</sub>, 400 MHz).

# 2.2. Structural analysis from X-Ray Diffraction and DFT studies.

Compound 2 crystallized in the monoclinic  $P2_1/c$  space group with 4 molecules per unit cell. As depicted in Figure 2, the acylpyridine fragment adopts a *transoid* conformation, which may be attributed to electronic repulsion between the lone pairs of the oxygen in the carbonyl group and those in the annular nitrogen of the pyridine ring. Crystal data and structure refinement details are listed in Table 1.



**Figure 2.** ORTEP drawing of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (2) with the thermal ellipsoids drawn at 50 % probability for every atom other than hydrogen.

It can be seen that in the solid state conformer of compound **2**, the pyridine and ethanone moieties are nearly coplanar, with a minimal torsion angle of  $0.38 \circ (C7-C6-C5-C4)$ . The most remarkable deviations from planarity arise from a 69.13  $\circ$  dihedral angle formed between the planes containing the pyridinium (C-1 to C-3) and pyridine (C-6 to C-8) rings (Figure 3) and from a 13.73  $\circ$  torsion angle (C6-C5-C4-N).

The main intermolecular interactions occurring within the crystal lattice of compound 2 are (a)  $\pi$ - $\pi$  stacking between two adjacent pyridinium rings with anti-parallel arrangement (3.718 Å inter-centroid distance) and (b) ion-dipole contacts between an iodine atom and both H-4 (3.062 Å) and C-5 (3.635 Å). Due to these interactions, compound 2 exhibits a centrosymmetric arrangement of infinite alternating pairs of pyridinium salts with face-to-face orientation (Figure 4).

Table 1			
Crystal structure and refinement.			
Compound	2		
Empirical formula	$C_{12}H_{11}IN_2O$		
Formula weight	326.13		
Temperature	293 K		
Crystal system	Monoclinic		
Space group	$P2_{1}/c$		
a (Å)	7.5629 (3)		

b (Å)	21.5694 (7)
c (Å)	7.8166 (3)
α (°)	90.0
β (°)	104.477 (1)
γ (°)	90.0
Volume $(Å)^3$	1234.61 (8)
Z	4
Density $(g \cdot cm^{-3})$	1.755
Crystal size (mm)	0.1 x 0.1 x 0.1
$\theta$ Range (°)	2.938 to 27.497
Index ranges	$-9 \le h \le 9, -28 \le k \le 27, -10 \le l \le 9$
Nref	2835
R (reflections)	0.0237 (2474)
wR <sub>2</sub> (reflections)	0.0604 (2816)



**Figure 4.** Crystal structure of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (**2**) viewed along the crystallographic *a* axis.

The geometry of compound **2** was optimized at the B3LYP/6-311G(d,p) level of theory, with the crystal structure geometry used as input. Main deviations from the solid state conformation (Figure 5) were observed in (a) the interplanar angle between the planes containing the pyridinium (C-1 to C-3) and pyridine (C-6 to C-8) rings (solid state: 69.13  $^{\circ}$ ,

DFT: 54.75 °) and (b) the distance between the pyridinium ring centroid and the iodide counterion (solid state: 4.749 Å, DFT: 3.847 Å).



**Figure 5.** The solid state and equilibrium conformers of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (2).

#### 2.3. Vibrational assignments

Vibrational modes of compound **2** were studied by solid-state FT-IR (ATR) spectroscopy and analytical DFT computation of both the IR and RAMAN spectra at the B3LYP/6-311G(d,p) level of theory from the equilibrium geometry. As expected for a molecule with 27 atoms and  $C_1$  symmetry, 75 normal modes are predicted by the DFT computation, all of which are expected to be IR and Raman active. A comparison between the experimental and predicted IR spectra is shown in Figure 6.



**Figure 6.** Experimental (FT-IR/ATR, top) and computed (B3LYP/6-311G\*\*, bottom) vibrational spectra for 1-[2-0x0-2-(2-pyridinyl)ethyl]pyridinium iodide (**2**).

As depicted in Figure 7, although the DFT method employed overestimated the vibrational frequencies, a good correlation between the experimental and theoretical values was found, ensuring the reliability of the computed frequencies.



**Figure 7.** Experimental FT-IR (ATR) vs computed (B3LYP/6-311G\*\*) frequencies for 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (**2**).

Further improvement of the computed frequencies was achieved using an appropriate scaling factor of 0.967.[20] Supplementary Table S1 shows the full final frequencies and intensities of the vibrational modes of compound **2**, along with their assignments aided by the total energy distribution (TED) calculation as implemented in VEDA 4 computer program.[21]

## 2.3.1. C-H and C-C vibrations

The methylene  $-CH_2$ - fragment in the ethanone moiety of compound 2 gives rise to six fundamental vibrations, exhibiting out of phase C-H stretching at  $\tilde{v} = 3045$  and  $\tilde{v} = 2832$ cm<sup>-1</sup> and HCH in phase bending at  $\tilde{v} = 1404$  cm<sup>-1</sup>. Lower frequency vibrations, namely the wagging, twisting and rocking resonate at  $\tilde{v} = 1332$ ,  $\tilde{v} = 1213$  and  $\tilde{v} = 952$  cm<sup>-1</sup>, correspondingly.

Vibrational modes involving aromatic hydrogens from the pyridinium and pyridine rings proved ubiquitous in the vibrational spectrum. Vibrations including changes in the C-H bond length lie at the 3262 to 2967 cm<sup>-1</sup> region as sharp and intense bands. On the other hand, in plane and out of plane HCC bending vibrations spanned from 1631 to 1027 cm<sup>-1</sup> and from 909 to 417 cm<sup>-1</sup>, respectively. These fundamental vibrations constitute mixed normal modes in which the corresponding C=C stretches are constantly involved.

#### 2.3.2. C-N and C-O vibrations

The C=O stretch from compound **2** appears at  $\tilde{v} = 1711 \text{ cm}^{-1}$  as a sharp and strong band, while the C=N bond from the pyridinium ring resonates strongly at  $\tilde{v} = 1332 \text{ cm}^{-1}$ .

Additional fundamental vibrations involving these groups occur at lower frequencies. The carbonyl group participates in CCO in plane bending vibrations which originate low energy bands such as those observed at  $\tilde{v} = 653 \text{ cm}^{-1}$  which include the C-6 atom from the pyridine ring according to the DFT calculations, that also predicted OCCC out of plane bends experimentally observed at  $\tilde{v} = 567$  and  $\tilde{v} = 417 \text{ cm}^{-1}$ .

# 2.4. Non-linear optical analysis

Non-linear optics (NLO) is a research field of increasing interest with potential applications in emerging technologies such as 3D data storage, microfabrication, photonic devices and molecular machines, as well as biological uses, e.g. in two-photon fluorescence imaging and photodynamic therapy.[22] The susceptibility of a material to produce a given

#### ACCEPTED MANUSCRIPT

NLO phenomenon is related to the macroscopic polarizability of its electron densities, which relies on the local electronic delocalization within the molecule, the molecular dipole moment and the symmetry elements of the bulk materials.[23, 24]

For second order nonlinear applications, such as second harmonic generation, molecules should ideally possess intense dipole moments ( $\mu$ ), low polarizability coefficients ( $\alpha$ ), high first order hiperpolarizability coefficients ( $\beta$ ) and non-centrosymetric supramolecular architectures, among other desired macroscopic features like high transparency in the visible spectrum and thermal stability of the molecular materials.[23]

A DFT of study these performed for 1-[2-oxo-2-(2parameters was pyridinyl)ethyl]pyridinium iodide (2) at the B3LYP/6-311G(d,p) level of theory from the equilibrium geometry (Table 2). It was found that the molecule has an intense dipole moment and a moderate  $\beta$  value, i.e. comparable with that of urea ( $\beta = 0.3728 \times 10^{-30}$  esu). Such characteristics, along with the potential of using the ethanone-pyridine submolecular fragment as a bidentate ligand, render this compound as an interesting building block for molecular materials with enhanced NLO properties.

compound 2 (B3L YP/6-311G**).						
Dipole moment, $\mu$		Polarizability, $\alpha$		First order		
_			-	hyperpolarizability, $\beta$		
Parameter	D	Parameter	$esu(x10^{-24})$	Parameter	$esu(x10^{-33})$	
$\mu_x$	-7.6710	$\alpha_{xx}$	-14.0224	$\beta_{xxx}$	-885.1476	
$\mu_{v}$	7.9674	$lpha_{xy}$	4.3863	$\beta_{xxy}$	114.4244	
$\mu_z$	1.3135	$lpha_{_{VV}}$	-17.4952	$\beta_{xyy}$	366.8940	
μ	11.1377	$\alpha_{xz}$	-0.2859	$\beta_{yyy}$	-147.9256	
		$\pmb{lpha}_{yz}$	0.7187	$\beta_{xxz}$	-161.6970	
		$\alpha_{zz}$	-16.4646	$\beta_{xyz}$	62.5282	
		$\alpha_{tot}$	24.4832	$\beta_{vvz}$	205.4760	

Electric dipole moment, linear polarizability and first order hyperpolarizability for compound 2 (B3LYP/6-311G\*\*).

Table 2

$\beta_{xzz}$	200.6097
$\beta_{vzz}$	-96.7801
$\beta_{zzz}$	24.3257
$oldsymbol{eta}_{tot}$	415.5692

#### 2.5. Electronic properties

The electronic absorption spectrum of **2** showed two intense bands at  $\lambda = 255$  nm and  $\lambda = 450$  nm. Aiming to characterize the electronic transitions involved, the molecule was fully optimized using the triple- $\zeta$  6-311G(d,p) polarized basis set and several DFT functionals; the resulting equilibrium geometries were used in the TD-DFT calculation of the electronic transitions of **2**. As shown in Table 3, none of the calculations with the iodide counterion omitted in the starting geometry were able to reliably reproduce the experimental electronic spectrum, indicating a relevant role of the iodine atom during photoexcitation. Nonetheless, once the full molecule was taken into account, all of the DFT methods predicted a redshift in the  $\lambda_{max}$  of compound **2**, with the B3LYP hybrid functional yielding the most accurate prediction of the electronic transitions. It may therefore be assumed that the presence of the iodide counterion produces charge stabilization in the molecular ground and first excited states, acting as an electron donor towards the pyridinium ring.

Table 3	3							
Experimental and TD-DFT calculated absorption maxima for pyridinium salt 2 and the								
cationic fragment $[2-I]^+$ employing the 6-311G(d,p) basis set (DMSO, nm).								
	Experimental	B3LYP	PBE0	ωB97X-D	CAM- B3LYP	M06-2X	LC- BLYP	
[ <b>2-I</b> ] <sup>+</sup>	_	288	271	242	236	238	229	
2	450	414	379	316	316	329	258	

It was also found that the first excited state of compound 2 is mainly populated by the electronic transition between the frontier molecular orbitals (FMOs), namely the highest

## ACCEPTED MANUSCRIPT

occupied and lowest unoccupied molecular orbitals (HOMO and LUMO, respectively). As shown in Figure 8, the HOMO is mainly located at the iodide counterion, whereas the LUMO shows a higher contribution of the pyridine (C-6 to C-10) and ethanone (C-4, C-5) fragments.



**Figure 8.** Frontier orbitals plots for 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (**2**) at the B3LYP/6-311G(d,p) level of theory.

The absence of covalent bonds between the submolecular fragments containing each of the FMOs, suggests that the first excited state of **2** is reached *via* through-space electronic polarization from the iodide counterion to the pyridinium ring, this is further confirmed by Natural Bonding Orbital (NBO) analysis of the molecule, that provided a localized description of the involved molecular orbitals and allowed us to characterize this process as an electronic n- $\pi$ \* transition.

The Molecular Electrostatic Potential Map (MEP) for compound **2** is presented in Figure 9 with the green and blue regions having the strongest repulsion and attraction to negative potential, correspondingly. It can be seen that not only the pyridinium ring and the iodine counterion have a predominant contribution to the HOMO, but also they hold most of the electronic density in the molecule. Moreover, the methylene hydrogens show high electrostatic potential, which helps explaining their remarkable acidity and thus the ability of the molecule to yield the corresponding enolate upon deprotonation, which has been widely used as a Michael donor in 1,4-additions.



**Figure 9.** Molecular Electrostatic Potential map for 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (2) (B3LYP/6-311G\*\*)

#### **3.** Conclusions

The molecular structure of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide was studied using a combination of experimental and theoretical approaches. The positive charge delocalized within the pyridinium ring dictates its crystal packing, which is dominated by ion-dipole contacts and  $\pi$ - $\pi$  stackings. Theoretical calculations show that the molecule holds a moderate first order hyperpolarizability ( $\beta$ ) and that its electronic density is mainly located at the pyridinium ring, with high electrostatic potential at the ethanone

hydrogens. This helped further understanding the acidity of these nuclei and the readiness of the molecule to act as Michael donor. Further studies dealing with comparing the stability of the enolate formed upon deprotonating this pyridinium salt with that of other Michael donors commonly used in the synthesis of polypyridyl compounds are ongoing.

#### 4. Experimental

#### 4.1. General considerations

Reactions were performed under an atmosphere of nitrogen (chromatographic grade) and monitored by TLC on pre-coated silica gel plates (ALUGRAM SIL G/UV<sub>254</sub>) and spots were visualized by exposure to a UV<sub>254</sub> lamp. Melting points were measured in a Barnstead Electrothermal 9300 apparatus and are uncorrected. IR experiments were registered in a PerkinElmer Spectrum 400 spectrometer. NMR experiments were recorded in DMSO- $d_6$  solution using a Varian MR-400 instrument; chemical shifts are relative to the residual DMSO- $d_5$  signal, fixed on  $\delta$ =2.50 ppm for <sup>1</sup>H and  $\delta$ = 39.52 ppm for <sup>13</sup>C. HRMS data was acquired in an Agilent Technologies MS TOF spectrometer. Starting materials were purchased from commercial sources and used without further purification. Physical and spectral data for compound **2** is in good agreement with that previously reported.[25]

*1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide* (**2**). To a solution of iodine (6.0 g, 23.8 mmol) in pyridine (35 mL) was added 2-acetylpyridine (**1**) (2.7 mL, 23.8 mmol) and the mixture was magnetically stirred under reflux for 2 hours. The brown solid thus formed was collected, washed with methylene chloride (2x50 mL), coevaporated with toluene (3x20 mL) to remove residual pyridine and dried *in vacuo* to yield 5.85 g (17.9 mmol, 75 %) of the title compound as a grayish crystalline solid. Melting point: 189-190 °C (Lit:

188-189).[25] <sup>1</sup>H-NMR (400 MHz, DMSO- $d_6$ )  $\delta$  9.03 (dd, J = 6.6, 1.3 Hz, 2H, H-1), 8.88 (ddd, J = 4.8, 1.6, 1.4 Hz, 1H, H-10), 8.74 (tt, J = 7.9, 1.3 Hz, 1H, H-3), 8.31 – 8.27 (m, 2H, H-2), 8.14 (td, J = 7.6, 1.4 Hz, 1H, H-8), 8.07 (dt, J = 7.6, 1.3 Hz, 1H, H-7), 7.84 (ddd, J = 7.6, 4.8, 1.3 Hz, 1H, H-9), 6.52 (s, 2H, H-4). <sup>13</sup>C-NMR (100 MHz, DMSO- $d_6$ )  $\delta$  192.05 (C-5), 150.82 (C-6), 150.18 (C-10), 146.96 (C-3), 146.75 (C-1), 138.81 (C-8), 129.91 (C-9), 128.36 (C-2), 122.92 (C-7), 67.18 (C-4). HRMS (ESI-TOF<sup>+</sup>) m/z: [M-I] Observed: 199.0869, required for C<sub>12</sub>H<sub>12</sub>N<sub>2</sub>O: 199.0866, error: 1.48 ppm.

#### 4.2 X-Ray crystal structure determination

Crystals of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide (**2**) suitable for singlecrystal X-ray diffraction studies were obtained by room temperature evaporation of a saturated solution of the analyte in dimethyl sulfoxide.

The intensity data were collected on an Enraf Nonius Kappa diffractometer with a CCD area detector ( $\lambda_{MoK\alpha} = 0.71073 \text{ A}^\circ$ , monochromator: graphite) at 293 K. The crystals were mounted on conventional MicroLoops.<sup>TM</sup> All heavier atoms were found by Fourier map difference and refined anisotropically. All reflection data set were corrected for Lorentz and polarization effects. The first structure solution was obtained using the SHELXS-97 program and the SHELXL-97 was applied for refinement and output data.[26] All software manipulations were done under the WinGX environment program set.[27] The programs Mercury 3.7 and ORTEP-3 were used to prepare artwork representations.[28, 29] CCDC 1500500 contains the supplementary crystallographic data for this paper. These data

can be obtained free of charge via https://summary.ccdc.cam.ac.uk/structure-summary-form

(or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033).

#### 4.3. Computational details

Theoretical calculations were performed within the framework of the Density Functional Theory using the *Gaussian* 09W software package.[30] The triple-ζ 6-311G(d,p) polarized basis set was used for all atoms including iodine.[31, 32] Several functionals were tested: B3LYP, PBE0, CAM-B3LYP and the long-range corrected ωB97X-D, LC-BLYP and M06-2X. The popular B3LYP functional yielded the most accurate prediction of the electronic and vibrational spectra and was consequently used to perform the full set of computations from the optimized geometry. Single-Point energies were computed at the same level of theory. TD-DFT computation of excitation energies were achieved in dimethylsulfoxide under the Polarizable Continuum Model.

#### 5. Acknowledgements

Thanks are due to CONACYT for financial support and the scholarships granted to P.L.-V. (337958) and M.P.-C. (730609) and to PAIP and PAPIIT 216616 for financial support. Authors would like to express their gratitude to M. Romero-Ávila (FQ-UNAM) and M. E. Ochoa (CINVESTAV-IPN) for technical assistance and to M. A. Leyva and G. Cuellar (CINVESTAV-IPN) for X-Ray diffraction studies and HRMS analyses, correspondingly.

#### 6. References

 D.L. Comins, A.H. Abdullah, Regioselective addition of Grignard reagents to 1acylpyridinium salts. A convenient method for the synthesis of 4-alkyl(aryl)pyridines, J. Org. Chem., 47 (1982) 4315-4319.

[2] R. Yamaguchi, E. Hata, T. Matsuki, M. Kawanisi, An efficient regio- and stereoselective synthesis of (.+-.)-monomorine I via the highly regioselective .alpha.- alkynylation of a 1-acylpyridinium salt, J. Org. Chem., 52 (1987) 2094-2096.

[3] T. Damiano, D. Morton, A. Nelson, Photochemical transformations of pyridinium salts: mechanistic studies and applications in synthesis, Org. Biomol. Chem., 5 (2007) 2735-2752.

[4] I. Sasaki, J.-C. Daran, G. Commenges, The simple production of nonsymmetric quaterpyridines through Kröhnke pyridine synthesis, Beilstein J.Org.Chem., 11 (2015), 1781-1785.

[5] M. Ziegler, V. Monney, H. Stoeckli-Evans, A. Von Zelewsky, I. Sasaki, G. Dupic, J.-C. Daran, G.G.A. Balavoine, Complexes of new chiral terpyridyl ligands. Synthesis and characterization of their ruthenium(II) and rhodium(III) complexes, J.Chem.Soc.,Dalton Trans. (1999), 667-675.

[6] P. Madaan, V.K. Tyagi, Quaternary Pyridinium Salts: A Review, J. Oleo Sci., 57 (2008)197-215.

[7] A. Roosjen, J. Šmisterová, C. Driessen, Joachim T. Anders, A. Wagenaar, D. Hoekstra,
R. Hulst, Jan B.F.N. Engberts, Synthesis and Characteristics of Biodegradable Pyridinium
Amphiphiles Used for in vitro DNA Delivery, Eur. J. Org. Chem., 2002 (2002) 1271-1277.

[8] Z. Liu, H. F., H. Xu, H. Wang, J. Wu, Y. Tian, A-π-D-π-A pyridinium salts: synthesis, crystal structures, two-photon absorption properties and application to biological imaging, CrystEngComm, 17 (2015) 5562-5568.

[9] A.K. Nedeltchev, H. Han, P.K. Bhowmik, Solution, thermal and optical properties of novel poly(pyridinium salt)s derived from conjugated pyridine diamines, J. Polym. Sci. A Polym. Chem., 48 (2010) 4408-4418.

[10] M. Jazbinsek, L. Mutter, P. Gunter, Photonic Applications With the Organic Nonlinear Optical Crystal DAST, IEEE J. Sel. Topics Quantum Electron., 14 (2008) 1298-1311.

[11] F. Kröhnke, Syntheses Using Pyridinium Salts (IV), Angew. Chem. Int. Ed., 2 (1963) 380–393.

[12] W. Zecher, F. Kröhnke, Eine neue Synthese substituierter Pyridine, I. Grundzüge der Synthese, Chem. Ber., 94 (1961) 690-697.

[13] F. Kröhnke, The Specific Synthesis of Pyridines and Oligopyridines, Synthesis, 1 (1976) 1-24.

[14] P. Korall, A. Börje, P.-O. Norrby, B. Åkermark, High Yield Preparation of 4'-(4-Bromophenyl)-2,2':6',2"-terpyridine by a Condensation Reaction. Determination of the Stereochemistry of Two Complex By-products by a Combination of Molecular Mechanics and NMR Spectroscopy, Acta Chem. Scand., 51 (1997) 760-766.

[15] E.C. Constable, G. Zhang, C.E. Housecroft, M. Neuburger, S. Schaffner, Phaseseparated hydrogen-bonded chloride ion–water–oxonium ion sheets and protonated 4'-(4bromophenyl)-2,2':6',2"-terpyridine stacks, and condensation products of 2-acetylpyridine and benzaldehydes revisited, CrystEngComm, 11 (2009) 1014–1021. [16] U. Siemeling, J. Vor der Brüggen, U. Vorfeld, A. Stammler, H.-G. Stammler, Large Scale Synthesis of 4'-(4-Bromophenyl)-2,2':6',2"-terpyridine and Nature of the Mysterious Green By-product, Z. Naturforsch, 58b (2003) 443 – 446.

[17] J. Akl, C. Billot, P.G. Lacroix, I. Sasaki, S. Mallet-Ladeira, I. Malfant, R. Arcos-Ramos, M. Romero, N. Farfán., Molecular materials for switchable nonlinear optics in solid state, based on Ruthenium-nitrosyl complexes, New J. Chem., 37 (2013) 3518-3527.

[18] J. Akl, I. Sasaki, P.G. Lacroix, I. Malfant, S. Mallet-Ladeira, P. Vicendo, N. Farfán, R. Santillan, Comparative photo-release of nitric oxide from isomers of substituted terpyridinenitrosylruthenium (II) complexes: experimental and computational investigations, Dalton Trans., 43 (2014) 12721-12733.

[19] P. Labra-Vázquez, A.Z. Lugo-Aranda, M. Maldonado-Domínguez, R. Arcos-Ramos, M.d.P. Carreon-Castro, R. Santillan, N. Farfán, On the molecular structure of (E)-3-(9H-fluoren-2-yl)-1-(pyridin-2-yl)prop-2-en-1-one, theoretical calculations and SXRD studies, J. Mol. Struct., 1101 (2015) 116-123.

[20] A.P. Scott, L. Radom, Harmonic Vibrational Frequencies: An Evaluation of Hartree–Fock, Møller–Plesset, Quadratic Configuration Interaction, Density Functional Theory, and Semiempirical Scale Factors, J. Phys. Chem., 100 (1996) 16502-16513.

[21] M.H. Jamroz, Vibrational Energy Distribution Analysis VEDA 4, Warsaw, 2004.

[22] M. Pawlicki, H.A. Collins, R.G. Denning, H.L. Anderson, Two-Photon Absorption and the Design of Two-Photon Dyes, Angew. Chem. Int. Ed., 48 (2009) 3244-3266.

[23] T.P. Radhakrishnan, Molecular Structure, Symmetry, and Shape as Design Elements in the Fabrication of Molecular Crystals for Second Harmonic Generation and the Role of Molecules-in-Materials, Acc. Chem. Res., 41 (2008). [24] G.S. He, L.-S. Tan, Q. Zheng, P.N. Prasad, Multiphoton Absorbing Materials: Molecular Designs, Characterizations, and Applications, Chem. Rev., 108 (2008) 1245–1330.

[25] F. Kröhnke, K.F. Gross, Beispiele zur King-Reaktion, Chem. Ber., 92 (1959) 22-36.

[26] G. Sheldrick, A short history of SHELX, Acta Crystallogr. Sect. A, 64 (2008) 112-122.

[27] L.J. Farrugia, WingGX suite for single crystal small molecule crystallography, J. Appl. Crystallogr., 32 (1999) 837-838.

[28] C.F. Macrae, P.R. Edgington, P. McCabe, E. Pidcock, G.P. Shields, R. Taylor, M. Towler, J.v.d. Streek, Mercury: visualization and analysis of crystal structures J. Appl. Crystallogr., 39 (2006) 453-457.

[29] L.J. Farrugia, ORTEP-3 for Windows-a version of ORTEP-III with graphical user interface (GUI), J. Appl. Crystallogr., 30 (1997) 565.

[30] M.J. Frisch, G.W. Trucks, H.B. Schlegel, G.E. Scuseria, M.A. Robb, J.R. Cheeseman,
G. Scalmani, V. Barone, B. Mennucci, G.A. Petersson, H. Nakatsuji, M. Caricato, X. Li,
H.P. Hratchian, A.F. Izmaylov, J. Bloino, G. Zheng, J.L. Sonnenberg, M. Hada, M. Ehara,
K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai,
T. Vreven, M.J. J. A., J.E. Peralta, F. Ogliaro, M. Bearpark, J.J. Heyd, E. Brothers, K.N.
Kudin, V.N. Staroverov, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J.C.
Burant, S.S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J.M. Millam, M. Klene, J.E. Knox, J.B.
Cross, V. Bakken, C. Adam, J. Jaramillo, R. Gomperts, R.E. Stratmann, O. Yazyev, A.J.
Austin, R. Cammi, C. Pomelli, J.W. Ochterski, R.L. Martin, K. Morokuma, V.G.
Zakrzewski, G.A. Voth, P. Salvador, J.J. Dannenberg, S. Dapprich, A.D. Daniels, Ö.

Farkas, J.B. Foresman, J.V. Ortiz, J. Cioslowski, D.J. Fox, Gaussian 09, Revision E.01, Gaussian, Inc., Wallingford CT, 2009.

[31] D. Feller, The role of databases in support of computational chemistry calculations, J.Comput. Chem., 17 (1996) 1571-1586.

[32] K.L. Schuchardt, B.T. Didier, T. Elsethagen, L. Sun, V. Gurumoorthi, J. Chase, J. Li,

T.L. Windus, Basis Set Exchange: A Community Database for Computational Sciences, J. Chem. Inf. Model., 47 (2007) 1045-1052.

23



**Figure 3.** Dihedral angle formed between the planes containing the pyridinium and pyridine rings in compound **2**.

# Highlights

- The molecular structure of 1-[2-oxo-2-(2-pyridinyl)ethyl]pyridinium iodide has been discussed based on Single Crystal X-Ray Diffraction Studies and DFT calculations.
- A full assignment of the <sup>1</sup>H and <sup>13</sup>C NMR spectra was attained through 2D experiments.
- A full vibrational and electronic study of the molecule was performed aided by DFT computations, which further suggested a potential use of the molecule as building block for enhanced Non-Linear Optical applications.
- The reactivity of the molecule as Michael donor was discussed based on the computed electrostatic potential map.