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Vibrational investigation of the 3,4-methylenedioxypyrovalerone designer drug

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Abstract
One of the most important synthetic cathinones, which is a popular family of designer drugs, is 3,4-methylenedioxypyrovalerone (MDPV). This β-keto phenylalkylamine, which represents a derivative of the natural alkaloid cathinone found in the *Catha edulis* plant, was detected for the first time in 2007 in Japan and was classified by the Drug Enforcement Agency of the United States (DEA) as a Schedule I drug [1-3]. This paper presents a broad vibrational characterization of MDPV, by using IR spectroscopy combined with Density Functional Theory (DFT) calculations. The basis of the quantum mechanical calculations performed, in the ground state, was the B3LYP hybrid functional with 6-311G (d, p). The evaluation of the vibrational frequencies was performed by analyzing the energy secondary derivatives, which were determined on the basis of harmonization. The process led to detailed vibrational allocations of the absorption bands, which were performed on the basis of the potential energy distribution (PED). The proposed method has led to a very good agreement between the computed and the experimental frequencies.

Keywords: synthetic cathinone, MDPV, DFT, vibrational analysis.

1. INTRODUCTION

A class of frequently traded synthetic drugs consists of synthetic cathinones. An important member of this class is 3,4-methylenedioxypyrovalerone (MDPV), a β-keto-phenylalkylamine that is a derivative of the natural alkaloid cathinone found in the *Catha edulis* plant (see Figure 1) [1-3].

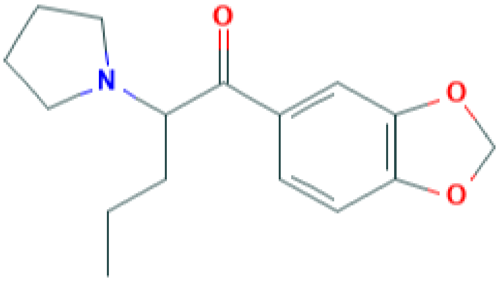

Fig. 1. Molecular structure of 3,4-methylenedioxypyrovalerone [4].

3,4-methylenedioxypyrovalerone (MDPV) is a psychoactive substance of the phenethylamines class, which, from a structural point of view, is closely related to 3,4-methylenedioxymethamphetamine (MDMA), methamphetamine, cathinone, and other phenethylamines. MDPV is sold through illicit channels as "bath salts" (Ivory Wave, plant fertilizer, Vanilla Sky, or Energy-1) and has a stimulating effect on the central nervous system (CNS). Various studies have reported its hallucinogenic effects [2,5-6].

The aim of this study was to characterize MDPV by IR spectroscopy in correlation with the functional density theory (DFT). Quantum mechanical calculations were performed in the solid state using the functional B3LYP hybrid with 6-311G (d, p) as the established basis. The vibrational allocation of the absorption bands was made on the basis of the potential energy distribution (PED). This distribution is important because it allows the characterization of the relative contributions starting with each internal coordinate to the total potential energy associated with the normal coordinate of the studied molecule.

2. EXPERIMENTAL

The optimization of the complete geometry in the gas phase for the investigated molecule was performed by using the *Gaussian 09* software [7]. Following the optimization, the geometric parameters were obtained, i.e. the length between the connections, the angle between the connections and the torsion angle. The geometric parameters and IR frequencies were determined based on the DFT theory, by using the functional hybrid B3LYP and 6-311G (d, p) as the basic set. Thus, the optimized geometry is situated at a generalized minimum on the surface of the potential energy.

The analysis in terms of contributions of the theoretical vibrational spectrum of the compound 3,4-methylenedioxypyrovalerone was performed by using the *VEDA 4* software [8].

3. RESULTS AND DISCUSSION

The first result obtained, after performing all the steps described above, is the determination of the optimized molecular structure of 3,4-methylenedioxypyrovalerone (MDPV), which is represented in Figure 2.

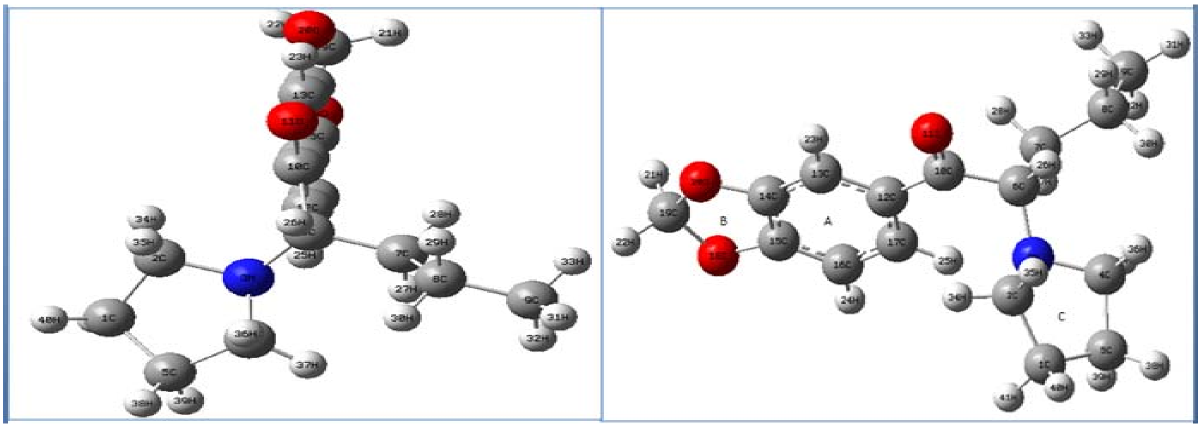

Fig. 2. Optimized molecular structure of 3,4-methylenedioxypyrovalerone (MDPV).

Figure 3 presents the calculated IR spectra and the experimental spectra of MDPV in the spectral region 3500-400 cm^{-1}. It indicates the similarity between the theoretical and experimental spectra. Some minor differences in the intensity or position of the absorption bands are due to the fact that the experimental spectrum corresponds to the solid phase of 3,4-methylenedioxypyrovalerone, and the theoretical spectrum corresponds to its gaseous phase.

The experimental and theoretical IR spectra of 3,4-methylenedioxypyrovalerone (MDPV) are presented in Table 1.

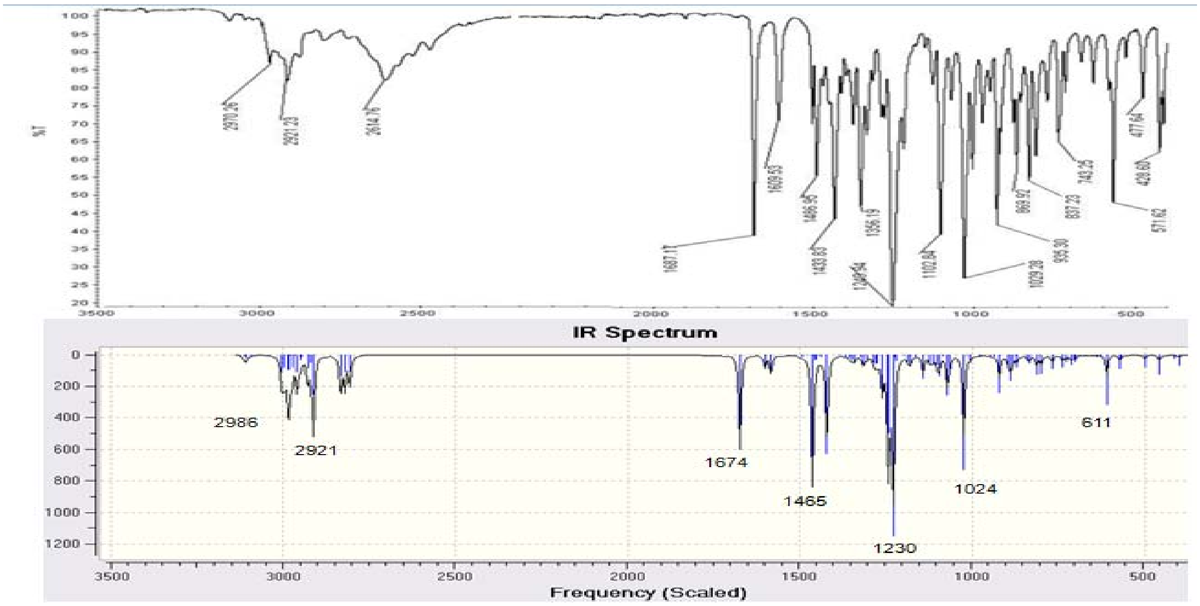

Fig. 3. Experimental [9] *and theoretical IR spectra of 3,4-methylenedioxypyrovalerone (MDPV) in the spectral region 3500 - 400 cm^{-1}.*

Table 1. The experimental and theoretical IR spectra of 3,4-methylenedioxypyrovalerone (MDPV)

No.	$IR_{teoretic}$ **intensity**	$\bar{\nu}_{theor.}$ (cm^{-1})	$\bar{\nu}_{scaled}$ (cm^{-1})	$\bar{\nu}_{\exp.}$ (cm^{-1})	**Assignment of vibrational modes in term of potential energy distribution** $PED(\%)$
1.	11,27	3214	3105	3090	$\nu^{s}(CH)_{ar,\,ring\ A}[85](C16,C17)$
2.	55,21	3088	2983	2970	$\nu^{as}(CH)_{al}[93](C9H_2)$
3.	142,13	3012	2910	2921	$\nu^{s}(CH)_{ring\ B}[79](C19H_2)$
4.	174,27	1732	1673	1687	$\nu(C=O)[89]$
5.	24,32	1657	1601	1610	$\nu(CC)_{ar,ring\ A}[60]$
6.	232,86	1515	1464	1487	$\nu(CC)_{ar,\,ring\ A}[23]+\beta^{sc}(CCH)_{ringA}[21]$
7.	172,49	1471	1420	1434	$\beta^{sc}(CCH)_{ring\ A}[25]+\nu(CCC)_{ring\ A}[16]$
8.	11,12	1389	1342	1356	$\nu(CC)_{ring\ A}[60]$
9.	134,91	1288	1244	1250	$\beta^{sc}(CCH)_{ring\ A}[37]+\nu(CC)_{ring\ A}[17]$
10.	28,78	1135	1096	1103	$\beta(CCC)_{ring\ A}[16]+\beta(CCH)_{ring\ A}[18]$
11	144,89	1061	1025	1029	$\nu^{s}(OC)_{ring\ B}[43]+\beta(COC)_{ring\ B}[24]$
12.	42,83	954	922	935	$\nu^{as}(OC)_{ring\ B}[36]+\beta(COC)_{ring\ B}[25]$
13.	28,50	921	890	870	$\nu(NC)_{ring\ C}[15]$
14.	6,04	869	839	837	$\tau(HCNC)_{ring\ C}[26]$
15.	13,35	795	768	743	$\tau(CCCH)[15](C7C8C9H33)$
16.	37,44	632	610	571	$\beta(CNC)[53](C6N3C2)$
17.	7,30	516	498	478	$\beta(CNC)[26](C4N3C6)$
18.	5,08	414	400	429	$\beta(CNC)[21](C6N3C2)$

Abbreviations: ν - stretching, β - in-plane deformation, β^{out} - out-of-plane deformation, τ - torsion, ar - aromatic, al - aliphatic, s - symmetric; as - asymmetric; PED <15% are not shown.

Analyzing Table 1, we can notice that the stretching vibrations, $\nu(CH)$, are found in the spectral region 3105-2910 cm^{-1} at the level of B3LYP / 6-311G (d, p), with relatively good PED percentages (79-93%). The aliphatic stretching vibrations, $\nu(CH)_{al}$, generate absorption bands at 2983 cm^{-1} in the theoretical IR spectrum and at 2970 cm^{-1} in the experimental FTIR spectrum. The symmetrical stretching vibration, which belongs to ring B, is found at 2910 cm^{-1} in the simulated spectrum and at 2921 cm^{-1} in the experimental one.

The first band associated with an almost normal pure mode $\nu(CC)_{ar}$ (PED allocation being 60%) for ring A, is identified at 1601 cm^{-1} in the scaled theoretical spectrum and at 1610 cm^{-1} in the experimental theoretical spectrum.

The next bands are assigned to the normal mixed modes obtained by the combination of vibrations $\nu(CC)_{ar}$ and $\beta^{sc}(CCH)_{ar}$. In the experimental FTIR spectrum, these bands show at 1487 cm^{-1} and 1434 cm^{-1}, respectively.

Torsional vibrations, $\tau(HCNC)$ and $\tau(CCCH)$, are found in the spectral region 839-768 cm^{-1} at the B3LYP / 6-311G (d, p) level, while the plane deformation vibrations, $\beta(CNC)$, are identified in the spectral range 571-429 cm^{-1}, in the experimental FTIR spectrum.

4. CONCLUSIONS

The PED allocations of the vibrational modes indicate that the spectral range 3090 - 2921 cm^{-1} contains only normal vibrational modes, while in the finger print region most normal modes are mixed. The results indicate that a good agreement was obtained between the calculated vibrational modes and the experimental ones at the level of the DFT / (B3LYP) / 6-311G theory (d, p).

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