

Spectroscopic investigations of a substituted amide of pyrazine-2-carboxylic acid - C₁₆H₁₈N₃O

L. USHAKUMARI¹, C. YOHANNAN PANICKER^{1*}, HEMA TRESA VARAGHESE², HASEENA¹, A.V. VAIDYAN³, NISHA SUDHAKARAN³ and K. RAJU⁴

¹Department of Physics, TKM College of Arts and Science, Kollam - 691 005 (India).

²Department of Physics, Fatima Mata National College, Kollam - 691 001 (India).

³Department of Chemistry, St. Stephen's College, Pathanapuram (India).

⁴Department of Physics, University College, Thiruvananthapuram (India).

(Received: August 22, 2008; Accepted: October 10, 2008)

ABSTRACT

A substituted amide of pyrazine-2-carboxylic acid was prepared and the IR spectrum is recorded and analysed. The vibrational wavenumbers of the title compound have been computed using the Hartree-Fock level of theory using 6-31G* basis set and compared with the experimental data. The first hyperpolarizability, Infrared intensities and Raman activities are reported. The red shift of the NH stretching wavenumber indicates the weakening of the NH bond. Methyl substitution affects all the carbon-nitrogen and carbon-carbon bond lengths of the pyrazine ring of the title compound in comparison with the corresponding bonds of pyrazine. Increase in conjugation, enhances the infrared intensity of the carbonyl stretching vibration. The splitting of NH stretching bond is due to Davidov coupling between neighbouring units.

Keywords: Amides of pyrazine carboxylic acid; IR; Hartree-Fock ab initio calculations, hyperpolarizability.

INTRODUCTION

Pyrazine is a building block of phenazine and pteridines, and occurs in many compounds with pharmaceutical and flavoring applications. Pyrazine is known to form complexes with carboxylic acids¹ and nuclear magnetic resonance studies show the 1:1 and 1:2 adducts are present in solution^{2,3}. Furthermore, pyrazine retains its high molecular symmetry and the two nitrogen atoms are involved in the complexation. Pyrazines are responsible for flavor of foodstuffs as diverse as cooked meats, cheese, tea and coffee. The 2-methylpyrazine is used in flavors in food, baccy. It is the intermediate of aldinamide and hydragog. Besides, the 2-methylpyrazine is an insecticide, photo medicine and pigment, sensitizer; polymer catalyst of ethylene and other unsaturated compounds, the curing agent of

epoxy resins, curing agent of halogen polymers, metal chelating agent and separating agent, brightener of copper plating. Dimethylpyrazines are added to impart or help a taste or aroma in food. The 2,3-dimethylpyrazine is found in asparagus, peanut, coffee and potato and used in gravies, beverages and candy. The 2,5-dimethylpyrazine is found in beef, blackberry, corn, grapefruit juice and used in breakfast cereal. The 2,6-dimethylpyrazine mainly used to confect the essence of cocoa, coffee, meat or potato flavor⁴. Pyrazine carboxamide is a well know anti tubercule bacillus drug and some of its complexes are widely used due to their antimycobacterial properties^{5,6}. Pyrazine and its derivatives form an important class of compounds present in natural flavours and complex organic molecules⁷. 2-chloropyrazine and 2,6-dichloropyrazine are mainly found as medical and

agricultural drug intermediates⁷. Billes and co-workers⁸ calculated the vibrational wavenumbers of the three parent diazines (pyrazine, pyridazine and pyrimidine) applying ab initio quantum chemical methods, Molles-Plessett perturbation and local density function methods. The dynamical pattern of the 2-aminopyrazine-3-carboxylic acid molecule by inelastic and incoherent neutron scattering, Raman spectroscopy and ab initio calculations are reported by Pawlukojc *et al.*⁹. Recent years have seen increased incidence of tuberculosis in both developing and industrialized countries, the wide spread emergence of drug-resistant strains and a deadly synergy with human immunodeficiency virus (HIV)^{10,11}. Pyrazinamide is a nicotinamide analogue that has been used for almost 50 years as a first-line drug to treat tuberculosis¹². Pyrazinamide is bactericidal to semidormant mycobacteria and reduces total treatment time¹³. Although the exact biochemical basis of pyrazinamide activity in vivo is not known, under acidic conditions it is thought to be a prodrug of pyrazinoic acid, a compound with antimycobacterial activity¹⁴. The finding that pyrazinamide-resistant strains lose amidase (pyrazinamidase or nicotinamidase) activity and the hypothesis that amidase is required to convert pyrazinamide to pyrazinoic acid intracellularly led to the recent synthesis and study of various prodrugs of pyrazinoic acid¹⁵. Various compounds possessing -NHCO- groups, e.g. substituted amides, acyl and thioacyl anilides, benzanilides, phenyl carbamates, etc., were found to inhibit photosynthetic electron transport¹⁶⁻¹⁹. The vibrational spectra of diazines have been extensively studied by several authors^{8,20-26}. However, the literature on methylated derivatives of pyrazine is very scarce²⁷⁻³¹. Therefore, the vibrational spectroscopic studies of the amides of pyrazine-2-carboxylic acid are added areas of interest. The synthesis and biological activity of substituted amides of pyrazine-2-carboxylic acids are reported by Dolezal *et al.*³².

EXPERIMENTAL

The protocol for preparation of the compound is reported elsewhere³². The IR spectrum was recorded on a Nicolet Impact 400 spectrometer in KBr pellets. The spectral resolution is 4 cm⁻¹. Standard KBr technique with 0.7 mg per 400 mg KBr is used.

Computational details

Calculations of the title compound were carried out with Gaussian03 program³³ using the HF/6-31G* basis set to predict the molecular structure and wavenumbers. Molecular geometry was fully optimized by Berny's optimization algorithm using redundant internal coordinates. Harmonic vibrational wavenumbers were calculated using the analytic second derivatives to confirm the convergence to minimum of the potential surface. The wavenumber values computed at the Hartree-Fock level contain known systematic errors due to the negligence of electron correlation³⁴. We therefore, have used the scaling factor value of 0.8929 for HF/6-31G* basis set. The absence of imaginary wavenumber on the calculated vibrational spectrum confirms that the structure deduced corresponds to minimum energy.

RESULTS AND DISCUSSION

The observed IR bands with their relative intensities and calculated wavenumbers and assignments are given in Table 1. Although the tertiary butyl substituent can provide six methyl asymmetric stretching vibrations, generally only three are observed as moderate to strong bands³⁵. These vibrations are expected in the region 3010-2900 cm⁻¹ and most tBu molecules give these ν_{as} Me stretching vibrations³⁵ between 2990 and 2930 cm⁻¹. The methyl symmetric stretching are active between 2950 and 2850 cm⁻¹. Aromatic molecules usually display these symmetric stretching vibrations³⁵ between 2915 and 2860 cm⁻¹. In the present case the tBu ν_{as} Me stretching vibration is observed at 2963 cm⁻¹ in the IR spectrum. The calculated values for these modes are 2947, 2931, 2925, 2921, 2920 and 2917 cm⁻¹. The symmetric stretching vibrations of the methyl group is calculated to be at 2873, 2863, 2860 cm⁻¹ and no bands are experimentally observed. The methyl asymmetric deformations³⁵ δ_{as} Me absorb between 1495 and 1435 cm⁻¹. Although three methyl symmetric bending vibrations are expected often only two emerge experimentally. In the present case the band observed at 1367 cm⁻¹ in the IR spectrum is assigned as the symmetric deformations of the methyl group. The ab initio calculations give these modes at 1482, 1475, 1474, 1458, 1455, 1455 cm⁻¹ and at 1418, 1393, 1388 cm⁻¹ as asymmetric

Table 1: Calculated vibrational wavenumbers, measured Infrared band positions and assignments

$\nu_{(HF)}$ (cm ⁻¹)	$\nu_{(IR)}$ (cm ⁻¹)	IR intensity (KM/Mol)	Raman activity (A**4/AMU)	Assignments
3403	3447 sbr3358 s	51.64	120.99	ν NH
3039	3048 w	11.87	86.56	ν CH Pz
3031		27.05	53.98	ν CH Pz
3029		19.23	217.31	ν CH
3017		33.40	47.05	ν CH
3008	3000 w	7.41	99.83	ν CH
2998	2983 m	3.14	41.30	ν CH
2947	2963 s	33.22	49.04	ν_{as} Me
2937		23.11	56.20	ν_{as} Me Ph
2931		87.92	161.15	ν_{as} Me
2925	2928 m	141.19	63.90	ν_{as} Me Ph
2925		57.68	69.75	ν_{as} Me
2921		18.92	28.58	ν_{as} Me
2920		26.48	66.81	ν_{as} Me
2917		2.88	10.25	ν_{as} Me
2873		34.27	253.96	ν_s Me
2872	2872 w	23.13	118.03	ν_s Me Ph
2863		20.79	52.38	ν_s Me
2860		31.59	1.38	ν_s Me
1767	1685 vvs	527.63	21.57	ν C=O
1616		3.15	19.51	ν Ph
1613	1608 w	22.34	67.04	ν Pz
1587	1592 s	0.31	13.46	ν Ph
1573	1576 m	16.82	12.10	ν Pz
1500	1537 vvs	36.70	1.61	ν CNH
1493	1486 m	44.03	2.19	ν Ph
1482		7.78	3.69	δ_{as} Me
1475		6.65	18.24	δ_{as} Me
1474		4.42	16.12	δ_{as} Me
1468		9.39	4.84	δ_{as} Me Ph
1459	1458 s	3.78	19.56	δ_{as} Me Ph
1458		0.02	26.33	δ_{as} Me
1455		0.11	20.81	δ_{as} Me
1455		0.01	0.74	δ_{as} Me
1446		16.92	3.62	ν Ph
1421		24.03	11.19	δ CH Pz
1418		1.90	1.38	δ_s Me
1406	1405 w	3.04	7.77	δ_s Me Ph
1393		5.76	1.17	δ_s Me
1388	1367 m	3.36	1.69	δ_s Me
1340	1345 w	332.24	5.09	ν Ph
1328	1335 w	21.48	0.88	ν Pz
1291	1312 m	45.74	5.90	ν_{as} CC ₃
1278	1285 m	25.94	3.25	ν Pz

1271	1255 m	4.02	1.98	δ CH
1222	1230 w	17.20	9.15	δ CNH
1206	1211 w	3.00	6.36	$\nu_{as}CC_3$
1206		4.93	4.05	ρ Me
1186	1190 w	4.44	1.06	δ Pz
1168		29.33	1.66	Ring breath Pz
1157	1147 s	78.40	0.63	δ CH Pz
1129	1131 w	32.92	23.73	δ CH
1102		2.54	5.48	δ CH
1084	1078 w	8.74	4.14	δ CH
1047		5.72	0.51	ρ Me Ph
1042	1042 w	35.38	4.30	ρ Me
1029		0.02	4.29	ρ Me
1025		0.89	14.98	δ CH
1020	1026 s	33.72	1.44	ν Pz
1002	1000 w	0.03	0.16	γ CH Pz
988		78.83	3.33	ρ Me
977		0.42	2.52	ρ Me Ph
967		1.88	1.36	γ CH
963		0.84	1.23	γ CH
944	940 w	6.19	0.13	ρ Me
938		9.44	0.36	$\delta\rho$ Me
915		0.56	7.70	ν CC
906	905 w	0.01	9.82	γ CH
889	893 w	4.31	2.75	γ CH
875		3.59	2.23	δ C=O
836		1.39	9.26	δ_sCC_3
815		10.72	1.66	γ CH Pz
780	790 w	6.44	14.59	δ Pz
771	767 s	19.06	0.61	γ CH
757		32.20	3.29	ω C=O
749	746 w	16.59	14.78	δ Ph(X)
718	698 w	25.54	4.97	Ring breath Ph
655	654 m	7.83	4.38	γ Ph
637		27.91	1.74	δ CC
623	611 w	7.87	3.98	δ Pz
588	583 w	8.20	1.32	γ Ph(X)
551		5.55	3.46	ρ C=O
541		69.12	2.68	ω NH
533	536 w	7.46	9.50	δ Ph(X)
497	500 w	4.90	1.05	γ Ph(X)
479		3.39	8.10	δ Ph(X)
454		6.85	1.45	δ Ph
448		0.83	1.40	$\delta_{as}CC_3$
426		17.40	0.25	γ Pz
414		1.31	0.52	δ Ph(X)
373		2.11	0.57	$\delta_{as}CC_3$
355		7.07	2.17	τ C=O
330		2.51	2.83	δ_sCC_3
322		0.70	0.62	δ Ph(X)

295	0.30	0.39	ρCC_3
291	0.64	1.56	$\delta\text{Ph(X)}$
274	0.43	1.31	ρCC_3
268	2.52	2.40	$\delta\text{CX(X)}$
250	3.73	2.44	δCN
225	0.41	0.89	τMe
217	0.54	1.68	τMe
193	0.27	4.00	τMe
148	0.52	1.82	δCN
133	0.06	0.32	τCC_3
121	0.31	1.21	$t\text{C=O}$
77	0.19	1.40	$\tau\text{Me Ph}$
66	1.71	1.77	τPh
51	1.04	2.81	τPz
33	0.09	4.92	τPh
29	0.29	3.00	τPz
16	0.12	1.96	τPh

ν -stretching; δ -in-plane deformation; γ -out-of-plane deformation; ρ -rocking; -wagging; τ -twisting; ω -wagging; t-torsion; s-strong; b-broad; v-very; w-weak; Me-methyl; Ph-phenyl; Pz- pyrazine; X-substituent sensitive

and symmetric methyl deformations, respectively for the title compound.

The $\nu_{\text{as}}\text{CC}_3$, $\nu_{\text{s}}\text{CC}_3$ modes are expected in the regions 1235 ± 60 and 800 ± 90 cm^{-1} respectively³⁵. Some times, the $\nu_{\text{s}}\text{CC}_3$ mode is of reasonable intensity, but normally this vibration mode absorbs weakly³⁵. For the title compound the bands observed at 1312, 1211 cm^{-1} in the IR spectrum and 1291, 1206 cm^{-1} (HF) are assigned as $\nu_{\text{as}}\text{CC}_3$ modes. The HF calculations give the symmetric $\nu_{\text{s}}\text{CC}_3$ stretching mode at 836 cm^{-1} and experimentally no band is observed. Most of the investigated molecules display the first methyl rock³⁵ in the region 1150 ± 35 cm^{-1} . The other methyl rocking modes³⁵ are expected in the regions 1035 ± 55 , 990 ± 50 and 925 ± 30 cm^{-1} . The HF calculations give these rocking modes of the tBu group at 1206, 1042, 1029, 988, 944, 938 cm^{-1} . Only two bands are observed at 1042 and 940 cm^{-1} in the IR spectrum, as rocking modes of the methyl group. The tBu group give rise to five skeletal deformations³⁵ absorbing in three regions: $\delta_{\text{as}}\text{CC}_3$ in 435 ± 85 , $\delta_{\text{s}}\text{CC}_3$ in 335 ± 80 and ρCC_3 in 300 ± 80 cm^{-1} . These modes normally produce bands of weak or medium intensity. The highest (lowest) values³⁵ for $\delta_{\text{as}}\text{CC}_3$ are observed around 510 (355) cm^{-1} . Most

of the $\delta_{\text{as}}\text{CC}_3$ modes have been assigned in the region 435 ± 65 cm^{-1} . The HF calculations give wavenumbers at 448, 373 and 330 cm^{-1} as asymmetric and symmetric deformations. The bands at 295 and 274 cm^{-1} (HF) are assigned as the rocking modes of CC_3 . The torsional modes τMe and τCC_3 are expected in the low wavenumber region³⁵.

The N-H stretching vibrations^{36,37} generally give rise to bands at 3500-3300 cm^{-1} . In the present study, the NH stretching band has split into a doublet, 3447, 3358 cm^{-1} in the IR spectrum owing to the Davidov coupling between neighbouring units. A similar type of splitting observed in acetanilide^{38,39} and N-methylacetamide⁴⁰ in the stretching band is attributed to the Davidov splitting. The splitting of about 89 cm^{-1} in the IR spectrum is due to strong intermolecular hydrogen bonding. Further more, the N-H stretching wavenumber is red shifted by 45 cm^{-1} in the IR spectrum with a strong intensity from the computed wavenumber, which indicates the weakening of the N-H bond resulting in proton transfer to the neighbouring oxygen atom⁴¹. In N-monosubstituted amides, the in-plane bending frequency and the resonance stiffened C-N band stretching frequency fall close together and

therefore interact. The CNH vibration where the nitrogen and hydrogen move in opposite direction relative to the carbon atom involves both N-H bending and C-N stretching⁴² and absorbs strongly near 1550 cm⁻¹. This band is very characteristic for mono-substituted amides. The CNH vibration where the N and H atoms move in the same direction relative to the carbon atom give rise to a weaker band⁴² near 1250 cm⁻¹. In the present case the bands observed at 1537, 1230 cm⁻¹ in the IR spectrum and 1500, 1222 cm⁻¹ (HF) are assigned as CNH bending modes. The out-of-plane NH wag is assigned at 541 cm⁻¹ theoretically.

In aromatic compounds the asymmetric stretching vibrations of CH₃ are expected in the range 2905-3000 cm⁻¹ and symmetric CH₃ vibrations^{35,42} in the range of 2860-2870 cm⁻¹. The first of these results from the asymmetric stretching $\nu_{as}CH_3$ mode in which two C-H bonds of the methyl group are extending while the third one is contracting. The second arises from the symmetrical stretching ν_sCH_3 in which all three of the C-H bonds extend and contract in phase. The asymmetric stretching modes of the methyl group are calculated to be 2937, 2925 cm⁻¹ and the symmetric mode at 2872 cm⁻¹. The bands observed at 2928 and 2872 cm⁻¹ in the IR spectrum are assigned as asymmetric and symmetric modes, respectively. Two bending can occur within a methyl group. The first of these, the symmetrical bending vibration, involves the in-phase bending of the C-H bonds. The second, the asymmetrical bending vibration, involves out-of-phase bending of the C-H bonds. The asymmetrical deformations³⁵ are expected in the range 1400-1485 cm⁻¹. The calculated values of $\delta_{as}CH_3$ modes are at 1468, 1459 cm⁻¹ and a band observed at 1458 cm⁻¹ in the IR spectrum. In many molecules, the symmetric deformations δ_sCH_3 appears with an intensity varying from medium to strong and expected in the range³⁵ 1380 ± 25 cm⁻¹. The band observed at 1405 cm⁻¹ in the IR spectrum is assigned as the δ_sCH_3 mode. The HF calculations give δ_sCH_3 mode at 1406 cm⁻¹. Aromatic molecules display a methyl rock³⁵ in the neighbourhood 1045 cm⁻¹. The second rock³⁵ in the region 970±70 cm⁻¹ is more difficult to find among the C-H out-of-plane deformations. In the present case, these $\bar{\nu}CH_3$ modes are calculated at 1047 and 977 cm⁻¹. Experimentally no bands are observed. The methyl

torsions³⁵ often assigned in the region 185 ± 65 cm⁻¹.

The pyrazine CH stretching modes are observed at 3048 cm⁻¹ in the IR spectrum and the ab initio calculations give these modes at 3039, 3031 cm⁻¹. The CH stretching bands of pyrazine was reported in the range⁴³⁻⁴⁵ 3100-3000 cm⁻¹. These νCH bands are observed at 3057, 3070, 3086 cm⁻¹ (IR), 3060, 3070, 3087 cm⁻¹ (Raman), 3061, 3074, 3079 cm⁻¹ (theoretical) for 2-chloropyrazine and at 3099, 3104 cm⁻¹ (IR), 3078, 3103 cm⁻¹ (Raman), 3096, 3100 cm⁻¹ (calculated) for 2,6-dichloropyrazine⁷. Akyuz⁴⁶ reported these νCH bands at 3088, 3066, 3052 cm⁻¹ for pyrazinamide.

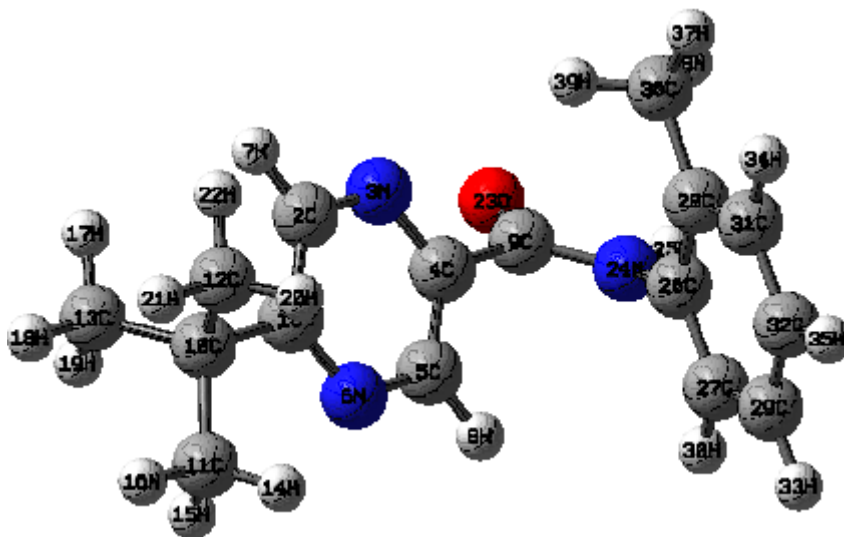
For 2-aminopyrazine-3-carboxylic acid⁹ the pyrazine ring stretching modes are observed at 1564, 1536, 1468, 1458, 1360, 1258, 1083 cm⁻¹ (Raman), 1567, 1565, 1415, 1373, 1231, 1068 cm⁻¹ (*ab initio*). For pyrazine, the ring stretching modes are reported at 1485, 1411, 1128, 1065 cm⁻¹ (IR), 1579, 1522, 1015 cm⁻¹ (Raman) and 1597, 1543, 1482, 1412, 1140, 1063, 1009 cm⁻¹ theoretically⁷. For 2-chloropyrazine the pyrazine ring stretching modes are reported at 1561, 1515, 1198, 1176, 1133, 1047 cm⁻¹ (IR), 1562, 1518, 1197, 1177, 1135, 1049 cm⁻¹ (Raman) and 1563, 1533, 1210, 1116, 1128, 1042 cm⁻¹ (DFT) and for 2,6-dichloropyrazine these vibrations are reported at 1550, 1412, 1230, 1189, 1151, 1136 cm⁻¹ (IR), 1551, 1407, 1172, 1152, 1131 cm⁻¹ (Raman) and 1547, 1541, 1407, 1229, 1170, 1167, 1143 cm⁻¹ (DFT)⁷ and at 1581, 1525, 1479, 1437, 1166, 1025 cm⁻¹ experimentally for pyrazinamide⁴⁶. In the present case, the ring stretching modes are observed at 1608, 1576, 1335, 1285, 1190, 1026 cm⁻¹ in the IR spectrum and the ab initio calculations give these modes at 1613, 1573, 1328, 1278, 1186, 1020 cm⁻¹.

The C-H in-plane bending modes in 2,6-dichloropyrazine are reported at 1189 and 1151 cm⁻¹ in the IR spectrum⁷. For 2-chloropyrazine these modes are reported at 1455, 1380, 1280, 1179 cm⁻¹ in the IR spectrum and at 1457, 1390, 1289, 1167 cm⁻¹ theoretically⁷. For pyrazine the δCH modes are observed at 1485, 1413, 1065 cm⁻¹ in the IR spectrum and at 1482, 1412, 1227, 1063 cm⁻¹ theoretically⁷ and for pyrazinamide⁴⁶ at 1305, 1183, 1054 cm⁻¹. In the present case the C-H in-plane

deformations are observed at 1421, 1157 cm^{-1} theoretically. Only one strong band is observed in the IR spectrum at 1147 cm^{-1} corresponding to $\bar{\alpha}\text{CH}$ mode of the pyrazine ring.

For the title compound the out-of-plane deformations $\bar{\alpha}\text{CH}$ vibrations of the pyrazine ring are observed in the IR spectrum at 1000 cm^{-1} and the calculated values are 1002, 815 cm^{-1} . For pyrazine⁷ γCH modes are observed at 790 cm^{-1} in the IR spectrum, 976, 925 cm^{-1} in the Raman spectrum and at 985, 974, 930, 790 cm^{-1} by DFT calculations. The γCH modes are reported at 954, 929, 844 cm^{-1} (IR), 960, 928, 847 cm^{-1} (Raman), 960, 923, 837 cm^{-1} (theoretical) for 2-chloropyrazine and at 897, 875 cm^{-1} (IR), 896 cm^{-1} (Raman), 919, 869 cm^{-1} theoretically for 2,6-dichloropyrazine⁷. For 2-aminopyrazine-3-carboxylic acid γCH modes are reported at 1006, 850 cm^{-1} in the Raman spectrum, 987, 852 cm^{-1} by HF calculations⁹ and at 988, 954, 786 cm^{-1} for pyrazinamide⁴⁶.

In the case of 2-aminopyrazine-3-carboxylic acid⁹ the vibrational modes of the carboxylic group were assigned to the observed wavenumbers as follows: torsional C=O 101 cm^{-1} (Raman), 111 cm^{-1} (HF); rocking C=O 537 cm^{-1} (Raman), 571 cm^{-1} (HF); wagging C=O 723 cm^{-1} (Raman), 736 cm^{-1} (HF); bending C=O 912 cm^{-1} (Raman), 886 cm^{-1} (HF); stretching mode C=O 1718 cm^{-1} (Raman), 1786 cm^{-1} (HF). For the title compound the C=O deformation bands are assigned at 875, 757, 551 cm^{-1} theoretically. The carbonyl group vibrations give rise to characteristic bands in the vibrational spectra. The intensity of these bands can increase owing to conjugation or formation of hydrogen bonds. The increase in conjugation, therefore, leads to intensification of IR bands. In the present case the stretching mode of C=O is assigned at the very strong band 1685 cm^{-1} in the IR spectrum and the HF calculations give this mode at 1767 cm^{-1} . The deviation of the calculated value in the HF calculation for this mode



Scheme 1: Optimized geometry of the molecule

can be attributed to the under estimation of the large degree of π -electron delocalization due to conjugation in the molecule.

According to Roeges³⁵ the CH stretching vibrations of the phenyl ring are expected in the region 3120-3000 cm^{-1} . The calculated values for

these modes are 3029, 3017, 3008, 2998 cm^{-1} . Experimentally only a medium band at 2983 cm^{-1} is observed in the IR spectrum. The benzene ring possesses six ring stretching vibrations, of which the four with the highest wavenumbers (occurring respectively near 1600, 1580, 1490 and 1440 cm^{-1}) are good group vibrations³⁵. The fifth ring

stretching vibration is active near $1315 \pm 65 \text{ cm}^{-1}$, a region which overlaps strongly that of the CH in-plane deformation. The sixth ring stretching vibration or ring breathing mode appears as a weak band near 1000 cm^{-1} in mono, 1,3-di- and 1,3,5-tri-substituted benzenes. In the otherwise substituted benzenes, however, this vibration is substituent sensitive³⁵. In the present case, the δPh modes are observed at 1592, 1486, 1345 cm^{-1} in the IR spectrum and the HF calculations showed this modes at 1616, 1587, 1493, 1446, 1340 cm^{-1} . These νPh modes are expected in the region³⁵ $1625\text{-}1275 \text{ cm}^{-1}$. In ortho-disubstitution the ring breathing mode has three frequency intervals according to whether both substituents are heavy, or one of them is heavy while the other is light or both of them are light. In the first case, the interval is $1100\text{-}1130 \text{ cm}^{-1}$, in the second case $1020\text{-}1070 \text{ cm}^{-1}$, while in the third case it is between⁴⁷ 630 and 789 cm^{-1} . The band observed at 698 cm^{-1} in the IR spectrum and 718 cm^{-1} (HF) is assigned as the ring breathing mode of the phenyl ring. For 1,2-disubstituted benzenes, the in-plane CH deformations are expected in the range³⁵ $1250\text{-}1300 \text{ cm}^{-1}$ and $1170\text{-}1000 \text{ cm}^{-1}$. The phenyl CH in-plane deformations δCH are observed at 1255, 1078 cm^{-1} in the IR spectrum. The ab initio calculations give these modes at 1271, 1102, 1084, 1025 cm^{-1} . The aromatic out-of-plane deformations³⁵ are observed in the range $1005\text{-}720 \text{ cm}^{-1}$. These $\bar{\alpha}\text{CH}$ modes are observed at 905, 893, 767 cm^{-1} in the IR spectrum and the corresponding calculated values are 967, 963, 906, 889, 771 cm^{-1} .

According to Roeges³⁵, in the case of 1,2-disubstitution only one strong absorption in the region $755 \pm 35 \text{ cm}^{-1}$ is observed and is due to γCH mode. This is confirmed by the presence of a strong γCH at 767 cm^{-1} in the IR spectrum and is supported by the computational result at 771 cm^{-1} .

The first hyperpolarizability of this novel molecular system is calculated using HF/6-31G* basis set, based on the finite field approach. In the presence of an applied electric field, the energy of a system is a function of the electric field. First hyperpolarizability is a third rank tensor that can be described by a $3 \times 3 \times 3$ matrix. The 27 components of the 3D matrix can be reduced to 10 components due to the Kleinman symmetry⁴⁸. The calculated first hyperpolarizability of the title compound is 0.947

10^{-30} esu, which is 4.2 times that of urea. To best of our knowledge, no X-ray crystallographic data of this molecule has yet been established. However, the theoretical results obtained are almost comparable with the recently reported structural parameters of similar molecules. In the present case the pyrazine bond lengths $\text{C}_1\text{-C}_2$, $\text{C}_2\text{-N}_3$, $\text{N}_3\text{-C}_4$, $\text{C}_4\text{-C}_5$, $\text{C}_5\text{-N}_6$, $\text{N}_6\text{-C}_1$ are 1.4029, 1.3082, 1.3251, 1.3780, 1.3235 and 1.3149 \AA . For a similar derivative, Mary *et al.*³¹ reported the corresponding values as 1.3917, 1.2996, 1.3229, 1.3840, 1.322 and 1.3116 \AA . Endredi *et al.*⁴ reported the bond lengths $\text{C}_1\text{-C}_2$, $\text{C}_2\text{-N}_3$, $\text{N}_3\text{-C}_4$, $\text{C}_4\text{-C}_5$, $\text{C}_5\text{-N}_6$ as 1.391, 1.331, 1.331, 1.331, 1.331 \AA for pyrazine, 1.4, 1.327, 1.333, 1.387, 1.334 \AA for 2-methylpyrazine, 1.41, 1.331, 1.33, 1.385, 1.331 \AA for 2,3-dimethylpyrazine, 1.396, 1.327, 1.335, 1.396, 1.335 \AA for 2,5-dimethylpyrazine and 1.399, 1.326, 1.332, 1.399, 1.332 \AA for 2,6-dimethylpyrazine. For 2-aminopyrazine-3-carboxylic acid⁷ and for a similar substituted amide of pyrazine³¹, the bond lengths $\text{C}_9\text{-O}_{23}$, $\text{C}_4\text{-C}_9$, $\text{C}_4\text{-N}_3$, $\text{C}_4\text{-C}_5$ are 1.212, 1.479, 1.333, 1.479 \AA and 1.2003, 1.5099, 1.3229, 1.384 \AA , respectively. In the present case, the corresponding values are 1.195, 1.5082, 1.3251 and 1.378 \AA , respectively. The CN bond lengths in the pyrazine ring of the title compound $\text{C}_2\text{-N}_3$ 1.3082, $\text{C}_4\text{-N}_3$ 1.3251, $\text{C}_1\text{-N}_6$ 1.3149, $\text{C}_5\text{-N}_1$ 1.3235 \AA are much shorter than the normal C-N single bond that is referred to 1.49 \AA . The same results are showed for the bond lengths of the two C-C bonds, $\text{C}_1\text{-C}_2$ 1.4029, $\text{C}_4\text{-C}_5$ 1.3780 \AA in the pyrazine ring and are also smaller than that of the normal C-C single bond of 1.54 \AA ⁴⁹. The C-N bond lengths $\text{C}_9\text{-N}_{24}$ 1.3650, $\text{C}_{26}\text{-N}_{24}$ 1.4297 \AA , are also shorter than the normal C-N single bond of 1.49 \AA which confirms this bond to have some character of double or conjugated bond⁴⁹. The $\text{N}_{24}\text{-H}_{25}$ bond is found to be 0.9994 \AA which is around the normal NH bond of 1.01 \AA ⁴⁹.

Due to $\text{C}(\text{CH}_3)_3$ substitution in the pyrazine ring the $\text{C}_1\text{-C}_2$ bond length is greater than the $\text{C}_4\text{-C}_5$ bond length. The +I>-M effect of the methyl substituent affects all the C-N and C-C bond lengths of the pyrazine ring of the title compound in comparison with the corresponding bonds of pyrazine⁴. At N_{24} position, the angles $\text{C}_9\text{-N}_{24}\text{-H}_{25}$ is 112° , $\text{C}_{26}\text{-N}_{24}\text{-H}_{25}$ is 120.6° and $\text{C}_9\text{-N}_{24}\text{-C}_{26}$ is 127.4° . This asymmetry of the angles at N_{24} position indicates the weakening of $\text{N}_{24}\text{-H}_{25}$ bond resulting

in proton transfer to the oxygen atom⁴¹ O₂₃. At C₂₈ position, the angle C₂₆-C₂₈-C₃₁ is reduced by 2.1° and C₂₆-C₂₈-C₃₆ is increased by 1.6° from 120°, which shows the repulsive interaction between the methyl group and NH group. At C₁ position of the pyrazine ring, there is asymmetry between the angles C₂-C₁-C₁₀ and N₆-C₁-C₁₀ which is due to the steric hindrance between H₇ and the tBu group.

ACKNOWLEDGEMENTS

L. Ushakumari and C.Yohannan Panicker thank University Grants Commission, India, for a minor research grant.

REFERENCES

1. Belabbes, Y. and Lautie, A., *Vib. Spectrosc.* **9**: 131 (1995).
2. Fujiwara, H, Yoshida, N and Ilkenoué, T., *Bull. Chem. Soc. Jpn.* **48**: 1970 (1975).
3. Rebek, J. and Nemeth, D., *J. Am. Chem. Soc.* **108**: 5637 (1986).
4. Endredi, H., Billes, F., and Keresztury, G., *J. Mol. Struct. Theochem.* **677**: 211 (2004).
5. Katzung, B.G., *Basic and Clinical Pharmacology*, fourth ed. Prentice Hall, London(1989).
6. Opletalova, V., Hartl, J., Patel, A., Palat Jr., K., and Buchta, V., *Il Farmaco* **57**: 135 (2002).
7. Endredi, H., Billes, F., and Holly, S., *J. Mol. Struct. Theochem* **633**: 73 (2003).
8. Billes, F., Mikosch, H., and Holly, S., *J. Mol. Struct. Theochem* **423**: 225 (1998).
9. Pawlukoic, A., Natkaniec, I., Makrski, Z., and Leciejewicz, J., *J. Mol. Struct.* **516**: 7 (2000).
10. Raviglione, M.C., Dye, C., Smidt, S., and Kochi, A., *Lancet.* **35**: 624 (1997).
11. Houston, S., and Fanny, A., *Drugs* **48**: 689 (1996).
12. Snider, D.E., Castro, K.G., *New Engl. J. Med.* **338**: 1689 (1998).
13. Mitchison, D.A., *Natur. Med.* **2**: 6 (1996).
14. Cynanon, M.H., Klemens, S.P., Chou, T.S., Gimi, R.H., and Welch, J.T., *J. Med. Chem.* **35**: 1212 (1992).
15. Bergmann, K.E., Cynanon, M.H., and Welch, J.T., *J. Med. Chem.* **39**: 3394 (1996).
16. Good, N.E., *Plant. Physiol.* **36**: 788 (1961).
17. Kralova, K., Sersen, F., and Cizmarik, J., *Chem. Pap.* **46**: 266 (1992).
18. Kralova, K., Sersen, F., Miletin, M., and Hartal, J., *Chem. Pap.* **52**: 52 (1998).
19. K.Kralova, K., F.Sersen, F., L.Kubicova, L., and K.Waissser, K., *Chem. Pap.* **53**: 328 (1999).
20. Arenas, J.F., Wolley, M.S., Lopez-Tocon, I., and Otero, J.C., *J. Chem. Phys.* **112**: 7669 (2000).
21. Moskovits, M., DiLella, D.P., and Maynard, K.J., *Langmuir* **4**: 67 (1988).
22. Brolo, A.G., and Irish, D.E., *Z. Naturforsch* **50**: 274 (1995).
23. Martin, J.M.L., and Van Alsenoy, C., *J. Phys. Chem.* **10**: 6793 (1996).
24. Boese, A.D., and Martin, J.M.L., *J. Phys. Chem.* **108A**: 3085 (2004).
25. Barone, V., *J. Phys. Chem.* **108A**: 4146 (2004).
26. Breda, S., Reva, I.D., Lapinski, L., Nowak, M.J., and Fausto, R., *J.Mol. Struct.* **786**: 193 (2006).
27. Arenas, J.F., Lopez-Tocon, I., Otero, J.C., and Marcos, J.L., *Vib. Spectrosc.* **19**: 213 (1999).
28. Arenas, J.F., Centeno, S.P., Lopez-Tocon, I., and Otero, J.C., *J.Mol. Struct.* **744-747**: 289 (2005).
29. Endredi, H., Billes, F., and Keresztury, G., *J. Mol. Struct. Theochem.* **677**: 211 (2004).
30. Centeno, S.P., Lopez-Tocon, I., Arenas, J.F., and Otero, J.C., *J. Mol. Struct.* **834-836**: 567 (2007).
31. Mary, Y.S., Varghese, H.T., Panicker, C.Y., and Dolezal, M., *Spectrochim. Acta* doi: 10.1016/j.saa.2007.12.055.
32. Dolezal, M., Miletin, M., Kunes, J., and Kralova, K., *Molecules* **7**: 363 (2002).

33. Frisch, M.J. et. al. *Gaussian 03*, Revision C.02, Gaussian, Inc., Wallingford CT (2004).
34. Foresman J.B., in: Frisch, E., (Ed.), *Exploring Chemistry with Electronic Structure Methods: A Guide to Using Gaussian*, Gaussian, Pittsburg, PA (1996).
35. Roeges, N.P.G., *A Guide to the Complete Interpretation of Infrared Spectra of Organic Structures*, Wiley, New York (1994).
36. Spire, A., Berthes, M., Kallouai, H., and DeNunzio, G., *Physics* **D137**: 392 (2000).
37. Bellamy, L.J., *The IR spectra of Complex Molecules*, John Wiley and Sons, New York (1975).
38. Edler, J., Pfister, R., Pouthier, V., Falvo, C., and Hamm, P., *Phys. Rev. Lett.* **93**: 106405 (2004).
39. Edler, J., Hamm, P., and Scott, A.C., *Phys Rev. Lett.* **88**: 067403 (2002).
40. Edler, J., and Hamm, P., *Phys Rev.* **B69**: 214301 (2004).
41. Barthes, M., DeNunzio, G., and Ribert, G., *Synth. Met.* **76**: 337 (1996).
42. Colthup, N.B., Daly, L.H., and Wiberly, S.E., *Introduction to Infrared and Raman Spectroscopy*, second ed., Academic Press, New York (1985).
43. Schettino, V., Sbrana, G., and Righini, R., *Chem. Phys.Lett.* **13**: 284 (1972).
44. Sbrana, G., Schettino, V., and Righini, R., *J. Chem. Phys.* **59**: 2441 (1973).
45. Arenas, J.F., Navarrete, I.T.L., Otero, J.C., Marcos, J.I., and Cardenate, A., *J. Chem. Soc. Faraday Trans.* **281**: 405 (1985).
46. Akyuz, S., *J. Mol. Struct.* **651-653**: 541 (2003).
47. Varsanyi, G., *Assignments of Vibrational Spectra of Seven Hundred Benzene Derivatives*, Wiley New York (1974).
48. Kleinman, D.A., *Phys. Rev.* **126**: 1977 (1962).
49. He, W., Zhon, G., Li, J., and Tian, A., *J. Mol. Struct. Theochem.* **668**: 201 (2004).