

N-Benzylidene Pyridine-4-amines: DFT and PM3 Theoretical Study

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Abstract- Two theoretical methods were used to optimise five synthesised *N*-benzylidene pyridine-4-amines. The methods are PM3 semiempirical and density functional theory (DFT) with B3LYP as the functional and 6-311++G(d,p) as the basis set. The optimised structures of the five *N*-benzylidene pyridine-4-amines were used to predict their vibration spectra. The bond lengths and bond angles are reported. The infrared vibration frequencies and the intensities for the most important and reactive bonds are also reported with appropriate assignments and they are compared with our experimental published data. The energy differences and thermodynamic parameters have been derived from the computations. The comparison between the thermodynamic parameters gives ideas about the effect of the side chain on the reactivity of these amines. The computed physical and chemical properties are in agreement with the experimental values.

Keywords- *N*-Benzylidene Pyridine-4-amines; Density Functional Theory; Semiempirical methods; PM3; Vibration spectra; Thermodynamic properties.

INTRODUCTION

Molecules with C=N bond or imine bond are the most interesting classes of compounds in organic chemistry. Ammonia, primary aliphatic amines, and primary aromatic amines react with the carbonyl group of aldehydes and ketones in the presence of an acid catalyst to give an imines or Schiff bases [1-2]. Imines or Schiff bases are widely used as medical, pharmaceutical and industrial materials. They have been used extensively in inorganic and coordination chemistry fields for synthesis new organometallic compounds.

These compounds are important, because they possess azomethine group or imine bond. For example, imine bond plays in the human retina to bind the active form of vitamin A aldehyde (retinal) with the protein opsonin to form of an imine [3]. Vigato and Tamburini have reviewed cyclic and acyclic imines compounds and related derivatives in macromolecules and complex compounds [4], while some complexes of amino imines are considered to constitute new kinds of potential antibacterial and anticancer reagents [5-7].

Given their importance in many areas of organic and bioorganic chemistry, we

have already synthesized several *N*-benzylidene pyridineamines, which are used as raw materials to synthesis new barbituric acid derivatives [8–11].

Thermodynamic properties for the organic molecules have great important in studying its stability and reactivity and at the same time it is difficult to find these information experimentally. The availability of fast computers enables the computations

of thermodynamic parameters for molecules. In the work, we compare predicted parameters obtained using theoretical methods with our experimental data. PM3 semiempirical method and density functional theory were used to compute the geometry optimization, vibrational frequencies, IR intensities and thermodynamic properties for five of *N*-benzylidene pyridine-4-amines compounds illustrated in Figure 1.

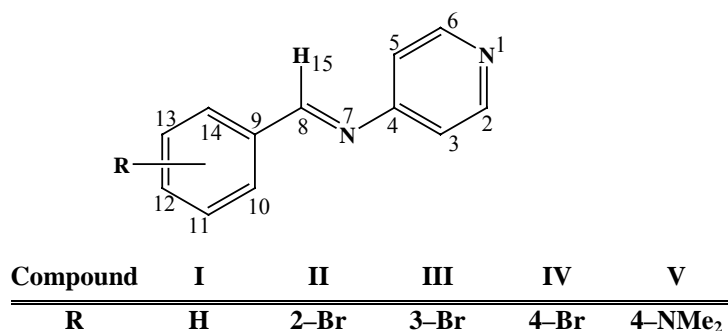


Figure 1: Structure and atom labels of *N*-benzylidene pyridine-4-amines.

METHODS OF COMPUTATIONS

It is well known that HF method tends to overestimate vibrational frequencies because it does not take electron correlation effects into consideration. In density functional theory (DFT), some correlation effects are taken into account through the effective exchange-correlation potential. The hybrid method, which mixes HF and DFT approximations, is recently developed and performs well for many properties including vibrational frequencies [12–13]. B3LYP is one of the most popular functional [14].

DFT/B3LYP and PM3 methods of calculations have been used for molecular geometry optimisation. The basis sets used for all atoms are 6-311++G(d,p). Frequency computations have been carried out using the optimised structures in order to provide a complete description of the molecular

motions involved in the normal modes. The frequency calculations have also allowed the determination of related thermodynamical parameters such as enthalpy and free energy changes. All computations have been done using Gaussian 03W program suite [15] and Gauss View [16] has been used for visualizing the conformers.

RESULT AND DISCUSSION

The condensation of 4-aminopyridine, with five aromatic aldehydes: benzaldehyde, **1**, 2-bromo benzaldehyde, **2**, 3-bromo benzaldehyde, **3**, 4-bromo benzaldehyde, **4**, and 4-*N,N*-dimethylamino benzaldehyde, **5**, in boiling absolute ethanol in the presence of 1–2 drops of glacial acetic acid for 1 hour produced *N*-benzylidene pyridine-4-amines:

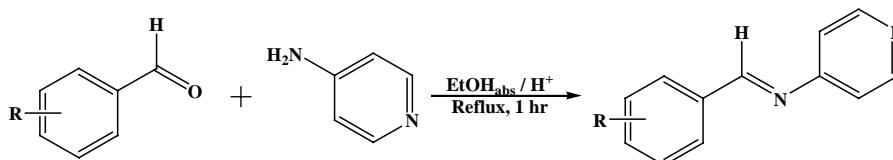


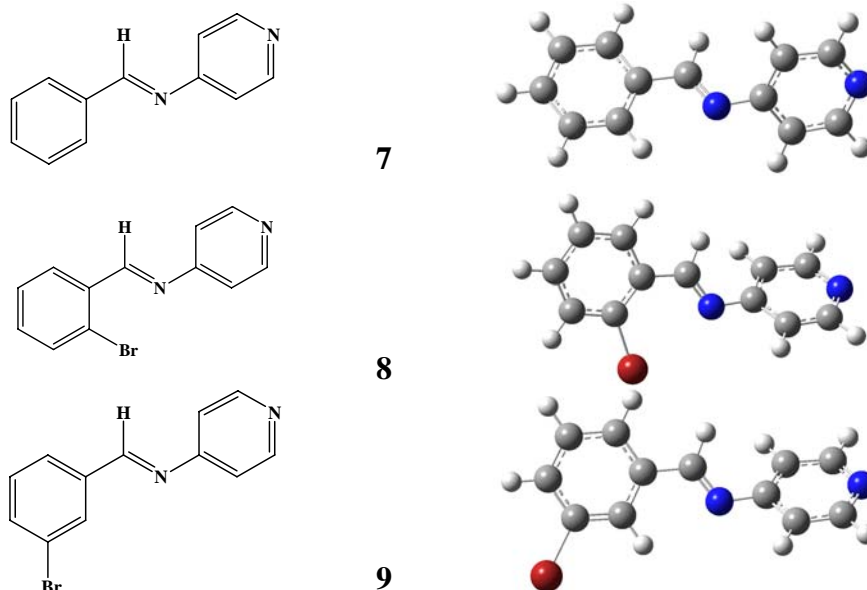
Table 1 reports the optimised structural parameters namely bond length, bond angle and dihedral angle for the most important region of the five derivatives computed using DFT/B3LYP method. The dihedral angle reflects the angle between the plane of the pyridine ring and the plane of the rest of the molecule.

TABLE 1
THE OPTIMISED STRUCTURES COMPUTED USING B3LYP/6-311++G(d,p)

	I R=H	II R=2-Br	III R=3-Br	IV R=4-Br	V R=4-N(CH ₃) ₂
Bond length (Å)					
r(C ₄ -N ₇)	1.400	1.399	1.401	1.401	1.397
r(N ₇ -C ₈)	1.277	1.273	1.275	1.276	1.282
r(C ₈ -C ₉)	1.467	1.471	1.469	1.467	1.455
r(C ₈ -H ₁₅)	1.099	1.099	1.098	1.099	1.099
Angle (°)					
∠(C ₃ C ₄ N ₇)	119.2	119.3	119.2	119.1	119.3
∠(C ₄ N ₇ C ₈)	120.1	119.9	120.1	120.1	120.0
∠(N ₇ C ₈ H ₁₅)	121.3	120.7	121.5	121.5	120.9
∠(C ₉ C ₈ H ₁₅)	115.6	113.4	115.6	115.7	115.5
∠(C ₁₀ C ₉ C ₈)	121.6	127.5	121.0	121.6	122.3
Dihedral angle (°)					
∠(C ₅ C ₄ N ₇ C ₈)	47.0	49.0	46.9	46.3	45.0

Some conclusions may be drawn by analysing the data from table 1. Firstly, there is only a small difference between the optimised structural data for the five compounds. To be more precise, the largest difference in bond length, bond angle and dihedral angle are 0.012 Å, 6.9°, 2.0° respectively. The highest angle value (6.9°)

is belong to the angle C₁₀C₉C₈ which is attributed to the steric hindrance between the Br atom in the position 2 and the hydrogen. Secondly, the C₈-C₉ bond length for the N(CH₃)₂ group is the highest. Interestingly, the substitution is not affecting the rotation around the C₄-N₇ bond. Figure 2, shows the optimized structure for the five derivatives.



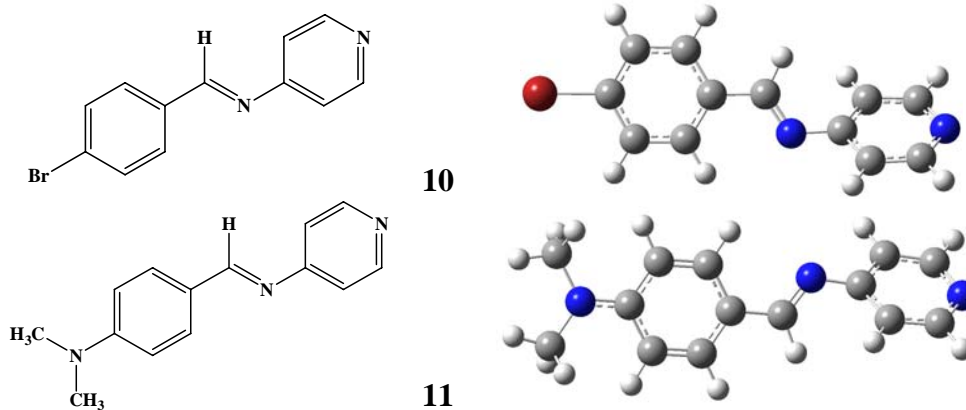


Figure 2: Optimised N-benzylidene pyridine-4-amine structures.

Two types of theoretical method are used for these five compounds, PM3 semiempirical method and DFT/B3LYP method. Since the computations end comparable results, we will discuss the DFT/B3LYP results. Tables 2 summarises energies of the optimised structures of the title compounds obtained by DFT/B3LYP method in the gas phase. Further, some thermodynamical functions (ΔH , ΔG) are also reported. The results from table 2

indicate that (i) the Br derivatives are more stable; (ii) the Br position in the ring is not affecting the molecule total energy; (iii) the effect of substituting hydrogen by dimethylamine does not lead to big change in the energy difference.

Figure 3 shows the change in total energy of the five compounds with the change in the kind and place of the substitution.

TABLE 2
THE ENERGIES (a.u.) OF THE OPTIMISED STRUCTURES COMPUTED USING B3LYP/6-311++G(d,p)

Compound	R	Energy ΔE	Thermal Enthalpy ΔH	Thermal Free Energy ΔG
7	H	-572.94	-572.73	-572.78
8	2-Br	-3146.47	-3146.27	-3146.33
9	3-Br	-3146.48	-3146.28	-3146.34
10	4-Br	-3146.48	-3146.28	-3146.34
11	4-NMe ₂	-706.94	-706.66	-706.72

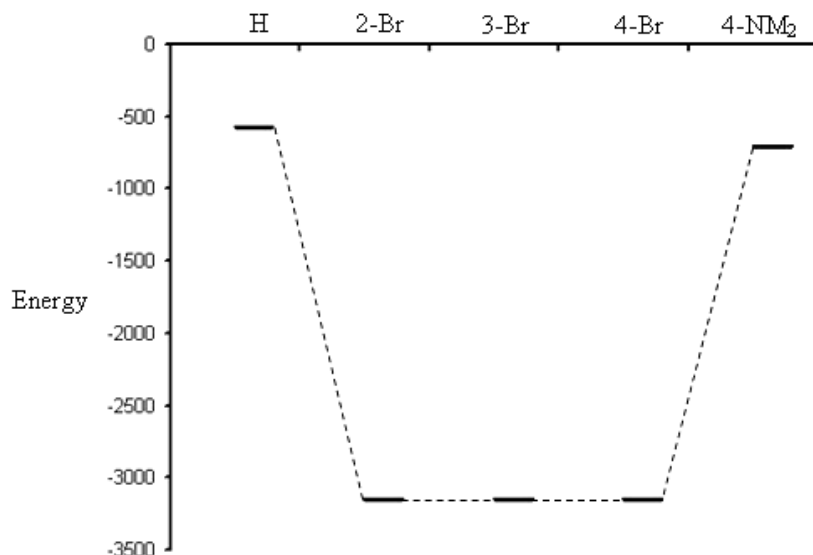


Figure 3. Energies (a.u) of the five derivatives optimized structure as calculated by B3LYP method.

Infrared vibrational wavenumbers calculated in the harmonic approximation, their intensities, Raman activities, depolarisation ratios P and U have been computed. Due to the large number of the frequencies, we report just the most important frequencies and those which we have experimental values for comparison.

The absence of the negative values frequencies for the five compounds proves that the optimized structure is minimum structure and not transition state structure.

Tables 3 and 4, show the values of the most important vibrational frequencies as computed using PM3 and DFT/B3LYP methods and the experimental values.

TABLE 3
COMPUTED INFRARED VIBRATIONAL FREQUENCIES (cm^{-1}) USING DFT/B3LYP METHOD.

Values in bracket are the experimental frequencies

Assignment	7	8	9	10	11
	R = H	R = 2-Br	R = 3-Br	R = 4-Br	R = 4-NMe ₂
ν C=C-H arom.	3200 (3080)	3204 (3045)	3211 (3020)	3207 (3030)	3211 (2960)
ν N=C-H arom.	3194 (3160)	3197 (3145)	3196 (3175)	3195 (3235)	3193 (3120)
ν N=C-H imine	3007	2998	3013	3011	2999 (2850)
ν C-H aliph.	---	---	---	---	3136 (2850)
ν C-N aliph.	---	---	---	---	1386 (1365)
ν C=N imine	1692 (1655)	1700 (1670)	1693 (1650)	1691 (1675)	1681 (1670)
ν C-C arom.	1641 (1620)	1628 (1605)	1630 (1600)	1629 (1610)	1647 (1610)
ν C-N arom.	1620 (1290)	1617 (1300)	1618 (1305)	1616 (1305)	1614 (1390)
δ C-H imine	1407	1421	1402	1400	1410
δ C-H arom.	1353 (1435)	1286 (1450)	1338 (1440)	1351 (1445)	1339 (1425)

δ C–H N–arom.	1351	1238	1238	1107	1245
δ C–H aliph.	---	---	---	---	1191

TABLE 4
COMPUTED INFRARED VIBRATIONAL FREQUENCIES (cm^{-1}) USING PM3 METHOD.

Assignment	7 R = H	8 R = 2-Br	9 R = 3-Br	10 R = 4-Br	11 R = 4-NMe ₂
ν C=C–H arom.	3078	3078	3079	3076	3051
ν N=C–H arom.	3072	3070	3069	3070	3070
ν N=C–H imine	2949	2894	2897	2896	2894
ν C–H aliph.	---	---	---	---	3124
ν C–N aliph.	---	---	---	---	1635
ν C=N imine	1851	1839	1836	1836	1830
ν C–C arom.	1795	1812	1809	1797	1795
ν C–N arom.	1770	1770	1770	1769	1768
δ C–H imine	1233	1247	1245	1250	1321
δ C–H arom.	1214	1197	1195	1203	1217
δ C–H N–arom.	1207	1169	1166	1167	1168
δ C–H aliph.	---	---	---	---	1040

CONCLUSION

This theoretical work targets five N-benzylidene pyridine-4-amines derivatives in the gas phase by using PM3 and DFT methods. The results indicate that in both methods the bromide derivatives are more stable than the other derivatives. The thermodynamic parameters coming from this study are difficult to be found experimentally and can be used in future study. Accepted agreement between the experimental and theoretical vibrational frequencies was the outcome from this study.

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