NTU JOURNAL OF PURE SCIENCES
EISSN: 2789-1097

RESEARCH ARTICLE
Open Access

Comparison Study of HOMO-LUMO Energy Gaps for Tautomerism of Triazoles in Different Solvents Using Theoretical Calculations

1st Ammar A. Ibrahim, , 2nd Maher A. Ibrahim, 3rd Entesar A. Sulliman , 4thSimaa M. Daood, 5thGhasan Q. Ismael

ammar74@uomosul.edu.iq , maibraim68@uomosul.edu.iq , entesar.ahmed@uomosul.edu.iq

1 Department of Chemistry, College of Science, University of Mosul, Iraq , 2 Department of Biochemistry, College of Medicine, University of Mosul, Mosul, Iraq , 3Department of Biochemistry, College of Medicine, University of Mosul, Mosul, Iraq
Corresponding author: Ammar A. Ibrahim, e-mail: ammar74@uomosul.edu.iq
Co-authors:MAI: maibraim68@uomosul.edu.iq ,EAS: entesar.ahmed@uomosul.edu.iq
Received: 17-10-2021, Accepted: 17-11-2021, Published online: 05-12-2021

Abstract: The phenomena of the tautomerism forms of the substituted triazoles compounds which are named [1-A] (5-phenyl-1H-1,2,4-triazol-3-amine), [1-B] (3-phenyl-1H-1,2,4-triazol-5-amine), [2-A] (5-(pyridin-2-yl)-1H-1,2,4-triazol-3-amine), [2-B] (3-(pyridin-2-yl)-1H-1,2,4-triazol-5-amine), [3-A] (5-(pyridin-3-yl)-1H-1,2,4-triazol-3-amine), [3-B] (3-(pyridin-3-yl)-1H-1,2,4-triazol-5-amine), [4-A] (5-(pyridin-4-yl)-1H-1,2,4-triazol-3-amine) and [4-B] (3-(pyridin-4-yl)-1H-1,2,4-triazol-5-amine) have been evaluated by Hartree-Fock (HF) method at the basis set (6-31G) in the both gas phase and at different type of solvents. This study of solvents effect was containing polar and non-polar solvent like water, acetone, acetonitrile, benzene and CCl4. The physico-chemical data's were evaluated for eigenvalues at different kinds of energy levels (HOMO, HOMO-1, HOMO-2, HOMO-3, LUMO, LUMO+1, LUMO+2 and LUMO+3). The difference of the energy gap (LUMO-HOMO) values for structures showed that the forms (1A, 2A, 3A and 4A) are more stable compare with (1B, 2B, 3B and 4B). From the results, we can showed that there is a difference between the two forms depends on the parameters. So, the imino form is not stable compare with the other structure.

Keywords: HOMO, LUMO, Tautomerism, Solvent effect, Theoretical Calculation

Introduction

The theoretical calculations were used in a wide range in different field like predicted for the ionization potential [1], drug compounds [2], interaction with alanine [3] and metabolites [4]. The phenomena for tautomerism known as transfer a proton from one site to another site in the same structure. It means that the structure having the same conformation but differs in the configuration which can be easy to distinguish between them. Despite of structures are in the equilibrium but different in the physical properties [5]. Quantum chemistry [6-7]) especially DFT method was applied in the wide range in this kind of study [8]. Tautomeric structure for pyrazoles substituents have been investigated theoretically and experimentally to study their reactivity [9-10]). Quantum calculations like B3LYP at basis set (6-31++G**) was applied to evaluate the tautomerism equilibrium and ionization for xanthine and iso-quanine in the gas and solvation phase [11]. While semi-empirical methods like PM3, AM1 and PM5 were determined the tautomeric equilibria for another study [12]. Mass spectroscopy [13] and 13C NMR have been studied the mechanism keto enol [14] compounds depending on the chemical shift parameters [15]. Stability of isomer oxadiazole was investigated using quantum calculations and spectroscopy NMR. Many parameters were calculated like softness, hardness, electro-negativity and energy gap [16]. The thermo-dynamic parameters for coumarin isomers were done using the (DFT). The results showed the stability of the amino and imine structures were different depend on ΔS and ΔH data [17].

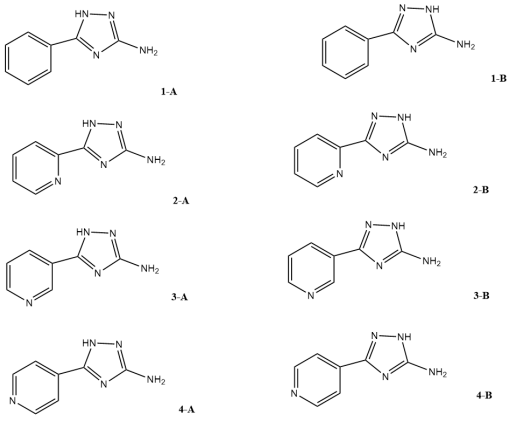


Fig. 1. The tautomerism compounds form

2. Computational Methods

All the theoretical calculations have been utilized using the Gaussian 03 package. The Hartree-Fock method (HF) was employed at basis set (6-31G). The physico-chemical parameters were located in gas

phase and at different solvents which are named (water, acetone, acetonitrile, benzene and CCl4).

3. Results And Discussion

All the compounds tautomerism forms have been illustrated in the following table. Starting from the gas phase and later with different solvents. Tables were showed the parameters for all the tautomerism form in the gas phase, acetone, water, acetonitrile, benzene and CCl4. The eigenvalues values were determined at different energy level like HOMO, HOMO-1, HOMO-2, HOMO-3, LUMO, LUMO+1, LUMO+2 and LUMO+3 as shown in table (1).

Table 1. The Physical properties using HF/6-31G method in the gas phase and acetone solvent

Gas	HOMO	HOMO-1	HOMO-2	HOMO-3
1-A	-0.3098	-0.3477	-0.3544	-0.4137
1-B	-0.3036	-0.3272	-0.3521	-0.4237
2-A	-0.3126	-0.3590	-0.3969	-0.4184
2-B	-0.3157	-0.3523	-0.3753	-0.3948
3-A	-0.3199	-0.3618	-0.3949	-0.4137
3-B	-0.3179	-0.3611	-0.3713	-0.3943
4-A	-0.3268	-0.3657	-0.3801	-0.4178
4-B	-0.3307	-0.3441	-0.3737	-0.3971
Acetone				
1-A	-0.3165	-0.3464	-0.3560	-0.4201
1-B	-0.3124	-0.3395	-0.3557	-0.4311
2-A	-0.3222	-0.3616	-0.3932	-0.4260
2-B	-0.3233	-0.3586	-0.3866	-0.4143
3-A	-0.3233	-0.3623	-0.3921	-0.4202
3-B	-0.3219	-0.3637	-0.3822	-0.4141
4-A	-0.3289	-0.3618	-0.3817	-0.4231
4-B	-0.3304	-0.3555	-0.3785	-0.4171

Table 1. Continued…

Gas	LUMO	LUMO+1	LUMO+2	LUMO+3
1-A	0.0914	0.1333	0.2076	0.2199
1-B	0.1182	0.1558	0.1969	0.2128
2-A	0.0790	0.1129	0.2179	0.2331
2-B	0.1060	0.1368	0.1973	0.2116
3-A	0.0772	0.1126	0.1968	0.2075
3-B	0.1058	0.1339	0.1917	0.2042
4-A	0.0692	0.1215	0.1987	0.2073
4-B	0.0967	0.1440	0.1894	0.2011
Acetone				
1-A	0.0911	0.1361	0.2128	0.2354
1-B	0.1053	0.1429	0.2108	0.2345
2-A	0.0774	0.1170	0.2115	0.2496
2-B	0.0919	0.1245	0.2081	0.2342
3-A	0.0788	0.1146	0.2056	0.2322
3-B	0.0949	0.1198	0.2061	0.2336
4-A	0.0701	0.1252	0.2032	0.2363
4-B	0.0841	0.1323	0.2042	0.2332

While tables (2) were present the physic-chemical parameters in water and acetonitrile solvents.

Table 2 . The Physical properties using HF/6-31G method in the water and acetonitrile solvent

Water	HOMO	HOMO-1	HOMO-2	HOMO-3
1-A	-0.3164	-0.3462	-0.3564	-0.4209
1-B	-0.3131	-0.3403	-0.3561	-0.4317
2-A	-0.3228	-0.3619	-0.3932	-0.4266
2-B	-0.3240	-0.3592	-0.3875	-0.4158
3-A	-0.3236	-0.3626	-0.3918	-0.4207
3-B	-0.3222	-0.3641	-0.3829	-0.4151
4-A	-0.3287	-0.3614	-0.3818	-0.4234
4-B	-0.3304	-0.3562	-0.3791	-0.4181
Acetonitrile				
1-A	-0.3165	-0.3463	-0.3562	-0.4207
1-B	-0.3127	-0.3400	-0.3559	-0.4314
2-A	-0.3225	-0.3617	-0.3932	-0.4263
2-B	-0.3236	-0.3589	-0.3871	-0.4150
3-A	-0.3238	-0.3627	-0.3919	-0.4207
3-B	-0.3221	-0.3639	-0.3827	-0.4149
4-A	-0.3288	-0.3616	-0.3818	-0.4234
4-B	-0.3304	-0.3560	-0.3788	-0.4177

Table 2 . Continued…

Water	LUMO	LUMO+1	LUMO+2	LUMO+3
1-A	0.0904	0.1365	0.2135	0.2367
1-B	0.1045	0.1421	0.2105	0.2362
2-A	0.0773	0.1172	0.2111	0.2501
2-B	0.0909	0.1236	0.2077	0.2359
3-A	0.0797	0.1147	0.2047	0.2353
3-B	0.0943	0.1191	0.2061	0.2355
4-A	0.0697	0.1257	0.2043	0.2380
4-B	0.0834	0.1317	0.2043	0.2352
Acetonitrile				
1-A	0.0906	0.1363	0.2133	0.2358
1-B	0.1049	0.1425	0.2107	0.2354
2-A	0.0774	0.1171	0.2113	0.2499
2-B	0.0914	0.1241	0.2079	0.2351

3-A	0.0801	0.1144	0.2037	0.2347
3-B	0.0946	0.1193	0.2062	0.2349
4-A	0.0694	0.1255	0.2043	0.2365
4-B	0.0837	0.1319	0.2043	0.2343

Otherwise, tables (3) was shown the evaluated parameters in benzene and CCl4 solvents.

Table 3 . The Physical properties using HF/6-31G method in the benzene solvent

Benzene	HOMO	HOMO-1	HOMO-2	HOMO-3
1-A	-0.3134	-0.3474	-0.3547	-0.4167
1-B	-0.3083	-0.3335	-0.3537	-0.4276
2-A	-0.3176	-0.3603	-0.3950	-0.4218
2-B	-0.3196	-0.3553	-0.3810	-0.4047
3-A	-0.3215	-0.3619	-0.3935	-0.4171
3-B	-0.3203	-0.3622	-0.3767	-0.4046
4-A	-0.3279	-0.3637	-0.3808	-0.4206
4-B	-0.3311	-0.3498	-0.3758	-0.4075
CCl4				
1-A	-0.3133	-0.3474	-0.3547	-0.4168
1-B	-0.3083	-0.3334	-0.3537	-0.4276
2-A	-0.3176	-0.3603	-0.3951	-0.4217
2-B	-0.3196	-0.3553	-0.3809	-0.4047
3-A	-0.3215	-0.3619	-0.3935	-0.4170
3-B	-0.3203	-0.3622	-0.3767	-0.4046
4-A	-0.3280	-0.3637	-0.3808	-0.4206
4-B	-0.3311	-0.3497	-0.3757	-0.4075

Table 3 . Continued…

Benzene	LUMO	LUMO+1	LUMO+2	LUMO+3
1-A	0.0914	0.1347	0.2162	0.2237
1-B	0.1117	0.1493	0.2119	0.2176
2-A	0.0785	0.1152	0.2149	0.2432
2-B	0.0991	0.1306	0.2101	0.2177
3-A	0.0780	0.1139	0.2069	0.2156
3-B	0.1005	0.1268	0.2054	0.2147
4-A	0.0697	0.1235	0.2051	0.2196
4-B	0.0904	0.1382	0.2029	0.2133
CCl4				
1-A	0.0912	0.1348	0.2166	0.2233
1-B	0.1118	0.1493	0.2119	0.2175
2-A	0.0785	0.1152	0.2149	0.2431
2-B	0.0991	0.1307	0.2101	0.2175
3-A	0.0780	0.1139	0.2068	0.2155
3-B	0.1005	0.1269	0.2054	0.2145
4-A	0.0698	0.1235	0.2050	0.2197
4-B	0.0905	0.1383	0.2029	0.2131

Table (4) have been tabulated the difference between the energy level for the eigenvalues at the energy gap (LUMO-HOMO). All the parameters were evaluated theoretically at all the field of the calculations.

Table 4. The energy gap LUMO-HOMO for all tautomerism compounds form

	Δ(LUMO-HOMO)		
	Gas Phase	Water	Acetone
1-A	0.4013	0.4069	0.4077
1-B	0.4218	0.4176	0.4178
2-A	0.3917	0.4001	0.3998
2-B	0.4218	0.4148	0.4152
3-A	0.3972	0.4033	0.4022
3-B	0.4238	0.4165	0.4169
4-A	0.3960	0.3984	0.3991
4-B	0.4275	0.4138	0.4145

Table 4. Continued…

	Δ(LUMO-HOMO)		
	Acetonitrile	Benzene	CCl_4
1-A	0.4071	0.4048	0.4045
1-B	0.4177	0.4200	0.4201
2-A	0.3999	0.3961	0.3961
2-B	0.4150	0.4187	0.4187
3-A	0.4039	0.3995	0.3995
3-B	0.4166	0.4208	0.4208
4-A	0.3982	0.3976	0.3977
4-B	0.4141	0.4215	0.4216

From the table (4) we can note that the compounds (1A, 2A, 3A and 4A) having less energy gap compare to the other tautomerism form (1B, 2B, 3B and 4B) respectively. These values gives a proof that there are difference in the energy between the tautomerism study forms. And one of the tautomerism form has less energy gap and having more stable compare to the other.

So, the compounds (1-A, 2-A, 3-A and 4-A) are more stable in the gas phase compare to other solvents which have less stable. While compounds (1-B, 2-B, 3-B and 4-B) are having small difference values

which mean that suffering more stability in the water solvent compare to other solvent.

While figures (2) was display the energy gap for the compounds form at the gas phase and at different solvents. The energy gap presented that the form (1A, 2A, 3A and 4A) having a small difference values between the LUMO and HOMO compare with others compounds form (1B, 2B, 3B and 4B) at the gas phase.

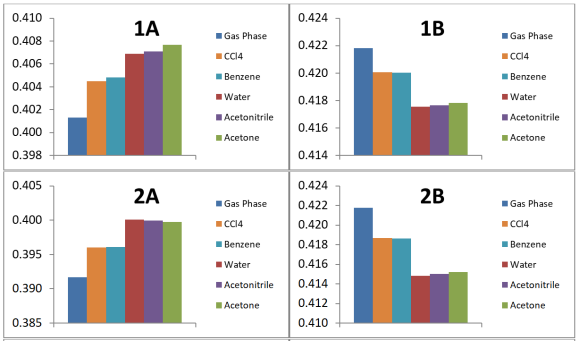


Fig. 2. Δ(LUMO-HOMO) for compounds (1 & 2) in gas phase and different solvents

Also, figure (3) was presented the free energy parameters for the tautomerism compounds form at Gas and aqueous solvents as examples.

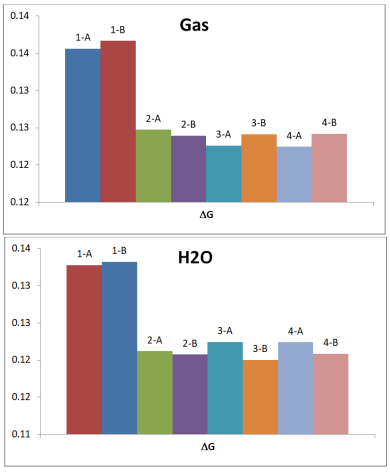


Fig. 3. Free energy parameters for compounds in gas phase and different solvent

Some of theoretical parameters have been determine depends on the energy levels. Where HOMO indicate to the ionization potential which mean the capability of the molecules to electro-philic attack. While LUMO refer to the affinity of the electrons which related to the capability the molecules to nucleo-philic attack. Whereas the electro-philicity index (ω) indicate to reactivity of the molecules. Table (5) was summarize parameters for hardness (η), softness (s), chemical potential (μ) and electro-philicity index (ω). It can be observe that compound (1-B) is having a greatest electrophile compare to the (4-A) which have the smallest electrophile in the (gas, acetone, acetonitrile, benzene, CCl4 and water) respectively.

Table (5): Physical properties of hardness (η), softness(s), Chemical potential(μ) and electrophilicity index(ω)

Compound	(η)	(s)	(μ)	(ω)
		Gas		
1-A	0.201	0.799	-0.109	0.030
1-B	0.211	0.789	-0.093	0.020
2-A	0.196	0.804	-0.117	0.035
2-B	0.211	0.789	-0.105	0.026
3-A	0.199	0.801	-0.121	0.037
3-B	0.212	0.788	-0.106	0.027
4-A	0.198	0.802	-0.129	0.042
4-B	0.214	0.786	-0.117	0.032
		Acetone		
1-A	0.204	0.796	-0.113	0.031
1-B	0.209	0.791	-0.104	0.026
2-A	0.200	0.800	-0.122	0.037
2-B	0.208	0.792	-0.116	0.032
3-A	0.201	0.799	-0.122	0.037
3-B	0.208	0.792	-0.114	0.031
4-A	0.200	0.800	-0.129	0.042
4-B	0.207	0.793	-0.123	0.037
		Acetonitrile		
1-A	0.204	0.796	-0.113	0.031
1-B	0.209	0.791	-0.104	0.026
2-A	0.200	0.800	-0.123	0.038
2-B	0.208	0.792	-0.116	0.032
3-A	0.202	0.798	-0.122	0.037
3-B	0.208	0.792	-0.114	0.031
4-A	0.199	0.801	-0.130	0.042
4-B	0.207	0.793	-0.123	0.037
		Benzene		
1-A	0.202	0.798	-0.111	0.030
1-B	0.210	0.790	-0.098	0.023
2-A	0.198	0.802	-0.120	0.036
2-B	0.209	0.791	-0.110	0.029
3-A	0.200	0.800	-0.122	0.037
3-B	0.210	0.790	-0.110	0.029
4-A	0.199	0.801	-0.129	0.042
4-B	0.211	0.789	-0.120	0.034
		CCl4		
1-A	0.202	0.798	-0.111	0.030
1-B	0.210	0.790	-0.098	0.023
2-A	0.198	0.802	-0.120	0.036
2-B	0.209	0.791	-0.110	0.029
3-A	0.200	0.800	-0.122	0.037
3-B	0.210	0.790	-0.110	0.029
4-A	0.199	0.801	-0.129	0.042
4-B	0.211	0.789	-0.120	0.034
		Water		
1-A	0.203	0.797	-0.113	0.031

1-B	0.209	0.791	-0.104	0.026
2-A	0.200	0.800	-0.123	0.038
2-B	0.207	0.793	-0.117	0.033
3-A	0.202	0.798	-0.122	0.037
3-B	0.208	0.792	-0.114	0.031
4-A	0.199	0.801	-0.130	0.042
4-B	0.207	0.793	-0.123	0.037

Figures (4) showed the diagram of the energy gaps for all compounds in the gas and aqua phase like examples. The energy gaps clearly appear that there are difference in the an eigenvalues (HOMO and LUMO) for every form in the tautomerism. The energy value for the first form is about (>0.39) for (1A, 2A, 3A and 4A), while the second form having an energy parameters about (>0.42) for (1B, 2B, 3B and 4B).

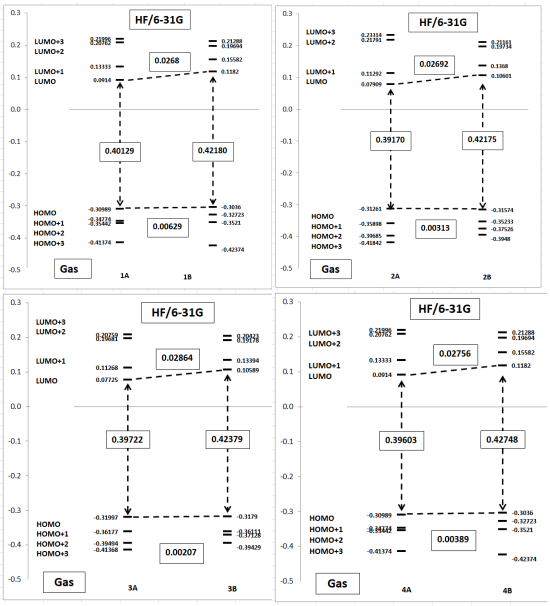
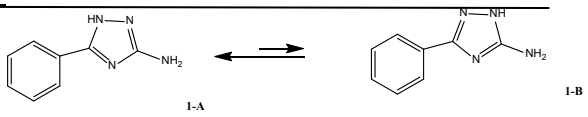


Fig. 4. Energy gap for all compounds in the gas phase using HF/6-31G

4. Conclusion

The eigenvalues HOMO and LUMO have been determine theoretically which are used to evaluate the softness, hardness, electro-philicity and chemical potential in different solvents.

From the above figures and tables, we can notice that there are a differences between the two form of the tautomerism compounds. Depends on this parameters , the prediction of mechanism can be written in the following :



So, the figures showed that the imino compound form (1-B) was less stable compare with the other form (1-A) which has more stable.

REFERENCES

1. Ibrahim A. A.; Abed G. M., (2018), Theoretical Prediction of the Ionization Potential Using Different Methods AM1, HF and DFT, *Inter. J. of Sci. & Eng. Res.,* vol. 9, Issue 1, January-2018, 726-733.
2. Ibrahim, A. A.; Abd-Alrazzak, A. Y.; Abdalrazaq, E. A.; Sulliman**,** E. A.; Shamil**,** T.**,** (2020)**,** Theoretical Prediction of Lipophilicity for Some Drugs Compounds**,** *Orient. J. Chem.,* Vol. **36**(1), 114-119.
3. Shahadha, K. M.; Ibrahim, A. A., (2020), Theoretical prediction of pKa for amino acids and voltammetric behaviour of the interaction of paracetamol with alanine, *Inter. J. of Adv. Sci. and Tech.,* vol. 29, No. 5, 12945-12954.
4. Ibrahim, A. A.; Abdalrazaq, E. A.; Ibrahim, M. A.; Yahya, R.; Sulliman, E. A., (2012), Quantum Chemical Calculations (QSAR) of Antipyrine Drug and Its Metabolites, *Asian J. of Chemistry*; Vol. 24, No. 1, 269-272.
5. Antonov, L. , (2014) Tautomerism: Methods and Theories, First Edition., Wiley-VCH Verlag GmbH & Co. KGaA. Published 2014 by Wiley-VCH Verlag GmbH & Co. KGaA.
6. Berber, H.; Uysal, U. D.; Aydogdu, A., (2017), Theoretical Study on the Stability, Acidity Constants and Molecular Electronic Properties of Certain o-Hydroxy Schiff Bases and their Tautomer, *JOTCSA*.; 4(sp. is. 1): 77-92.
7. Tolosa, S. ; Mora-Diez, N.; Hidalgo, A.; Sanson, J. A., (2014), Amide-imide tautomerism of acetohydroxamic acid in aqueous solution: quantum calculation and SMD simulations, *RSC Adv*., 4, 44757–44768.
8. Yaraghi, A.; Ozkendir, O. M.; Mirzaei, M., (2015), DFT studies of 5-fluorouracil tautomers on a silicon graphene nanosheet , *Superlattices and Microstructures* 85 , 784-788.
9. El-Mekabaty, A., Chemistry of 2-Amino-3-carbethoxythiophene and Related Compounds, (2014), *Synth. Commun.*, 44, 875–896.
10. Secrieru, A.; O'Neill, P. M.; Cristiano, M. L. S., (2020), Revisiting the Structure and Chemistry of 3(5)-Substituted Pyrazoles , *Molecules*, 25(1), 42.
11. Rogstad, K. N.; Jang, Y. H.; Sowers, L. C.; Goddard, W. A., (2003), First Principles

Calculations of the pKa Values and Tautomers of Isoguanine and Xanthine, *Chem. Res. Toxicol.*, 16,11 ,1455-1462.

12. Ogretir, C. ; Ozturk, I. I.; Tay, N. F.,(2007), Quantum chemical studies on tautomerism, isomerism and deprotonation of some 5 (6)-substituted benzimidazole-2-thiones, *ARKIVOC* (xiv) 75-99.
13. Allegretti, P. E.; Schiavoni, M. de las M.; Castro, E. A.; Furlong, J. J. P.(2007), Tautomeric Equilibria Studies by Mass Spectrometry , *World Journal of Chemistry* 2 (2): 25-62.
14. Moradi, R.; Bozorghi, S. J.; Kadivar, R.; Mahdiani, A.; Soleymanabadi, H.,(2012), , *APCBEE Procedia* 3, 70-74.
15. Salman, S. R.; Kamounah, F. S., (2003), Tautomerism in 1-hydroxy-2-naphthaldehyde Schiff bases: Calculation of tautomeric isomers using carbon-13 NMR , *Spectroscopy* 17(4), 747–752.
16. Karimi, M., (2016), Investigation of the Stability of Oxadiasole and Their Analogs Using Quantum Mechanics Computation, *Computational Chemistry*, 4, 11-16.
17. Al-Amiery, A. A.; Jaffar, H. D.; Obayes, H. R.; Musa, A. Y.; Kadhum, A. A. H.; Mohamad, A. B.,(2012), Thermodynamic studies on 4-aminocoumarin tautomers, *Int. J. Electrochem. Sci.,* 7, 8468 - 8472.