Quantum Calculations of pKa values for Some Amine Compounds

Ammar A. Ibrahim[1]* Entesar A. Sulliman[2] Simaa M. Daood[1]

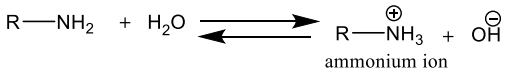
[1]Department of Chemistry, College of Science, University of Mosul, Iraq
[2]Al-Noor University College, ammar74@uomosul.edu.iq

Abstract: The theoretical calculations methods DFT/STO-3G, DFT/6-31G, DFT/6-31G(d,p), HF/STO-3G, HF/6-31G and HF/6-31G(d,p) are used to determination the physic-chemical parameters for some aliphatic amine. This data was used to predict pKa values. Two methods of statistics are used to evaluate the pKa depends on the theoretical data. The first statistical method is used ΔG data to determine the pKa. The second statistical method depends on the enter all the thermodynamic and physic-chemical values in the equation using multiple linear regression. Finally, the two methods are compared with experimental.

Keywords: DFT, HF, pKa, Theoretical calculation, HOMO, LUMO

1 Introduction:

Amines define as a strong base which were converted to protonated form at using dilute acid solutions or in aqueous media:



Also, amines compounds are known as the strongest base because of the free non-bonding electron on the nitrogen atom. This property makes the amine group accepted the proton from other compounds and converted to ammonium ion. The cycle to calculate the thermodynamic parameters of the compound can be determined depending on the equation of the dissociation for acid:

$$HA^{+}_{(aq)} \rightarrow A_{(aq)} + H^{+}_{(aq)}$$

So, the equation is became : $\Delta G_{gas} = G_{gas.}(H^{+}) + G_{gas.}(A) - G_{gas.}(HA^{+})$ for gas state. And, $\Delta G_{sol.} = \Delta G_{sol.}(H^{+}) + \Delta G_{sol.}(A) - \Delta G_{sol.}(HA^{+})$ for the solvation state. Value of ($G_{gas.}$ H^{+}) is taken as (-6.28) kcal/mol[1,2], while ($\Delta G_{sol.}$ H^{+}) is taken different value at different papers like (-254), (-261.4), (-264.61), (-265.6), and (-267.9) in kcal/mol[3-6]. So, we choose the value (-267.9) kca/mol in the statics.

Because of the importance of the nitrogen atoms in life especially in caffeine, amino and nucleic acids, nicotine and hormones. Many compounds are synthesis or studied like drugs[7,8], heterocyclic[9], biological acticity[10], antioxidant[11,12], and complex[13]. Also, azo-compounds which containing series of (-N=N-) were calculated theoretically[14] and electrochemically[15]. The physico-chemical parameters are used to estimate the pKa-values by using computational chemistry depending on the theoretical calculations. It's used in the accuracy of drugs [16] and its metabolism[17].

The pKa can be determined depending on the different descriptors like charge, hardness, steric energy, LUMO, HOMO, etc[18]. The dissociation constant (pKa) are accurate for many pharmaceutical antibiotic compounds (amoxicillin, ampicillin, penicillin, sulfonamides)[19]. The shift of pKa in nucleotides on the RNA compounds has been determined using the equation of Poisson Boltzmann[20]. Drugs of substituted carbo-xamides structure contain many nitrogen atoms were studied their basicities theoretically using (DFT) methods[21]. Also, UV spectroscopic instrumental was used to evaluate the pKa parameters[22].

Density function theory(DFT/B3LYP) was used for a series of pyridinium and anilinum ion at a different solvent to predicted the (pKa) parameters[23]. The thermodynamic-cycles for a reaction that

IMDC-SDSP 2020, June 28-30, Cyberspace

DOI 10.4108/eai.28-6-2020.2297886

depends on the gas and salvation phase were calculated to find the (pKa) parameters[24,25]. Finally, the theoretical calculation is an important tool for the prediction of the ionization potential[26].

AM1 and PM3 methods were used to predict the pKa for series of aniline compound depend on the linear correlation between the experimental pKa with hardness rely on the LUMO and HOMO parameters[27]. Substituted of pyridine which is used as anti viral[28], anti cancer[29] and anti inflammatory[30] have been determined by theoretical calculations upon by WB97XD and B3LYP at different basis set in the gas phase. While AM1 and PM5 were used to study the salvation effect to find the pKa for a series of protonation of pyridine[31].

2 Experimental:

Gaussian 03 program was used in the determination and calculations of the compounds. These compounds have been optimized in the gas, ion, gas-solvation and ion-solvation using Hartree-Fock and density functional theory (B3LYP) at different basis set STO-3G, 6-31G and 6-31G(d,p). Later, CPCM method was used in the solvation in water media.

Table 1. The number, names and the experimental pKa values for compounds

No.	Compounds	Exp. pKa	No.	Compounds	Exp. pKa
1	Benzylamine	9.34	7	n-propylamine	10.53
2	Dimethylamine	10.60	8	t-butylamine	10.45
3	di-n-butylamine	11.25	9	Triethylamine	10.76
4	Ethylamine	10.63	10	Trimethylamine	9.76
5	Methylamine	10.62	11	tri-n-propylamine	10.65
6	n-butylamine	10.59			

3 Results and Discussion:

In this research, we try to choose two methods to the determination of pKa values. The first one depends on the calculation of the compounds in the gas phase and in salvation media. The seconds method is evaluated by all the parameters and used to predict by the statistical program. Also, chemical potential, softness and hardness were determined depending on the HOMO and LUMO parameters.

Chemical potential = (LUMO+HOMO)/2

Hardness = (LUMO-HOMO)/2

Softness = 1- hardness

Electro-philicity = $(\text{Chemical potential})^2 / (2 \times \text{hardness})$

3.1 The First Method:

Used the methods of calculations DFT/STO-3G, DFT/6-31G, DFT/6-31G(d,p), HF/STO-3G, HF/6-31G, HF/6-31G(d,p) in the gas and in salvation phase. The free energy factor (ΔG) was used to found the pKa practically using the methylamine as a reference (pKa= 10.62). Later, the ΔG_{total} values were represented by the summation between the compound in the gas and solvation media which were shown in tables (2-7).

Table (2): Free energy for neutral and ion in gas and solvation using DFT/STO-3G

DFT/STO-3G	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal.mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.12334	0.13766	0.12389	0.13586	1.1791	9.44	9.34	0.10
2	0.07486	0.08891	0.07465	0.08797	0.5033	10.12	10.60	-0.48
3	0.24930	0.26318	0.24840	0.26366	-0.6124	11.23	11.25	-0.02
4	0.07490	0.08932	0.07461	0.08837	-0.0088	10.63	10.63	0.00
5	0.04606	0.06058	0.04582	0.05947	0.0000	10.62	10.62	0.00
6	0.13312	0.14748	0.13269	0.14645	0.0264	10.59	10.59	0.00
7	0.10401	0.11834	0.10362	0.11736	0.0609	10.56	10.53	0.03
8	0.13265	0.14671	0.13249	0.14622	0.2391	10.38	10.45	-0.07
9	0.19072	0.20428	0.19064	0.20566	-0.2579	10.88	10.76	0.12
10	0.10378	0.11735	0.10373	0.11669	1.0329	9.59	9.76	-0.17
11	0.27767	0.29170	0.27740	0.29099	0.3464	10.27	10.65	-0.38

Table (3): Free energy for neutral and ion in gas and solvation using DFT/6-31G

DFT/6-31G	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal.mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.11564	0.13090	0.11360	0.13002	-0.4374	11.06	9.34	1.72
2	0.06740	0.08330	0.06705	0.08201	0.0734	10.55	10.60	-0.05
3	0.22639	0.24221	0.22474	0.24164	-1.0906	11.71	11.25	0.46
4	0.06760	0.08333	0.06712	0.08200	0.2353	10.38	10.63	-0.25
5	0.04113	0.05713	0.04075	0.05573	0.0000	10.62	10.62	0.00
6	0.12064	0.13635	0.11992	0.13472	0.2887	10.33	10.59	-0.26
7	0.09406	0.10983	0.09344	0.10831	0.2058	10.41	10.53	-0.12
8	0.12035	0.13561	0.11988	0.13465	0.5917	10.03	10.45	-0.42
9	0.17349	0.18900	0.17334	0.18880	0.0038	10.62	10.76	-0.14
10	0.09376	0.10952	0.09372	0.10856	0.2328	10.39	9.76	0.63
11	0.25301	0.26899	0.25276	0.26667	0.6815	9.94	10.65	-0.71

Table (4): Free energy for neutral and ion in gas and solvation using DFT/6-31G(d,p)

DFT/6-31G(d,p)	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal.mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.11457	0.12908	0.11438	0.12589	1.9296	8.69	9.34	-0.65
2	0.06725	0.08248	0.06681	0.08115	-0.2918	10.91	10.60	0.31
3	0.22490	0.23995	0.22329	0.23934	-1.2418	11.86	11.25	0.61
4	0.06750	0.08227	0.06684	0.08090	0.1782	10.44	10.63	-0.19
5	0.04130	0.05629	0.04075	0.05486	0.0000	10.62	10.62	0.00
6	0.12007	0.13485	0.11912	0.13319	0.1663	10.45	10.59	-0.14
7	0.09373	0.10853	0.09291	0.10699	0.1431	10.48	10.53	-0.05
8	0.11965	0.13407	0.11912	0.13306	0.4750	10.14	10.45	-0.31
9	0.17194	0.18694	0.17152	0.18675	-0.7028	11.32	10.76	0.56
10	0.09331	0.10869	0.09320	0.10776	-0.5215	11.14	9.76	1.38
11	0.25123	0.26649	0.25056	0.26654	-1.3422	11.96	10.65	1.31

Table (5): Free energy for neutral and ion in gas and solvation using HF/STO-3G

HF/STO-3G	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal.mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.13829	0.15347	0.13919	0.15158	1.1552	9.46	9.34	0.12
2	0.08439	0.09910	0.08423	0.09837	0.3476	10.27	10.60	-0.33
3	0.27617	0.29084	0.27551	0.29151	-0.7875	11.41	11.25	0.16
4	0.08458	0.09958	0.08436	0.09875	0.0082	10.61	10.63	-0.02
5	0.05275	0.06783	0.05256	0.06689	0.0000	10.62	10.62	0.00
6	0.14862	0.16360	0.14828	0.16268	0.0226	10.60	10.59	0.01
7	0.11660	0.13159	0.11631	0.13073	-0.0025	10.62	10.53	0.09
8	0.14820	0.16297	0.14807	0.16253	0.1117	10.51	10.45	0.06
9	0.21177	0.22631	0.21144	0.22794	-1.0247	11.64	10.76	0.88
10	0.11614	0.13050	0.11610	0.13007	0.6790	9.94	9.76	0.18
11	0.30811	0.32288	0.30779	0.32219	0.1519	10.47	10.65	-0.18

Table (6): Free energy for neutral and ion in gas and solvation using HF/6-31G

HF/6-31G	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal. mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.12657	0.14285	0.12634	0.13863	2.5822	8.04	9.34	-1.30
2	0.07353	0.09028	0.07325	0.08907	0.0646	10.56	10.60	-0.04
3	0.24374	0.26033	0.24238	0.25971	-0.7794	11.40	11.25	0.15
4	0.07383	0.09043	0.07339	0.08911	0.2215	10.40	10.63	-0.23
5	0.04544	0.06228	0.04512	0.06095	0.0000	10.62	10.62	0.00
6	0.13054	0.14721	0.12988	0.14552	0.2272	10.39	10.59	-0.20
7	0.10216	0.11883	0.10160	0.11731	0.1795	10.44	10.53	-0.09
8	0.13041	0.14670	0.13004	0.14571	0.4462	10.17	10.45	-0.28
9	0.18775	0.20402	0.18734	0.20027	2.1775	8.44	10.76	-2.32
10	0.10174	0.11838	0.10166	0.11753	0.1060	10.51	9.76	0.75
11	0.27289	0.28959	0.27235	0.28786	0.2880	10.33	10.65	-0.32

Table (7): Free energy for neutral and ion in gas and solvation using HF/6-31G(d,p)

HF/6-31G(d,p)	ΔG Gas a.u	Ion a.u	ΔG Solv. a.u	Ion a.u	ΔG (gas+sol.) kcal.mol	pKa Calc.	pKa Exp.	ΔpKa Calc.-Exp.
1	0.12503	0.14065	0.12478	0.13957	0.3263	10.29	9.34	0.95
2	0.07344	0.08957	0.07302	0.08834	-0.3282	10.95	10.60	0.35
3	0.24206	0.25817	0.24030	0.25751	-1.5060	12.13	11.25	0.88
4	0.07371	0.08940	0.07305	0.08806	0.1387	10.48	10.63	-0.15
5	0.04564	0.06150	0.04509	0.06016	0.0000	10.62	10.62	0.00
6	0.12996	0.14574	0.12902	0.14402	0.0879	10.53	10.59	-0.06
7	0.10181	0.11759	0.10099	0.11605	0.0621	10.56	10.53	0.03
8	0.12979	0.14527	0.12925	0.14423	0.2962	10.32	10.45	-0.13
9	0.18625	0.20216	0.18571	0.20288	-1.3523	11.97	10.76	1.21
10	0.10244	0.11772	0.10128	0.11691	0.0176	10.60	9.76	0.84
11	0.27077	0.28719	0.27004	0.28500	-0.2780	10.90	10.65	0.25

Table (8): Experimental and predicted pKa at different methods and basis set

Compounds	pKa Exp.	DFT/STO-3G Calc.	DFT/6-31G Calc.	DFT/6-31G(d,p) Calc.	HF/STO-3G Calc.	HF/6-31G Calc.	HF/6-31G(d,p) Calc.
1	9.34	9.44	11.06*	8.69	9.46	8.04	10.29*
2	10.6	10.12*	10.55	10.91	10.27	10.56	10.95
3	11.25	11.23	11.71	11.86	11.41	11.40	12.13
4	10.63	10.63	10.38	10.44	10.61	10.40	10.48
5	10.62	10.62	10.62	10.62	10.62	10.62	10.62
6	10.59	10.59	10.33	10.45	10.60	10.39	10.53
7	10.53	10.56	10.41	10.48	10.62	10.44	10.56
8	10.45	10.38	10.03	10.14	10.51	10.17	10.32
9	10.76	10.88	10.62	11.32	11.64*	8.44*	11.97*
10	9.76	9.59	10.39*	11.14*	9.94	10.51*	10.60*
11	10.65	10.27*	9.94*	11.96*	10.47	10.33	10.90
R (R*)		0.932 (0.989)	0.125 (0.972)	0.702 (0.963)	0.863 (0.954)	0.569 (0.988)	0.631 (0.959)
St. error (*)		0.194 (0.089)	0.532 (0.063)	0.382 (0.144)	0.270 (0.167)	0.441 (0.081)	0.415 (0.074)
Fisher Value (*)		59.5 (306.55)	0.14 (101.63)	8.74 (89.98)	26.34 (80.80)	4.313 (290.29)	5.96 (69.06)
* Removed at regression							

3.2 The Second Method:

This method is used the parameters which were calculated theoretically. All the data entered in the statistical equations. The experimental values of pKa were made as a dependent factor, while all data were independent factors.

Table (9): Physico-chemical parameters in the gas phase using HF/STO-3G

HF/STO-3G Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.27081	0.27041	0.16995	0.17648	0.17743	110.74	23.61	82.36	-320.78
2	-0.30687	0.59349	0.10977	0.11395	0.11489	71.50	12.43	64.20	-132.61
3	-0.30062	0.54071	0.31474	0.32625	0.32720	204.73	37.96	107.38	-364.09
4	-0.32525	0.59164	0.11001	0.11420	0.11514	71.66	12.61	64.33	-132.62
5	-0.32852	0.60923	0.07562	0.07889	0.07984	49.51	8.53	57.00	-94.03
6	-0.32428	0.57034	0.17854	0.18505	0.18599	116.12	21.05	78.67	-209.78
7	-0.32461	0.58156	0.14431	0.14963	0.15057	93.89	16.82	71.51	-171.20
8	-0.31806	0.56324	0.17701	0.18336	0.18431	115.06	22.64	75.99	-209.78
9	-0.27614	0.54183	0.24560	0.25447	0.25541	159.68	30.07	91.85	-286.93
10	-0.28946	0.57924	0.14335	0.14852	0.14947	93.20	17.07	70.14	-171.19
11	-0.27438	0.53076	0.34813	0.36077	0.36172	226.39	42.84	112.82	-402.67

Table (10): Physico-chemical parameters in ion phase using HF/STO-3G

HF/STO-3G Ion Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.42665	0.09345	0.18513	0.19183	0.19278	120.38	24.26	82.72	-321.22
2	-0.74374	0.23824	0.12480	0.12913	0.13007	81.03	12.98	65.18	-133.05
3	-0.56519	0.24793	0.32975	0.34142	0.34236	214.24	38.60	108.44	-364.55
4	-0.68432	0.23226	0.12529	0.12962	0.13056	81.34	13.17	65.22	-133.05
5	-0.77496	0.22763	0.09104	0.09441	0.09536	59.25	8.98	57.93	-94.46
6	-0.58310	0.23587	0.19381	0.20049	0.20144	125.81	21.66	79.64	-210.21
7	-0.62493	0.23500	0.15959	0.16508	0.16602	103.59	17.42	72.47	-171.63
8	-0.63692	0.23264	0.19208	0.19867	0.19961	124.67	23.41	77.13	-210.22
9	-0.64370	0.24623	0.26056	0.26949	0.27043	169.10	30.46	92.85	-287.39
10	-0.72427	0.24601	0.15803	0.16337	0.16432	102.52	17.61	71.17	-171.64
11	-0.59392	0.25021	0.36318	0.37591	0.37685	235.89	43.25	113.59	-403.13

Table (11): Physico-chemical parameters in gas-solvation using HF/STO-3G

HF/STO-3G Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.27336	0.26783	0.16928	0.17498	0.17593	109.80	21.64	77.32	-320.79
2	-0.30956	0.59673	0.10961	0.11379	0.11473	71.40	12.41	64.20	-132.60
3	-0.30354	0.54241	0.31428	0.32580	0.32675	204.44	37.96	107.83	-364.10
4	-0.32535	0.59898	0.10979	0.11397	0.11491	71.52	12.59	64.31	-132.62
5	-0.32899	0.61897	0.07544	0.07872	0.07966	49.40	8.52	57.03	-94.04
6	-0.32464	0.57530	0.17822	0.18474	0.18568	115.92	21.05	78.71	-209.78
7	-0.32494	0.58764	0.14403	0.14935	0.15030	93.72	16.81	71.54	-171.20
8	-0.31838	0.56789	0.17685	0.18317	0.18411	114.94	22.57	75.87	-209.78
9	-0.27976	0.54215	0.24541	0.25427	0.25522	159.56	30.07	92.13	-286.93
10	-0.29515	0.57791	0.14329	0.14844	0.14939	93.15	17.04	70.06	-171.19
11	-0.27923	0.53057	0.34784	0.36047	0.36142	226.20	42.83	112.86	-402.67

Table (12): Physico-chemical parameters in ion-solvation using HF/STO-3G

HF/STO-3G Ion-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.29743	0.23435	0.18391	0.19065	0.19159	119.63	24.16	84.22	-321.33
2	-0.56460	0.43052	0.12403	0.12834	0.12928	80.53	12.89	65.06	-133.15
3	-0.43638	0.42198	0.32875	0.33954	0.34049	213.07	36.50	103.08	-364.64
4	-0.51280	0.43911	0.12443	0.12873	0.12967	80.78	13.07	65.07	-133.15
5	-0.58225	0.44172	0.09008	0.09346	0.09440	58.65	8.94	57.91	-94.57
6	-0.45316	0.43799	0.19288	0.19954	0.20048	125.21	21.55	79.57	-210.31
7	-0.47641	0.43919	0.15869	0.16414	0.16509	103.00	17.31	72.32	-171.74
8	-0.47824	0.41958	0.19152	0.19801	0.19895	124.25	23.13	76.66	-210.32
9	-0.49569	0.40531	0.26006	0.26804	0.26898	168.20	28.37	86.38	-287.47
10	-0.55728	0.41885	0.15752	0.16280	0.16375	102.16	17.47	70.87	-171.73
11	-0.45918	0.40465	0.36256	0.37525	0.37620	235.48	43.14	113.67	-403.22

Table (13): Physico-chemical parameters in gas phase using HF/6-31G

HF/6-31G Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.31859	0.15033	0.15790	0.16458	0.16553	103.28	24.99	81.99	-324.64
2	-0.34376	0.23112	0.09904	0.10345	0.10440	64.92	13.45	64.98	-134.18
3	-0.34212	0.22905	0.28262	0.29447	0.29542	184.79	40.25	108.77	-368.30
4	-0.36164	0.23053	0.09931	0.10368	0.10462	65.06	13.78	64.80	-134.19
5	-0.36211	0.23334	0.06840	0.07189	0.07284	45.11	9.60	57.67	-95.17
6	-0.36067	0.23028	0.16058	0.16737	0.16832	105.03	22.77	79.50	-212.23
7	-0.36099	0.23164	0.12995	0.13551	0.13645	85.03	18.30	72.18	-173.21
8	-0.36133	0.20876	0.15916	0.16563	0.16657	103.93	24.09	76.10	-212.24
9	-0.32480	0.22592	0.22113	0.23008	0.23102	144.38	31.43	91.07	-290.24
10	-0.33212	0.22260	0.12913	0.13452	0.13546	84.41	17.88	70.96	-173.19
11	-0.32331	0.22139	0.31267	0.32559	0.32653	204.31	45.07	112.90	-407.30

Table (14): Physico-chemical parameters in ion phase using HF/6-31G

HF/6-31G Ion Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.47546	-0.03050	0.17434	0.18111	0.18205	113.65	25.02	82.52	-325.02
2	-0.75429	-0.02090	0.11600	0.12040	0.12135	75.55	13.47	65.39	-134.56
3	-0.59555	0.00754	0.29944	0.31139	0.31234	195.40	40.53	109.46	-368.69
4	-0.69953	-0.02884	0.11611	0.12048	0.12143	75.61	13.67	65.23	-134.57
5	-0.78799	-0.04068	0.08547	0.08889	0.08984	55.78	9.25	58.00	-95.54
6	-0.60833	-0.02357	0.17746	0.18428	0.18523	115.64	22.68	80.01	-212.61
7	-0.64583	-0.02538	0.14683	0.15241	0.15336	95.64	18.19	72.66	-173.59
8	-0.66218	-0.01551	0.17565	0.18224	0.18318	114.36	24.29	76.78	-212.62
9	-0.66024	0.03149	0.23788	0.24690	0.24784	154.93	31.85	92.23	-290.64
10	-0.73598	-0.00360	0.14592	0.15134	0.15229	94.97	18.28	71.37	-173.58
11	-0.61758	0.04044	0.32972	0.34270	0.34365	215.05	45.42	113.78	-407.70

Table (15): Physico-chemical parameters in gas-solvation using HF/6-31G

HF/6-31G Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.32405	0.14400	0.15648	0.16237	0.16332	101.89	22.95	77.82	-324.65
2	-0.35088	0.23499	0.09872	0.10307	0.10401	64.68	13.27	64.74	-134.19
3	-0.34827	0.23137	0.28162	0.29349	0.29443	184.17	40.21	109.55	-368.30
4	-0.36750	0.23673	0.09883	0.10314	0.10408	64.72	13.54	64.61	-134.20
5	-0.36914	0.24045	0.06805	0.07148	0.07242	44.85	9.30	57.47	-95.18
6	-0.36682	0.23398	0.15991	0.16665	0.16759	104.57	22.55	79.38	-212.24
7	-0.36718	0.23646	0.12938	0.13488	0.13582	84.64	18.06	72.03	-173.22
8	-0.36563	0.21376	0.15873	0.16513	0.16607	103.62	23.83	75.83	-212.24
9	-0.32766	0.22828	0.22068	0.22961	0.23055	144.08	31.47	90.96	-290.25
10	-0.34022	0.22339	0.12898	0.13432	0.13526	84.28	17.86	70.71	-173.19
11	-0.32921	0.22373	0.31205	0.32494	0.32589	203.90	45.09	112.69	-407.30

Table (16): Physico-chemical parameters in ion-solvation using HF/6-31G

HF/6-31G Ion-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.34694	0.11843	0.17218	0.17907	0.18002	112.37	24.93	87.11	-325.12
2	-0.57686	0.17430	0.11475	0.11913	0.12007	74.75	13.38	65.26	-134.66
3	-0.46780	0.18722	0.29743	0.30858	0.30952	193.63	38.51	104.84	-368.78
4	-0.52703	0.17835	0.11475	0.11910	0.12004	74.73	13.56	65.11	-134.67
5	-0.59475	0.17382	0.08413	0.08754	0.08849	54.93	9.18	57.96	-95.65
6	-0.47680	0.18086	0.17585	0.18268	0.18362	114.63	22.58	80.19	-212.71
7	-0.49430	0.18061	0.14532	0.15089	0.15183	94.68	18.08	72.66	-173.69
8	-0.50357	0.16895	0.17456	0.18105	0.18199	113.61	23.97	76.35	-212.72
9	-0.51386	0.18875	0.23670	0.24578	0.24672	154.23	31.84	97.76	-290.72
10	-0.57107	0.17087	0.14499	0.15036	0.15131	94.35	18.17	71.08	-173.67
11	-0.48414	0.19675	0.32817	0.34115	0.34210	214.08	45.38	114.16	-407.78

Table (17): Physico-chemical parameters in gas phase using HF/6-31G(d,p)

HF/6-31G(d,p) Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.31807	0.14950	0.15645	0.16316	0.16410	102.38	25.11	82.23	-324.78
2	-0.36063	0.23017	0.09880	0.10306	0.10400	64.67	13.06	64.33	-134.25
3	-0.35751	0.22848	0.28066	0.29246	0.29340	183.52	40.44	108.07	-368.48
4	-0.38102	0.22767	0.09907	0.10331	0.10425	64.83	13.36	64.27	-134.26
5	-0.38256	0.22992	0.06849	0.07183	0.07277	45.07	9.03	57.11	-95.22
6	-0.38001	0.22885	0.15986	0.16652	0.16747	104.50	22.47	78.94	-212.34
7	-0.38042	0.22951	0.12947	0.13490	0.13585	84.65	17.94	71.63	-173.30
8	-0.37854	0.20750	0.15847	0.16485	0.16579	103.44	23.81	75.77	-212.34
9	-0.33738	0.22783	0.21955	0.22845	0.22939	143.35	31.60	90.81	-290.39
10	-0.34581	0.22409	0.12857	0.13380	0.13475	83.96	17.68	67.99	-173.28
11	-0.33580	0.22324	0.31038	0.32326	0.32420	202.85	45.43	112.45	-407.51

Table (18): Physico-chemical parameters in ion phase using HF/6-31G(d,p)

HF/6-31G(d,p) Ion Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.47274	-0.02871	0.17217	0.17904	0.17998	112.35	25.62	82.78	-325.15
2	-0.75589	-0.01977	0.11520	0.11956	0.12050	75.03	13.50	65.10	-134.63
3	-0.59858	0.00943	0.29712	0.30909	0.31003	193.96	41.00	109.16	-368.88
4	-0.70088	-0.02809	0.11503	0.11939	0.12034	74.92	13.81	65.11	-134.63
5	-0.78687	-0.03986	0.08465	0.08804	0.08899	55.25	9.30	57.85	-95.59
6	-0.61044	-0.02257	0.17592	0.18274	0.18369	114.67	22.93	79.86	-212.71
7	-0.64784	-0.02442	0.14552	0.15110	0.15205	94.82	18.38	72.52	-173.67
8	-0.66338	-0.01513	0.17419	0.18077	0.18172	113.44	24.45	76.72	-212.72
9	-0.66336	0.03232	0.23609	0.24512	0.24607	153.82	32.11	92.41	-290.79
10	-0.73994	-0.00253	0.14514	0.15050	0.15145	94.44	18.24	70.99	-173.66
11	-0.62033	0.04193	0.32725	0.34025	0.34120	213.51	45.87	113.66	-407.90

Table (19): Physico-chemical parameters in gas-solvation using HF/6-31G(d,p)

HF/6-31G(d,p) Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.32232	0.14432	0.15492	0.16086	0.16180	100.94	23.25	77.93	-324.79
2	-0.36398	0.23557	0.09838	0.10263	0.10357	64.40	13.03	64.29	-134.26
3	-0.36056	0.23256	0.27950	0.29137	0.29231	182.84	40.52	109.47	-368.49
4	-0.38246	0.23643	0.09841	0.10265	0.10360	64.42	13.35	64.30	-134.27
5	-0.38501	0.23992	0.06796	0.07130	0.07224	44.74	9.00	57.14	-95.20
6	-0.38144	0.23523	0.15897	0.16566	0.16660	103.95	22.50	79.11	-212.35
7	-0.38186	0.23709	0.12869	0.13414	0.13508	84.17	17.95	71.75	-173.31
8	-0.37924	0.21437	0.15789	0.16425	0.16519	103.07	23.74	75.65	-212.35
9	-0.34010	0.23012	0.21907	0.22797	0.22892	143.06	31.64	90.93	-290.40
10	-0.35164	0.22556	0.12841	0.13361	0.13456	83.84	17.66	70.03	-173.29
11	-0.33977	0.22594	0.30968	0.32256	0.32350	202.41	45.47	112.51	-407.51

Table (20): Physico-chemical parameters in ion-solvation using HF/6-31G(d,p)

HF/6-31G(d,p) Ion Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.34359	0.12017	0.16995	0.17601	0.17696	110.45	23.57	78.69	-325.26
2	-0.57782	0.17587	0.11394	0.11828	0.11922	74.22	13.41	64.99	-134.73
3	-0.47080	0.18946	0.29506	0.30621	0.30715	192.15	38.98	104.48	-368.97
4	-0.52804	0.17961	0.11365	0.11799	0.11894	74.04	13.70	64.98	-134.74
5	-0.59351	0.17506	0.08329	0.08668	0.08763	54.39	9.25	57.82	-95.70
6	-0.47887	0.18237	0.17427	0.18110	0.18204	113.64	22.85	80.02	-212.82
7	-0.49615	0.18211	0.14399	0.14955	0.15050	93.85	18.28	72.50	-173.78
8	-0.50484	0.17040	0.17306	0.17955	0.18049	112.67	24.16	76.32	-212.82
9	-0.51675	0.19014	0.23493	0.24307	0.24402	152.53	30.11	86.58	-290.87
10	-0.57435	0.17242	0.14426	0.14956	0.15051	93.85	18.11	70.72	-173.76
11	-0.48663	0.19904	0.32565	0.33869	0.33963	212.53	45.83	114.99	-407.99

Table (21): Physico-chemical parameters in gas phase using DFT/STO-3G

DFT/STO-3G Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.15302	0.09195	0.15518	0.16219	0.16313	101.77	26.12	83.74	-322.86
2	-0.13665	0.32111	0.10034	0.10464	0.10559	65.67	13.27	64.67	-133.49
3	-0.13082	0.29280	0.28842	0.30050	0.30144	188.57	40.84	109.74	-366.58
4	-0.14530	0.32717	0.10050	0.10486	0.10580	65.80	13.49	65.05	-133.49
5	-0.14786	0.33551	0.06900	0.07233	0.07327	45.38	8.99	57.27	-94.64
6	-0.14476	0.31621	0.16341	0.17024	0.17118	106.82	22.59	80.11	-211.18
7	-0.14498	0.32145	0.13199	0.13756	0.13850	86.32	18.03	72.59	-172.34
8	-0.14191	0.31013	0.16192	0.16875	0.16970	105.90	24.45	77.98	-211.19
9	-0.11636	0.28671	0.22483	0.23419	0.23513	146.96	32.51	93.47	-288.88
10	-0.12758	0.30833	0.13114	0.13653	0.13747	85.67	18.31	70.91	-172.33
11	-0.11428	0.28035	0.31881	0.33224	0.33319	208.49	46.27	116.83	-405.42

Table (22): Physico-chemical parameters in ion phase using DFT/STO-3G

DFT/STO-3G Ion phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.33938	-0.09297	0.16962	0.17683	0.17778	110.97	26.96	84.44	-323.30
2	-0.59124	-0.02841	0.11477	0.11927	0.12022	74.84	13.94	65.90	-133.92
3	-0.42618	-0.00805	0.30271	0.31498	0.31593	197.66	41.61	111.01	-367.00
4	-0.53303	-0.02840	0.11520	0.11970	0.12064	75.11	14.11	65.92	-133.92
5	-0.61691	-0.03649	0.08386	0.08731	0.08825	54.79	9.51	58.25	-95.06
6	-0.43600	-0.02361	0.17804	0.18505	0.18600	116.12	23.29	81.07	-211.62
7	-0.47624	-0.02490	0.14662	0.15238	0.15333	95.62	18.72	73.62	-172.77
8	-0.49721	-0.01973	0.17627	0.18334	0.18428	115.05	25.27	79.07	-211.63
9	-0.50045	-0.01067	0.23907	0.24854	0.24948	155.96	32.96	95.14	-289.34
10	-0.57635	-0.02188	0.14519	0.15085	0.15179	94.66	19.04	72.48	-172.77
11	-0.45397	-0.00423	0.33316	0.34671	0.34765	217.56	46.77	117.77	-405.89

Table (23): Physico-chemical parameters in gas-solvation using DFT/STO-3G

DFT/STO-3G Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.14937	0.08881	0.15432	0.16053	0.16147	100.73	24.20	79.11	-322.87
2	-0.13900	0.32411	0.10013	0.10443	0.10538	65.53	13.25	64.68	-133.49
3	-0.13392	0.29466	0.28780	0.29990	0.30085	188.19	40.86	110.38	-366.59
4	-0.14515	0.33500	0.10022	0.10458	0.10552	65.62	13.48	65.05	-133.49
5	-0.14782	0.34453	0.06878	0.07211	0.07305	45.25	8.97	57.31	-94.64
6	-0.14477	0.32211	0.16298	0.16982	0.17076	106.56	22.59	80.14	-211.19
7	-0.14503	0.32832	0.13162	0.13720	0.13815	86.10	18.04	72.67	-172.34
8	-0.14223	0.31511	0.16171	0.16851	0.16945	105.74	24.38	77.79	-211.19
9	-0.12180	0.28577	0.22462	0.23396	0.23490	146.81	32.51	93.16	-288.88
10	-0.13389	0.30642	0.13107	0.13645	0.13739	85.62	18.30	70.84	-172.33
11	-0.12088	0.27882	0.31846	0.33185	0.33280	208.24	46.28	116.61	-405.42

Table (24): Physico-chemical parameters in ion-solvation using DFT/STO-3G

DFT/STO-3G Ion Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.20931	0.05285	0.16829	0.17553	0.17647	110.14	26.78	85.47	-323.41
2	-0.41289	0.16372	0.11381	0.11828	0.11923	74.22	13.83	65.79	-134.02
3	-0.30155	0.16670	0.30152	0.31291	0.31385	196.35	39.48	105.63	-367.12
4	-0.36303	0.17752	0.11420	0.11868	0.11963	74.48	14.01	65.80	-134.03
5	-0.42574	0.17585	0.08275	0.08620	0.08715	54.09	9.48	58.25	-95.18
6	-0.31018	0.17803	0.17699	0.18397	0.18492	115.44	23.15	80.95	-211.73
7	-0.32947	0.17848	0.14560	0.15132	0.15226	94.95	18.59	73.45	-172.88
8	-0.33930	0.16624	0.17563	0.18257	0.18352	114.57	24.95	78.51	-211.73
9	-0.35377	0.14764	0.23834	0.24688	0.24782	154.92	30.86	88.73	-289.42
10	-0.40933	0.15096	0.14443	0.15002	0.15097	94.14	18.89	72.15	-172.87
11	-0.32183	0.15004	0.33224	0.34575	0.34669	216.96	46.66	117.24	-405.97

Table (25): Physico-chemical parameters in gas phase using DFT/6-31G

DFT/6-31G Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.21450	0.00788	0.14727	0.15442	0.15536	96.90	27.32	83.61	-326.83
2	-0.19849	0.08756	0.09294	0.09743	0.09837	61.14	14.05	65.18	-135.12
3	-0.19909	0.09047	0.26565	0.27797	0.27891	174.43	42.67	110.53	-370.95
4	-0.20743	0.08631	0.09319	0.09770	0.09864	61.31	14.56	65.33	-135.13
5	-0.20597	0.08790	0.06413	0.06768	0.06862	42.47	10.01	57.87	-95.83
6	-0.20723	0.08782	0.15090	0.15795	0.15889	99.11	24.10	80.50	-213.74
7	-0.20742	0.08786	0.12202	0.12779	0.12873	80.19	19.37	72.99	-174.44
8	-0.21039	0.06965	0.14943	0.15631	0.15726	98.09	25.71	77.68	-213.75
9	-0.18969	0.08656	0.20756	0.21699	0.21793	136.16	33.49	93.53	-292.34
10	-0.19464	0.08322	0.12120	0.12672	0.12766	79.52	18.82	71.36	-174.42
11	-0.18922	0.08387	0.29370	0.30727	0.30821	192.81	47.97	116.18	-410.25

Table (26): Physico-chemical parameters in ion phase using DFT/6-31G

DFT/6-31G Ion Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.39288	-0.17508	0.16273	0.16996	0.17091	106.65	27.40	84.20	-327.21
2	-0.60383	-0.16981	0.10909	0.11360	0.11454	71.28	14.20	65.76	-135.50
3	-0.45670	-0.13854	0.28161	0.29401	0.29496	184.50	43.07	111.02	-371.30
4	-0.55143	-0.17609	0.10910	0.11361	0.11455	71.29	14.44	65.72	-135.50
5	-0.62917	-0.18886	0.08035	0.08382	0.08476	52.60	9.65	58.16	-96.19
6	-0.46623	-0.17079	0.16682	0.17389	0.17484	109.12	24.03	81.01	-214.12
7	-0.50196	-0.17274	0.13800	0.14379	0.14473	90.23	19.25	73.46	-174.81
8	-0.52475	-0.15995	0.16492	0.17191	0.17285	107.88	25.90	78.38	-214.13
9	-0.51942	-0.11575	0.22347	0.23294	0.23388	146.17	33.96	94.46	-292.73
10	-0.59147	-0.15222	0.13723	0.14286	0.14380	89.64	19.41	72.15	-174.80
11	-0.47967	-0.10821	0.30986	0.32348	0.32443	202.99	48.40	116.67	-410.65

Table (27): Physico-chemical parameters in gas-solvation using DFT/6-31G

DFT/6-31G Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.21509	0.00428	0.14594	0.15315	0.15409	96.10	27.26	85.22	-326.83
2	-0.20369	0.09324	0.09256	0.09699	0.09794	60.86	13.93	65.01	-135.12
3	-0.20422	0.09385	0.26460	0.27695	0.27790	173.79	42.69	111.87	-370.96
4	-0.21233	0.09429	0.09267	0.09712	0.09806	60.94	14.32	65.12	-135.13
5	-0.21207	0.09659	0.06372	0.06720	0.06814	42.17	9.71	57.65	-95.83
6	-0.21233	0.09505	0.15018	0.15718	0.15812	98.63	23.89	80.41	-213.74
7	-0.21276	0.09640	0.12141	0.12712	0.12807	79.77	19.11	72.88	-174.44
8	-0.21406	0.07563	0.14893	0.15575	0.15669	97.73	25.49	77.47	-213.75
9	-0.19418	0.08900	0.20726	0.21662	0.21757	135.93	33.49	93.09	-292.33
10	-0.20168	0.08396	0.12110	0.12657	0.12751	79.42	18.81	71.12	-174.42
11	-0.19449	0.08611	0.29319	0.30669	0.30764	192.45	47.98	115.49	-410.25

Table (28): Physico-chemical parameters in ion-solvation using DFT/6-31G

DFT/6-31G Ion Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.26196	-0.02471	0.16068	0.16709	0.16804	104.85	25.28	80.01	-327.31
2	-0.42716	0.02733	0.10777	0.11225	0.11320	70.44	14.11	65.65	-135.60
3	-0.33515	0.04173	0.27962	0.29120	0.29214	182.73	41.00	106.29	-371.43
4	-0.38001	0.03285	0.10774	0.11222	0.11316	70.42	14.32	65.60	-135.61
5	-0.43786	0.02718	0.07894	0.08240	0.08335	51.71	9.60	58.13	-96.30
6	-0.33608	0.03439	0.16525	0.17231	0.17326	108.13	23.91	81.11	-214.22
7	-0.35163	0.03418	0.13650	0.14226	0.14320	89.27	19.13	73.43	-174.91
8	-0.36705	0.02765	0.16384	0.17072	0.17167	107.13	25.57	77.91	-214.22
9	-0.37015	0.04313	0.22249	0.23185	0.23280	145.49	33.90	92.60	-292.81
10	-0.42663	0.02346	0.13619	0.14177	0.14271	88.96	19.29	71.88	-174.89
11	-0.34806	0.04746	0.30819	0.32188	0.32282	201.98	48.40	118.17	-410.72

Table (29): Physico-chemical parameters in gas phase using DFT/6-31G(d,p)

DFT/6-31G(d,p) Gas Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.22939	0.00519	0.14628	0.15341	0.15435	96.27	27.29	83.74	-326.92
2	-0.21507	0.08720	0.09268	0.09705	0.09799	60.90	13.79	64.70	-135.17
3	-0.21407	0.08891	0.26386	0.27614	0.27708	173.28	42.98	109.81	-371.07
4	-0.22913	0.08415	0.09298	0.09736	0.09831	61.10	14.16	64.83	-135.18
5	-0.22894	0.08544	0.06420	0.06759	0.06854	42.42	9.46	57.34	-95.86

6	-0.22871	0.08591	0.15021	0.15714	0.15808	98.61	23.84	80.00	-213.81
7	-0.22896	0.08593	0.12158	0.12723	0.12817	79.84	19.03	72.49	-174.49
8	-0.22982	0.06876	0.14868	0.15550	0.15644	97.58	25.51	77.43	-213.82
9	-0.20105	0.08751	0.20608	0.21548	0.21643	135.22	33.74	93.64	-292.43
10	-0.20720	0.08400	0.12060	0.12602	0.12697	79.08	18.75	70.84	-174.49
11	-0.20020	0.08479	0.29158	0.30511	0.30605	191.46	48.42	115.38	-410.38

Table (30): Physico-chemical parameters in ion phase using DFT/6-31G(d,p)

DFT/6-31G(d,p) Ion Phase	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.39225	-0.17426	0.16094	0.16826	0.16920	105.58	27.93	84.43	-327.29
2	-0.60315	-0.16785	0.10821	0.11270	0.11365	70.72	14.31	65.59	-135.54
3	-0.45661	-0.13568	0.27926	0.29172	0.29266	183.06	43.65	110.95	-371.46
4	-0.55135	-0.17427	0.10800	0.11252	0.11346	70.61	14.64	65.65	-135.55
5	-0.62778	-0.18712	0.07949	0.08295	0.08389	52.05	9.77	58.09	-96.22
6	-0.46632	-0.16865	0.16527	0.17237	0.17331	108.16	24.37	80.95	-214.18
7	-0.50212	-0.17069	0.13666	0.14247	0.14341	89.40	19.53	73.42	-174.87
8	-0.52395	-0.15845	0.16335	0.17037	0.17131	106.91	26.20	78.38	-214.20
9	-0.51895	-0.11439	0.22159	0.23110	0.23204	145.02	34.34	94.92	-292.82
10	-0.58935	-0.15068	0.13631	0.14191	0.14285	89.05	19.46	71.91	-174.86
11	-0.47916	-0.10611	0.30732	0.32099	0.32194	201.43	49.00	116.69	-410.78

Table(31):Physico-chemical parameters in gas-solvation using DFT/6-31G(d,p)

DFT/6-31G(d,p) Gas-Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.22885	0.00342	0.14477	0.15112	0.15207	94.83	25.45	79.32	-326.93
2	-0.21724	0.09363	0.09224	0.09660	0.09754	60.62	13.78	64.68	-135.17
3	-0.21622	0.09396	0.26272	0.27505	0.27600	172.60	43.08	110.92	-371.08
4	-0.22979	0.09428	0.09232	0.09671	0.09765	60.69	14.17	64.86	-135.18
5	-0.23045	0.09676	0.06367	0.06707	0.06801	42.09	9.44	57.38	-95.86
6	-0.22952	0.09537	0.14933	0.15629	0.15723	98.07	23.89	80.20	-213.82
7	-0.22979	0.09604	0.12081	0.12647	0.12742	79.36	19.05	72.62	-174.50
8	-0.23015	0.07609	0.14812	0.15490	0.15585	97.20	25.46	77.29	-213.83
9	-0.20332	0.08994	0.20567	0.21506	0.21600	134.95	33.78	93.61	-292.44
10	-0.21186	0.08521	0.12046	0.12586	0.12680	78.98	18.75	70.72	-174.49
11	-0.20362	0.08730	0.29092	0.30444	0.30538	191.04	48.49	115.39	-410.38

Table(32):Physico-chemical parameters in ion solvation using DFT/6-31G(d,p)

DFT/6-31G(d,p) Ion Solvation	HOMO	LUMO	Zero energy	Thermal energy	Thermal enthalpy	Total energy	C.V	S	HF
1	-0.26047	-0.02506	0.15885	0.16626	0.16721	104.33	27.82	86.95	-327.40
2	-0.42572	0.02892	0.10686	0.11133	0.11227	69.86	14.22	65.50	-135.64
3	-0.33452	0.04384	0.27723	0.28886	0.28981	181.26	41.61	106.22	-371.55
4	-0.37917	0.03449	0.10661	0.11109	0.11204	69.71	14.54	65.53	-135.66
5	-0.43594	0.02883	0.07805	0.08151	0.08245	51.15	9.74	58.08	-96.33
6	-0.33553	0.03618	0.16366	0.17074	0.17169	107.14	24.27	81.02	-214.29
7	-0.35115	0.03596	0.13513	0.14091	0.14185	88.42	19.42	73.36	-174.98
8	-0.36607	0.02919	0.16224	0.16916	0.17010	106.15	25.88	77.97	-214.30
9	-0.36944	0.04443	0.22050	0.22993	0.23088	144.29	34.33	92.88	-292.90
10	-0.42517	0.02476	0.13530	0.14085	0.14179	88.38	19.32	71.63	-174.96
11	-0.34720	0.04995	0.30563	0.31843	0.31937	199.82	46.93	111.18	-410.86

Multiple linear regressions were used the pKa as dependent factors and the other data were independent values.

Table (33): Predicted of pKa values from regression using DFT/STO-3G

DFT/STO-3G	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34	9.49	8.43	9.40	9.18
2	10.60*	10.45	9.69	10.25	10.04
3	11.25	11.70	10.03	11.29	11.07
4	10.63	10.62	9.66	10.62	10.53
5	10.62	10.77	10.05	10.69	10.56
6	10.59	10.77	9.90	10.59	10.44
7	10.53	10.66	9.73	10.57	10.49
8	10.45	10.58	9.56	10.50	10.34
9	10.76	10.78	9.47	10.75	10.61
10	9.76	10.37	9.30	9.81	9.67
11	10.65*	12.31	10.05	11.75	9.62
R		0.937	0.872	0.999	0.996
St. error		0.210	0.294	0.030	0.051
Fisher Value		50.30	22.22	2665.41	964.91
* Removed at regression					

Table (34): Predicted of pKa values from regression using DFT/6-31G

DFT/6-31G	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34*	28.06	9.97	12.35	10.04
2	10.60	10.65	10.66	10.68	10.65
3	11.25	11.23	11.22	11.17	11.29
4	10.63	10.51	10.55	10.57	10.64
5	10.62	10.54	10.58	10.46	10.62
6	10.59	10.71	10.58	10.70	10.59
7	10.53	10.65	10.56	10.62	10.60
8	10.45	10.49	10.45	10.44	10.48
9	10.76	10.87	10.73	10.75	10.79
10	9.76*	10.40	10.60	10.72	10.65
11	10.65*	10.82	11.07	10.92	10.48
R		0.929	0.985	0.924	0.995
St. error		0.098	0.046	0.101	0.026
Fisher Value		37.85	191.67	35.21	612.33
* Removed at regression					

Table (35): Predicted of pKa values from regression using DFT/STO-3G(d,p)

DFT/6-31G(d,p)	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34	9.36	9.43	9.36	9.45
2	10.60	10.61	10.72	10.66	10.67
3	11.25	11.12	11.35	11.17	11.37
4	10.63	10.58	10.59	10.60	10.66
5	10.62	10.47	10.61	10.48	10.61
6	10.59	10.75	10.66	10.75	10.62
7	10.53	10.66	10.62	10.67	10.63
8	10.45	10.44	10.53	10.46	10.52
9	10.76	10.84	10.83	10.82	10.86
10	9.76*	10.64	10.72	10.70	10.72
11	10.65*	11.07	11.27	10.99	11.54
R		0.977	0.994	0.981	0.996
St. error		0.113	0.056	0.103	0.047
Fisher Value		148.62	624.68	180.71	906.32
* Removed at regression					

Table (36): Predicted of pKa values from regression using HF/STO-3G

HF/STO-3G	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34	9.37	9.47	9.16	9.36
2	10.60	10.29	10.49	10.22	10.26
3	11.25	11.17	11.28	10.92	11.25
4	10.63	10.56	10.71	10.48	10.68
5	10.62	10.70	10.75	10.64	10.67
6	10.59	10.78	10.70	10.61	10.55
7	10.53	10.68	10.67	10.56	10.65
8	10.45	10.33	10.46	10.18	10.37
9	10.76*	9.87	10.74	9.85	10.57
10	9.76	9.96	9.86	9.85	9.99
11	10.65	10.73	10.91	10.48	10.68
R		0.952	0.983	0.950	0.960
St. error		0.170	0.103	0.175	0.156
Fisher Value		78.17	226.60	73.36	93.40
* Removed at regression					

Table (37): Predicted of pKa values from regression using HF/6-31G

HF/6-31G	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34	9.24	9.28	9.46	9.27
2	10.60	10.64	10.62	10.71	10.60
3	11.25	11.04	11.16	11.37	11.16
4	10.63	10.52	10.48	10.55	10.57
5	10.62	10.42	10.62	10.61	10.56
6	10.59	10.67	10.61	10.73	10.50
7	10.53	10.57	10.52	10.67	10.54
8	10.45	10.39	10.41	10.41	10.40
9	10.76*	10.28	10.29	10.86	10.19
10	9.76*	10.62	10.49	10.30	10.60
11	10.65	10.53	10.60	10.81	10.56
R		0.977	0.994	0.984	0.997
St. error		0.112	0.059	0.095	0.040
Fisher Value		150.30	553.61	208.56	1228.39
* Removed at regression					

Table (38): Predicted of pKa values from regression using HF/6-31G(d,p)

HF/6-31G(d,p)	Exp. pKa	Gas phase	Ion phase	Gas Solvation	Ion Solvation
1	9.34*	13.71	10.26	7.44	9.88
2	10.60	10.67	10.65	10.69	10.60
3	11.25	11.15	11.24	11.16	11.22
4	10.63	10.63	10.52	10.67	10.57
5	10.62	10.43	10.64	10.40	10.58
6	10.59	10.75	10.67	10.78	10.54
7	10.53	10.64	10.56	10.65	10.56
8	10.45	10.45	10.46	10.25	10.43
9	10.76*	10.46	10.36	10.07	11.47
10	9.76*	10.16	10.53	11.20	10.65
11	10.65	10.68	10.68	10.58	10.62
R		0.888	0.973	0.832	0.993
St. error		0.121	0.060	0.146	0.031
Fisher Value		22.42	107.91	13.47	430.61
* Removed at regression					

From the table (9-38), all the regression was near to each other's and can't recognize between them to choose the best method. So, the fisher values are the best data to compare between them and choose the best method in the calculations as shown below:

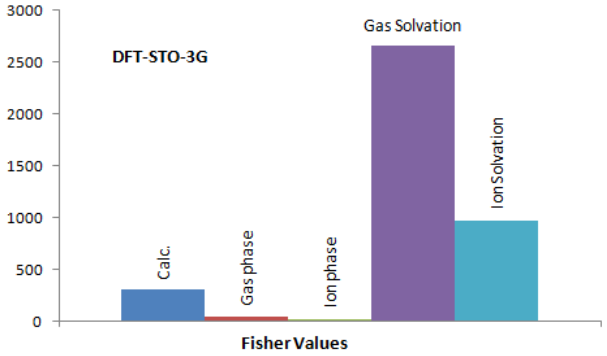


Fig. 1. Compare between the fisher data for the first method (calc.) and second method (gas, ion, gas-solvation and ion-solvation) using DFT/STO-3G

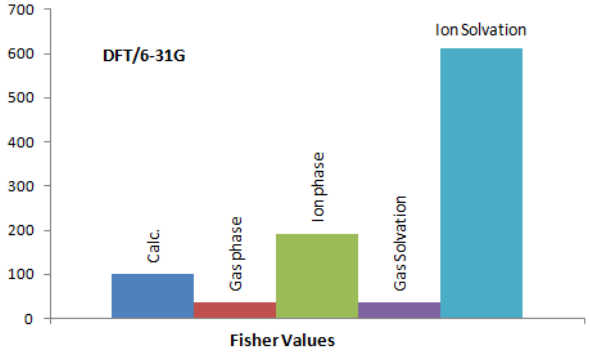


Fig. 2. Compare between the fisher data for the first method (calc.) and second method (gas, ion, gas-solvation and ion-solvation) using DFT/6-31G

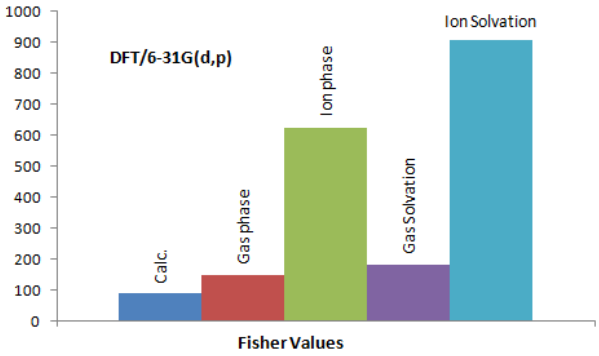


Fig. 3. Compare between the fisher data for the first method (calc.) and second method(gas, ion, gas-solvation and ion-solvation) using DFT/6-31G(d,p)

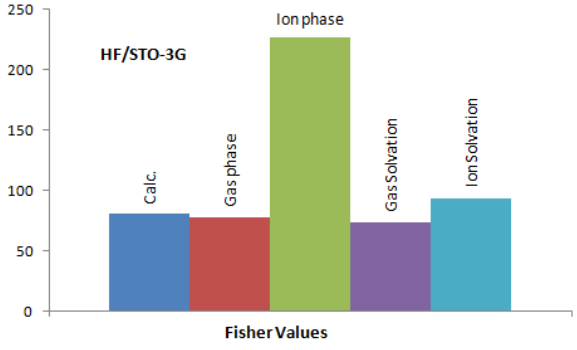


Fig. 4. Compare between the fisher data for the first method (calc.) and second method (gas, ion, gas-solvation and ion-solvation) using HF/STO-3G

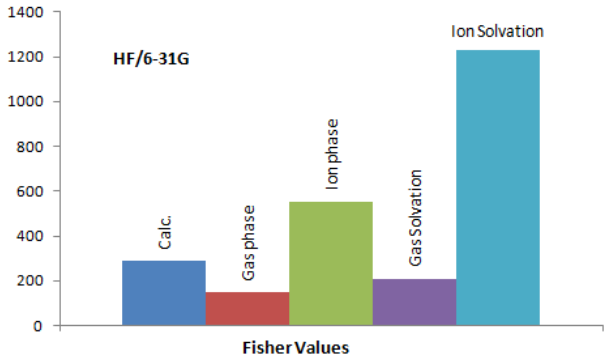


Fig. 5. Compare between the fisher data for the first method (calc.) and second method (gas, ion, gas-solvation and ion-solvation) using DFT/6-31G

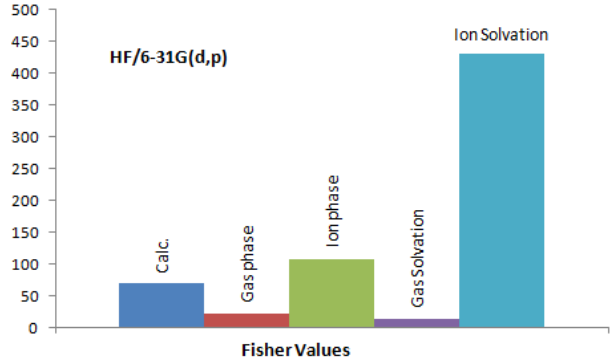


Fig. 6. Compare between the fisher data for the first method (calc.) and second method (gas, ion, gas-solvation and ion-solvation) using HF/5-31G(d,p)

4 Conclusion:

In this research, two methods of statistics were used to evaluated and predicted pKa values. The first method gives an excellent predicted value of pKa depends on the correlation coefficient (R>0.95). The (DFT/STO-3G) give the best method for the determination of pKa depends on the fisher data. The second method somewhat, the ion-solvation gives excellent data for evaluated and predicted pKa data in four methods compare to others.

References:

[1] Liptak, M.D.; Gross, K.C.; Seybold, P.G.; Feldgus, S.; Shields, G.C.; Absolute pKa determinations for substituted phenols. J. Am. Chem. Soc., 124(22), 6421-7(2002).

[2] Liptak, M.D.; Shields, G.C.; Accurate pKa calculations for carboxylic acids using complete basis set and Gaussian-n models combined with CPCM continuum solvation methods. J. Am. Chem. Soc., 123(30), 7314-9 (2001).

[3] Zhan, C.G.; Dixon, D.A.; Absolute hydration free energy of the proton from first-principles electronic structure calculations. J. Phys. Chem. A, 105(51), 11534-40(2001).

[4] Takano, Y.; Houk, K.N.; Benchmarking the conductor-like polarizable continuum model (CPCM) for aqueous solvation free energies of neutral and ionic organic molecules. J. Chem. Theory. Comput., 1, 70-7(2005).

[5] Kelly, C.P.; Cramer, C.J.; Truhlar, D.G.; Aqueous solvation free energies of ions and ion-water clusters based on an accurate value for the absolute aqueous solvation free energy of the proton. J. Phys. Chem. B, 110(32), 16066-81 (2006).

[6] Schuurmann, G.; Cossi, M.; Barone, V.; Tomasi, J.; Prediction of the pK(a) of carboxylic acids using the ab initio continuum-solvation model PCM-UAHF. J. Phys. Chem. A, 102(33), 6706-12 (1998).

[7] David C. Blakemore ; Luis C.; Ian C.; David C. Rees; Andrew W. Thomas; David M. Wilson; Anthony W.; Organic synthesis provides opportunities to transform drug discovery, Nature Chemistry, vol 10, , 383-394, (April 2018).
[8] Anjali B.; A Review on Diverse Role of Heterocyclic Moieties Containing Amino-quinoline and Azoles, Int.J.Curr.Res.Aca.Rev., 6(8): 12-39 (2018).
[9] Mossaraf H.; Ashis K. N.; A Review on Heterocyclic: Synthesis and Their Application in Medicinal Chemistry of Imidazole Moiety, Science Journal of Chemistry; 6(5): 83-94(2018).
[10] Md. Sajjad H., Farzana K. C.; Nayon U.; Laila A. B., Md. Kudrat-E-Z., Md. Masuqul H.; Synthesis, Characterization and Biological Activity Studies of Mixed Ligand Complexes with Schiff base and 2,2'-Bipyridine, International Journal of Applied Science - Research and Review, Vol.6 No.1: 2, (2018).
[11] Johnson M.;Alias A.,Janakiraman N.; Murugesan S.;Studies on Antioxidant and Phyto-chemical Profiles of Leptochloa uniflora Hochst, Int. Biol. Biomed. J. Autumn; Vol 1 No 4, 146-156(2015).
[12] Elena P. , Danuta Z. , Piotr G., Henryk Z., Juana F., Vitamin C, Phenolic Compounds and Antioxidant Capacity of Broccoli Florets Grown under Different Nitrogen Treatments Combined with Selenium, Pol. J. Food Nutr. Sci., Vol. 68, No. 2, pp. 179-186 (2018).
[13] Al-Ramadane O.M., Akrawi O.A., Ibrahim A.A., Al-Kazzaz A.S., National Journal of Chemistry, Volume 35, 512-520 (2009)
[14] Ammar A. Ibrahim, Asian Journal of Chemistry; vol. 23, no. 1, 215-218 (2011).
[15] Ammar A. Ibrahim, Rosiyah Y., Asian Journal of Chemistry; vol. 24, no. 6, 2634-2636 (2012).
[16] Milan R., Anna R.; Ria B., A Comparative Study of Molecular Structure, pKa, Lipophilicity, Solubility, Absorption and Polar Surface Area of Some Anti-platelet Drugs, Int. J. Mol. Sci., 17, 388; doi:10.3390/ijms17030388 (2016).
[17] Marco T.; Antonino L.; Anna M. A., Theoretical Determination of the pKa Values of Betalamic Acid Related to the Free Radical Scavenger Capacity: Comparison Between Empirical and Quantum Chemical Methods, Interdiscip Sci Comput Life Sci, DOI 10.1007/s12539-015-0101-3, 08 August (2015).
[18] Ammar A. Ibrahim; Eid A. Abdalrazaq, American Journal of Applied Sciences 6 (7): 1385-1389, (2009).
[19] Sandra B.; Alka J.M. Horvat, Dragana M. Pavlovic; Marija K. Macan, Trends in Analytical Chemistry, Vol. 26, No. 11, (2007).
[20] Christopher L. Tang; Emil A., Anna M. Pyle, Barry H. ; J. Mol. Biol.,366, 1475-1496 (2007).
[21] Raghab P.; Medhi C.; J. Chem. Sci., Vol. 116, No. 4, July, pp. 235-241 (2004).
[22] Funda T.; Murat D.; Cihan I.; Seref D.; Determination And Evaluation Of Acidity Constants Of Some Imidazole And Thiazole Linked Acetamide Compounds, Anadolu Univ. J. of Sci. and Technology-A– Appl. Sci. and Eng. 17 (2)- (2016).
[23] Peter P.; Acta Chimica Slovaca, Vol. 7, No. 1, pp. 25−30 (2014).
[24] Bishnu T.; Bernhard H. Schlegel, Density Functional Theory Calculation of pKa's of Thiols in Aqueous Solution Using Explicit Water Molecules and the Polarizable Continuum Mode, J. Phys. Chem. A, 120, 5726-5735 (2016).
[25] Mauro S.; Sandra L.; Determination of pKa Values via ab initio Molecular Dynamics and its Application to Transition Metal-BasedWater Oxidation Catalysts, Inorganics, 7, 73; doi: 10.3390/inorganics7060073 (2019).
[26] Ammar A. Ibrahim, Ghufran M. Abed, Theoretical Prediction of the Ionization Potential Using Different Methods AM1, HF and DFT International Journal of Scientific & Engineering Research Volume 9, Issue 1, January, 726-733 (2018).
[27] Abhishek D.; Someswar C.; Physical Chemistry an Indian Journal, vol. 4, Issue 2, December (2009).
[28] Vrábel M.; Hocek M.; Havran L.; Fojta M.; Votruba I.; Klepetářová B.; Pohl R.; Eur. Jour. ofInorg. Chem., 1752 (2007).
[29] Yang X. T.; Wu H.; Ma S. J.; Hu J. J.; Wang Y.;Trans. Met. Chem., 1 (2011).
[30] Marquez-Flores Y. K.; Campos-Aldrete M. E., Salgado H. Z.; Correa-Basurto J., Melendez-Camargo M. E., Med. Chem. Res., (2011).
[31] Alaattin G. ; Int. J. Mol. Sci., 6, 257-275 (2005).