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STRUCTURAL STUDY AND INVESTIGATION OF NMR TENSORS IN INTERACTION OF DOPAMINE WITH ADENINE AND GUANINE

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ABSTRACT. The interaction of dopamine with adenine and guanine were studied at the Hartree-Fock level theory. The structural and vibrational properties of dopamine-4-N7GUA and dopamine-4-N3ADE were studied at level of HF/6-31G*. Interaction energies (ΔE) were calculated to be -11.49 and -11.92 kcal/mol, respectively. Some of bond lengths, angels and tortions are compared. NBO studies were performed to the second-order and perturbative estimates of donor-acceptor interaction have been done. The procedures of gauge-invariant atomic orbital (GIAO) and continuous-set-of-gauge-transformation (CSGT) were employed to calculate isotropic shielding, chemical shifts anisotropy and chemical shifts anisotropy asymmetry and effective anisotropy using 6-31G* basis set. These calculations yielded molecular geometries in good agreement with available experimental data.

KEY WORDS: Ab initio, Dopamine, GIAO, CSGT, DNA, Hartree Fock

INTRODUCTION

The neurotransmitter DA is formed in the cell bodies of the dopaminergic neurons of the substantia nigra [1]. The etiology of Parkinson's disease [2-7] and its underlying mechanism of loss of DA neurons are unknown. There is evidence, however, that DA is involved in the etiology of this disease, based on the observation by Graham *et al*. [8] DA is oxidized to the corresponding quinone. Covalent binding of DA to DNA occurs upon incubating DA with HL-60 cells or human glioblastoma cell lines [9] by copper-mediated oxidation of DA [10] or by oxidation of DA with prostaglandin H synthase [11, 12]. We hypothesize that oxidation of DA to its quinone and subsequent reaction with DNA cause DNA damage via formation of specific depurinating adducts, and the mutations generated by that damage might play a major role in initiating the series of events leading to neurodegenerative disorders such as Parkinson's disease.

To demonstrate binding to DNA *in vitro*, CAT and DA were oxidized in reactions catalyzed by horseradish peroxidase, tyrosinase or phenobarbital-induced rat liver microsomes in the presence of DNA. All the three enzymes catalyzed formation of detectable amounts of the depurinating adducts of DA, DA-6-N3Ade and DA-6-N7Gua, as well as the CAT-4-N7Gua depurinating adduct of CAT. In contrast, the CAT-4-N3Ade adduct was detected only after activation by tyrosinase.

If oxidation of DA to its quinone does not occur in a properly controlled environment, we hypothesize that the quinone might react with DNA to form depurinating DNA adducts, generating mutations that could initiate neurodegenerative disorders such as Parkinson's disease.

The first step in cancer initiation is the reaction of chemical carcinogens with DNA to form stable adducts, which remain in DNA unless removed by repair, and depurinating adducts, which detach from DNA following destabilization of the glycosyl bond. Depurinating DNA adducts of polycyclic aromatic hydrocarbons play a major role in the initiation of cancer, as shown by the correlation between depurinating adducts and oncogenic mutations of the H-ras oncogene in mouse skin.

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All of the optimized structures were carried out at the HF/6-31G* level. Electronic structures were analyzed with the natural bond order method [13] (NBO). In the NBO method, for optimally transforming a given wave function into localized form, corresponding to the one-center (lone pair) and two-center (bond) elements of the chemists Lewis structure picture. This carried out by examine all possible interactions between filled (donor) Lewis type NBOs and empty (acceptor) non Lewis NBOs and estimating their energetic importance by two second-order perturbation theory. Since these interactions lead to loss of occupancy from the localized NBOs of the idealized. Lewis structure into the empty non-Lewis orbitals (and thus, to departures from the idealized Lewis structure description), they are referred to as delocalization corrections to the zeroth-order natural Lewis structure.

In this report, we describe in detail the structures of dopamine-4-N7GUA and dopamine-4-N3ADE using ab initio quantum-chemical calculation made at the Hartree-Fock (HF) theoretical level with 6-31G* basis set. The structures were supported by comparing the measured ^{1}H NMR spectra to the results of ab initio gauge-invariant atomic orbital (GIAO) [14-17] and continuous-set-of-gauge-transformation (CSGT) [18] computations of chemical shifts.

We also study the NBO analysis is based on a method for optimally transforming a given wave function into localized form, corresponding to the one-center (lone pair) and two-center (bond) elements of the chemists Lewis structure picture [13].

EXPERIMENTAL

All the calculations reported here carried out using the Gaussian 98 [19]. The system studied by using geometry optimization consisted of dopamine and DNA. The structures were optimized using the framework of Hartree-Fock and 6-31G* basis set. A natural bond orbital (NBO) analysis, which localizes the many-electron wave function into Lewis-type electron-pairs were carried out at the HF level and 6-31G* basis set of theory to determine donor-acceptor interactions. All NMR analysis have been performed using 6-31G* basis set and the HF level. The GIAO and CSGT methods were used to calculate the isotropic NMR shielding at the HF/6-31G* of theory. Interaction energy (ΔE) are calculated due to the difference between the total energies of adducts with the sum of the components:

$$\Delta E = E_{CX} - (E_{BC} + E_{AC})$$

where ΔE is the energy interaction, E_{CX} the complex energy, E_{BC} the energy of proton-donor component (i.e. Brönsted acid), E_{AC} the energy of proton acceptor component (i.e. Brönsted base).

RESULTS AND DISCUSSION

Theoretical results of calculated optimized geometries for compounds are given in Table 1 and optimized structures obtained in the HF/6-31G* is shown in Figure 1. Length of N_4-C_1 in dopamine-4-N7GUA is less than dopamine-4-N3ADE, therefore dopamine and guanine form stronger bond.

The computed energies of the complexes are compared by HF/6-31G* method (Table 2). Stablization energy of dopamine-4-N7GUA is further than dopamine-4-N3ADE.

Thermodynamic data and interaction energy are given in Table 3. Entropies are negative, because is produced an adduct from two compound. NBO calculations shown the N or O-bonding contribution in the compounds (Table 4). A filled bonding or lone pair orbital can act as a donor and an empty or filled bonding, antibonding or lone pair orbital can act as acceptor. These interactions can strengthen and weaken bond. For example, a lone pair donor antibonding acceptor orbital interaction will weaken the bond associated with the antibonding orbitals.

Conversely, an interaction with a bonding pair as the acceptor will strengthen the bond. Strong electron delocalization in a best Lewis structure will also show up as donor-acceptor interaction. Table 5 shown the interactions that give the strongest stabilization. For formation of adducts, C_1-dopamine were contacted to N4-adenine or N7-guanine. Hybrid coefficients of C_1-N_4 were calculated in both adducts. For **d**opamine-4-N7GUA, stabilization energy E(2) associated with delocalization of C_1-N_4 as charge of C_1, is further than dopamine-4- N3ADE.

Therefore, the increasing N_4 basicity (and Rydberg) of dopamine-4-N7GUA can be attributed to the relative stabilization and increased stability of the adduct.

Table 1. Optimized bond length (Å) and angles of dopamine-4-N7GUA and dopamine-4-N3ADE.

Dopamine-4-N7GUA		Dopamine-4-N3ADE	
	Distance (Å)		Distance (Å)
N_4-C1	1.4312	N_4-C1	1.4399
NH_2-$C1_2$	1.4564	NH_2-$C1_2$	1.4562
C_5-O_{16}	1.35	C_5-O_{16}	1.35
C_{11}-O_{25}	1.36	C_{11}-O_{25}	1.36
C_7-C_{12}	1.532	C_7-$C1_2$	1.533
C_{15}-O_{21}	1.21	N_{29}-C_{22}	1.33
N_4-C_8	1.341	N_4-C_8	1.344
N_4-C_9	1.387	N_4-C_9	1.376
	Angles (degree)		Angles (degree)
C_9-N_4-C1	129.285	C_9-N_4-C1	122.952
C_8-N_4-C1	120.588	C_8-N_4-C1	120.588
N_4-C_9-$C1_5$	132.657	N_4-C_9-N_{15}	129.566
C_2-C1-C_3	121.51	C_2-C1-C_3	121.83
C_3-C1-N_4-C_9	93.410	C_2-C1-N_4-C_8	79.533
C_7-C_3-C1-N_4	-3.00	C_7-C_3-C1-N_4	-2.530
$C1_5$-C_9-N_4-C_8	179.413	N_{15}-C_9-N_4-C_8	-179.700
C_3-C_7-C_{12}-N_{22}	-178.978	N_{21}-C_{12}-C_7-C_3	179.766
O_{25}-$C1_1$-C_6-C_3	-179.875	O_{25}-C_{11}-C_6-C_3	-179.768

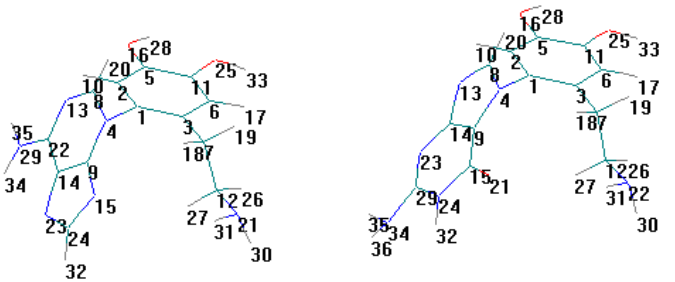

Figure 1. Optimized structures of dopamine-4-N3ADE and dopamine-4-N7GUA.

Table 2. Energies (kcal/mol) obtained for dopamine-4-N7GUA and dopamine-4-N3ADE and components.

Compounds	Energy (kcal/mol)
Dopamine	-390.15
Adenine	-388.88
Guanine	-460.34
Dopamine-4-N7GUA	-861.98
Dopamine-4-N3ADE	-790.75

Table 3. Thermodynamic parameters of the compounds.

Dopamine-4-N7GUA			Dopamine-4-N3ADE		
ΔE	ΔH	ΔS	ΔE	ΔH	ΔS
-11.49	-12.48	-45.86	-11.92	-13.18	-44.73

Table 4. Hybrid coefficients of bonds calculated by NBO method in HF/6-31G* level

Bond	Dopamine-4-N7GUA	Bond	Dopamine-4-N3ADE
C_1-N_4	σ 0.6012($sp^{2.87}$)C_1 + 0.7991($sp^{1.85}$)N_4	C_1-N_4	σ 0.5973($sp^{2.7}$)C_1 + 0.8020($sp^{1.98}$)N_4
N_4-C_8	σ 0.804 ($sp^{2.04}$)N_4 + 0.5944 ($sp^{2.24}$)C_8	N_4-C_8	σ 0.8054($sp^{2.02}$)N_4 + 0.5927($sp^{2.17}$)C_8
N_4-C_9	σ 0.7919 ($sp^{2.12}$)N_4 + 0.6106 ($sp^{2.5}$)C_9	N_4-C_9	σ 0.799($sp^{1.99}$)N_4 + 0.6013($sp^{2.31}$)C_9
C_5-O_{16}	σ 0.5760 ($sp^{2.86}$)C_5 + 0.8174($sp^{1.8}$)O_{16}	C_5-O_{16}	σ 0.5755($sp^{2.9}$)C_5 + 0.8178($sp^{1.81}$)O_{16}
C_{14}-N_{13}	σ 0.7632($sp^{1.98}$)C_{14} + 0.6462($sp^{2.24}$)N_{13}	N_{13}-C_{22}	σ 0.7678($sp^{1.9}$)N_{13} + 0.6407($sp^{2.37}$)C_{22}
C_8-N_{13}	σ 0.6412($sp^{1.9}$)C_8 + 0.7674 ($sp^{1.18}$)N_{13}	C_8-N_{13}	σ 0.6356($sp^{1.69}$)C_8 + 0.7720($sp^{1.56}$)N_{13}
	π 0.5968 ($sp^{1.0}$)C_8 + 0.8024 ($sp^{1.0}$)N_{13}		π 0.5659($sp^{1.0}$)C_8 + 0.8244($sp^{1.0}$)N_{13}
C_{11}-O_{25}	σ 0.5684($sp^{3.06}$)C_{11} + 0.8227($sp^{1.75}$)O_{25}	C_{11}-O_{25}	σ 0.5685($sp^{3.04}$)C_{11} + 0.8227($sp^{1.77}$)O_{25}
C_{12}-N_{22}	σ 0.6320($sp^{3.18}$)C_{12} + 0.775($sp^{2.11}$)N_{22}	C_{12}-N_{21}	σ 0.634($sp^{3.26}$)C_{12} + 0.7733($sp^{2.16}$)N_{21}
N_{22}-H_{31}	σ 0.8284($sp^{3.08}$)N_{22} + 0.5601(s)H_{31}	C_{14}-N_{23}	σ 0.6556($sp^{2.23}$)C_{14} + 0.7549($sp^{2.1}$)N_{23}
C_{14}-N_{23}	σ 0.6420($sp^{2.12}$)C_{14}+ 0.7667($sp^{1.88}$)N_{23}	N_{23}-C_{14}	σ 0.778($sp^{1.67}$)N_{23} + 0.6283($sp^{1.96}$)C_{24}
			π 0.7896($sp^{1.0}$)N_{23} + 0.6136($sp^{1.0}$)C_{24}
C_{15}-O_{21}	σ 0.5919($sp^{1.93}$)C_{15} + 0.806($sp^{1.28}$)O_{21}	C_9-N_{15}	σ 0.6527($sp^{1.92}$)C_9 + 0.7576($sp^{1.76}$)N_{15}
	π 0.8624($sp^{99.99}$)C_{15}+ 0.5062($sp^{99.99}$)O_{21}		π 0.5802($sp^{1.0}$)C_9 + 0.8145($sp^{1.0}$)N_{15}
C_{15}-N_{24}	σ 0.5950($sp^{2.57}$)C_{15} + 0.8037($sp^{1.8}$)N_{24}	N_{15}-C_{24}	σ 0.7829($sp^{2.06}$)N_{15} + 0.6221($sp^{2.14}$)C_{24}
N_{23}-C_{29}	σ 0.7652($sp^{1.67}$)N_{23} + 0.6438($sp^{1.69}$)C_{29}	C_{22}-N_{29}	σ 0.6317($sp^{2.15}$)C_{22} + 0.7752($sp^{1.54}$)N_{29}
	π 0.5571($sp^{1.0}$)N_{23} + 0.8304($sp^{1.0}$)C_{29}		
N_{24}-C_{29}	σ 0.7916($sp^{1.73}$)N_{24} + 0.611($sp^{2.17}$)C_{29}	N_{29}-H_{34}	σ 0.8494($sp^{2.27}$)N_{29} + 0.5277(s)H_{34}
C_{29}-N_{34}	σ 0.6335($sp^{2.2}$)C_{29} + 0.7738($sp^{1.8}$)N_{34}	N_{29}-H_{35}	σ 0.8461(sp2.34)N_{29} + 0.5331(s)H_{35}

Table 5. The stabilization energy E(2) associated with delocalization for interaction that to give the strongest stabilization in HF/6-3G* level.

Dopamine-4-N3ADE			Dopamine-4-N7GUA		
Donor NBO	Acceptor NBO	E(2) kcal mol^{-1}	Donor NBO	Acceptor NBO	E(2) kcal mol^{-1}
LP(1)N4	BD*(1)C1-N4	0.6332	LP(1)N4	BD*(1)C1-N4	0.6737
	BD*(1)C8-N4	0.7405		BD*(1)N4-C8	0.7769
	BD*(1)C9-N4	0.7390		BD*(1)N4-C9	0.7377
LP(1)N13	BD*(1)C8-N13	0.8709	LP(1)N13	BD*(1)C14-N13	0.8027
	BD*(2)C8-N13	0.1542			
LP(1)N15	BD*(1)C9-N15	0.888	LP(1)O21	BD*(1)O21-C15	0.9568
	BD*(2)C9-N15	0.1637		BD*(2)O21-C15	0.2003
LP(1)O16	BD*(1)C5-O16	0.669	LP(1)O16	BD*(1)C5-O16	0.6698
	BD*(1)O16-H31	0.7709		BD*(1)O16-H28	0.7743
LP(1)N21	BD*(1)C12-N21	0.6191	LP(1)N22	BD*(1)C12-N22	0.6496
	BD*(1)N21-H30	0.7798		BD*(1)N22-H30	0.795
	BD*(1)N21-H31	0.7709		BD*(1)N22-H31	0.7881
LP(1)N23	BD*(1)N23-C24	0.9082	LP(1)N23	BD*(1)N23-C29	0.9143
	BD*(2)N23-C24	0.2053		BD*(2)N23-C29	0.1821
				BD*(1)N23-C14	0.7932
LP(1)O25	BD*(1)O25-H33	0.7421	LP(1)O25	BD*(1)O25-H33	0.7497
	BD*(1)C11-O25	0.6368			
LP(1)N29	BD*(1)N29-H34	0.7818	LP(1)N24	BD*(1)N24-C29	0.728
	BD*(1)N29-H35	0.7695		BD*(1)N24-H32	0.745
				BD*(1)N24-C15	0.6851
			LP(1)N34	BD*(1)N34-H35	0.7709
				BD*(1)N34-H36	0.7507
				BD*(1)N34-C29	0.7245

With using the Gaussian 98 program, we first optimized adducts with HF/6-31G* level. Then, we calculated isotropic spectroscopic shielding for all atoms. We use both the GIAO method and CSGT procedure, which is implemented in the Gassian 98 program.

Ab initio calculations yield the data in Tables 6 and 7 shown the values for the isotropic shielding, chemical shifts anisotropy and chemical shifts anisotropy asymmetry and effective anisotropy. In Table 8 were compared NMR spectrum of adducts and free dopamine. GIAO method is better procedure because the data agree with experimental results [20]. For **d**opamine-4-N3ADE, the 2-H and 8-H of bound adenine were observed at 8.27, 8.49 ppm (8.02, 8.40 ppm in exp.), respectively. Two singlets at 6.52, 7.15 ppm (6.80, 6.86 ppm in exp.) were assigned to aromatic protons. For dopamine-4-N7GUA, 8-H guanine were observed at 8.153 ppm (8.15 ppm in exp.) and peaks at 6.68, 7.64 ppm (6.76, 6.70 ppm in exp.) were assigned to aromatic protons. Also analysis of the atomic charges is done by the natural bonding orbital (NBO) method. Natural charge, valence, rydberg, total of some of atoms were reported in Table 9.

Table 6A. Isotropic shift, relative (to TMS) shifts in ppm for ^{13}C and ^{1}H NMR of dopamine-4-N3ADE using GIAO method at HF/6-31G*.

Atom	(GIAO)				
	Isotropic shift	$\Delta\delta$	S_{ISO}TMS -S_{iso} atom	$\Delta\sigma_{eff}$	$\Delta\eta$
1	67.9201	0.564268	133.7944	147.8121	-0.96318
2	83.2211	0.1935	118.4933	175.28	-0.2349
3	79.9888	0.661887	121.7256	145.2058	0.450758
4	111.813				
5	62.8689	0.554737	138.8455	134.2857	9.249687
6	91.9804	1.429729	109.7344	119.2645	-0.71417
7	158.859	-45.1989	42.8549	15.03335	-4.9297
8	47.3077	0.061568	154.4067	137.1771	1.322572
9	48.1856	0.013137	183.5288	145.8753	-1.04595
10	24.6300	-3.84618	8.2700	22.46747	-0.85301
11	62.6648	0.505634	139.0496	141.6432	-0.96251
12	159.898	-27.0698	41.8165	41.47948	-2.80022
13	49.0769				
14	89.2958	1.939713	112.4186	92.46519	-0.45907
15	25.4171				
16	279.164				
17	26.3807	-10.5897	6.5253	8.548782	1.759601
18	29.2000	-4.70179	3.7012	23.80678	-1.02847
19	29.4738	42.31834	3.4322	3.069568	-1.32096
20	24.9400	-3.11175	7.1500	27.56672	-0.999
21	244.529				
22	49.2141	-0.01666	152.5003	154.1248	-0.57298
23	21.8478				
24	47.4833	0.249452	154.2311	118.7056	2.017666
25	275.957				
26	30.0271	-11	2.8970	9.032626	-0.22762
27	29.8631	33.13712	3.0430	6.512748	-1.59466
28	28.5855	-5.93577	4.3205	18.9771	-0.86421
29	204.241				
30	32.4138	-38.6051	0.4922	5.965179	-2.76897
31	32.7942	-9.04884	0.1118	13.08319	-0.79595
32	24.4868	-12.1866	8.492	6.632466	0.650281
33	29.5721	-7.18656	3.3339	14.70076	-0.56208
34	27.6561	-7.21645	5.2499	13.86662	-0.65613
35	28.5732	-9.0514	4.3328	12.14536	38.69782

Table 6B. Isotropic shift, Relative (to TMS) shifts in ppm for ^{13}C and ^{1}H NMR of dopamine-4-N3ADE using CSGT method at HF/6-31G*.

Atom	(CSGT)				
	Isotropic shift	$\Delta\delta$	$S_{ISO}TMS - S_{iso}$ atom	$\Delta\sigma_{eff}$	$\Delta\eta$
1	62.1291	0.436286	135.2909	145.5382	-0.93583
2	76.8868	0.51466	120.5332	153.6531	0.606401
3	76.074	0.551091	121.346	147.6213	0.327553
4	99.5601				
5	54.5573	0.37477	142.8627	132.7728	11.80409
6	85.4387	1.158644	111.9813	125.1993	-0.73342
7	160.3004	-25.5682	37.1196	22.88492	-42.7031
8	40.3431	-0.10771	157.0769	139.8805	1.549275
9	39.6281	-0.18894	157.7919	150.0614	-0.55052
10	21.52	-3.81635	8.27	23.35671	-0.50864
11	53.793	0.291525	143.627	142.6893	-0.97702
12	159.1479	-31.4362	38.2721	40.18893	-2.64821
13	37.2943				
14	80.1104	1.589884	117.2789	94.03575	-0.43734
15	18.1601				
16	247.6236				
17	26.4905	-12.3299	3.2995	7.266117	1.761644
18	268900	-5.21995	2.900	20.48972	-0.89705
19	27.8166	61.19486	1.9734	1.343305	-0.15626
20	20.6341	-3.6469	9.1559	24.87413	-0.77113
21	225.354				
22	41.5791	-0.15869	155.8409	153.586	-0.63772
23	12.476				
24	39.1853	0.046539	158.2347	117.1895	2.124196
25	247.6539				
26	28.3731	-13.7905	1.4169	6.659066	-0.11485
27	27.7585	188.8014	2.0315	3.764294	-1.87305
28	29.541	-6.38137	0.249	17.78053	-0.82698
29	187.5085				
30	30.5455	-54.4524	-0.7555	2.547333	-4.21239
31	30.8463	-10.3307	-1.0563	11.28937	-0.97009
32	25.2574	-11.8687	4.5326	7.012685	-0.31778
33	30.335	-7.97436	-0.545	13.13902	-0.33938
34	26.9903	-7.20802	2.7997	13.08357	-0.24067
35	27.9797	-9.27999	1.8103	11.52166	28.97388

Table 7A. Isotropic shift, relative (to TMS) shifts in ppm for ^{13}C and ^{1}H NMR of dopamine-4-N7GUA using GIAO method at HF/6-31G*.

Atom	(GIAO)				
	Isotropic shift	$\Delta\delta$	$S_{ISO}TS - S_{iso}$ atom	$\Delta\sigma_{eff}$	$\Delta\eta$
1	75.634	1.357336	126.0804	127.5941	-1.2023
2	83.0563	1.04713	118.6581	129.4813	3.383343
3	70.4657	0.424588	131.2487	149.9166	0.662907
4	123.1673				
5	63.4715	0.773994	138.2429	115.9215	4.813277
6	89.3677	1.331071	112.3467	119.4196	1.876268
7	170.7729	-92.2833	30.9415	18.68516	-2.44441
8	54.95	-2.65677	146.7644	119.6774	-14.6904
9	96.5176	-6.55937	105.1968	90.71493	-3.36058
10	24.7533	-13.7824	8.1527	6.383927	-0.74117
11	62.6937	0.749469	139.0207	118.7749	-0.89716
12	161.7944	-31.2451	39.92	24.66419	-3.95818
13	23.3924				
14	12.0252	-3.26809	159.6892	134.8131	-2.70746
15	50.5408	-23.3479	151.1736	113.665	-2.07152
16	283.5574				
17	26.2208	-12.5056	6.6852	7.344846	-0.80951
18	31.1329	-24.44	1.7731	5.288498	-5.91064
19	30.4426	-45.3607	2.4634	2.079699	0.65969
20	25.2674	13.25923	7.6386	6.070545	42.41228
21	37.3373				
22	248.1331				
23	89.5918				
24	136.1288				
25	280.3466				
26	30.5894	-33.3271	2.3168	2.900899	-0.53381
27	24.7815	-32.8651	2.7314	5.785458	-2.96495
28	23.9671	-7.07594	4.3159	16.00656	-0.96151
29	51.8592	20.87919	149.8552	136.3059	-1.94144
30	32.8852	83.71213	0.0208	9.276725	-1.86385
31	33.4753	-15.3446	-0.5693	8.528839	-1.093
32	26.7964	18.55867	6.1096	8.701301	-2.89613
33	29.6285	-7.70931	3.2775	13.95766	2.70116
34	212.4515				
35	29.6015	91.36053	3.3044	10.74554	-2.10943
36	30.3671	11.39343	2.5389	9.450513	-7.00685

Table 7B. Isotropic shift, relative (to TMS) shifts in ppm for ^{13}C and ^{1}H NMR of dopamine-4-N7GUA using CSGT method at HF/6-31G*.

Atom	(CSGT)				
	Isotropic shift	Δδ	S_{ISO}TMS -S_{iso} atom	$\Delta\sigma_{eff}$	Δη
1	69.9171	1.165022	127.5029	126.5824	-1.18583
2	76.8176	0.852849	120.6024	131.8645	3.127599
3	66.3407	0.344818	131.0793	148.9767	0.500449
4	113.9537				
5	55.0731	0.559368	142.3469	115.0111	5.44508
6	82.4940	1.066061	114.926	124.3731	1.875875
7	170.8004	-74.1495	26.6196	19.92909	-2.55349
8	47.5840	-2.39669	149.836	122.5649	-15.6679
9	86.9112	-6.36756	110.5088	93.39286	-3.0845
10	23.7701	-14.4219	6.0199	6.34966	-0.8911
11	53.2537	0.068117	144.1663	125.2815	-0.46309
12	160.4955	-38.0061	36.9245	23.69116	-3.22274
13	11.2174				
14	34.6508	-2.8271	162.7692	133.6083	-2.74621
15	42.8459	-25.4925	154.5741	111.6287	-2.05587
16	251.7234				
17	26.1105	-14.9935	3.6795	6.76408	-1.08043
18	29.1423	-27.9836	0.6477	4.923178	-4.03754
19	28.4990	-76.1556	1.291	1.978526	-1.42274
20	25.8375	13.72938	3.9525	5.986864	31.12748
21	28.8837				
22	228.2572				
23	78.1164				
24	126.3327				
25	251.1764				
26	28.4875	-32.0966	1.3025	2.785014	-0.44219
27	28.0199	-28.7687	1.771	4.628501	-3.99378
28	29.4395	-7.5822	0.3505	14.91651	-0.91373
29	43.2344	33.38834	154.1856	6.463606	-1.58175
30	30.8515	-18.8099	-1.0615	5.87881	-0.93271
31	31.1594	21.86034	-1.3694	8.778138	-2.69368
32	27.2462	-8.50778	2.5438	13.0948	5.333941
33	30.2155	31.12002	-0.4255	8.454807	-2.48275
34	195.0885				
35	28.8904	12.3711	0.8996	8.038021	-12.2249
36	29.4839	10.55211	0.3061	141.2191	-1.91196

Table 8. Isotropic shift, relative (to TMS) shifts in ppm for ^{1}H NMR of using GIAO and CSGT method at HF/6-31G* adducts and free dopamine.

Atom	Dopamine-4-N7GUA			Atom	Dopamine-4-N3ADE			Atom	Dopamine	
	GIAO	CSGT	Exp.		GIAO	CSGT	Exp.		GIAO	CSGT
10	8.153	6.02	8.15	10	8.27	13.32	8.05	—	—	—
17	6.68	3.679	6.76	17	6.52	3.30	6.86	17	7.06	4.21
18	1.77	0.648	2.45	18	3.70	2.90	2.40	18	2.296	1.19
19	2.46	1.29	—	19	3.43	1.97	—	19	2.716	1.60
20	7.64	3.95	6.70	20	7.15	9.15	6.80	20	6.609	3.61
26	2.32	1.30	2.75	26	2.88	1.41	2.82	26	2.440	1.60
27	2.73	1.77	—	27	3.04	2.03	—	27	2.626	1.90
				32	8.49	4.53	8.40			

Table 9. Natural charge, valence, Rydberg and total of some of atoms.

Atom	Dopamine-4-N7GUA				Atom	Dopamine-4-N3ADE			
	Charge	Valence	Rydberg	Total		Charge	Valence	Rydberg	Total
N4	-0.4602	5.4416	0.0194	7.4602	N4	-0.4777	5.4625	0.0153	7.4769
N13	-0.5749	5.5489	0.0259	7.5742	N13	-0.6427	5.6561	0.0256	6.6061
O16	-0.7497	6.7324	0.1760	8.7497	N15	-0.6803	4.0360	0.0245	7.6803
O21	-0.7188	6.6976	0.0215	8.7188	O16	-0.7481	6.7308	0.0176	8.748
N22	-0.9195	5.9003	0.0196	7.9195	N21	-0.9201	5.9011	0.0193	7.9201
N23	-0.6441	5.6201	0.0246	7.6440	N23	-0.5811	5.5574	0.0242	7.5810
N24	-0.7346	5.7212	0.0142	7.7346	O25	-0.7662	6.7502	0.0162	8.7662
O25	-0.7692	6.7532	0.0162	8.7692	C1	0.1624	3.8145	0.0242	5.8376
N34	-0.8961	5.8786	0.0180	7.8961	C7	-0.3781	4.3604	0.0185	6.3781
C1	1.3853	3.8368	0.0259	5.8615					
C7	-0.2455	4.2269	0.0197	6.4473					

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