MOLECULAR ORBITAL AND DFT STUDIES OF THE ALIMEMAZINE RADICAL CATION

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Abstract—Semiempirical molecular orbital methods including CNDO, MNDO, AM1 and PM3, and density function theory method B3LYP/3-21G(d) were employed in the study of the alimemazine radical cation. It was found that PM3 was much better than CNDO, MNDO and AM1 in the structural optimization. The bond lengths and bond angles by PM3 were close to the experimental data, and comparable with the results by the density function theory method.

INTRODUCTION

Phenothiazine and its derivatives are important bio-active molecules [1] which have been widely used as dyestuffs, antioxidants, sedative drugs, solar energy storage materials, and especially medicines for nervous illnesses [2-5]. They are easily oxidized to the corresponding radical cations which are relatively stable [4]. The interesting chemical and pharmaceutical properties of phenothiazines are believed to relate with their radical cations, whose formations and reactions have subjected to extensive studies [6-10].

Structural studies of the phenothiazine radical cations are obviously important for understanding their chemical and pharmaceutical properties. These studies are also interesting because it has been indicated that the conformations of phenothiazines could exert unexpected influences on their chemical reactivities [11-12]. Though the geometry of a few phenothiazine derivatives has been determined experimentally [13-15], the structures of many others are still unknown.

Theoretical studies provide an alternative approach for the conformation analysis of the phenothiazine radical cations. Recently, semiempirical molecular orbital method INDO was successfully applied to the structural and property studies of several phenothiazine derivatives [16-17]. Herein, the structure and properties of the alimemazine radical cation were investigated with different levels of semiempirical quantum mechanism methods and density function theory (DFT)

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method.

METHODS

All the calculations were performed with GAUSSIAN 98 software package [18]. The initial geometry of the alimemazine radical cation was constructed with the help of MOLDEN. Full geometry optimization is performed with CNDO, MNDO, AM1, and PM3 semiempirical molecular orbital methods, using the Berny analytical gradient algorithm. In comparison, the DFT method B3LYP/3-21G(d) was also used to optimize the structure, using the spin-unrestricted Hartree-Fock approximation.

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15
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13
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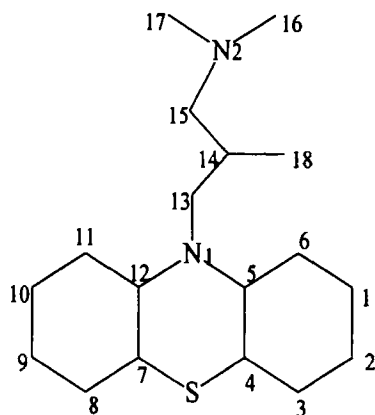
RESULTS AND DISCUSSION

Different levels of semiempirical molecular orbital methods including CNDO, MNDO, AM1, and PM3 were applied to the geometry optimization of the alimemazine radical cation. The bond lengths and bond angles obtained were summarized in Tables 1 and 2. Comparison of the calculated results with the experimental data indicated that the CNDO method performed very poorly in the optimization, especially that of the bond angles. In comparison, MNDO offered substantially better results. However, AM1 and PM3 provided further better results, which were nearly within the experimental errors. The standard deviation in bond lengths obtained by PM3 was 0.023 Å, which was comparable to the errors by DFT calculation (0.025 Å) with medium-sized bases. The standard deviation in bond angles by PM3 was 1.38 deg, which was even smaller than that by DFT calculation (2.01 deg).

The PM3 and B3LYP/3-21G(d) methods were also performed to optimize the

Table 1

The experimental and theoretical bond lengths of the alimemazine radical cation (Å).

Bond Length	Exp.[13]	CNDO	MNDO	AM1	PM3	B3LYP/ 3-21G(d)
C4-S	1.709(11)	1.899	1.674	1.665	1.726	1.734
C5-N1	1.398(9)	1.406	1.409	1.393	1.415	1.404
C13-N1	1.470(10)	1.425	1.514	1.471	1.493	1.506
C1-C6	1.405(15)	1.380	1.405	1.383	1.380	1.382
C3-C4	1.406(13)	1.431	1.423	1.407	1.408	1.408
C5-C6	1.394(16)	1.394	1.441	1.435	1.424	1.419
C7-C12	1.401(11)	1.416	1.445	1.428	1.419	1.424
C9-C10	1.375(14)	1.389	1.419	1.406	1.403	1.405
C10-C11	1.370(16)	1.382	1.405	1.383	1.380	1.383
C11-C12	1.406(10)	1.392	1.442	1.435	1.423	1.420
C13-C14	1.536(9)	1.482	1.561	1.537	1.543	1.555
C14-C15	1.510(13)	1.485	1.572	1.544	1.541	1.549
C14-C18	1.522(23)	1.473	1.546	1.512	1.521	1.541
C15-N2	1.509(8)	1.440	1.471	1.455	1.494	1.491
N2-C16	1.486(14)	1.416	1.472	1.448	1.481	1.491
N2-C17	1.467(13)	1.414	1.472	1.448	1.481	1.491
S-C7	1.710(7)	1.899	1.674	1.664	1.726	1.735
N1-C2	1.392(11)	1.406	1.406	1.394	1.415	1.407
C1-C2	1.357(19)	1.399	1.419	1.406	1.404	1.405
C2-C3	1.336(21)	1.383	1.410	1.388	1.384	1.381
C4-C5	1.395(11)	1.417	1.443	1.428	1.419	1.425
C7-C8	1.408(15)	1.430	1.422	1.407	1.407	1.408
C8-C9	1.358(14)	1.384	1.410	1.388	1.385	1.382
Standard Deviation	0.014	0.067	0.039	0.032	0.023	0.025

geometry of the neutral alimemazine. The DFT calculations showed that the energies of the alimemazine and its radical cation were -3.148814×10^6 and -3.148522×10^6 kJ/mol, respectively. The dihedral angle between the two aryl planes of the alimemazine radical cation is 176.5 deg, while this angle of the neutral alimemazine is calculated to be 155.3 deg. It indicates that the π-delocalization plays a more important role in the alimemazine radical cation than in the neutral form. The results

Table 2

The experimental and theoretical bond angles of the alimemazine radical cation (deg).

Bond Angle	Exp.[13]	CNDO	MNDO	AM1	PM3	B3LYP/ 3-21G(d)
C4-S-C7	102.6(4)	46.1	103.5	104.2	101.6	103.1
C5-N1-C13	117.4(6)	119.9	119.6	119.6	119.2	124.4
C2-C1-C6	120.9(12)	121.7	120.7	121.0	120.5	120.8
C2-C3-C4	121.4(11)	118.1	120.9	121.0	121.1	120.8
C3-C4-C5	120.0(8)	119.8	119.6	120.7	120.0	121.0
N1-C5-C4	123.3(7)	110.6	120.3	122.0	122.0	122.3
N1-C5-C6	120.4(8)	128.8	121.3	121.1	120.2	121.2
S-C7-C12	124.2(6)	172.7	122.8	124.0	125.1	123.7
C8-C7-C12	121.0(7)	119.7	119.7	120.6	119.9	120.9
C8-C9-C10	118.7(9)	121.2	119.6	119.3	119.5	119.2
C10-C11-C12	121.8(8)	118.9	120.6	121.0	121.1	121.0
N1-C13-C14	115.1(7)	115.4	113.6	115.3	112.8	114.1
C13-C14-C15	110.6(7)	111.7	111.1	108.4	109.7	106.5
C14-C15-N2	113.6(6)	114.4	112.4	113.1	110.5	110.5
C15-N2-C16	110.6(7)	108.3	115.7	113.6	112.9	111.3
C12-N1-C13	119.8(6)	119.6	120.0	117.7	118.0	116.2
C5-N1-C12	122.7(6)	106.7	120.4	122.7	122.9	124.4
C1-C2-C3	119.5(10)	121.1	119.7	119.3	119.5	119.1
S-C4-C3	114.9(7)	67.5	117.7	115.1	114.9	115.2
S-C4-C5	124.1(6)	172.6	122.7	124.2	125.2	123.9
C4-C5-C6	116.3(7)	120.3	118.4	116.9	117.8	116.5
C1-C6-C5	121.0(10)	119.0	120.5	121.2	121.3	121.8
S-C7-C8	114.8(6)	67.6	117.5	115.3	115.0	115.4
C7-C8-C9	121.0(9)	118.1	121.0	120.9	121.0	120.6
C9-C10-C11	121.5(9)	121.7	120.7	121.1	120.5	121.2
C7-C12-C11	116.0(7)	120.5	118.3	117.1	117.9	117.2
N1-C12-C7	123.0(6)	110.7	120.3	122.2	122.1	122.5
C13-C14-C18	108.9(9)	110.8	113.2	112.4	110.8	112.4
C15-C14-C18	112.4(9)	112.3	109.9	108.8	109.4	110.8
C15-N2-C17	113.7(7)	109.5	115.9	112.9	113.1	111.3
C16-N2-C17	111.6(8)	102.5	114.3	112.7	112.7	110.5
Standard Deviation	0.8	20.98	2.07	1.41	1.38	2.01

could explain why the bio-active phenothiazine derivatives were almost in their radical cation forms.

In summary, the geometry optimization of the alimemazine radical cation by PM3 method was as good as that by the DFT method. However, taking account of the high CPU cost of the DFT calculation for these kinds of radical cations [19-20], PM3 was an efficient and reliable theoretical tool [21-23] for calculating the phenothiazine radical cation systems.

According to the above results, PM3 was applied to the analysis of the charge distributions (Figure 1) and spin density distributions (Figure 2) of the alimemazine radical cation. The results indicated that the positive charge and the spin were mainly distributed on N and S atoms. Therefore, the π-electron delocalization of the alimemazine radical cation lowered the energy of the system, and stabilized the radical cation.

Figure 1. The charge distributions of the alimemazine radical cation.

CONCLUSIONS

Semiempirical molecular orbital methods including CNDO, MNDO, AM1 and PM3, and density function theory method B3LYP/3-21G(d) were applied to the structural study of alimemazine and its radical cation. It was found that PM3 could predict the
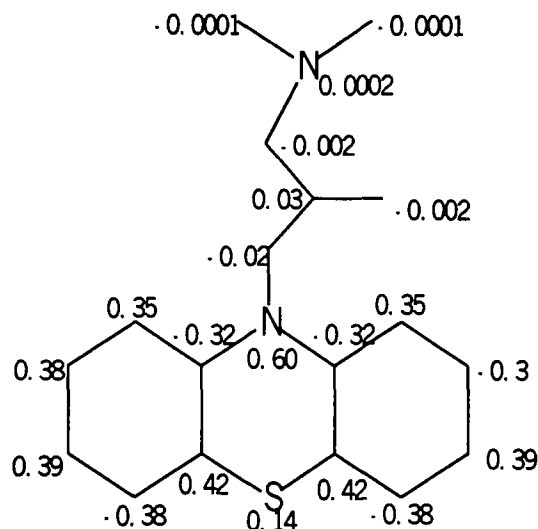
Figure 2. The spin distributions of the alimemazine radical cation.

structure correctly within the experimental error and comparable to that obtained by density function theory calculation. Hence, PM3 is an efficient and reliable theoretical tool for calculation of phenothiazine radical cations. The calculation also indicates that the π-delocalization plays an important role in stabilization of the alimemazine radical cation.

Acknowledgment

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