

Electronic Spectral Study of Barbituric and Thiobarbituric Acid with Molecular Orbital Calculations

A.A.HASANEIN, M.S.MASOUD AND A.M.HEIBA
*Department of Chemistry, Faculty of Science,
Alexandria University, Alexandria, Egypt.*

[Received 25th March, 1985, revised 1st Jan. 1986]

Summary: The electronic spectra of barbituric acid (BA) and thiobarbituric acid (TBA) in different solvents have been analyzed using the multiple linear regression technique to relate the shift in peak locations to some solvent polarity parameters. The PPP method has been used to study the tautomerism and calculate the different singlet-singlet electronic transitions in these molecules.

Introduction

Different solvent dependent phenomena have been extensively investigated [1-2] where various mechanisms for the solute-solvent interactions have been proposed. Many empirical solvent polarity parameters have been also introduced and have had varying degrees of success correlating solvent-dependent data. The spectra calculated by the LCAO-SCF-MO method using the π -electron dipole moments for the excited singlet states, molecular radii and McRae formulae [1] for solvent effects were found [8] to be in good agreement with the observed spectra.

Barbituric acid and its derivatives are used extensively in medical and biological studies and it is important to understand the relationship between their chemical structure and their pharmacological activities. No indication of the presence of two tautomeric forms (lactam \rightleftharpoons lactim) could be seen in the p.m.r. spectra of the free barbituric acid [13]. However, a very thorough experimental study of the near ultraviolet chiroptical properties of barbituric acid derivatives in a number of solvents has

been recently given by Carroll and Sobti [14], where considerable structural information about species in solution has been reported. On the other hand, molecular orbital calculations of the electronic structure and spectra of different substituted barbituric acid derivatives have been performed [15,16]. Using the semiempirical PCILO method and assuming that the trioxopyrimidine system is planar the total energy and net atomic charges were calculated [15] as a function of conformational variables characteristic of the substituent stereochemistry. Also, spectra-structure relationships for some alkyl substituted barbituric acids have been examined [16] using the CNDO/S-CI method.

In the present work the electronic spectra of barbituric and thiobarbituric acids have been investigated in different solvents. Changes in peak locations of the electronic transitions have been analyzed in relation to different empirical solvent polarity parameters. The PPP calculated tautomeric equilibria and singlet-singlet electronic transitions for both systems are reported.

Experimental

A Pye Unicam SP 1750 spectrophotometer was used. Barbituric and thiobarbituric acids were obtained as reagent grade materials and the solvents used were spectroquality.

Methods of Calculations

a) Data Analysis:

We suppose that ν_{\max} of an electronic transition in a given solvent, the dependent variable Y, may be expressed as a function of different solvent polarity parameters, the independent variables X_1, X_2, X_3, \dots , as follows:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + \dots (1)$$

The constants a_1, a_2, a_3, \dots , are the different regression coefficients and a_0 the regression intercept will be considered as the peak position of the band in the gaseous state [12].

A comprehensive study [7] of the empirical solvent polarity parameters covering spectroscopic, rate and equilibrium data has shown that the most generally successful treatment is that which combines Dimroth's E values [5,6] with dielectric and index of refraction functions. Thus we have selected the independent variables to be the solvent interaction mechanisms E, M and N [7]. The empirical solvent polarity parameter E is sensitive to both solvent-solute hydrogen bonding and to dipolar interactions [5-7]. The parameter M is a measure of the solute permanent dipole-solvent induced dipole interactions [1,7] defined as follows:

$$M = \frac{n^2 - 1}{2n^2 + 1}$$

where n is the solvent refractive index. The parameter N is a measure of the permanent dipole-permanent dipole interactions [1,7] given the following expression

$$N = \frac{d - 1}{d + 2} - \frac{n^2 - 1}{n^2 + 2}$$

The intercept a_0 and the coefficients a_1, a_2, a_3, \dots have been calculated by multiple linear regression analysis using a Fortran IV program [17]. The program utilizes the Gauss-elimination method to solve the sets of multilinear equations using standard matrix methods.

b) MO Calculations:

The tautomeric equilibria and different singlet-singlet electronic transitions in BA and TBA have been calculated using the PPP method [18,19] with CI including only singly excited configurations. The different parameters namely; VSIP's, one-center electron repulsion integrals and the one-electron two-center integrals have been assigned their well known standard values [20,21]. The Mataga-Nishimoto approximation [22] was used for the two-center electron repulsion integrals. Calculations have been done on a PDP 11/70 computer using a Fortran IV program [23] and using standard bondlengths and angles [24].

Results and Discussion

a) Spectral Analysis:

The electronic spectra of BA in different solvents are reported in Table 1. A reasonably accurate description of the electronic transitions in BA and some of its 5-substituted derivatives has been reported before. Carroll and Sobti [14] have shown that the circular dichroism spectra of these

Table-1: Observed ν_{\max} values for BA and TBA in different solvents.

E(b)	BA			TBA		
	M	N	$\nu_{\max} (\times 10^{-15} \text{ sec}^{-1})$	M	N	$\nu_{\max} (\times 10^{-15} \text{ sec}^{-1})$
CCl ₄	0.22	0.01	0.96707(0.95538)	1.16198(1.1564)	-	-
1,4-Dioxane	0.20	0.03	0.90846(0.92061)	1.17565(1.1834)	1.33241	0.89490
Acetone	0.18	0.65	-	-	1.04457 (1.0341)	1.24913
DMF	0.20	0.67	0.96707(0.97925)	1.11863(1.1492)	0.90846	1.13129
DMSO	0.22	0.66	-	1.14424(1.0344)	1.03376 (1.0362)	1.13989
MeCN	0.18	0.71	0.96707(0.95631)	1.17565(1.1709)	1.04457 (1.0423)	1.29221
Acetic Acid	0.19	0.41	0.88174(0.87986)	-	1.05933(1.0388)	-
Ethanol	0.18	0.67	-	1.22364(1.1908)	1.04457 (1.0636)	1.12704
Water	0.17	0.76	-	1.20884(1.2236)	1.05933 (1.0566)	1.24913
					1.09015 (1.0841)	1.13989
					1.09015 (1.0841)	1.24913
						1.49896

(a) Values in parentheses are the estimates of ν_{\max} ($\times 10^{15} \text{ sec}^{-1}$) calculated using the E, M & N fit. (b) KCal/mole.

Table-2: The calculated regression coefficients for different fits (a);

	BA			TBA		
	First n $\rightarrow \pi$ band	Second n $\rightarrow \pi$ band		Second n $\rightarrow \pi$ band		*
	E only	E and M	E and N	E only	E and M	E, M and N
a ₀	1.01941	1.13743	0.99361	1.08513	1.40740	1.27616
a ₁	-0.00194	-0.00265	-0.00648	0.00193	0.00007	0.00278
a ₂	-	-0.44626	0.77534	-	-1.21535	-0.95158
a ₃	-	-	0.17057	-	-	-0.08731
MCC(c)	0.361	0.374	0.957	0.541	0.687	0.828
				0.541	0.687	0.828
				0.749	0.752	0.797
				0.94647	0.91815	0.91033
				0.00215	0.00228	0.00281
				-	0.11638	0.11837
				-	-	-0.03086

(a) All values are multiplied by 10^{-15} . (c) The multiple correlation coefficient.

(b) The longest wavelength n $\rightarrow \pi$ transition.

compounds exhibit three CD bands centered around 260, 240 and 212 nm. Solvent studies indicated that the 260 and 240 nm bands arise from $n \rightarrow \pi^*$ transitions while that centered at 212 nm arise from a $\pi \rightarrow \pi^*$ transition, since the 260 and 240 nm bands were observed to undergo red shifts on changing from polar to less polar solvents while the CD band at 212 nm was blue shifted. On the other hand Yeh and Richardson [16] have performed CNDO/S-CI molecular orbital calculations on these systems and have indicated that three $n \rightarrow \pi^*$ transitions contribute to the absorption and CD spectra of BA derivatives in the near ultraviolet region $\lambda > 220$ nm. Two of these transitions were predicted to be nearly degenerate, thus, giving rise to one CD band. Each of these three lowest energy $n \rightarrow \pi^*$ transitions involves some charge-transfer character insofar as electron density is shifted out of localized oxygen 2p(n) orbitals into molecular orbitals which are somewhat delocalized over all the three carbonyl groups of the trioxopyrimidine moiety.

As clear from table 1, the spectra of BA exhibit four bands. In 1,4-dioxane as the solvent three bands with λ_{\max} located at 330, 255 and 225 nm are observed ($\nu_{\max} = 0.90846 \times 10^{15}$, 1.17565×10^{15} and $1.33241 \times 10^{15} \text{ sec}^{-1}$ respectively). In view of previous findings [14,16] these bands can be assigned as $n \rightarrow \pi^*$ transitions. The $\pi \rightarrow \pi^*$ transition appeared with λ_{\max} at 212 nm ($\nu_{\max} = 1.41411 \times 10^{15} \text{ sec}^{-1}$) in ethanol and 195 nm ($\nu_{\max} = 1.53739 \times 10^{15} \text{ sec}^{-1}$) in water. The absorption intensities of these bands are moderately high except for the longest wavelength $n \rightarrow \pi^*$ transition which is broad and of weak absorption intensity.

The spectra of TBA in different solvents are also given in Table 1.

Three $n \rightarrow \pi^*$ transitions are also observed in 1,4-dioxane with λ_{\max} located at 335, 287 and 240 nm ($\nu_{\max} = 0.89490 \times 10^{15}$, 1.04457×10^{15} and $1.24913 \times 10^{15} \text{ sec}^{-1}$ respectively). The $\pi \rightarrow \pi^*$ transition appeared also with λ_{\max} at 205 nm ($\nu_{\max} = 1.46240 \times 10^{15} \text{ sec}^{-1}$) in ethanol and at 200 nm ($\nu_{\max} = 1.49896 \times 10^{15} \text{ sec}^{-1}$) in water. Since these $n \rightarrow \pi^*$ transitions involve excitations from 3p(n) orbitals into π^* molecular orbitals with some charge transfer character [16], this may explain why these transitions are centered around longer wavelengths compared with those observed for BA. The 3p(n) electrons of sulphur are more weakly bound than those of oxygen and their excitation will in general require less energy.

The solvent induced spectral shifts observed for BA and TBA have been analyzed using the multiple linear regression technique. In each case fits are obtained as a function of the parameter E alone, the parameters E and M and then the E, M and N parameters. As an indication of the fit the sum of the squared residuals is calculated for each case. As it is clear from Table 2, the values of the multiple correlation coefficient indicate that the experimental data are best fitted when taking the dependence on the three parameters E, M and N, and an appreciable dependence of the solvent spectral shifts on the solute-solvent hydrogen bonding is shown by the fit using E alone. However, the calculated estimates of ν_{\max} given in table 2 are showing deviations from the observed values. This may indicate that the assumption that Dimroth's E values [5-7] are sensitive to only

dipolar and hydrogen bonding interactions is probably not valid and other interactions such as dispersion forces are probably operative. Also, this may reveal that the multiple correlation coefficient alone is not a reliable measure for the quality of the regression analysis.

According to McRae [1] the solvent induced shift $\Delta\nu$ in an absorption transition is expressed as:

$$\Delta\nu = (\text{dispersion term}) + \frac{1}{hc} \frac{(\mu_g^2 - \mu_e^2)}{a^3} \frac{n^2 - 1}{2n^2 + 1} + \frac{2}{hc} \frac{\mu_g(\mu_g - \mu_e)}{a^3} \left| \frac{d-1}{d+2} \frac{n^2 - 1}{n^2 + 2} \right| \quad (4)$$

where h is the Planck's constant, c is the velocity of light μ_g and μ_e are the dipole moments in the ground and excited states, respectively, and a denotes the cavity radius. Comparing the linear regression approach eqns. (1), (2) and (3) with the McRae theoretical model eqn. (4), the coefficient a_0 can be considered as the peak location in the gas phase spectrum and the coefficients a_2 and a_3 can be expressed as follows:

$$a_3 = \frac{1}{hc} \frac{\mu_g^2 - \mu_e^2}{a^3} \quad (5)$$

$$a_3 = \frac{2}{hc} \frac{\mu_g(\mu_g - \mu_e)}{a^3} \quad (6)$$

and we can write

$$\frac{\mu_e}{\mu_g} = \frac{2 a_2}{a_3} - 1 \quad (7)$$

From eqn. (7) $\mu_e = 8.09 \mu_g$ for the longest wavelength $n \rightarrow \pi^*$ transition in BA, $\mu_e = 20.80 \mu_g$ for the second

$n \rightarrow \pi^*$ transition in BA and $\mu_e = -8.67 \mu_g$ for the second $n \rightarrow \pi^*$ transition in TBA. This indicates that these excitations are accompanied by an increase in dipole moment which reflects the charge transfer characters of these transitions leading to highly polar excited states.

b) MO Calculations:

It is well known that both BA or TBA can exist in different tautomers [13]. These molecules are assumed to tautomeric structures are considered (Fig. 1). The PPP calculated ground state properties and different singlet-singlet electronic transitions for BA and TBA with configuration interactions calculations including only singly excited configurations are reported in tables 3 and 4, respectively.

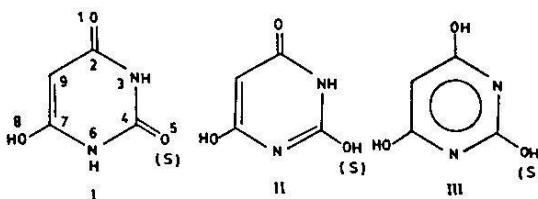


Fig. 1

Keeping in mind that energy changes of the molecular sigma skeleton is of considerable importance in tautomeric equilibria calculations, inspection of the PPP calculated π -binding energies for the different tautomers of BA given in table 3 show that tautomer I is the most stable one having a binding energy of -597.699 eV and a dipole moment of 10.33 debyes. The calculated charges of atoms show that the carbonyl oxygen has a negative charge while the hydroxyl oxygen has a positive charge as expected. The calculated three lowest energy singlet-singlet transitions for tautomer I (4.14, 5.27 and 6.02 eV) are in a

reasonable agreement with those observed in 1,4-dioxane as solvent (3.76, 4.86 and 5.51 eV). For TBA tautomer I is also found to be the most stable with a calculated binding energy of -564.801 eV and a dipole moment of 6.53 debyes. The trend of the calculated atomic charges is somewhat different from that found in case of BA. The charge on the sulfur atom is slightly positive and not negative as in the case of the BA oxygen. Such different electronic charge distributions leads to the difference in calculated dipole moments of BA and TBA as expected. The calculated three

lowest energy singlet-singlet transitions for tautomer I of TBA (3.94, 5.08 and 5.77 eV) are in a reasonable agreement with those observed in 1,4-dioxane as the solvent (3.70, 4.32 and 5.17 eV). However, the difference between the calculated and observed transition energies may be attributed mainly due to the fact that calculations do not take into considerations the different solute-solvent interactions taking place in solution.

A comparison between the calculated regression intercept a_0 consider-

Table-3: Calculated properties for different BA tautomers.

	I	II	III
B.E. (eV) ^a	-597.70	-568.53	-547.43
μ^b	10.33	10.24	0.56
(1)	-0.958	-0.964	+0.180
(2)	+0.601	+0.605	+0.463
(3)	+0.402	+0.362	-0.715
(4)	+0.490	+0.152	+0.516
q^c (5)	-0.935	+0.280	+0.194
(6)	+0.378	-0.567	-0.711
(7)	-0.032	+0.321	+0.438
(8)	+0.313	+0.236	+0.198
(9)	-0.258	-0.424	-0.562
ΔE (eV) ^d	4.14 (0.16)	4.16 (0.09)	5.93 (0.48)
	5.27 (0.27)	5.29 (0.20)	7.06 (0.59)
	6.02 (0.19)	5.99 (0.15)	7.18 (0.26)
	7.53 (0.50)	7.41 (0.06)	8.08 (0.01)

a- Binding energy

b- Dipole moment in Debye units.

c- Atomic charges with the numbering given in Fig.1

d- Energies for singlet-singlet transitions and values in parentheses are the oscillator strengths.

Table-4: Calculated properties for different TBA tautomers.

	I	II	III
B.E. (eV) ^a	-564.80	-534.68	-515.65
μ^b	6.53	5.08	14.46
(1)	-0.947	+0.223	+0.124
(2)	-0.190	-0.075	-0.419
(3)	+0.384	+0.386	-0.730
(4)	+0.447	+0.140	+0.502
q ^c (5)	+0.012	-0.163	+1.354
(6)	+0.336	-0.580	-0.764
(7)	-0.168	+0.240	+0.321
(8)	+0.209	+0.183	+0.115
(9)	-0.084	-0.354	-0.503
ΔE (eV) ^d	3.94 (0.17)	4.01 (0.52)	6.46 (0.18)
	5.08 (0.28)	5.15 (0.63)	7.59 (0.29)
	5.77 (0.38)	5.72 (0.31)	7.68 (0.29)
	6.69 (0.59)	6.50 (0.46)	7.98 (0.49)

a- Binding energy

b- Dipole moment in Debye units.

c- Atomic charges with the numbering given in Fig.1

d- Energies for singlet-singlet transitions and values in parentheses are the oscillator strengths.

ed as the band position in the gas phase spectrum and the PPP calculated energy of the transition for which the regression analysis has been performed is worth doing. For BA the calculated regression intercepts for the first and second $n \rightarrow \pi^*$ transitions are 4.20 and 5.32 eV respectively which are in a good agreement with the PPP calculated values 4.14 and 5.27 eV respectively. On the other hand, for TBA the regression intercept for the second $n \rightarrow \pi^*$ transition is 3.82 eV which is approximately 1 eV lower than

the PPP calculated value 5.08 eV.

Although both approaches are expected to give the band position in the gas phase spectrum agreement can be fortuitous. The regression intercept is corresponding to an $n \rightarrow \pi^*$ transition and is dependent on the spectral data base and the different solute-solvent interactions considered in the regression analysis while the PPP calculated values are pure $\pi \rightarrow \pi^*$ transitions and are parameter and geometry sensitive. This may explain the observed deviations.

Acknowledgement

The facilities made possible to us at the computer center of Alexandria University, supported financially by the Faculty of Science, Alexandria University are very much appreciated.

References

1. D.G. McRae,
J. Phys. Chem., **61**, 562 (1957).
2. S. Winstein, A.H. Fainberg and E. Grunwald,
J. Amer. Chem. Soc., **79**, 4146 (1957).
3. L.M. Kutsyna and L.A. Ogurtsova,
Bull. Acad. Sci. (USSR) Phys. Ser., **27**, 738 (1963).
4. N. Mataga, Y. Torihashi and K. Ezumi,
Theoret. Chim. Acta, **2**, 158 (1964).
5. C. Reichardt,
Angew. Chem. Intern. Edn., **4**, 29 (1965).
6. C. Reichardt and K. Dimroth,
Fortschr. Chem. Forsch., **11**, 1 (1968).
7. F.W. Fowler, A.R. Katritzky and R.J.D. Rutherford,
J. Chem. Soc. (B), 460 (1971).
8. K. Egami, Y. Gondo and Y. Kanda,
Mem. Fac. Sci., Kyushu Univ., Ser. C, **8(1)**, 93 (1972).
9. H.S. Gold, C.E. Rechsteiner and R.P. Buck,
Anal. Chem., **48**, 1540 (1976).
10. C.E. Rechsteiner, H.S. Gold and R.P. Buck,
Anal. Chim. Acta, **95**, 51 (1977).
11. H.S. Gold, C.E. Rechsteiner and R.P. Buck,
Anal. Chim. Acta, **103**, 167 (1978).
12. L.J. Hilliard, D.S. Foulk and H. S. Gold,
Anal. Chim. Acta, **133**, 319 (1981).
13. G.A. Neville and D. Cook,
Can. J. Chem., **47**, 743 (1969).
14. F.I. Carroll and A. Sobti,
J. Am. Chem. Soc., **95**, 8512 (1973).
15. B. Pullman, J.L. Coubeils and Ph. Courriere,
J. Theoret. Biol., **35**, 375 (1972).
16. C. Yeh and F.S. Richardson,
Theoret. Chim. Acta, **39**, 197 (1975).
17. B. Carnahan, H.A. Luther and J.O. Wilkes,
"Applied Numerical Methods", John Wiley and Sons, Inc., (1969).
18. R. Pariser and R.G. Parr,
J. Chem. Phys., **21**, 466, 767 (1953).
19. J.A. Pople,
Trans. Faraday Soc., **49**, 1375 (1953).
20. R.L. Flurry, Jr.,
"Molecular Orbital Theories of Bonding in Organic Molecules", Marcel Dekker, Inc., New York, (1968), Page: 208.
21. J.N. Murrell and A.J. Harget,
"Semi-empirical Self-consistent-field Molecular Orbital Theory of Molecules", John Wiley and Sons Ltd., (1972), Page: 14.
22. N. Mataga and K. Nishimoto,
Z. Physik. Chem. (Frankfurt), **12**, 335 13, 140 (1957).
23. QCPE Program No.167.
24. Tables of Interatomic Distances. The Chemical Society, London (1965).