Chem. Pharm. Bull. 21(4) 888—893 (1973)

UDC 547.211.03

Studies on the Magnetic Resonance Spectra in Aliphatic Systems. III.[1] M-CNDO/2 Calculation and NMR Parameters of CH_3R

Yoshio Sasaki and Miyoko Suzuki

Faculty of Pharmaceutical Sciences, Osaka University[2]

(Received July 21, 1972)

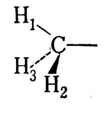
Introduction

Quantum chemical treatment of nuclear magnetic resonance (NMR) parameters—the chemical shift and coupling constant—has been well established by Pople[3] and Yonezawa.[4] Starting by substituting simple independent-electron LCAO MO wave function in the conventional perturbation formula and using an approximation of the mean excitation energy, more exact expressions for the NMR parameters have been obtained recently by substituting INDO MO wave functions in the SCF finite perturbation formula. Moreover, the contribution to the chemical shift of the inner shell electron began to be estimated.[4d,5] In these numerous quantum chemical treatments of NMR parameters, we were especially interested in the influences of the excitation energy when using the conventional perturbation method.

In this paper the M-CNDO/2 method[6] was used in calculation of the NMR parameters and the influences of excitation energy on the NMR parameters were examined.

Calculation

a) **M-CNDO/2 Method**——In this method parametrization used in the CNDO/2 method[7] is modified[8] and semi-empirical values are used which are valid for calculation of σ-electronic spectra. The observed ionization potentials obtained by photoelectron spectroscopy[9] and the orbital energies calculated by the CNDO/2 and M-CNDO/2 methods using Koopmans' theorem are compared in Table I. Values calculated by the M-CNDO/2 method obviously agree better with observed values than those calculated by the CNDO/2 method. The molecular geometry of each compound was assumed to be as described in the previous paper.[1] In calculation of the coupling constant, the hydrogens in the CH_3R series were numbered as follows.



b) **Calculation of NMR Parameters**——Calculation of the chemical shift and spin-spin coupling constant are as described in Ref. 3*a* and Ref. 3*f*, 10, 11)

---

1) Part II: Y. Sasaki and M. Suzuki, *Chem. Pharm. Bull.* (Tokyo), 20, 2522 (1972).

2) Location: *Toneyama 6-1-1, Toyonaka, Osaka.*

3) *a*) J.A. Pople, *J. Chem. Phys.*, 37, 53 (1962); *b*) *Idem, ibid.*, 37, 60 (1962); *c*) *Idem, ibid.*, 38, 1276 (1962); *d*) M. Karplus and J.A. Pople, *ibid.*, 38, 2803 (1963); *e*) J.A. Pople, J.W. Mclver, Jr. and N.S. Ostlund, *ibid.*, 49, 2960, 2965 (1968); *f*) J.A. Pople and D.P. Santry, *Mol. Phys.*, 8, 1 (1964); *g*) J.A. Pople, *ibid.*, 7, 269, 301 (1964); *h*) G.E. Maciel, J.W. McIver, Jr., O.S. Ostlund and J.A., Pople, *J. Am. Chem. Soc.*, 92, 1, 11, 4151, 4497, and 4506 (1970).

4) *a*) T. Yonezawa, I. Morishima, and H. Kato, *Bull. Chem. Soc. Japan*, 40, 487 (1967); *b*) *Idem. ibid.*, 39, 1398 (1966); *c*) H. Kato, H. Kato, and T. Yonezawa, *ibid.*, 43, 1921 (1970); *d*) H. Kato, K.A. Ishida, H. Nakatsuji, and T. Yonezawa, *ibid.*, 44, 2857 (1971).

5) R. Ditchfield, D.P. Millers, and J.A. Pople, *J. Chem. Phys.*, 54, 4186 (1971).

6) A. Tajiri, N. Ohmichi, and T. Nakajima, *Bull. Chem. Soc. Japan*, 44, 2347 (1971).

7) J.A. Pople and G.A. Segal, *J. Chem. Phys.*, 43, S129, S136 (1965).

8) J.M. Sichel and M.A. Whitehead, *Theoret. Chim. Acta*, (Berl.), 7, 32 (1967).

9) *a*) H. Ogata and H. Kamata, Abstract Papers of the Symposium on Molecular Structure, Kyoto, October, 1971, p. 389; *b*) H. Ogata, private communication; *c*) D.W. Turner, C. Baker, A.D. Baker, and C.R. Brundle, "Molecular Photoelectron Spectroscopy," John Wiley and Sons, Inc., New York, N. Y. 1969, p. 175; *d*) J.W. Rabalais, T. Bergmak, L.O. Werme, L. Karlson, and K. Siegbahn, *Physica, Scripta*, 3, 13, (1971).

10) Ramsey, N.F., *Phys. Rev.*, 91, 303 (1953).

11) J.W. Emsley, J. Feeney, and L.H. Sutclifee, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Vol. 1, Pergamon Press (Oxford), 1965, p. 103.

Table I. Comparison between Observed Ionization Potentials and Calculated Orbital Energies (eV)[a]

R		1 st	2 nd	3 rd	4 th	5 th
	I.P.[9a]	11.0	12.7	15.1	15.7	17.5
CH_3OH	M-CNDO/2	11.3	12.8	17.3	18.8	20.8
	CNDO/2	15.3	16.2	19.3	21.9	22.9
	I.P.[9b]	9.7	13.1	14.3	15.3	16.6
CH_3NH_2	M-CNDO/2	11.3	13.4	15.3	17.5	19.4
	CNDO/2	12.5	16.5	18.6	22.5	23.5
	I.P.[9c]	11.5	14.7	(20.0)	(19.2)	
CH_3CH_3	M-CNDO/2	12.7	12.7	13.9	17.8	17.8
	CNDO/2	16.4	16.4	18.2	23.4	23.4
	I.P.[9d]	12.5				
CH_4	M-CNDO/2	15.1				
	CNDO/2	19.7				

[a] Reorganization energy is neglected.

Result and Discussion

a) Chemical Shift

The calculated values of σ_p are shown in Table II. The values of σ_p calculated by the M-CNDO/2 method show that the substituent effect is clearer than when the CNDO/2 method is used,[1] but the signs are opposite to those of observed values. This may be due to the serious cancellation effect on the Ramsey's second-order perturbation formula and the inapplicability of the CI operation necessary for satisfactory construction of the excited-state wave function which are used in calculation of the ^{13}C chemical shift. But as excitation energy is still considered to be dominant factor for the chemical shift, the M-CNDO/2 method modified for use in calculation of the excitation energy used in the present work should theoretically be a better method, within the limits of infinitesimal expressions.[3e] Accordingly, the contribution of each excited state to the ^{13}C chemical shift of ethane was examined rather precisely. As shown in Table III, rather high excited states, including the transition to the highest vacant orbital, give large contributions to the chemical shifts. That is, transitions of 5→13 (y→x), 7→13(x→z) and 5→12(y→x) give values of −86.2, −42.9 and −86.2 ppm, respectively. This means that the transitions which contribute to the x,y and z components of the ^{13}C chemical shift are not confined to the lower excited states but spread over all excited states. To examine the chemical shifts of the CH_3R series with non-bonding orbitals, the excited states which give the largest contributions to $(\sigma_p)_{XX}$, $(\sigma_p)_{YY}$ & $(\sigma_p)_{ZZ}$ and their excitation energies were collected. As shown in Table IV, for methanol and methylamine, transitions from non-bonding orbitals do not contribute appreciably to the ^{13}C chemical shift. Compared to

Table II. Correlation between Observed and Calculated ^{13}C Chemical Shifts of the CH_3R Series

R	$-\sigma_P$(calcd.) ppm	δ_C(calcd.) ppm	δ_C(obsd.) ppm
OH	142.8	+29.8	−49.8[a]
NH_2	166.4	+6.2	−14.8[a]
CH_3	164.1	+8.5	−8.0[b]
H	172.6	0.0	0.0[b]

[a] C.H. Holm, *J. Chem. Phys.*, **26**, 707 (1957).
[b] H. Spiesecke and W.G. Schneider, *J. Chem. Phys.*, **35**, 722 (1961).

TABLE III. Contribution of Each Excited State to ^{13}C Chemical Shifts of Ethane

i → j	$[\sigma_P]_{XX}$ ppm	$[\sigma_P]_{YY}$ ppm	$[\sigma_P]_{ZZ}$ ppm
1 → 12			−1.5
1 → 13	−1.5		
2 → 10	−5.9		
2 → 11			−5.8
3 → 8	−1.7		
3 → 11		−33.5	
3 → 14	−61.9		
4 → 8			−1.7
4 → 10		−33.5	
4 → 14			−61.6
5 → 12			−86.2
5 → 13	−86.2		
6 → 9	−12.4		
6 → 12		−42.9	
7 → 9			−12.4
7 → 13		−42.9	

TABLE IV. Transition States Which Give Largest Contribution to ^{13}C Chemical Shifts of CH_3R

R	X		Y		Z	
	i→j	ΔE	i→j	ΔE	i→j	ΔE
		a.u.		a.u.		a.u.
OH	3→12	0.82	6→10	0.40	4→12	0.73
NH_2	4→13	0.62	4→10	0.55	3→13	0.68
CH_3	5→13	0.45	7→13	0.44	5→12	0.45
H	2→ 7	0.45	2→ 8	0.45	4→ 8	0.45

hydrocarbons, the energies of the substituted compounds are large and approximately correlated with the electronegativities. When considering only the transitions which contribute most to the ^{13}C chemical shifts, it is evident that the calculated values show opposite signs to the observed values. To overcome this controversy, as previously stated, it is necessary to exclude the cancellation effect and the inapplicability of the CI operation inherent in Ramsey's second-order perturbation formula and to use a finite perturbation method.

b) Coupling Constant

It is reported that variation in the H-H coupling in the CH_3R series is due to a direct effect of the substituent[11a] and variation in the C-H coupling constant is very closely dependent on the s-character of the C-H bond.[12] So the calculated and observed coupling constants of H_1–H_2 and ^{13}C–H_1 were plotted against the group electronegativities of the substituents[13] (*cf.* Table VII, VIII). The calculated values agree qualitatively with the observed values, but the former are smaller. The calculated and observed values of the H–H coupling constants especially show opposite signs. One center atomic-exchange integrals must be included in a MO description of the coupling constant if a negative value for the H–H coupling in methane is to be obtained. Table V, VI show the correlation of each excited state with the coupling constants of H_1–H_2 and ^{13}C–H for ethane and methanol. Yonezawa, *et al.*[4a,14] demonstrated

---

12) N. Muller and D.E. Prichard, *J. Chem. Phys.*, **31**, 768, 1471 (1959).
13) J.R. Cavanaugh and B.P. Dailey, *J. Chem. Phys.*, **34**, 1099 (1961).
14) T. Yonezawa, I. Morishima, M. Fujii and H. Kato, *Bull. Chem. Soc. Japan*, **42**, 1248 (1969).

systematically from calculation of the extended Hückel type MO that a dominant contribution to the geminal H_2–H_3 coupling constant for the CH_3R series is the excitation from the highest occupied MO *a*, to the lowest or second lowest vacant MO *a**. In the present work using M-CNDO/2 MO, the excitation from the higher occupied MO *a* to the lower vacant MO *a** contributes almost as much to the coupling constant as the excitation from the higher occupied MO *a* to the lower vacant MO *s**. On the other hand, with regard to the ^{13}C–H coupling constant, the orbitals having the 2s character of the carbon atom occupy the lowest or second lowest positions both in the bonding and antibonding orbitals. Thus the number of excited states which contribute to the ^{13}C–H coupling constant is limited, being restricted to between the lowest or second lowest occupied orbitals and the lowest or second lowest vacant orbitals.

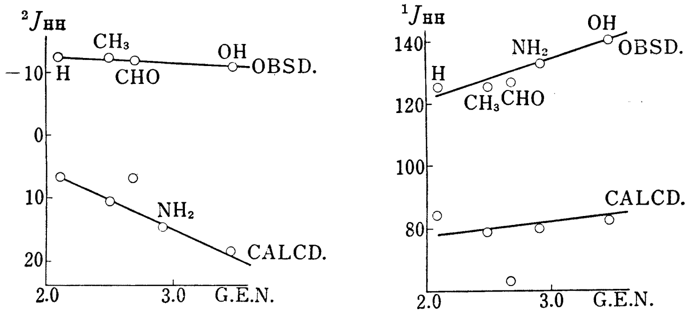


Fig. 1. Correlation between Coupling Constant and Group Electronegativity

TABLE V. Contribution to $^2J_{HH}$ from Each Excited State

CH_3CH_3				CH_3OH			
i	→	j	Contribution to $^2J_{HH}$	i	→	j	Contribution to $^2J_{HH}$
1	→	8	−3.4	1	→	8	−1.9
1	→	9	−3.8	1	→	9	+1.5
1	→	10	+4.0				
1	→	13	+2.6	2	→	8	−18.9
1	→	14	−0.8	2	→	9	+14.2
				2	→	11	+0.6
2	→	8	−6.9	2	→	12	−0.6
2	→	9	−7.6				
2	→	10	+7.9	3	→	8	+9.2
2	→	13	+5.1	3	→	9	−6.8
2	→	14	−1.6				
				5	→	8	−10.6
3	→	8	+10.5	5	→	9	+7.6
3	→	9	+11.2				
3	→	10	−11.4	6	→	8	+75.5
3	→	13	−7.2	6	→	9	−50.7
3	→	14	+2.3	6	→	11	−2.0
				6	→	12	+1.8
5	→	8	−6.2				
5	→	9	−6.4				
5	→	10	+6.2				
5	→	13	+3.9				
5	→	14	−1.3				
6	→	8	+23.4				
6	→	9	+24.3				
6	→	10	−24.1				
6	→	13	−14.4				
6	→	14	+4.6				

The transition states which give the largest and second largest contributions to the H_1–H_2 and ^{13}C–H coupling constants and their energy values are shown in Table VII and VIII. In calculation of the H–H coupling constant, the transitions which give the largest and second largest contributions are almost limited to those to the lowest vacant orbitals and their energy values are −7—−11 eV and −10—−13 eV, respectively. The ratio of the largest and second largest contributions to the H_1–H_2 coupling constant are rather constant (1—2) which is favorable to application of the mean excitation energy approximation. But the transition energies of the third largest contribution vary (−8—−25 eV) and moreover the contribution

Table VI. Contribution to $^1J_{CH}$ from Each Excited State

CH_3CH_3		CH_3OH	
i → j	Contribution to $^1J_{CH}$ cps	i → j	Contribution to $^1J_{CH}$ cps
1 → 8	+20.7	1 → 8	+11.0
1 → 9	+17.0	1 → 12	−0.8
1 → 14	−2.2		
		2 → 8	+79.4
2 → 8	+29.3	2 → 9	−2.2
2 → 9	+23.8	2 → 11	+0.6
2 → 14	−3.0	2 → 12	−4.7
5 → 8	−3.9	3 → 8	−9.4
5 → 9	−3.0	3 → 12	+0.5
5 → 14	+0.3		
		5 → 8	+17.0
		5 → 12	−9.1
		6 → 8	+0.7

Table VII. Transition States Which Give Large Contribution to $^2J_{HH}$ of CH_3R

CH_3R	J(obsd.) cps	J(calcd.) cps	First	ΔE eV	Contribution to J_{HH} cps	Second	ΔE eV	Contribution to J_{HH} cps
CH_3OH	−10.8[a]	+18.3	6→ 8	−8.097	+75.47	6→ 9	−9.92	−50.68
CH_3NH_2		+14.5	7→ 8	−7.20	+36.94	4→ 8	−12.72	+18.53
CH_3CH_3	−12.4[b]	+10.6	6→ 9	−9.15	+24.27	6→10	−10.00	−24.09
CH_4	−12.4[b]	+6.6	2→ 5	−9.68	+62.87	2→ 7	−11.30	−62.20
CH_3CHO	−12.0[c]	+6.6	7→13	−11.15	−43.47	7→12	−10.34	+35.17

a) H.J. Bernstein and N. Sheppard, *J. Chem. Phys.*, **37**, 3012 (1962).
b) M. Barfield and D.M. Grant, *J. Am. Chem. Soc.*, **82**, 4276 (1961).
c) E. Sackmann and H Dresskamp, *Spectrochim. Acta*, **21**, 2005 (1965).

Table VIII. Transition States Which Give Large Contribution to $^1J_{CH}$ of CH_3R

CH_3R	J(obsd.)[a] cps	J(calcd.) cps	First	ΔE eV	Contribution to J_{CH} cps	Second	ΔE eV	Contribution to J_{CH} cps
CH_3OH	+141	+82.7	2→ 8	−21.34	+79.42	5→ 8	−12.67	+16.96
CH_3NH_2	+133	+80.1	2→ 8	−20.27	+59.40	1→ 8	−31.86	+19.76
CH_3CH_3	+126	+79.1	2→ 8	−18.94	+29.32	2→ 9	−19.92	+23.84
CH_4	+125	+84.8	1→ 5	−22.82	+84.76			
CH_3CHO	+127	+63.1	2→12	−26.91	+38.12	2→11	−25.55	+22.27

a) N. Müller and D.E. Pritchard, *J. Chem. Phys.*, **31**, 768, 1471 (1959).

of this transition to the coupling constant is rather large. For example, in ethane, the three transition states which give the large contributions to the H_1–H_2 coupling constant are almost the same. In the ^{13}C–H coupling constant, the transitions which give the largest and second largest contributions are almost those to the lowest vacant orbitals or so and their energy values vary, being —19——27 eV and —13——32 eV, respectively. The ratios of the largest and second largest contributions to the coupling constant vary, being 1—5. For example in ethane, the two transition states which give the largest and second largest contributions to the ^{13}C–H coupling constant and their energy values are almost the same, but in methanol the two values are rather different. Accordingly, application of the mean excitation energy approximation seems to be meaningless. In conclusion, the contribution of excitation state to the two NMR parameters is not limited to that of the highest occupied and lowest vacant orbitals, but spreads to rather a large scale.

Acknowledgement The authors thank Dr. A. Tajiri, Chemical Research Institute of Non-Aqueous Solutions and Dr. A. Ohmichi, Department of Chemistry, Tohoku University, for providing a computer-program which could be used with the M-CNDO/2 method. They also thank Dr. H. Ogata, Faculty of Engineering, Tokyo University, for kindly providing charts of photoelectron spectra and for helpful suggestions. They are also grateful to the staff of Kyoto University Computer Center where the calculations were carried out.

[Chem. Pharm. Bull.
21(4) 893—894 (1973)]

UDC 547.94.057

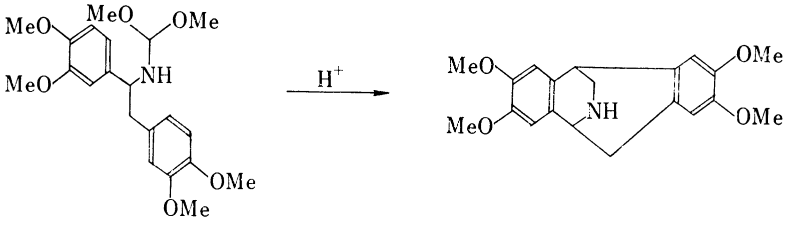
A Novel Synthesis of Isopavine Ring System

Tetsuji Kametani and Kunio Ogasawara

Pharmaceutical Institute, Tohoku University[1]

(Received July 26, 1972)

In 1958, Battersby and Yeowell[2] have reported the synthesis of the isopavine (II) from the benzylaminoacetal (I) preceding the discovery of natural isopavine alkaloids.[3,4]



I II

Chart 1

---

[1] Location: *Aobayama, Sendai.*
[2] A.R. Battersby and D.A. Yeowell, *J. Chem. Soc.*, **1958**, 1988.
[3] T. Kametani, "The Chemistry of the Isoquinoline Alkaloids," Hirokawa (Tokyo) and Elsevier (Amsterdam), 1968, p. 235.
[4] S.M. Kupchan and A. Yoshitake, *J. Org. Chem.*, **34**, 1062 (1969).