Tetrahedron Letters No. 4, pp 249 - 252, 1975. Pergamon Press. Printed in Great Britain.

THE DIFFERENT NATURE OF THE ANOMERIC EFFECT FOR METHOXY AND CHLORINE SUBSTITUENTS

I. Tvaroška[x] and T. Bleha[xx]

Slovak Academy of Sciences, Chemical Institute[x] and Polymer Institute[xx],
809 33 Bratislava, Czechoslovakia

(Received in UK 29 November 1974; accepted for publication 16 December 1974)

The preference for the gauche conformation in compounds of type C-X-C-Y (X=O,N,S; Y=O, Hal) has recently been termed the generalized anomeric effect[1-2]. Various attempts have been made to rationalize this effect. The electrostatic interactions between C-X and C-Y bond dipoles[3,4], sometimes visualized as repulsive interactions between lobes of the unshared sp^3 electron pairs ("rabbit-ears effect"[1,2]) have usually been emphasized. Another, most frequently discussed cause of the anomeric effect (especially if Y=Cl, Br) is the delocalization of oxygen (X) lone pairs into the anti-bonding orbital σ^* of the bond C-Y[5-7]. It has recently been shown by David et al.[8] that this delocalization stabilization is associated with different energy of two lone pairs on oxygen atoms. In the ab initio theoretical study of the anomeric effect on methanediol, Jeffrey et al.[9] expressed the total potential curve of the internal rotation around the C-O bond by means of the first three terms of Fourier's expansion.

$$V(\varphi)=V_1/2(1-\cos\varphi)+V_2(1-\cos 2\varphi)+V_3/2(1-\cos 3\varphi) \qquad (1)$$

where the dipole-dipole interaction, the electron delocalization and the intrinsic torsional potential are attributed to the respective terms. This procedure will be used in the present work in analysing the curves of internal rotation around the C-O bond within dimethoxymethane (DMM) and chlorine methoxymethane (CMM). The curves of the potential energy of rotation were obtained using the standard version of CNDO/2 method[10]. The details of calculation for DMM is to be found in ref.11. CMM was calculated without including the d-orbitals using the length of C-Cl bond 1.81 Å.

The change of the substituent Y from OCH_3 to Cl in molecule CH_3-O-CH_2-Y is reflected in the shape of the potential function of the internal rotation, particularly in the region of eclipsed position (cis-φ=0°- Fig.1). The individual Fourier coefficients (in kcal/mole) obtained from eq.1 differ in the same way. The values of the V_3 coefficients are negative for both molecules and suggest preference of staggered conformations trans (φ = 180°) and gauche (φ= ± 60°) in the C-O-C-Y segment. The term V_1 describing above all the dipole-dipole interaction indicates the preference for cis conformation, in which the orientation of segment dipoles C-O-C and C-Y is mutually opposite to the trans conformation where these dipoles are almost parallel. Besides the dipole-dipole interaction, the substantially lower value of V_1 term in CMM might be due to the higher steric repulsion of chlorine in cis position (r_{CCl}= 2.71 Å). The term V_2 characterizes the electron delocalization caused by lone pair interactions on heteroatoms. Term V_2 has a small positive value in the case of DMM, whereas in CMM the pronounced negative value suggests the orthogonal conformation (φ= 90°) to be preferred with respect to trans and cis conformations.

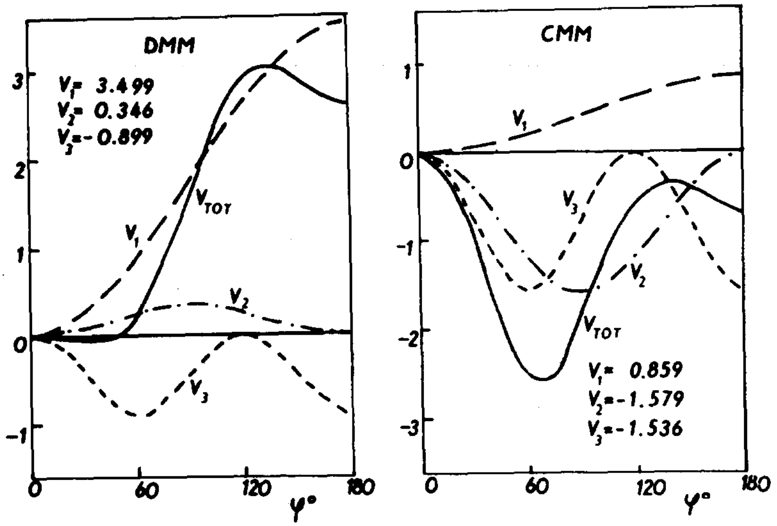

Figure 1.

The anomeric effect is determined by the difference of energies in trans and gauche conformations (in pyranose ring by different energy of equatorial and axial substituents on C_1 carbon). The energy difference ΔE (eq.2) is derived from eq.1

$$\Delta E = V(180^\circ)-V(60^\circ) = 0.75\ (V_1-V_2) \qquad (2)$$

Consequently, though the localization of both the minimum and maximum on the curve of internal rotation is determined by all three components of expansion (1), the value of the anomeric effect is determined by two of them only (V_1 and V_2). Thus, the anomeric effect may well be interpreted as the result of mutual balance of dipole-dipole interactions (V_1) and electron delocalization caused by lone pairs interactions (V_2). The character of the X and Y atoms influences the correlation of these two components and one or the other type of interaction may predominate. In the case of the two molecules analyzed, the dipole-dipole interaction prevails in DMM, whereas the mutual balance is shifted in favour of the V_2 term in CMM. The analogous situation is presumed to occur in methoxy and chlorine derivatives of such heterocycles as tetrahydropyran.

The different conformational dependence of electron delocalization in both molecules can also be seen from detailed MO analysis. Energetically non-equivalent oxygen lone pairs of the type p and sp, as well as those on the Y substituent may interact in two ways, through bond and through space mechanisms[12] with methylene group orbitals. The conformational dependence of these interactions may approximately be described by the function cos 2φ and thus, they should determine both the value and the sign of the V_2 coefficient. The differences between CMM and DMM can be estimated qualitatively from elements of density matrix and energy of MO's formed as the result of the mentioned interaction. The comparison of overlap population (OP) X_C-Z_O reveals a considerable difference in its value for trans and orthogonal conformations. In going from trans into the orthogonal position, this change is of a repulsive character (OP (180°) - OP (90°) = 0.0364 e) in DMM, whereas in CMM it is of an attractive one with the difference -0.0305 e. Contribution arising from an MO formed through bond interaction of the p lone pair with the π_x and π_x^* orbital of methylene group is the decisive term determining the OP value. The character of this interaction affects the energetic difference between individual orbitals.

The higher energy of the lone pair orbital in CMM, when compared with DMM, (by about 3 eV) causes the interaction with the π_x^* orbital to prevail and, consequently, the through-bond interaction acquires an final attractive character in CMM as compared with DMM. This interaction is exhibited by the change of C–O and C–Cl bonds lengths and affects the value of the resonance contribution E^R_{AB} (Tab. 1). E^R_{AB} is the resonance part of the total two-centric energy used in the CNDO/2 method as a measure of bonding[13]. From Table 1 it can be seen that the elongation of the C–Cl bond and the shortening of the C–O bond in CMM occur in the gauche position when compared with the trans position, whereas the changes are not so pronounced in DMM. In the case of chlorine-substituted heterocycles of the pyran type the changes of bond lengths in this sense have been observed experimentally[4,5]. On the basis of the previous reasoning it is obvious that during discussion of the anomeric effect, the authors studying chlorine derivatives[5-8] emphasize the delocalisation conception, whereas the analysis based mainly on oxygen derivatives leads to the electrostatic interpretation of the anomeric effect[1-4].

Table 1 E^R_{AB} values in kcal/mole

	CMM		DMM	
	E^R_{C-O}	E^R_{C-Y}	E^R_{C-O}	E^R_{C-Y}
180°	-708.067	-390.896	-697.814	-697.814
60°	-711.450	-388.535	-697.954	-696.145

REFERENCES

1. E.L.Eliel, Angew.Chem., Int.Ed.Engl., 11, 739 (1972).
2. R.U.Lemieux, Pure Appl.Chem., 25, 527 (1971).
3. J.T.Edward, Chem.Ind. (London), 1102 (1955).
4. R.U.Lemieux, in Molecular Rearangements, Vol.II., Wiley, N.Y., 1964.
5. C.Romers, C.Altona, H.R.Buys, and E.Havinga, Topics in Stereochemistry, Vol. 4, Wiley, N.Y., 1969.
6. E.A.Lucken, J.Chem.Soc. (London), 2954 (1959).
7. G.Baddeley, Tetrahedron Letts. 1645, (1973).
8. S.David, O.Eisenstein, W.J.Hehre, L.Salem, and R.Hoffmann, J.Amer.Chem. Soc., 95, 3806 (1973).
9. G.A.Jeffrey, J.A.Pople, and L.Radom, Carbohyd.Res., 25, 117 (1972).
10. J.A.Pople, and D.Beveridge, Approximative Molecular Orbital Theory, McGraw-Hill, N.Y., 1970.
11. I.Tvaroška, and T.Bleha, J.Mol.Struct. 24, (1975).
12. R.Hoffmann, Accounts Chem.Res., 4, 1 (1971).
13. H.Fischer, and H.Kollmar, Theor.Chim.Acta 16, 163 (1970).