



Polar and stereoelectronic effects on the structural and spectroscopic properties of halomethanols



Josué M. Silla, Matheus P. Freitas*

Department of Chemistry, Federal University of Lavras, P.O. Box 3037, 37200-000 Lavras, MG, Brazil

ARTICLE INFO

Article history:

Received 28 February 2014
Received in revised form 4 April 2014
Accepted 5 April 2014
Available online 16 April 2014

Keywords:

Conformational analysis
Theoretical calculations
Anomeric effect
Halogenated methanols

ABSTRACT

Halogenated methanol derivatives (halogen = F, Cl and Br) were theoretically studied and the *gauche* conformer relative to the X–C–O–H torsional angle was the single energy minimum found at the MP2/6-311G++(d,p) and B3LYP/6-311G++(d,p) levels in the gas phase, implicit and explicit aqueous solution. The generalized anomeric effect is operative, since the structure (*gauche*) with an electron lone pair in the *anti* orientation relative to the halogen is the stable conformation. Natural bond orbital calculations show that this conformational preference, in comparison with the stationary *anti* structure that exhibits imaginary frequency, is due to hyperconjugation rather than electrostatic effects, while internal hydrogen bond OH...X does not operate. However, the $^1J_{C,F}$ coupling constant for the fluorinated derivative is exponentially dependent on the molecular dipole moment and linearly correlated with the C–F distance, but a correlation with the $n_O \rightarrow \sigma_{C-F}^*$ hyperconjugation was not observed. Thus, the generalized anomeric effect in some model systems agrees with the hyperconjugation model, while the Perlin-like effect does not appear to have hyperconjugative dependence, but a polar instead.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Studies performed with alkyl pyranosides by Jungins [1] show that alkyl- α -pyranosides are more stable than their β -anomers. This phenomenon is known as the anomeric effect and interpreted by Edward in 1955, [2] so that some substituents in the equatorial position at the anomeric carbon suffer stronger dipolar repulsion than axial ones. In 1969, Limieux et al. [3] found experimentally that the conformational preference of 2-methoxytetrahydropyran varies according to the solvent polarity; polar solvents would weaken the dipolar repulsion between the endocyclic oxygen and the equatorial methoxy group. The dipolar origin of the anomeric effect has also been supported theoretically [4,5]. According to the valence-bond study by Mo [4], the conformational preferences in various compounds experiencing the anomeric effect have been interpreted in terms of steric, hyperconjugation and dispersion effects; intramolecular electrostatic interactions between local dipoles were found to be responsible for the anomeric effect in these cases, in the gas phase. However, recent studies have shown that exchange effects dominate the anomeric effect, revealing that such an effect does not have electrostatic origin [6], despite different findings from QTAIM analysis for methanediol, in which

differences in exchange terms between conformers are reported and they do not seem to play a leading role [7]. In fact, an experimentally supported interpretation based on the hyperconjugation model has been used to explain the anomeric effect in methyl D-galactose and D-glucose in a solvent-free environment [8,9]. Hyperconjugation has also been invoked to control the anomeric effect in a variety of 2-substituted tetrahydropyrans (2-X-THPs) even in aqueous solution [10]. In 2-X-THPs, the hyperconjugative nature of the anomeric effect is commonly described as an electron donation from the endocyclic oxygen to the low-lying σ_{C-X}^* orbital in the axial configuration [11]. This interaction is supposed to increase the C–X bond length and to shorten the C–O distance, which is not completely explained by the dipolar interpretation. The generalized anomeric effect applies this concept to acyclic systems, such as fluorinated pnictogen compounds (Fig. 1) [12].

The anomeric effect for the simplest halogenated alcohols (1–3, Fig. 2) are studied in this work, since the σ_{C-X}^* orbitals (X = F, Cl and Br) are good electron acceptors either due to the polarity of the C–X bond or to the poor overlap between the C and X (Cl and Br) atomic orbitals, because of their different atomic sizes. In addition, the fluorine derivative has important spectroscopic properties, which can give insights about stereoelectronic effects governing conformational stabilities. For example, the Perlin effect can give important information about the structures of sugars [13]. According to the Perlin effect, [14–17] the $^1J_{C-2,H-axial}$ coupling constant in a

* Corresponding author. Tel.: +55 35 3829 1891; fax: +55 35 3829 1271.
E-mail address: matheus@dqj.ufla.br (M.P. Freitas).

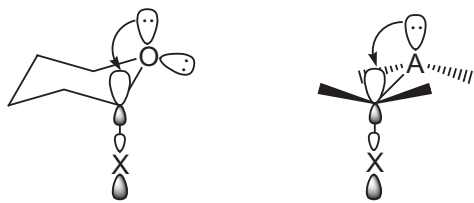


Fig. 1. The hyperconjugation model for the anomeric effect in 2-substituted tetrahydropyrans and the generalized anomeric effect in acyclic derivatives containing an electron donor (n_A orbital) and an electron acceptor (σ_{C-X}^* orbital).

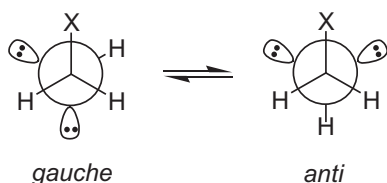


Fig. 2. Conformational isomerism in halomethanols [X = F (1), Cl (2) and Br (3)].

pyranoside derivative is smaller than the corresponding $^1J_{C-2,H-equatorial}$, because the C_2-H_{axial} bond is longer than the $C_2-H_{equatorial}$ bond due to the $n_O \rightarrow \sigma_{C-H_{ax}}^*$ hyperconjugative interaction. The opposed trend in the coupling constants is called reverse Perlin effect, which has been observed in 1,3-dithianes as a consequence of dominant $\sigma_{C-S} \rightarrow \sigma_{C-Heq}^*$ or $\sigma_{C-Heq} \rightarrow \sigma_{C-S}^*$ stereoelectronic interactions [18,19]. However, more recent interpretations for the Perlin effect invoke dipolar interactions [20]. Since the C–F bond is highly polar and ^{19}F is magnetically active, the fluoromethanol derivative can be valuable to probe for the origin of the Perlin-like effect using the $^1J_{C,F}$ coupling constant.

2. Computational details

The two possible minima *gauche* and *anti* for **1–3** were optimized at the MP2 [21] and DFT/B3LYP [22] methods using the 6-311G++(d,p) [23] basis set, including frequency calculations to obtain thermodynamic energies and the thermal corrections and also to search for true minima, which should not exhibit imaginary frequencies, using the Gaussian 09 program [24]. The stationary *anti* structure for all compounds exhibited imaginary frequency and, therefore, it is not a stable conformer. The calculations were performed in gas phase, as well as in explicit solvent (using six water molecules in an octahedral arrangement as input) and implicit solvation (water) using the polarizable continuum model by Tomasi and coworkers [25] (using a cavity built up using the UFF, *i.e.* radii with spheres around each solute atom) at the B3LYP/6-311G++(d,p) level. Natural bond orbital (NBO) analysis [26] were carried out over the optimized geometries, and the NOSTAR and STERIC keywords were used to determine the hyperconjugative and steric exchange energy, respectively. Analysis of possible intramolecular hydrogen bond was performed using the quantum theory of atoms in molecules (QTAIM) [27] and the non-covalent interactions (NCI) method [28]. The NMR calculations (in the gas phase and implicit water) were performed at the B3LYP/EPR-III level [29] for **1** to analyze the angular dependence of the $^1J_{C,F}$ coupling constant.

3. Results and discussion

Halomethanols **1–3** undergo rotation along with the X–C–O–H dihedral angle, but only one stable conformer, *gauche*, is present in the gas phase and using an implicit solvent (water) model

(Fig. 2); the stationary *anti* structure was not found to be stable, because of the presence of imaginary frequency, in agreement with earlier findings [30]. The energy difference between the *gauche* conformer and the stationary *anti* form obtained using both B3LYP and MP2 methods are similar, which is consistent with various methods applied in the literature (Table 1) [31]. In order to guarantee that such a preference is not due to intramolecular hydrogen bond, QTAIM and NCI calculations were performed over the optimized structures, and no bond path between X and H(O) was detected in **1–3** and, likewise, the NCI surface did not indicate the formation of OH...X hydrogen bond. Thus, the generalized anomeric effect operates in **1–3** and it is not dictated by intramolecular hydrogen bond. Indeed, intramolecular hydrogen bond forming small rings has not been found to be stable [32].

Because the *gauche* conformer is the single form using both implicit and explicit aqueous solution, the generalized anomeric effect is not expected to be due to the dipolar model, in which the electrostatic repulsion between halogen and oxygen lone pairs would be expected to be attenuated and, therefore, the *anti* conformer should appear. Thus, hyperconjugation can be invoked to explain the *gauche* preference, despite an analysis of the total atomic population and localization, as well as delocalization indices in showing trends that are not in line with the hyperconjugative explanation [30]. Indeed, the larger C–X and shorter C–O distances in the *gauche* conformer relative to the *anti* form support the hypothesis of hyperconjugative anomeric effect.

The hyperconjugative nature of the anomeric effect was investigated using natural bond orbital (NBO) analysis. This analysis is carried out by examining all possible interactions between “filled” (donor) Lewis-type NBOs and “empty” (acceptor) non-Lewis NBOs, and estimating their energetic importance by second-order perturbation theory. In addition, the contributions from Lewis-type (steric and electrostatic interactions) and non-Lewis-type (such as hyperconjugation) interactions to the overall energy of a molecular system can be estimated, in such a way that the full energy can be decomposed according to $E_{full} = E_{Lewis} + E_{non-Lewis}$, where $E_{Lewis} = E_{steric} + E_{electrostatic}$. These energy components are depicted in Table 2 and show that hyperconjugation really plays the major role for the anomeric effect if compared to Lewis-type interactions, both in the gas phase and implicit aqueous solution. The hyperconjugative contribution for **1** appears to be slightly weaker than the electrostatic effect in implicit water, but the steric component, which cannot be precisely separated from the electrostatic one in the Lewis-type term, reduces the electrostatic contribution. According to the well-known interpretation for the anomeric effect, the $n_O \rightarrow \sigma_{C-X}^*$ interaction plays a key role for the overall hyperconjugative stabilization of the *gauche* conformer, which is calculated to be strongly enhanced in explicit solvation (Table 2).

Overall, the generalized anomeric effect in **1–3** was found to be due to hyperconjugation rather than dipolar effects, even in solution. In addition, the contribution from the $n_O \rightarrow \sigma_{C-X}^*$ interaction

Table 1

Bond lengths (Å) and standard thermodynamic parameters (kcal mol⁻¹/298 K) for **1–3** in the gas phase, implicit and explicit solvent (water), obtained at the B3LYP/6-311G++(d,p) and MP2/6-311G++(d,p) (in parenthesis) levels.

Compound	d_{C-O} (a/g)	d_{C-X} (a/g)	ΔG (a-g)	ΔH (a-g)	ΔS (a-g)
1 (gas)	1.398/1.378	1.373/1.402	4.6 (4.5)	4.3	–0.3
1 (implicit)	1.398/1.376	1.389/1.419	3.6 (3.4)	3.3	–0.3
1 (explicit)	–/1.335	–/1.494	–	–	–
2 (gas)	1.402/1.378	1.796/1.845	4.6 (3.7)	4.3	–0.3
2 (implicit)	1.402/1.371	1.811/1.871	3.8 (2.7)	3.4	–0.4
2 (explicit)	–/1.324	–/1.992	–	–	–
3 (gas)	1.401/1.373	1.962/2.021	5.0 (4.0)	4.6	–0.4
3 (implicit)	1.401/1.366	1.976/2.054	4.3 (3.0)	3.9	–0.4
3 (explicit)	–/1.315	–/2.196	–	–	–

Download English Version:

<https://daneshyari.com/en/article/5393732>

Download Persian Version:

<https://daneshyari.com/article/5393732>

[Daneshyari.com](https://daneshyari.com)