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Theoretical Study of Benzylic Oxidation and Effect of Para- Substituents by Using Hyperchem Program

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Abstract

In this work, study of benzylic oxocations and effect of para-substituents on the original compound has been done by using HyperChem8.0 Program. A theoretical treatment of the formation of compounds was studied; this was done using the HyperChem8.0 program for the Molecular mechanics and Semi-empirical calculations. The heat of formation (Δ H) and Conformational Energetic in (kcal/mol) for the compounds were calculated by (PM3 and AM1) method, at (298 K) .Furthermore, the conclusion by investigating the stabilities of similar cations using a computational chemistry that called an isodesmic equation.

Keywords: Thermochemistry; Isodesmic equation; Relative Stabilization Energy; Heat of formation
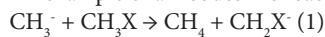
Introduction

Theoretical chemistry seeks to provide theories that explain chemical observations. Often, it uses mathematical and computational methods that, at times, require advanced knowledge [1]. Theoretical chemistry may be broadly divided into electronic structure, dynamics, and statistical mechanics. In the process of solving the problem of predicting chemical reactivates, these may all be invoked to various degrees [2].

Thermochemistry is the study of the energy and heat associated with chemical reactions and/or physical transformations [3]. A reaction may release or absorb energy, and a phase change may do the same, such as in melting and boiling. Thermochemistry focuses on these energy changes, particularly on the system's energy exchange with its surroundings. Thermochemistry is useful in predicting reactant and product quantities throughout the course of a given reaction [4]. It is also used to predict whether a reaction is spontaneous or non-spontaneous, favorable or unfavorable. Endothermic reactions absorb heat. Exothermic reactions release heat. Thermochemistry coelesces the concepts of thermodynamics with the concept of energy in the form of chemical bonds [5]. The subject commonly includes calculations of such quantities as heat capacity, heat of combustion, heat of formation, enthalpy, entropy, free energy, and calories [6].

An isodesmic reaction is a chemical reaction in which the type of chemical bonds broken in the reactant are the same as the type of bonds formed in the reaction product. This type of reaction is often used as a hypothetical reaction in thermo chemistry [7].

An example of an isodesmic reaction is :
$$CH_3^- + CH_3X \rightarrow CH_4 + CH_2X^- \quad (1)$$
X = F, Cl, Br, I

Equation 1 describes the deprotonation of a methyl halide by a methyl anion. The energy change associated with this exothermic reaction which can be calculated *in silico* increases going from fluorine to chlorine to bromine and iodine making the CH_2I^- anion the most stable and least basic of all the halides [8]. Although this reaction is isodesmic the energy change in this example also depends on the difference in bond energy of the C-X bond in the base and conjugate acid. In other cases, the difference may be due to steric strain [9]. This difference is small in fluorine but large in iodine (in favor of the anion)

and therefore the energy trend is as described despite the fact that C-F bonds are stronger than C-I bonds [10].

Isodesmic reactions represent a subclass of isogyric reactions, the latter of which are defined as transformations in which reactants and products have the same number of electron pairs. These reactions can, in principle, be purely hypothetical [11].

Homodesmotic reactions are a subclass of isodesmic reactions in which reactants and products share even larger similarity. It also takes into account orbital hybridization and in addition there is no change in the number of carbon to hydrogen bonds [12].

The homodesmotic and isodesmic reactions have been used for a long time to make estimations of the stabilization energy of aromatic systems [13].

It is a common perception that relative stabilization energies (RSE) can be rationalized, alternatively, by considering the effect of substitution on the intrinsic stability of the molecule with its intact bond [14].

Object of this work is theoretical study on the effect of adding substitution on cyclic ether at Para position but according to Isodesmic reactions to find the Relative Stabilization Energy (RSE) by compare the energies (which equals ΔH) of the difference adding groups.

Computational details

All structures, were optimized in the gas phase using Parameterized Model number3 (PM3) [15] a semi-empirical method for the quantum calculation of molecular electronic structure in computational chemistry [16], implemented in the HyperChem8.0 package [17]. Adding substituted and conjugate acids flowing the order in Figure 1 and Table 1.
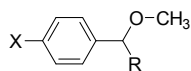
Figure 1: Adding substituted and conjugate acid to 4-substituted benzaldehyde methyl ether.
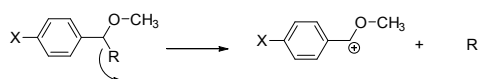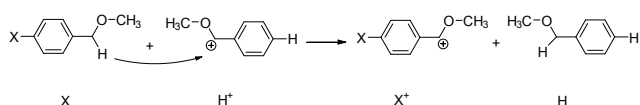

Figure 2: Acid catalyzed hydrolysis of an acetal.
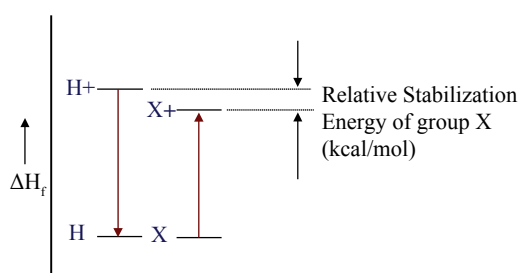

Figure 3: Formation of the cation.

Figure 4: Definition of Relative Stabilization Energy.

Compounds	X	R
Original Compound	H	H
1	OCH$_3$	H
2	CH$_3$	H
3	H	H
4	F	H
5	NO$_2$	H
6	OCH$_3$	CH$_3$
7	CH$_3$	CH$_3$
8	H	CH$_3$
9	F	CH$_3$
10	NO$_2$	CH$_3$

Table 1: Adding substituted and conjugate acid to 4-substituted benzaldehyde methyl ether.

Compounds	Δ H for H (R=H)	Δ H for H$^+$ (R=H)	Δ H for X	Δ H for X$^+$	R.S.E (X$^+$ - H$^+$)
Original compound	-18.859	169.392	---	---	---
1	-18.859	169.392	-56.988	124.932	-6.331
2	-18.859	169.392	-28.285	157.171	-2.795
3	-18.859	169.392	-18.856	169.419	0.024
4	-18.859	169.392	-62.571	128.473	2.793
5	-18.859	169.392	10.107	-62.286	-260.644
Compounds	Δ H for H (R=CH^3)	Δ H for H$^+$ (R=CH^3)	Δ H for X	Δ H for X$^+$	R.S.E (X$^+$ - H$^+$)
6	-23.951	157.373	-62.034	113.517	-5.773
7	-23.951	157.373	-33.367	145.514	-2.443
8	-23.951	157.373	-23.952	157.374	0.002
9	-23.951	157.373	-67.688	116.475	2.839
10	-23.951	157.373	5.102	-70.921	-257.347

Table 2: Theoretical value of calculated Relative Stabilization Energy (RSE).

Heat of Formation and Total Energy have been found, calculation of Relative Stabilization Energy (RSE) has done by calculating of differences in heats of formation are close to difference in binding energies (which we often use just for the sake of convenience), however in this case we will follow the practice of most chemistry journal authors such as El-Nahas and Clark [18].

Result

Study of acid catalyzed hydrolysis of an acetal related to a 4-substituted benzaldehyde methyl ether, benzaldehyde, and the effect different 4-substituents might have on the rate of hydrolysis. We test that conclusion by investigating the stabilities of similar cations using a computational chemistry tool called an isodesmic equation, as shown in Figure 2. The rates of these reactions were measured experimentally by Rose and Williams [19].

Object of this study is computationally determination of the effect of different groups X on formation of the cation. But because the groups X differ, it is difficult to just compare the energies of the different cations. the difference in energy between the above reaction for X= H, and X = another group, as shown in Figure 3. This is called the "relative stabilization energy", which equals ΔH for the following reaction.

This is an isodesmic reaction, defined as a chemical reaction in which the type of chemical bonds broken in the reactant are the same as the type of bonds formed in the reaction product. This is often used to calculate substituent effects. The definition of Relative Stabilization Energy (RSE) is shown graphically above, Figure 4. It is simply ΔH for the X$^-$ > X$^+$ reaction minus ΔH for the H$^-$ < H$^+$ reaction. This energy difference can be directly translated into relative reaction rates, but we will not do so here. If RSE is > 0, then the 4-X group stabilizes the cation less than H; if RSE is < 0, then the 4-X group stabilizes the cation more than H. Cation-forming reactions with RSE < 0 will go faster than reactions with RSE > 0. From Table 2, after calculation of Relative Stabilization Energy (RSE) , it shown that when substituted group (R) is Hydrogen (H) at compounds (1,2,3,4,5) , the Relative Stabilization Energy (RSE) increase at the Sequence of 4>3>2>1>5 .

Negative value of Relative Stabilization Energy (RSE) less than zero (RSE < 0) refer to that substituted group will increase the ability to form the cation more than if the substituted group is hydrogen.

Also at compound 5 when the substituted group is (NO$_2$), that will increase stability of cation in very big amount according to the RSE is less than zero (RSE < 0) in very big amount. That will increase the stability of an intermediate carbocation formation, and that will increase reaction speed. That is because the ability of resonance that could happen between the phenyl and substituted group. So that for compound 4 the Relative Stabilization Energy (RSE) is in heights amount and that will lead to difficulties of an intermediate carbocation formation. That is because the Electronegativity of substituted fluoride (F) is to height and that will lead to decrease the stability of an intermediate carbocation formation.

When substituted group (R) is Methyl (CH$_3$) at compounds (6,7,8,9,10) , the Relative Stabilization Energy (RSE) increase at the Sequence of 9>8>7>6>10 , and this methyl group is increase the all amount of Relative Stabilization Energy (RSE) more than how Hydrogen do. That will decrease the stability of an intermediate carbocation formation and will lead to decrease reaction speed . All this has been done comparing to when the substituted group (R) is Hydrogen (H). In all compound the ability of reaction increase with increasing of stability for an intermediate carbocation formation when (RSE < 0)

and the ability of reaction decrease with decreasing of stability for an intermediate carbocation formation when (RSE > 0).

Conclusions

In this work, Relative Stabilization Energy (RSE) of benzylic oxocations and effect of para-substituents on the original compound has been calculated to investigate the stabilities of similar cations using a computational chemistry that called an isodesmic equation. when substituted group (R) is Hydrogen (H) , the Relative Stabilization Energy (RSE) increase at the Sequence of 4>3>2>1>5 and when substituted group (R) is Methyl (CH3) , the Relative Stabilization Energy (RSE) increase at the Sequence of 9>8>7>6>10.

Acknowledgement

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