VISUALIZING THE MECHANISMS OF ORGANIC REACTIONS

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Abstract

Using several Molecular Modeling programs, we have animated various reaction mechanisms of the most important reaction used in Organic Chemistry. These provide a learning tool for students to foster their knowledge of the many events taking place in a reaction. The use of 3D helps understanding the details of the reactions. These tools are aimed to first-year students of University courses at the Faculty of Chemistry, UNAM. With the visualization, students improve their learning skill dramatically.

Keywords: Chemical reactions, Animation, Organic Chemistry, Reaction Mechanism, Molecular modeling, 3D visualization.

1 INTRODUCTION

Chemistry is an experimental discipline, relies heavily in observation of exploratory results and the handling of data. The chemical reactions involve the collision between a large numbers of molecules, moving around rapidly in a random way. Molecules will be colliding with each other in different angles and speed. Most of the time they will bump each other in a non-productive event, only the collisions with the right orientation and enough energy will yield a product. Electrons on the surface of the molecules take part in the reactions leading to a change of connectivity within the atoms within the molecules. Understanding which bonds are broken and formed and the order of events, lead toward an understanding of chemical reactivity. Reaction mechanism is a way to show how chemical reactions occur at the molecular level, how many steps are involved and which steps are faster or slower. Using the Molecular Modeling programs; Spartan and Odyssey1, we have animated the most important reactions used in Organic Chemistry. These provide a learning tool for students to foster their knowledge of the several events taking place in a reaction. The use of 3D helps understanding the details of the reactions. These tools are aimed to first-year students of University courses at the Faculty of Chemistry, UNAM. With the visualization, students improve their learning skill dramatically.

1.1 Reaction mechanisms fundamentals

A reaction mechanism is the detailed, step by step description of a chemical reaction. By knowing how a reaction takes place; changes in the experimental condition can be made to improve the yield of the products, or even alter the course of the reaction completely and obtain an entirely different product. A mechanism must account for all the known facts of a reaction, and predictions about the outcome based on the mechanism can be done.

Mechanisms can form the basis for chemical reasoning, allowing the recognition of patterns of reactivity when a new reagent, reaction or processes are presented without the need of blind memorization.

In practice, a reaction mechanism is described by a series of ordered steps within a time framework. When all these steps are taken into account, the net result is a reaction patway. The most important part through the mechanism is the outcome of particular bonds, in the reactant molecules are broken and in the product, molecules are formed. The synchronization of these events is important in the reaction.

1.1.1 Polar reactions

In the polar reaction mechanism one electron pair moves together, when bonds are formed or broken. Bond breaks and forms in a heterolytic process. Bond polarity is essential to this type of reactions. The fundamental characteristic of all polar reactions is that electron-rich sites in one molecule react with an electron-poor site in another molecule, mainly for the attractions of negatively charged regions on one reactant and the positively charge region of a second reactant.

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The negative charged (electron rich) reactant is called nucleophile and the positively changed (electron-poor) electrophile. Nucleophile molecules have lone pairs of electrons and can be neutral (ammonia, water) or negatively charged, (chloride ion, hydroxide) they can be considered as Lewis bases. On the other hand, the electrophile is an electron loving and attract a negative charge.

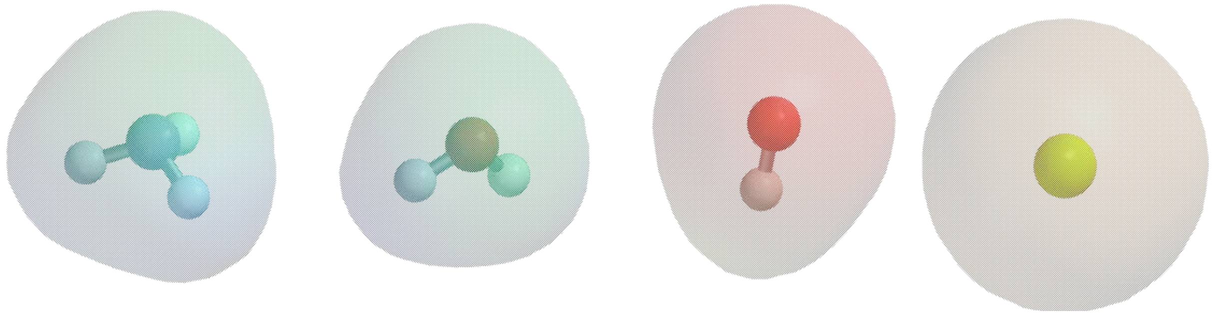


Fig. 1 Nucleophiles and their electrostatic potential map. (NH_3,H_2O,HO^-, Cl^-).

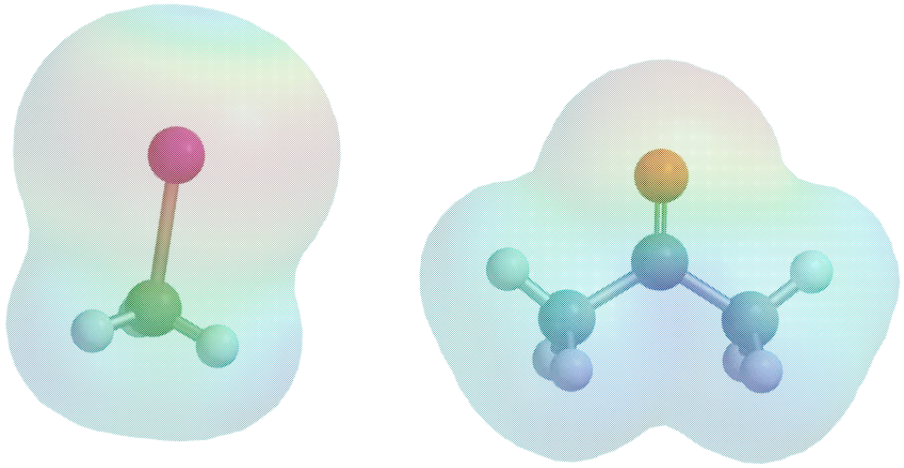


Fig 2. Electrophiles and their electrostatic potential map (CH3I, $(CH_3)_2C=O$).

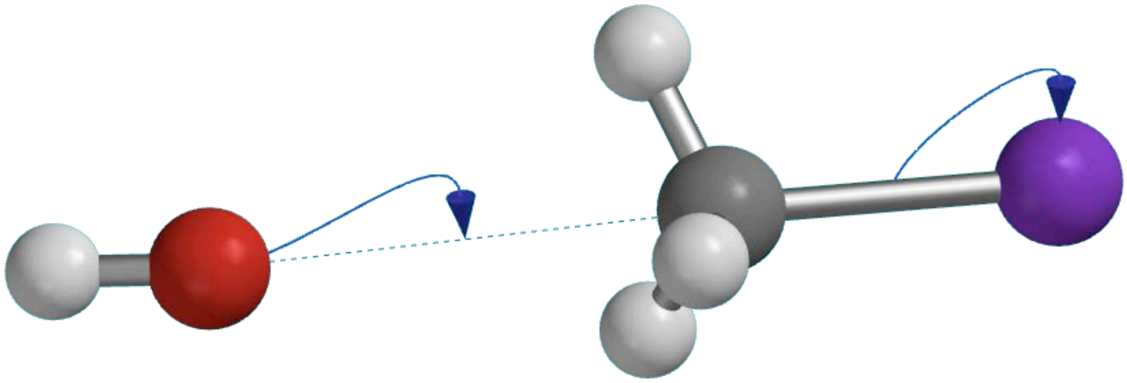


Fig 3. Electron flow between the nucleophile to the electrophile.

The nucleophile has an electron-rich site, either because they have a functional group containing an atom that has a lone pair of electron, or because they are negatively charged.

The electrophile have an electron-poor site, either because they have a functional group containing an atom that is positively polarizer, or because they are positively charged.

1.1.2 Radical reactions

When the electrons involved are unpaired the reactions goes by radical. Bond breaking and forming are called homolytic, single electrons move, they are also named free radical reactions.

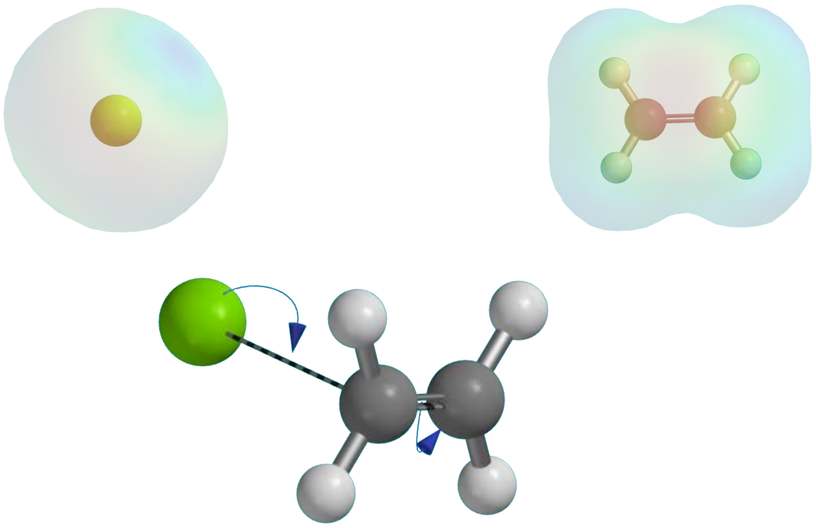


Fig 4. Addition of Cl radical to ethylene.

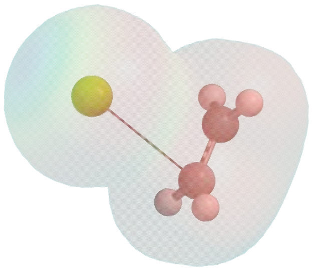
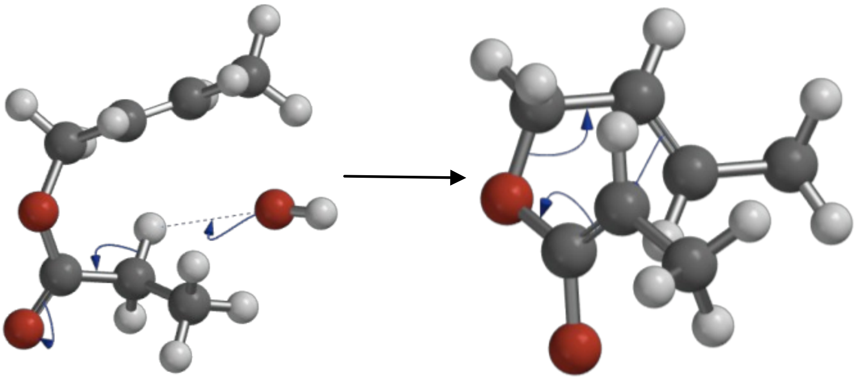


Fig 5. Transition state of Chlorine radical addition to ethylene.

In this, categories are included the three electron pair moving to produce a concerted rearrangement reaction.

The Ireland-Claisen rearrangement is a classic example it was discovered by Robert Ireland in 1972, the [3,3]-sigmatropic rearrangement of O-trioalkylsilylkenete acetals to gama,delta-unsaturanted carboxylic acids. Using lithium diisopropylamide and trimethylsilyl.



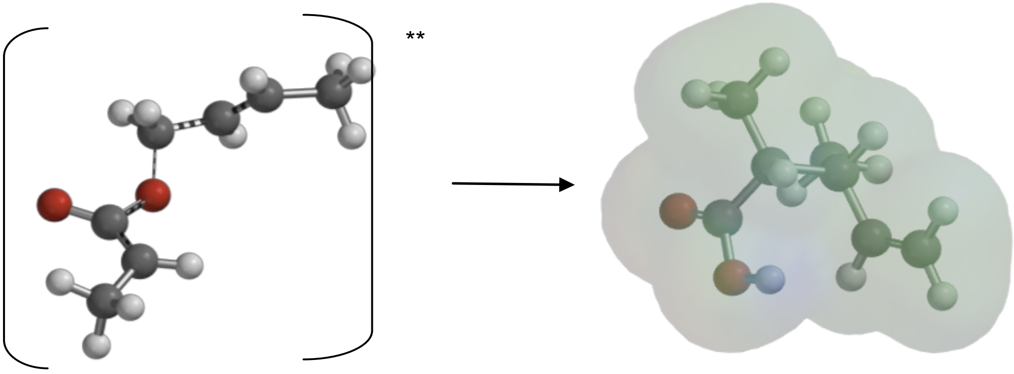


Fig 6. Ireland-Claisen rearrangement of three electron pair moving.

1.1.3 Henry reaction.

The forming of carbon-carbon bond is very important in Organic Chemistry in order to build a complex carbon framework. The nitro-aldol reaction, was discovered in 1895 by L. Henry2 Is a coupling reaction between a carbonyl compound and an alkylnitro compound with alpha hydrogens, the overall transformation forms a new carbon-carbon bond with new functional groups, a hydroxyl and a nitro. This beta-nitroalkanol functionality can be transformed into new groups, by oxidation, reduction and dehydration.

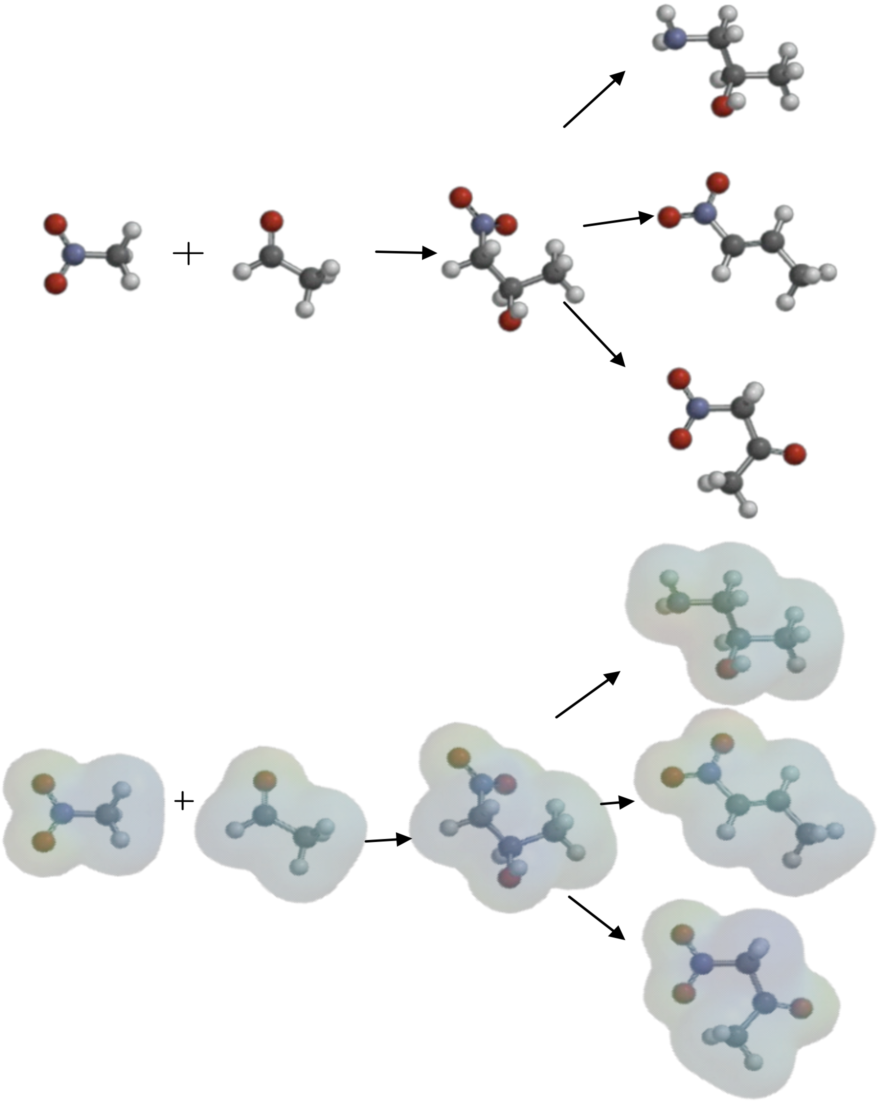


Fig 7 Henry reaction with further transformation.

The first nitroaldol reactions were catalysed by bases, actually many different set of conditions are used; organic bases, inorganic bases, quaternary amonium salts, protic and aprotic solvents, and even without solvents. This variety of conditions allows the presence of different type of functionality, and wide variation in solubility of reactants and products.

The first asymmetric synthesis of the Henry reaction was reposted by Sasai[3]. Since then, interest in this area has been expanded upon considerably and various

When a nitroalkane is reacted with n-butyllithium in presence of isopropoxytitanium trichloride ((THF/-78°C) to afford the corresponding beta-nitroalkanols the in situ-formed dichloroisopropoxytitanium nitronate promotes high *erythro* selectrivity[4].

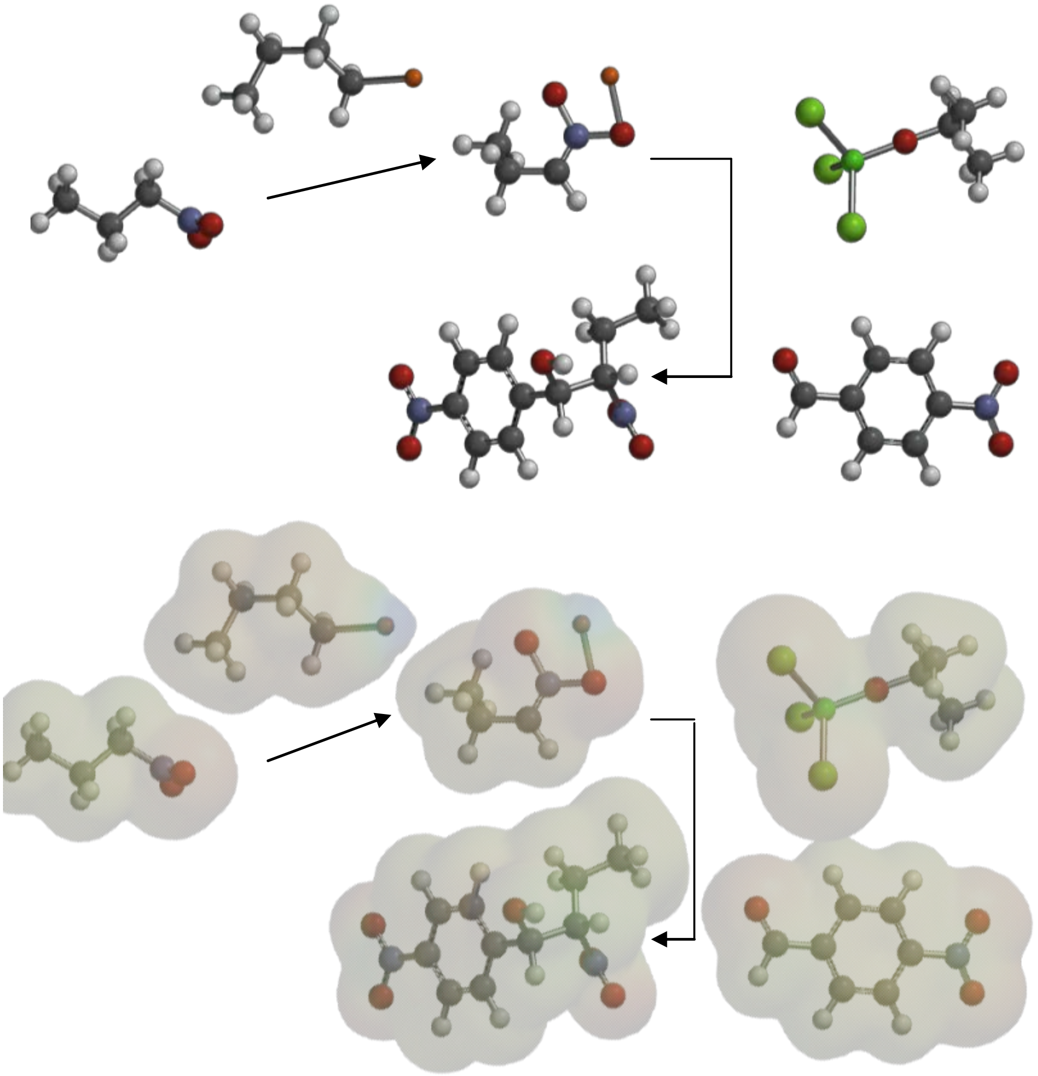
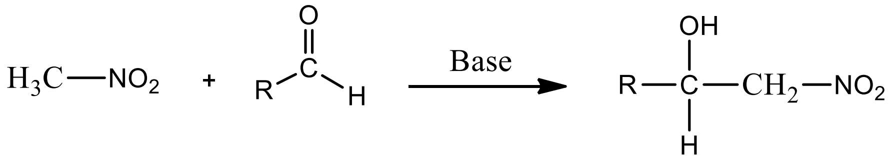


Fig 8 nitroaldohol asymmetric reaction.

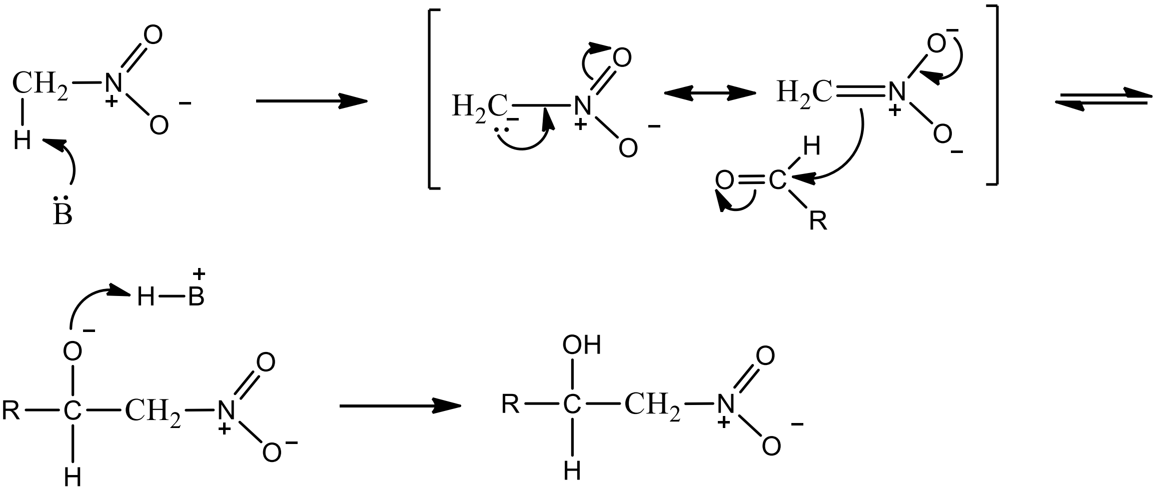
The chiral nitroaldol products find increasing applications in pharmaceutical industries. The utility is based on the versatility of the nitroalchols which can be converted into 1,2-aminoalcohols, amino sugars, nitro ketones, nitroalkenes, alfa-beta-unsaturated nitrocompounds, ketones, carboxylic acids, polyamino alcohols and polyhydroxylated amides[5,6]. Both aromatic and aliphatic nitro aldols play an essential role in synthetic organic chemistry.

1.1.4 Mechanism of reaction

General reaccion



Reaccion Mechanism



The steps of the mechanism involve in the first step the elimination of a proton to produce an anion.

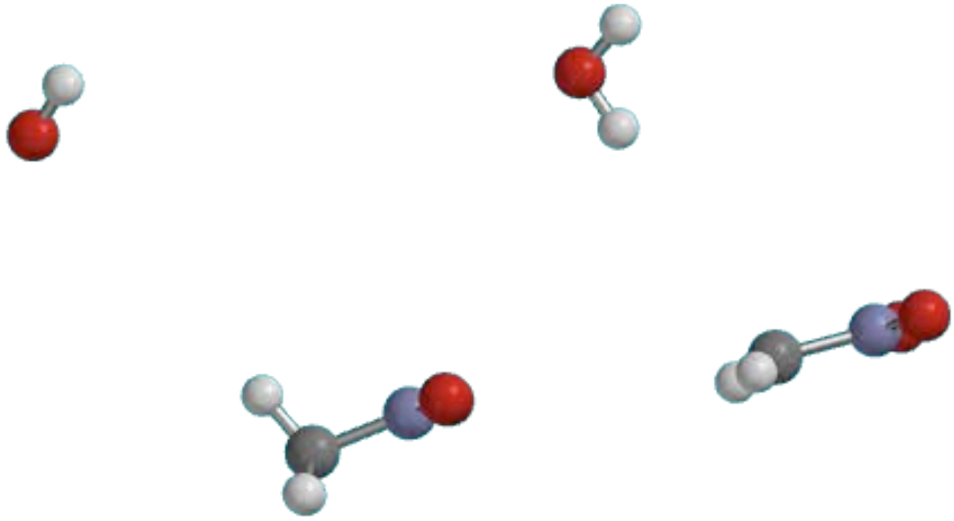


Fig 9. Formation of nitroalkane anion.

This formation in steps the base is approached in the right angle and right energy to abstract a proton.

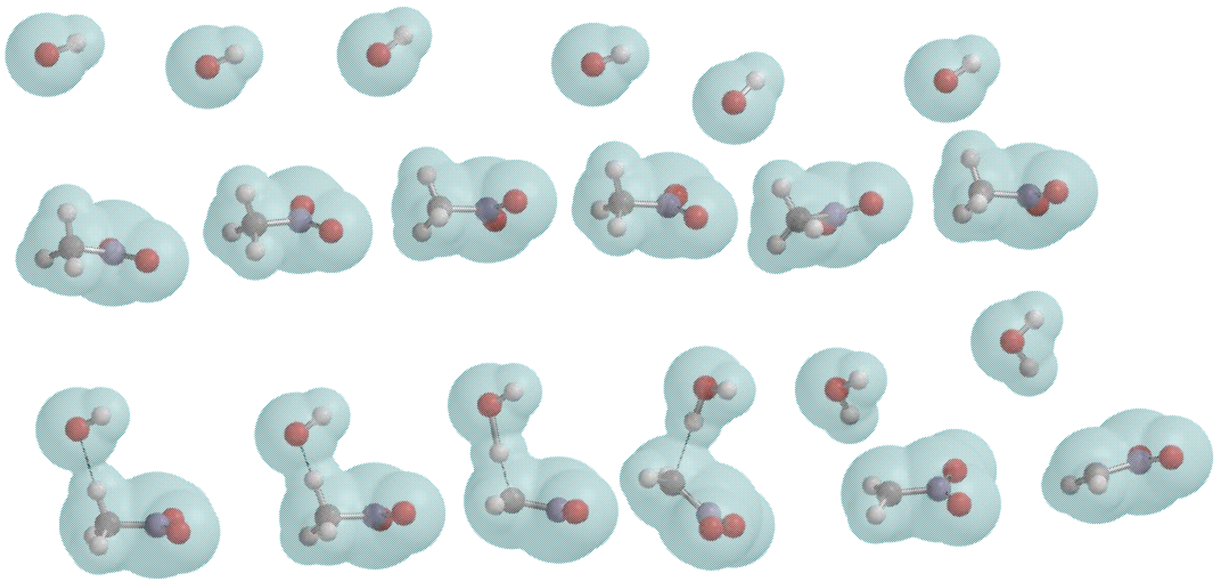


Fig 10. Sequence showing the approaching of the base the transition state and the leaving of the protonated base.

The next step is the attack of the anion to the aldehyde:

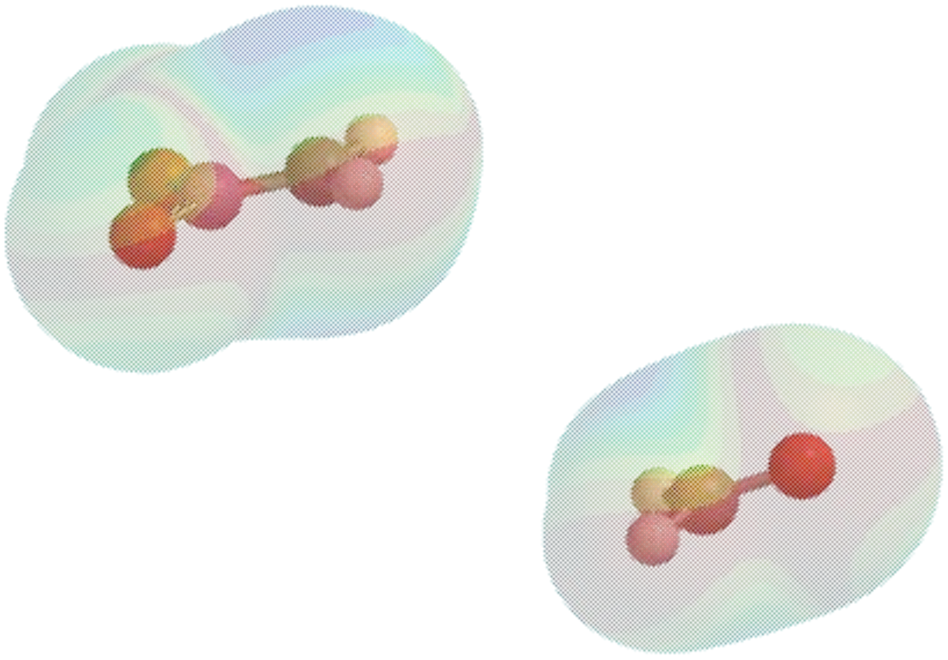


Fig 11 Attack of the anion to the aldehyde.

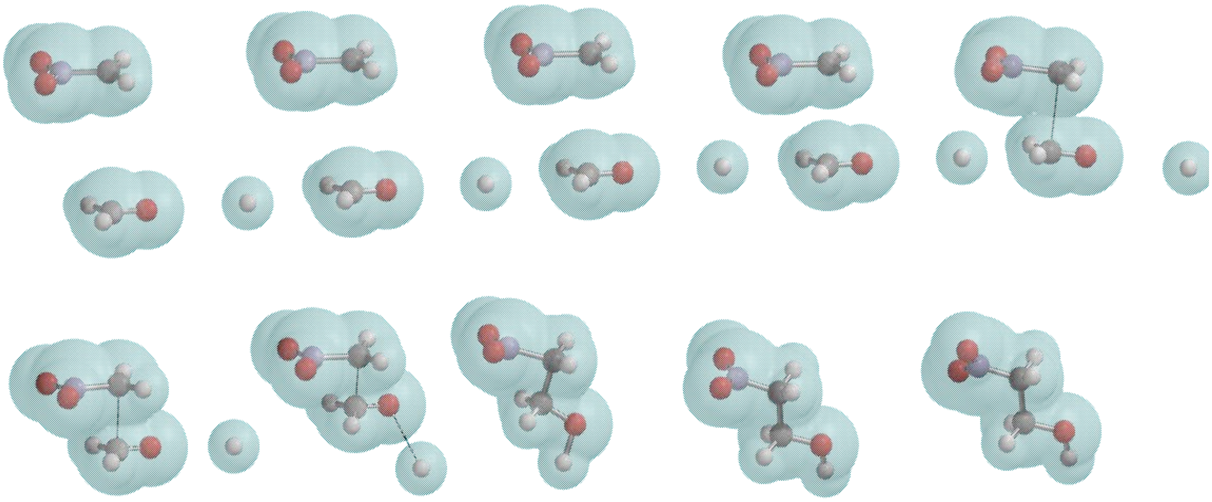


Fig 12 Second attack of the anion to the aldehyde, showing the electron density map.

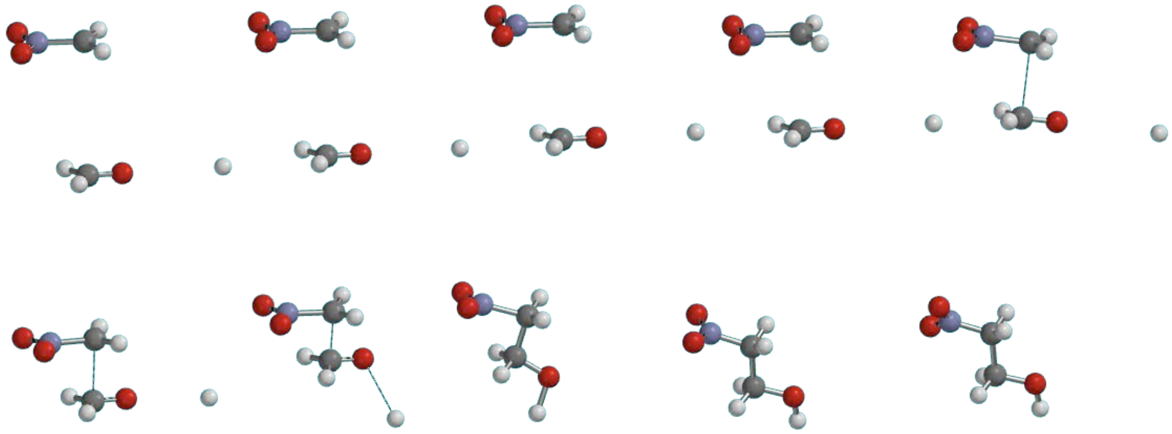


Fig 13. Anion Attack to the aldehyde. Bond forming.

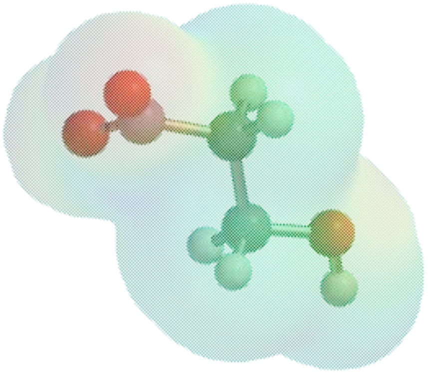


Fig 14. Final product nitro alcohol.

2 CONCLUSIONS

This work shows that with the aid of molecular modelling programs like Spartan and Odyssey, it is easy to illustrate some properties to the molecules involved in a reaction. It is possible to illustrate complex reactions in a simple way and discuss with students the different factors involved in a reaction.

AKNOWLEDGMENTS

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REFERENCES

[1] http://www.wavefun.com/

[2] Henry, L. C. R. Acad. Sci. Ser. C. 1895, 1265; Henry, L. *Bull. Soc. Chim. Fr*. **1895,** *13, 999*

[3] Sasai,H; Suzuki,T; Arai,S; Shibasaki,M. *J. Am. Chem. Soc*. **1992**,*114, 4418-4420.*

[4] Barret,A.G.M.; Robyr,C.; Spilling,C.D. J. Org. Chem. **1989**,54,1234-1236.

[5] Matt C. Wagner A, Mioskowski C. J. Org Chem**.** ***62,*** *1997 234.*

[6] Pouper .A. Fazal G. Goulet S Mar L.T. *J. Org Chem.* **64**, *1999,1356.*