

DYNAMIC REPRESENTATION TO STUDY THE MECHANISMS OF ORGANIC CHEMICAL REACTIONS BY PERSONAL COMPUTER

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We have prepared computer programs for the study of the mechanisms of 18 organic chemical reactions. All reactions are shown as changes of animated molecular structures. These programs can be used not only for individual study, but also effectively as an aid for the teacher during the usual lecture, via TV set or on a screen. In addition, we have arranged these programs so as to use them on the Local Area Network of our campus. The repeated use of them is very beneficial for our students. Their input regarding this approach has been positive and we conclude that our method of presentation is suitable and effective for the study of organic reaction mechanisms.

1 INTRODUCTION

In a first course in organic chemistry, most students have difficulty in understanding reaction mechanisms. However, when they are familiar with reaction mechanisms they like the subject. So even in an introductory course, it is important to show students what is happening when organic reactions take place. Since a personal computer has an efficient capacity to present animated pictures, at first, we programmed SN and aldol reactions using normal size molecular structures [1]. Although this is satisfactory for individual study, we can not use such small size presentations in the classroom. Therefore we modified the programs by representing magnified molecular structures by use of machine language for the expansion and the rotation of characters [2]. The enlarged representations used for the molecular structures were shown on the display or screen.

We have already reported on the programs for 12 reactions in previous papers [3][4].

In this paper, we have emphasized various aspects of the programs for the study of specific

mechanisms. Some mistakes have been corrected and 7 programs for 6 reactions and the study of the charge concept were added.

In all, 19 programs were produced, the first one being concerned with the study of nuclear charge and the other 18 showing reaction mechanisms.

2 PROGRAMMING

The programs produced work on the PC-9801 personal-computer series of NEC. The programming language is N88-BASIC. Large-size structures are displayed on a graphic screen by using [PUT@] and on a text screen by employing [LOCATE] sentences. The animation was shown by using GET and PUT sentences, and also by alternate visual presentation of the chemical entity involved. The animations were also displayed by repeated drawing of the molecular structure and deletion. We added short explanations in English on the bottom of the screen so as to allow for individual study and emphasized important aspects intentionally by changing the colour or moving the pictures in order to make our students focus on the points stressed.

3 ADOPTED REACTIONS

Most of the reactions were referenced to the text "A SHORT COURSE IN ORGANIC CHE-

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~~~~~ MAIN MENU ~~~~~	
1 CHARGE	11 ETHANOIC ACID
2 METHANE	12 AMINES
3 PROPENE	13 AMINO ACIDS
4 PROPYNE	14 MALONIC ESTER
5 ACETANILIDE	15 CANNIZZARO
6 SN1, SN2 REACTIONS	16 LITHIUM ALUMINUM
7 ORGANIC HALIDES	17 CLAISEN
8 ETHANOL	18 GRIGNARD
9 ALDOL	19 BECKMANN
10 PROPANONE	20 E N D
HIT ANY NUMBER ?	

Fig.1 REACTION MENU

MISTRY" by prof. Edward E. Burgoyne[5]. The Fig.1 shows the MENU of reactions on a display.

#### 4 PRESENTATION SYSTEMS

These programs can be used not only for individual study but also as an aid for the teacher who can explain the reaction mechanisms verbally in class and thus keep to the usual style during a lecture.

The use of the personal computer for education is appropriate for the purpose of individual study. On the other hand, in the usual classroom lecture the general style of teaching caters to mass education. Many students look at and listen to the teacher's presentation and explanation at the same time. Our presentation system consists of a personal computer, a scan converter, a projector and a screen [6]. Fig.2 shows students studying the addition of hydroxylamine to propanone.

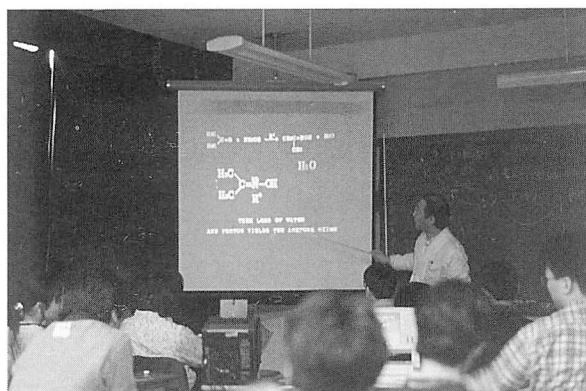


Fig.2 A Lecture Scene

Each piece of information is transmitted as

an NTSC signal from the scan converter. These programs can be used by teachers having absolutely no previous knowledge of computers. The students can study chemical reaction mechanisms in class by observing the dynamic changes represented by the computer program on a screen. The usual type of CAI is devoted to individual study, whereas, our programs may be used as an aid for the teacher in the normal lecture.

From the viewpoint of mass instruction, such a handy presentation system using a liquid crystal projector is quite helpful for not only chemical education but also other subjects.

In addition, since it can be used repeatedly, the teacher can help weaker students individually. When using a 27 inch TV set only about 10 students can see the animated reactions on the display. The programs can be employed more effectively after the lecture where chalk and a blackboard are used.

They are also provided via a Local Area Network in order to use them individually and repeatedly after class using an optional terminal computer connected with the main computer.

#### 5 CONCLUSION

We have prepared computer programs for the study of organic chemical reaction mechanisms. In all, 18 reactions are shown as continuous animated presentations. Student input (from a 40 member class) regarding this approach has been positive and we conclude that our method of presentation is suitable and effective for the study of organic reaction mechanisms.

Animated representations via television or large screen, as an alternative to the chalk and blackboard treatment, are useful for understanding organic reaction mechanisms.

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## SUPPLEMENTARY NOTES

The contents of the 19 programs shown in the Fig.1 are as follows.

### 1 CHARGE

This program was developed for the purpose of studying how to write plus or minus symbols, namely + or -, on carbon C, nitrogen N and oxygen O in molecular formulas. Students can study cases where they must write + or - symbols. At the same time, they can review covalent bonds and pairs of unshared electrons on C, N and O atoms.

### 2 METHANE

This reaction is a chlorination of methane. The mechanism is considered as a radical type. Chlorination of methane is initiated by light, so that the chlorine molecule fragments into two chlorine atoms. This starting reaction is called the chain-initiating step. Each atom has an unpaired electron shown as a coloured symbolic sign. Furthermore, the reaction follows chain-propagating and chain-terminating steps. A chlorine atom attacks the methane with formation of a methyl radical and hydrogen chloride. The highly reactive methyl radical reacts with a chlorine molecule. A molecule of chloromethane and a chlorine atom are formed. The chain-terminating steps are collisions of the free radicals with each other.

### 3 PROPENE

This shows the addition of hydrogen bromide to propene. This program was prepared for the understanding of Markovnikov's rule. The first step is the attack by a proton at the carbon of the double bond bearing the larger number of hydrogen atoms. It is realized that the slightly positive inductive effect of methyl group leads to the symbol  $\delta^+$  on the right side carbon atom. The proton attack produces a more stable tertiary carbonium ion. The reaction is completed by the attack of bromide ion at the left side carbon bearing the methyl group. The major product of this reaction is 2-bromopropane, rather than 1-bromopropane.

### 4 PROPYNE

This is an addition reaction of water to propyne. Propyne adds water when the reaction is catalyzed by sulfuric acid and mercuric ions. Initially vinyl alcohol is produced by the addition of one mole of water. The vinyl alcohol is usually unstable, as a result of the addition of a proton to the adjacent carbon, it rearranges to propanone. The program shows that the proton in the unstable enol form moves from the oxygen atom to the carbon atom dynamically to produce propanone.

### 5 ACETANILIDE

This program presents the nitration of acetanilide by mixed acid. Nitration of acetanilide with a mixture of concentrated nitric and sulfuric acids yields o- and p-nitroacetanilide. By the resonance effect, the o- and p- positions have relatively high electron density. Easy attack at the p-position gives p-nitroacetanilide. However, attack at the o-position is difficult due to the bulk of the acetyl amino group. In the latter case we show that the nitronium cation rebounds when it attacks the o-position.

### 6 S_N1, S_N2 REACTIONS

These reactions present a comparative study of hydrolysis involving two organic halides, namely 2-chloro-2-methylpropane and bromomethane. In the former case, ionization of the halide gives the t-butyl cation and the chloride ion. This step is the rate-determining step and the reaction is said to be first order, with the designation S_N1. The tertiary carbonium cation reacts with a water molecule and the loss of a proton yields t-butyl alcohol. In the latter case, i.e. reaction of bromomethane with sodium hydroxide, the nucleophilic substitution is found to be second order. This means that the rate of the reaction is proportional to both the concentration of the halide and that of the nucleophile, hydroxide ion. The hydroxide ion attacks the electron-deficient carbon atom caused by the electronegative bromine atom. On the display the transition state is shown by the flashing on and off at the O-C-Br bonds. The

transition state leads to the formation of methanol. The bromine leaves as a bromide ion from the front. This is the case for all groups bonded to the carbon atom and involved in the substitution. The configuration of the product thus becomes the opposite of that of the starting material. Such a reversal of configuration is referred to as Walden inversion.

## 7 ORGANIC HALIDES

This reaction concerns the elimination of hydrogen halide from an alkyl halide. By the hydrolysis of 2-chloro-3-methylbutane, the major product is 2-methyl-2-butanol. The minor products are 3-methyl-2-butanol and 2-methyl-2-butene. By the releasing of a chloride ion, a 2° carbonium ion is produced and migration of hydride ion can lead to a stable 3° carbocation. The major product is formed by reaction of this more stable carbocation with the hydroxide ion. Before migration occurs hydroxide ion can attack a 2° carbocation to form 3-methyl-2-butanol. The other minor product 2-methyl-2-butene is produced by elimination of a proton. The resulting electrons form a double bond. By this program, students can understand migration and elimination reactions simultaneously.

## 8 ETHANOL

This program treats the dehydration of ethanol with sulfuric acid. The initial step is protonation of the oxygen atom of ethanol. A proton from sulfuric acid attacks the oxygen atom which has two lone pairs. Elimination of a water molecule yields an ethyl carbocation. Loss of a proton from the ethyl carbocation gives ethene(ethylene) at 170°C. At lower temperature, 140°C, the carbocation reacts with another ethanol molecule and elimination of a proton produces diethylether.

## 9 ALDOL

This is a condensation reaction of ethanal(acetaldehyde). The polar carbonyl group increases the acidity of the C-H bond on the  $\alpha$ -carbon atom. Hydroxide ion abstracts a proton from the  $\alpha$ -carbon of one molecule of aldehyde. A resonance-stabilized anion is formed. The dotted lines on the C-C and C-O bonds show the effect of resonance. This enolate ion attacks the carbonyl carbon of another molecule of aldehyde. The intermediate alkoxide ion is a stronger base than a hydroxide ion. This ion abstracts a proton from water to form 3-hydroxybutanal(aldol).

## 10 PROPANONE

This is an addition reaction of hydroxylamine to propanone(acetone). The propanone reacts with hydroxylamine in the presence of an acid catalyst. The reaction starts by the attack of a proton upon an electron pair of the carbonyl oxygen. The resulting protonated carbonyl compound reacts with a molecule of hydroxylamine. The carbon having a plus charge receives the pair of electron on the nitrogen atom of the hydroxylamine. Then loss of water and a proton yields the acetone oxime. Generally, solid derivatives produced by this reaction are helpful for the identification of aldehydes and ketones.

## 11 ETHANOIC ACID

This program shows the esterification of ethanoic acid with ethanol in the presence of an acid catalyst. The reaction begins with protonation of the carbonyl oxygen atom of the carboxylic acid, namely acetic acid. Then an ethanol molecule attacks the protonated species. A proton is removed from the oxygen together with loss of a water molecule. The resulting product then loses a proton with the formation of ethyl acetate. The program shows that the resulting water molecule contains an oxygen atom from the carboxylic acid rather than the alcohol. The oxygen in the alcohol, coloured in yellow, is contained in the ester. Therefore, this reaction involves the rupture of the C-O bond of the carboxyl group in the acid. This reaction is typical nucleophilic substitution at an acyl carbon atom.

## 12 AMINES

This is a diazo-coupling reaction of p-nitroaniline with  $\beta$ -naphthol. By this program students can study the formation of the diazonium ion from an amine and an example of a coupling reaction. At first, sodium nitrite reacts with a proton to give nitrous acid and a water molecule. Then two molecules of nitrous acid produce a dinitrogen trioxide molecule and water. The dinitrogen-trioxide subsequently

reacts with the electron pair of the nitrogen atom of the amino group. Protonation of the derivative formed and loss of another proton leads to a product. The position of the plus charge on the proton, namely + symbol, changes one after another from H to O, N and H. Loss of a water molecule gives the diazonium ion of p-nitroaniline. This diazonium ion couples with the  $\beta$ -naphthol at the  $\alpha$  position to give p-nitrophenazo-naphthol, namely p-red.

### 13 AMINO ACIDS

This program deals with the condensation reaction of aspartic acid with phenylalanine. Interaction between the carboxyl group of aspartic acid and the amino group of phenylalanine gives a dipeptide, via loss of a water molecule. The reaction involves attack by the electron pair of the amino group of one amino acid on the electron deficient carbon atom of the other amino acid and leads to the formation of the dipeptide and water.

### 14 MALONIC ESTER

Pentanoic acid can be synthesized from malonic ester and propyl bromide. Diethyl malonate is used as the starting material for the malonic ester synthesis. An ethoxide ion attracts a methylene hydrogen of the diethylmalonate. The enolate anion formed is stabilized by resonance and then can be alkylated with halide, in this case, propyl bromide is used. The malonic ester can be hydrolyzed to the corresponding malonic acid. Propyl malonic acid decarboxylates readily to the monoalkyl acetic acid, namely: pentanoic acid.

### 15 CANNIZZARO

This reaction is a simultaneous oxidation-reduction involving two molecules of benzaldehyde. In the presence of concentrated alkali, for example sodium hydroxide, an aldehyde will undergo an oxidation-reduction reaction. The first step is the nucleophilic addition of a hydroxide ion to the carbonyl carbon. In the second step, oxidation-reduction takes place through transfer of a hydride ion. The overall reaction leads to a carboxylic acid, benzoic acid, in the form of its salt and an alcohol, benzyl alcohol.

### 16 LITHIUM ALUMINUM

This program shows the reduction of propanone to 2-propanol. Lithium aluminum hydride reduces a carbonyl compound to an alcohol. For example, reduction of propanone (acetone) to 2-propanol. The mechanism of the reduction of a ketone by lithium aluminum hydride is illustrated as follows. The key step in this reaction is the transfer of a hydride ion. The hydride ion acts as a nucleophile and attacks the carbonyl group. Transfer of hydride ions occurs successively until all hydrogens have been transferred. The repeated representation of this step is shown dynamically on the display. After the reaction, water is added to decompose the complex, and 2-propanol is produced.

### 17 CLAISEN

This program represents a condensation reaction between two ethyl acetate molecules to produce the acetoacetate. In the presence of a strong base, such as sodium ethoxide, ethyl acetate is transformed into ethyl acetoacetate. The ethoxide ion abstracts an  $\alpha$ -proton from the ester. The enolate anion is stabilized by resonance. The flashing on and off of C-C and C-O bonds shows the resonance-stabilized carbanion. The enolate anion attacks the carbonyl carbon of another ester molecule. The products are a  $\beta$ -keto ester and an ethoxide ion.

### 18 GRIGNARD

This program shows a reaction producing 1, 1-diphenylethanol from methylmagnesium iodide and benzophenone, namely the Grignard reaction. Here, conversion of an alkyl halide to an alkyl magnesium halide occurs. Magnesium attracts the iodide of methyl iodide. The methyl anion interacts with the magnesium iodide cation from the opposite side. This complex is known as a Grignard reagent. Then the active reagent reacts with benzophenone, an example of a carbonyl compound, to give a tertiary alcohol. This reaction occurs via an ionic mechanism. After addition of a proton, the product is

a tertiary alcohol, namely: 1,1-diphenyl ethanol.

#### 19 BECKMANN

This is a program to study the rearrangement of a ketoxime to an amide. A keto oxime is converted to an amide in the presence of an acid catalyst. An isomerization reaction known as the Beckmann rearrangement occurs. The reaction is catalysed by a proton. Loss of water leads to an initial cation. Then migration of the R group from the carbon to the nitrogen atom takes place. Almost without exception, it is found that the R group anti to the -OH group migrates. In this migration the shift of the R group is trans. The initial cation stabilizes by resonance. This cation reacts with a water molecule. Loss of a proton gives an enolic intermediate. Ketonization of the enolic intermediate gives an N-substituted amide. In this program the general formula is used for the presentation of a keto oxime.

