USING SYSTEMIC PROBLEM SOLVING (SPS) TO ASSESS STUDENT ACHIEVEMENT IN CHEMISTRY[ϒ]

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ABSTRACT

This paper focuses on the uses of systemic problem solving in chemistry at the tertiary level. Traditional problem solving (**TPS)** is a useful tool to help teachers examine recall of information, comprehension, and application. However, systemic problem solving **(SPS)** can challenge students and probe higher cognitive skills like analysis, synthesis, and evaluation. Also**,** systemic problem solving **(SPS)** helps students to connect chemistry concepts, and facts and covers a wide range of intended learning outcomes (**ILO,s)**. As an example, the type of chemical bonding in compounds, molecular structure, and their relations to stereochemistry, reflected on certain physical properties (e.g., dipole moment, IR, UV, NMR, M**S,…**), as well as chemical properties. So, by using **SPS** we assess the student achievement in three systemic levels of learning chemistry: the macro (properties, and reactions), the sub-micro (atoms, molecules, and molecular structure), and the representational (symbols, formulas, equations). In this issue we illustrate two examples on the uses of systemics in chemistry problems and their solutions. *[AJCE, 2(3), July 2012]*

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INTRODUCTION

It was stated (1-2) that much of chemistry contents, at the secondary and tertiary levels, taught and assessed in terms of facts and concepts without emphasizing conceptual understanding In the traditional linear way of teaching students are taught and assessed in many pieces of knowledge without any emphasis on connecting this knowledge into a functional framework.

For example, chemistry program in tertiary level might group learning into a separate course topics, such as stoichiometry, the periodic table, chemical bonding, molecular structure, stereochemistry, chemical equilibrium, oxidation-reduction reactions, thermo chemistry, thermodynamics, reaction mechanisms, and spectroscopic analysis. The student learns these topics in a separate way without any connection between them.

In response to these concerns, many reform efforts have called for a shift of chemistry education from memorization of facts and concepts to a deeper understanding of the subject matter. This focuses on learning for understanding and is grounded in the theory of conceptual change to explain how learners achieve conceptual understanding by connecting concepts, experience, and strategies (3).

In the last fifteen years we (4-8) designed, implemented, and evaluated the systemic approach to teaching and learning chemistry (SATLC) model that organizes the overarching concepts of chemistry into a framework from level of understanding to analysis and synthesis. Also we have designed a new type of objective tests in chemistry based on systemics (9-10). We have also proposed systemic assessment (SA) of learners to produce a more efficient evaluation of the systemic- oriented objectives in the SATL techniques and as an effective tool for assessing students' meaningful understanding of chemistry topics at the secondary and tertiary levels (11).

This paper focuses on the use of the systemic approach to teach problem solving in chemistry at the tertiary level. Traditional, problem solving (TPS) as a process has been presented to students by the teacher doing problems, in effect showing them how to do certain types of "hard" problems, and then assigning similar problems for students to practice. It is usually assumed that students will reach conceptual understanding through sufficient practice of problem solving (12). By repetitive practice on this kind of approach to problem solving many students may develop speed and accuracy for routine problems, but they fail to develop their ability to reflect on what they have done or how to adapt this to solving new different problems. Over and above, the students solve these routine problems as snapshots without any framework connecting their ideas or even solutions to the context of the problem. This approach stresses linearity in problem solving, and linear thinking; as such, it relies on memorization.

In contrast, systemic problem solving (SPS) helps students to connect concepts, facts, for example, the type of chemical bonding in compounds, and its relationship to stereochemistry with certain physical properties (e.g., dipole moment, IR, UV, NMR, MS,…), as well as chemical properties. SPS can assess student achievements at higher cognitive skills like analysis, synthesis and evaluation.

Systemic problems were designed to assess chemistry students from different class levels of faculty of science. So we can design the systemic problems into different grade levels (grades 1, 2, 3, and 4) according to the tested items.

- *In grade -1*: The students are able to identify the organic compounds from their molecular formulas and chemical behavior, as the students progress to more sophisticated levels of understanding. They can apply their understanding of bonding to monitor the changes in hybridization of the carbon atoms, and changes in physical properties like dipole moment when they move from one type of compounds to another type in the systemic.

- *In grade -2:* The students are able to do the previous items beside monitor the changes in the stereo isomerism of the compounds under consideration.
- *In grade -3*: the students are able to do the previous items beside the use of stereo chemistry to explain the mechanisms of all the reaction steps.
- *In grade-4:* At this point the students are able to do the previous items and relate them with spectroscopic data of all compounds under consideration.

WHY SYSTEMIC PROBLEM SOLVING (SPS)?

Systemic problem solving (SPS) has the following advantages:

i. it measures the students' ability to correlate between concepts;

ii. it measures the student skills to monitor the changes in physical and chemical properties in a series of chemical reactions;

iii. it measures the cognitive structure from the quantitative through the qualitative domains;

iv. it assesses students' higher-order thinking skills where they are required to analyze, synthesize, and evaluate;

v. it assesses students in a wide range of concepts in the course units; or in the different courses unites;

vi. it measures the systemic intended learning outcomes (SILOs) beside linear intended learning outcomes (LILOs);

vii. it develops the student ability to think systemically, critically, and creatively, and to solve problems systemically.

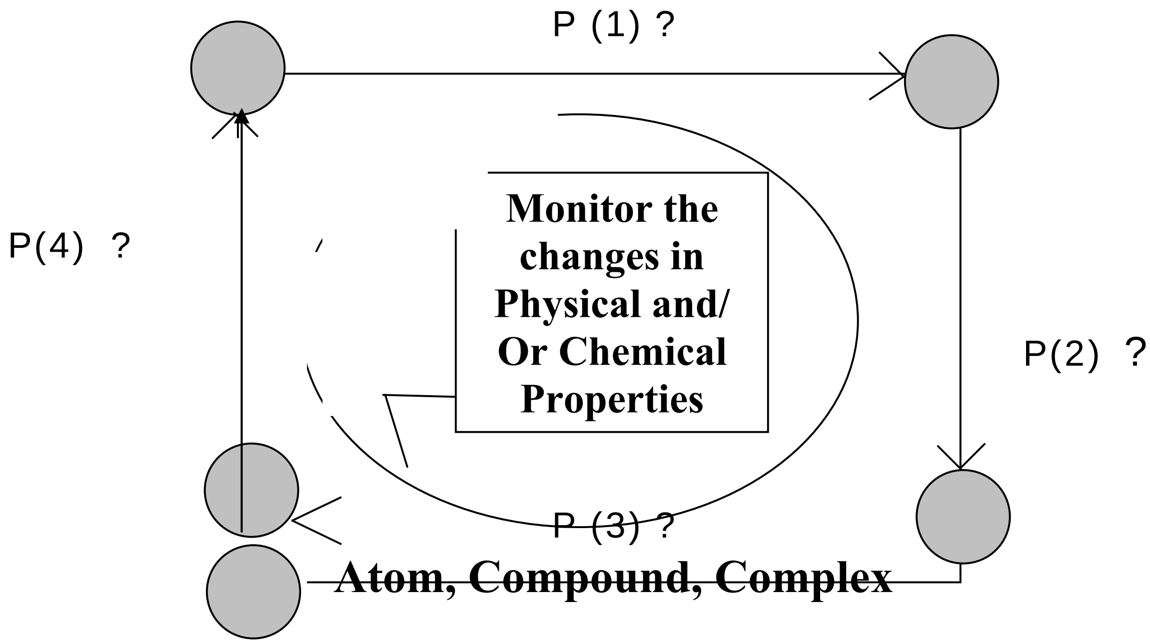
In terms of objectives of the SPS, we expect from our chemistry students after training on SPS to i) produce systemic solutions for any complex chemical problem, ii) enrich their problem solving ability, iii) monitor the changes in physical and chemical properties of different types of compounds formed in a series of reactions, iv) make maximum connections between, compounds and their properties, v) achieve three systemic levels of learning chemistry (13): the macro (properties and reactions), the sub-micro (atoms, molecules and molecular structure), and the representational (symbols, formulas and equations).

REQUIRMENTS FOR BUILDING SYSTEMIC PROBLEMS

We start the problem by giving the students the molecular formulas of all compounds in the given series of reactions with reaction conditions, and then we ask the students to do the following;

1. Write the structural formulas and names of all compounds under consideration (sub-micro and *representational levels*).
2. Write the series of chemical reactions of compounds with reagents and reaction conditions (macro and *representational levels*).
3. Build a systemic diagram of the above chemical reactions (*representational*). The size of systemic will depend on the number of compounds including in the series of reactions.
4. Then monitor the following changes among the compounds presented in the systemic diagram:
    - The state of hybridization (*sub-micro level*)
    - The stereochemistry (*macro level*)
    - Some physical properties like dipole moment (*macro level*)
    - The spectroscopic data like IR, UV, HNMR, C13NMR, MS (*macro level*)

GENERAL PRESENTATTION OF SYSTEMIC PROBLEMS (SP)



Examples: The following examples are intended to illustrate how SPS in Chemistry have been and can be used to assess 4th grade students of Faculty of Science, Ain Shams University, Egypt.

Systemic problem -1: (SP-1)

Compound $\mathbf{C_4H_8}$ (**A**) exists in two geometrical isomers and reacts with dilute alkaline $KMnO_4$ to give $\mathbf{C_4H_{10}O_2}$ (**B**). Compound (B) reacts with PBr_3 to give vicinal dibromo compound $\mathbf{C_4H_8Br_2}$ (**C**). The dibromo derivative (C) reacts with alcohol KOH to give $\mathbf{C_4H_6}$ (D).

1) Write the names and draw the structural formulas of compounds (**A** $\longrightarrow$ **D**).
2) Draw the stereo isomers of compounds (**A** $\longrightarrow$ **C**).
3) What are the types of hybridizations in compounds (**A**), (**D**)?

4) Give the systemic clockwise chemical relations between compounds (**A**$\rightarrow$ **D**) in a systemic diagram.

5) Monitor the changes of the following items in this systemic:

i) Functional groups.

ii) Reaction type for each step.

iii) Systemic change in hybridization of (C_2-C3) when we move from compound (**A to B-C-D**)

iv) Systemic change in stereoisomerism when we move from compound (**A to B-C- D**)

v) Systemic change in **IR** bands when we move from compound (**A to B-C- D**)

vi) Systemic change in **1H. N. M. R**. signals, when we move from compound (**A to B-C- D)**

Answer:

1) **Butene - 2**: $CH_3-\underset{}{\overset{H}{\overset{|}{C}}}=\overset{H}{\overset{|}{C}}-CH3$

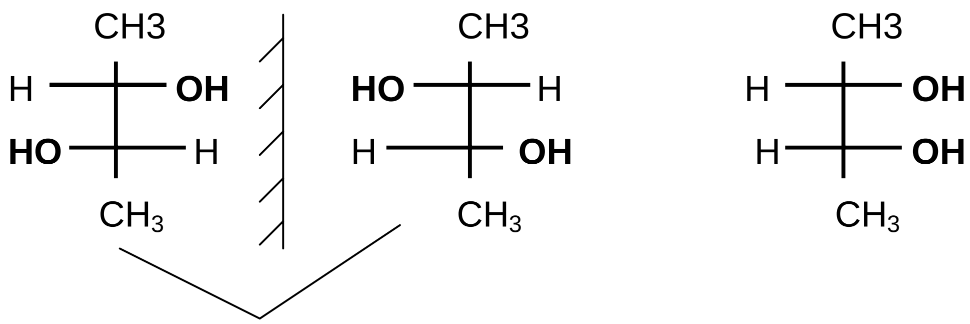
2 , 3 –Dihydroxy butane: $CH_3-\underset{OH}{\underset{|}{CH}}-\underset{OH}{\underset{|}{CH}}-CH_3$

2, 3-Dibromobutane: $CH_3-\underset{Br}{\underset{|}{CH}}-\underset{Br}{\underset{|}{CH}}-CH_3$

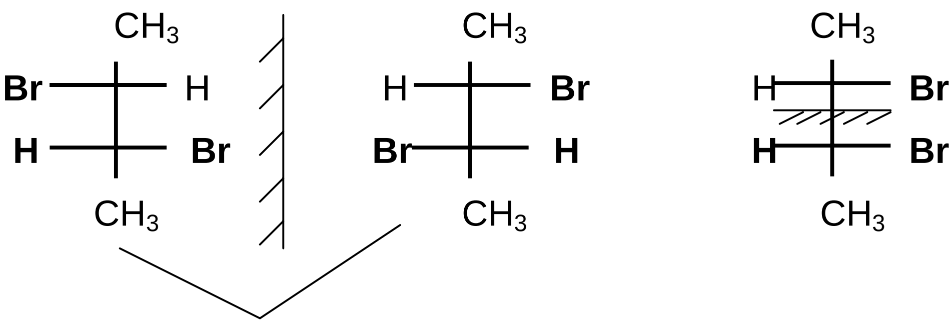
2 - Butyne: $CH_3-C\equiv C-CH_3$

2)

Z - Butene– 2 **E - Butene- 2**



(DL) **(meso)**

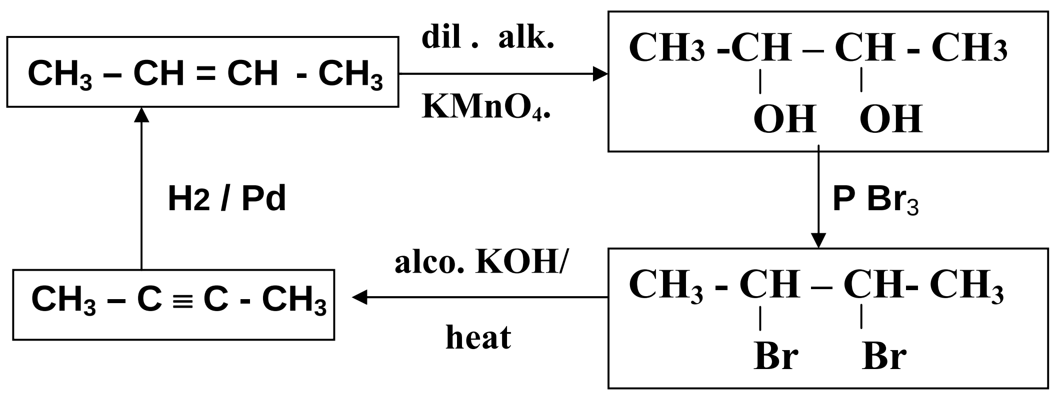


(DL) **(meso)**

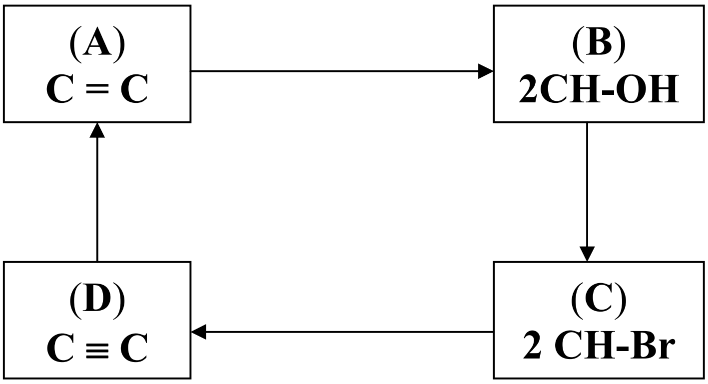
3) $CH_3 - \overset{\overset{H}{|}}{C} = \overset{\overset{H}{|}}{C} - CH_3$ **(A)** $CH_3 - C \equiv C - CH_3$ **(D)**

2 3 2 3

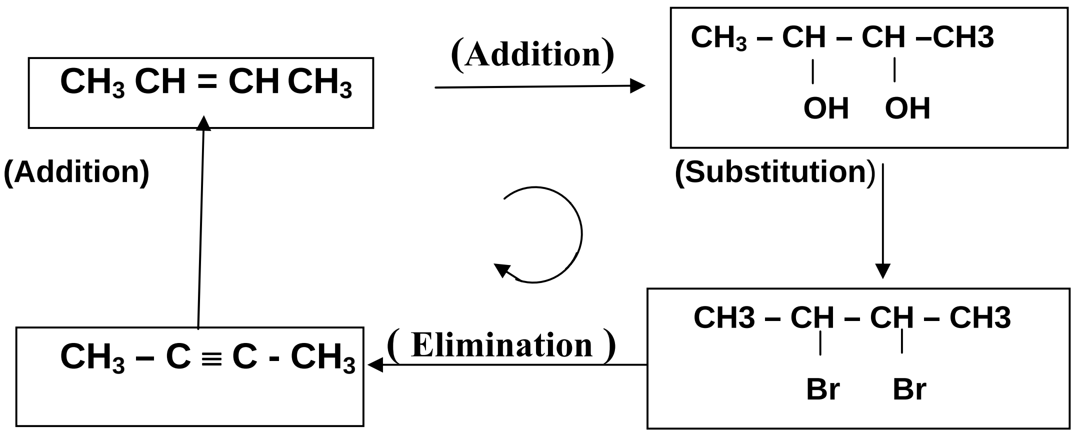
(Sp2) **(Sp3)**

4) 

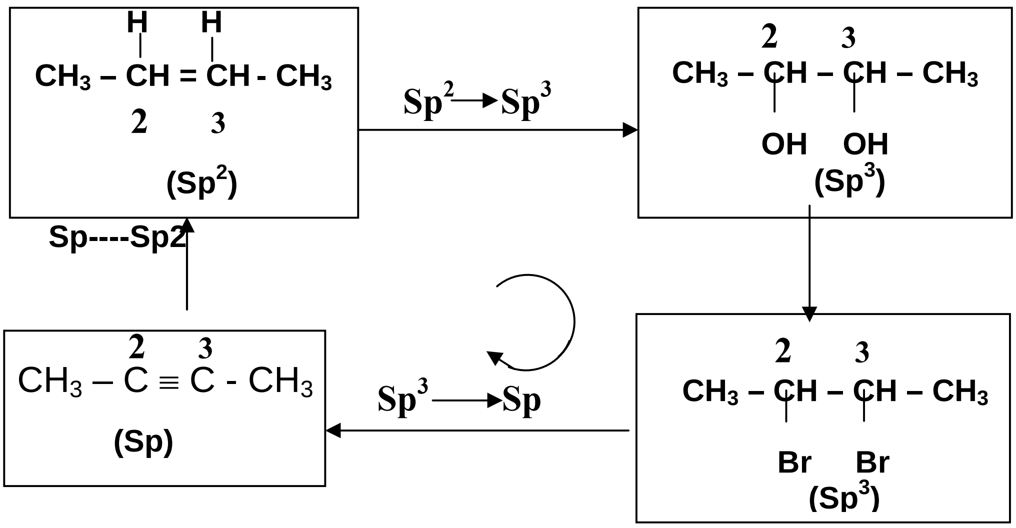
5) –i Monitory of the Changes in the Functional Groups:



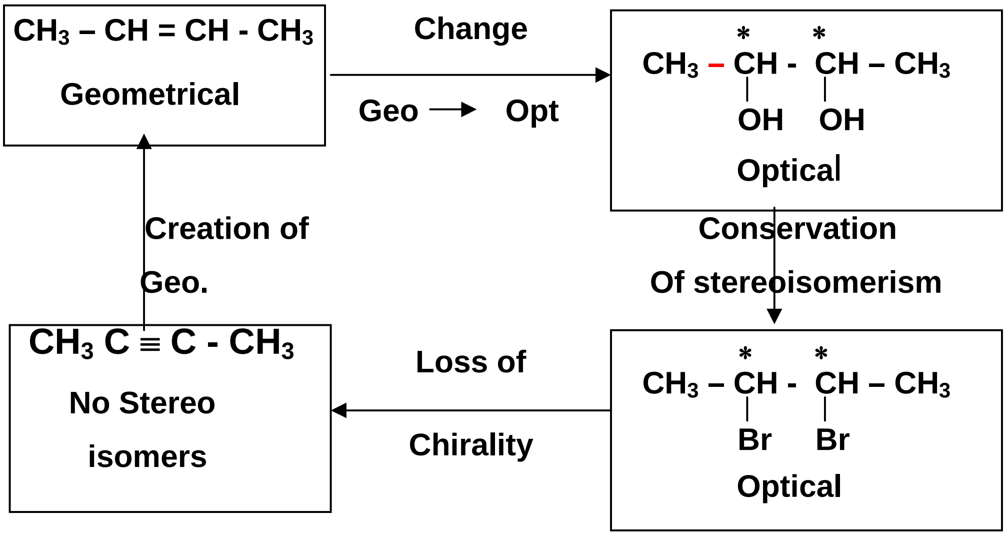
(ii) Monitory of the Change in the reactions type:



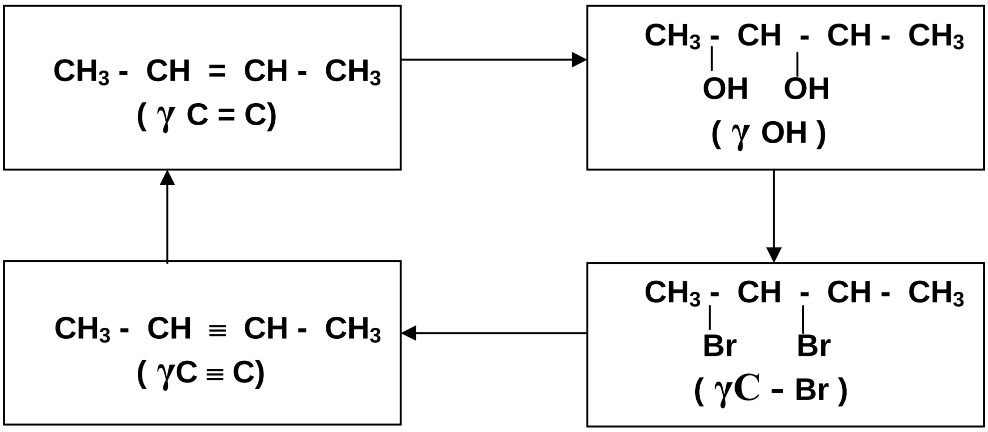
(iii) Monitory of the Systemic Change in hybridization of (C2- C3)



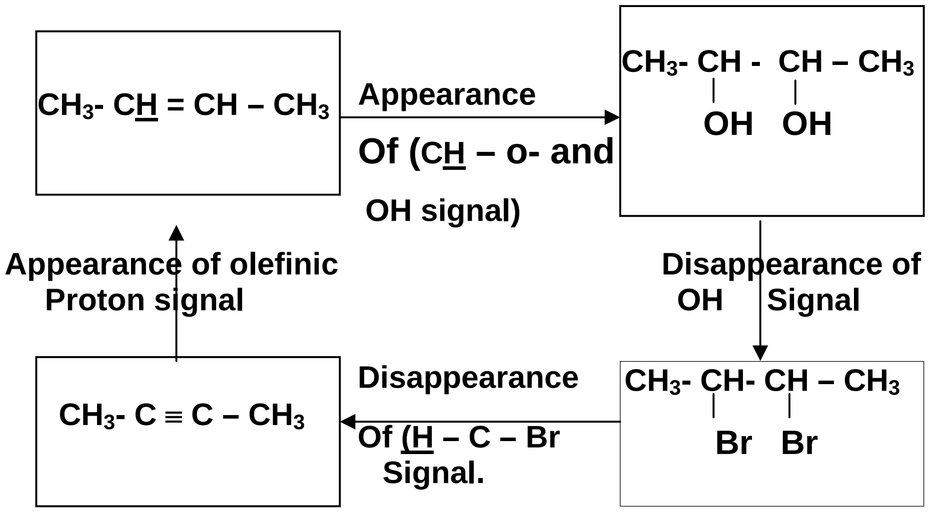
iv) **Monitory of the Systemic Change in the stereoisomerism:**



(V) **Monitory of the Systemic Change in the IR bands:**



(vi) Monitory of the Systemic Change in the 1HNMR:



Systemic problem -2: (SP-2)

Aromatic compound $\mathbf{C_7H_8}$ (**A**) reacts with Cr_2O_3 / acetic acid to give $\mathbf{C_7H_6O}$ (**B**) which reacts with $KMnO_4$ / Conc. H_2SO_4 to give $\mathbf{C_7H_6O_2}$ (**C**). By heating (**C**) with soda lime under dry conditions gives liquid (**E**).

(1) Write the names and draw the structural formulas of Compounds (**A**$\longrightarrow$**D**).

(2) Give the systemic clockwise chemical relations between compounds (**A** $\longrightarrow$ **D**) in a systemic diagram.

(3) Monitor the changes of the following items in the systemics.

a. Functional groups

b. Type of reaction in each step.

c. I. R spectra.

d. 1H. N. M. R. Spectra.

e. Molecular ion peaks in the Mass spectra.

f. Ease of reactions with Electrophiles.

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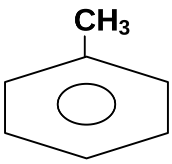
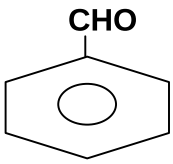
Answer:

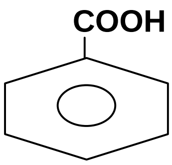
1)



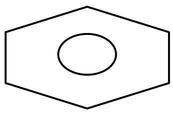
Toluene (A)



Benzaldehyde (B)

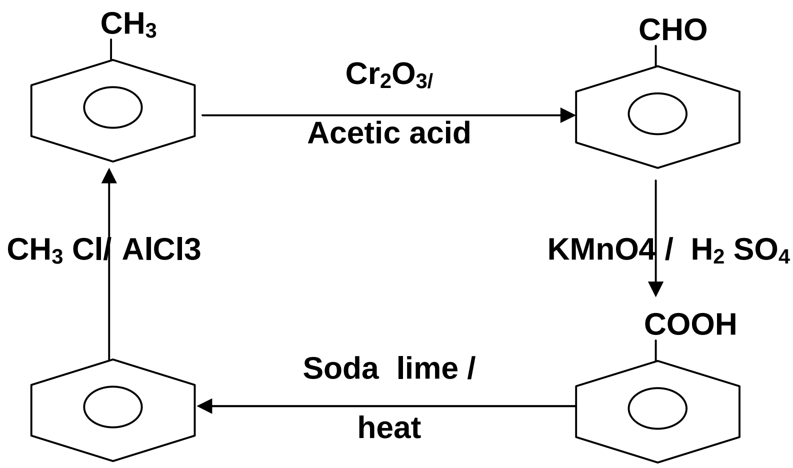


Benzoic acid (C)

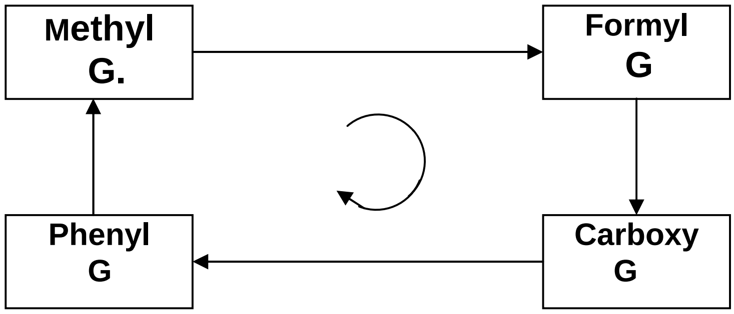


Benzene (D)

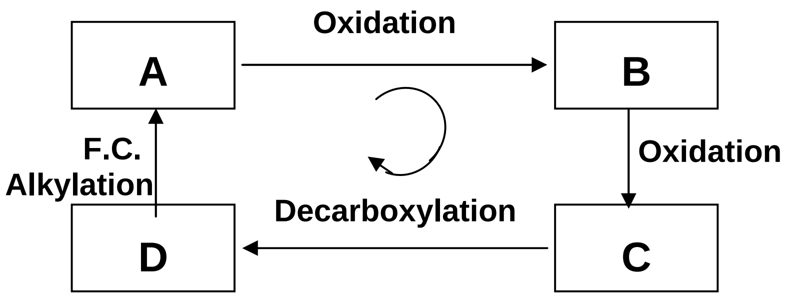
2)



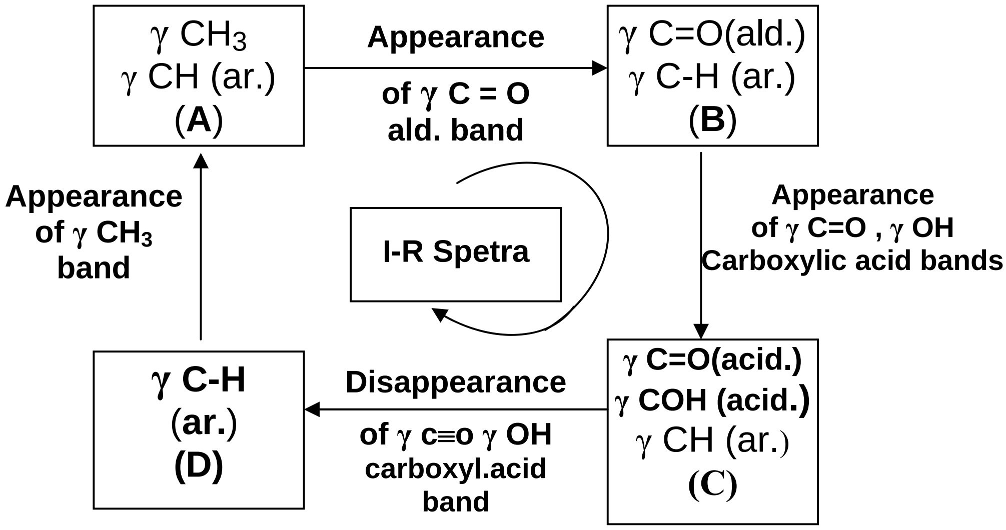
3. i.



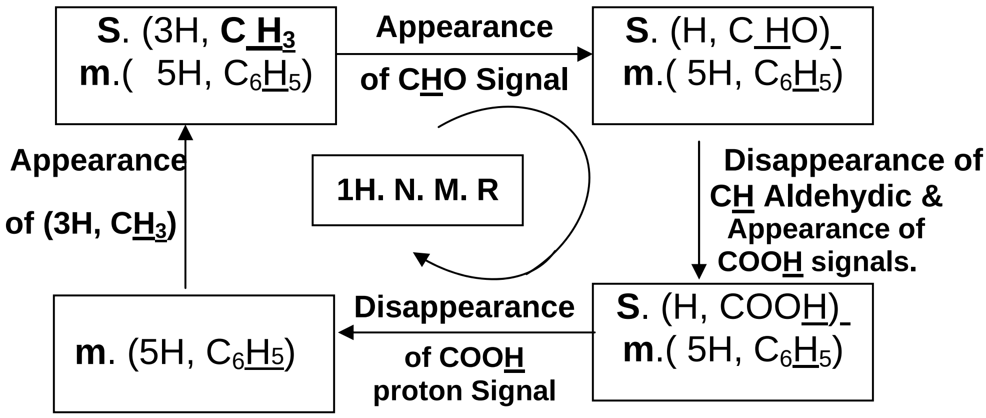
3. ii.



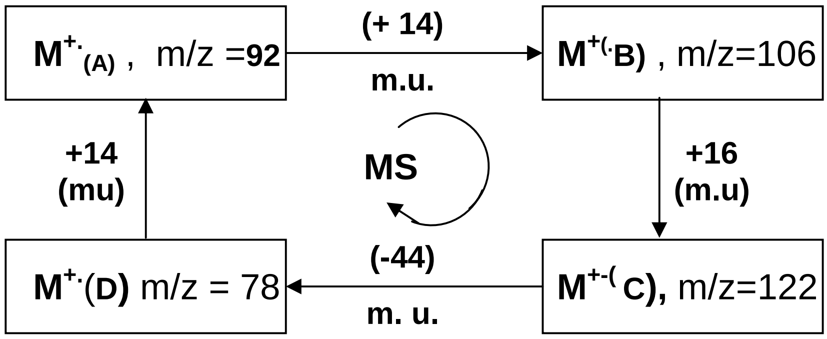
3. iii <u>Monitory of the Systemic Change in the IR- Spectra</u>.



3. iv. <u>Monitory of the Systemic Change in the 1HNMR:</u>

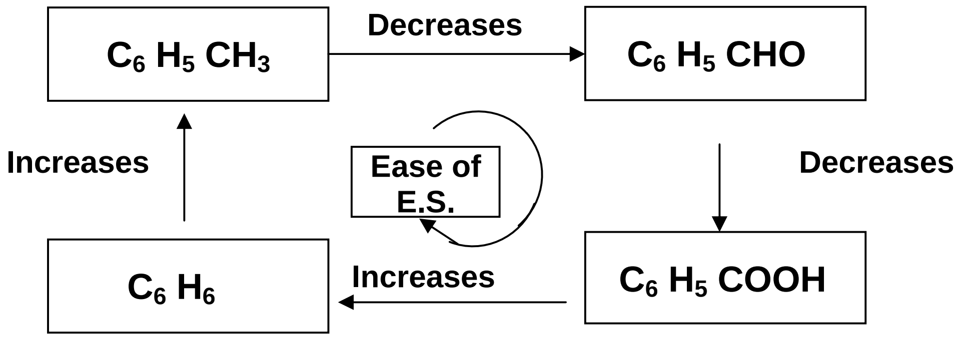


3. V. Monitory of the Systemic Change in Mass Spectra:



(mu = Mass Unites)

3.vi. Monitory of the Systemic Change in Electrophilic substitution.



By using SPS strategy students reached to higher levels of competence as the new concepts are linked to the existing concepts in their cognitive structure. This is in contrast to a traditional linear problem solving which gives the students more fragmented view of the discipline in which students often fail to integrate their knowledge.

REFERENCES

1. Hesse, J. & Anderson, C.W. (1992). Students Conceptions of Chemical Change. *Journal of Research in Science Teaching* 29 (3) 277-299.
2. Phelps, A. (1996). Teaching to Enhance Problem Solving.: It's more than just numbers. *Journal of Chemical Education* 73(4) 301-304.
3. Smith, J.P., diSessa, A. & Roschelle, J. (1993). Misconceptions Reconceived: A Constructivist Analysis of Knowledge in Transition. *The Journal of the Learning Sciences* 3(2) 115-163.
4. Fahmy, A. F. M. and Lagowski, J. J. (1999).The Use of Systemic Approach in Teaching and Learning for 21st Century, J. J. Pure Appl. Chem, 71,
5. Fahmy,A.F.M ; Lagowski J (2003). Systemic Reform in Chemical Education an International Perspective, J. Chem. Educ. 80, 1078–1083.
6. Fahmy; A.F.M. J. Lagowski, J. (2011). The systemic approach to teaching and learning (SATL) A 10-year review,AJCE.1 (1), 29-47.
7. Lagowsk, J; Fahmy, A.F.M. (2011). The systemic approach to teaching and Learning (SATL): operational steps for building teaching units,AJCE.1 (1), 62-80.
8. Fahmy, A.F.M.; Said, A, (2011),The systemic approach to teaching and learning water chemistry, AJCE.1 (2), 62-80.
9. Fahmy, A. F. M.; Lagowski, J. J. (2004). Using SATL Techniques to Assess Student achievement. In Proceedings, 18th International Conference on Chemical Education, August, 3-8, Istanbul, Turkey].
10. Fahmy,A.F.M, Lagowski,J.J. (2006),Systemic Multiple Choice Questions (SMCQs) in Chemistry [19th ICCE, Seoul, South Korea, August 12-17].
11. Fahmy, A. F. M.; Lagowski, J. J.(2012). Systemic assessment as a new tool for assessing students learning in chemistry using SATL Methods; Systemic True False [STFQs] and Systemic Sequencing [SSQs] Question Types, AJCE.2(2) 57-78.
12. Hollingworth, R,(2001) Chemical Education Journal (CEJ) 5(.2), http://www.juen.ac.jp/scien/cssj/cejrnlE.html
13. Johnstone A.H. (2000). Teaching of Chemistry – logical or psychological? CERAPIE 1, 9.
14. Barke ,H.D.(2012). Two ideas in the redox reactions, AJCE.2(2), 32-50.