Actual Molecule of Benzene and its Resonance Structures: An Explanation Using the Analogy of a Macro Entity and Its Sketches

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ABSTRACT

Confusions about basic concepts are common among number of students during early stages of education in any field, which later on reduced as they got more advance knowledge about their subject. This study is focused on the most important basic concept of chemistry i.e. Resonance phenomena to explain the benzene molecule structure and its canonical forms. Enormous literature available on this topic; however, still chemistry students find difficult to understand the difference between a real molecular moiety and it's proposed sketch or model at early stages of their learning. To solve this issue macro entity and its sketches analogy used in front of students and found it more effective. A tough or difficult topic during class lecture can be simplified by using a suitable analogy with minimal resources.

GRAPHICAL ABSTRACT

KEYWORDS

Resonance Theory, Analogies, Molecular Properties / Structure, Organic Chemistry, Introductory Chemistry

INTRODUCTION

Resonance theory is one of the most important constituent of structural chemistry,[1] still highly useful and important section of the pedagogy of organic chemistry concepts.[2] Understanding of resonance phenomena play a central role in basic concepts of organic chemistry.[3] During basic concepts lecture students often demonstrate difficulty with the resonance phenomena.[4],[5] Misconceptions in student's mind about basic concepts (i.e. resonance structure)[6] in undergraduates chemistry class sometime create an environment which force the teacher to think out of the box[7] and try to explain these questions using a story[8] or analogy[9] i.e. Wheland enthusiast of resonance theory in his book about resonance phenomena used the analogy of mule which is a hybrid between a horse and a donkey,[10] in an attempt to explain the theories of intermediate stages and of mesomerism picture of the benzene molecule. Real benzene molecule is a hybrid moiety, not identical with either of the Kekulé's structure or proposed canonical forms but intermediate between them.[11] In some situations this use of imaginary institution to describe real molecules was incompatible with the dialectical materialism.[10-12] Similar type of problem faced by the chemistry teachers while explaining the structure of organic compounds[13] especially the canonical forms and the actual molecule while discussing the Rules of resonance.[14] During basic chemistry courses all over the world a small fraction of students struggle with basic concepts of chemistry i.e. resonance phenomena and number of instructors observed this concept difficult for students to grasp and understand.[15] Sometime this small fraction of students raise simple questions during the lecture,[16] which are ignored by the teachers to save the lecture time and utility on more important concepts.[17] However suitable analogy presentation related to the query or topic make it easy,[18],[19] understandable and develop students interest in the subject [20],[21],[22] i.e. cartoon characters analogy for resonance by R. Starkey. [23]

Explanation of Canonical Structure Vs Real Molecule in Resonance Phenomena:

Chemistry educators observed different misconceptions in students mind about fundamental concepts of organic chemistry,[15] i.e. "*All canonical forms do not contribute equally to the true molecule and it is more stable than all these canonical forms*".[14] Students immediately raise

questions, what is real molecule and why we are unable to draw its exact structure?[6] To explain these questions educators adopt different strategies i.e. Wheland analogy,[11] however students curiosity remain unsatisfied.[24] Sometime few raise objection on Wheland that mule, donkey and horse are three different animals and all has existence, while here we are discussing only one molecule that is benzene molecule. After the flash of these questions more students join that small fraction of students with doubts. In such situations an effective approach or demonstration required to explain these basic concepts more successfully in limited resources. To explain the difference between canonical structure and real molecule in resonance phenomena following methodology has been developed and evaluated.

Methodology:

This methodology adopted during lectures on basic chemistry concepts in the Department of Chemistry, Government College University Faisalabad, Pakistan (GCUF) and University Community College of GCUF. Methodology is based on question-answer and sketch analogy to involve students. Participation of students during lecture explore their quires and thoughts about the subject. Questions and answers can be modified according to subject and students level of understanding or where instructor found explanation is not clear.

Questions and Answers:

1. Question: Class can we represent a person in any discussion or story by writing his name or using his photo?

Answer: Yes we can represent a person by writing his name or using his photo.

2. Question: In chemistry how we can represent a chemical substance?

Answer: Through its name, chemical formula, CAS Registry Number or draw its structure to discuss it.

3. Question: Why in organic reactions/equations mostly compounds are represented through structural formula?

Answer: Due to the isomerism phenomenon i.e. ethanol and dimethyl ether both have same chemical formula C_2H_6O. "*A structural formula tells us not only how many atoms of what kinds*

are in a molecule but also how they are joined together" (ref *25*, p 104)[25]

Sketch Analogy:

After these questions and answers discussion instructor can draw few sketches about himself (or any student from the class) on white/black board or display photos or emojis on screen according to the situation (other examples i.e. cat, dog etc. sketches can also be presented however involvement of person within the class make the argument more effective and easy to present) along with different structure of benzene molecule proposed by different scientists (See **Figure 1**).

After showing **Figure 1**, ask the students following questions:

Question: Is column **A**, **B** and **C** photos represents the person under consideration i.e. instructor's sketch?

Answer: Yes.

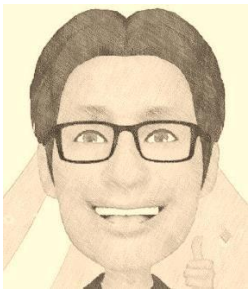
	A	B	C	D
Instructor's sketch				Instructor/student standing in front of class discussing Resonance Theory
Benzene molecule sketch				Isolated benzene molecule in liquid benzene inside the bottle or container.

Figure 1. Four different situations (**A**) Cartoon sketch vs. Claus Benzene, (**B**) Pencil sketch vs. Dewar Benzene, (**C**) Photo sketch vs. Kekule's Benzene and (**D**) Real benzene molecule vs. Instructor in class.

Question: In current situation which photo/sketch represents the person under consideration most and which one least?

Answer: In instructors sketch row, photo in column **C** represents instructor more while emoji in column **A** represents least.

Then continue that even **C** does not represent instructor or person under consideration completely because it only represent his one side view which is in front of camera, it also does not move as the instructor/student is moving in front of whole class, which create fourth situation **D** real existence of a person. Due to limitations of two dimensional sketch on paper it is not

possible to create a duplicate copy of a person on a paper. Similarly, same case is with the benzene molecule sketch row where three different canonical structure in column **A**, **B** and **C** are drawn, however these canonical structures provide us an opportunity to discuss a molecule on a paper, on board or in a book. Although we are unable to represent a real benzene molecule which is present in liquid benzene inside the bottle on the desk which also creates fourth situation **D**. By following resonance rules it is possible to represent one molecule of benzene with the help of different sketches or structures and discuss it. These structures of benzene molecule under consideration is based on different type of scientific evidences and observations.

In science observations or evidences can be divided into two groups direct and indirect evidence/observation. Direct observation or evidence that is perceived through our five senses without any instrumental assistance, while indirect evidence/observation perceived by our sense organs with the help of an instrument i.e. microscope, electron microscope, camera or any suitable instrument to measure a physical parameter or phenomena. In chemistry we use different instrument like nuclear magnetic resonance or mass spectrometer etc. which give us indirect evidence about the existence of atoms and their linkages in molecules. On the basis of these pieces of evidence we draw a model or structure to represent molecules. Just like sketches or photos of a person/student under consideration on screen give us clue or information about his body features and on the basis of these features we can assume that this sketch or photo represents a specific person, while presence of that person in front of the class is a real existence. Similarly molecular structures or atomic models are drawn on the basis of indirect evidences also represents molecules and atoms which also has existence, however we are unable to see them even they are in front of us due to their extreme small size, which is smaller than the wavelength of visible light detected by human eye. Likewise visible light spectrum consist of seven colours which can be observed when sunlight is passed through a prism.

Benzene which is present in the bottle also consist of small molecules which we are unable to see with our eyes, doesn't mean that these molecules don't have existence. So scientist built a model of benzene molecule on the basis of indirect evidences obtained through different instruments and techniques (see **Figure 2**). All these structures can never be a substitute of real

molecule just like a sketch or photo cannot replace the real existence of person a body because sketch or structural representations on paper or board has few defects or limitations which are not present in real molecule that's why we say real molecule is more stable than all its canonical forms or representation.

Dewar benzene structures

Kekule benzene structure and resonance hybrid

Figure 2: Canonical Structures of Benzene Molecule

After this explanation effectiveness of sketch analogy can be checked through a quiz in next lecture or session example of such quiz is presented below.

Methodology to Check Macro entity and its Sketch Analogy Effectiveness:

To check the effectiveness of above analogy, conduct the short quiz survey among three different levels of students, **Level I** (Higher Secondary School), **Level II** (BS Chemistry) and **Level III** (MS Chemistry), with class strength ranges from 15 – 30 students per class. This quiz survey consist of five statements with true and false option along with one short question with three to four line answer limit to keep the response to the point within stipulated time (see **Box 1**). On the basis of quiz result each level students are further subdivided into three subgroups **A**, **B** and **C.** Subgroup **A = Have Understanding**: Students can clearly explain the real molecule and its canonical structures, subgroup **B = Confused** : Students have confusion between real molecule and its canonical structures and subgroup **C = Have no Idea**: Student have no knowledge or no idea about real molecule or did not responded. From each level about 150 students response on average was collected and summarized the conclusion of quiz survey in the form of students percentage in each subgroup on graph (see **Figure 3**). This short quiz survey is conducted into two parts **Part – 1** before the lecture and **Part – 2** after the lecture with the gap of one or two days from the students who attended the lecture "*Demonstration to Explain the Difference Between Resonance Structure and Real Molecular structure*" using above discussed methodology. **Part – 1** quiz results reflects the students previous knowledge and understand about resonance structure and real molecule, while **Part – 2** results indicates the significance of above used analogy and demonstration to explain the basic concept of canonical forms and real molecule

Box 1: Quiz before and after Discussion

Part – 1 Quiz survey before discussion Time 10 min

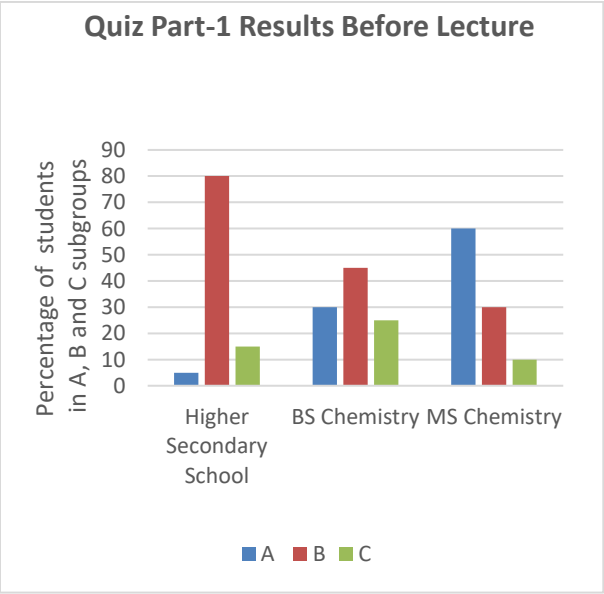
1. **Choose the Correct Option**			
i).	Structure drawn on the Paper are the real molecules.	Yes	NO
ii).	Structure drawn on the paper are the sketches or representation of real molecules.	Yes	NO
iii).	Real molecule has existence.	Yes	NO
iv).	Each canonical structure or form of a molecule has existence.	Yes	NO
v).	Humans unable to see real molecular structure due to	Small size	Non existence

2. Explain real molecule and its canonical structure in three to four lines.

Part – 2 Quiz survey after discussion Time 10 min

1. **Choose the Correct Option**			
i).	Real molecules can be represented through structure drawn on the Paper.	True	False
ii).	Canonical structures are the ways to discuss a real molecule's structure.	True	False
iii).	We are unable to see a real molecule so it has no defined structure.	True	False
iv).	There is no need to discuss canonical structures of a molecule in resonance.	True	False
v).	Only visible substances have proper structure.	True	False
vi).	Different structure of benzene are its canonical forms while real molecule is more stable than all of these.	True	False

2. Explain real molecule and its canonical structure in three to four lines.



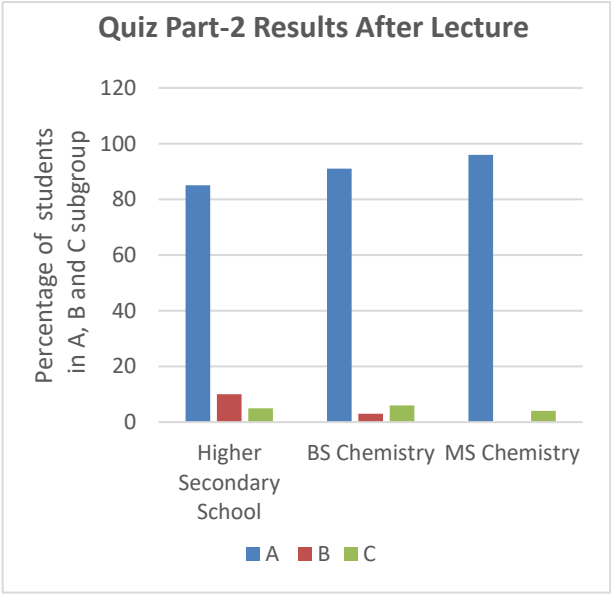


Figure 3 Conclusion of Quiz Part-1 & Part -2 results before and after lecture respectively. **A**, **B** and **C** subgroups on the basis of students responses (**A = Have Understanding**, **B = Confused** and **C = Have no Idea)**, Standard error : ± 1.4

Conclusion :

Quiz Part – 1 results show that students at Higher Secondary School (HSS) level are most

confused about canonical forms and real molecule concept while MS Chemistry level students concept about the topic are more clear, however after lecture and demonstration confusion of students at all level decreased. More interestingly at HSS level students concept about canonical form vs real molecule become more clear and understanding level increased from 5% to 85% which indicates that living organism sketch analogy is a powerful tool to explain the difference between canonical forms and real molecule. Views and downloads at https://chemrxiv.org after submission of above discussed content proves that real molecule structure and its canonical forms explanation still searched by the chemist and chemistry students. Thus a simple analogy act as a powerful tool to develop the interest of students in subject with better elucidation, so there is need to share more such personal experiences and analogies to spread scientific knowledge more effectively all around the world. We can also use any other living organism sketches i.e. dog, cat etc. as an example, however different sketches and photos of instructor or student from the class and their presence in front of class act as an influential instrument for students understanding toward the difference between canonical structure and real molecule.

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