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An Introductory Organic Chemistry Review Homework Exercise: Deriving Potential Mechanisms for Glucose Ring Opening in Mutarotation

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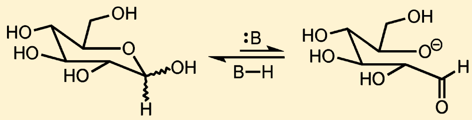
Supporting Information

ABSTRACT: A unique homework assignment has been designed as a review exercise to be implemented near the end of the one-year undergraduate organic chemistry sequence. Within the framework of the exercise, students derive potential mechanisms for glucose ring opening in the aqueous mutarotation process. In this endeavor, 21 general review principles are addressed. The pedagogical approach employed is referred to as the question-guided, data-driven exercise. Students derive principles from answering questions posed and from the interpretation of provided structural (NMR spectroscopy) and kinetic data (generated in a research laboratory). An emphasis on designing experiments to address specific questions is incorporated throughout. The questions posited, and the data provided, are formulated to build on one another and thus emphasize a student's knowledge of each preceding concept. The concepts reviewed are as folllows: resonance structures, isomers, conformations, electrophiles, nucleophiles, thermodynamics versus kinetics, enthalpic and entropic considerations regarding intramolecular cyclization, hybridization, geometry, chirality, Brønsted–Lowry acid–base theory, pH, pK_a, hydrogen bonding, and NMR spectroscopy (chemical shift, inductive effects on shielding and deshielding, spin–spin splitting, and integration).



KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, Inquiry-Based/Discovery Learning, Problem Solving/Decision Making, Bronsted-Lowry Acids/Bases, Carbohydrates, Equilibrium, NMR Spectroscopy, Mechanisms of Reactions*

INTRODUCTION

A unique homework assignment has been designed as a review exercise to be implemented near the end of the one-year introductory organic chemistry sequence. Within the framework of the exercise, a student will derive potential mechanisms for glucose ring opening in the mutarotation process.

OVERVIEW OF EXERCISE

The exercise (Supporting Information) opens with a brief treatment on glucose structure and the concept of mutarotation. A question-driven approach follows where students derive principles from answering questions posed and from the interpretation of provided structural and kinetic data (generated in a research laboratory). The questions posited, and the data provided, are formulated to build upon one another and thus emphasize a student's knowledge of each preceding concept. An emphasis on designing experiments to address specific questions is incorporated throughout. Within the framework of the exercise, students derive potential mechanisms for glucose ring opening in the mutarotation process. In this endeavor, 21 general review principles are addressed, each with a link to online resources to equip students to proceed through the exercise. These review elements are

- Resonance structures vs isomers vs conformations
- Electrophiles and nucleophiles
- Mechanism; thermodynamics; kinetics
- Enthalpic and entropic considerations regarding intramolecular cyclization
- Hybridization; geometry; chirality
- Brønsted–Lowry acid–base theory
- pH; pK_a
- Hydrogen bonding
- Nuclear magnetic resonance spectroscopy
  - Chemical shift; inductive effects on shielding and deshielding
  - Spin–spin splitting; integration

The exercise has 50 questions structured such that the answer from a preceding question serves as the basis for answering the present question.

PEDAGOGICAL APPROACH TO EXERCISE

Historically, both lecture and laboratory concepts are conveyed to second-year organic chemistry students in a context whereby principles are simply stated, and experimental data, if presented or collected, are used to justify a previously established principle. This principle-first-then-data justification approach is a time-efficient method of content delivery, but it does come

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with trade-offs.[1] This traditional approach does not develop the logic of the scientific method. The result of such an approach is that independent concepts are relegated to mere stated facts that need to be memorized rather than being derived via the interpretation of data. Concepts delivered in such a fashion are unlikely to have further utility in the generation of new principles or in the explanation of related phenomena. In the scientific process, principles are derived *from* the interpretation of data. Because students in the lecture component of a course are typically not presented with data and, instead, simply are given a principle stated as fact, they cannot see the process of how principles were generated and how that same process can be applied to generate new principles. Students then struggle when challenged with the task of interpreting data (as in open-ended research). They do not make important connections because they have had very few examples from which to draw. To ensure that students leave organic chemistry with a firm grasp of the problem-solving skills that will enable them to derive principles from data, the question-driven laboratory experiment (QDLE) approach, whereby data interpretation leads to principle, was developed[2] and applied.[3] This pedagogy was extended to the question-guided data-driven lecture approach (QGDDL).[4] Here, the homework exercise is structured as a question-guided data-driven exercise (QGDDE).

■ GENERAL UNIQUENESS OF EXERCISE

To date, only two homework sets for use in organic chemistry have been published.[3,5] Neither of these possesses a review element, and only one of them involves a data-driven approach, in general.[3] No exercises regarding mutarotation mechanisms have been published, though many mutarotation experiments exist in the literature.[6−11] To our knowledge, no experiment/exercise involving the derivation of glucose mutarotation mechanisms of any sort exists in the literature. Interestingly, the concept of glucose mutarotation is very central in Organic Chemistry textbooks. Each of the seven current mainstream texts evaluated have a treatment on glucose mutarotation.[12−18] In these seven texts, while schemes describing the mutarotation process are forwarded, there is no ring-opening mechanism posited. Partial mechanisms for ring-closing are shown in five of the texts,[12,15−18] but no detail as to acid or base effects are addressed.

■ IMPLEMENTATION OF EXERCISE

Specifically, a question-guided, data-driven approach is applied to deriving the mechanisms for aqueous glucose ring opening in the mutarotation process with an emphasis being an exhaustive review of fundamental organic chemistry concepts. The homework set is designed to be completed within a 2 to 3 h time period for an average Organic Chemistry student. The exercise was field tested with multiple organic chemistry students who completed the exercise in the designed time frame and who in evaluation stated that the review concepts were clearly understood.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Two documents are provided within the Supporting Information: the homework exercise in final form suitable for distribution to students; An instructor's guide with the complete answers for the entire exercise. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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