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Web-Based 2D NMR Spectroscopy Practice Problems

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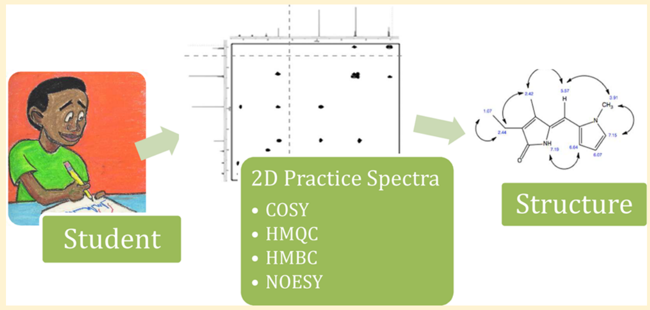
ABSTRACT: 2D NMR spectroscopy is regularly utilized for determination of organic structures. Problem-solving using a variety of 2D techniques is increasingly covered in the undergraduate curriculum. While several advanced texts provide some practice problems, these books are often expensive and aimed at graduate students. A free and publicly available set of 2D NMR problems with answers was developed to provide students an opportunity to develop their advanced structure elucidation skills.



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STRUCTURE ELUCIDATION

In 1999, Alexander et al. completed a national survey on the use of spectroscopic analysis in the introductory organic chemistry sequence.[1] At that time, it was clear that a vast majority of schools were teaching students to analyze IR spectroscopy and ^{1}H and ^{13}C NMR spectroscopy but only about 10−15% of schools were including 2D NMR spectral techniques. In the past 15 years, the number of laboratory experiments incorporating 2D NMR spectroscopy coupled with analysis has exploded in the chemical literature.[2−18]

It is important to remember that solving spectral problems is not something that can be learned from simply reading; practice in interpreting spectra is essential. Most organic textbooks have a limited number of spectral problems, and while many online compilations of spectral problems exist, they are focused primarily on 1D NMR spectra.[19−27] These spectral problem sets comprise a critical resource for the student learning to interpret spectral data. However, only a few of these resources implement 2D NMR spectroscopy examples; the UCLA Web site[19] has four problems that employ COSY, the Mahidol University Web site[22] provides two problem sets with 2D techniques, and Widener's Web site[24] nicely delineates the process of interpreting a set of spectral problems for four compounds. Nowick provides extensive 2D NMR spectra, but, as no answers are provided, this site has limited utility for students' ability to master the basics of 2D NMR analysis.[26] Other sites provide valuable resources about the analysis of NMR spectroscopy[27,28] or provide a database of useful spectra for instructors.[29−31] The utility of different web-based resources is detailed in a publication in this journal.[32]

While advanced texts provide some practice 2D NMR problems, these books are often expensive and aimed at graduate students.[33,34] These texts rarely provide many beginning and intermediate level problems for students to use to solidify their knowledge. During the teaching of an advanced structure elucidation course, it became clear that beginning students needed an easily accessible set of 2D NMR spectral problems with answers for practice. Thus, a database of 2D NMR problems with answers was developed to help students practice their structure elucidation skills.

2D NMR PRACTICE PROBLEMS

A set of 2D NMR problems with answers is now available on our Web site.[35] This set of approximately 55 practice problems was developed for use with undergraduate students, either advanced second-year or upper-division students. This collection of spectroscopy problems gives the students experience with COSY, NOESY, and heteronuclear NMR spectra for the determination of various molecular structures. Included in this problem set are a few problems to determine small peptide structures. While the problems employ more complex analysis than a typical second-year undergraduate course, there are plenty of problems that are accessible to an undergraduate student. Solutions are provided, so that students can quickly check their answers to determine if they are on the right track. Some of the solutions are more extensive, walking through the problem more carefully for novice learners. Although not unique to this site, a number of problems in 1D NMR are also available at the same Web site.

Extraneous peaks due to solvents, impurities, or unexpected long-range coupling often confuse introductory students. Consequently, many of the introductory problems included simulated ^{1}H and ^{13}C NMR 1D spectra using the *Predict ^{1}H NMR* and *Predict ^{13}C NMR* functions in ChemDraw.[36] Simulated 2D NMR spectra were subsequently drawn using ChemDraw as a drafting tool, with ovals symbolizing cross-

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peaks. To help students make the transition to working with real data, a variety of experimentally obtained spectra were also added to the site.[37] A table of selected solvent impurities is included on the site as well as a reference to a more extensive guide in the literature.[38]

These resources have been used in multiple laboratory courses and an upper division course; a full description of the implementation of NMR spectral analysis in our curriculum is described elsewhere.[39] 1D NMR spectroscopy is introduced in the first-year laboratory sequence (Chem 201 and 202). Typically, over two hundred students are enrolled in the introductory year of laboratory courses at CSB/SJU. Assessment data on the implementation of 1D NMR techniques is provided elsewhere.[39]

2D NMR data is introduced to second-year undergraduates in our curriculum in the Synthesis Lab (Chem 203). These students had the opportunity to use the newly developed materials for the first time during Fall 2015. Two experiments used 2D NMR: COSY in a hydride reduction and HMQC in the identification of an unknown esterification product. Results on those experiments, although promising, were comparable to the previous year (hydride, AY 2014−15, 53 students, average score on lab report = 80 ± 20%, vs Fall 2015, 34 students, average = 84 ± 14%; esterification, AY 2014−15, average = 74 ± 17%, vs Fall 2015, average = 79 ± 18%). Anecdotally, CSB/SJU faculty members teaching these laboratory courses have found these resources to be helpful in demonstrating how to solve spectroscopy problems.

Finally, students have the opportunity to consolidate their skills in spectral interpretation in an upper division undergraduate course on structure elucidation (Chem 363). This course typically enrolls 15−20 third- or fourth-year chemistry majors. This material was developed in response to student requests for additional 2D NMR problems with answers; students have subsequently commented that extra problems are useful in studying. By the end of this course, all students have been able to solve 2D NMR spectral problems from current literature examples on exams.

■ CONCLUSION

As 2D NMR spectral techniques are added to the undergraduate curriculum, students will need access to practice problems. A web-based set of 2D NMR problems has been developed to provide students an opportunity to develop their structure elucidation skills. Students are provided with immediate feedback via an answer key. In conjunction with a curriculum that scaffolds the introduction of spectral data analysis, the addition of these spectral problems may help transition students from novice learners to more advanced users of 2D NMR spectroscopy.

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Notes

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