Laser-Based Liquid Prism Sucrosemeter

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Experiment Overview

The majority of disciplines in science involve instrumentation to provide meaningful data for a wide range of applications. The automation of many modern instruments means the user can often obtain reliable data easily without requiring an in depth understanding of the underlying science. Such automation (including computer-interfaced data acquisition) is extremely beneficial to the scientist and researcher, but can actually detract from student learning in a practical sense as it compels the student to rely solely on theoretical knowledge to understand potential limitations and overall reliability of acquired data. Students often have difficulty in achieving this, particularly when core components of an instrument cannot be clearly observed.

While the chemistry involved in this experiment is not challenging (refraction of light as a consequence of refractive index), its main benefit is that it reinforces the importance of critically assessing instrumentation and experimental design when considering data reliability (as opposed to attributing all error to ‘experimental error’).

The experiment focuses on instrumentation that is entirely transparent and easily controlled by the student. They construct their own analytical instrument that has an observable response signal (visible laser beam diffraction), enabling students to directly recognise the function of each core component. Using their instrument to perform analysis of real samples reveals not only the success of the instrument but also limitations in its applicability. For successful analyses, students consider accuracy and precision of their instrument. This is aided via a comparison of their experimentally obtained data with data obtained from a commercial instrument as well as literature values. For analyses that were not successful, students further explore experimental design by considering modifications to their set-up that could overcome its current limitations.

Aims and Objectives

In this experiment students construct their own sucrosemeter using a He-Ne laser and hollow equilateral prism. Sugar solutions are placed in the prism and the diffraction of a laser beam through these solutions can be monitored as a function of concentration, enabling determination of ‘real’ unknown solutions (cordial, soft drinks etc.). If available, a commercial refractometer is an ideal addition to the experiment as students can compare the results of their constructed sucrosemeter to the commercial one.

The benefits to student learning in this experiment are more of a general nature than specific to concepts presented by lectures. The fact that real samples are analysed is always a plus to student learning. Technical skills in making standard solutions and drawing results from calibration curves expose the student to core analytical skills.

Constructing their own apparatus which is simple yet yields accurate results reinforces in students that instrumentation and design does not always need to be complicated or expensive. With continued advances in the technology of instrumentation as well as interfaced data acquisition software, it is easy for students to simply 'press a button' to obtain results without considering the chemistry that occurs within a fully enclosed instrument. The simplicity of the experimental set-up as well as the transparency of the response signal (visible laser beam diffraction) in this experiment encourages students to consider 'cause and effect' components of instrumentation. Students critically analyse experimental design by probing both strengths (reliable determination of refractive indices and sucrose concentrations) and limitations of their experimental set-up (analysis of dilute samples and samples of complementary colour to the laser beam cannot be reliably made without modifications to the design and/or sampling). Comparison of direct readings of diffraction angles to calculated angles also encourages students to assess accuracy over simplicity when considering data collection methods (for this experiment, direct readings of deflection angles gives poor accuracy, whereas calculated angles yield great accuracy due to relatively small error propagation).

Level of Experiment

The experiment as presented here is undertaken by our second year students, however I feel that it is simple enough to be adapted as a first year practical.

Keyword Descriptions of the Experiment

Domain
physical chemistry

Specific Descriptors
He-Ne laser, sucrosemeter, refraction, Snell's Law, error analysis

Course Context and Prerequisite Knowledge and Skills

This experiment has little direct linkage to general course material in Physical Chemistry, unless a component regarding refraction of light through prisms / solutions, Snell's Law, simple laser chemistry etc. is incorporated. Indirectly, this experiment can enhance a student's confidence in their own ability to simplify and comprehend new concepts they are taught in Physical Chemistry. (New concepts in Physical Chemistry can be difficult for students to grasp if the language and mathematical relationships overwhelm them - this experiment is easily understood, and the associated mathematics is easily applied.)

Minimal prior knowledge is required by students to successfully conclude this experiment. Advantageous skills to have are competency in using volumetric techniques / glassware, basic knowledge of light refraction trends and adeptness in constructing and applying calibration curves.

Time Required to Complete

Prior to Lab: 30 min - 1 h (reading)
In Laboratory: 2-3 h
After Laboratory: 2-3 h (plotting data, analysing results, calculations, and report writing)

Experiment History

This experiment was adapted from Narayanan and Narayanan (1997).

Comments

In my opinion this experiment is not very challenging when compared to other experiments offered by us at second year level. Despite this, I find it works very well in the laboratory as it incorporates several analytical methodologies common to many experiments. When the students are exposed to the second year laboratories (esp. physical chemistry) for the first time, they are often overwhelmed by the instrumentation, equations involved in analyses and graphing techniques that they have had little prior experience in. This experiment enables students to “re-focus” on many common features of experiments (calculations, using equations, linearity relationships and subsequent calibration curves, error analysis) in a straightforward easy to follow way. I have found that students sometimes gain a better perspective on the subject area as a whole when they are able to “practice” common features (such as graphical analyses) using a protocol that is easy to follow and understand, and has very little prospect of failing to yield reliable results.

As a learning tool this experiment is most effective if it is extended to incorporate scenarios where the design yields accurate and reliable data as well as scenarios where accuracy is not possible without modifying the design and / or approach. In general, students often attempt to designate poor results to ‘experimental error’ (error in pipetting, human error in weighing etc.). In many cases such sources of error cannot significantly account for deviations in response signals (for example if the concentration range is beyond an instruments detection limits, or if specified conditions for optimal output are not maintained). It is therefore imperative that students develop the ability to critically assess experimental limitations and distinguish these from sources of error. Addressing limitations in their experimental design and exploring ways to overcome these can precipitate such critical assessment in students.

It is intended to incorporate comparison of student’s results to results they obtain when using a commercial refractometer. The attached experimental write-up has not been modified to incorporate this as we are yet to trial the refractometer we have available to us.

On a further note, it is a reliable simple analytical experiment that can be very cheap to set-up and maintain. Commercial sugar and cordials are the only consumable expenses; the He-Ne laser could be replaced with a commercial laser pointer; the hollow prism could be constructed using microscope slides.

References

Narayanan, V. A. & Narayanan, R. (1997). Laser-based liquid prism sucrosemeter – A precision optical method to find sugar concentration. *Journal of Chemical Education,* **74,** 221-223.