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Activity

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Using a Carbide Lantern To Illustrate General Chemistry Concepts and Introduce Students to Artisanal and Small-Scale Gold Mining

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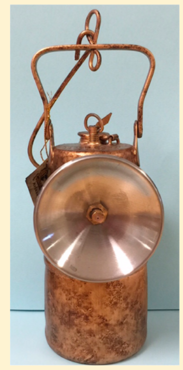
Supporting Information

ABSTRACT: Carbide lanterns were once the preferred lighting source for mining operations and are still utilized today in Artisanal and Small-scale Gold Mining (ASGM). These lanterns can be used to demonstrate a wide variety of chemical principles. To this end, an activity was developed to highlight the chemistry of a traditional carbide lamp used by miners. After a brief introduction to the lantern, students were challenged to complete problems that integrate multiple concepts such as balancing equations, unit conversions, limiting reactants, and thermochemistry. Although the activity as written serves as a review of General Chemistry I, the use of these lanterns in ASGM provides an additional opportunity to introduce students to a topic that encourages global engagement and cultural consideration. To make the activity accessible to a wide variety of audiences, a video is provided demonstrating the operation of a carbide lantern and a brief introduction to ASGM.



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Calcium carbide reacts with water to produce flammable acetylene gas and calcium hydroxide. This reaction is a "fan-favorite" at chemistry demonstration shows, as the acetylene gas is often ignited to produce a bright white flame (Scheme 1). Numerous educational demonstrations harnessing the explosive powers of acetylene generated in this fashion are described in the literature.[1−6]

Scheme 1. Formation and Subsequent Combustion of Acetylene Gas from Calcium Carbide

$$CaC_2(s) + 2\,H_2O(l) \longrightarrow C_2H_2\,(g) + Ca(OH)_2\,(s) \quad (1)$$

$$2\,C_2H_2\,(g) + 5\,O_2\,(g) \longrightarrow 4\,CO_2\,(g) + 2\,H_2O\,(g) \quad (2)$$

These chemical reactions also provide the basis for carbide lanterns, which are a 100-year-old technology still in use by artisanal and small-scale gold miners in El Oro province, Ecuador. When acetylene is produced by the controlled addition of water to calcium carbide, as it is in the case of a carbide lamp, the acetylene produced can be burned for hours. A carbide lamp is divided into two chambers. The lower chamber is reserved for pellets of calcium carbide, while the upper chamber acts as a reserve for water. Upon turning a screw on the water reserve, water slowly drips on the calcium carbide. The resulting gaseous acetylene is forced through an outlet and can be ignited. The light from the resulting flame is then reflected using a polished, concave metal pan. Carbide lamps will not burn in low oxygen environments, and so they also serve to warn miners of dangerously low oxygen concentrations.

Herein, we present an activity using a carbide lantern that has been coupled with an end-of-semester review session for students in the last week of General Chemistry I. While a physical demonstration of a carbide lamp is easily accomplished and valuable to pique student interest in course material, it may not be feasible for all institutions to purchase a carbide lamp or the calcium carbide required to operate the lamp. For this reason, an approximately 8 min YouTube video has been provided to the reader for use in a lecture setting.[7]

■ MATERIALS

To demonstrate a functioning carbide lantern, the following materials are required.

- Carbide lamp: Carbide lamps are available from online suppliers and used lamps are available on eBay. For this activity, a Hercursa lantern was used.[8]
- Calcium Carbide: Mining grade calcium carbide is available in bulk online.[9]
- Water: Deionized or distilled water is recommended to prevent accumulation of metal salts.
- Matches

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HAZARDS

Calcium carbide reacts rapidly with water to produce acetylene gas, which is highly flammable. Follow the lamp manufacturer's instructions for safe operation. Powdered calcium carbide reacts too rapidly with water for safe use in a lantern and should never be used. A fire extinguisher (CO_2 or dry powder) should be readily available when the lamp is lit. The calcium hydroxide produced in the reaction is a strong base and should be disposed of accordingly.[10]

OVERVIEW OF THE ACTIVITY

Twenty students enrolled in the first semester of General Chemistry attended the review session. Students worked independently or in groups of 3–4, depending on the question being worked on the corresponding worksheet (Supporting Information).

Students were provided with a brief background on ASGM practices and an overview of how to safely operate a carbide lamp. Approximately 50 mL of water was added to the water reservoir, and 6.5 g of CaC_2 was placed in the lower chamber. The lamp was assembled, and the water valve was slowly opened, dripping water on the calcium carbide. A lit match was held in front of the lantern burner until the acetylene ignited. The lights to the room were turned off, and the lantern was used to illuminate various parts of the classroom. After approximately 1 min, the lights were turned on, and students were given an 8-question worksheet. Upon completion of each question, students provided answers and discussed how they approached each question.

When the flame went out, the water valve was closed. Upon completion of the limiting reagent question on the worksheet, students were asked to determine whether water would remain in the top chamber. When students responded that the calcium carbide was the limiting reagent and there was an excess of water, the water chamber was inverted and the excess water was drained into a sink. An inspection of the lower chamber revealed that the calcium carbide was entirely consumed.

The final question on the worksheet asked students to rationalize why miners might continue to use carbide lanterns when newer technology is available. This question led to a brief discussion of safety in ASGM and provided students with insight on poverty-driven employment in developing nations. The entire activity provided students with a review of key concepts in general chemistry through questions examining a carbide lamp and opened discussion that highlighted the dangers associated with ASGM.

RESULTS AND DISCUSSION

This activity was designed for a 75 min review session during the last week of General Chemistry I; however, with student questions about the course material, the session lasted approximately 2 h. This activity was not designed to be an exhaustive review of the course material, but rather to (1) highlight key concepts covered during the semester[11,12] and (2) introduce students to Artisanal and Small-scale Gold Mining (ASGM).

The production of acetylene gas from calcium carbide and water, as well as the combustion of acetylene, can be used to demonstrate numerous chemical and physical properties. The design of the carbide lamp allows for a particularly effective visual demonstration of limiting reagents. For this particular activity, students were asked to apply their understanding of

- States of matter
- SI units and unit conversion
- Dimensional analysis
- Balancing reactions and predicting products
- Stoichiometry and limiting reagents
- Redox chemistry and combustion reactions
- Enthalpy and specific heat
- Properties of light
- Lewis structures, VSEPR model, VBT and hybridization

Additionally, it is possible to use the carbide lamp to review concepts related to acid–base chemistry, emission spectroscopy, and the ideal gas law among others. The work sheet provided to students can be easily modified to stress any number of key concepts in General Chemistry or Organic Chemistry.

The worksheet was intentionally designed to cover course material in a different order than had been done throughout the semester. In addition, questions with multiple components were written to combine concepts that may not have been previously incorporated together. The first four questions engaged students in balancing two chemical reactions, as well as identifying products and reaction type. Students explored the structures of reagents and products and were asked to determine the hybridization and bond angles of the central atom in each compound. Students then were tasked with relating the structure of acetylene to the structure of the acetylide anion (C_2^{2-}). Each group was also required to think about why carrying around a tank of acetylene was less efficient for a miner than solid calcium carbide to highlight practical considerations about the states of matter. Throughout the activity, it was important to relate the carbide lamp back to the miners that used it.

Question 5 required students to determine the limiting reagent for the experimental conditions provided at the beginning of the activity. Upon successful completion of the problem, the water chamber was opened and the excess water was drained demonstrating that water was clearly in excess. Additional components of this question asked students to determine the amount of chemical reagents needed by a miner for a full work day.

Question 6 challenged students to think about the type of light produced by the acetylene flame and relate their observations back to a visible spectroscopy laboratory conducted during the semester. Question 7 was written to have students think about the heat energy evolved over the course of both reactions. Students were asked to assume that all heat energy was transferred directly to the brass lantern and to determine the increase in temperature of the lantern during operation. Although this is very clearly not what happens, it provides an opportunity for students to think about heat transfer and sign conventions.

This activity also allowed for the introduction of students to the area of Artisanal and Small-scale Gold Mining. ASGM employs an estimated 16 million people in developing countries throughout Asia, Africa, and South America.[13] Miners often use mercury to separate gold and silver from gangue,[14,15] and recently, ASGM activities have been recognized by the United Nations as being the largest contributor to mercury emissions in air and water.[16] In addition to the environmental damages ASGM practices cause, artisanal and small-scale gold miners often endure hazardous working conditions and heavy metal intoxication in order to provide for themselves and their

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families.[17−20] Although it is impractical to demonstrate many aspects of ASGM in the lecture or laboratory, the chemistry related to carbide lamps allows instructors to introduce students to a global issue and provides real-world examples of safety hazards and use of technology in developing nations. This activity could facilitate social awareness in other chemistry courses, particularly in a high school and nonmajor's chemistry course.

Through this connection to ASGM, students also see practical applications of chemical concepts. Question 8 asks students to consider reasons for the continued use of these lanterns. This is supported by the previous question examining thermochemistry, since heat production is one of the many reasons miners continue to use these lanterns in an age of battery-powered lanterns. These lamps not only provide an inexpensive source of light, but have a built-in safety feature. When the oxygen level decreases in a mine shaft, the flame is extinguished, and miners know that they have limited time to evacuate.

Students were asked for feedback about the value of this activity as a review session for General Chemistry I. All students that responded to the survey either strongly agreed or agreed with the statement "I liked how all of the problems related to the carbide lantern". A majority of the students that responded strongly agreed with the statements "I liked learning about the practical applications of chemistry concepts" and "I liked learning about ASGM and reviewing chemistry concepts in the session". Student open responses were positive and included the statement "It was entertaining and held my attention throughout the review".

Although students liked the use of the lamp and the exposure to ASGM, there were concerns about the use of this activity as a review session for the final examination. One student directly commented "I didn't love having it as review for our final", and overall, students were neutral on the use of this topic as a review session. However, over half of the student respondents said that they would recommend this activity as a General Chemistry review to other students. On the basis of this feedback, this activity may be more beneficial as a structured class activity than a final review.

■ CONCLUSION

This activity provides a review of General Chemistry I concepts and can be related to ASGM activities that affect environmental and human health in developing nations. It provides numerous examples of "real-world" chemistry and highlights the practical application of foundational chemical concepts. The chemistry involved in the operation of a miner's carbide lamp can be used to explore numerous concepts in the general chemistry curriculum and is particularly effective demonstration of limiting reactants in chemical reactions. Although the activity presented here is particularly designed to explore concepts relevant to first semester General Chemistry, the worksheet is easily modified to incorporate concepts across the general chemistry sequence.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00604.

Student worksheet (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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