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Resuscitating the Mercury Beating Heart: An Improvement on the Classic Demo

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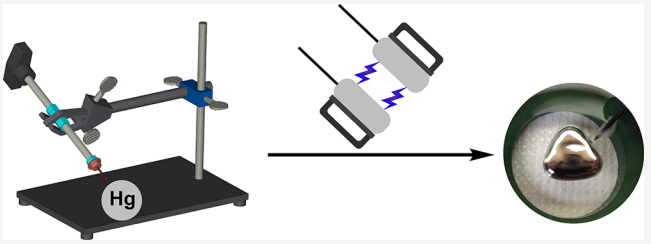
ABSTRACT: The mercury beating heart is a dramatic demonstration of redox chemistry that allows for the direct conversion of chemical energy to mechanical energy without involving a machine to accomplish the transfer. Unfortunately, instructors often avoid this demonstration due to difficulties initiating the oscillating redox reaction that drives the process. Here, we describe a new method for initiating the mercury beating heart demonstration that significantly reduces the setup time and makes it easier to sustain the "beating heart" oscillations.



KEYWORDS: *First-Year Undergraduate/General, Demonstrations, Aqueous Solution Chemistry, Electrochemistry, Metals, Oxidation/Reduction, Surface Science*

OVERVIEW OF THE MERCURY BEATING HEART

The mercury beating heart phenomenon was first reported almost 200 years ago, and it was introduced as a demonstration in 1932.[1−9] Since that time, the mercury beating heart has served as a captivating, but temperamental, example of redox chemistry in which chemical energy is converted directly into mechanical energy without using a machine to accomplish the transfer.[5,10−12] For those interested in the mechanism, it provides an engaging introduction to catalytic intermediates.[13−16] In the demonstration, a round pool of mercury repeatedly changes shape in a regular pattern of inverting polygons (usually triangles) as it is brought into contact with an iron nail, demonstrating the intermediate states of the oxidation−reduction reaction in a clearly observable way. In addition to the redox chemistry, the rhythmic oscillations and eye-catching shapes taken on by the mercury pool are visually appealing (if not downright mesmerizing).[17,18] The best-known procedure for performing this demonstration is described by Shakhashiri in *Chemical Demonstrations* (1992).[11] Despite showcasing several chemical principles, this demo has not been widely utilized in chemistry classrooms due to two major barriers: increased concerns about the use of mercury in classrooms, and the amount of time required to initiate a stable beating motion.

HAZARDS

Specific precautions must be taken when utilizing and disposing of the reagents used in the demonstration. While these safety techniques are well-known and commonly used at chemistry departments at the college and university level, it is important to note explicit hazards inherent to this demonstration: Gloves, eye protection, proper laboratory attire, and a well-ventilated space are required during the demonstration; sulfuric acid is corrosive and should be handled with care; potassium chromate is an oxidizing agent and should likewise be handled cautiously; hexavalent chromium produced by the demonstration reaction has high environmental toxicity and must be disposed of properly; mercury is toxic and should only be handled in a well-ventilated area using appropriate protective equipment with proper disposal of contaminated materials in accordance with local guidelines. We suggest reviewing the respective Safety Data Sheets for sulfuric acid, potassium chromate, and mercury before conducting the demonstration.[19−21] As an alternative to potassium chromate, procedures have also been suggested that successfully use hydrogen peroxide as the oxidizing reagent.[22,23]

DIFFICULTIES WITH THE CLASSICAL DEMONSTRATION

While safety concerns can be directly addressed, even seasoned veterans of the mercury beating heart demo often struggle to achieve a regular "beating" of the mercury pool within a reasonable amount of time.[22,24] Previous procedures suggest carefully positioning the tip of the iron nail at the edge or the pool of mercury,[22] or affixing the nail to an iron wire and calibration weight.[11] These methods can succeed with sufficient patience (and a healthy dose of luck),[17,25,26] but a significant barrier remains to the use of this demonstration in classrooms where efficiency and consistency are paramount. One method to

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increase reliability has been suggested by Demiri et al. in which a DC power supply and two graphite electrodes can be used to elicit the mercury beating motion;[22] however, this modification encumbers an already-difficult demonstration.

NEW APPARATUS FOR THE MERCURY BEATING HEART

We were interested in finding a fast and reliable method that does not require an external source of current so that the classic design of the demonstration can be preserved. We addressed the problems associated with this demonstration by building a device that allows easy and precise positioning of the iron nail in relation to the pool of mercury. Fine control of the distance between the nail and the pool is provided by a screw apparatus mounted on a ring stand (Figure 1). The iron nail is affixed on

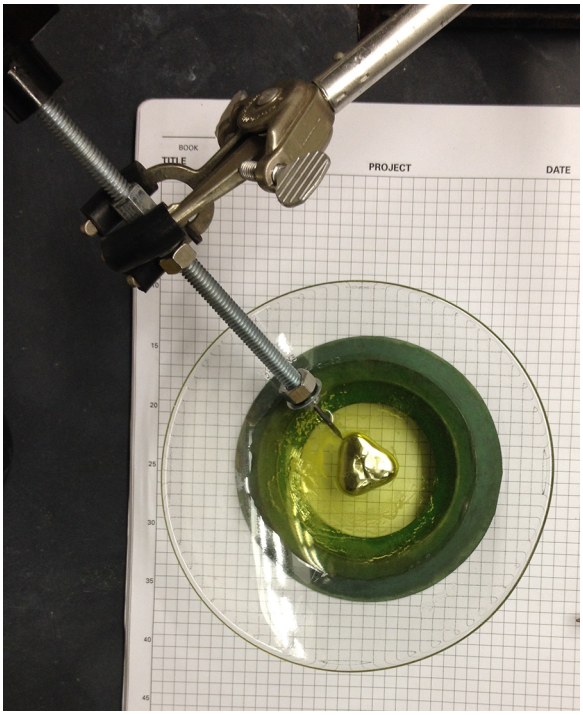

Figure 1. Screw apparatus for the mercury beating heart demonstration.

one end of a threaded rod, and a handle is attached to the other end to allow precise control of nail's distance from the mercury pool. In addition to being simple to construct, the parts required to build the apparatus (Figure 2) are all easily obtained at any regular hardware store (parts list included in Table S1 and assembly instructions on page S3, Supporting Information).[27] Using this apparatus, the demonstration can then be easily displayed to a classroom or large group using a document camera, or by attaching a camera to the ring stand apparatus.[28]

This apparatus drastically reduces the setup time required to achieve a stable "beating" motion of the mercury pool, from 7−10 min to 1−2 min. Although this difference may not seem large, we found a roughly 7 min reduction in setup time to be significant when presenting this demonstration in a 50 min class period. This modification led to increased use of the mercury beating heart demonstration in the general chemistry courses offered by our department, as well as a pronounced increase in the attention of students during and after the demonstration. The stability of the rhythm provided by the apparatus also allowed observation of several different shapes taken on by the mercury pool (Figure 3). The Supporting Information includes

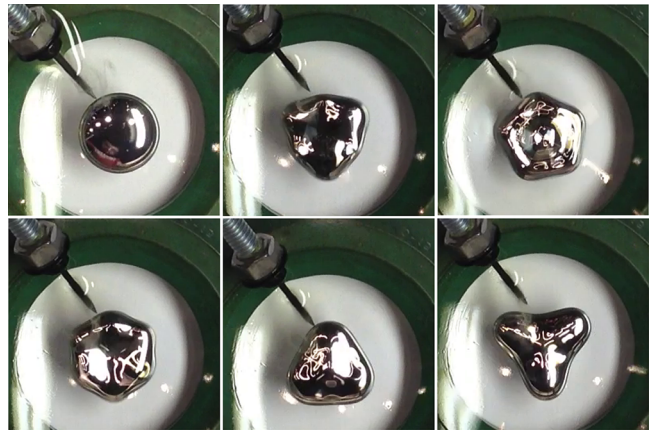

Figure 3. Shapes observed during the mercury beating heart demonstration.

the information necessary to construct, utilize, and clean the apparatus. We also included a video showing the setup and execution of the demonstration.

CONCLUSION

The ease of setup and high success rate provided by this new apparatus have elevated the mercury beating heart demonstration to be our go-to demonstration for introducing electrochemistry, redox reactions, and the conversion of chemical energy into mechanical motion. Its widespread use at our university, and the corresponding student response, has effectively resuscitated this classic demo.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00845.

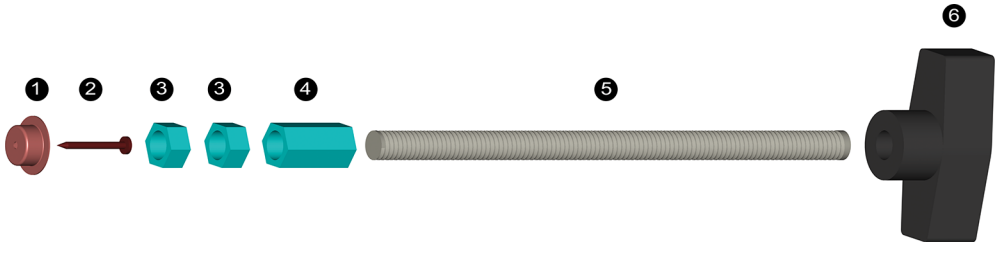

Figure 2. Exploded diagram of the screw apparatus: (1) axle cap, (2) Fe nail, (3) hex nut, (4) coupling nut, (5) threaded rod, (6) hand knob.

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Mercury beating heart parts list and assembly instructions (PDF)

Video of the mercury beating heart demonstration (MP4)

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Notes

The authors declare no competing financial interest.

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(28) This latter approach was used to capture the images in Figure 3, and to record the example demonstration video included in the Supporting Information.

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