An Alternative Demonstration of Chemical Waves: A Video Clip of a One-Dimensional Wave in the Iodate–Arsenite System

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Abstract: A chemical wave was initiated in a system (glass tube or graduated cylinder) containing a water solution of potassium iodate, potassium hydrogen sulfate, starch, and an excess of potassium arsenite. A large number of photos (329) were taken with a digital camera (one snapshot every 30 seconds). These photos were linked to give a unique video clip. This video clip may be used as a time-saving alternative to the classical demonstration. Similar clips may be made for other long-lasting processes.

Introduction

Chemical waves in the iodate–arsenite system have been known for a long time and are well understood phenomena. Epik and Shub [1, 2] were perhaps the first to point out that under appropriate conditions the oxidation of arsenite with iodate can result in the generation of a chemical wave. Gribschaw et al. [3] gave an explanation of these waves in terms of a reaction-diffusion model. The same example has also been dealt with by Scott [4] in his excellent book on waves and oscillations. More examples of chemical waves and oscillations may easily be found in the rather extensive literature [5, 6].

The chemical reactions in a system containing potassium iodate, sulfuric acid, and an excess of arsenite are fairly simple and well-understood. Eagert and Scharnow [7] showed that the reaction is autocatalytic. The reaction is usually explained as consisting of two processes (A and B)

$$5I^- + IO_3^- + 6H^+ \rightarrow 3I_2 + 3H_2O \quad \text{(process A)}$$

$$H_3AsO_3 + I_2 + H_2O \rightarrow H_3AsO_4 + 2I^- + 2H^+ \quad \text{(process B)}$$

In the presence of an excess of iodate, the overall reaction is of the type 2A + 5B, that is

$$5H_3AsO_3 + 2IO_3^- + 2H^+ \rightarrow 5H_3AsO_4 + I_2 + H_2O$$

and a chemical wave initiated in a tube (usually with a microscopic drop of KI solution) leaves a brown tail of elementary iodine. If, on the other hand, the arsenite is in excess, the overall reaction is of the type A + 3B:

$$3H_3AsO_3 + IO_3^- + 5I^- \rightarrow 3H_3AsO_4 + 6I^-$$

The above form of the equation (instead of the more familiar)

$$3H_3AsO_3 + IO_3^- \rightarrow 3H_3AsO_4 + I^-$$

is used to emphasize its autocatalytic nature. In this latter case (an excess of arsenite), any iodine produced is rapidly consumed. As a consequence, the light-brown color persists only at a certain, localized ringlike region in the test tube (this is the wave front), which slowly propagates with time. As stated earlier, this is all well known and understood.

Chemical waves of the type described above were also dealt with in chemical demonstrations [8]. A few points, however, may complicate these demonstrations.

- The chemicals used must be of high purity or the reaction may easily go out of control.
- For the same reason, the pH value must be carefully adjusted, neither too low, nor too high.
- The reaction with an excess of arsenite performed under appropriate conditions (pH values slightly above 2.0) is a rather slow one. It cannot be completed in a lesson period because the wave front moves slowly with time.

This last fact, the duration of the experiment, places a severe restriction on its use as a classical chemical demonstration. Also, the required purity of the chemicals and the relatively narrow range of pH values often result in a failed demonstration.

For the above reasons, we propose that a demonstration be strengthened by a video clip (a movie), which we offer to the public. The details are given below.

Experimental

Preparation of Solutions. Approximately 150 mL of water (redistilled water was used for all solutions) was added to a 200-mL beaker. About 1.0 g of As_2O_3 and 0.6 g of KOH were added and dissolved in the water. This solution contains potassium arsenite. A previously prepared concentrated $KHSO_4$ solution was slowly added until the pH value was about 2.2. The content of the beaker was transferred to a 250-mL flask and the flask was filled with water to the mark. This is solution A.

In another 250-mL flask 0.54 g of KIO_3 was dissolved in about 100 mL of water, and the flask was refilled with water to the mark. This is solution B.

It seemed a good idea to add starch (as an indicator) in the system because the deep-blue color of the iodine–starch indicator is more easily detectable than the color of iodine in a dilute water solution. A colloidal suspension of starch (0.5 %) was prepared by adding 0.25 g

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of reagent grade starch to small amount of water (1–2 mL), mixing it thoroughly, and adding the milky liquid to 50 mL of boiling distilled water again with mixing. The colloidal suspension was left to cool to room temperature. This is solution C (for best results it can be used for no more than two days, so one should avoid the preparation of large quantities).

The Demonstration. A clean test tube or a graduated cylinder (total volume of about 30 mL) was filled with 11 mL of solution A, 8 mL of solution B, and 7 mL of solution C. The vessel was inverted several times (to blend the mixture, containing an excess of arsenite), and was then clamped.

The reaction was initiated with a microscopic drop of KI solution (0.1 mol/L), added by a syringe needle with a gentle swirl of the needle over the liquid surface in the test tube. After some practice, it was possible to initiate the wave in the form of a fairly regular blue ring. The wave moved slowly downwards and disappeared after about 3 hours. This was obviously rather slow (primarily due to the relatively low acidity of the solution), but prevented the evolution of parasite waves at other points in the interior of the vessel.

The Video Clip. The digital camera was fixed in position on a tripod and was focused on the graduated cylinder with the initiated mixture. Once the blue ring was formed (see Photo 1), snapshots were taken every 30 seconds. A large number (329) of medium resolution snapshots were accumulated and linked to make a short movie. Music was added to the clip for its entertainment value (see Movie 1).

Safety Tips and Disposal

Arsenic compounds are highly toxic and carcinogenic! Potassium hydroxide is corrosive to the skin. Always wear safety goggles and gloves when preparing the solutions. The chemicals should be disposed of according to local safety regulations. Solutions that contain arsenic should never be poured into a drain.

Conclusion

The video clip offered here can be used to illustrate this well-known phenomenon and demonstration (the demonstration is otherwise very slow). The positive response of our students convinced us that it is useful in demonstrating this subject. There are many other chemistry phenomena that may be presented in this way (diffusion, osmosis, chemical waves in gel-media, etc.). To make a video clip of these, it is essential to know the duration of the process and the number of snapshots that should be taken with the digital camera; however, for longer-lasting processes (several days) this may turn out to be an extremely tedious job (snapshots need to be taken every half hour or every hour). Consequently, more than one camera operator is needed, which may hamper the successful completion of the documentation for the process. (*Si duo faciunt idem, non est idem*).

Supporting Materials. Photo 1 and Movie 1 were taken with a FUJIFILM *FinePIX4700* digital camera. Movie 1 was a result of linking 329 snapshots (each of 640 × 480 resolution). Photo 1 is in JPEG format, and Movie 1 is in MPEG format, playable with the Windows Media Player. When playing the file, it is recommended that it be viewed using the full-screen option. The added music is optional (one can always switch off the speakers). Photo 1 a chemical wave initiated in a clamped test tube, containing an iodate–arsenite–starch mixture (http://dx.doi.org/10.1007/s00897000519b), and Movie 1 a one-minute movie showing the propagation of a chemical wave in a graduated cylinder (http://dx.doi.org/10.1007/s00897000519c) are available.

References and Notes

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