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Alternative Demonstrations of Slow Processes II: A Video Clip of One-Dimensional Waves in the Hypochlorite–Iodide–Water System

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Abstract: A chemical wave was initiated in a system (test tube) containing an aqueous gel of potassium iodide and starch by carefully pouring an excess of bleaching solution (aqueous solution of sodium hypochlorite) over it. A blue disk is formed immediately at the boundary surface, which propagates slowly downwards. Photos (a total of 240) were taken with a digital camera (one snapshot every 20 s), and they were linked to give a video clip that may be used as a time-saving alternative to the classical demonstration.

Introduction

Chemical waves have been known for a long time and are well-understood phenomena [1–9]. The systems of interest may be very different, such as those containing mixtures of arsenite and iodate [1–5] or aqueous gels containing gelatin and mercury(II) chloride as one component and an aqueous solution of potassium iodide as the other [6–7]. In the first example, the wave appears as a brown (or blue, providing the solution contains starch) ring containing iodine that propagates downwards in the vessel (test tube or cylinder). In the latter, a yellowish-orange circular region is formed (containing HgI_2), and this also propagates slowly downwards. The more diluted the gel, the faster the motion [8]. Soon, the colored region splits into a number of circular regions (Liesegang rings), which differ in color (HgI_2 has two different polymorphs: a red and a yellow one [6, 7]). Other systems where chemical waves may propagate are also known [9].

The system $HgCl_2$–KI–water is particularly interesting and serves as a basis for the chemical wave discussed in the present paper. If the gel contains water, gelatin, and $HgCl_2$ (as a standard preparation for this system) and an aqueous solution of KI is carefully poured over it, the chemical reaction immediately taking place may be presented as

$$HgCl_2(aq) + 2KI(aq) = 2KCl(aq) + HgI_2(s) \quad (1)$$

The product HgI_2 is colored, and, thus, it is easily noticeable; however, the excess of potassium iodide solution converts the colored mercury(II) iodide into a colorless and soluble complex, $K_2[HgI_4]$:

$$HgI_2(s) + 2KI(aq) = K_2[HgI_4](aq) \quad (2)$$

giving rise to a colored circle (and later to series of circles or rings—Liesegang rings) rather than to a colored band, which would be expected if the reaction in eq 2 did not occur. The mechanism of formation and disappearance (due to the excess of iodide ions) of the colored circles of HgI_2 may, in the simplest approximation (not taking into account the appearance of Liesegang rings, for example), be explained in nonchemical terms as a coupled pencil and eraser motion over a piece of paper. The result of this motion, although time-dependent, will always be a segment of a length *d* where *d* is the distance between the pencil and the eraser. It is even useful to make this model, binding together the pencil and the eraser with a piece of sealing tape. With regard to the chemical system in question, the pencil (in the mentioned analogy) is equivalent to the boundary surface between the gel and the KI solution (colored HgI_2 is formed as a result of the propagating reaction-diffusion wave), and the excess of KI solution is equivalent to the eraser. It may also be useful to mention that, if the reaction in eq 2 is not possible (like in a system containing aqueous gel of $Pb(NO_3)_2$ and KI solution, but also in many others), the simplest analogy of the wave and its motion would be of a pencil moving over a paper (whatever has been written, remains written on the paper).

The chemical wave in the arsenite–iodate system that was dealt with in our first paper [10] may also be treated as being of the pencil-and-eraser type; however, there are many disadvantages of the arsenite–iodate system (a need for carefully adjusted pH of the solution, use of high purity chemicals, etc.), and this system may not be the first choice for many instructors. Taking this under consideration, we decided to look for an alternative system where propagation of chemical waves is possible, sufficiently fast (the reaction should be completed in a couple of hours), does not suffer from the above-mentioned (or any similar) disadvantages, and is preferably an original one. The solution was found by considering the NaOCl–water–KI system.

The NaOCl–Water–KI System

Looking for an alternative to the $HgCl_2$–KI–water system (i.e., looking for a new pencil-and-eraser-like one-dimensional wave), we came across with two closely related systems that, to the best of our knowledge, were not explored in this context earlier.

In inorganic chemistry it is well known that the following pair of reactions occur in a Cl_2–KI–water system (providing a surplus of chlorine is present):

$$Cl_2(aq) + 2KI(aq) = 2KCl(aq) + I_2(s) \quad (3)$$

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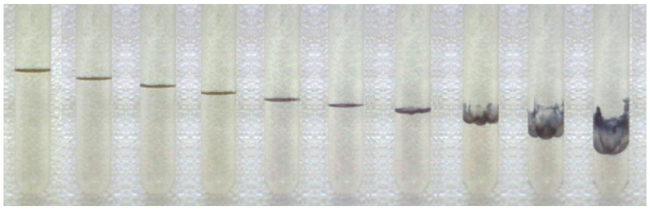

Figure 1. A chemical wave is initiated (a blue disk appears immediately) in a clamped test tube containing an iodide–water–starch mixture after hypochlorite solution has been added. Changes with time may be seen going from left to right (photos taken at different time intervals and merged on a single picture).

$$5Cl_2(aq) + I_2(s) + 6H_2O(l) = 2HIO_3(aq) + 10HCl(aq) \quad (4)$$

A gel of an aqueous solution of KI was prepared in this case (this also contains a colloidal suspension of starch as an indicator), and chlorine water was added over it. A dark-blue disk is formed instantaneously and it moves slowly downwards; however, the chlorine (and its aqueous solution as well) appear to be very destructive in the presence of gelatin. This can be noticed soon after the formation of the dark-blue disk: a white skin-like entity is also formed at the boundary surface of the solution–gel, suggesting that the chlorine is destructively oxidizing the gelatin. The product (the skin-like entity) seems to restrict the diffusion of chlorine water severely; thus, it slows down the process that is already rather slow. The chlorine, it was reasoned, should be substituted for by something less destructive.

A bleaching solution was tried instead of chlorine water, and the results were more than satisfactory. The chemical reactions in this case are analogous to eqs 3 and 4:

$$NaOCl(aq) + 2KI(aq) + H_2O(l) = NaCl(aq) + 2KOH(aq) + I_2(s) \quad (5)$$

$$5NaOCl(aq) + I_2(s) + H_2O(l) = 2HIO_3(aq) + 5NaCl(aq) \quad (6)$$

There are two benefits derived from using the bleaching solution: (a) no oxidation of the gelatin occurs (at least, not one that can be visually noticed) and (b) the wave propagates faster.

Experimental

Preparation of Solutions. The bleaching solution was a commercial product, claimed to contain 5 g L^{-1} NaOCl. No independent check of this claim was undertaken.

The concentration of the KI solution was 0.1 mol dm^{-3}. Approximately 20 mL of this solution were warmed to about 30 °C, and 0.3 g gelatin and 10 mL of a colloidal suspension of starch are added. The mixture was poured into a clean large test tube (total volume of about 60 mL) and the test tube was fixed in a vertical position and put in a refrigerator for at least a couple of hours (preferably overnight) in order for the gel to set.

Starch colloid sol (as an indicator) was added in the system because the deep-blue color of the iodine–starch clathrate is much more easily detectable than the color of iodine in aqueous solution. A colloidal suspension of starch (1 %) was prepared by the following procedure. An aliquot of 0.5 g of starch was added to a small amount of water (1–2 mL) and mixed thoroughly. The milky liquid was added to 50 mL of boiling distilled water and mixed again. The colloidal suspension was left to cool to room temperature. (The solution can be used for no more than two days, so one should avoid the preparation of large quantities.)

The Demonstration. The test tube that is half-filled by the mixture (after the gel is set) is clamped on a stand vertically. The bleaching solution is carefully added over the gel. A blue disk is immediately formed, moving slowly downwards with time. The whole process takes between 2 and 3 h, depending mostly on the quantity of gelatin used. Because this is a rather long time, a video clip was prepared similarly to that for our previous demonstration [10].

In the beginning, the disk moves smoothly with time and is rather sharp (cf. Figure 1, first five test tubes from the left). After the wave propagates over about half of the available distance, the disk becomes thicker and thicker. Soon after that, sporadic tails grow and disappear from the disk. We suspect that these changes in the shape of the disk result from depleting of the bleaching solution (NaOCl being permanently consumed). The whole appearance is very interesting and enables the instructor to discuss various chemical aspects (redox reactions, diffusion, importance of the NaOCl concentration, the pencil and eraser analogy, etc.).

The Video Clip. The digital camera was fixed in position on a Styrofoam block (this could also be done using a tripod) and was focused on the clamped test tube containing the initiated heterogeneous mixture. Because the blue disk is formed immediately, snapshots were taken every 20 s in a 2-hour period during which the wave propagates practically the entire distance. In this way, 360 medium resolution snapshots (640 × 480 pixels per inch) were obtained, the first 240 being used. These were linked to make a short movie. Music was added to the clip for more fun (cf. the movie ChemWave2 in the Supporting Material).

The video clip shows very nicely the changes occurring in the system.

Safety Tips and Disposal. Sodium hypochlorite (the bleaching solution) is an oxidizing and irritating agent (it is also strongly alkaline). Safety gloves are recommended when handling this solution. Safety goggles should be worn at all times during preparation of the solutions and when performing the demonstration. In case of a contact with skin, wash off with plenty of water for several minutes. In case of an eye contact, also wash off thoroughly with water and ask for an assistance of a physician.

The used chemicals are best disposed of by dilution in a large quantity of water and slowly pouring off in a sink. Actually, one of the biggest advantages of the system in question is the lack of either a heavy metal or any other dangerous pollutant.

Conclusion

We offer a chemical-wave demonstration that is very easy to perform. Compared to other chemical waves in gel media (like the waves in the system $HgCl_2$–KI–water, which may last several weeks), this wave occurs fairly quickly (a few hours). It is both educational (one may discuses various chemical aspects of the process) and a novel presentation. Although the chemical reactions have been known for a long time, to the best of our knowledge they have not been used in the context of demonstrating chemical waves.

The video clip further strengthens the demonstration and enables the study of some details (the demonstration is otherwise very slow). The response of students has been positive.

As we mentioned in our first paper [10], there are many other chemical phenomena that may be presented in this way (demonstrations on diffusion; effusion in liquids; osmosis). In our next contribution we will use the same video technique to accelerate slow processes to present effusion in liquids.

Supporting Material

Both Figure 1 and the movie ChemWave2 were taken using a ToUcamXS (Phillips) digital camera. The camera was coupled to, and software controlled by a PC. ChemWave2 was the result of linking 240 snapshots (each of 640 × 480 pixel per inch resolution). Photo 1 is in .jpg format and ChemWave2 is in .mpg format, viewable with the Windows Media Player. When viewing the file, it is recommended to use the full-screen option. The added music is, of course, optional (one can always switch off the speakers).

A 40-s movie (s00897040752asm.zip) showing propagation of the chemical wave in a clamped test tube is available as supporting material (http://dx.doi.org/10.1333/s00897040752asm).

References and Notes

1. Gribschaw, T. A.; Showalter, K.; Banville, D. L.; Epstein, I. R. *J. Phys Chem.* **1981,** *85,* 2152–2155.
2. Scott, S. K. *Oscillations, Waves, and Chaos in Chemical Kinetics;* Oxford University Press: New York, 1995; p 14–25.
3. Pojman, J. A. *J. Chem. Educ.* **1994,** *71,* 84.
4. Epstein, I. R; Pojman, J. A. An Introduction to Nonlinear Chemical Dynamics: Oscillations, Waves, Patterns and Chaos; Oxford University Press: New York, 1998.
5. Epstein, I. R. *J.Chem. Educ.* **1983,** *60,* 494–496.
6. Das, I; Pusharna, A; Agrawal, A. R. *J. Phys Chem.***1989,** *93,* 7269–7275.
7. Das, I; Pusharna, A; Bhattacharjee, A. *J. Phys Chem.* **1990,** *94,* 8968–8973.
8. Aleksovska, R. *Diploma work*, Institute of Chemistry, Faculty of Natural Sciences & Mathematics, Sts. Cyril & Methodius University, Skopje, 2001; pp 16–18.
9. Summerlin, L. R.; Ealy, J. L., Jr. *Chemical Demonstrations Volume 1*, 2nd ed., American Chemical Society: Washington DC, 1988; pp. 105–106.
10. Najdoski, M.; Aleksovska, R.; Petruševski, V. M. *Chem. Educator*, **2001,** *6,* 319–320; DOI 10.1333/s00897010519a.