

The Vitamin C Clock Reaction

This experiment, adapted from the January 2002 issue of the *Journal of Chemical Education* (see following reprint) is a clock reaction that uses all household materials.

Materials

- distilled water 250-mL beakers or plastic cups
- 1000 mg vitamin C tablets alcohol thermometer
- tincture of iodine (2%) ice cubes
- hydrogen peroxide (3%) bucket or tub for ice bath
- liquid laundry starch warm water bath

Procedure

1. Make a vitamin C solution by crushing a 1000 mg vitamin C tablet and dissolving it in 60 mL of distilled water. Label as “vitamin C stock solution”.
2. Combine 5 mL of the vitamin C stock solution with 5 mL of iodine and 60 mL of water. Label this “solution A”.
3. Prepare “solution B” by adding 60 mL of water to 15 mL of hydrogen peroxide and 2 mL of liquid starch solution.
4. Pour solution A into solution B, and pour the resulting solution back into the empty cup to mix them thoroughly. Begin timing as soon as they first mix and continue until there is a color change. Record the time it takes for the color to change.

Activity 2. The effect of concentration on the clock reaction

1. Repeat the experiment, but this time use 30 mL of water when preparing solutions A and B. Time the reaction and record the results.
2. Repeat the experiment, but this time use 90 mL of water when preparing solutions A and B. Time the reaction and record the results.
3. Repeat at other concentrations.

Activity 3. The effect of temperature on the clock reaction

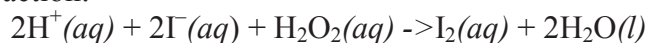
1. Repeat the original experiment using 60 mL of water to prepare solutions A and B, but cool the solutions to 15 °C before mixing by placing the containers in an ice bath. Mix as before, timing the reaction and recording the result.
2. Repeat again, this time using a warm water bath to heat the solutions to 25 °C. Mix as before, timing the reaction and recording the result.
3. Repeat again, this time at room temperature. Record the temperature. Mix as before, timing the reaction and recording the result.
4. Repeat at other temperatures.

Instructional notes on activity 1. The vitamin C clock reaction

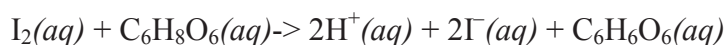
This lab is presented as an example of green chemistry. It introduces an alternative way to do a traditional lab, using safer starting materials. Since your students are new to chemistry, they will not have any experience with the “old” ways. You will need to put

this lab into perspective for them by reviewing the older versions of this experiment and discussing what was so bad about them. You might want to do a calculation similar to question 5, only dealing with the amount of formalin used in the formaldehyde clock reactions. (See Reference 2 for this demonstration.)

Although this activity is very popular with students, there are some issues to deal with when you use it in your class. One of the key issues is explaining what is going on in the reaction. Part of the reaction is easy to explain. When iodine and starch combine, they make a black-blue complex. Students will probably recognize this from their biology class, where iodine is used as a test reagent for starch. The reaction rate being studied is for the following reaction:



The I^- is produced by adding excess vitamin C (ascorbic acid $\text{C}_6\text{H}_8\text{O}_6$) to household tincture of iodine.



When the H_2O_2 is added to the first reaction, it begins to produce I_2 . But since the ascorbic acid reacts with the I_2 immediately, it prevents the I_2 from reacting with the starch. The color change occurs only after all the vitamin C is used up.

Another issue to talk about is what is meant by the term *rate*. Chemists measure rates of reaction in terms of the rate of appearance of a product or the rate of disappearance of a reactant.

Another issue is that students are measuring time in this lab, rather than rate. The rates would actually be proportional to $1/T$. It is important to convey that as the reaction time gets smaller, the rate is actually larger. If this distinction is not made, students might be thinking the reverse of the proper relationship. It should be noted that this experiment only approximates an authentic rate of reaction. Since the color-change reaction that we are actually seeing is distinct from the reaction rate we are studying, we are only approximating the actual rate. Despite this minor shortcoming, the lab gives students a good concept of rates of reaction.

Instructional notes on activity 2. The effect of concentration on the clock reaction

By lowering the concentration of the reactants (using more dilute solutions), the rate of reaction tends to decrease. If there are fewer molecules in a given volume of solution, then it is reasonable there would be fewer effective collisions and fewer products formed. Note that the quantitative change in reaction rate brought about by a change in concentration involves a complex interaction. Advanced-level courses consider reaction order and how the reaction mechanism affects rate.

A related extension would be to have students calculate the effect of mixing on the rate of reaction. Students could experiment with different ways of combining the solutions, varying the amount of mixing that occurs.

Instructional notes on activity 3. The effect of temperature on the clock reaction

Be sure to arrange appropriate hot and cool water baths in advance. It is usually easier to set up some central water baths and have all students use them. If you do not have a dedicated water bath, you can always improvise by placing a water-filled metal pan on a hot plate. You will need to replenish the water in these baths during the day.

Alternatively, you can have students create their own water baths by using a large beaker at their lab station. Consider grouping students, giving each group a different temperature range to try.

Questions & Answers

1. What is the difference between the clock reaction and other color-changing reactions that you have done previously in your studies?

The big difference is that most reactions used in chemistry classes tend to change immediately. This experiment uses a combination of reactions, with the final reaction marking when the reaction series is completed. The analogy is that it is like an alarm clock. The clock runs for a time, and then the alarm sounds.

The running clock is like the first reaction above, the “alarm” is like the combination with starch.

2. Rate of reaction is defined as how fast reactants are used up or products appear. What is the relationship between the time it takes for a reaction to occur and the rate of reaction?

The rate is the amount of substance reacting per unit of time. Thus the faster (smaller number) the reaction time, the greater (bigger number) the rate.

3. What appears to be the relationship between the concentration of the reactants and the rate of this reaction?

The higher the concentration, the greater the rate of reaction. It should make sense that higher concentration means a greater number of collisions and a greater possibility of effective collisions.

4. What appears to be the relationship between the temperature of the reactants and the rate of reaction in this experiment?

The higher the temperature, the greater the rate of reaction. In this reaction, a higher temperature means greater kinetic energy in the particles and a higher proportion of effective collisions (collisions that lead to reactions). Also, with greater kinetic energy, more collisions will occur.

5. One of the mercury-based clock reactions used approximately 150 mL of 0.01 M HgCl₂ solution per experiment for each lab group (2 students per group). For example, assume that all of the approximately 2 million introductory chemistry students in the nation did the safer experiment described in this activity rather than the mercury-based experiment; how much mercury waste would be avoided?

This calculation entails a lot of “what ifs”. If 150 mL of solution is used for each pair of students, then This assumes that every classroom in the United

States is doing this experiment, which is unlikely. Nevertheless, this single modification would save about 900 pounds of mercury from being used.

6. What are the advantages of limiting the use of mercury compounds in lab experiments? What are some of the health and environmental problems associated with mercury? Explain why it is desirable to limit the release of mercury into the environment.

Elemental mercury is used in hundreds of applications, from electrical switches to street lamps. If mercury gets into the bloodstream and into the brain, it can cause serious damage to the central nervous system. Young people are particularly susceptible to this type of damage. Most mercury pollution is released through the burning of coal and waste incinerators. The dangers of long-term accumulation of mercury in the environment have led to the elimination of most industrial contributions of mercury waste.

7. Suppose a researcher were doing work on mercury compounds and its use couldn't be avoided. What precautions should be taken when disposing of mercury compounds? Consult a Materials Safety Data Sheet (MSDS) on mercuric chloride or another mercury compound and note the suggestions for disposal.

Elemental mercury is not very toxic. Damaging effects occur when it crosses the blood–brain barrier. The compounds of methylmercury are far more toxic. Flinn Scientific suggests that mercury compounds can be safely disposed of by converting them to an insoluble salt and placing them in an approved hazardous materials landfill. Flinn advises that the only safe disposal of mercury metal is to return it to a supplier for recycling.

References

1. Wright, Stephen W. The Vitamin C Clock Reaction. *J. Chem. Educ.*, January **2002**, 79 (1), 41–43.
2. Wright, Stephen W. Tick Tock, a Vitamin C Clock. *J. Chem. Educ.* **2002**, 79, 40A–40B.
3. Shakhashiri, B. Z. *Chemical Demonstrations*, Vol. 4; University of Wisconsin Press: Madison, WI, 1992.

Tick Tock, a Vitamin C Clock

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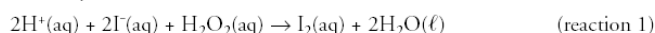
This Activity uses supermarket chemicals to perform a clock reaction. The endpoint is signaled by an abrupt change in the appearance of the reaction solution from colorless to blue-black. Students vary the concentrations of the reactants and observe the resulting changes in the time required for the reaction to reach its endpoint. A complete discussion of the chemistry involved, experimental procedure, and notes for successful reproduction of this reaction as a Tested Demonstration is presented in this issue and the references cited therein (1).

Integrating the Activity into Your Curriculum

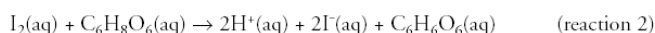
This Activity can be used to explore reaction kinetics, and in particular the effect of reactant concentrations on the apparent rate of a reaction. It can also be used in a discussion of redox chemistry, the descriptive chemistry of iodine, and the chemistry of vitamin C.

About the Activity

In this Activity students collect information about the rate of the reaction



The reactant I^- is generated from I_2 by adding an excess of vitamin C (ascorbic acid, $\text{C}_6\text{H}_8\text{O}_6$) to tincture of iodine dissolved in water



When H_2O_2 is added, reaction 1 begins, but because reaction 2 uses up the I_2 as fast it is formed by reaction 1, the concentration of I_2 in the solution remains very small and no blue-black starch-iodine color appears. Only after all of the vitamin C is used up does reaction 1 produce a concentration of I_2 high enough to form the blue-black color. The faster reaction 1 produces I_2 , the faster reaction 2 uses up vitamin C, and the shorter the time until the blue-black color appears. Available on *JCE Online*^W are videos of the vitamin C tablet and orange juice versions of the clock reaction.

In the Activity, vitamin C tablet(s) are finely crushed under water and dissolved. Some variability in the time required to reach the endpoint may be encountered, depending upon how completely the vitamin C in the tablet(s) is dissolved. Do not use tablets marked "chewable" or "flavored" as they contain ingredients that may interfere with the reaction. For best results, use only distilled or deionized water for all solutions. If purified water is unavailable, use white vinegar. Softened water can give erratic results. Be sure to use antiseptic tincture of iodine, USP 2%. Similar products such as 7% tincture of iodine and "tincture of iodides" (also known as "decolorized iodine") are not suitable.

Linit and Sta-Flo laundry starch were used in testing, but other laundry starches may also be used. If laundry starch is unavailable, an alternative can be prepared by mixing 5 grams (1–2 teaspoons) of cornstarch with 30 mL (2 tablespoons) of cold tap water until a uniform thin suspension is formed. Pour the suspension slowly into 500 mL (2 cups) of vigorously boiling water with stirring so that the boiling does not stop. Allow it to cool before use.

CAUTION: Tincture of iodine is poisonous and flammable. Tincture of iodine and the clock reaction mixture must be kept away from children. Before disposal, the clock reaction mixture should be reduced by the addition of ascorbic acid (vitamin C).

Answers to Questions

1. A difference is that a clock reaction's endpoint is accompanied by a visible change in the reaction mixture. In this example, the change is brought about by a second reaction that occurs rapidly when the first reaction is exhausted.
2. The red-brown color of the iodine rapidly disappears. This suggests that elemental iodine has been reduced to iodide (I^-) ion. Ask the students what was oxidized in this reaction.
3. Reaction times may vary among groups, even though the same procedure was followed. Variability can occur in the dissolution of the vitamin C tablets and in measuring liquid volumes. Experiment 2 is the fastest, followed by experiment 1 and experiment 3. The more concentrated the reaction mixture, the faster the reaction takes place. Experiment 2's mixture is more concentrated than 1's, which in turn is more concentrated than 3's.
4. Vitamin C can be accurately determined by titration with standard iodine solution. You might be able to estimate it by how long it takes before the clock-reaction color change occurs.
5. The insoluble substances are typically starches and waxes. They are added to the tablet mixture to help form and maintain the shape of the tablet and facilitate its breakup in the stomach.

References, Activities, and Resources

1. Wright, Stephen W. The Vitamin C Clock Reaction; *J. Chem. Educ.* 2002, 79, 41–43.

JCE Classroom Activities are edited by Nancy S. Gettys and Erica K. Jacobsen

Tick Tock, a Vitamin C Clock

Clocks have been used to measure time since antiquity. They have been fashioned from various materials, as simple as stones arranged to form a sundial and as complex as a liquid crystal display. A clock can also be constructed from molecules that react at a rate that allows an interval of time to elapse between the mixing of the chemicals and the completion of the reaction. Such “clock reactions” are important regulators of biological cycles in nature. In this Activity, you will make a chemical clock using chemicals found in the supermarket. You will then investigate what happens to the speed of the clock when the reactant solutions are made more or less dilute.

Try This

You will need: distilled or deionized water, 1000 mg of vitamin C tablet(s), tincture of iodine (2%), hydrogen peroxide (3%), liquid laundry starch, stopwatch or clock, plastic measuring spoons or graduated cylinders, marker pen, six 6–8-ounce colorless transparent plastic cups, metal spoon, plastic coffee stirrers. **Optional:** orange juice, one 10–20-ounce colorless transparent plastic cup.

Use distilled or deionized water for all solutions.

- __1. Prepare a vitamin C stock solution by using a metal spoon to crush 1000 mg of vitamin C tablet(s) in a plastic cup with 4 tablespoons (60 mL) of water. This is easier if the tablets are allowed to stand in the water before crushing. Break up the tablet(s) until no pieces of solid can be seen. The solution will be slightly hazy owing to small amounts of other substances in the tablet that will not dissolve in water. Label the cup “Vitamin C stock solution”.
- __2. Label another plastic cup “Solution A”. Place 4 tablespoons (60 mL) of water in the cup. Add 1 teaspoon (5 mL) of the vitamin C stock solution and 1 teaspoon (5 mL) of tincture of iodine. What do you observe? Stir the mixture with a coffee stirrer. What do you observe?
- __3. Label another plastic cup “Solution B”. Place 4 tablespoons (60 mL) of water in the cup. Add 1 tablespoon (15 mL) of 3% hydrogen peroxide and 1/4 to 1/2 teaspoon (1.2 to 2.5 mL) of laundry starch. What do you observe?
- __4. Label another plastic cup “Experiment 1”. Pour Solution A into the cup. Add Solution B all at once, record the time, and stir with a plastic coffee stirrer for about 5 seconds. What happens? Continue to watch the mixture until you note a change and record the time again.
- __5. Label another plastic cup “Experiment 2”. Repeat steps 2, 3, and 4 but this time use 2 tablespoons (30 mL) of water when preparing Solutions A and B.
- __6. Label another plastic cup “Experiment 3”. Repeat Steps 2, 3 and 4 but this time use 6 tablespoons (90 mL) of water when preparing Solutions A and B. Predict what will happen.

Orange Juice Option: Prepare Solution A in a 10–20-ounce plastic cup by adding 1 teaspoon (5 mL) of tincture of iodine to 18 tablespoons (270 mL) of room-temperature orange juice. Stir thoroughly, then add 1/4 to 1/2 teaspoon (1.2 to 2.5 mL) of laundry starch. Add 4 tablespoons (60 mL) of 3% hydrogen peroxide to start the reaction.

Questions

- __1. What is the difference between a “clock reaction” and the many other chemical reactions that take seconds, minutes, or hours to complete?
- __2. What happened when the tincture of iodine was first added to the vitamin C solution? When it was stirred? What does this suggest might have happened?
- __3. Compare your time to endpoint in experiment 1 with the times recorded by others. Are they the same? If not, why might they be different? How do the rates of experiments 1, 2, and 3 compare? Why?
- __4. How could you accurately determine the amount of vitamin C in a sample of orange juice?
- __5. What are the substances in the tablet that don't dissolve in water? Why are they included in the tablet?

Information from the World Wide Web (accessed November 2001)

1. Vitamin C Web sites: <http://www.encyclopedia.com:80/articles/13531VitaminC.html>; <http://www.bowstuffworks.com/vitamin-c.htm>.
2. Iodine Web sites: <http://www.encyclopedia.com:80/articles/06436.html>; <http://www.webelements.com/webelements/elements/text/I/key.html>.



Be Safe! Tincture of iodine is poisonous and flammable. Check with your instructor for disposal instructions for all solutions.

This Classroom Activity may be reproduced for use in the subscriber's classroom.