THE “VOICE ACTIVATED” REACTION AND HOW IT WORKS

Kathryn M. Wagner, Princeton University Chemistry Department,
kmwagner@princeton.edu

Brief description of demonstration

When students talk to a pink solution in a flask, the solution turns yellow. Students are asked to suggest possible reasons for the change. Hypotheses are listed and tested.

Concepts illustrated

- Scientific method
- Experimental design
- Chemistry of carbon dioxide
- Acid/base indicators

Materials

For the “Voice-activated” reaction:

- 500-ml Florence flasks with stoppers [1 flask/10-15 students, plus additional flask(s) for control solution]
    - Florence flasks are preferred for this experiment because they provide the greatest surface area per volume of solution. If Florence flasks are not available, use a different wide-bottom, narrow-mouth container.
- Water-soluble phenol red indicator [phenol red, sodium salt, CAS 34487-61-1]
- Dilute sodium hydroxide or concentrated sodium bicarbonate solution and dropper
- Water [150-200 ml per flask, plus additional water for control solutions]
- Large beaker or flask to prepare solution
- Small spatula
- Stirring rod

For modeling the scientific method:
Have available

- Control solution from “voice-activated” reaction
- Small beakers and/or clear cups
- Mild heat source (e.g.- overhead projector, room radiator, hotplate on low)
- Water
- Ice and/or dry ice
- Sodium hydroxide and dropper
- Hydrochloric acid (or other acid) and dropper

To produce hot carbon dioxide:

- Candle mounted on glass plate
- Matches
- Wide-mouth Erlenmeyer flask to fit over candle

Preparation

Prepare a slightly basic dilute aqueous solution of phenol red indicator. (Use the water-soluble sodium salt.) You will need about 150-200 milliliters for each flask to be circulated, plus 300-500 milliliters for controls and tests. Add just enough dilute sodium hydroxide or sodium bicarbonate solution to turn the indicator pink. Immediately transfer the solution to Florence flasks and stopper the flasks.

Helpful hints:

- The batch method is the easiest way to prepare a large number of flasks: Measure out enough water-soluble phenol red to barely cover the tip of a micro spatula and put it into a beaker or flask large enough to hold the amount of solution you need. Add a drop or two of dilute base per liter of solution and pour in the water. Stir the solution, if necessary, and adjust the pH by adding more base, drop by drop, stirring between drops, until the solution just turns pink.
- Transfer the solution to the flasks immediately after the pH is adjusted, and keep the flasks tightly closed. Solution left open to the air will absorb carbon dioxide and turn yellow.
- If solution must be prepared a long time ahead, store it in containers with minimal head space and measure it into flasks a short time before the demonstration.
- If the solution in a flask starts to turn yellow before the demonstration, add a drop or part of a drop of 0.1M sodium hydroxide.
- If you have several presentations to do, you may re-use the flasks. Add just enough dilute base to each flask to restore the pink color. A caution: bicarbonate forms a buffer with carbonic acid, and the higher the concentration of bicarbonate, the longer the solution will take to turn yellow. If you notice that the solution in a given flask takes more than a few drops of dilute base to return to pink, replace the solution in the flask with fresh solution or use a different flask.

Presentation

"Voice-Activated" Reaction:

Remove stoppers from flasks and distribute one flask to every 10-15 students. [For small classes, divide the class into two groups and give each group a flask. A little friendly competition adds to the excitement!] Instruct students to take turns telling the solution in the flask to turn yellow. Since chemistry is universal, they may talk to the solution in any language they choose, as long as they speak directly into the flask. At some point, suggest that they try whispering to the solution. Whispering not only lowers the noise level in the classroom, but also decreases the time required for the color change.

To use the demonstration to introduce the scientific method and experimental design:

After the solution in a group’s flask has turned yellow, ask students in that group to start to think of hypotheses that explain how talking to the liquid could lead to a color change. When the color changes are complete, begin to list the hypotheses. List all suggestions with equal enthusiasm, and do not stop when the “correct” hypothesis has been proposed. The goal is to encourage students to think of as many factors as possible that could influence the experiment.

Most students realize that the reaction is initiated by something associated with exhaled breath. Since most students are also aware that exhaled breath contains carbon dioxide, at least one person from almost every class (even a class of six-year-olds) will suggest carbon dioxide. If you have an exceptional class in which no one mentions carbon dioxide, guide the discussion a bit by asking students about the contents of exhaled breath.

Test each hypothesis with solution from a control flask using the materials you have at hand. (Try to make the experiments look spontaneously devised to emphasize that scientific thought can be used as a way of solving problems in everyday life.) Doing science does not always require sophisticated equipment. Doing science does require critical thought and experimentation.

The protocol you develop will depend on the list of hypotheses proposed, with two caveats: Always test carbon dioxide next to last, and always introduce ambiguity into the experiment for carbon dioxide. If dry ice is your source of carbon dioxide and cold is one of the students’ hypotheses, test cold last. If a burning candle is your source of carbon dioxide and heat is one of the students’ hypotheses, test heat last. You may test all other hypotheses in whatever order is convenient, and you may combine two or more variables in a single experiment when appropriate. As you do each experiment, briefly explain the logic of your design. If you do not have adequate means to test a particular hypothesis, discuss with the class possible methods and the materials and conditions that would be required.

Some frequently proposed hypotheses, with possible experiments:

- **Mixing**: Swirl and shake a tightly closed flask of control solution.
- **Vibration** from the voice: Hold a tightly closed flask of control solution against your throat and vocalize loudly. (“Ahhh” and “Ommm” are particularly effective.)
- **Water vapor** or moisture: Add no more than a milliliter of distilled water to a beaker or flask of control solution. (The class should agree that, unless someone spit in the flask, a milliliter is much more moisture than would be added to the solution under the conditions of the experiment.)
- **Oxygen** (and/or **nitrogen**): Place an open beaker on a table or shelf. (The class should agree that exhaled breath contains a slightly smaller concentration of oxygen and about the same concentration of nitrogen as ambient air.)

- **Heat**: Place a small beaker or flask of control solution on an overhead projector stage, working radiator, or hotplate. (You may combine this with a test of oxygen and/or nitrogen by putting an open beaker on the heat source.) [Note: If you are using a candle as your source of carbon dioxide, test heat separately and test it last.]
- **Cold:** Place a small beaker or flask of control solution in an ice bath (You may combine this with a test of oxygen and/or nitrogen by putting an open beaker in the ice bath.) [Note: If you are using dry ice as your source of carbon dioxide and you have no candle to produce hot carbon dioxide, test cold separately and test it last.]
- **Carbon dioxide, method 1 (requires dry ice)**
    1) Drop a small piece of dry ice (solid, concentrated carbon dioxide) into a flask or beaker of control solution. The solution will immediately turn yellow.
    2) Make a great show of having found the “correct” hypothesis—and then catch yourself. Ask students if the conclusion that carbon dioxide was the cause of the color change is valid. Was anything else changed by the addition of dry ice? Someone will say temperature.
    3) Devise an experiment to rule out cold as a factor.
        - If you have ice, you may put a flask or beaker in an ice bath.
        - If you have more than a small piece of dry ice, you may put a tightly closed control flask in the dry ice briefly. (See the hint for success below.)
        - If you have time and materials, produce hot carbon dioxide and test that. See “Carbon dioxide, method 2,” below.
- **Carbon dioxide, method 2 (requires candle, glass plate, and flask)**
    1) Light the candle and invert the wide-mouth flask over the candle. Seat the flask firmly on the glass plate. [Ask students to predict what will happen to the flame and why. Make certain that they realize that the product of the combustion reaction is carbon dioxide.]
    2) After the flame goes out, remove the flask, quickly cover the mouth with your hand, and turn it upright. The warm gas in the flask will have a high concentration of carbon dioxide.
    3) Pour a small amount of control solution into the flask and swirl it gently. The solution will turn yellow.

Hint for success:

Avoid false positives by protecting solutions from ambient carbon dioxide.

- Keep all solutions in closed flasks or covered containers, unless the experiment requires heat or exposure to air.
- Keep dry ice in a closed container below the level of the tabletop.
- Hold open beakers high, and keep them as far away from sources of carbon dioxide as possible.

To illustrate a possible next step in an investigation, to illustrate a chemical property of carbon dioxide, or to introduce acid/base indicators:

Now that evidence has been presented that carbon dioxide is involved in the color change, the next step is to investigate the properties of carbon dioxide that could be responsible. One chemical property of carbon dioxide is that it dissolves in water to make an acid. This also happens to be a convenient property to test.

To test the hypothesis that the color change is related to the acidity of carbon dioxide,

- Add a different acid (dilute acetic acid or dilute hydrochloric acid) to some of the control solution. (The solution will turn yellow.)

[At this point, if you are using the demonstration to illustrate the scientific process, you could discuss with the class the advisability of using this reaction as a test for carbon dioxide. Would it be a good test? Why or why not? Under what conditions (if any) would it be effective? What problems might be encountered in its use?]

To introduce acid/base indicators:

- Add base to one or more flasks or beakers of yellow solution. (The color returns to pink.)
- Add acid of any type to the test flask(s) to change the color to yellow again.

Discussion

Phenol red is an acid/base indicator with a pK_a of 7.3. It is yellow in acid and pink in base.

Further investigation into color change is beyond the scope of this demonstration. If you are using the demonstration to illustrate the scientific process, ask students to suggest the next question to investigate.

If you are using the demonstration as part of a unit on carbon dioxide, you may wish to make the “combustion connection” between students and candles. Both a student and a burning candle “breathe in” oxygen and “breathe out” carbon dioxide. They both get energy from reacting oxygen with compounds containing carbon and hydrogen to produce carbon dioxide and water. Students burn sugar and candles burn paraffin. Of course, students have nothing to fear. The kinetics and mechanism are considerably different!

If you are introducing acid/base indicators, you may follow this demonstration with demonstrations of other indicators, such as methyl red, bromothymol blue or red cabbage juice. [If dry ice and a universal indicator are available, the Dry Ice Rainbow makes an excellent finale to a demonstration of indicators.]

Disposal

Neutralize any test solutions that contain a large excess of acid or base and flush waste down the drain with water.