INVESTIGATION 5

Sticky Question: How Do You Separate Molecules That Are Attracted to One Another?

CENTRAL CHALLENGE

The central challenge in this laboratory is to develop a method to separate three similar molecules.

CONTEXT FOR THIS INVESTIGATION

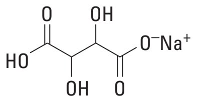
You are working for a crime lab and a chemical residue has been turned in for analysis. To identify the chemicals in the residue, you will need to separate them from the mixture and identify them individually. Another lab technologist has made an attempt to separate the molecules but was not as successful as the boss would like. There was only one molecule separated from the mixture, but the boss suspects that there are at least three different molecules. Science is often a process, in which a method is tried and then modified for a second attempt. Your job will be to propose a modification and attempt to improve the separation attained.

PRELAB GUIDING QUESTIONS/SIMULATIONS

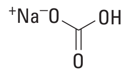
Part I

Your teacher is going to show you a demonstration.

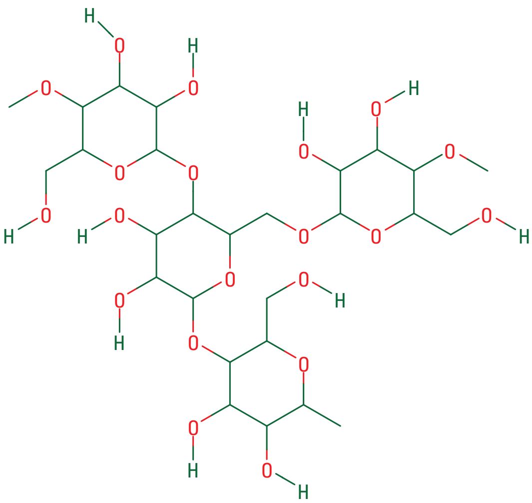
1. Why does the water creep up the paper? Explain this. Draw the molecular interactions associated with the macroscopic observation.



Sodium bitartrate



Sodium bicarbonate



Cornstarch polymer

Figure 1. Components of baking powder

2. In your kitchen there is a mixture that is usually listed as a single ingredient in recipes: baking powder. Baking powder is actually a mixture of sodium bicarbonate, cream of tartar (sodium bitartrate), and cornstarch (see Figure 1). Looking at the three molecules in Figure 1, how are they similar and how are they different? Draw a picture of how each molecule would interact with a bunch of water molecules
3. How would you separate this baking powder mixture into the three parts?

Part II

Your teacher may or may not ask you to perform this part of the prelab.

Computer simulation at Concord Consortium: *http://mw.concord.org/modeler/*

Select "More" at the bottom of the "Selected Curriculum Modules" section and then, from the chemistry column, select "Intermolecular attractions." When doing the simulation, make sure to take snapshots and answer all the questions. On the final page, there is a button labeled "Create a report of my work" that will include all written answers and snapshots. Your teacher may also assign the following questions for you to answer after performing the simulations.

1. How can molecules attract each other when they are in a mixture? Predict how ethanol would interact with those molecules. Draw a picture illustrating the interactions between the components of the mixture and the solvent, ethanol.
2. What does the R_f value describe on a microscopic level? Why is this important?
3. If the molecule had a very high affinity for the stationary phase, how would this affect the R_f value? Explain.

4. What role does the mobile phase play in the distance a molecule travels in chromatography? What does the mobile phase describe?
5. If you combined a polar solvent with a molecule that has a carbonyl group (carbon with a double-bonded oxygen) would it have a high or low R_f value? Justify your answer with what you understand of intermolecular forces.

EXPLANATION TO STRENGTHEN STUDENT UNDERSTANDING

There are two phases in paper chromatography, a stationary phase (the paper) and a mobile phase (the solvent). A molecule can have a greater affinity for either the paper or for the solvent. The filter paper is made of cellulose, a polymer. Cellulose will attract water molecules to the exposed hydroxyl groups along the polymer. This interaction makes a thin layer of water on the paper that competes for the attraction of the molecules being separated. Alternately, the molecule can be attracted to the solvent and travel with the solvent up the paper. When doing chromatography, a small amount of solvent is placed in a sealed container. The mixture being separated is put on a piece of paper, the starting point is marked, and the paper is put into the solvent. The container must be sealed so the solvent saturates the paper and does not evaporate first. The level of separation is measured by a ratio that compares the distance that the molecule travels to the distance the solvent travels. This ratio is called the R_f value. To get the R_f value, the experimenter must identify the distance that the solvent traveled on the paper and measure the distance. Secondly, the experimenter must identify the distance that each molecule traveled and measure that distance. It is best to run the test more than once to reach the best separation values possible. The R_f value is a ratio of the distance of the molecule divided by the distance of the solvent. The greater the distance the molecule travels, the greater its affinity for the solvent and the greater the R_f value.

In this experiment you will have a choice of different solvents to use. When you propose the best solvent for separation of the mixture you will also need to evaluate it in terms of "greenness." In modern chemistry, chemists use principles of green chemistry to evaluate solvents that are used in a chemical process for their level of toxicity to humans and the environment. Solvents are also evaluated in terms of their life cycle or how long the molecule remains in the environment and if the molecule breaks down to become more benign or more toxic. The overall focus of green chemistry is to be more efficient in chemical production, producing less waste, using fewer toxic molecules, and producing waste that biodegrades and does not pose a risk to the environment. See Tables 1 and 2 in the GSK solvent selection guide, available at *http://pubs.rsc.org/en/content/articlelanding/2011/gc/c0gc00918k* under "supplementary information," for an evaluation of solvents based on these guidelines. To understand the differences between solvents, look up the green rating for hexane (found in "chromatography solvent") and compare it to that for 2-propanol.

The food dyes that are in the mixture have their own green chemistry issues. For example, the molecules used may have a life cycle that is longer than previously anticipated and possibly increased toxicity. While scientists evaluate the toxicity of molecules based on the experimental data, efforts to understand the origins of toxicity often look at the structure of the molecule. A key strategy for looking at molecular structure is to identify functional groups that are present. There are specific functional groups that are known to create toxic by-products when they are metabolized in the human body, such as acetaminophen that can be converted to N-acetyl-p-benzoquinoneimine. Some of the food dyes used in this lab are azo dyes, which means that they contain a double-bonded nitrogen connecting multiple aromatic carbons. While the molecules resemble each other, only red 40 has been linked to allergic reactions in some people, but the FDA has not found conclusive evidence that such a dye is unsafe. In Europe these food dyes are not used and natural pigments are used instead.

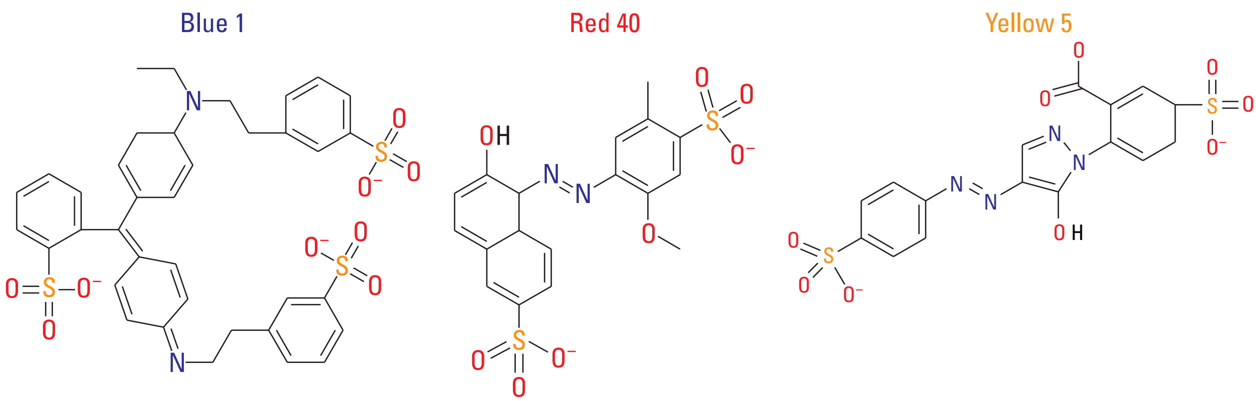


Figure 2. Molecular structure of food dyes

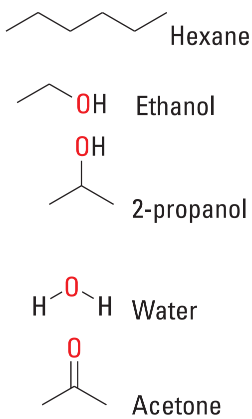


Figure 3. Molecular structure of typical solvents

PREPARATION

Materials

Sample mixture to separate	Small (25–50 mL) cylindrical glass containers with lids	Tape to make labels
Pencils	100 mL graduated cylinders	Ethanol (C_2H_5OH)
2-propanol ($(CH_3)_2CHOH$)	Distilled water	Acetone ($(CH_3)_2CO$)
Chromatography solvent (petroleum ether and acetone mixture)	Metric rulers accurate to mm	Laboratory filter paper or chromatography paper (cut into strips narrow enough to fit into container and shorter than container)

Safety and Disposal

The mixture of food dyes is safe to dispose down the sink, as well as the distilled water. The other solvents — acetone, 2-propanol, ethanol, and chromatography solvent — should be collected and disposed of in an organic waste container. Teachers and students should take normal laboratory precautions, including wearing splash-proof goggles at all times. If solutions are spilled on skin, wash with copious amounts of water. For student-friendly MSDS, use the searchable index found at the following link: *http://www.ehso.com/msds.php*

INVESTIGATION

You will design an experiment that tests the solvents that you believe will provide the best separation of the three food dyes in Figure 2. There are five solvents listed as available for you to use in this experiment, including chromatography solvent (petroleum ether/acetone mix), acetone, ethanol, 2-propanol, and distilled water. If there are other materials you would like to use, check with your teacher to see if they are available.

Procedure

Develop a hypothesis as to what could lead to an effective separation of the three food dyes in the sample your teacher has provided. Include intermolecular attractions in your hypothesis. You must test at least two of the solvents provided by your teacher (see Figure 3). You will need to write a step-by-step procedure and design a data table to record data. The procedure needs to be clear enough that someone else could repeat the experiment and get the same results. Your teacher will have materials set out for you to choose from.

Data Collection and Computation

1. Why did you select the solvents that you tested? Did your data support your hypothesis or disprove your hypothesis?
2. What explanations can you provide for your separation of the three molecules? How was the choice of the solvent connected to the separation process?
3. What part of the chromatography setup did the molecules interact with, stationary or mobile phase? How would you explain this interaction using intermolecular forces?
4. Draw a picture of how the chromatography worked. Explain your picture using the following terms: stationary phase, mobile phase, and intermolecular forces.
5. Evaluate which solvent is the one with the best "green chemistry" rating (using the reference in the Explanation to Strengthen Student Understanding section). What intermolecular forces would this solvent form with the three molecules in the mixture?
6. Which molecule spent the most time in the stationary phase and why?
7. Calculate the R_f values for each chromatography trial that you completed and include them in the data table.

Argumentation and Documentation

Write an explanation of how intermolecular forces and molecular structure of the molecules being separated determine the ideal solvent for use in chromatographic separation. Be sure to cite specific evidence from this experiment to support your explanation.

POSTLAB ASSESSMENT

Write an explanation of what are the intermolecular forces that would explain why pyridine is soluble in water and benzene is not.

SUPPLEMENTAL RESOURCES

Links

"Chromatography Basics." Science Spot. Accessed July 28, 2012. *http://sciencespot.net/Media/FrnsScience/chromacard.pdf*

"GSK Solvent Selection Guide." RSC Publishing. Accessed July 28, 2012. *http://pubs.rsc.org/en/content/articlelanding/2011/gc/c0gc00918k* (under "supplemental resources")

"Isolation of Plant Pigments by Column Chromatography." Amrita. Accessed July 28, 2012. *http://amrita.vlab.co.in/?sub=3&brch=64&sim=160&cnt=1*

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Fulton, April. "FDA Probes Link Between Food Dyes, Kids' Behavior." *Morning Edition*, NPR. Accessed July 28, 2012. *http://www.npr.org/2011/03/30/134962888/fda-probes-link-between-food-dyes-kids-behavior#chart*

Gilman, Victoria. "Food Coloring." *Chemical & Engineering News* 81, no. 34 (2003): 34. Accessed July 28, 2012. *http://pubs.acs.org/cen/whatstuff/stuff/8134foodcoloring.html*

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