JCE Classroom Activities are edited by Erica K. Jacobsen

Instructor Information

JCE Classroom Activity: #101

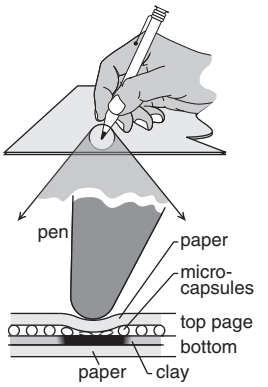
The Secret of Smart Paper

Lynn Diener,[1]* Brian McCall,[2] and J. Aura Gimm[3]

[1]Mount Mary College, Milwaukee, WI; [2]University of Wisconsin–Madison, Madison, WI; [3]Duke University, Durham, NC; **dienerl@mtmary.edu*

In this Activity, students learn about special papers that use microencapsulation—such as grocery store receipts, carbonless lab notebooks, and some questionnaires—that they encounter every day. Students will perform a hands-on exploration of three-part carbonless copy paper, learning about the paper through their own personal observations.

Background



Nearly everyone has filled out a carbonless copy form. You write on one sheet, yet two, three, or more copies are produced. The technology of how carbonless copy paper works is the basis for this activity. The "secret" is that dye precursors coat the back of one paper sheet and the color developer (which changes the reactant from colorless to colored) coats the front of the next paper sheet. A microcapsule (3–8 μm diam, usually made of gelatin) houses the dye precursor, preventing the dye from turning color until mechanical force from a pencil or pen breaks open the microcapsule. (See ref *1* for animation.) The dye precursor generally reacts with acid to go from colorless to colored *(2).* Crystal violet lactone is a common precursor: upon reaction with acid, its phthalide bond breaks, changing the molecule's hybridization from sp^3 (tetrahedral) to sp^2 (planar) resulting in color formation *(2, 3).* The color developer is usually a clay (e.g., bentonite or attapulgite), which tends to produce hydrogen ions *(3).* For three-part carbonless copy paper the middle sheet is coated on both sides: the front with color developer, the back with microcapsules. A third sheet will be coated on the front with color developer. This pattern can continue to create many copies.

In an analogous use, microcapsules are being tried to target medicine to certain diseased cells. For instance, in typical cancer treatment, toxic drugs are given that harm many cells in the body, leading to negative side effects (e.g., hair loss, and tingly, painful fingers). Targeting a drug to affect only cancer cells saves patients from many negative side effects.

Integrating the Activity into Your Curriculum

This activity introduces encapsulation, specifically showing students how microencapsulation works and how it is useful for making identical copies without a photocopy machine. Students can discuss further applications for this technology and explore other ways this technology is used, such as in medicines *(4)* and scratch-and-sniff stickers.

About the Activity

Prepare the carbonless copy paper in advance, using all white, three-ply copy paper if possible and cutting the paper into 2.5-inch squares (to conserve paper). It is important that no copies appear when students first write on the paper [step 4]. To create a stack that has this "no transfer" orientation, switch the top and bottom sheet in three-ply carbonless copy paper. Once stacked in the "no transfer" order, label the sheets A, B, and C and staple them in that order. This allows students to track the different orientations they try. Carbonless copy paper can be found at most office supply stores, however this will most likely be pre-printed, tri-colored forms with text. An online vendor *(5)* offers all-white, three-part carbonless copy paper (~$15 per ream); another Web site has links to local vendors for carbonless paper *(1).* For a class of 25 students several sheets of the three-ply paper should suffice.

Answers to Questions

1. The order C, B, A results in complete transfer.
2. The papers are coated with a colorless ink and a co-reactant that makes the colorless ink colored. Without the side of the paper that has colorless ink being in contact with the co-reactant no color formation will occur.
3. They are on different sheets of paper, separating them spatially. To further separate them one of the reactants is encapsulated.
4. A miniature capsule. Similar to a capsule you might take vitamin E in, but much smaller. You could encapsulate a colorless ink within them, keeping the ink away from the co-reactant.
5. Dissolution of the capsule could open it. Microcapsules can be used for controlled release of medicines; bodies must dissolve the coating of the microcapsule before getting the drug dose.

References, Additional Related Activities, and Resources *(accessed Jan 2009)*

1. Appleton Carbonless Paper. *http://www.appletonideas.com/; http://www.appletonideas.com/Appleton/jsps/swf/Animation.mpg*
2. White, Mary Anne. The Chemistry behind Carbonless Copy Paper. *J. Chem. Educ.* **1998,** *75,* 1119–1120.
3. Smart Papers for the High School Classroom. *http://www.ret.neu.edu/NSTA-Dallas/Resources/Carbonless%20Paper%20Module.pdf.*
4. Lai, M.-K; Tsiang, R.C.-C. 2004. Encapsulating Acetaminophen into (L-lactide) Polymicrocapsule by Solvent-Evaporation Techniques in an O/W Emulsion. *Journal of Microencapsulation* **2004,** *21,* 307–316.
5. Top Value Printing Carbonless (NCR) Paper Source. *http://www.topvalueprinting.com/carbonless-paper.htm.*
6. Criswell, Brett. Connecting Acids and Bases with Encapsulation... and Chemistry with Nanotechnology. *J. Chem. Educ.* **2007,** *84,* 1136–1139.

Funding for the Internships in Public Science Education (IPSE) program which developed this activity was provided by the National Science Foundation [DMR-0120897 (UW-IPSE) and DMR-0079983 (MRSEC).] The authors also thank Appleton for assistance and samples of "smart" paper.

Supporting JCE Online* Material at *http://www.jce.divched.org/Journal/Issues/2009/Apr/abs464A.html

The Secret of Smart Paper

Have you ever taken a vitamin supplement in capsule form? For example, vitamin E normally comes in a gelatin capsule. The capsule acts as a barrier to keep the inner liquid from coming out before you want it to. A microcapsule is similar to this larger counterpart, just shrunk to a size of about 3–8 μm in diameter (one hair from your head is about 40–100 μm in diameter, see the figure), and acts in much the same way, holding something in, such as a colorless ink, until it is needed. Many grocery store and restaurant receipts use this technology to make duplicate receipts. This paper certainly seems to be "smart", it is able to copy what you write, exactly as you write it, without a copy machine in sight. In this activity you will uncover the secret of this "smart" paper. You will learn about microencapsulation technology and how it can be used in the creation of smart paper.

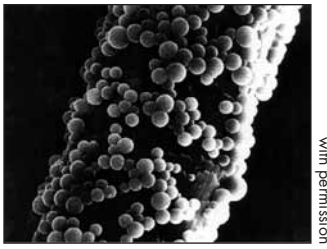


Image by Appleton; used with permission

Microcapsules coated on a human hair seen via a scanning electron microscope. The diameter of the hair is approximately 80 μm.

Try This

You will need: white paper, lemon juice or vinegar, red cabbage, blender, water, sieve, funnel, spray bottle, cotton swab, a packet of smart paper from your instructor, a pencil, a pen, and a sheet of paper to record your observations. It will also be useful to have other objects that can be used to scratch (like fingernails or a coin).

__1. Using lemon juice or vinegar as your ink and a cotton swab as your paintbrush, write a secret message on a piece of white paper.

__2. While the paper dries, prepare red cabbage juice indicator. Tear one or two red cabbage leaves into small pieces and place in a blender. Add enough water to just cover the leaves. Blend well. Strain the resulting mixture through a sieve and place the liquid in a spray bottle.

__3. Spray the dried message from step 1 with the red cabbage juice indicator from step 2. What happens to your invisible message? Why does this happen to your message? Is lemon juice (or vinegar) an acid or a base?

__4. Obtain from your instructor a stapled packet of the "smart" paper with the first sheet labeled A, the second labeled B, the third C. On a separate sheet of paper create a data table with two columns: "paper orientation" (here you will write down the order of your sheets, for instance your first trial will leave the sheets in the order A, B, C) and "observations" (indicate here whether you see writing or not, and on which pages, A, B, or C, you see it). Record your observations about the paper on this table. How does smart paper compare to regular paper? To keep track of your trials, mark a different number each time you write on the paper, so you won't lose track of which orientations had which result.

__5. Now pull the sheets of paper apart and reorganize them, (to begin with keep them facing in the same direction). Try B-front, A-front, C-front, instead of A, B, C: what do you observe? Can you relate what is happening with the smart paper to what happened with the lemon juice and red cabbage juice? Continue trying different orientations until you have found at least 3 that demonstrate image transfer. Remember to record all your observations in the table.

__6. After you have found an orientation in which writing appears on sheets below the top sheet, try to write using a pen versus a pencil: is there a difference?

__7. Try "writing" on the sheets with the cap of your pen. Try using your fingernail or a coin: what happens?

__8. What happens if you flip the whole thing over and you write on the back sheet of paper instead of the front?

More Things To Try

Try turning one sheet of smart paper over while keeping the other two in their original orientation; now write on the paper: what do you see? Try this with each sheet. Why do you think it is important to keep the front of the paper facing up?

Consider how a scratch-and-sniff sticker uses microencapsulation technology.

Questions

1. What order resulted in the appearance of writing on all sheets of the paper?
2. Why is the order of the papers important when using the "smart" paper?
3. A chemical reaction must be taking place when you write on the paper. When the two reactants mix, the reaction leads to the formation of color. How could the dye precursor and color developer be kept apart? How does writing on the paper bring the precursor and developer together?
4. What is a microcapsule? How might they be used in the manufacture of "smart" paper?
5. Microcapsules are also used in medicines. What mechanism might be used to "open" the capsule in a medicine? Why would microcapsules be attractive for use in medicines?

Information from the World Wide Web *(accessed Jan 2009)*

1. Food pH Indicators. *http://www.seed.slb.com/en/scictr/lab/food_ph/index.htm*
2. Bayer Research. *http://www.research.bayer.com/edition_15/15_microcapsules.pdfx*
3. Appleton Carbonless Paper. *http://www.appletonideas.com/*