The Shrinking Genie and Other Adventures with Polymers

Introduction: One of the classic demonstrations of decomposition is the breakdown of hydrogen peroxide to oxygen and water. Performing this demonstration in a 2-L bottle illustrates properties of polymers as the bottle "participates" in this reaction. One can use this reaction as a springboard to discuss the properties of polymers.

Chemical Concepts:
Decomposition reactions
Thermochemistry
Properties of polymers
Consumer chemistry

Materials Needed:
30% hydrogen peroxide solution, H_2O_2
2 Liter Soda Bottle
Kleenex or empty tea bag
Potassium iodide, KI
Safety shield

For further polymer demonstrations:
Polyurethane Foam Kit (Flinn C0335)
Heat gun (can be obtained in the paint section of a hardware or home improvement store)
2 cleaned 1 gallon milk jugs or distilled water bottles (make sure they are they are recycling code 2, HDPE.)

Safety Precautions: Hydrogen peroxide is a strong oxidizer. Avoid all contact with the solution and wear goggles and proper protective equipment. This reaction generates a significant amount of heat and steam. Use a safety shield or keep students several feet away from the bottle as the reaction occurs. The heat gun can cause severe burns. Please read all directions before using. Avoid all contact with the polyurethane foam solutions as they can cause skin irritation. You should wait 24 hours until the foam has completely cured before handling.

Procedure

1) Add 50 ml of the 30% H_2O_2 solution to the 2-L bottle. Place the bottle behind a safety shield or at least several feet away from the audience.
2) Add a small scoop of potassium iodide to a Kleenex. The amount is not critical. Wrap the KI loosely in the Kleenex, making a ball small enough so it can be placed into the 2-L bottle. Alternatively, place the KI into an empty tea bag and reseal the bag with a staple or tape. Slide the tea bag through the top of the bottle so it rests just below the neck. Use a stopper to secure the bag (I use a stopper

with a hole so that if the bag accidentally falls before the demonstration, the steam released by the reaction can escape).

3) When ready to perform the demonstration, allow the potassium iodide to dissolve into the hydrogen peroxide (If using the stopper method, simply remove the stopper to allow the tea bag to drop into the H_2O_2). Immediately, steam will erupt from the flask and the bottle will begin to shrink.
4) After the reaction is completed, allow students to observe and feel the bottle.

Demonstration of Thermoplastic Polymers (optional)

1) Obtain two 1-gallon HDPE milk or spring water jugs.
2) Using a heat gun, gently begin to heat the side of the jug. Note as the temperature of the HDPE increases, the jug wall becomes transparent. If the polymer is allowed to cool, the HDPE begins to recrystallize, resulting it becoming translucent again.
3) Using the second jug, again heat a sidewall until it becomes transparent and looks gelatinous. Remove the heat from the jug and then gently blow into the jug opening. An HDPE "bag" will appear where the jug was heated, mimicking a process by which HDPE bags can be made.

Demonstration of Thermoset Polymers (Optional)

See the following CHEMFAX on the polyurethane foam system.

Discussion: Hydrogen peroxide readily decomposes in the presence of potassium iodide to form water and oxygen gas:

$$2H_2O_2(aq) \rightarrow 2H_2O(g) + O_2(g)$$

The reaction is exothermic, causing the water formed to be produced as steam, which escapes from the top of the bottle in a "genie-like" effect. In actuality, two reactions are occurring, as the iodide anion acts both as a catalyst and as a reducing agent. Observant students may note the yellowish color of the solution after the reaction is completed, indicating the presence of molecular iodine.

This reaction can also offer insights to the molecular structure of polymers. The 2-L bottle is composed of the polymer polyethylene terephthalate (recycling code 1, PETE). PETE is a *thermoplastic* polymer, indicating that it can be heated and molded at elevated temperatures multiple times. PETE bottles are formed from a "prefrom" that is heated to make the PETE pliable, and the bottle is then blown into a mold. The bottle is then cooled in its blown state to "lock" the polymeric molecules into this stretched position. When the bottle is heated as a consequence of the exothermic reaction, the molecules gain enough kinetic energy to unlock from these stretched positions and return to a more relaxed state. This causes the bottle to uniformly shrink, similar to popular "Shrinky Dinks".

One can use this demonstration as an introduction to the basic types of polymeric materials. Polymers are long chain molecules that can be grown in a variety of ways in the lab (look at the references for details on further reading). Because of the extremely long chain lengths of these molecules, the majority of polymers do not have an immediate phase transition from the solid to the liquid state. This is due to the fact that many polymers are not truly crystalline solids, due to the fact that the extremely long molecular chains cannot pack in a crystalline fashion. In contrast, many polymers are semi-crystalline, having regions that are ordered (crystalline) and regions that are unordered (amorphous). The existence of both regions in the polymer can yield exceptional physical properties to the material. For example, as long as these chains have a minimum amount of kinetic energy to rotate within the solid, many polymeric materials show the ability to deform under impact without shattering. The High Density Polyethylene (HDPE) exhibits exactly this type of behavior. It is a thermoplastic with both amorphous and crystalline regions, allowing it to have both strength and impact resistance. In addition, the semicrystallinity makes the polymer translucent, but not optically clear, as the crystalline regions diffract visible light, limiting the transparency of the material. Heating the material destroys the crystallinty of the polymer, making the material transparent. If heated enough, the HDPE can be blown to form a "plastic" bag upon cooling.

The rigid polyurethane foam discussed in the accompanying CHEMFAX is an example of a *thermoset* polymer. These polymeric materials have extensive cross-linking between polymer chains, which can greatly add to the strength of the material. However, once formed, these cross-links are a permanent feature of the molecular structure, resulting in a polymer that cannot be heated and remolded as in thermoplastic materials.

Disposal: Allow the polyurethane foam to cure for 24 hours before handling. Empty the 2-L bottle down the drain with copious amounts of water. All materials can then be disposed by Flinn Suggested Disposal Method #26a.

Reference: Summerlin, L; Borgford, C.; Ealy, J. *Chemical Demonstrations: A Sourcebook for Teachers Vol. 2*; Amer. Chemical Soc.: Washington D.C., 1988.

Teegarden, D. *Polymer Chemistry: An Introduction to an Indispensable Science*; NSTA press: Arlington, Va., 2004

The Polymer Science Learning Center at the University of Southern Mississippi. http://pslc.ws/ (accessed Jan 2007)

The Polymer Ambassadors. *http://www.polymerambassadors.org* (accessed Jan 2007)