Blueprint T-Shirt

Student Activity

What is this activity about?

"What does it mean to have color?" wondered a young Bassam. In his quest to answer his own question, Bassam pursued the study of chemistry. He noted that "Color changes happen because of chemical transformations." When light initiates the chemical change, it is called a photochemical reaction. One such photochemical change is blueprinting. Commonly used in architecture, white paper coated with a sensitizing solution of ammonium iron(III) citrate and potassium hexacyanoferrate(III) react to form Prussian blue, an insoluble blue substance, when exposed to UV light. Areas that are blocked from exposure to the UV light do not react, remain soluble, and can be rinsed from the paper with water. This versatile process may also be done on cloth. In this activity, you will generate a blueprint design on a T-shirt.

What Materials do I need?

Cotton T-shirt (prewashed to remove sizing materials)
Sensitizing Solution (mixture of ammonium iron (III) citrate and potassium hexacyanoferrate (III) solutions)
9” x 12” piece of cardboard (or size of the desired 'blue' area)
Permanent black markers
Acetate sheet (overhead transparency)
Straight pins
2 paint brushes or spray bottle
Chemical Splash Goggles
Chemical-resistant Rubber gloves
Chemical-resistant Apron
Dust mask (if using spray bottles)

What safety precautions and disposal actions must I take?

1) Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when preparing, dispensing, applying and rinsing the solutions.
2) Wear a dust mask if using spray bottles to apply the sensitizing solution.
3) Ammonium iron (III) citrate and potassium hexacyanoferrate (III) are tissue irritants. Avoid contact with skin, eyes, and clothing.
4) Follow your teacher’s directions for proper storing and/or disposal of chemicals.
5) Wash your hands before leaving the lab.
6) Return all unused solutions to your teacher.

What procedure must I follow?

Day 1-Preparing the T-shirt for the blueprint.

Turn the lights out in the classroom if they are fluorescent and work by natural light.

1) Plan your design. You may want to sketch it on paper first and then lay it on you T-shirt.
2) Transfer (draw) the design onto the acetate sheet using black markers. Save your design for Day 2.
3) Place the cardboard between the front and back of the T-shirt. Fold the shirt so that the fabric that will not be treated with the sensitizing solution is protected under the cardboard. Tape or pin the folds to keep the cardboard from sliding.
4) Put on your goggles. If using a spray bottle, put on a mask also.
5) Apply the "sensitizing solution" to the fabric using a paint brush or spray bottle. Apply evenly so that you cover the area thoroughly and it feels wet, but not dripping.
6) Allow the fabric to dry in a dark room. (It is important to not expose the shirt to fluorescent or UV light)

Day 2-Developing your design

6) Place your design acetate on the “sensitized” area of your t-shirt and pin it to the fabric. Put pins in the black design portion of the acetate sheet and keep the design flat against the fabric.
7) Take your fabric board outside into the direct sunlight.
8) Allow approximately 15 min of exposure. When the blueprint turns slightly darker than desired, bring your work back to the classroom.
9) Remove the design acetate and cardboard.
10) Rinse the fabric in plain water until the water runs clear.
11) Place your shirt on a hanger to dry.
12) Enjoy wearing your blueprint t-shirt!

Safety and Disposal:

How do I care for my T-shirt?

The blueprint is permanent, but the color will become yellow if not properly washed.
To preserve the blue color, wash your shirt with liquid laundry or dish soap. Do not use powdered detergents or detergents that contain phosphates, soda, borax or bleach.
Iron using a dry iron setting.

How is this activity related to my knowledge of science/chemistry? (Questions)

1) Name a common photochemical reaction.
2) Will the chemical reaction take place on a cloudy day? Explain.
3) Why should the ammonium iron(III) citrate and potassium hexacyanoferrate(III) solutions be stored in dark, opaque bottles?
4) Why can the sensitizing solution be applied in a room with incandescent light?
5) Write the half-reaction showing the reduction of Fe^{3+} to Fe^{2+}.
6) Explain what would happen to your shirt if you did not rinse it in water after exposure to sunlight.

7) Prussian blue is slightly soluble in ammonia water. Explain why washing your shirt in ammonia water will cause the print to fade.

How can I extend my learning with this activity? (Extensions)

1) Be creative with your design. Place different object such as leaves, stencils cutouts and flat, opaque objects on the fabric in place of a design on an acetate.
2) Expose the T-shirts under different conditions: direct sun, in the shade, on a cloudy day to show the effect of different degrees of brightness.
3) Use white paper or foam board in place of fabric.

Blueprint T-Shirt

Teacher's Guide

Concepts:

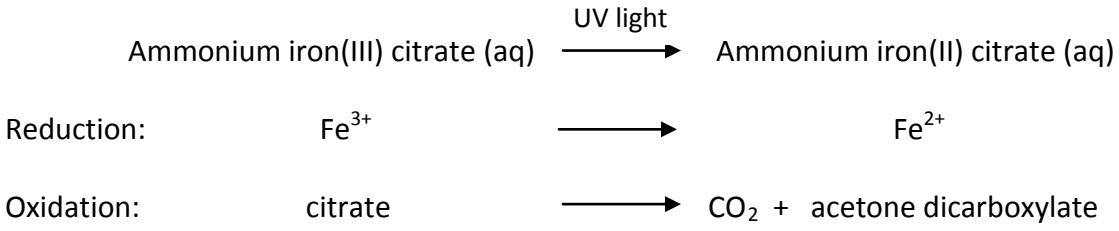
- Solubility
- Catalysis
- Redox

Background:

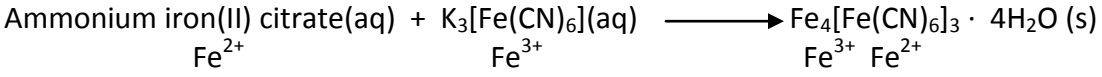
This activity focuses on the chemical change that occurs when two chemicals are exposed to UV light from the sun. The UV light provides the activation energy for the redox reaction between ammonium iron (III) citrate and potassium hexacyanoferrate (III) to produce insoluble Prussian blue. When a "negative" that contains a design containing clear and darkened areas is placed on a fabric that has been treated with a mixture of the two salts and then exposed to UV light, the soluble salts protected by the dark areas of the negative remain unreacted and can be washed away with water. The exposed areas turn dark blue due to the formation of Prussian blue. Prussian blue is an insoluble complex and remains in the fabric.

Chemistry:

Step 1: Ammonium iron(III) citrate is reduced to ammonium iron(II) citrate in the presence of UV light. The molecular formula for ammonium iron(III) citrate is variable and contains about 7.5% NH_3, 14.5-% - 16% Fe, and 75% hydrated citric acid.



Step 2: Fe^{2+} complexes with the hexacyanoferrate(II) ion to form insoluble iron(III)-hexacyanoferrate(II) or Prussian blue



The intense blue color of the Prussian blue is due to the energy associated with the transfer of electrons from the Fe^{2+} to the Fe^{3+}.

Materials:

T-shirts (pre-washed to remove sizing materials)

Ammonium iron (III) citrate (green)
Potassium hexacyanoferrate (III)
Beaker to mix the sensitizing solution
Paint brush (inexpensive bristle or inexpensive sponge type that fit in the beakers)
Clear acetate sheets
Permanent Black markers
Sunny day or UV light source
Chemical Splash Goggles
Chemical-resistant Rubber gloves
Chemical-resistant Apron

Safety and Disposal:

Ammonium iron (III) citrate and potassium hexacyanoferrate (III) are tissue irritants. Avoid contact with skin, eyes, and clothing. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when preparing, dispensing, applying and rinsing the solutions. Wear a dust mask if you are spraying the sensitizing solution.

Excess solutions can be stored in properly labeled brown bottles. Dispose of unused portions according to federal, state, and local requirements.

Procedure:

The "sensitizing solution" is a combination of two iron salt solutions: ammonium iron (III) citrate and potassium hexacyanoferrate (III), $K_3Fe(CN)_6$. Prepare the solutions separately and mix them shortly before use. Wear a dust mask when working with the solid reagents.

Class amount: 2 L of “sensitizing solution”:

Soln A: 240 g of ammonium iron (III) citrate in 1 L of solution
Soln B: 120 g of potassium hexacyanoferrate (III) in 1 L of solution

Individual student amount: 100 mL of “sensitizing solution”

Soln A: 12 g of ammonium iron (III) citrate in 50 mL of solution
Soln B: 6 g of potassium hexacyanoferrate (III) in 50 mL of solution

Mix equal amounts of each solution in dispensing beakers or spray bottles. If using spray bottles, you and your students should wear a dust mask while students are spraying the sensitizing solution.

Have students prepare their designs and insert the cardboard between the front and back of the t-shirts.

Dispense the sensitizing solution in beakers or spray bottles.

Fluorescent lighting contains some UV light. If you are able, *turn the lights out in the classroom and work by natural light.*

Apply the sensitizing solution to the fabric area with a paint brush or spray bottle. Do not be concerned if the solution spreads outside of the desired area. Cover that area with tape before exposure to the sun.

Pin the design to the fabric. Remind students to put the pins through the design and not on the clear acetate. The pin will block the sunlight and make marks on the blue area.

Keep hands off the 'painted' area.

Take the project outside and leave in the direct sunlight until the area becomes dark blue. (approx. 15-20 min)

When the blueprint has developed, rinse the shirt in running water until it runs clear and colorless.

Allow the shirt to dry.

How is this activity related to my knowledge of science/chemistry? (Questions/Targeted Responses)

1) Name a common photochemical reaction.
   Photosynthesis, O_2 to O_3 in the stratosphere, formation of vitamin D, plastics becoming brittle are some examples.
2) Will the chemical reaction take place on a cloudy day? Explain.
   Yes, there is still UV light present. Exposure time may be longer.
3) Why should the ammonium iron(III) citrate and potassium hexacyanoferrate(III) solutions be stored in dark, opaque bottles?
   To prevent the reduction of Fe^{3+} to Fe^{2+}
4) Why can the sensitizing solution be applied in a room with incandescent light?
   The energy of the visible light is below the activation energy needed for the reduction of Fe^{3+}.
5) Write the half-reaction showing the reduction of Fe^{3+} to Fe^{2+}.
   $Fe^{3+} + e^- \rightarrow Fe^{2+}$ UV light acts as a catalyst.
6) Explain what would happen to your shirt if you did not rinse it in water after exposure to sunlight.
   The undeveloped areas that were originally protected from the UV light would eventually be exposed to UV light and form Prussian blue.
7) Prussian blue is slightly soluble in ammonia water. Explain why washing your shirt in ammonia water will cause the print to fade.
   Some Prussian blue would dissolve in the ammonia water and wash away. This would cause the color to fade.

Extensions:

1) Place different object such as leaves, stencils cutouts and flat, opaque objects on the fabric in place of a design on an acetate.

2) Expose the T-shirts under different conditions: direct sun, in the shade, on a cloudy day to show the effect of different degrees of brightness.
3) Use white paper or foam board in place of fabric.

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