VISUALIZING BASIC NUCLEAR REACTIONS

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Abstract

There are few instructional tools available to teach basic nuclear reactions to beginning students. The activity described in this paper can be used to help students visualize and write basic nuclear reactions such as alpha, beta, and positron decay, as well as electron capture. These reactions are represented using the technology of thermochromic paints, which either change color or turn colorless depending upon the temperature. By using a special thermochromic paint that turns colorless upon heating, students are able to visualize nuclear interactions. For instance, when positron decay occurs, the object depicting a proton will "decay" into a neutron by the application of heat. In order to avoid confusion, the heating instrument is referred to as a "time gun." This paper includes the details of preparing and incorporating the activity into the classroom environment.

Introduction

Nuclear chemistry is an interesting topic with many opportunities for real-world application and discussion in a general chemistry class [1-5]. Inclusion of nuclear chemistry topics has been encouraged in the undergraduate and high school chemistry curriculum since the late 1980s [6-8]. A published review, "Teaching Aids for Nuclear Chemistry," contains a number of articles that can be used as resources when incorporating nuclear chemistry topics into the classroom [9]. In addition, several activities and labs are available for modeling decay, or half-life, of nuclear particles [10-16], radioactive dating [17], experiments involving properties of isotopes [18-19], and simple radon measurements [20]. However, there are very few instructional tools available to teach basic nuclear reactions to beginning students [21-22]. Nucleogenesis, an instructional game, requires students to be able to quickly evaluate several possible decay reactions, as well as recognize unstable atoms with every player's turn [23].

Nuclear chemistry is a very abstract topic for students to comprehend. Confusion sets in when students discover that the particles that they used to identify specific atoms and elements when learning atomic chemistry can "decay" causing the identity of the atom to change. Not only

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do the particles decay, they do so in such a manner that a proton can become a neutron and a neutron can become a proton. Also, students are introduced to the concept that electrons can be ejected from the nucleus during decay or that an orbiting electron can be captured by a proton to cause a nuclear reaction. These concepts can be very bewildering to students. Therefore, a more basic instructional tool can be useful in introducing students to the nature of nuclear reactions. The activity described below can be used as an instructional tool to introduce students to visualizing and writing basic nuclear reactions such as alpha, beta, and positron decay, as well as electron capture.

Alpha, beta, and positron decay, and electron capture are presented using the technology of thermochromic paint. Thermochromic paint has color changing properties that are dependent upon temperature. Some thermochromic paints may change colors while others turn colorless with an increase or decrease in temperature. By using a special thermochromic paint that turns colorless upon heating, students are able to visualize nuclear interactions. For instance, when positron decay occurs, the object depicting a proton will "decay" into a neutron by the application of heat. Although heat is the factor that makes this activity possible, instructors should be advised not to suggest that the decay occurs as a result of the heat. We have successfully avoided this potential problem by presenting the heat gun as a "time gun." The details of preparing and incorporating the activity are described below.

Materials and Preparation

Blue thermochromic pigment and acrylic base can be obtained from Middlesex University Teaching Resources (see Appendix A). One 5ml tube is ample for this activity. Blue, orange, red, black, and white acrylic paints can be purchased at any local arts and crafts store. One tube of 2-4 fl oz each is sufficient. Other light colors may be substituted for the orange. Wooden plugs (1/2"), flat or rounded, can also be obtained at an arts and crafts store or woodworking store. A total of nine plugs are needed per group. Hairdryers or heat guns are used for applying heat. Masking tape (2" width) is useful for holding the plugs in place during the activity.

Prior to using the paints, they need to be prepared for certain shades and consistencies. The regular orange acrylic paint should be mixed with a little white to brighten its color. The blue thermochromic pigment should be mixed with the acrylic base (approximately 1.75g of base for every 1g of pigment). The pigment must be mixed with the base in order to obtain an easily applicable form of the pigment that will be transparent upon heating (see Appendix B). The regular blue acrylic paint should be mixed with white, red, and black as needed to obtain the same shade of blue as the thermochromic paint mixture.

To prepare the materials for use in the activity, five wooden plugs are painted with orange acrylic paint. Only one side of the plug is painted because the other side will remain face down during the activity. Once the painted plugs are dry, one of the orange plugs is painted again with the blue thermochromic paint. A soft, camel hair paintbrush can be used to prevent the paint from streaking. This thermochromic blue plug is demarcated by placing an "X" on the back of it using a permanent marker. It is the color of this thermochromic plug that must be matched by the regular blue acrylic paint. As stated previously, the blue paint can be mixed with white, red, and black paints, as needed, to obtain the same shade of blue as the thermochromic paint mixture. Compare the colors when the painted plugs are dry. Once the correct shade of blue is obtained, it is used to paint four plugs. This supplies one set of plugs for the activity: four orange, four blue, and one orange covered with thermochromic paint. The paint can be used to make additional sets according to the number of students or groups that will complete the activity.

Procedure

In the activity, students build representations of nuclei using the blue and orange plugs as protons and neutrons. A piece of masking tape should be folded in a loop with adhesive side out and placed flat on the table. Students should group the particles of each nucleus close together on the masking tape so that heat can be applied evenly to all the plugs. The heating instrument should be referred to as a "time gun." Instructors should be careful not to mislead students that heat is necessary for the decay to occur. When the particles are heated, the blue (X) plug turns orange corresponding to the opposite particle type. Students make observations before and after heating their particles and then write corresponding nuclear reactions. Different nuclei are used to represent different types of nuclear reactions. A copy of the handout that accompanies this activity is provided. Prior to beginning the activity, students only need to be familiarized with the proper notation needed for writing nuclear reactions: mass number as superscript, and number of protons as subscript in front of the atomic symbol.

Using this Activity as an Instructional Tool

There are four basic types of reactions covered in this activity: alpha, beta, and positron decay, and also electron capture. The reactions used as examples in the activity are given below in the order that they appear in the activity.

Alpha Decay	${}^{7}_{3}\mathrm{Li} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{H}$
Positron Decay	${}^{8}_{5}\mathrm{B} \rightarrow {}^{8}_{4}\mathrm{Be} + {}^{0}_{1}\mathrm{e}$
Electron Capture	${}^{7}_{4}\mathrm{Be} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{7}_{3}\mathrm{Li}$
Beta Decay	${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{0}_{-1}\mathrm{e}$

Each part of the activity introduces a different nuclear reaction. Students are taken through four steps for each reaction. The steps are outlined below.

<u>Step 1</u>: Use the particles to make a representation for the nucleus. Sketch a representation of the nucleus in your notes.
<u>Step 2</u>: Observe the reaction by moving particles (alpha decay) or using the time gun (positron/beta decay and electron capture).
<u>Step 3</u>: Identify the new atom based on the particles that remain. Sketch a representation in your notes.
<u>Step 4</u>: Write a reaction corresponding to the changes that have just taken place by using the skeleton provided.

By beginning with the alpha decay, students can easily observe how an alpha particle can be removed from lithium-7 by displacing two blue and two orange plugs. In order to do this, students must know that an alpha particle is equivalent to the nucleus of a helium atom. After counting the particles and identifying the two new daughter atoms, students can fill in the reaction using the proper notation. Precise accounting of particles on each side of the equation will help students write the remaining reactions.

When students move on to the positron decay of boron-8 the steps are the same, but the reaction takes place when the "time gun" is used. One of the blue (darker) protons will change to an orange neutron because of the thermochromic properties of the blue paint used on that plug. Students then note their observations and write the reaction by using the appropriate skeleton. By using the concepts learned during the alpha decay, students are able to write the reaction for the positron decay without first knowing the notation for a positron. This pattern continues for the other nuclear reactions. Figure 1 shows an example of positron decay by boron-8.

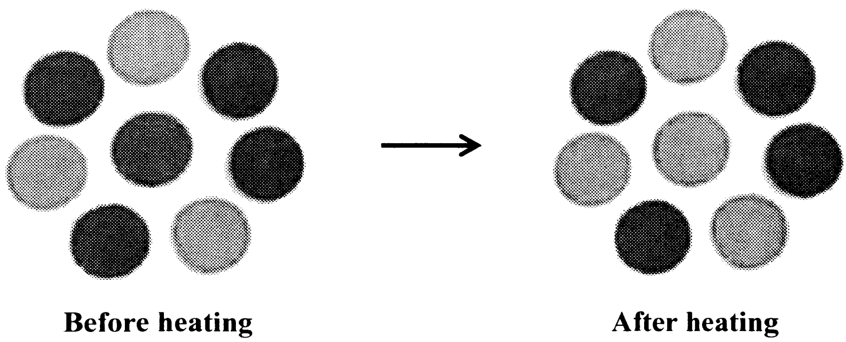

Figure 1. Visualization of positron decay

Conclusion

This activity is appropriate for use in both high school and introductory undergraduate classrooms. Students are given the opportunity to manipulate particles in a hands-on fashion in order to familiarize themselves with the nature of basic nuclear reactions. This is accomplished in a discovery format where no previous knowledge of nuclear reactions is necessary. By completing the activity, students are able to write and describe the basic nuclear reactions of alpha, beta, and positron decay, as well as electron capture. A good foundation in writing and understanding these reactions provides the necessary skills to study more complex fission, fusion, and bombardment reactions that are to follow.

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Appendix A

SUPPLIES

Middlesex University Teaching Resources — The blue pigment (order #IT9004 – blue thermochromic pigment) comes in 5ml syringes and must be mixed with the acrylic base. Other colors are available, but blue has the best coverage for use in this activity; the black thermochromic pigment was not tried. The acrylic base comes in a 400ml container (order #IT9011). Information on these materials is available at the following URL: http://www.mutr.co.uk/SmartCol/Smartcol.htm.

Acrylic Paints — The authors used Daler-Rowney System3 Zinc Mixing White and Liquitex® Phthalocyanine Blue and Cadmium Red (Light Hue), which is orange. However, any deep blue, orange, and white acrylic paints will be sufficient in preparing the activity. The red and black paints were inexpensive acrylic craft paints.

Appendix B

METHODOLOGY

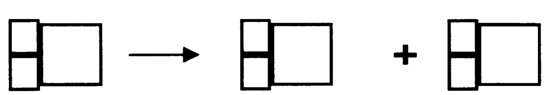
The thermochromic pigment is mixed with a white paste for distribution. When heated, the blue goes colorless and leaves behind a white paste that is not transparent. When mixed with the appropriate amount of acrylic base, the mixture will be transparent upon heating. The authors recommend that the base be added in small increments to avoid mixtures that become too thin. A testing plate can be prepared by painting a small piece of white cardboard with the orange paint and allowing it to dry. A small spot of the thermochromic paint mixture on this plate should be tested. The spot is allowed to dry and then heat is applied. When the heated mixture is transparent enough for the orange to show through clearly, then enough base has been added.

Appendix C
STUDENT HANDOUT

In order to begin this activity you first need to become familiar with how the particles are being represented. For the first three parts of the activity the blue wooden plugs are the protons and the orange plugs are the neutrons. ALWAYS USE THE ONE BLUE PLUG THAT HAS AN "X" ON THE BACK OF IT. A blowgun or hair dryer is supplied as a source of time or a "time" gun.

Alpha Decay

1. Let's begin by constructing a simple nucleus. Using your particles make a representation for the nucleus of Lithium-7. Place the particles on masking tape to stabilize them. Sketch a representation of this in your notes.
2. Now we are going to make observations of an alpha decay. During an alpha decay an alpha particle is lost from the nucleus. An alpha particle is equivalent to the nucleus of a helium atom. So, using your plugs representing the nucleus of Lithium-7, remove an alpha particle.
3. What is the new identity of the atom based on the particles that are left? Sketch a representation in your notes.
4. Write a reaction corresponding to the alpha decay that has just taken place by using the skeleton provided below.

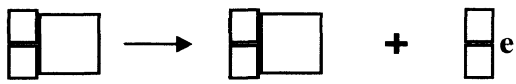


Note that the superscripts and subscripts on the product side of the reaction add up to the superscripts and subscripts on the reactant side. THIS WILL ALWAYS BE TRUE!

Positron Decay

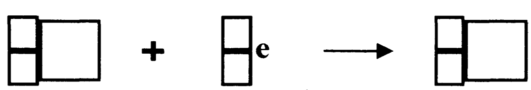
5. Using the appropriate number of particles, construct the nucleus of boron-8. Place them on masking tape. Sketch a representation in your notes.

6. Now we are going to observe positron decay. Use the "time" gun.
7. Make immediate observations. What is the new identity of the atom based on the particles you now observe? Sketch a representation in your notes.
8. Write a reaction corresponding to the positron decay that has just taken place by using the skeleton provided below. Remember superscripts and subscripts should be equal on both sides.



Electron Capture

9. Using the appropriate number of particles, construct the nucleus of beryllium-7. Place them on masking tape. Sketch a representation in your notes.
10. Now we are going to observe electron capture (EC). Use the "time" gun.
11. Make immediate observations. What is the new identity of the atom based on the particles you now observe? Sketch a representation in your notes.
12. Write a reaction corresponding to the beta decay that has just taken place by using the skeleton provided below.

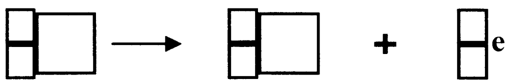


Beta Decay

NOW ALLOW THE ORANGE PLUGS TO BE PROTONS AND THE BLUE PLUGS TO BE NEUTRONS!

13. Using the appropriate number of particles, construct the nucleus of tritium (hydrogen-3). Place them on masking tape. Sketch a representation in your notes.
14. Now we are going to observe beta decay. Use the "time" gun.
15. What is the new identity of the atom based on the particles that are left? Write a reaction corresponding to the positron emission. Sketch a representation in your notes.

16. Write a reaction corresponding to the beta decay that has just taken place by using the skeleton provided below.



Questions

1. Give the notation for an alpha particle and briefly describe what occurs during alpha decay.
2. Give the notation for a positron particle and briefly describe the process of positron decay.
3. Give the notation for an electron and briefly describe what occurs during an electron capture.
4. Give the notation for a beta particle and briefly describe what occurs during a beta decay.