Classifying Matter: A Physical Model Using Paper Clips W

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Many students find it difficult to visualize the chemical world and comprehend the specific language that chemists use. Beginning students have particular difficulties in understanding the classification system that we use for matter. As students struggle to learn and apply the definitions of the terms molecule, compound, mixture, and pure substance, they are often handicapped by their lack of knowledge of how the world is composed. Very few students even know what the components of brass are, so they have a very little chance of being able to classify it properly as a mixture of zinc and copper. Likewise, few know how to describe sand as a chemist would. Several years ago, we realized that simple physical models of chemical systems could be constructed using colored paper clips. These models would allow students who had little knowledge of how the world was composed to practice applying the simple classification system that chemists use for matter. In the years that we have been using this activity, we have found that it effectively helps students to build accurate conceptual pictures of what constitutes molecules, compounds, mixtures, and pure substances. Other instructors have used similar physical models in their classrooms, such as collections of small coins to represent collections of molecules undergoing a reaction or painted hex nuts to represent the atoms that form molecules *(1–4)*.

Materials

Vinyl-coated steel paper clips work well for this activity. Stockman Office Products paper clips (product number 30009) can be purchased from Staples Superstore. One box of paper clips contains 100 each of black, white, pink, orange, blue, red, green, and yellow paper clips, which are conveniently separated in individual compartments. Clear, colorless, reclosable plastic bags are best for this activity. Bags measuring 2 in. × 2 in. are a convenient size for each set of paper clips and larger clear plastic reclosable bags are useful to contain the sets of smaller bags.

Constructing the Model

This activity is most effective when the instructor prepares the activity for the students. The model is constructed using two large reclosable plastic bags for each student or team of students. Each large plastic bag contains eight smaller reclosable bags. Each small bag contains an assortment of colored vinyl-coated paper clips, some of which are attached to each other in specific ways as described. The larger bags can be labeled as set I and set II, with the smaller bags being labeled A through H. It is easier for the students to organize their work if the two sets of bags are labeled using different colors. Table 1 summarizes the suggested contents of each bag.

For instance, to assemble Bag H for Set I, one would need 4 black paper clips, 2 red paper clips, and 3 blue paper clips. Five items are placed into the bag: 3 unattached blue paper clips and 2 strings of paper clips attached in the order black, red, and black. Essentially the hyphens in the above table represent attachments between paper clips. In each set, Bag G contains items constructed by attaching 4 red paper clips such that they form squares. Pictures of the contents of Bag G for Set I are shown in Figure 1.

Table 1. Contents of the Bags

Set I	Set I Contents	Set II	Set II Contents
Bag A	3 pink-white	Bag A	4 pink-white
Bag B	2 blue-blue; 4 white	Bag B	3 blue-blue; 3 white
Bag C	3 pink-black-pink	Bag C	2 pink-black-pink
Bag D	4 yellow	Bag D	5 yellow
Bag E	3 orange-yellow-orange; 2 yellow-orange-orange	Bag E	2 orange-yellow-orange; 3 yellow-orange-orange
Bag F	2 green-green-green; 3 green-green	Bag F	3 green-green-green; 2 green-green
Bag G	2 red-red-red-red (squares)	Bag G	3 red-red-red-red (squares)
Bag H	2 black-red-black; 3 blue	Bag H	3 black-red-black; 2 blue

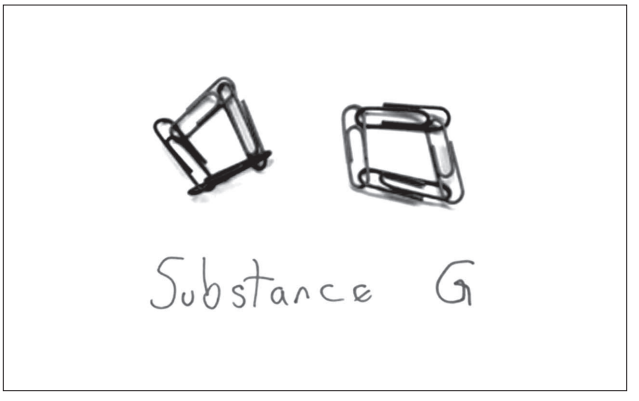

Figure 1. Contents of bag G in Set I.

Using the Activity

We recommend that the students do this activity in groups. Beginning students often have difficulty conceptualizing written definitions or understanding models that they are unfamiliar with. During the activity, many students ask questions and are unable to complete the activity without guidance, so it is useful to have a knowledgeable supervisor to help guide students through the activity.

Various types of instructions can be given to the students to promote their exploration of this model. An example of one set of instructions is given in Box 1. This exercise illustrates several important concepts that sometimes escape beginning students. The following observations are generally made by students during the exploration of this model.

A bag containing different colored paper clips is not necessarily a mixture. For instance, bag A of Set I contains six paper clips: three pink ones and three white ones. When visualizing the contents of this bag using the classification scheme of a chemist, a student should count three items in the bag, not six. Each pink paper clip has been attached to a white one, uniting the two different items into a single new item (similar to atoms uniting to form molecules). With guidance, students can see that a compound is a pure substance.

Box 1. Instructions Given to Students

1. Define the following terms:
   a. Atom
   b. Element
   c. Molecule
   d. Compound
   e. Pure substance
   f. Mixture
2. Compare your definitions for question 1 to the definitions for these terms that other students in your group provided and to the definitions that are given in your textbook. What are the similarities and differences between the various definitions?
3. What is the difference between a molecule and a compound?
4. If a compound is made of different elements, is it then a mixture?
5. Compare the definitions of mixtures and pure substances. What are the differences between them?
6. Obtain a set of paper clips (either Set I or Set II) from your instructor. These sets of paper clips represent matter. Each paper clip represents an atom. Carefully examine the contents of each bag and record your observations in a table. Make sure you can answer the following questions.
   a. Why are the paper clips hooked together?
   b. Describe the contents of each bag in terms of per cent composition.
   c. Which bags contain paper clips that represent mixtures and which represent pure substances?
   d. Which bags contain paper clips that represent elements, molecules, or compounds?
7. When your group has answered all of the questions, compare your answers with those from a group that had a different set of paper clips.
   a. What are the similarities between contents of Set I and II?
   b. What is the main difference between bags that con tain mixtures and bags that contain pure substances?

A sample of matter does not have to be exclusively named an element, a compound, or a mixture. Mixtures can be mixtures of elements, mixtures of compounds, or a mixture of elements and compounds. In many cases a combination of terms is required to classify the contents of a bag and likewise, a sample of matter. For example, bag H contains a mixture of a compound and an element.

Percent composition is a general term that has different meanings, depending on what analysis is being used and what is being counted. There is subjectivity in how to calculate percent composition using the formula

$$\% \text{ composition} = (\text{part}/\text{whole}) \times 100$$

To determine the formula of a pure compound, a chemist would do an elemental analysis, but to determine the composition of a mixture, a chemist would do a physical separation. Thus in this exercise, there should be two entries for the percent composition of each bag containing a mixture. Bag A of either set only contains assemblies of pink and white paper clips and thus is 100% pure, analogous to a pure compound that is not separable into simpler substances by physical means. Analogous to a chemical analysis, bag A contains 50% pink paper clips and 50% white paper clips and can be reported as such. Bag B of Set I contains a mixture. Analogous to the result of a physical separation, it can be reported as 33% of the blue-blue substance and 67% of the white substance. Analogous to a chemical analysis, it can be described as being 50% blue and 50% white by counting the number of paper clips of each color in the bag.

Two compounds can have the same formula but be different substances. Bag E of either set illustrates this point effectively. After the concept is understood, the term isomer can be introduced as a technical term for this idea. Likewise, pure elements can have different identities. Bag F can be seen as a representation of a mixture of ozone and oxygen. After this concept is understood, the technical term allotrope can be introduced.

The composition of any pure substance is fixed. The composition of mixtures can vary. This is the purpose of having two sets of bags and asking the students to compare the results for the two sets. This model does not represent the difference between homogeneous and heterogeneous mixtures, although many students will attempt to interpret the contents of each bag in those terms.

[w]Supplemental Material

Answers to the student questions presented in Box 1 are available in this issue of *JCE Online*.

Literature Cited

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