Teacher Guide for “Recognizing Chemical Reactions”

LEGO models and lessons created by Kathleen M. Vandiver, Ph.D.
Graphics by Amanda Gruhl
Teacher’s guide by Jessica Garrett
Instructional testing and review by Amy Fitzgerald

Acknowledgements:

Kathy Vandiver created this lesson in her Lexington, Massachusetts classroom in 2002. She now works for the MIT Center for Environmental Health Sciences, and the Edgerton Center, and continues creating interesting and engaging curriculum for students.

This lesson was further tested, taught, and written up at the MIT Edgerton Center by Amy Fitzgerald and Jessica Garrett. Amanda Gruhl did the graphics.

Our “wet” lesson modified a chemical reaction outlined in the Lawrence Hall of Science (Gems Guide). “Teacher’s Guide: Chemical Reactions.” Berkeley, CA: Lawrence Hall of Science, 1986. www.lhsgems.org

Other versions of this guide, student sheets, layout mats, and additional materials, as well as a photosynthesis lesson using the same LEGO bricks may be downloaded at:

http://www.mindandhandalliance.org/educators

General Edgerton Center information: http://web.mit.edu/edgerton
Edgerton Center field trips: http://web.mit.edu/edgerton/outreach

“Recognizing Chemical Reactions” Objectives

Objectives:
Students will be able to do the following (as described in the Massachusetts State Frameworks for grades 6-8, Physical Sciences Strand: Elements, Compounds & Mixtures):

6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).

> *Note: We have found that the above definition of molecule has exceptions that lead to student confusion. For example, O2 and O3 are molecules that are considered forms of the element oxygen instead of “compounds of oxygen”. Therefore, we will define a molecule more broadly: A molecule is two or more atoms bonded together.

8. Differentiate between mixtures and pure substances.

10. Differentiate between physical changes and chemical changes.

The LEGO Chemical Reactions lesson illustrates other concepts as well:

- **Conservation of mass/matter:** as the students complete the LEGO portion of the activity, they will see that every atom of the reactants is used to create the final products. In this closed system, matter has been neither created nor destroyed.
- **Exothermic vs. endothermic reactions**: the reaction of these chemicals is a surprisingly exothermic one.

Overview of "Recognizing Chemical Reactions" Lesson

1. Introduction

The class will experience a "wet lab" which will include a chemical reaction, followed by a "LEGO lab" where LEGO bricks are used to model what happened to the chemical molecules in the wet experiment. Preconceptions of chemical reactions are explored through a class discussion. Several shared ideas will be written on the board for class record. Finally, lab safety is reviewed in terms of this classroom and this experiment. Methods of observation and chemical handling are especially detailed.

2. "Wet Lab"

The lab experiment uses fairly common substances as reactants in this visually exciting and dynamic reaction. Baking soda and calcium chloride (one type of de-icer) are mixed, and then phenolsulfonphthalein (phenol red) in solution is added. The water in which the phenol red is dissolved allows the other molecules to get close enough to react, but its atoms do not recombine. It is just a solvent but not a reactant. Students safely observe the chemicals before mixing, the reaction itself, and the new products after the reaction. The key concept is that all chemical reactions produce new substances.

3. "LEGO Lab"

LEGO bricks are introduced as a way of modeling the atoms of the materials used in the wet lab reaction. A key indicates which element each LEGO brick represents. Vocabulary useful in describing chemical reactions vs. physical mixtures is explained using the LEGO bricks. Students will create the reactants used in the chemical reaction out of LEGO bricks. They will then disconnect the reactant LEGO models and recombine them to make the chemical structures of the products. They will discover that they did not need to add any extra LEGO bricks to the reactants, nor did they have to discard any extra LEGO once the products were made.

4. Optional -- separation of the products in the mixture

All the separation steps are actually physical steps: settling, filtering, evaporation. This proves that the products in the cylinder were present as a mixture. A mixture can be separated by physical means. Pour off water through filter onto plates for evaporation. Make standard samples for comparison if you wish. (See Appendix A) Wait a week or so (depending on the evaporation rate) show the separated products after evaporation and compare to the standard samples.

“Recognizing Chemical Reactions” Materials

(Amounts are for one class unless otherwise indicated.)

Wet Lab: (some extra amounts are included)

- **Chemical Reactions Student Worksheet packet** pages 1-2
- **Baking soda** 1 lb box
- **Calcium chloride** a common de-icer found in grocery stores in the USA. A 9 lb container will be more than enough for 5 classes. **Be sure to keep it in an airtight container, and only scoop out right before class, as it absorbs moisture in the air. Test it first to be sure it does heat when in contact with water.** If your stores do not have this chemical it can be purchased from chemistry supply companies.
- **Phenolsulfonphthalein (phenol red) in aqueous solution (0.02% weight by volume, 500ml solution)** You'll need 30-40 ml per student pair, so 500 ml will be plenty for a class of 24. The chemical formula is $C_{19}H_{14}O_5S$. It can be purchased as an aqueous solution, or you can mix a powder in water. (Note: the absolute concentration is not necessary for the success of this experiment. You just need the solution to be red when the dye is dissolved in water. You'll need to adjust the amount for your local water.)
- **Covered test tube or other small vessel.** 10-15 ml capacity, 1 tube per student pair
- **Resealable freezer bags** 1-2 qt size, 1 bag per student pair. (Note: The bag with a zipper closure system may not hold the gas in very well.)
- **Plastic spoons** 2 per student pair. Label one “baking soda” and the other “calcium chloride”.
- **50 ml beakers or similar container** 2 per 4 students. Label one “baking soda”. Label the other “calcium chloride”.
- **Large tray** 1 for every pair. This is just to catch any spills. Could be omitted.
- **Book of matches** For the teacher.
- **Pencils and erasers** 1 per student.
- **Splash goggles** 1 per student, a good precaution, but not absolutely necessary.
- **Chemical bin (optional)** 1 per student pair. A small plastic container with a flat bottom is handy to hold the chemical-filled beakers, vials of phenol red, and spoons.
- **Gloves (optional)** 1-2 pairs per student.

LEGO Lab:

- **LEGO Atoms and Molecules Kit** 1 kit per student pair. Each kit contains the following LEGO bricks: 24 white1x2, 4 brown 2x4, 12 black 2x4, 8 yellow 2x4, 8 green 2x4, 36 red 2x4, 32 blue 2x4, 8 light green 2x4, 8 pink 2x4
- **Chemical Reactions Student Worksheet packet**
- **Laminated sheets**: Print out in color and laminate or put in protective sleeves for future use (1 double-sided page per student):
    - **LEGO Atoms & Molecules Layout Mat** (front) **and LEGO Atom Key** (back)
    - **Chemical Reactants** (front) **and Chemical Products** (back)

Materials for proving the products exist:

- **6 petri dishes** (or other small plates)
- **1 coffee filter or other paper filter**
- **1 large graduated cylinder (or other tall container)**
- **1 piece of thin cardboard**
- **1 rubber band**

Safety Issues:

1) The chemicals are not toxic in the amounts used for class. Goggles and gloves are not absolutely necessary. However, because calcium chloride can irritate the skin, you should be sure that students do not taste anything, do not touch their eyes, and that they wash their hands after the lab.

2) The bags will expand quickly because of the carbon dioxide gas created. You need to be aware of this and instruct students to open their bags before they get too full. We tried exploding a bag and it took 3 times the amount of ingredients and a lot of waiting to get it to pop. However, a bag could have a small hole, could come unzipped, or the contents might spit out upon opening so it is best to open before the bags get too full.

Class Preparation:

- Print enough student worksheets for every student:
- Prepare 1 tray for every 2 students: 1 resealable bag and 4 paper towels
- Prepare one set of chemicals on the tray for every 4 students (two pairs) to share: 2 tubes of phenol red, 2 plastic teaspoons labeled "calcium chloride" and "baking soda", 1 small beaker labeled "calcium chloride" with about 4 teaspoons calcium chloride in it, and 1 small beaker labeled "baking soda" with about 2 teaspoons baking soda in it. Keep these trays off to the side until you are ready to hand them out.

Optional Prior Preparation:

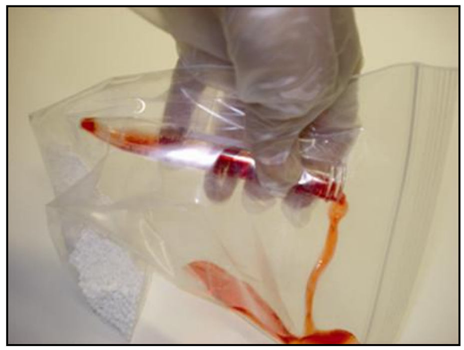
You may wish to do this experiment yourself first, and prepare a container of each reactant and product for comparison, or begin to do the separation.

If you plan to do the separation of the products over a few days in class, you can use the products from your students' experiments. Please see Appendix A for instructions on how to separate the products.

Review of the instructions for the wet lab:

1) As directed in the video, put the test tube, standing upright, into the bag. Hold it from the outside of the bag.

2) Show students that they would unscrew the top and then close the bag. The tube stays in the bag, but the top can be put on the tray. Make sure the bag is well sealed - really emphasize the need to be sure the bag is really closed. Tell the students to have partners check each other. Have the students do those same steps.



Mixing the reactants.

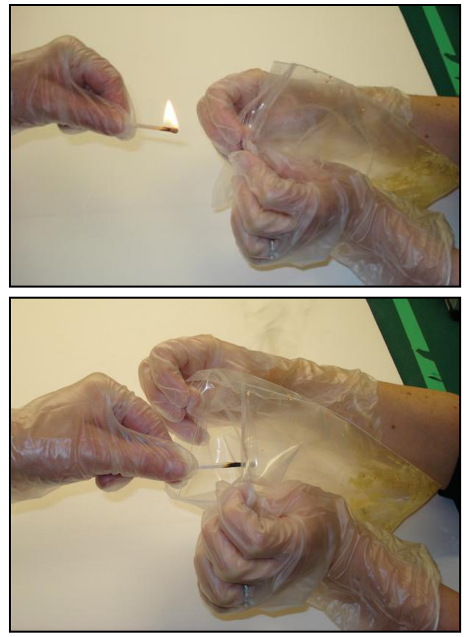
3) Tell the students to make extra sure the bag is sealed. Then, (over the tray) allow them to tip the tube of phenol red solution so that it mixes with the solids. Tell them they should flip the bag back upright, and use their fingers to help mix the reactants together.

4) Gas will start forming and puffing up the bag. Tell the class that they should carefully open their bag before it gets too full.

The reaction in action!

5) After 3-5 minutes, instruct students to put down their bags on their trays. Discuss student observations. (Be sure the bags have been opened once to deflate. Then they can be closed again.)

Instructions for the flame test:


Flame test

You may wish to mix together the reactants in your bag in front of the class, and talk about the gas that is formed.

Tell them that if you were to light a match, you could tell what kind of gas it is. If it is oxygen, the flame will burn brighter, if it is hydrogen gas, there will be a popping sound, and if it is carbon dioxide, the flame will go out. You can write this on the board.

When your bag has filled with gas, have a student help you. You light the match and ask the student to open the bag gently, so as not to create a whoosh of gas. (In fact, protect the flame with your hand after you light it.) Move your hand so that the match is inside the bag. The match will go out. Ask the students what this tells them. You can now add production of carbon dioxide as one of the observations.

Once groups have finished, instruct them on clean up procedures and have them wash their hands.

Final cleanup:
Pour the products from the bags into a graduated cylinder. Save the phenol red vials and wash them out. You can discard the bags or rinse them out and recycle. Rinse out the beakers, spoons, and chemical bins. You may wish to discard the extra chemicals, as the students may have accidentally mixed them. The calcium chloride should not be left in the open air as it will absorb moisture.

Further notes on the reaction--
Temperature change (Heat):
Students will notice that calcium chloride plus any liquid causes heat. You can show them a container of calcium chloride from the grocery store if you purchased it there. People in cold climates sprinkle this chemical on their icy driveways in the winter to melt the ice.

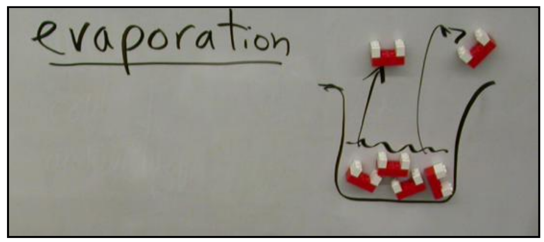
Color change (yellow): The phenol red caused the change in color. It is an indicator. The phenol red indicates the pH of substances. It turns yellow below a pH of 6.6 (indicating an acid) and turns pink above pH of 8.0 (thus indicating a base). It is *in aqueous solution* meaning it is a powder dissolved in water. So in addition to the phenolsulfonphthalein you are adding water to the reaction.

Gas produced: The combination of calcium chloride, baking soda, and either liquid produces carbon dioxide gas. Looking at the chart, you had to have both solids and a liquid to produce the gas. (The water is not actually a reactant…its atoms do not recombine. However, it allows the calcium chloride and baking soda molecules to get close enough together to react.)

Ask students about other chemical reactions they know about. You can suggest cooking, rusting, and digestion. Discuss how these reactions don't always produce heat, a color change or a temperature change. Tell students that the one thing all chemical reactions have in common is that new products are made.

Comparing Physical and Chemical Changes
Emphasize that in physical changes the molecules stay the same, while in chemical changes, new and different molecules are formed. Examples: water freezes, melts, or evaporates; metal is crushed; sugar dissolves in water; a person picks the tomatoes out of their salad.

A physical change can be represented by putting some LEGO molecules of water and carbon dioxide or water and salt together in a bowl to demonstrate dissolving, or having LEGO water molecules evaporate out of the bowl. Phase changes can be shown by moving bricks around (faster and further apart or slower and closer together) without changing how they are bonded (or clicked together). Ice would have the water molecules jiggling just a little. Liquid water would have them moving more rapidly, and boiling and evaporation would have them moving so quickly that some escape the container.



LEGO water molecules evaporating out of a beaker.

A chemical change is represented by clicking or unclicking bricks. Examples: baking a cake; rusting; burning sugar; digesting food. Fire and rusting are examples of a chemical change called oxidation: the addition of oxygen to the molecules.

*Note that there are 2 molecules of baking soda and only one of calcium chloride in the reactants. This is the opposite of the number of TEASPOONS of the reactants, and some students may notice this. You added 2 teaspoons of calcium chloride because of calcium chloride was a less dense powder. (It was not packed together.) When balancing the equation, actually more baking soda molecules than calcium chloride molecules are needed.

Appendix A

Chemical Reaction: Proving the New Products Exist

In order to prove that a chemical reaction has taken place, new products must be demonstrated. The new products are carbon dioxide (CO_2), water (H_2O), calcium carbonate or chalk ($CaCO_3$), and sodium chloride table salt (NaCl) and they are all now in a mixture inside the sealed bags. This is a teachable moment for learning about mixtures. In mixtures, substances keep their own individual properties. That's how your class will be able to separate the molecules and prove what they are.

We have already used the flame test and identified the carbon dioxide product. Explain that we can't prove the existence of the newly formed water molecules with simple techniques. However, we can separate the rest of the new material in the mixture, the chalk and the sodium chloride salt because they keep their own properties. Chalk has a property that it is insoluble in water, for example. Students could take chalk powder and try to dissolve it in water, but it will not dissolve.

Class Time:10 minutes first day preparation and ~10 min last day for analysis and discussion, with about one week between for evaporation. After you have done this once, save the products that you have made for quick demonstrations in the future as needed.

Steps for showing that sodium chloride salt and chalk were formed in the sealed bag:
Day 1: Put on gloves and empty all the bag contents into a large graduated cylinder. If possible, have students watch you put a least one bag into the cylinder so they associate the cylinder contents with the chemical reaction. Let settle overnight.

Day 2:
Show the separated mixture to students and ask for suggestions. *"How could you separate chalk from the water and its dissolved salt?"* (Point out the settled bits of chalk.) *"And how then could you separate the salt from the water?"* Students may come up with lots of useful ideas and you may like to try them.

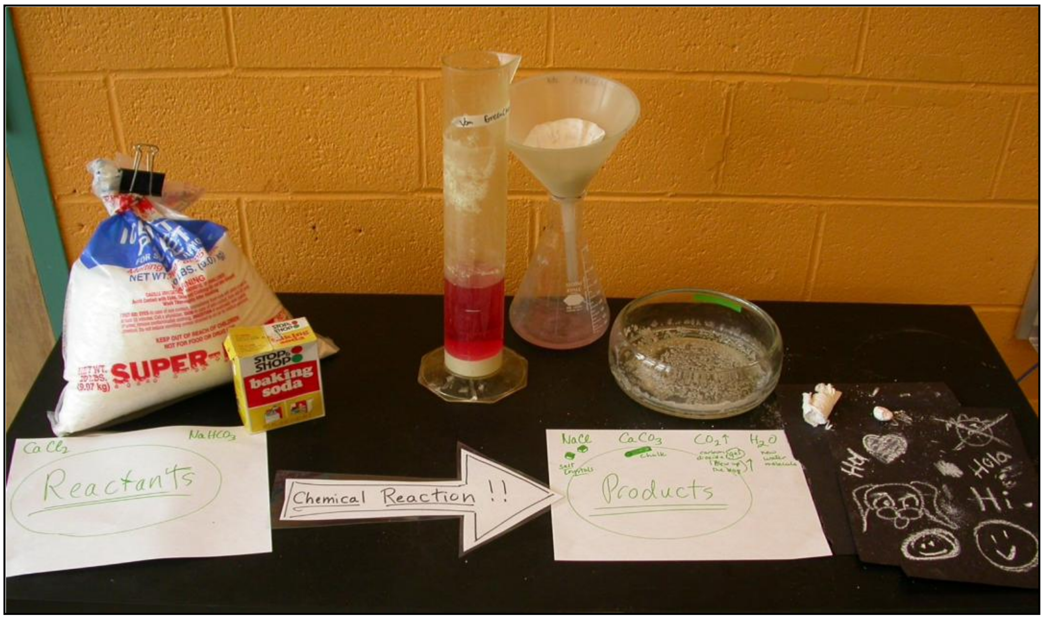
(It is common for middle school students to predict that salt will be retained by the coffee filter. This could be an optional homework assignment. At home mix kitchen table salt with water. Taste the solution. Filter the solution and taste the solution again.)

Day 2 or 3:

1) Pour off most of the top solution (salt and water) through a coffee filter in a funnel. Avoid pouring much of the settled chalk at this time. The filtered solution that comes through should have no chalk particles. Pour this

solution onto several plates for evaporation. Beautiful cubic salt crystals will appear if you leave them undisturbed.

2) Place the funnel over a new cup and pour the rest of the cylinder through the coffee filter. Rinse the chalk by running some tap water through. (Do this step after you have made the evaporation dishes, as you do not want to add more water to the evaporation sample.)
3) You may wish to let the chalk sit in the funnel for a day or two. Then roll up the chalk paste in the filter paper. Squeeze dry. To make a cylinder of chalk that the students can write with, wrap the chalk with a piece of thin cardboard and a rubber band. Speed dry by heating on a radiator or using a hair dryer. Otherwise it may take a few more days to dry.



This photo shows the actual chemical reactants, calcium chloride and baking soda, and the new products that were formed in the chemical reaction. The graduated cylinder contains the mixture of the products. Photo credit: May 2003 K. Vandiver

Comparing standard samples:
It is good to demonstrate what the chemical *reactants* would look like after being dissolved in water. This is very easy and fun to do. Mix the following <u>three</u> standard solutions and pour on evaporation dishes.

1) Table salt from a commercial box
2) Calcium chloride
3) Baking soda

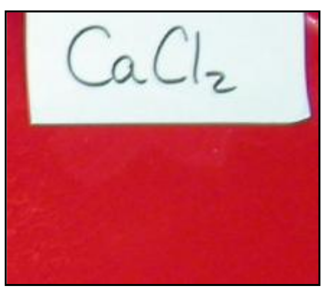
Only the salt will form the characteristic crystals with evaporation. The other compounds look very different. For older students, the role of standards in chemistry can be discussed. Chemistry often uses standards for comparison and evaluation when working with unknowns.

This photo shows standards of known chemicals for use in comparing with products of the reaction.

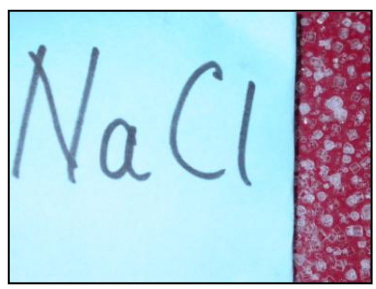
The drawing on the board with LEGO water molecules helps students to envision the change of state used in preparing the standards. When water molecules evaporate, they still have the same shape and formula. Evaporation is not a chemical change/chemical reaction. It is a physical change because the water molecule is the same before and after.

<u>The standard solutions after evaporation are shown in detail below.</u>

Baking soda or sodium bicarbonate
(forms white streaks)



Calcium chloride or de-icer
(forms a clear layer)

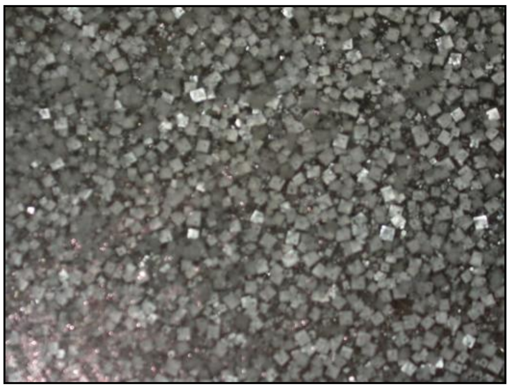


Sodium chloride salt
(forms cubic crystals)

Analysis of products as identified by properties:

Properties of the compound NaCl: Forms characteristic cubic crystals, dissolves in water.

Properties of the compound chalk ($CaCO_3$): On the scratch/streak test (Mohs test) chalk is not as hard as paper. Students can write on a black construction paper with the new chalk. It will leave a chalk streak on the paper. Chalk is also insoluble in water.



Salt crystals separated from other products by evaporation.

Chalk or calcium carbonate separated and dried.