Teacher's Guide for

"Atoms and Molecules: Chemical Reactions"

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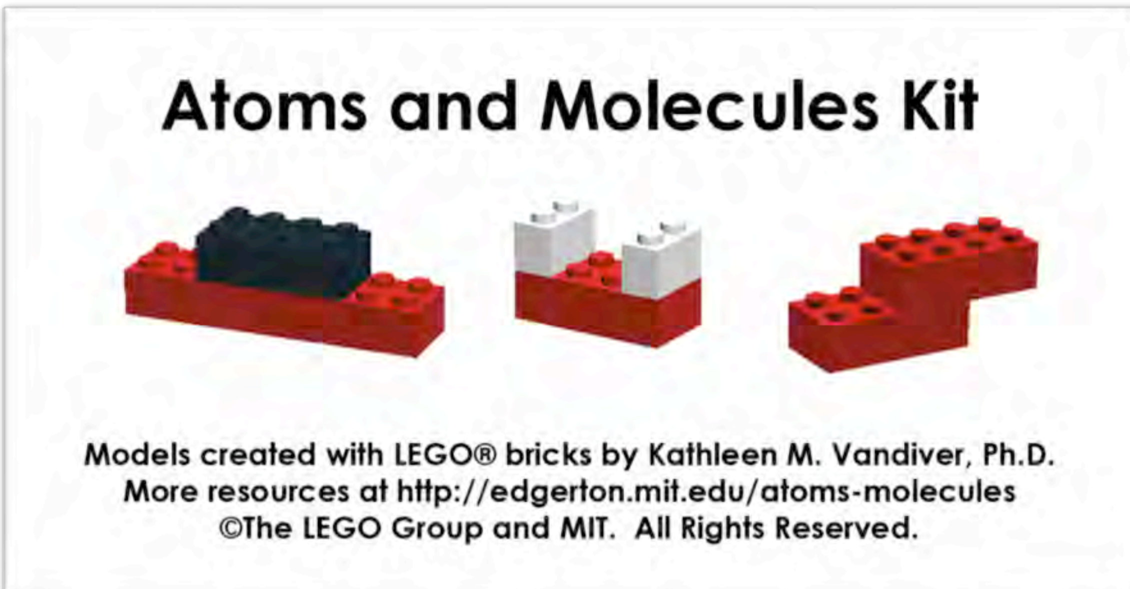

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Table of Contents:

This teacher's guide describes a workshop (2.5 hour) lesson version and has a suggested lesson outline for multiple 45 minute class sessions. (See p. 4)

This guide, student sheets, layout mats, and additional materials, as well as a photosynthesis lesson and a climate change lesson using the same LEGO bricks may be downloaded at:

http://edgerton.mit.edu/atoms-molecules

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

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Atoms and Molecules: Chemical Reactions Objectives

The Chemical Reactions lessons are intended to supplement other chemistry lessons you currently teach. They can be used as:

- An introduction to the understanding that chemical reactions make new products.
- A concrete way to demonstrate the abstract concepts of elements, atoms, molecules, compounds and mixtures.
- An exciting introduction to a chemistry unit
- An enrichment activity after the students have an initial understanding of molecules and chemical reactions

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):

> **5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.**
>
> **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, O_2 and O_3 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.
>
> **7. Give basic examples of elements and compounds.**
>
> **8. Differentiate between mixtures and pure substances.**
>
> **10. Differentiate between physical changes and chemical changes.**

You can also use the Chemical Reactions lessons to illustrate other concepts that students may have studied. Some additional topics include:

- **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 Chemical Reactions Lesson

Following are two schedules for the teaching of this lesson. The first describes the way the lesson is taught at the MIT Edgerton Center as a 2.5 hour workshop. See page 4 for a suggestion for 45-minute classroom use.

Schedule (as taught in a 2.5 hour workshop):

20 minutes	Introduction to Chemical Reactions lesson. Class discusses preconceptions of a "chemical reaction," then the instructor details lab safety procedures.
30 minutes	**Wet Lab.** As a class, student pairs will go through the chemical reaction activity, which includes observation of the reactants before mixing, the reaction itself, and the resulting products.
20 minutes	Student pairs will work a second (and possibly a third) experiment, choosing some of the same materials, attempting to determine which combinations produced which results in the initial experiment. Clean up.
20 minutes	The class discusses the results of their experiments. The discussion then returns to the preconceptions, and the new understanding that a chemical reaction creates new products. The new products for this reaction are revealed.
40 minutes	**LEGO Lab.** LEGO bricks as a model of atoms is introduced. Chemical terms are introduced/ reviewed using LEGO models as examples, and students will learn how to write chemical formulas.
20 minutes	Groups will use LEGO bricks to model the chemical reaction, demonstrating the conservation of matter as well as the distinction between physically mixing materials and different molecules being created during the chemical reaction. They will further practice writing chemical formulas.

Total time = 2.5 hours

1. Introduction

The class is welcomed and a schedule of the unit/lesson is laid out for the class, including 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. Students are encouraged to share any and all ideas. Finally, lab safety is reviewed in terms of this classroom and this experiment. Methods of observation and chemical handling are especially detailed. Both splash goggles and gloves (non-latex) will be worn throughout the entirety of the wet lab.

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 the phenol red solution allows the other molecules to get close enough to react. The phenol red is not a reactant in the chemical reaction we will focus on. [*It is crucial to use an aqueous rather than alcohol solution for the reaction*. An explanation of the role of the phenolsulfonphthalein versus plain water will come about when students try out their own experiments.] Students safely observe the chemicals before mixing, the reaction itself, and the new products after the reaction. Groups will talk about how their actual chemical reaction compared to their predictions. The key concept is that all chemical reactions produce new substances.

3. Further Experiments (optional)

Student pairs are asked to choose among the chemicals used in the first chemical reaction to make another mixture/reaction. The goal of this second experiment is to determine which combination of materials created a: temperature change (heat), color change (yellow), and produced a gas. Each pair of students will work through the same lab directions as with the initial reaction, including the same quantities of materials. After noting all reactions, student pairs may wish to combine their products with other groups in the class, and are welcome to do so if time permits.

4. "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 with 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 bricks once the products were made.

Students are then introduced to writing chemical formulas. Each student will create a LEGO "compound" using 10 or fewer bricks, attaching them in any manner. After building the compound, each student will write its formula following the rules of chemical notation, including element order and subscripts. Student pairs will then trade compounds, write their partner's formula on the paper and then compare answers.

Suggestions for 45 minute class use

Day 1: "Wet Lab"

1) Introduction and discuss preconceptions of chemical reactions
2) Safety discussion
3) "Wet Lab" observations, procedure, and results.
   Use pages 1-2 in student worksheet. Skip the further experiments section for now.
4) Clean up, remove goggles and gloves.
5) Revisit preconceptions, and point out that new products have been made. Tell students what those products are. Begin the separation of the mixture to prove that the products exist by pouring contents of bags into a big graduated cylinder. (See Appendix A for a full description.)

Day 2: "LEGO Lab"

1) Vocabulary including LEGO bricks as models of atoms, molecules and compounds.
   Use pages 3-4 of student worksheet, laminated Atoms and Molecules Layout Mat (front) and Atom Key (back).
2) Model the "Wet Lab" reaction using LEGO bricks.
   Use page 5 of student worksheet, laminated Atoms and Molecules Layout Mat (front) and Atom Key (back), and Chemical Reactants (front) and Chemical Products (back).
3) Point out the separation of the liquid from the chalk layer in the graduated cylinder. All the separation steps are actually physical steps: settling, filtering, and evaporating. 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. (See Appendix A.)

Day 3: (Optional) Further Experiments to find what chemical combinations produced the temperature change (heat), color change (yellow), and a new gas. Each pair of students does 2 further experiments.
Use page 2 of student worksheet, and supplies for the wet lab. Note that these "further experiments" may also be accomplished more quickly as teacher demonstrations. (Student helpers may be involved; a beaker with increased quantities of the reactants produces a greater effect.) Demonstrations may be prudent if classroom management is an issue.

Day 4: (This may occur a week later depending on evaporation rates)

1) Show separated products after evaporation and compare to standards.
2) Practice writing chemical formulas using LEGO bricks.
   Use page 6 of student packet and laminated Atoms and Molecules Layout Mat (front) and Atom Key (back).

Chemical Reactions Materials

(Amounts are for one class unless otherwise indicated.)

Wet Lab: (includes amounts for optional further experiments)

- **Chemical Reactions Student Worksheet packet** pages 1-2
- **Baking soda** 1 lb box
- **Calcium chloride** a common de-icer found in grocery stores. 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 first to be sure it does heat when in contact with water.**
- **Phenolsulfonphthalein (phenol red) in aqueous solution (0.02% weight by volume, 500ml solution)** You will need 10 ml per student pair (30-40 ml per student pair if doing the optional further experiments), 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 vital for the success of this experiment. It just needs to be red when dissolved in 10 ml water. You'll need to adjust the amount for your specific tap water.)
- **Covered test tubes or vials** 10-15 ml capacity, 1 tube per student pair (3-4 tubes per student pair if you do the optional further experiments)
- **Resealable freezer bags** 1-2 qt size, 3 bags per student pair. The kind with a zipper may not hold the gas in very well.
- **Plastic spoons** 2 per student pair. Label one "baking soda," the other "calcium chloride".
- **50 ml beakers or similar container** 2 per 4 students. Label one "baking soda". Label the other "calcium chloride". (It is helpful to color code the spoon and beaker labels)
- **Large tray (optional)** 1 for every pair. Aluminum trays from the grocery store are fine.
- **Book of matches** For the teacher.
- **Pencils and erasers** 1 per student.
- **Splash goggles** 1 per student.
- **Chemical bin (optional)** 1 per student pair. A small plastic container with a flat bottom is handy to hold the chemical-filled beakers, tubes of phenol red, and spoons.
- **Gloves (optional)** 1-2 pairs per student.

LEGO Lab:

- **Atoms and Molecules Kit** 1 kit per student pair. Each kit contains the following: 24 white 1x2, 4 brown 2x4, 8 pink 2x4, 8 yellow 2x4, 8 light green 2x4, 8 green 2x4, 12 black 2x4, 36 red 2x4, 32 blue 2x4.
- **Chemical Reactions Student Worksheet packet** pages 3-6
- **Laminated sheets**: Print out in color and laminate or put in protective sleeves for future use (1 double-sided page per student): **Atoms and Molecules Layout Mat** (front) **and 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**
- **1 50 ml graduated cylinder**
- **1 piece of thin cardboard**
- **1 rubber band**

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

The bags will expand quickly because of the carbon dioxide gas created. You need to be aware of this and instruct students to open/deflate their bags before they get too full. We tried to pop open 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 deflate before the bags get too full.

Class Preparation:
Wet Lab:
- Print enough for every student: Student worksheet packet, Pages 1-2.
- Lay out goggles and gloves (latex free) for every student and teacher.
- Prepare 1 tray for every 2 students: 1 resealable bag and 4 paper towels (put out 2 extra resealable bags if you plan to do the further experiments).
- Prepare one chemical bin for every 4 students (two pairs) to share: 1 covered test tube 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 off to the side until you are ready to hand them out.
- Have the following extra materials ready: paper towels, match book, pencils and erasers. If you do the optional further experiments, you will also need test tubes of water (1-2 for every 2 students), extra tubes of phenol red (1-2 for every 2 students), extra baking soda, and extra calcium chloride.

LEGO Lab:
- Print enough for one class (in color, and laminate or put in protective sleeve to use again):

    Double sided: Atoms and Molecules Layout Mat (front) and Atom Key (back)

    Double sided: Chemical Reactants (front) and Chemical Products (back)
- Have 1 Atoms and Molecules Kit ready for every 2 students.

Optional Prior Preparation: Please see Appendix A for instructions on how to separate the new products produced in this reaction. This demonstration will be worthwhile, because the demonstration illustrates the definition of a mixture. (Substances in a mixture maintain their original properties.) If you teach this as a 1 day workshop, you may wish to separate the products ahead of time to show to students. If you plan to do this over a few days, you can separate the products of your students' experiments.

Suggested Teacher Script (as taught at the MIT Edgerton Center)

Wet Lab (Requires 45 minutes for initial experiment. An additional 45 minutes for optional further experiments.)

5 minutes - Introduction to Chemical Reactions

Divide the class into groups of 4. Within those groups, students will work in pairs.

"There are 2 halves of this lesson, a wet lab for experimenting, and a dry lab for understanding. The wet lab involves mixing chemicals together and figuring out what defines a chemical reaction. The dry lab is where we'll use LEGO pieces to build models of the molecules we used in the wet lab."

15 minutes - Class discusses preconceptions of a "chemical reaction", then the instructor details lab safety procedures. (Your class may have already had these procedures in place, allowing more time at the end for discussion of products.)

"Today we'll be dealing with chemical reactions. What is a reaction?"

Students give ideas…

"You 'react' when someone does something. You change your facial expression or jump back or say something. It's similar with chemicals…things change as the chemicals combine."

"What might you expect in a chemical reaction?"

Common student comments: explosion, light, smoke, monsters, colors, fire, foam, energy, carbon dioxide, mutations, heat/cold, melting, water, electricity, separation, radioactivity, etc. Teacher writes ideas on board. If students don't suggest that new things are made, consider writing that as well.

"We will see some, but not all of these things in today's chemical reaction. Then we'll figure out what all chemical reactions have in common."

Safety discussion:

"Now for some lab safety procedures…we are not using dangerous chemicals, but they could irritate your skin, so we'll be careful. We'll wear gloves and goggles at all times. If you need to take them off, then step back from the table. Here's how you remove a glove. Slide your opposite hand's thumb into

the inside of the glove, without touching your wrist. Use your thumb to flip the glove inside out so that any chemicals are kept inside.

Goggles will protect your eyes. If you need to take them off, step to the back of the room. Remove your gloves first and then take off your goggles.

Now we'll hand out safety equipment. Be sure all food and drink is put away, put away hats, and tie back long hair. Be sure your gloves fit and ask for different ones if they don't. Your hands will get sweaty, but you need to keep your gloves on."

We will observe 3 different chemicals shortly. You've got goggles to protect your sight, gloves to protect your hands when you touch things. What other senses might we be using today?"

Student comments: Sounds, smell, taste….

"Great ideas. However, there will be NO TASTING today. We might hear some things, and we could use ear protection, but we won't need that today. We could smell things, but is it safe to just sniff any old chemical? NO! Here's how you smell things safely. You hold the item away from your nose and use your hand to 'waft' or wave the smell towards your nose. Start further away and move the item closer to your nose each time. Thus, it is called, "wafting." (Pronounced wahft-ing) *You do NOT want to directly breathe in a high concentration. It could be very harmful to directly breathe in certain chemicals like ammonia or acids."*

Demonstrate wafting. Instruct students to write down one safety rule on their paper. (**Student Sheet, section A**) Hand out trays (1 per 2 students) with gloves, goggles, bags, and paper towels as they do so. Allow them time to put on and adjust gloves and goggles.

30 minutes - As a class, student pairs will experience a chemical reaction, which includes observation of the reactants before mixing, the reaction itself, and the resulting products.


This student writes down his observations of the chemicals.

"We will first make observations before we watch the chemical

reaction so we can see how things change. The chemicals are calcium chloride, baking soda (or sodium bicarbonate), and phenolsulfonphthalein (phenol red) in solution. Please look at these chemicals as we hand them out, touch them, smell them with wafting, and write down at least 5 words descriptions of each chemical. Don't be afraid to write down the obvious. Share and borrow ideas from your classmates. We'll share ideas with the whole class in about 10 minutes."

Hand out chemical bins with paper towels, teaspoons, and chemicals (1 bin per 4 students). Encourage students to write down their observations of the chemicals by comparing them to other things they know. (**Student sheet, section B**) They should share the chemicals with the rest of the table. After about 10 minutes, ask the class for their observations.

Common student comments:
Calcium Chloride – pebbly, solid, white, little balls, different sizes, no smell, solid, like mothballs, hard.
Baking Soda – powder, white, solid, like salt, no smell, snowy, very small particles.
Phenol Red Solution – red, watery, liquid, like cough syrup, like cranberry juice, transparent, not viscous.

> Be sure to emphasize mixing over the tray and having students wait for your permission to move on to the next step. You demonstrate the step, the class watches, and then they repeat what you did. Save a bag with just the solids for demonstration later.

Student sheet, section C: *"Now is the mad scientist portion of the class. We'll mix together our chemicals and observe what happens. Once you've observed the reaction, I want you to write down what you noticed.*

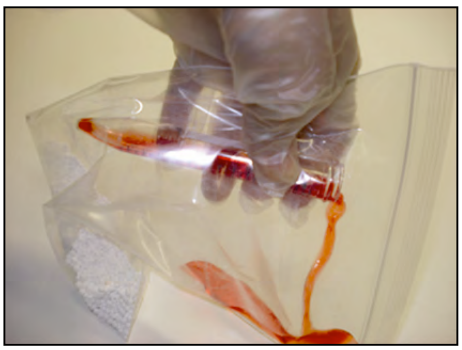
1) Put 1 teaspoon of baking soda into a bag and ask the class to do the same.
2) Put 2 teaspoons of calcium chloride into the same bag and ask the class to do the same.

"Is anything happening yet?" (… no)

3) Tell the class to watch you first, before they do anything. Put the tube, standing upright, into the bag. Hold it from the outside of the bag.

4) Don't take the top off yourself, but show students that they would unscrew the top and then close the bag. The test tube stays in the bag, but the top can be put on the tray. Emphasize the need to be sure the bag is

really closed. Tell the students to have partners check each other. Then allow students to perform those same steps.



Mixing the reactants.

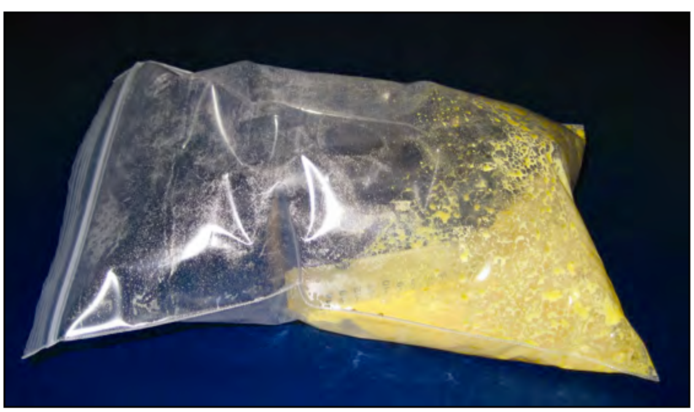
5) Tell the students to make extra sure the bag is sealed; then, (over the tray) allow them to tip the tube of phenol red solution so that it mixes with the solids. Tell them they should flip the bag back upright, and use their fingers to help mix the reactants together.

You'll probably hear lots of "Ooohs!" and "Ahhhs!"
Gas will start forming and puffing up the bag.
<u>IMPORTANT:</u> Tell the class that they should carefully open their bag before it gets too full.

Encourage students to start writing down their observations, including smelling (**Student sheet, section D**).

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

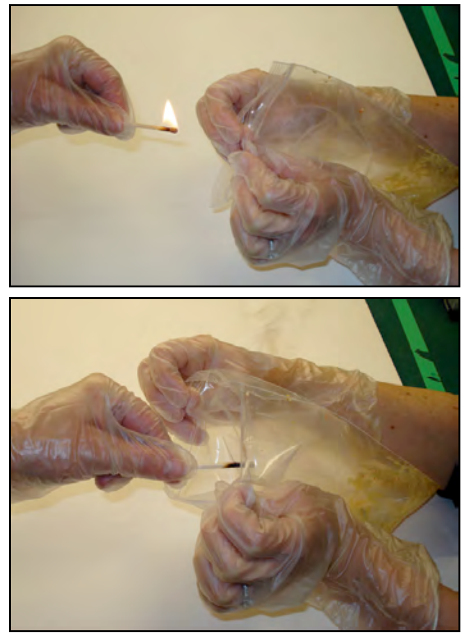
Common observations: "It got hot! It turned yellow. A gas expanded. It was like eggs. It bubbled and made a sound. The solids seemed to dissolve, but there was still some calcium chloride left."



The reaction in action!

If students are wearing gloves, you might consider letting them reach in and touch the yellow substances after a while. They'll need to wipe off their glove before touching their pencil again.

Flame test: 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. 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.



Flame test

If you are doing this in 45 minute class period, you would now clean up, and then hold a discussion about what happened.
Clean up should involve you or selected students pouring the contents of the bags into a graduated cylinder. Collect the bags in a pile because you will want to remove and wash the test tubes for reuse. Desks should be wiped to remove any calcium chloride residue.
(Skip to page 14 for the class discussion.)

Optional further experiments (to be done now if in a workshop setting, or on day 3 if doing this lesson in 45 minute class periods) :

20 minutes –Student sheet, part E) Student pairs will work a second and third experiment, choosing some of the same materials, attempting to determine which combinations produced which results in the initial experiment.

Explain to the class that it is now their job to try new experiments to discover which combinations produce the following: temperature change (heat), color change (yellow), production of a gas. Circle those observations on the board. Each partner team will do 2 more experiments. Instruct students to turn to page 2, "Further Experiments." They should talk with their partner about which 2 experiments they will do. They can use any combination of the ingredients (calcium chloride, baking soda, phenol red, water), but must keep the quantities the same as in the original experiment. The teacher should encourage groups to try different ideas, so that the whole class will cover as many combinations as possible. The students will make observations and write down conclusions for each experiment. Check student's ideas for their experiments and encourage some to change if you don't have all the combinations. You could also ask some of the faster pairs to do one extra experiment. Each team should use the 2 other bags on their tray. You may need to restock some of their supplies. Remind groups that if their experiment produces a gas to let it out of the bag before it gets too full.

The results of a number of different experiments.

Once groups have finished, and have recorded their observations, instruct them on clean up procedures:

Cleanup:
"Put everything back on the tray and carry to the sink or back table. Remove your gloves first, then your goggles. Then wash your hands and come back to your desks."

Meanwhile, assistants or the teacher should quickly wipe down the desks with a wet paper towel to remove any chemical spills.

10 minutes – (part of optional further experiments) Group discussion to determine which combinations of ingredients produced the changes noticed in the initial experiment.

Draw a table on the board and fill it in as students give you their observations. There are at least 8 key combinations that will help the students determine the causes of the particular reactions, but you should include all of the tests that the students perform. Fill in the ingredients that they used on the chart. (You may wish to avoid the use of the abbreviation "bs" for baking soda!) Put a check in the boxes where they observed a temperature change (heat), a change in color (yellow), or the production of a gas. The first line is the experiment that everyone did together.

Ingredients	Temperature change (heat)	Color change (yellow)	Gas produced?
Cc+baks+pr	✓	✓	✓

In the end it will look like something like this:

Ingredients	Temperature change (heat)	Color change (yellow)	Gas produced?
Cc+baks+pr	✓	✓ (yellow)	✓
Cc+pr	✓	✓ (pink)	-
Baks+ pr	-	✓ (pink)	-
Cc + H20	✓	-	-
Baks + cc + H2O + pr	✓	✓(yellow)	✓✓
Baks+pr+H20	-	✓ (pink)	-
Baks+H20	-	-	-
Cc+baks+h20	✓	-	✓

Now hold a discussion about which combinations produced heat, gas and color. Ask the students to use the data on the board. When looking at heat, for example, see what ingredient was used each time heat was produced.

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. People sprinkle this 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.

Students may write the conclusions in **Section F**.

10 minutes - The final discussion returns to preconceptions, and the fact that the reaction produced new products. Those new products are revealed.

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. This is a key understanding, and one that is commonly missed.

Ask the students to write the reactants and products at the bottom of page 2 (**Student sheet, section G**). The reactants were baking soda and calcium chloride. The water was not a reactant, so you write it above the arrow. (It was a solvent, and allowed the molecules to separate, so that the atoms could recombine in new ways.) The phenol red was also not a reactant; it was an indicator of pH. The products were chalk, salt, carbon dioxide and water. (A new water molecule was formed.)

> If students ask about the formation of a new water molecule, you could explain that the formation of new water molecules could be shown by following the reaction with a radioisotope of hydrogen. The radioactivity would start in the baking soda with the reactants and later be found in the water with the products. Evaporation and condensation steps might help to demonstrate that radioactive hydrogen atoms were incorporated into the water molecules.

As you write these on the board, you can discuss how you know what these products are. For now, students will have to take your word for some of them. Later you will show them the separated products.

- You know about the carbon dioxide already. It was released into the air, and its presence was proven by a match test.
- The chalk sinks to the bottom as it precipitates out of solution. It is not soluble in water. Chalk may feel gritty to the touch.
- What's left on top is salty water. Ask students how they might separate this mixture. You could siphon it off, run it through a coffee filter to remove any extra chalk, and then evaporate the water, leaving salt crystals behind.

It is interesting to do the separation with the class's bags over the next few days. You can then compare the products with the original reactants to see the difference. **(See instructions in Appendix A.)**

Final cleanup:

Pour the products from the bags into a graduated cylinder if you have not already done so. Save the test tubes and wash them out for reuse. 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.**

LEGO Lab (45-50 minutes depending on how much vocabulary your students already know. 10 minutes of chemical formula writing can be done on another day. We recommend day 4.)

30 minutes - LEGO bricks as models of atoms are introduced.
Chemical terms are introduced/reviewed using LEGO models as examples.

Materials:

- **Atoms and Molecules Kits** (one kit per pair)
- **Atoms and Molecules Layout Mat** (front) **and Atom Key** (back)
- **Chemical Reactants** (front) **and Chemical Products** (back) (hand this out later in the lesson)

"We'll now be modeling the atoms that made up our chemicals in the wet lab. We'll be zooming in on the chemical reaction. You'll be sharing LEGO bricks with a partner. Let's make sure you have the right number of LEGO bricks. When I tell you to, take them out of the box and line them up on the layout mat. As you do this, look at the labels that we are using to describe each LEGO brick. When you are sure you've got them all, put them back in the box and close it. If you are missing any, please let me know." Students line up the LEGO bricks on the mat. You can visually check to be sure they have all the bricks. If they don't, you can give them an extra brick. You can use this same procedure for a quick and easy clean up at the end of class.

Lining up the bricks on the layout mat makes set up and clean up a snap!

Review the chemical terms:

Matter: anything that has mass and takes up space.
There are 3 major types of matter: elements, compounds, and mixtures. Ask students for examples of matter. They may name things like their desk, a tree, or themselves! Check for understanding by asking whether air is matter.

You can quickly demonstrate how air takes up space, by blowing air into a plastic bag, closing it, and pressing on the sides. Another demo: Put a tissue in the bottom of a small beaker so that it stays in place when you invert the beaker. Invert this beaker in a larger beaker of water. Push the small beaker completely under water, keeping it level. Ask students if the tissue will get wet as you lower it. As you push down, no water will enter the beaker with the tissue because air is trapped in there, taking up space.

Another way to demonstrate that gasses have mass is to put the class's CO_2 fire extinguisher on a simple bathroom scale and record the weight. Then release some of the CO_2 and reweigh the tank. Record the results for each of the 4 classes during the day. The first class has the most dramatic results--a couple pounds, and although the last class's change may be barely measureable, overall the data from the all classes is very convincing. This activity can be a part of the lab safety unit, teaching the students how to use a fire extinguisher, and in that way, the cost of the CO_2 is well justified.
One can also show the tag on the CO_2 tank, where it says how many pounds of CO_2 were put into the tank by the suppliers. A heavy walled cylinder is needed for CO_2 because many gas molecules must be squeezed into it.

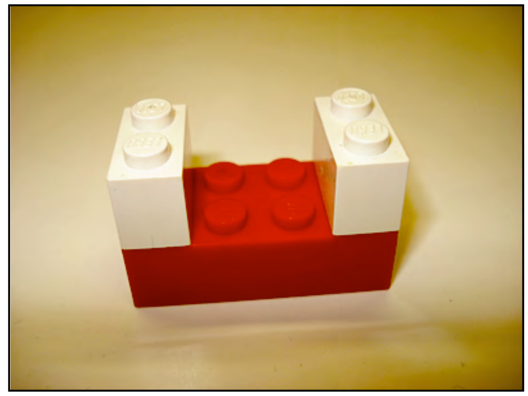
Element: a pure substance that has only one kind of **atom** in it.
Ask the class for examples: nitrogen, carbon, magnesium, aluminum, gold, silver etc. It is helpful to write the chemical symbol next to each example to begin to show students why we use these symbols.

Explain that different LEGO pieces represent different elements. Hold up a stack of carbon and explain that it represents the element carbon. It could represent the carbon in a diamond, or if it was arranged differently, the graphite in their pencil. The kit does not represent all of the known elements, but is a selection of some common ones. The kit uses the standard colors in chemistry for these elements.

More advanced classes can discuss how all of an element's atoms have an identical number of *protons* in their center or *nucleus*. For example, the element carbon has 6 protons. The element uranium has 92 protons.

Atom: the smallest unit of an element. Have students pick out one black LEGO to represent one atom of carbon. Discuss how you could keep dividing an element up until you got to its smallest part. This is similar to how you could divide up your stack of LEGO pieces until you have just one LEGO piece. If you cut that in half, it would no longer be a LEGO; it would be a broken piece of plastic. If you cut an atom, it would no longer be that element, but would instead be a bunch of protons, neutrons and electrons.

Compound: a pure substance made up of 2 or more different kinds of atoms bonded together. New properties appear. Examples students often mention are water (H_20), salt (NaCl), carbon dioxide (CO_2), and sugar ($C_6H_{12}O_6$). A compound is represented by LEGO bricks attached to one another in specific ways. The bricks (in a compound) are always attached at the same points, facing the same direction, with the same number of "clicks". If you were to separate the bricks, it would no longer be carbon dioxide.



A LEGO water molecule

Have students build the carbon dioxide models shown on the paper.

Molecule: a combination of atoms bonded together. It comes from a Latin word meaning "little lump." Hold one carbon dioxide model up and explain that it is known as a molecule. It is a molecule of the compound carbon dioxide.

> **Note:** We find the Massachusetts state framework's definition of a molecule being "the smallest part of a compound" confusing to students. For example, O_2 and O_3 are molecules, but are considered to be part of the element oxygen and not "compounds of oxygen". We therefore prefer the definition of a molecule as 2 or more atoms bonded together. We have placed the word "molecule" under both element and compound on our page of definitions.

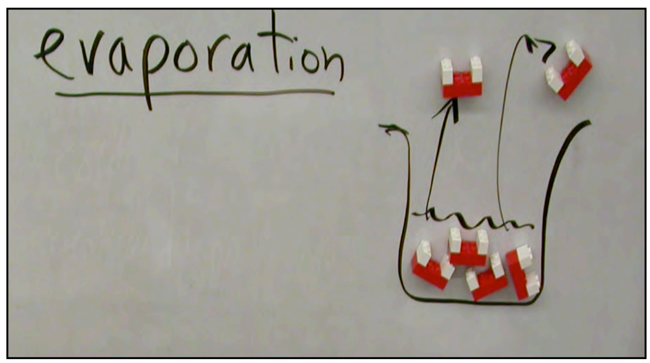
Have students each build a water molecule. Let them first show you the right number of hydrogen and oxygen bricks bonded together, even if their models do not look like the one in the photo. Then correct the structure. All their water molecules should now look like the photo. Show how the 2 hydrogen molecules would be on either end of the oxygen molecule in real life. Talk about how molecules have specific structures in real life, and that we will attempt to model that with the LEGO bricks. You can also talk about how they have some atoms of hydrogen and oxygen left in their kit. You can state that in order to make a particular compound, you must have the exact proportion of elements. Collect a cup of LEGO water molecules from the students. Draw the chemical formula on the board. (H_20 and H-O-H) Discuss the properties of water: liquid at room temperature, wet, freezes at 32° F, 0 ° C, boils at 212 ° F and 100 ° C.

Mixture: a combination of two or more pure substances (elements or compounds) that can be separated by physical methods. Examples of mixtures are gold and lead (used to purify gold), salt and water, copper and zinc (brass), the dry calcium chloride and baking soda. Steel is a mixture of iron, carbon, and often other elements. It is important to explain how you could separate these mixtures. We often describe a salad. Discuss how you can pick out the ingredients that you don't like. Another example is iron filings and sand. You can remove the iron by using a magnet. Evaporation can separate a salt water mixture.

Compare mixtures and compounds. A mixture is represented by individual LEGO bricks, and LEGO molecules mixed up together without being "clicked", or bonded together.

Instruct students to make a LEGO mixture of carbonated water. Discuss how you could separate the two compounds, water and carbon dioxide, by a physical process of letting the gas escape from the water by opening their bottle of soda.

Physical and Chemical Changes
Emphasize that in physical changes the molecules stay the same, while in chemical changes, new and different molecules are formed.



This photo shows an example of LEGO water molecules evaporating out of a beaker.

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. Changes of state 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 tightly together 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. (We have fun juggling the molecules in the air.) Examples: water freezes, melts, or evaporates; metal is crushed; sugar dissolves in water; a person picks the tomatoes out of their salad.

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.

Be sure that students do not misinterpret the production of a gas in the reaction as a change of state. Carbon dioxide molecules were actually made through a chemical change, they didn't simply change from a liquid to a gas.

You may also wish to discuss **endothermic** and **exothermic** reactions, and which one(s) happened in the wet lab. Students will notice that overall, their bag got hot, indicating an exothermic reaction.

Students may actually notice that the bags got hot and then cold and sometimes both hot and cold in different corners of the bag simultaneously. If they mix just calcium chloride ($CaCl_2$) and water, they notice that it is very hot. If they mix just baking soda ($NaHCO_3$) and water, they notice it is cooler. What is going on? Here is a possible explanation (which you may or may not wish to share with students, depending on their level of understanding). $CaCl_2$ going into solution in water is strongly exothermic, so that gives off heat. However, $NaHCO_3$ going into solution is mildly endothermic, so that absorbs heat (gets cold). If the powders aren't mixed, that explains why the bag can be both hot and cold at first. Then there is another endothermic reaction: The intermediate reaction product of this complex reaction is H_2CO_3 (carbonic acid) which decomposes to H_2O and CO_2 (driven by the $CaCO_3$ (chalk) precipitating out of solution). This decomposition is endothermic. These multiple processes occur at different times and at different rates determined by, among other things, the morphology of the powders, but overall, students will experience it as exothermic.

10 minutes - students learn about formula writing.

Have the students fill in page 5 in the student worksheet. Explain how important it is to write the formula exactly as shown, in order for chemists to clearly communicate which atoms they are talking about.

Reactants	$\xrightarrow{H_20}$	Products
$NaHCO_3$		$NaCl$
$NaHCO_3$		$NaCl$
$CaCl_2$		$CaCO_3$
		CO_2
		H_2O

> Note that there are 2 molecules of baking soda and only one of calcium chloride. Students may notice that this is the opposite of the number of TEASPOONS of the reactants. You added 2 teaspoons of calcium chloride because of the larger size of the balls of calcium chloride. However, when thinking about the molecular structure and balancing the equation, you actually need more baking soda molecules than calcium chloride molecules.

10 minutes - Groups will use LEGO bricks to model the chemical reaction, demonstrating the conservation of matter as well as the distinction between physically mixing materials vs. creating different molecules during the chemical reaction.

Explain that now students will build the reactants and products out of LEGO bricks. Hand out the "Chemical Reactants" and "Chemical Products" cards as instructions for building the chemicals out of LEGO bricks.

Have each student build the reactants using the "Chemical Reactants" side of the building mat. You can explain that this is just the dry mixture of calcium chloride and baking soda. Have partners check each other. Then instruct students to move all other LEGO bricks out of the way. (This is important or they will mix up stray bricks with the bricks being used for the reaction and may erroneously conclude that new atoms were formed.) Ask the students to complete the reaction by breaking up the reactants, and then making the products using the "Chemical Products" side of the building mat.

When the students are finished, ask if they needed any additional atoms/LEGO bricks or had any left over. Point out that the atoms are rearranged (or regrouped) in a chemical reaction, not created or destroyed. Discuss how the LEGO model matches the chemical equation.

Ask if the products are now a mixture or a compound.

'We now have a mixture made of new compounds. Remember, in our bag the CO2 separated itself out."

Remind students that when you let the bag's contents sit for a while (either in a bag or in a graduated cylinder) the chalk separated and sank to the bottom. You can then pour off the salty water, and evaporate the water to get just the salt. (If you are doing this in a classroom setting, you could now demonstrate filtering the chalk from the salt water mixture. See appendix A. In a workshop setting, you would now show off the products you pre-separated.)

You may wish to reinforce the idea of the molecules rearranging by going to the board and crossing off each atom first on the reactant side, and then on the product side, showing where each atom started and ended up. It is quite a powerful demonstration of conservation of matter.

"Chemical reactions don't destroy or make new matter. Atoms just get rearranged to make new products."

10 minutes - students further practice writing chemical formulas.

Instruct students to look at the final page of their packet. Explain that they will soon build their own compound. Any shape they want. Tell them that they can't just call it Bob or Steve; they need to name it by its chemical formula, just like we did with CO_2 or $CaCO_3$. It is a language that chemists use to communicate with each other. Tell them that they need to be very clear and careful about how they write their formulas. Be aware of capital and lowercase letters and subscript numbers. Explain that chemists have specific rules for how they name molecules and compounds, including the order in which the atoms are named. For this exercise, however, the students will use the order of the atoms on the "Atom Key" to name their compounds.

Show them an example. (We make $NaCa_2N_7$ in an interesting shape.)

"Look at the top of the Atom Key. Do we have any white LEGO hydrogen atoms? The answer is no, so now, check for yellow sodium (Na). Write down just Na. We don't need to write the subscript 1. Now look for calcium. We have 2 so we write Ca_2. Continue counting and writing until you've reached the bottom of the list."

Next, students build and name their own compound on their page. Then they switch LEGO compounds with their partner, and name their partner's compound. They should then compare formulas and help each other to get the naming correct.
Encourage them to repeat the process with a second compound.

Clean up:
Partners should click together all LEGO bricks of the same color and place them on their layout mats. When they are sure they have all their bricks (and you have quickly checked), they can place them back in the kit and close it.

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:

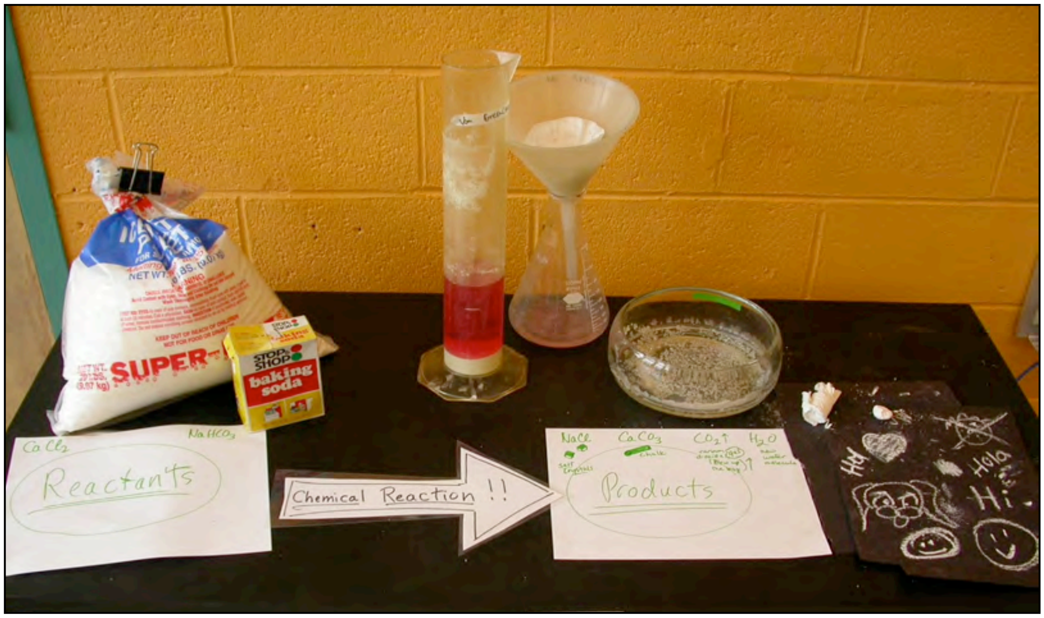
Show the separated mixture to students and ask for suggestions. *"How could you separate chalk from the water and its dissolved salt?"* (Point out the settled bits of chalk.) *"And how then could you separate the salt from the water?"* Students may come up with lots of useful ideas and you may like to 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 to do in the kitchen. Mix salt and water. Filter. Taste.)

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 in a couple of days 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.

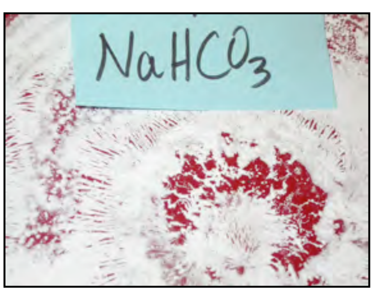


This photo shows the actual chemical reactants, calcium chloride and baking soda, and the new products that were formed in the chemical reaction. The graduated cylinder contains the mixture of the products.

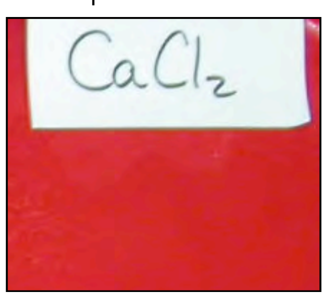
Comparing standard samples:
It is good to demonstrate what the chemical *reactants* would look like after being dissolved in water. This is very easy and fun to do. Mix the following <u>three</u> standard solutions and pour on evaporation dishes.
1) Table salt from a commercial box
2) Calcium chloride
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.

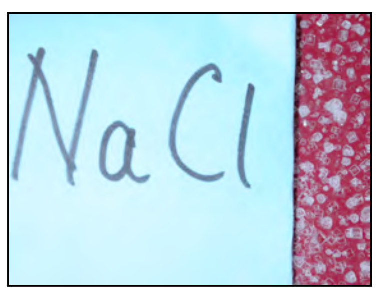
The standard solutions after evaporation are shown in detail below.



Baking soda or sodium bicarbonate
(forms white streaks)



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

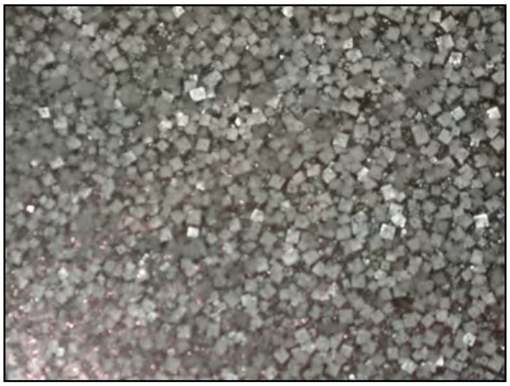


Sodium chloride salt
(forms cubic crystals)

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.

Appendix B

About the Authors:

Kathy Vandiver, Ph.D. created this lesson in her Lexington, Massachusetts classroom. 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 tested, taught, and written up at the MIT Edgerton Center by Amy Fitzgerald, M.Ed. and Jessica Garrett, M.Ed. Amanda Gruhl Ph.D. did the graphics.

All the authors have taught in public schools and informal science settings, and are strong proponents of hands-on learning.

Appendix C

Acknowledgements:

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

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