Activity 3 Atoms and Their Masses

What Do You See?

GOALS

In this activity you will:

- Explore the idea of atoms by trying to isolate a single atom.
- Measure how many times greater mass a copper atom has than a magnesium atom.
- Practice careful laboratory technique with measuring masses and filtration.
- Locate sources of the variation in the class's experimental results.
- Compare Dalton's experimental results to the masses of atoms known today.
- See that atoms react in definite proportions of mass when forming a compound.
- Relate the mole concept to real quantities.
- Use scientific notation in calculations.

What Do You Think?

Atoms are the smallest, indivisible part of an element.

- **When did you first hear of atoms? What did they mean to you then, and what do they mean to you now?**
- **State three comments about atoms and place them under the headings given below. (You can place one comment under each heading or all three comments under one heading.)**

Use the following three headings: Things I Know about Atoms, Things I Think I Know about Atoms, Things I Would Like to Know about Atoms.

Record your ideas in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

1. One way to think about an atom is to imagine trying to isolate a single atom from a large number of atoms.

   Take a piece of aluminum foil (5 cm by 5 cm) and cut it in half. Take one of the resulting pieces and cut it in half again. Repeat this process with each successive half until you cannot make another cut.

   a) Record how many cuts you were able to make.

Safety goggles and a lab apron must be worn *at all times* in a chemistry lab.

b) How does the size of the smallest piece of aluminum compare to the size of the original piece?

c) Does the smallest piece of aluminum have the same properties as the original piece of aluminum foil? How could you test this assumption?

2. An atom is the smallest part of an element. Since you can still cut the aluminum in pieces, you have not reached the size of a single atom. Now imagine that there may be a way to cut the smallest piece of aluminum you have into even smaller and smaller pieces.

a) How small can the smallest piece be and still retain the properties of aluminum? Could you cut the piece in half and half again 10 more times? 100 more times? 1000 more times?

Using your imagination of cutting and cutting, you will eventually get to one atom of aluminum.

3. Chemists combine elements to form new substances. Each of the original elements has different properties. The new substance has properties different from either of the combined elements. By measuring the amounts of elements used and substances formed, they are able to draw conclusions about the properties of the elements involved. You will study the reaction between magnesium metal and a solution of copper (II) chloride.

Read through the procedure below.

a) Make a table in your *Active Chemistry* log for the data you will be collecting. You will need room for measurements (mass) and observations. You can use a table similar to the one provided below.

4. Check your balance to make sure that it reads zero with nothing on it. Then measure the mass of a 50-mL beaker to the precision of your balance.

a) Record the mass in your *Active Chemistry* log.

Finding the mass of the magnesium metal	
1. Mass of empty 50-mL beaker	g
2. Mass of beaker and magnesium metal	g
3. Calculate the mass of magnesium metal from 1 and 2 above.	g
Finding the mass of copper (II) chloride	
4. Mass of weighing paper	g
5. Mass of paper and copper (II) chloride	g
6. Calculate the mass of copper (II) chloride from 4 and 5 above.	g
Finding the mass of the product	
7. Mass of dry filter paper	g
8. Mass of filter paper with product, after drying	g
9. Calculate the mass of the product material from 7 and 8 above.	g

5. Measure out approximately 0.20 g of magnesium metal into the empty beaker. Try to get your mass measurement close to the assigned value.

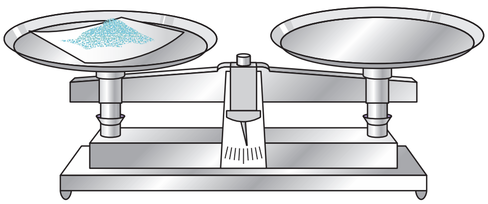
If you have a centigram balance, you'll need to adjust the balance to read 0.20 more grams than the beaker alone. Then add pieces of magnesium metal until it rebalances.

If you have an electronic balance, simply add pieces of magnesium until the display indicates 0.20 g more than the empty beaker.

a) Record the value that you obtain, even though you might not hit the target value.

6. Measure the mass of a piece of weighing paper.

Place approximately 2.00 g of copper (II) chloride on the weighing paper. (The elements you would expect to find in copper (II) chloride are copper and chlorine.) Again, remember that your target value is 2.00 g and that you may be slightly over or under this value.



a) Record the masses in your *Active Chemistry* log.

7. Add the copper (II) chloride to the beaker with the magnesium metal. Next add water to the beaker until it is approximately half full.

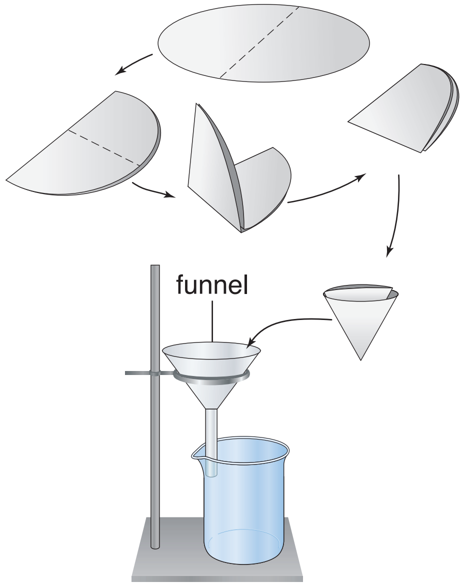
a) Record your observations in your *Active Chemistry* log. Consider including the following: how the beaker feels when you touch it; what you hear when you listen closely to the beaker; what you see happening in the beaker.

b) What color forms on the magnesium metal? What do you think is responsible for this color? Where is the color coming from?

8. You will now need to find the mass of the substance formed in the chemical reaction. You can filter out this substance and then find its mass. First measure the mass of a piece of dry, clean filter paper.

a) Record the mass in your log.

9. Set up a filtration system, as shown in the diagram.



10. Wait until you no longer see or hear any reaction and the liquid begins to clear. Pour the contents of the 50-mL beaker through the filter paper into a second beaker. Rinse the first beaker a couple of times with some distilled water to be sure that all of the contents of the beaker are transferred. Carefully remove the filter from the funnel and place it on a piece of folded paper towel. Allow it to dry overnight or use a drying oven. Label the paper

Wipe up any spills immediately.

Wash your hands and arms thoroughly after the activity.

towel so that you can identify your filter paper. Clean and put away your equipment and dispose of your chemicals as directed by your teacher.

Safety goggles and a lab apron must be worn *at all times* in a chemistry lab.

Wash your hands and arms thoroughly after the activity.

11. When the filter paper is dry, measure the mass of the filter paper and its contents. Dispose of the filter paper and its contents as directed by your teacher.

    a) Record the mass in your *Active Chemistry* log. Determine and record the mass of the contents of the filter paper.

12. The element on the filter paper appears by its color to be copper. The reaction you witnessed is called a *single-displacement reaction*. Before the reaction, there was copper (II) chloride compound and the magnesium metal. After the reaction, there was magnesium chloride compound and copper metal. In this reaction, a single element (magnesium) replaces another element (copper) in its combined form (copper (II) chloride). As a result of this reaction, the copper leaves its combined form to become an uncombined, or free, element. The magnesium leaves its uncombined form to join with the chlorine to form a new compound, magnesium chloride. It's time to look at your data and see if you can make some sense of the numbers.

    a) How many grams of magnesium metal did you start with? How many grams of copper did you end up with (contents of the dry filter paper)?

    b) How many times as great is the mass of the copper as compared to the mass of magnesium you originally used? (What is the ratio of mass of copper to mass of magnesium?)

    c) If one atom of copper is released for each atom of magnesium that becomes combined (with chlorine), the masses of copper and magnesium determined in (a) should contain the same number of atoms. What does this tell you about the relative masses of copper and magnesium atoms?

    d) If the data you recorded showed 0.20 g of magnesium and 0.52 g of copper, then the number of atoms in 0.20 g of magnesium *equals* the number of atoms in 0.52 g of copper. From your data, how many times more massive is a copper atom than a magnesium atom? (You may wish to compare objects that you are familiar with: a dozen bowling balls of mass 60.0 kg can be compared to a dozen eggs of mass 0.50 kg. Since there are a dozen bowling balls and a dozen eggs, you can find that the bowling balls are 60.0/0.50 or 120 times as heavy as the eggs.)

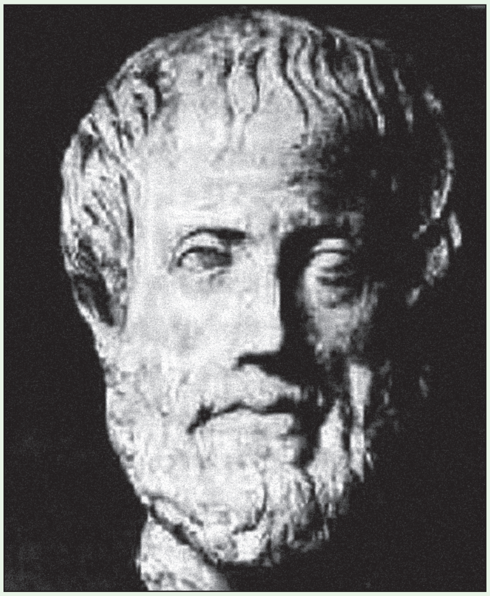
13. Recall that every group in your class reacted the same mass of magnesium with the same mass of copper (II) chloride. Discuss the similarities and differences in the data and calculations among the groups in the class.

    a) Record your thoughts on how and why the results are similar and/or different.

Chem Talk

ATOMIC MASS

Atoms



Aristotle

In *Activity 2*, you defined the term element and explored the properties of some common elements. In this activity, you focused on atoms. An **atom** is the smallest representative part of an element. The ancient Greek philosopher Aristotle did not believe in the existence of atoms. In his thinking, if atoms did exist, there would have to be empty space between them.

Aristotle did not believe it was possible to have empty space. Not everyone agreed with Aristotle. Another ancient Greek named Democritus believed that matter was made up of tiny particles that could not be broken down further. He called the particles atoms, from the Greek word *atomos*, meaning indivisible.

If you could have continued cutting the aluminum foil until it could no longer be cut, by any method, you would have reached one atom of aluminum. A mind-expanding fact is that if you started with 27 g of aluminum, you would find that there are 6.02×10^{23} atoms of aluminum (that is, 602,000,000,000,000,000,000,000 atoms). Nobody has ever counted this nor could they. Scientists have determined this number by other means and are very confident that it is correct.

Masses of Elements and Compounds in a Reaction

By the turn of the 19th century, chemists were combining elements to form new substances. The new substance was called a **compound**, because the atoms of the elements were believed to combine to form what was called a compound atom. The chemists were also particularly interested in measuring the amounts of elements used and substances formed. Their first attempts in determining masses were wrong, possibly due to the equipment that they had available at that time.

Chem Words

atom: the smallest, representative part of an element.

compound: a material that can be dissociated chemically into two or more kinds of atoms.

John Dalton was an early 19^{th} century chemist born in England. He did much to advance the belief in the existence of atoms. He expected that atoms combined in the simplest possible relationship. He reported that seven parts of oxygen reacted with one part of hydrogen to form water. Accurate modern experiments give eight parts to one. (We will use modern values rather than historical ones to avoid confusion.) He also reported that eight parts of oxygen reacted with seven parts of nitrogen to form a compound he called nitrous gas.

Gay-Lussac

Joseph Gay-Lussac was a French chemist and physicist. In 1809, he reported that the hydrogen reacting with oxygen to form water occupied twice as much volume as the oxygen. He also noted that the hydrogen reacting with nitrogen to form ammonia occupied three times as much volume as the nitrogen. Furthermore, he found that equal volumes of nitrogen and oxygen reacted to form nitrous gas. (This gas is now known as nitric oxide or nitrogen monoxide, NO.)

Avogadro

Gay-Lussac's data did not agree with Dalton's idea that water, ammonia, and nitrous gas are formed from one atom of each of the combining elements. Amedeo Avogadro, an Italian scientist, later resolved this disagreement. He furthered the understanding of the correct chemical formulas and atomic masses.

This historical information shows how difficult it was to learn about atoms. The chemists who did this research were very intelligent people. They devoted most of their lives to trying to make sense of experiments like the one you did with magnesium and copper chloride. You can benefit from their hard work and insights.

This is how knowledge evolves. That is why you are able to have the world that you live in with chemicals being used in transportation, food, medicines, clothing, and every other aspect of your life. By becoming student chemists, you are able to better understand how scientists have come to understand the world of atoms.

Relative Mass of Atoms

Eventually, chemists determined a scale of relative masses of atoms. They did this through the organized study of chemical reactions. They measured the masses of two elements reacting with each other, as you did in the activity. This allowed them to find relative masses. They could find out which elements were more massive than others, given the same number of atoms of each. Chemists were able to determine, for example, that one element has twice the mass of a second element. Relative mass does not tell you the exact mass measured in kilograms. It does provide a relative scale. Comparison of many reactions resulted in a scale of relative masses. Atoms of carbon were found to have a mass 12 times greater than the mass of hydrogen atoms. Oxygen atoms were found to have a mass 16 times greater than the mass of hydrogen. The units for this scale are called **atomic mass units**. They are defined in such a way that the mass of one type of carbon (carbon-12) is exactly 12 atomic mass units. The average mass of an atom of a given element in atomic mass units is known as the **atomic mass**. Atoms of hydrogen have an atomic mass of one unit. As he organized his table, Mendeleev understood the physical and chemical properties of elements. He also knew the relative mass of each element. The atomic mass is still one of the important pieces of information provided for each element on the periodic table. The table shown gives the relative atomic masses of the nine elements that you observed in *Activity 2*, plus hydrogen. (The elements are in alphabetical order.)

Element	Relative atomic mass
aluminum	26.98
carbon	12.01
copper	63.55
hydrogen	1.01
iodine	126.90
iron	55.85
magnesium	24.31
silicon	28.09
sulfur	32.06
zinc	65.38

Chem Words

atomic mass unit (amu): a unit of mass defined as the mass of $\frac{1}{12}$ of a carbon-12 atom.

atomic mass: the average mass of an atom of a given element in atomic mass units.

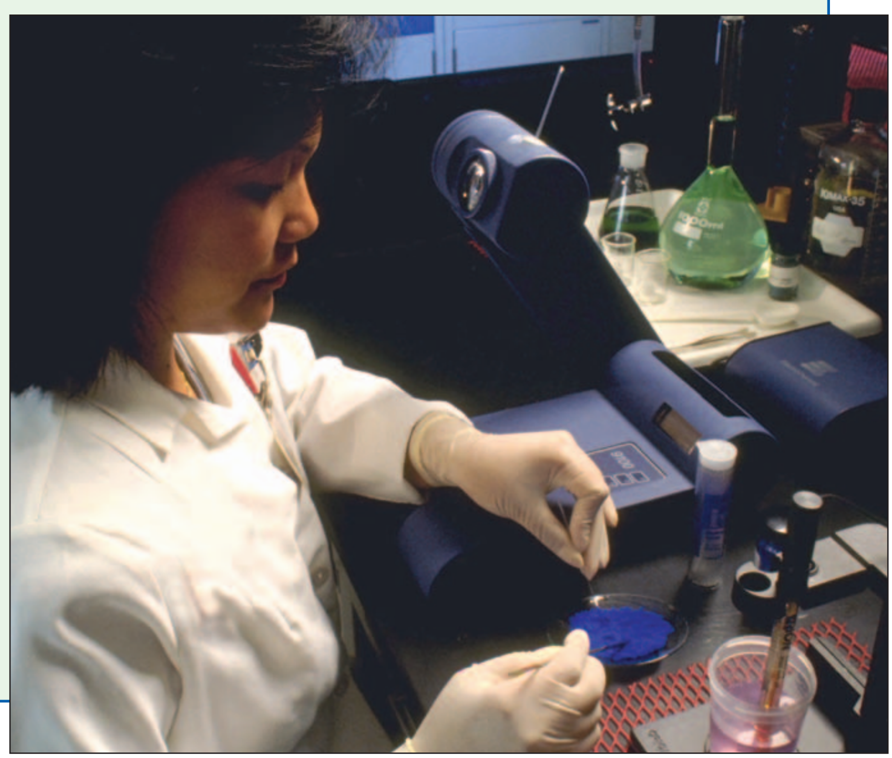
Chem Words

Law of Definite Proportions: a law that states that whenever two elements combine to form a compound, they do so in a definite proportion by mass.

The Law of Definite Proportions

Joseph Proust

Chemists at the beginning of the 19th century noted that eight parts of oxygen always reacted with one part of hydrogen to form nine parts of water. This observation is an example of **the Law of Definite Proportions.** Joseph Proust, a French chemist, first stated this law in 1799. The law says that whenever two elements combine to form a compound, they do so in a definite proportion by mass. Proust based this statement on his observations. (He observed that 100 g of copper, dissolved in nitric acid and precipitated by carbonates of soda (sodium) or potash (potassium), gave 180 g of green carbonate.) The Law of Definite Proportions is not a direct proof of the existence of atoms. However, if you believe in the existence of atoms it does make it easier to explain why the Law of Definite Proportions should hold. The existence of atoms can also help explain why a given mass of magnesium reacting with sufficient copper (II) chloride in solution should always produce a specific mass of copper.



Checking Up

1. What is the difference between an element and a compound?
2. What is an atom?
3. How is an atomic mass unit defined?
4. How can the existence of atoms help to explain the Law of Definite Proportions?

What Do You Think Now?

At the beginning of the activity you were asked to:

- **State three comments about atoms and place them under the appropriate heading.**

Return to your chart. Would you like to move any of your comments to different columns or add items to the list? Try to add at least two comments based on what you have learned from this activity.

Chem Essential Questions

What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
Explain what you observed when the magnesium metal was added to the copper solution.	*Explain the single displacement of magnesium metal with copper solution at the nanoscopic level (atoms and molecules).*	*Math is often used as a symbolic way of describing relationships. Give an example of how math was used or described in this activity to relate atoms and mass.*

How do you know?

What evidence do you have about the reaction of magnesium and copper chloride? How do you know that the mass of magnesium and the mass of copper were not identical in the reaction?

Why do you believe?

Baking a cake is a chemical reaction. How do you use the concept of definite proportions in the recipe for baking a cake?

Why should you care?

The challenge in this chapter is to create a game that will help people understand the periodic table. The atomic mass of elements is another property that will be added to your cards and help you to better understand the periodic table. Describe how you can creatively use atomic masses as part of a game and not require players to memorize these numbers.

Reflecting on the Activity and the Challenge

In this activity, you learned how chemists measured elements in chemical reactions to determine the relative masses of atoms and how these masses were assembled into a scale of atomic masses. The atomic mass is one of the most important pieces of information listed for each element on the periodic table. When you incorporate atomic mass into your game about the periodic table, you will have to decide whether you will test players' ability simply to identify the atomic mass from a periodic table or require that players understand how the relative scale was determined.

Chem to Go

1. John Dalton believed that water was formed from the simplest combination of hydrogen and oxygen atoms—one of each. Observations today show that 8 g of oxygen react with 1 g of hydrogen to form water.

John Dalton

   a) Based on these two statements, what conclusion could Dalton draw about the relative masses of oxygen and hydrogen atoms? How many times more massive is an oxygen atom than a hydrogen atom?

   b) The atomic mass of oxygen is 16 and the atomic mass of hydrogen is 1. How do the current atomic masses of oxygen and hydrogen compare to Dalton's?

   c) You know that water molecules are not made from one atom of hydrogen and one atom of oxygen. Water is H_2O. A water molecule is made up of two atoms of hydrogen and one atom of oxygen. The gram of hydrogen reacting with eight grams of oxygen is due to the fact that there are twice as many hydrogen atoms as there are oxygen atoms. How many times more massive is an oxygen atom than a hydrogen atom?

   d) Are the values of these revised masses closer to the current atomic masses of oxygen and hydrogen atoms?

2. In Dalton's time, it was observed that ammonia formed when nitrogen reacted with hydrogen. Today's values show that fourteen grams of nitrogen react with three grams of hydrogen.

   a) If ammonia were formed from Dalton's simplest formula of one atom of each element, what would he have concluded about the relative masses of nitrogen and hydrogen atoms?

   b) Ammonia molecules are actually made from three atoms of hydrogen and one atom of nitrogen. If the three grams of hydrogen reacting with fourteen grams of nitrogen is due to three times as many hydrogen atoms as there are nitrogen atoms, how many times more massive is a nitrogen atom than a hydrogen atom?

3. Instead of magnesium, a student uses aluminum in this activity and obtains the following data:

   Mass of beaker: 30.20 g

   Mass of beaker + aluminum: 30.40 g

   Mass of beaker + aluminum + copper (II) chloride: 32.40 g

   Mass of beaker + aluminum + copper (II) chloride + water: 57.40 g

   Mass of dry filter paper: 0.67 g

   Mass of new beaker: 30.50 g

   Mass of beaker + wet filter and residue + solution: 58.37 g

   Mass of dry filter + residue: 1.38 g

   a) How many grams of aluminum did the student use in this experiment?

   b) How many grams of copper did the student measure in the dry filter paper?

   c) How many times as great is the mass of the copper as the mass of aluminum the student originally used? (What is the ratio of mass of copper to mass of aluminum?)

   d) If three atoms of copper were released for two atoms of aluminum that become combined (with chlorine), the masses of copper and aluminum determined in (a) and (b) should contain the same number ratio of atoms (3:2). What does this tell you about the relative masses of copper and aluminum atoms? How many times more massive is a copper atom than an aluminum atom?

4. Look at the table. It gives the atomic masses of the nine elements that you observed in *Activity 2*, plus hydrogen. Add this data to your element cards. Can you now improve upon the way you sorted the cards in the previous activity taking this new information about relative masses into account?

Element	Relative atomic mass
aluminum	26.98
carbon	12.01
copper	63.55
hydrogen	1.01
iodine	126.90
iron	55.85
magnesium	24.31
silicon	28.09
sulfur	32.06
zinc	65.38

5. If you cut a piece of aluminum into two equal pieces and cut those pieces into two equal pieces and repeat this 10 times, the tiny piece of aluminum is about 1000 (2^{10}) times smaller than the original piece. How many cuts would it take to get down to 1 atom of aluminum if the size of an atom was one billion times smaller than a 1-cm piece of aluminum?

6. ***Preparing for the Chapter Challenge***

   In a paragraph, explain how the relative scale of atomic masses is determined.