

Fundamental Chemical Laws

Why?

In the late 1700s, French and English scientists measured how the mass of products of a chemical reaction related to the masses of the reactants, with special interest in reactions by which different elements are reacted together to form compounds, or by which compounds are decomposed (usually by heating) into elements. Based on the mass measurements, three fundamental chemical laws were discovered that had (and still have) useful predictive power, and that helped John Dalton develop his Atomic Theory in the early 1800s. You will learn about these laws using a guided-inquiry exercise similar to those that will be used extensively in Section 3 of Chemistry 100, and this will help you decide whether to sign up for the lottery for enrollment in this section.

Learning Objectives

- To understand three laws about mass that were important for development of atomic theory.
- To experience a POGIL (Process Oriented Guided Inquiry Learning) exercise.

Success Criteria

- Be able to state, describe the usefulness of, and use the laws named in the New Concepts section.
- Determine whether POGIL or a lecture-based instruction is a better learning environment for you.

Resources

Zumdahl and Zumdahl, *Chemistry* (6th ed.), sections 2.1 & 2.2.

Prerequisites

Meaning of “mass” and units of grams

Vocabulary (these definitions predate Atomic Theory)

Substance - a given substance is defined by a set of properties that do not change with time or location.

Properties include color, density, melting and boiling temperatures, etc.

Element - a substance that cannot be decomposed into another substance.

Compound - a substance that can be synthesized from, or decomposed into two or more elements.

Reactant - a substance that is consumed by a chemical reaction

Product - a substance that is produced by a chemical reaction.

New Concepts

Law of conservation of mass

Law of definite proportions

Law of multiple proportions

Small group Roles

L) **Leader** - decides on strategy (when to move on to the next question, when to ask neighboring group or instructor for guidance) and assures that all group members are involved with the exercises.

R) **Recorder** - fills out the group answer form

S) **Spokesperson** - The only person allowed to speak for a group (can approach neighboring groups, raise hand to seek instructor help, or may be called on by instructor).

If you have a fourth person in your group, the fourth person in the **Technician** - the designated user of a calculator when calculations are needed. If you have only two people, combine roles L and S.

Focus Information (a.k.a. the “Model”)

Three fundamental chemical laws:

1. Conservation of Mass (Lavoisier, 1743-1794): The total mass of products of a chemical reaction is exactly the same as the mass of reactants consumed by the reaction.
2. Law of Definite Proportions (Proust, 1754-1826): A given compound always contains exactly the same proportion of elements by mass.
3. Law of Multiple Proportions (Dalton, 1766-1844): When elements A and B form a series of compounds, the ratio of masses of B that combine (in different compounds) with 1 g of A can be reduced to small whole numbers.

Key Questions (relatively simple to answer using the Focus Information)

1. 27.0 g of mercuric oxide (a red solid compound) is heated and completely decomposes to give the elements oxygen and mercury. If 2.0 g of oxygen is produced by this reaction, how much mercury is produced?
2. Which law did you assume was true in order to answer question 1?
3. If another sample containing 54.0 g of mercuric oxide (i.e. twice as much as in question 1) is completely decomposed by heating, how much oxygen and how much mercury will be produced?
4. Which law did you assume was true in order to answer question 3?
5. How much mercury is combined with 1.00 g of oxygen in mercuric oxide?
6. Mercurous oxide is a different compound of mercury and oxygen. It contains 25.0 g of mercury for every 1.00 g of oxygen. Compare this ratio with that determined in question 5. Are these results consistent with the Law of Multiple Proportions? (Hint: assume mercury is “B”, oxygen is “A”. What is the “ratio of masses of B that combine (in different compounds) with 1 g of A”?)

Exercises (may require a bit more thought and strategy than the Key Questions)

1. Imagine that you briefly heat 84.0 g of a red powder known to be mercuric oxide. After the sample has cooled, you notice a few globs of liquid mercury are mixed together with unreacted red powder. If the mass of the resulting mixture is 82.5 g, how much oxygen was produced during the heating? Which law are you making use of for this answer?

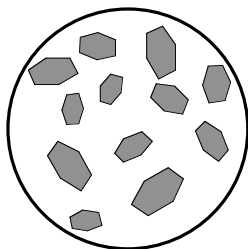
2. A chemist analyzes crystals obtained from four different reactions. The chemist finds that in all cases the crystals contain only the elements mercury and chlorine, and the amounts of each element found are shown in the table below. Based on these observations, is it possible that more than one of the reactions produced the same compound? (If so, which ones?)

	mg analyzed	mg mercury	mg chlorine
Reaction #1	687.0	583.8	103.2
Reaction #2	479.3	354.1	125.2
Reaction #3	753.2	562.8	190.4
Reaction #4	892.3	659.2	233.1

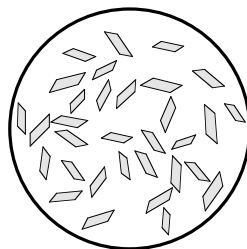
3. According to the law of definite proportions, does having the same proportion of elements by mass **prove** that two samples are the same compound?

Problems (these are generally the most challenging)

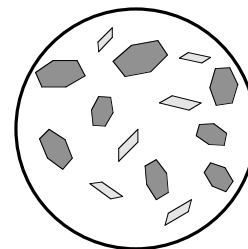
1. Sometimes reactions produce **mixtures** of different compounds. When the mixture is crystalline, it is usually possible to tell it is a mixture by looking at the crystals under a microscope; crystals of different compounds have different shapes and/or colors.



crystals of pure substance



crystals of pure substance

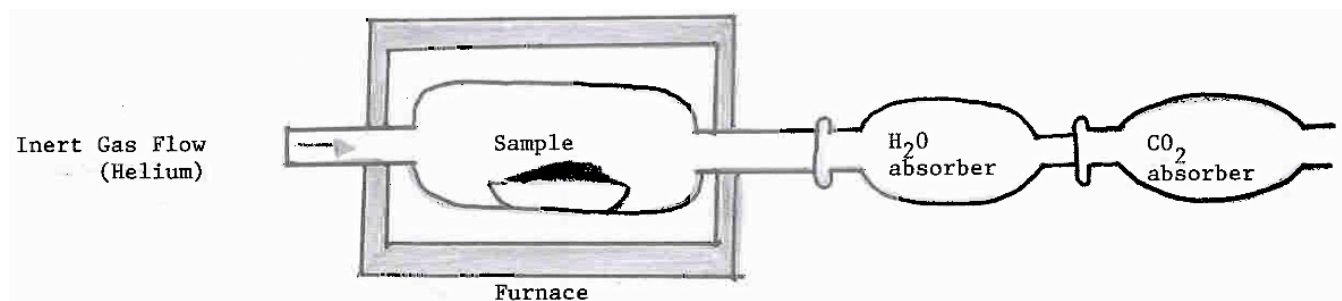


crystals of mixture

The chemist of exercise 2 looks at the crystals from the four different reactions and finds one of the reactions produced crystals that appear to be a mixture (the other three reactions produced crystals that appeared to be of pure substances). Use the Law of Multiple Proportions to predict which of the reactions gave the mixed product.

2. Restate the law of conservation of mass in your own words. As a group, agree on a “best” wording for the law and be ready to defend your choice.

3. On a separate piece of paper, write out answers to the problems 5, 6 and 86 from the end of chapter 2 of Z&Z (pp. 74, 79)
4. When the green mineral malachite is heated to about 400°C , it decomposes to give water vapor, carbon dioxide and a greenish powder (copper oxide). To monitor the mass changes, the reaction can be carried out in an apparatus as shown below (modified from Figure 2.7 of Spencer, Bodner and Rickard *Chemistry, Structure and Dynamics*, 2nd Ed.: Wiley, 2003).



The malachite is put into the furnace in a non-reactive ceramic crucible, which is weighed before and after the heating. The “H₂O absorber” and “CO₂ absorbers” are cartridges that contain chemicals that react completely with water and carbon dioxide to form solid products. For instance, CO₂ absorbers often contain finely divided particles of sodium hydroxide, and these rapidly react with carbon dioxide to form particles of sodium carbonate. The mass of water and carbon dioxide produced can be determined by weighing the cartridges before and after the heating.

The table below shows data from one such experiment. Does this data support (or refute) the Law of Conservation of Mass? Explain.

Mass, in grams	Crucible + malachite (before) or copper oxide (after)	H ₂ O absorber cartridge	CO ₂ absorber cartridge
Mass before heating	343.59	32.5673	41.9430
Mass after heating	339.94	33.6306	44.5401