Learning Outcomes

In this section you will

• Use stoichiometry to determine the amount, mass, or volume of a substance produced or required in a chemical reaction.

What Do You Think?

Suppose you have decided that you want to inflate a balloon to a volume of 50 mL with carbon dioxide gas as a part of your Chemical Dominoes apparatus.

• What information would you need to predict how much of the reactants you would need?

• How could you use that information to determine the final volume of the balloon?

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

Investigate

Part A: Equivalent Measures — Mass of One Mole

1. Your teacher will give you a bag of pennies, a single penny, and a balance. Without opening the bag of pennies, and without counting the pennies individually, figure out how many pennies are in the bag. (Assume the mass of the bag is so much smaller than a penny that it doesn’t matter.)

⚠️ a) Write down any data you have to take and calculations you have to do in your Active Chemistry log.
b) Explain in writing how to figure out the number of pennies in the bag.

c) If you have a bunch of pennies with a mass of 143 g, how many pennies are there? Show your work or explain how you arrived at your answer.

2. The *Equivalent Measures* game uses dominoes. There is only one rule to this game. By studying the examples below, can you figure out the rule?

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a) What is the rule? Write it down in your *Active Chemistry* log.

3. You will be creating your own dominoes to use when you solve chemistry problems. The dominoes will include both a number and a unit. The top and bottom of each domino must be equivalent. For example, 24 h (hours) is equal to 1 d (day). The numbers 24 and 1 are different but the values are the same because they are just a different way of expressing 1 day. The following are some equivalent dominoes for time measurements.

<table>
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<th>a)</th>
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<th>c)</th>
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<tr>
<td>12 h</td>
<td>30 minutes</td>
<td>45 h</td>
</tr>
<tr>
<td>1 year</td>
<td>5 weeks</td>
<td>365 d</td>
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4. Complete the dominoes below in your *Active Chemistry* log.

<table>
<thead>
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<th>a)</th>
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<tbody>
<tr>
<td>60 seconds</td>
<td>12 inches</td>
<td>1 kilogram</td>
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<table>
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<tr>
<th>d)</th>
<th>e)</th>
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<tbody>
<tr>
<td>2.50 g of pennies</td>
<td>1 penny</td>
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5. When you use equivalent dominoes to solve problems, the “game” is played using the unit instead of the number in the domino. To change from one domino to another, the unit in the bottom of the second domino must be the same as the unit in the top of the first domino. The numbers in the dominos may differ.

6. Atoms and molecules are like the pennies. All particles of one kind have the same average mass. If you know the mass of one particle, you can figure out the mass of a bunch of particles. But since atoms and molecules are so small, it doesn’t make sense to talk about the masses of individual ones. Instead, chemists talk about the mass of a “counting group” of them, called a *mole*. A mole is like a dozen. There are always 12 in a dozen, and there is always a specific quantity of atoms or molecules in a mole. If you know the mass of a mole of some chemical, then you can figure out how many moles of that chemical
there are in a sample. This is just like when you figured out how many pennies were in the bag once you knew the mass of one penny.

7. First, you have to be able to determine the masses of different elements. This is given on the periodic table. Each element on the periodic table has an atomic mass. This is the average mass of one atom of the element measured in atomic mass units (amu).

Conveniently, the mass of one mole of atoms of the element has a mass with the same numerical value but measured in grams. For example, the average mass of a single atom of chlorine is 35.45 amu. The mass of a mole of chlorine atoms is 35.45 g. The unit “grams” is the unit you will use to measure mass. An equivalent domino relating mass of Cl and moles of Cl is shown. Answer each of these questions by drawing a domino for the answer.

What is the mass of 1 mole of
a) oxygen?    b) magnesium?  
c) carbon?     d) hydrogen?

8. Not all of the substances you will encounter exist as single atoms. To determine the mass of one mole of a chemical that is not an individual atom, you need to know how many atoms of each kind are represented by the formula. You use the subscripts present in the formula to do this. How many of each kind of atom are in
a) NaNO₃?    b) Mg(OH)₂?    
c) Al₂(SO₄)₃?  d) KC₂H₃O₂?

9. To figure out the mass of one molecule of a chemical, you add up the masses of the atoms inside it.  
What is the mass of one mole of
a) CO₂?      b) NaHCO₃?     
c) NaCl?

10. Make dominoes for the following chemicals. Use the example for H₂O.
   a) CO₂    b) NaHCO₃    c) NaCl

11. Use these dominoes to figure out the answers to the following questions. The first one is done for you as a sample. Remember that it’s important to figure out where you’re starting and where you’re finishing before you do any calculations. (You can use a domino either right-side-up or upside-down to answer a question.)
   a) If you have 36.04 g of water, how many moles of water are there?

   36.04 g      1 mol       18.02 g
            = 2 mol

   Note that the “g” in the “numerator” cancels with the “denominator” of the dominoes.
   b) If you have 3.0 mol of NaCl, how many grams of NaCl are there?
   c) How many moles of CO₂ are in 66.0 g of CO₂?
   d) What is the mass of 0.80 mol of NaHCO₃?
Part B: Equivalent Measures—
Coefficients from a Balanced Chemical Equation

1. A second kind of equivalent measure (domino) comes from balanced chemical equations. You can make equivalent-measure dominoes out of any two substances in a balanced chemical equation. Do the following problems using the equivalent-measures method. This equation $2\text{AgNO}_3 + \text{CaCl}_2 \rightarrow 2\text{AgCl} + \text{Ca(NO}_3)_2$ tells you that 1 mol of the reactant CaCl$_2$ produces 2 mol of the product AgCl. (Ignore the other reactants and products.) This domino illustrates this

If you begin with 2 mol of CaCl$_2$ you can find the number of moles of AgCl produced

\[
\begin{align*}
\text{start} & \\
2.0 \text{ mol of CaCl}_2 & \quad \text{2 mol of AgCl} \quad \text{1 mol of CaCl}_2 \\
\text{finish} & \\
4.0 \text{ mol of AgCl} &
\end{align*}
\]

\( \text{a)} \) For the following equation, create a domino to show that 2 mol of HCl produce 1 mol of CaCl$_2$.
\[
\text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}
\]

\( \text{b)} \) If you want to make 3.0 mol of CaCl$_2$, how many moles of HCl must you use?

\( \text{c)} \) If you use 7.5 mol of O$_2$, how many moles of Al$_2$O$_3$ will be made?
\[
4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3
\]

\( \text{d)} \) The following chemical equation is not balanced, so you will first have to balance it. If you use 5.0 moles of CH$_4$, how many moles of O$_2$ will you need?
\[
\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

Part C: Equivalent Measures—
Space Occupied by One Mole of Gas

1. Finally, consider a third use for equivalent-measure dominoes. This third use is to change between moles of a gas and volume of that gas. Chemists have found that it is a good approximation to say that the same number of moles of any gas will take up the same space as long as the temperature and pressure are the same. Under standard conditions of temperature and pressure (273 K temperature and 1.0 atm pressure), 1 mol of any gas will fill 22.4 L of space. That’s about 11 two-liter soda bottles worth of space. Therefore, the equivalent-measure domino you would use looks like the one shown. For conversions between 1 mol of any gas at standard conditions and the volume of that gas, always use the same domino. Try the following problems using the equivalent measure.

\( \text{a)} \) How many liters of space will 2.0 mol of O$_2$ gas fill at standard conditions?

\( \text{b)} \) If a helium balloon fills 5.6 L of space at standard conditions, how many moles of He are in it?

\( \text{c)} \) If you wanted to fill a balloon to 0.50 L with CO$_2$ at standard conditions, how many moles of CO$_2$ would you need?
2. Back in Section 1, you filled a balloon with gas in order to make a lever tip by 2 cm. To do this, you had to blow up the balloon with gas so that its diameter was 4 cm. You can now determine what volume of gas had to be produced to inflate the balloon. Think of the balloon as a sphere. The volume of the gas you need to produce to do this, then, can be calculated from the volume equation for a sphere that has a radius of 2 cm.

\[ V = \frac{4}{3} \pi r^3 \]

\[ = \frac{4}{3} (3.1416)(2 \text{ cm})^3 \]

\[ = \frac{4}{3} (3.1416)(8 \text{ cm}^3) \]

\[ = 33.5 \text{ cm}^3 \]

\[ = 33.5 \text{ mL} \]

In the metric system, it is convenient that volume in cm\(^3\) is the same as volume in mL. You can also use an equivalent measure to convert from mL to L, since there are 1000 mL in 1 L.

\[ 33.5 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.0335 \text{ L} \]

of CO\(_2\) gas needed

3. The balanced equation that describes the reaction between baking soda and acetic acid is

\[ \text{NaHCO}_3 + \text{HC}_2\text{H}_3\text{O}_2 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} + \text{CO}_2 \]

If you had 1 mol of sodium bicarbonate and added it to 1 mol of acetic acid, you could produce 1 mol of carbon dioxide. The 1 mol of carbon dioxide would fill a balloon of 22.4 L. That would be a big balloon!

Your balloon only has to be filled to a volume of 33.5 mL or 0.0335 L of gas. You will need much less than 1 mol of baking soda.

Assume that you have plenty of acetic acid available and that you are working at standard conditions.

a) What mass of baking soda would you have to add to the vinegar in order to fill the balloon enough to tip the lever?

4. Look back at your recorded observations from Method 1 in Section 1.

a) How much baking soda was required to get the balloon to tip the lever by 2 cm? Is your prediction equal to it? Account for any differences between the two amounts.
STOICHIOMETRY

Moles and Molar Mass

“Dozen” is a counting word used to count groups of things, such as eggs and donuts. One dozen is always the same number. A mole is a counting word used to count very large quantities of very small objects (primarily atoms and molecules). 1 mol = \(6.022 \times 10^{23}\). However, in this section, the actual number doesn’t matter very much. What is more important is that one mole of anything is always the same quantity. Three moles of something is three times as much as one mole.

The next important thing to know about moles is that one mole of any single kind of atom or molecule has a mass equal to its atomic or molecular mass expressed in grams. For example, an oxygen atom has an atomic mass of 16.00 amu (this can be found on the periodic table). One mole of oxygen atoms has a mass of 16.00 g. This is called the molar mass of oxygen atoms. An oxygen molecule (O\(_2\)) is made of two oxygen atoms. One mole of oxygen molecules has a mass of 32.00 g. This is the molar mass of an oxygen molecule. To find the mass of a compound, the masses of each atom in the compound are added together. The molecular mass of water (H\(_2\)O) is 18.02 amu (1.01 amu + 1.01 amu + 16.00 amu). One mole of water has a mass of 18.02 g.

How Balanced Chemical Equations Are Involved

Recall the equation for one method you used to generate carbon dioxide gas.

\[
\text{NaHCO}_3 + \text{H}_2\text{C}_2\text{H}_3\text{O}_2 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} + \text{CO}_2
\]

You know from the balanced equation that one mole of baking soda and one mole of vinegar form one mole each of sodium acetate, water, and carbon dioxide. Three moles of baking soda would be enough to produce three moles of carbon dioxide. If you know how many moles of carbon dioxide you need to make, you can calculate the number of moles of baking soda you need. The molar mass of baking soda will let you convert moles of baking soda to grams.

**Chem Words**

- **mole**: \(6.022 \times 10^{23}\) units, the number equal to the number of carbon atoms in exactly 12 g of pure \(^{12}\text{C}\).
- **molar mass**: the mass of one mole of a pure substance.
Chem Words

**standard temperature and pressure (STP):** standard temperature is 273.15 kelvins and standard pressure is 760 mm Hg.

**stoichiometry:** the study of the relationships (mass-mole-volume) among substances involved in chemical reactions.

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**The Molar Volume of a Gas**

Another piece of information you have learned in this section is that one mole of almost any gas at **standard temperature and pressure (STP)** will occupy the same volume (22.4 L). Standard pressure (1 atm or 760 mm Hg) is close to the pressure under which you live. It is a reasonable approximation for the pressure in the laboratory. However, room temperature is likely to be closer to 298 K than 273 K.

When the temperature of a gas increases, the volume occupied by the gas increases. So, while one mole of a gas at standard conditions will occupy 22.4 L, one mole of the gas at room temperature will be a bit larger.

**Stoichiometric Calculations**

In the investigation, you calculated the volume of carbon dioxide gas needed to blow up a balloon. You also calculated the number of moles of the reactants needed. This kind of computation is called **stoichiometry**. The heart of a stoichiometric calculation involves calculating the number of moles of one chemical in a reaction based on the number of moles of one of the other chemicals in the balanced chemical equation. The coefficients in the balanced equation set the proportions. These proportions relate the number of moles of any reactant or product in the reaction to the other reactant or product. For example, look at the following balanced equation:

\[
\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3
\]

It tells you that nitrogen and hydrogen gases combine to form ammonia. It also tells you that one mole of nitrogen molecules and three moles of hydrogen molecules will produce two moles of ammonia molecules. These ratios or proportions never change, because compounds have fixed formulas or proportions.
If you use three times as much of a starting material, that will be enough to make three times as much product. You can use equivalent-measure dominoes to do this calculation.

This can be written mathematically as

\[
3 \text{ mol } N_2 \times \frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2} = 6 \text{ mol } NH_3
\]

Although the amount of a substance generated or consumed during a chemical reaction is based on the number of moles of particles that interact, there is no equipment that can measure moles directly. Therefore, moles must be converted into something you can actually measure. Two measurements that are easy to make in the lab are mass of a solid or liquid and volume of a gas. That’s why chemists work with these measurements in stoichiometry. Using the stoichiometry method, you can convert a known mass of any chemical (or the volume of a gas at STP) into moles, and then convert your answer in moles back into grams (or liters of a gas at STP).

For example, if you begin with 84.0 g of nitrogen gas, you can calculate the volume of ammonia that should be produced at STP. Doing this is a three-step process and involves three dominoes. \(N_2\) has a molar mass of \(2 \times 14.01 \text{ g} = 28.02 \text{ g}\) (since each of the two N atoms has an atomic mass of 14.01 amu). This is one domino. One mole of \(NH_3\) occupies 22.4 L of space at STP. This is another domino. The balanced chemical equation provides another domino. One mole of \(N_2\) produces two moles of \(NH_3\).

\[
84.0 \text{ g } N_2 \times \frac{1 \text{ mol } N_2}{28.02 \text{ g } N_2} \times \frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2} \times \frac{22.4 \text{ L } NH_3 \text{ at STP}}{1 \text{ mol } NH_3} = 134 \text{ L } NH_3 \text{ at STP}
\]

To solve a stoichiometry problem, you have to figure out what measurement you are beginning with and what measurement you want to end with before you do the problem. Then you look at ways you can convert, using dominoes, between one unit and another. There are three kinds of dominoes at your disposal.

1. You can use the molar mass of a substance. The domino will include one mole of the substance and its molar mass. To use this domino, you will need the periodic table.
2. You can use the coefficients from a balanced chemical equation. When using this domino, both units will be moles.
3. You can use the volume (amount of space) that one mole of gas takes up. This will always be the same domino: 1 mol of gas at STP is equivalent to 22.4 L of gas.
Dimensional Analysis

Notice that in all these calculations, the units multiply and divide (canceling each other out) to give the proper units for the answer. This is called **dimensional analysis**. It indicates that your method of solution is reasonable. If the procedure you followed to produce an answer was incorrect, it would be unlikely to yield the proper units. One way to think about the mole ratio is that you put the chemical and measure (moles, grams or liters) you’re converting from on the bottom of the ratio so that it will cancel the chemical and measure on the top of the preceding domino. This leaves only the units from the top half of the ratio (domino), which come from the chemical and measure you are converting to.

\[
\frac{84.0 \text{ g N}_2}{28.02 \text{ g N}_2} \times \frac{1 \text{ mol N}_2}{2 \text{ mol NH}_3} \times \frac{22.4 \text{ L NH}_3 \text{ at STP}}{1 \text{ mol NH}_3} = 134 \text{ L NH}_3 \text{ at STP}
\]

**Percent Yield**

When a reaction is carried out and the product is recovered and measured, it is common to find that less than 100 percent of the expected product is found. This is because there are many ways to lose small amounts of the product. Therefore, scientists commonly report a **percent yield** for a reaction.

In the reaction above, 134 L of NH₃ is expected under standard conditions. Suppose only 121 L of NH₃ is recovered. How would the percent yield be calculated? The percent yield can be calculated in the following way:

By volume:

\[
\frac{\text{volume found}}{\text{volume expected}} \times 100\% = \frac{121 \text{ L}}{134 \text{ L}} \times 100\% = 90.3\% \text{ yield}
\]

Suppose only 75.8 g of ammonia, NH₃, was recovered:

By mass:

\[
\frac{\text{mass found}}{\text{mass expected}} \times 100\% = \frac{75.8 \text{ g}}{102 \text{ g}} \times 100\% = 74.5\% \text{ yield}
\]

The concept of percent yield has the following two purposes:

- Scientists attempting to reproduce the original work will know how much product they can expect to recover.
- If a company needs 100 kg of a certain product, but can only expect a 50 percent yield of the product from the reaction, they know they have to use twice the mass of reactants to obtain 100 kg of the product.

**Stoichiometry in the Real World**

Chemical changes produce new substances with new properties. Knowing what new substances and new properties will be produced allows chemists to produce remarkable results: new chemicals that can cure diseases, withstand the most difficult conditions, explode or react with other chemicals, or help you do things that couldn’t be done before. In order to control the results and produce the desired effect, you need to be able to predict the amounts...
of these new chemicals. Stoichiometry allows you to do that. In this case, you were able to inflate a balloon to move a lever by a specific amount. If you were producing a new chemical, you would also want to produce just the amount you wanted. Stoichiometry is crucial in calculating the amounts of materials that are needed in a process, without unnecessary waste.

**What Do You Think Now?**
At the beginning of this section you were asked the following questions about producing a gas to inflate a balloon:
- What information would you need to predict how much of the reactants you would need?
- How could you use that information to determine the final volume of the balloon?

How would you answer these questions now that you have completed this section?

<table>
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<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
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<tr>
<td>In this investigation, you developed a method for determining an unknown number of pennies without counting them. Explain how the mole concept is similar to buying a bag of flour without counting the particles of flour.</td>
<td>On a molecular level, describe what is happening when two substances react to form new products.</td>
<td>Describe the information provided in the symbolic notation of a chemical equation. Can you make an equivalent domino with any two units? Explain why or why not.</td>
</tr>
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**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.

**How do you know?**
At the beginning of this section you carried out an investigation using pennies. Explain how this investigation relates to stoichiometry.

**Why do you believe?**
One example of stoichiometry used in the real world is in recipes. Different amounts of certain ingredients must be combined together to produce a certain amount of a food. Describe another real-life application of stoichiometry.

**Why should you care?**
Some of the requirements for the *Chapter Challenge* are that the sequence of events be reliable, repeatable, and safe. Describe how stoichiometry will be important in ensuring that these three requirements are met. What might be the consequences of forming too little product? What might be the consequences of forming too much product?
Reflecting on the Section and the Challenge

If you want to use a chemical reaction to do anything in your Chemical Dominoes apparatus, chances are you will have to calculate how much starting materials to use to make the chemical reaction do what you want it to do. It’s helpful to use stoichiometry to begin with a prediction. Then you have a place to start and you won’t have to waste time and supplies trying to figure out the right amount by trial and error.

1. The following questions are about the reaction that you used to fill the balloon with gas and tip the lever in Section 1.
   a) What gas filled the balloon?
   b) Where did it come from?
   c) If it comes from only one of the starting materials, is the other one necessary to complete the reaction?
   d) Does it matter how much of the other starting material was available?

2. Prove that mass is conserved in the chemical reaction you used to fill the balloon to tip the lever. That is, prove that the mass of the compounds on the input side of this chemical equation equals the mass of the compounds on the output side.
   \[
   \text{NaHCO}_3 + \text{HC}_2\text{H}_3\text{O}_2 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} + \text{CO}_2
   \]
   sodium bicarbonate  acetic acid  sodium acetate  water  carbon dioxide

3. What is the mass of one mole of each of the following substances:
   a) C (graphite in the lead of your pencil)
   b) Al (aluminum foil)
   c) NH₃ (ammonia gas)
   d) CaCO₃ (chalk dust)
   e) NaAl(SO₄)₂ (sodium aluminum sulfate, an ingredient in baking powder)

4. Use your answers from Question 3 to do the following calculations. Show your work using equivalent measures.
   a) How many moles of C are in 18.0 g of graphite pencil leads?
   b) What is the mass of 0.50 mol of aluminum foil?
   c) What is the mass of 2.84 mol of ammonia gas?
   d) How many moles of CaCO₃ are in 10.0 g of calcium carbonate (chalk dust)?
   e) A container of baking powder has 198 g of baking powder in it. If one-fourth of this (49.5 g) is sodium aluminum sulfate, how many moles of NaAl(SO₄)₂ are in the container?
5. The chemical reaction represented by the balanced equation
\[2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2\]
is not a very good method for producing oxygen gas for the purpose of blowing up a balloon to tip a lever, because it requires heating the \( \text{KClO}_3 \). However, it can be used as an illustration of the conservation of mass.

a) Prove that the moles of each atom in the chemical equation are balanced.

b) Prove that the mass in the chemical equation is balanced.

c) How many moles of \( \text{KClO}_3 \) are required to make 22.4 L of \( \text{O}_2 \) gas at STP?

6. Three balloons are filled to the same volumes of 3.73 L at standard conditions. The first balloon contains \( \text{CO}_2 \) gas, the second contains \( \text{H}_2 \) gas, and the third contains \( \text{He} \) gas.

a) How many moles of gas are in each balloon?

b) What is the mass of the \( \text{CO}_2 \) balloon?

c) What is the mass of the \( \text{H}_2 \) balloon?

d) What is the mass of the \( \text{He} \) balloon?

7. The balanced equation
\[\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2\]
describes the production of hydrogen gas from hydrochloric acid and zinc. It is another option for blowing up a balloon that works faster than the one in this section. However, hydrogen gas is highly flammable, so you’ll have to make sure not to have any flames near it.

a) If you wanted to blow up a balloon to a size of 0.56 L at standard conditions, how many moles of \( \text{H}_2 \) gas would you need to produce?

b) A much more realistic size for a balloon to tip a lever is 0.035 L of \( \text{H}_2 \). How many grams of zinc would this require? Assume standard conditions.

c) For all the zinc to react, there must be enough HCl that some is left over. To blow up a balloon to 0.035 L as in Part b), what is the minimum amount of moles of HCl that you must use?

8. The balanced equation
\[2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}\]
describes the burning of acetylene gas \((\text{C}_2\text{H}_2)\) in a torch used by welders.

a) If the tank attached to the torch contains 100 g of acetylene, how many liters of oxygen are used at standard conditions if you burn the entire contents of the tank?

b) How many liters of \( \text{CO}_2 \) would be produced at standard conditions?

c) What is the mass of the \( \text{CO}_2 \) that would be produced?

d) If only 305 g of \( \text{CO}_2 \) is recovered, what is the percent yield?

e) If a scientist needs 425 g of \( \text{CO}_2 \) for her process, how much acetylene would she have to burn, assuming the percent yield calculated in 8.d)?
9. Preparing for the Chapter Challenge

If you are going to use a lever tipped by a gas-filled balloon as part of your Chemical Dominoes apparatus, you will need to calculate the quantity of starting materials necessary to do this. In your Active Chemistry log, write down the equation that represents the reaction you will use to make the gas, and calculate the quantity of starting materials you will need to be able to blow up a balloon enough to tip a lever a distance of 5 cm. You may not decide to tip a lever this distance, but writing down these calculations now will help you later when you return to your notes to prepare for the Chapter Challenge.

Inquiring Further

1. Limiting reagent

The reactant that is used up first in a reaction is called the limiting reagent. In the reaction you used to blow up the balloon and tip a lever (baking soda and vinegar), which reactant is the limiting reagent? To figure this out, you'll need to find out how much acetic acid is in vinegar as well as how much vinegar you used.

Design an experiment to determine whether it matters which of the two starting materials, baking soda or acetic acid, is the limiting reagent.

2. Whipped cream’s a gas!

Nitrous oxide is often used for making whipped cream commercially. Investigate the promotional materials of two or more brands of nitrous oxide cartridges with regard to cost, purity, volume, and convenience. Determine which brand might be best for a baker in a small bakery.