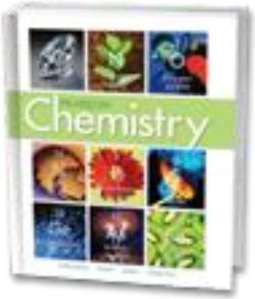


Chapter 12
Stoichiometry

12.1 The Arithmetic of Equations

12.2 Chemical Calculations

12.3 Limiting Reagent and Percent Yield

PEARSON

How do you figure out how much starting material you need to make a finished product?

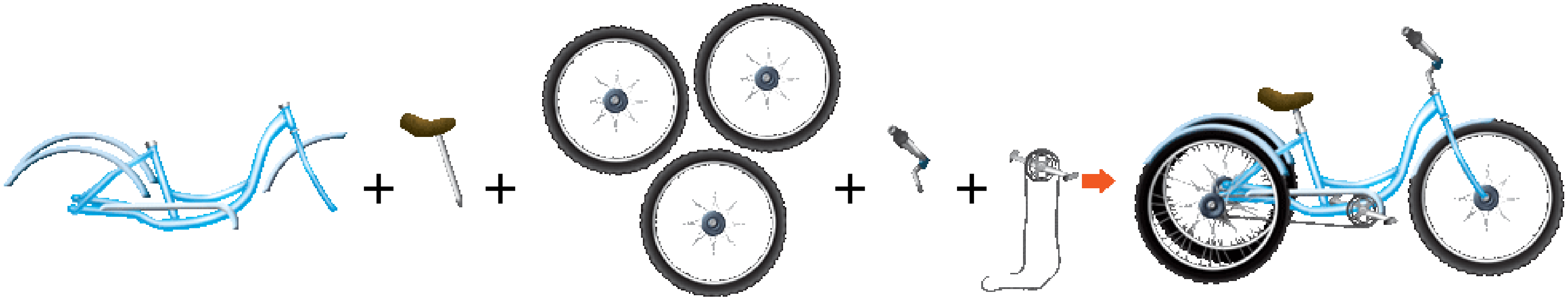
When making bikes, you need parts like wheels, handlebars, pedals, and frames.

Using Equations

How do chemists use balanced chemical equations?

Everyday Equations

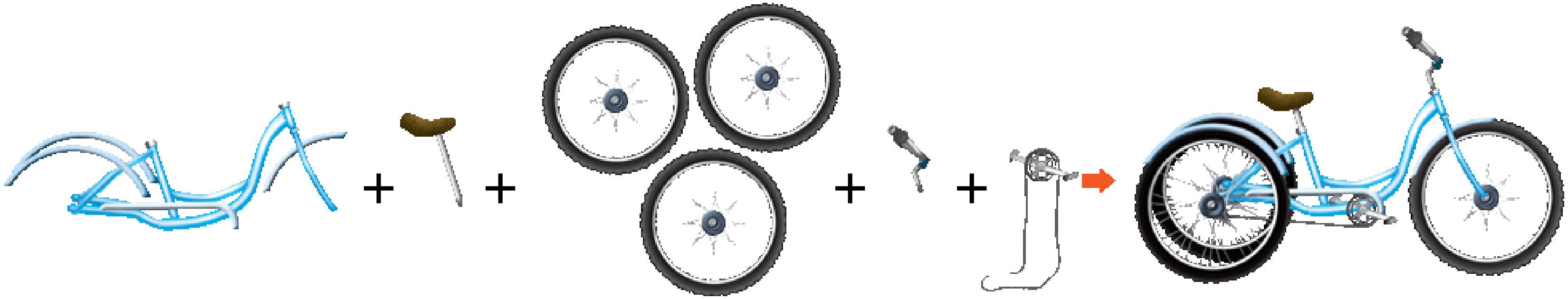
Travel Time Tricycle company produces 640 tricycles each week. How can you determine the number of parts they need per week?



Everyday Equations

Travel Time Tricycle company produces 640 tricycles each week. How can you determine the number of parts they need per week?

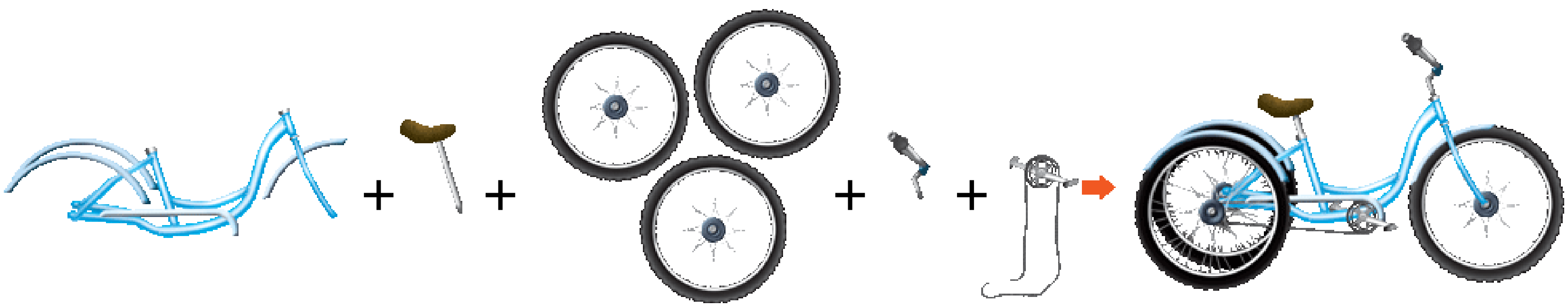
- The major components are the frame (F), the seat (S), the wheels (W), the handlebars (H), and the pedals (P).



Everyday Equations

Travel Time Tricycle company produces 640 tricycles each week. How can you determine the number of parts they need per week?

- The finished tricycle, your product, has a "formula" of FSW_3HP_2.

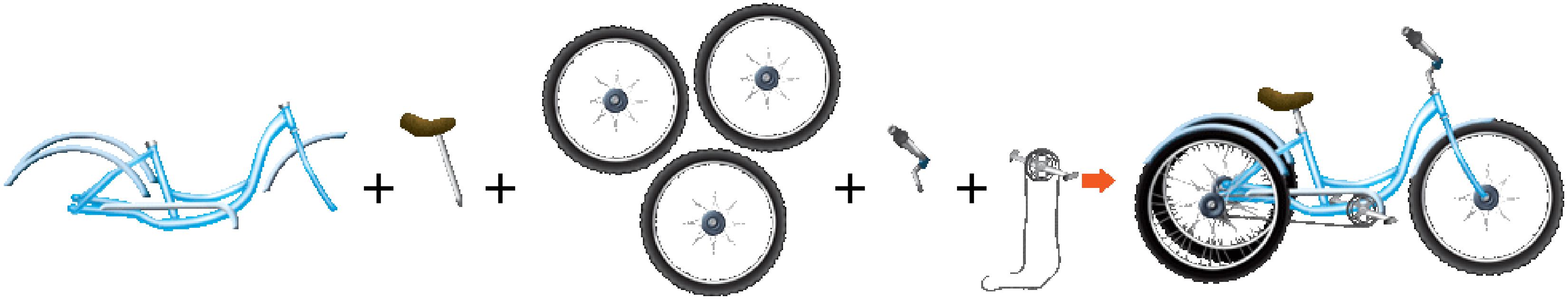


Everyday Equations

Travel Time Tricycle company produces 640 tricycles each week. How can you determine the number of parts they need per week?

- The balanced equation for making a single tricycle is:

$$F + S + 3W + H + 2P \rightarrow FSW_3HP_2$$



Using a Balanced Equation as a Recipe

In a five-day workweek, Travel Time is scheduled to make 640 tricycles. How many wheels should be in the plant on Monday morning to make these tricycles?

1 Analyze List the knowns and the unknown.

Use the balanced equation to identify a conversion factor that will allow you to calculate the unknown. The conversion you need to make is from tricycles (FSW_3HP_2) to wheels (W).

KNOWNS

number of tricycles = 640 tricycles = 640 FSW_3HP_2

$F + S + 3W + H + 2P \rightarrow FSW_3HP_2$

UNKNOWN

number of wheels = ? wheels

2 Calculate **Solve for the unknown.**

Identify a conversion factor that relates wheels to tricycles. You can write the two conversion factors relating wheels to tricycles.

$$\frac{3\text{ W}}{1\text{ FSW}_3\text{HP}_2} \quad \text{and} \quad \frac{1\text{FSW}_3\text{HP}_2}{3\text{ W}}$$

2 Calculate Solve for the unknown.

The desired unit is W; so use the conversion factor on the left. Multiply the number of tricycles by the conversion factor.

$$\frac{3\ \text{W}}{1\ \text{FSW}_3\text{HP}_2} \quad \text{and} \quad \frac{1\ \text{FSW}_3\text{HP}_2}{3\ \text{W}}$$

$$640\ \cancel{\text{FSW}_3\text{HP}_2} \times \frac{3\ \text{W}}{1\ \cancel{\text{FSW}_3\text{HP}_2}} = 1920\ \text{W}$$

When using conversion factors, remember to cross out like units when they are in both the numerator and denominator. This will help you check that you are using the correct conversion factor.

3 Evaluate Does the result make sense?

- If three wheels are required for each tricycle and more than 600 tricycles are being made, then a number of wheels in excess of 1800 is a logical answer.
- The unit of the known (FSW_3HP_2) cancels.
- The answer has the correct unit (W).

Balanced Chemical Equations

Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or how much product will be formed in a reaction.

Balanced Chemical Equations

Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or how much product will be formed in a reaction.

- When you know the quantity of one substance in a reaction, you can calculate the quantity of any other substance consumed or created in the reaction.

Balanced Chemical Equations

The calculations of quantities in chemical reactions is a subject of chemistry called **stoichiometry**.

Balanced Chemical Equations

The calculations of quantities in chemical reactions is a subject of chemistry called **stoichiometry**.

- For chemists, stoichiometry is a form of bookkeeping.
- It allows chemists to tally the amounts of reactants and products using ratios of moles or representative particles.

Checkpoint

Cayla is using a recipe to make chocolate chip cookies. She wants to double the number of cookies that the recipe will make. The original recipe calls for 2 cups of chocolate chips. How many cups of chips should Cayla use for a double recipe?

A. 2 cups

B. 4 cups

C. 1 cup

D. 8 cups

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Chemical Equations

In terms of what quantities can you interpret a balanced chemical equation?

Ammonia is produced industrially by the reaction of nitrogen with hydrogen.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

- The balanced chemical equation tells you the relative amounts of reactants and product in the reaction.

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$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

- The balanced chemical equation tells you the relative amounts of reactants and product in the reaction.
- Your interpretation of the equation depends on how you quantify the reactants and products.

How can you determine the amount of each reactant you need to make a product?

How can you determine the amount of each reactant you need to make a product?

A recipe or an equation, such as a balanced chemical equation, is used to determine how much starting material is needed or how much product will be made.

A balanced chemical equation can be interpreted in terms of different quantities, including numbers of atoms, molecules, or moles; mass; and volume.

Number of Atoms

At the atomic level, a balanced equation indicates the number and types of atoms that are rearranged to make the product or products.

- In the synthesis of ammonia, the reactants are composed of two atoms of nitrogen and six atoms of hydrogen.

$$2 \text{ atoms N} + 6 \text{ atoms H} \longrightarrow 2 \text{ atoms N and } 6 \text{ atoms H}$$

Number of Molecules

Nitrogen and hydrogen will always react to form ammonia in a 1:3:2 ratio of molecules.

- It is not practical to count very small numbers of molecules and allow them to react.
- You could take Avogadro's number (6.02×10^{23} molecules) of nitrogen molecules and make them react with three times Avogadro's number of hydrogen molecules.

$$1 \times \left(\begin{array}{c} 6.02 \times 10^{23} \\ \text{molecules } N_2 \end{array} \right) + 3 \times \left(\begin{array}{c} 6.02 \times 10^{23} \\ \text{molecules } N_2 \end{array} \right) \rightarrow 3 \times \left(\begin{array}{c} 6.02 \times 10^{23} \\ \text{molecules } NH_3 \end{array} \right)$$

Moles

Since a balanced chemical equation tells you the number of representative particles, it also tells you the number of moles.

- In the synthesis of ammonia, one mole of nitrogen molecules reacts with three moles of hydrogen molecules to form two moles of ammonia molecules.

$$1 \text{ mol } N_2 + 3 \text{ mol } H_2 \rightarrow 2 \text{ mol } NH_3$$

Mass

A balanced chemical equation obeys the law of conservation of mass.

- Mass can be neither created nor destroyed in an ordinary chemical or physical process.
- The total mass of the atoms in a reaction does not change.

$$28\text{ g }N_2 + (3 \times 2\text{ g }H_2) \rightarrow (2 \times 17\text{ g }NH_3)$$

$$28\text{ g }N_2 + 6\text{ g }H_2 \rightarrow 34\text{ g }NH_3$$

Volume

If you assume standard temperature and pressure, the balanced chemical equation also tells you about the volumes of gases.

- 1 mol of any gas at STP occupies a volume of 22.4 L.

$$22.4\ \text{L}\ N_2 + (3 \times 22.4\ \text{L}\ H_2) \rightarrow (2 \times 22.4\ \text{L}\ NH_3)$$

$$22.4\ \text{L}\ N_2 + 67.2\ \text{L}\ H_2 \rightarrow 44.8\ \text{L}\ NH_3$$

Interpreting a Balanced Chemical Equation

Hydrogen sulfide, which smells like rotten eggs, is found in volcanic gases. The balanced equation for the burning of hydrogen sulfide is:

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$

Interpret this equation in terms of

a. numbers of representative particles and moles.

b. masses of reactants and produces.

PEARSON

1 Analyze Identify the relevant concepts.

- The coefficients in the balanced equation give the relative number of representative particles and moles of reactants and products.
- A balanced chemical equation obeys the law of conservation of mass.

2 Solve **Apply concepts to this situation.**

Use the coefficients in the balanced equation to identify the number of representative particles and moles.

$$2 \text{ molecules } H_2S + 3 \text{ molecules } O_2 \rightarrow 2 \text{ molecules } SO_2 + 2 \text{ molecules } H_2O$$

$$2 \text{ mol } H_2S + 3 \text{ mol } O_2 \rightarrow 2 \text{ mol } SO_2 + 2 \text{ mol } H_2O$$

Remember that atoms and molecules are both representative particles. In this equation, all the reactants and products are molecules; so all the representative particles are molecules.

2 Solve Apply concepts to this situation.

Use the periodic table to calculate the molar mass of each reactant and product.

$$1 \text{ mol } H_2S = 34.1 \text{ g } H_2S$$

$$1 \text{ mol } O_2 = 32.0 \text{ g } O_2$$

$$1 \text{ mol } SO_2 = 64.1 \text{ g/mol } SO_2$$

$$1 \text{ mol } H_2O = 18.0 \text{ g/mol } H_2O$$

2 Solve **Apply concepts to this situation.**

Multiply the number of moles of each reactant and product by its molar mass.

$$2 \text{ mol } H_2S + 3 \text{ mol } O_2 \rightarrow 2 \text{ mol } SO_2 + 2 \text{ mol } H_2O$$

$$\left(2 \cancel{\text{mol}} \times 34.1 \frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(3 \cancel{\text{mol}} \times 32.0 \frac{\text{g}}{\cancel{\text{mol}}}\right) \rightarrow$$

$$\left(2 \cancel{\text{mol}} \times 64.1 \frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(2 \cancel{\text{mol}} \times 18.0 \frac{\text{g}}{\cancel{\text{mol}}}\right)$$

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Multiply the number of moles of each reactant and product by its molar mass.

$$2\text{ mol } H_2S + 3\text{ mol } O_2 \longrightarrow 2\text{ mol } SO_2 + 2\text{ mol } H_2O$$

$$\left(2\,\cancel{\text{mol}} \times 34.1\,\frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(3\,\cancel{\text{mol}} \times 32.0\,\frac{\text{g}}{\cancel{\text{mol}}}\right) \longrightarrow$$

$$\left(2\,\cancel{\text{mol}} \times 64.1\,\frac{\text{g}}{\cancel{\text{mol}}}\right) + \left(2\,\cancel{\text{mol}} \times 18.0\,\frac{\text{g}}{\cancel{\text{mol}}}\right)$$

$$68.2\text{ g } H_2S + 96.0\ O_2 \rightarrow 128.2\text{ g } SO_2 + 36.0\text{ g } H_2O$$

$$164.2\text{ g} = 164.2\text{ g}$$

The table below summarizes the information derived from the balanced chemical equation for the formation of ammonia.

$N_2(g)$		+	$2H_2(g)$		$\longrightarrow$	$2NH_3(g)$
		+			$\longrightarrow$	
2 atoms N		+	6 atoms H		$\longrightarrow$	2 atoms N and 6 atoms H
1 molecule N_2		+	3 molecules H_2		$\longrightarrow$	2 molecules NH_3
10 molecules N_2		+	30 molecules H_2		$\longrightarrow$	20 molecules NH_3
$1 \times \left(\begin{array}{l} 6.02 \times 10^{23} \\ \text{molecules } N_2 \end{array}\right)$		+	$3 \times \left(\begin{array}{l} 6.02 \times 10^{23} \\ \text{molecules } H_2 \end{array}\right)$		$\longrightarrow$	$2 \times \left(\begin{array}{l} 6.02 \times 10^{23} \\ \text{molecules } NH_2 \end{array}\right)$
1 mol N_2		+	3 mol H_2		$\longrightarrow$	2 mol NH_3
23 g N_2		+	3×2 g H_2		$\longrightarrow$	2×17 g NH_3
			34 g reactants		$\longrightarrow$	34 g products
Assume STP	22.4 L	+	22.4 L 22.4 L 22.4 L		$\longrightarrow$	22.4 L 22.4 L
	22.4 L N_2		67.2 L H_2			44.8 L NH_3

PEARSON

Mass and atoms are conserved in every chemical reaction.

- Molecules, formula units, moles, and volumes are not necessarily conserved—although they may be.

Interpret the following equation in terms of volumes of gas at STP.

$$2H_2(g) + 2NO(g) \rightarrow N_2(g) + 2H_2O(g)$$

Interpret the following equation in terms of volumes of gas at STP.

$$2H_2(g) + 2NO(g) \rightarrow N_2(g) + 2H_2O(g)$$

$$44.8\ L\ H_2(g) + 44.8\ L\ NO(g) \rightarrow 22.4\ L\ N_2(g) + 44.8\ L\ H_2O(g)$$

PEARSON

- A balanced chemical equation provides the same kind of quantitative information that a recipe does.
- Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.
- A balanced chemical equation can be interpreted in terms of different quantities, including numbers of atoms, molecules, or moles; mass; and volume.
- Mass and atoms are conserved in every chemical reaction.

stoichiometry: that portion of chemistry dealing with numerical relationships in chemical reactions; the calculation of quantities of substances involved in chemical equations

The Mole and Quantifying Matter

- Balanced chemical equations are the basis for stoichiometric calculations.
- The coefficients of a balanced equation indicate the number of particles, mole, or volumes of gas in the reaction.

END OF 12.1