ACTIVITY 5

Balanced Chemical Reaction Equations

WHY?

Chemical reaction equations are fundamental tools for communicating how chemical compounds are synthesized and changed. Representing a chemical reaction with an equation is one key to understanding chemical change. To make use of these equations, you need to be able to write formulas for chemical compounds, balance the chemical equation, and deduce information from it about the amounts of material needed for the reaction and the amounts of material produced by the reaction.

LEARNING OBJECTIVE

- Understand and make use of chemical reaction equations

SUCCESS CRITERIA

- Write and balance chemical reaction equations
- Determine the amounts of substances consumed and produced in a chemical reaction

PREREQUISITES

- **Activity 2:** *Mole and Molar Mass*
- **Activity 3:** *Molecular Representations*

MODEL: Burn Propane Burn – A One-Act Play in Two Scenes

(Have fun by acting this play out in class! See if you can extract the key ideas about balancing reaction equations.)

Scene 1 opens with Nimka, Chris, and Diana hanging out and talking about their favorite subject–chemistry.

Nimka: I just read that when propane burns, carbon dioxide and oxygen are produced.

Chris: I know the molecular formulas, so I can write an equation for it.

Chris writes: $C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$

Nimka: That's neat! Does it mean that one molecule of propane combines with one molecule of oxygen as the reactants?

Chris: Yup! To produce the products: molecules of carbon dioxide and water.

Diana: What happened to all the atoms?

Chris: What do you mean?

Diana: Well, you know, there are 13 atoms on the left side and only 6 atoms on the right side.

Nimka: It's OK, there are 2 molecules on the left and 2 molecules on the right, and Dr. Dave told us that reaction equations need to be balanced.

Diana: But molecules are just atoms connected together, and the atoms don't balance.

Nimka: Yeah, on the right side there are too many oxygen atoms and too few carbon and hydrogen atoms.

Chris: Perhaps the protons, neutrons, and electrons rearranged, and carbon and hydrogen turned into oxygen.

(The three friends huddle together to count the number of protons, neutrons, and electrons comprising the reactants and products.)

Chris: Darn, that doesn't seem to work.

Diana: Maybe if we add more molecules.

Chris: Of what?

Diana: Carbon dioxide and water.

Nimka: And then put more oxygen on the left!

(The three friends huddle together again and come up with a new equation.)

Chris: We got it! Look, it works!

Chris writes: $C_3H_8 + 5\ O_2 \longrightarrow 3\ CO_2 + 4\ H_2O$

Nimka: Let's go ask Dr. Dave if this is right.

Scene 2 opens in Dr. Dave's office.

Dr. Dave: Yes, you three figured that out. The number of atoms of each element must be the same on both sides of the equation because atoms are not created or destroyed in a chemical reaction, just regrouped to form different molecules. That's the key point! Let me say that a bit louder — ***That's the key point!***

Nimka with emphasis on "that": So **that** is what is meant by balanced.

Dr. Dave: Well almost. Here's something else for you to think about. Why isn't the following reaction equation balanced? $Cu^{2+} + Ag \longrightarrow Cu + Ag^{+}$

Nimka: It looks balanced, 1 copper and 1 silver on each side!

Diana: But what about the charge? On the left it is +2, and on the right it is +1.

Dr. Dave: That's right. An electron got transferred from silver to copper in the reaction, but two electrons are needed to reduce copper from +2 to 0.

Nimka: So you mean we need 2 silver atoms to provide 2 electrons?

Dr. Dave: You got it! Congratulations! There are a couple of other points about writing balanced reaction equations. Would you like to hear about them?

The three friends loudly shout in unison, yes!

Dr Dave: A complete equation specifies the state of the reactants and products with a symbol: (s) for solid, (g) for gas, (l) for liquid, and (aq) for dissolved in water. So the copper/silver reaction is better written as,

$$Cu^{2+}(aq) + 2Ag(s) \longrightarrow Cu(s) + 2Ag^{+}(aq)$$

Also, a balanced reaction equation can be read two ways: in terms of molecules reacting or in terms of moles reacting. For example, you could say that 1 molecule of propane reacts with 5 molecules of oxygen to produce 3 molecules of carbon dioxide and 4 molecules of water. Or you could say, 1 mole of propane reacts with 5 moles of oxygen to produce 3 moles of carbon dioxide and 4 moles of water.

(The scene closes as Dr. Dave rushes off to a faculty meeting, and the three friends race to their favorite class — chemistry recitation where they get to work in teams, talk about chemistry, and figure out how to ace the exam by understanding rather than memorizing.)

Key Questions

1. What are the reactants in the combustion of propane?

   Propane C_3H_8 and oxygen O_2

2. What are the products in the combustion of propane?

   Carbon dioxide CO_2 and water H_2O

3. What meaning is given to the arrow in a chemical reaction equation?

   It shows the direction of the reaction with the reactants on the left forming the products on the right.

4. In the reaction equation, what information is provided by the numerical subscripts in the molecular formulas for the reactants and products?

   The number of atoms of each type in the compound

5. In a balanced reaction equation, what information is provided by the stoichiometric coefficients? Note: The number in front of a reactant or product is called a *stoichiometric coefficient*. The absence of an explicit stoichiometric coefficient means the value is 1.

   The number of reactant and product molecules (or moles of molecules) involved in the reaction

6. How does the second reaction equation that Chris wrote differ from the first reaction equation that he wrote?

   The first reaction is not balanced, the second reaction is balanced. The correct stoichiometric coefficients in the second reaction have the same number of atoms of each kind as reactants and as products.

7. Why is the second reaction equation that Chris wrote more useful than the first reaction equation that he wrote?

   The second reaction accounts for the fact that atoms are neither created nor destroyed in a chemical reaction. The balanced reaction equation therefore can be used in accounting for the amounts of reactants that are consumed and amounts of products that are produced in a chemical reaction.

8. What two things must be true for a reaction equation to be balanced?

   The number of atoms of each kind must be the same on both sides of the equation, and the charge must be the same on both sides of the equation.

9. Why is it possible to interpret a reaction equation in the following two ways? (a) As specifying how many molecules of reactants are consumed to produce the specified number of product molecules. (b) As specifying how many moles of reactants are consumed in producing the indicated number of moles of products.

   The balanced equation tells how many reactant molecules are needed to make the indicated number of product molecules. A mole is just a way of counting molecules so there really is no difference. We also could see the balanced equation tells us how many dozen molecules are involved in the reaction. We use moles to describe chemical reactions because we generally cannot measure out individual molecules.

   Reactions occur between individual molecules according to the numbers in the balanced equation. These numbers also correspond to moles because moles are directly proportional to the number of individual molecules

Exercises

1. Write balanced reaction equations for the following reactions. Be sure to add the states if they are missing.

   a) $Zn + Ag^{+} \longrightarrow Zn^{2+} + Ag$

   $Zn\mathbf{(s)} + \mathbf{2}Ag^{+}\mathbf{(aq)} \longrightarrow Zn^{2+}\mathbf{(aq)} + \mathbf{2}Ag\mathbf{(s)}$

   b) $Na_2CO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

   $Na_2CO_3(s) + \mathbf{2}HCl(aq) \longrightarrow \mathbf{2}NaCl(aq) + CO_2(g) + H_2O(l)$

   c) $CH_3OH(l) + O_2 \longrightarrow CO_2(g) + H_2O(g)$

   $\mathbf{2}CH_3OH(l) + \mathbf{3}O_2(g) \longrightarrow \mathbf{2}CO_2(g) + \mathbf{4}H_2O(g)$

   d) In the gas phase: $N_2 + H_2 \longrightarrow NH_3$

   $N_2\mathbf{(g)} + \mathbf{3}H_2\mathbf{(g)} \longrightarrow \mathbf{2}NH_3\mathbf{(g)}$

   e) $LiOH(s) + CO_2 \longrightarrow Li_2CO_3(s) + H_2O(l)$

   $\mathbf{2}LiOH(s) + CO_2\ \mathbf{(g)} \longrightarrow Li_2CO_3(s) + H_2O(l)$

   f) $Pb(NO_3)_2\ (aq) + H_2S(g) \longrightarrow PbS(s) + HNO_3(aq)$

   $Pb(NO_3)_2\ (aq) + H_2S(g) \longrightarrow PbS(s) + \mathbf{2}HNO_3(aq)$

2. Using the balanced reaction equation for the combustion of propane, determine the number of moles of oxygen that would react with 0.50 mol propane and the number of moles of carbon dioxide that would be produced.

   $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

   $$\frac{x \text{ mol oxygen}}{0.50 \text{ mol propane}} = \frac{5 \text{ mol oxygen}}{1 \text{ mol propane}}$$

   $$x = (0.50 \text{ mole propane}) \times \frac{(5 \text{ mole } O_2)}{1 \text{ mole propane}} = 2.5 \text{ mole } O_2$$

   $$\frac{x \text{ mol carbon dioxide}}{0.50 \text{ mol propane}} = \frac{3 \text{ mol carbon dioxide}}{1 \text{ mol propane}}$$

   $$x = (0.50 \text{ mole propane}) \times \frac{(3 \text{ mole } CO_2)}{1 \text{ mole propane}} = 1.5 \text{ mole } CO_2$$

3. Using the reaction equation for the combustion of propane, determine the number of grams of oxygen that would react with 44 g of propane and the number of grams of water that would be produced.

Need to convert quantities to moles because molecules react with each other.

$$\text{mol propane} = \frac{44\text{ g}}{44\text{ g/mol}} = 1\text{ mol propane}$$

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

1 mol propane requires 5 mole O_2 and produces 4 mole water

$$\text{mass of } O_2 = 5\text{ mol} \times 32\text{ g/mol} = 160\text{ g}$$

$$\text{mass of water} = 4\text{ mol} \times 18\text{ g/mol} = 72\text{ g}$$