11.E: Stoichiometry Applications (Exercises)

The following questions are related to the material covered in this chapter. For additional discussion on each topic, also check the links included in each heading.

11.1: Stoichiometry

1. Think back to the pound cake recipe. What possible conversion factors can you construct relating the components of the recipe?
2. Think back to the pancake recipe. What possible conversion factors can you construct relating the components of the recipe?
3. What are all the conversion factors that can be constructed from the balanced chemical reaction:

$$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(\ell)? \tag{11.E.1}$$

4. What are all the conversion factors that can be constructed from the balanced chemical reaction $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$?
5. Given the chemical equation : $Na(s) + H_2O(\ell) \rightarrow NaOH(aq) + H_2(g)$
   a. Balance the equation.
   b. How many molecules of H_2 are produced when 332 atoms of Na react?
6. Given the chemical equation: $S(s) + O_2(g) \rightarrow SO_3(g)$
   a. Balance the equation.
   b. How many molecules of O_2 are needed when 38 atoms of S react?
7. For the balanced chemical equation:

$6H^+(aq) + 2MnO_4^-(aq) + 5H_2O_2(\ell) \rightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(\ell)$

how many molecules of H_2O are produced when 75 molecules of H_2O_2 react?

8. how many molecules of CO_2 are produced when 56 molecules of C_6H_6 react?
9. how many molecules of $Fe_2(SO_4)_3$ are produced if 321 atoms of S are reacted?
10. how many molecules of CuS are formed if 9,044 atoms of H react?
11. suppose we need to make 145,000 molecules of $Fe_2(SO_4)_3$. How many molecules of SO_3 do we need?
12. One way to make sulfur hexafluoride is to react thioformaldehyde, CH_2S, with elemental fluorine:

$CH_2S + 6F_2 \rightarrow CF_4 + 2HF + SF_6$

If 45,750 molecules of SF_6 are needed, how many molecules of F_2 are required?

13. Construct the three independent conversion factors possible for these two reactions:
    a. $2H_2 + O_2 \rightarrow 2H_2O$
    b. $H_2 + O_2 \rightarrow H_2O_2$

Why are the ratios between H_2 and O_2 different?

The conversion factors are different because the stoichiometries of the balanced chemical reactions are different.

14. Construct the three independent conversion factors possible for these two reactions:
    a. $2Na + Cl_2 \rightarrow 2NaCl$
    b. $4Na + 2Cl_2 \rightarrow 4NaCl$

What similarities, if any, exist in the conversion factors from these two reactions?

Answers

1. $$\frac{1\,pound\,butter}{1\,pound\,flour} \tag{11.E.2}$$

   or

   $$\frac{1\,pound\,sugar}{1\,pound\,eggs} \tag{11.E.3}$$

   are two conversion factors that can be constructed from the pound cake recipe. Other conversion factors are also possible.
2.

3. 2 molecules H21 molecule O2" role="presentation" style="position:relative;" tabindex="0">

$$\frac{2\ molecules\ H_2}{1\ molecule\ O_2} \tag{11.E.4}$$

,

$$\frac{1\ molecule\ O_2}{2\ molecules\ H_2O} \tag{11.E.5}$$

,

$$\frac{2\ molecules\ H_2}{2\ molecules\ H_2O} \tag{11.E.6}$$

and their reciprocals are the conversion factors that can be constructed. 2 molecules H21 molecule O2" role="presentation" style="position:relative;" tabindex="0">

4.
5. a. $2Na(s) + 2H_2O(\ell) \rightarrow 2NaOH(aq) + H_2(g)$
   b. 166 molecules
6.
7. 120 molecules
8.
9. 107 molecules
10.
11. 435,000 molecules
12.
13. a.

$$\frac{2\ molecules\ H_2}{1\ molecule\ O_2}, \frac{1\ molecule\ O_2}{2\ molecules\ H_2O}, \frac{2\ molecules\ H_2}{2\ molecules\ H_2O} \tag{11.E.7}$$

   b.

$$\frac{1\ molecules\ H_2}{1\ molecule\ O_2}, \frac{1\ molecule\ O_2}{2\ molecules\ H_2O_2}, \frac{1\ molecule\ H_2}{1\ molecule\ H_2O_2} \tag{11.E.8}$$

11.1.1: Mole-Mass and Mass-Mass Calculations

1. What mass of CO_2 is produced by the combustion of 1.00 mol of CH_4?$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$
2. What mass of H_2O is produced by the combustion of 1.00 mol of CH_4? $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$
3. What mass of HgO is required to produce 0.692 mol of O_2? $2HgO(s) \rightarrow 2Hg(\ell) + O_2(g)$
4. What mass of $NaHCO_3$ is needed to produce 2.659 mol of CO_2? $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(\ell) + CO_2(g)$
5. How many moles of Al can be produced from 10.87 g of Ag? $Al(NO_3)_3(s) + 3Ag \rightarrow Al + 3AgNO_3$
6. How many moles of HCl can be produced from 0.226 g of $SOCl_2$? $SOCl_2(\ell) + H_2O(\ell) \rightarrow SO_2(g) + 2HCl(g)$
7. How many moles of O_2 are needed to prepare 1.00 g of $Ca(NO_3)_2$? $Ca(s) + N_2(g) + 3O_2(g) \rightarrow Ca(NO_3)_2(s)$
8. How many moles of C_2H_5OH are needed to generate 106.7 g of H_2O? $C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(\ell)$
9. What mass of O_2 can be generated by the decomposition of 100.0 g of $NaClO_3$? $2NaClO_3 \rightarrow 2NaCl(s) + 3O_2(g)$
10. What mass of Li_2O is needed to react with 1,060 g of CO_2? $Li_2O(aq) + CO_2(g) \rightarrow Li_2CO_3(aq)$
11. What mass of Fe_2O_3 must be reacted to generate 324 g of Al_2O_3? $Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(s) + Al_2O_3(s)$
12. What mass of Fe is generated when 100.0 g of Al are reacted? $Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(s) + Al_2O_3(s)$
13. What mass of MnO_2 is produced when 445 g of H_2O are reacted? $H_2O(\ell) + 2MnO_4^-(aq) + Br^-(aq) \rightarrow BrO_3^-(aq) + 2MnO_2(s) + 2OH^-(aq)$
14. What mass of $PbSO_4$ is produced when 29.6 g of H_2SO_4 are reacted? $Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(\ell)$
15. If 83.9 g of ZnO are formed, what mass of Mn_2O_3 is formed with it? $Zn(s) + 2MnO_2(s) \rightarrow ZnO(s) + Mn_2O_3(s)$
16. If 14.7 g of NO_2 are reacted, what mass of H_2O is reacted with it? $3NO_2(g) + H_2O(\ell) \rightarrow 2HNO_3(aq) + NO(g)$
17. If 88.4 g of CH_2S are reacted, what mass of HF is produced? $CH_2S + 6F_2 \rightarrow CF_4 + 2HF + SF_6$
18. If 100.0 g of Cl_2 are needed, what mass of NaOCl must be reacted?

$NaOCl + HCl \rightarrow NaOH + Cl_2$

Answers

1. 44.0 g
2.
3. 3.00×10^2 g
4.
5. 0.0336 mol
6.
7. 0.0183 mol
8.
9. 45.1 g
10.
11. 507 g
12.
13. 4.30×10^3 g
14.
15. 163 g
16.
17. 76.7 g

11.1.3: Solution Stoichiometry

1. What volume of 3.44 M HCl will react with 5.33 mol of $CaCO_3$? $2HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$
2. What volume of 0.779 M NaCl will react with 40.8 mol of $Pb(NO_3)_2$? $Pb(NO_3)_2 + 2NaCl \rightarrow PbCl_2 + 2NaNO_3$
3. What volume of 0.905 M H_2SO_4 will react with 26.7 mL of 0.554 M NaOH? $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$
4. What volume of 1.000 M Na_2CO_3 will react with 342 mL of 0.733 M H_3PO_4? $3Na_2CO_3 + 2H_3PO_4 \rightarrow 2Na_3PO_4 + 3H_2O + 3CO_2$
5. It takes 23.77 mL of 0.1505 M HCl to titrate with 15.00 mL of $Ca(OH)_2$. What is the concentration of $Ca(OH)_2$? You will need to write the balanced chemical equation first.
6. It takes 97.62 mL of 0.0546 M NaOH to titrate a 25.00 mL sample of H_2SO_4. What is the concentration of H_2SO_4? You will need to write the balanced chemical equation first.
7. It takes 4.667 mL of 0.0997 M HNO_3 to dissolve some solid Cu. What mass of Cu can be dissolved? $Cu + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2 + 2H_2O$
8. It takes 49.08 mL of 0.877 M NH_3 to dissolve some solid AgCl. What mass of AgCl can be dissolved? $AgCl(s) + 4NH_3(aq) \rightarrow Ag(NH_3)_4Cl(aq)$
9. What mass of 3.00% H_2O_2 is needed to produce 66.3 g of $O_2(g)$? $2H_2O_2(aq) \rightarrow 2H_2O(\ell) + O_2(g)$

Answers

1. 3.10 L
2.
3. 8.17 mL
4.
5. 0.1192 M
6.
7. 7.39 mg

8.

9. 4.70 kg

11.1.4: Gas Stoichiometry

1. How many liters, at STP, of CO_2 are produced from 100.0 g of C_8H_{18}, the approximate formula of gasoline? $2C_8H_{18}(\ell) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(\ell)$
2. How many liters, at STP, of O_2 are required to burn 3.77 g of butane from a disposable lighter?

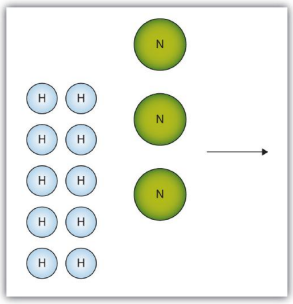
$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(\ell)$

Answers

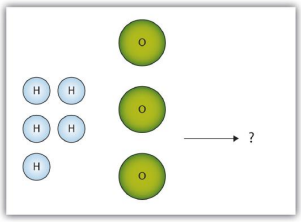
1. 157 L
2.

11.2: Limiting Reagents

1. The box below shows a group of nitrogen and hydrogen molecules that will react to produce ammonia, NH_3. What is the limiting reagent?



2. The box below shows a group of hydrogen and oxygen molecules that will react to produce water, H_2O. What is the limiting reagent?



3. Given the statement “20.0 g of methane is burned in excess oxygen,” is it obvious which reactant is the limiting reagent?
4. Given the statement “the metal is heated in the presence of excess hydrogen,” is it obvious which substance is the limiting reagent despite not specifying any quantity of reactant?
5. What is the limiting reagent? How much of the other reactant is in excess?
6. What is the limiting reagent? How much of the other reactant is in excess?
7. Given the initial amounts listed, what is the limiting reagent, and how much of the other reactant is in excess?

$$\underset{35.6\ g}{P_4O_6(s)} + \underset{4.77\ g}{6H_2O(l)} \rightarrow 4H_3PO_4 \tag{11.E.9}$$

8. Given the initial amounts listed, what is the limiting reagent, and how much of the other reactant is in excess?

$$\underset{377\ g}{3NO_2(g)} + \underset{244\ g}{H_2O(l)} \rightarrow 2HNO_3(aq) + NO(g) \tag{11.E.10}$$

9. To form the precipitate $PbCl_2$, 2.88 g of NaCl and 7.21 g of $Pb(NO_3)_2$ are mixed in solution. How much precipitate is formed? How much of which reactant is in excess?

10. In a neutralization reaction, 18.06 g of KOH are reacted with 13.43 g of HNO_3. What mass of H_2O is produced, and what mass of which reactant is in excess?

Answers

1. Nitrogen is the limiting reagent.
2.
3. Yes; methane is the limiting reagent.
4.
5. C is the limiting reagent; 4.33 g of H_2 are left over.
6.
7. H_2O is the limiting reagent; 25.9 g of P_4O_6 are left over.
8.
9. 6.06 g of $PbCl_2$ are formed; 0.33 g of NaCl is left over.

11.3: Yields

1. What is the difference between the theoretical yield and the actual yield?
2. What is the difference between the actual yield and the percent yield?
3. A worker isolates 2.675 g of SiF_4 after reacting 2.339 g of SiO_2 with HF. What are the theoretical yield and the actual yield? $SiO_2(s) + 4HF(g) \rightarrow SiF_4(g) + 2H_2O(\ell)$
4. A worker synthesizes aspirin, $C_9H_8O_4$, according to this chemical equation. If 12.66 g of $C_7H_6O_3$ are reacted and 12.03 g of aspirin are isolated, what are the theoretical yield and the actual yield? $C_7H_6O_3 + C_4H_6O_3 \rightarrow C_9H_8O_4 + HC_2H_3O_2$
5. A chemist decomposes 1.006 g of $NaHCO_3$ and obtains 0.0334 g of Na_2CO_3. What are the theoretical yield and the actual yield? $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(\ell) + CO_2(g)$
6. A chemist combusts a 3.009 g sample of C_5H_{12} and obtains 3.774 g of H_2O. What are the theoretical yield and the actual yield? $C_5H_{12}(\ell) + 8O_2(g) \rightarrow 5CO_2 + 6H_2O(\ell)$
7. What is the percent yield in Exercise 3?
8. What is the percent yield in Exercise 4?
9. What is the percent yield in Exercise 5?
10. What is the percent yield in Exercise 6?

Answers

1. Theoretical yield is what you expect stoichiometrically from a chemical reaction; actual yield is what you actually get from a chemical reaction.
2.
3. theoretical yield = 4.052 g; actual yield = 2.675 g
4.
5. theoretical yield = 0.635 g; actual yield = 0.0334 g
6.
7. 66.02%
8.
9. 5.26%

1. 11.4 Energy and Chemical Processes

Sulfur dioxide (SO_2) is a pollutant gas that is one cause of acid rain. It is oxidized in the atmosphere to sulfur trioxide (SO_3), which then combines with water to make sulfuric acid (H_2SO_4).

1. Write the balanced reaction for the oxidation of SO_2 to make SO_3. (The other reactant is diatomic oxygen.)

2. When 1 mol of SO_2 reacts to make SO_3, 23.6 kcal of energy are given off. If 100 lb (1 lb = 454 g) of SO_2 were converted to SO_3, what would be the total energy change?

Ammonia (NH_3) is made by the direct combination of H_2 and N_2 gases according to this reaction:

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g) + 22.0$ kcal

1. Is this reaction endothermic or exothermic?
2. What is the overall energy change if 1,500 g of N_2 are reacted to make ammonia?

A 5.69 g sample of iron metal was heated in boiling water to 99.8°C. Then it was dropped into a beaker containing 100.0 g of H_2O at 22.6°C. Assuming that the water gained all the heat lost by the iron, what is the final temperature of the H_2O and Fe?

A 5.69 g sample of copper metal was heated in boiling water to 99.8°C. Then it was dropped into a beaker containing 100.0 g of H_2O at 22.6°C. Assuming that the water gained all the heat lost by the copper, what is the final temperature of the H_2O and Cu?

When 1 g of steam condenses, 540 cal of energy is released. How many grams of ice can be melted with 540 cal?

When 1 g of water freezes, 79.9 cal of energy is released. How many grams of water can be boiled with 79.9 cal?

The change in energy is +65.3 kJ for each mole of calcium hydroxide [$Ca(OH)_2$] according to the following reaction:

$Ca(OH)_2(s) \rightarrow CaO(s) + H_2O(g)$

How many grams of $Ca(OH)_2$ could be reacted if 575 kJ of energy were available?

The thermite reaction gives off so much energy that the elemental iron formed as a product is typically produced in the liquid state:

$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(\ell) + 204$ kcal

How much heat will be given off if 250 g of Fe are to be produced?

A normal adult male requires 2,500 kcal per day to maintain his metabolism.

1. Nutritionists recommend that no more than 30% of the calories in a person's diet come from fat. At 9 kcal/g, what is the maximum mass of fat an adult male should consume daily?
2. At 4 kcal/g each, how many grams of protein and carbohydrates should an adult male consume daily?

A normal adult male requires 2,500 kcal per day to maintain his metabolism.

1. At 9 kcal/g, what mass of fat would provide that many kilocalories if the diet was composed of nothing but fats?
2. At 4 kcal/g each, what mass of protein and/or carbohydrates is needed to provide that many kilocalories?

The volume of the world's oceans is approximately 1.34×10^{24} cm^3.

1. How much energy would be needed to increase the temperature of the world's oceans by 1°C? Assume that the heat capacity of the oceans is the same as pure water.
2. If Earth receives 6.0×10^{22} J of energy per day from the sun, how many days would it take to warm the oceans by 1°C, assuming all the energy went into warming the water?

Does a substance that has a small specific heat require a small or large amount of energy to change temperature? Explain.

Some biology textbooks represent the conversion of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and phosphate ions as follows:

ATP → ADP + phosphate + energy

What is wrong with this reaction?

Assuming that energy changes are additive, how much energy is required to change 15.0 g of ice at −15°C to 15.0 g of steam at 115°C? (Hint: you will have five processes to consider.)

Answers

1. $2SO_2 + O_2 \rightarrow 2SO_3$
2. 16,700 kcal

2.

exothermic 1177 kcal

about 23.1°C

4. about 23.0°C

5. 6.76 g

6. 0.148 g

652 g

8. 457 kcal

1. 83.3 g
2. 438 g

10.

a. 278 g

b. 625 g

11.

1.34×10^{24} cal 93 days

12. A substance with **smaller specific heat** requires **less energy** per unit of mass to raise its temperature,

13. A reactant is missing: H_2O is missing.

14. Total energy = 11,019 cal

11: Additional Exercises

1. How many molecules of O_2 will react with 6.022×10^{23} molecules of H_2 to make water? The reaction is $2H_2(g) + O_2(g) \rightarrow 2H_2O(\ell)$.
2. How many molecules of H_2 will react with 6.022×10^{23} molecules of N_2 to make ammonia? The reaction is $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$.
3. How many moles are present in 6.411 kg of CO_2? How many molecules is this?
4. How many moles are present in 2.998 mg of SCl_4? How many molecules is this?
5. What is the mass in milligrams of 7.22×10^{20} molecules of CO_2?
6. What is the mass in kilograms of 3.408×10^{25} molecules of SiS_2?
7. What is the mass in grams of 1 molecule of H_2O?
8. What is the mass in grams of 1 atom of Al?
9. What is the volume of 3.44 mol of Ga if the density of Ga is 6.08 g/mL?
10. What is the volume of 0.662 mol of He if the density of He is 0.1785 g/L?
11. assume that 13.4 g of C_4H_{10} reacts completely to products. The density of CO_2 is 1.96 g/L. What volume in liters of CO_2 is produced?
12. if 223 g of $GaCl_3$ reacts completely to products and the density of Ga is 6.08 g/mL, what volume in milliliters of Ga is produced?
13. What do you notice about the sum of the masses of the products? What concept is being illustrated here?
14. What do you notice about the sum of the masses of the products? What concept is being illustrated here?
15. What mass of CO_2 is produced from the combustion of 1 gal of gasoline? The chemical formula of gasoline can be approximated as C_8H_{18}. Assume that there are 2,801 g of gasoline per gallon.
16. What mass of H_2O is produced from the combustion of 1 gal of gasoline? The chemical formula of gasoline can be approximated as C_8H_{18}. Assume that there are 2,801 g of gasoline per gallon.
17. A chemical reaction has a theoretical yield of 19.98 g and a percent yield of 88.40%. What is the actual yield?
18. A chemical reaction has an actual yield of 19.98 g and a percent yield of 88.40%. What is the theoretical yield?
19. Given the initial amounts listed, what is the limiting reagent, and how much of the other reactants are in excess?

$$\underset{35.0\ g}{P_4} + 3NaOH + 3H_2O \rightarrow 2Na_2HPO_4 + PH_3 \qquad (11.E.11)$$

20. Given the initial amounts listed, what is the limiting reagent, and how much of the other reactants are in excess?

$$\underset{46.3\ g}{2NaCrO_2} + \underset{88.2\ g}{3NaBrO_4} + \underset{32.5\ g}{2NaOH} \rightarrow 3NaBrO_3 + 2Na_2CrO_4 + H_2O \tag{11.E.12}$$

21. Verify that it does not matter which product you use to predict the limiting reagent by using both products in this combustion reaction to determine the limiting reagent and the amount of the reactant in excess. Initial amounts of each reactant are given.

$$\underset{26.3\ g}{C_3H_8} + \underset{21.8\ g}{5O_2} \rightarrow 3CO_2(g) + 4H_2O(l) \tag{11.E.13}$$

22. Just in case you suspect Exercise 21 is rigged, do it for another chemical reaction and verify that it does not matter which product you use to predict the limiting reagent by using both products in this combustion reaction to determine the limiting reagent and the amount of the reactant in excess. Initial amounts of each reactant are given.

$$\underset{35.0\ g}{2P_4} + \underset{12.7\ g}{6NaOH} + \underset{9.33\ g}{6H_2O} \rightarrow 3Na_2HPO_4 + 5PH_3 \tag{11.E.14}$$

1. 1.2044×10^{24} molecules
2.
3. 145.7 mol; 8.77×10^{25} molecules
4.
5. 52.8 mg
6.
7. 2.99×10^{-23} g
8.
9. 39.4 mL
10.
11. 20.7 L
12.
13. 67.91 g of $CuCl_2$; 32.09 g of Cu. The two masses add to 100.0 g, the initial amount of starting material, demonstrating the law of conservation of matter.
14.
15. 8,632 g
16.
17. 17.66 g
18.
19. The limiting reagent is NaOH; 21.9 g of P_4 and 3.61 g of H_2O are left over.
20.
21. Both products predict that O_2 is the limiting reagent; 20.3 g of C_3H_8 are left over.