Section: Limiting Reactants and Percentage Yield

Complete each statement below by choosing a term from the following list.
Terms may be used more than once.

excess          product          limiting          stoichiometric
percentage      actual          theoretical

1. A(n) ________________ reactant is not completely used up in a chemical reaction.

2. A(n) ________________ reactant is used up first and thus controls the quantity of ________________ that can be formed in a chemical reaction.

3. The reactant that runs out first is the ________________ reactant.

4. The limiting reactant should be used in ________________ calculations to determine the maximum amount of product expected.

5. Cost is a factor in selecting the ________________ reactant.

6. In industry, the least expensive reactant is usually used as the ________________ reactant. In this way, the more expensive reactant is completely used up, while some of the cheaper reactant is left over.

7. The ________________ yield is a way to describe reaction efficiency.

8. The percentage yield describes how close the ________________ yield is to the ________________ yield.

9. The ________________ yield must be measured experimentally.

10. The percentage yield figures can be used to predict what the ________________ yield will likely be.

Answer the following items in the space provided.

11. When 3.00 g of Mg is ignited in 2.20 g of pure oxygen, what is the limiting reactant? What is the theoretical yield of MgO?

\[ 2\text{Mg(s)} + \text{O}_2(g) \rightarrow 2\text{MgO(s)} \]
12. When 32 g of O₂ reacts with 23 g of C₂H₅OH, what is the limiting reactant? What is the theoretical yield in grams of CO₂?

\[ \text{C}_2\text{H}_5\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(l) \]

13. What is the limiting reactant when 154 g of Ag reacts with 189 g of HNO₃? What is the theoretical yield in grams of AgNO₃?

\[ 3\text{Ag}(s) + 4\text{HNO}_3(aq) \rightarrow 3\text{AgNO}_3(aq) + \text{NO}(g) + 2\text{H}_2\text{O}(l) \]

14. A student used 1.34 g of silver to produce silver nitrate. The actual yield was 2.01 g. Calculate the percentage yield.

\[ 3\text{Ag}(s) + 4\text{HNO}_3(aq) \rightarrow 3\text{AgNO}_3(aq) + \text{NO}(g) + 2\text{H}_2\text{O}(l) \]

15. To prepare the paint pigment chrome yellow, PbCrO₄, a student started with 5.552 g of Pb(NO₃)₂. The actual yield of PbCrO₄ was 5.096 g. Calculate the theoretical yield and the percentage yield.

\[ \text{Pb(NO}_3)_2(aq) + \text{Na}_2\text{CrO}_4(aq) \rightarrow \text{PbCrO}_4(s) + 2\text{NaNO}_3(aq) \]
16. Determine the actual yield in grams of MgO when 20.0 g of magnesium is burned in air. The percentage yield of the reaction is 97.9%.

\[ 2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s) \]

17. Determine the actual yield of Fe\textsubscript{2}O\textsubscript{3} when 10.0 g of iron(II) sulfide is burned in air. The percentage yield of the reaction is 88.1%.

\[ 4\text{FeS}(s) + 7\text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s) + 4\text{SO}_2(g) \]

18. Determine the actual yield in grams of CCl\textsubscript{4} if 175.0 g of Cl\textsubscript{2} reacts with methane. The percentage yield of the reaction is 75.4%.

\[ \text{CH}_4(g) + 4\text{Cl}_2(g) \rightarrow \text{CCl}_4(g) + 4\text{HCl}(g) \]
Concept Review: Calculating Quantities in Reactions

1. mole
2. balance
3. relative
4. coefficients
5. molar mass
6. liquids
7. density
8. Avogadro’s number
9. c
10. b
11. b
12. c
13. c
14. 1.00 g Ca₃(PO₄)₂ \times 
    \begin{aligned}
    &1 \text{ mol } \text{Ca}_3(\text{PO}_4)_2/310.18 \text{ g } \text{Ca}_3(\text{PO}_4)_2 \\
    &\times 2 \text{ mol } \text{P}/1 \text{ mol } \text{Ca}_3(\text{PO}_4)_2 \\
    &\times 30.97 \text{ g } \text{P}/1 \text{ mol } \text{P} \\
    &= 0.200 \text{ g } \text{P}
    \end{aligned}
15. 18 g Al \times 1 mol Al/26.98 g Al
    \times 2 \text{ mol } \text{AlCl}_3/2 \text{ mol Al} \\
    \times 133.33 \text{ g } \text{AlCl}_3/1 \text{ mol } \text{AlCl}_3
    = 89 \text{ g } \text{AlCl}_3
16. 1150 g C₆H₁₂O₆ \times 1 \text{ mol} \\
    \begin{aligned}
    &\text{C}_6\text{H}_{12}\text{O}_6/180.18 \text{ g } \text{C}_6\text{H}_{12}\text{O}_6 \\
    &\times 2 \text{ mol } \text{C}_2\text{H}_5\text{OH}/1 \text{ mol } \text{C}_6\text{H}_{12}\text{O}_6 \\
    &\times 46.08 \text{ g } \text{C}_2\text{H}_5\text{OH}/1 \text{ mol } \text{C}_2\text{H}_5\text{OH} \\
    &= 588 \text{ g } \text{C}_2\text{H}_5\text{OH}
    \end{aligned}
17. 25.5 g Mg \times 1 \text{ mol Mg}/24.30 g Mg
    \times 1 \text{ mol } \text{O}_2/2 \text{ mol Mg} \\
    \times 0.525 \text{ mol } \text{O}_2
    = 0.123 \text{ mol Mg}
18. 1.0 \text{ mol } \text{C}_5\text{H}_11\text{OH} \times 10 \text{ mol } \text{CO}_2/2 \text{ mol } \text{C}_5\text{H}_11\text{OH} \\
    \times 44.01 \text{ g } \text{CO}_2/1 \text{ mol } \text{CO}_2 \\
    = 220 \text{ g } \text{CO}_2
19. 500.0 \text{ g } \text{CCl}_3\text{NO}_2 \times 1 \text{ mol} \\
    \begin{aligned}
    &\text{CCl}_3\text{NO}_2/164.37 \text{ g } \text{CCl}_3\text{NO}_2 \\
    &\times 1 \text{ mol } \text{CH}_2\text{NO}_2/1 \text{ mol } \text{CCl}_3\text{NO}_2 \\
    &= 3.042 \text{ mol } \text{CH}_2\text{NO}_2
    \end{aligned}
20. 122 g KClO₃ \times 1 \text{ mol } \text{KClO}_3/122.55 g \\
    \begin{aligned}
    &\text{KClO}_3/32.00 \text{ g } \text{O}_2/1 \text{ mol } \text{O}_2 \\
    &\times 3 \text{ mol } \text{O}_2/2 \text{ mol } \text{KClO}_3 \\
    &\times 1 \text{ L } \text{O}_2/1.33 \text{ g } \text{O}_2 = 35.9 \text{ L } \text{O}_2
    \end{aligned}
21. 3.4 \text{ L } \text{O}_2 \times 1.33 \text{ g } \text{O}_2/1 \text{ L } \text{O}_2 \\
    \begin{aligned}
    &\times 2 \text{ mol } \text{KCl}/3 \text{ mol } \text{O}_2 \\
    &\times 74.55 \text{ g } \text{KCl}/1 \text{ mol } \text{KCl} \\
    &= 7.0 \text{ g } \text{KCl}
    \end{aligned}
22. 910 g \text{Ca}_3\text{P}_2 \times 1 \text{ mol } \text{Ca}_3\text{P}_2/182.18 g \\
    \begin{aligned}
    &\text{Ca}_3\text{P}_2/2 \text{ mol } \text{PH}_3/1 \text{ mol Ca}_3\text{P}_2 \\
    &\times 33.99 \text{ g } \text{PH}_3/1 \text{ mol } \text{PH}_3 \\
    &\times 1 \text{ L } \text{PH}_3/1.517 \text{ g } \text{PH}_3 \\
    &= 220 \text{ L } \text{PH}_3
    \end{aligned}
23. 93 g \text{P} \times 1 \text{ mol } \text{P}/30.97 g \text{P} \times 5 \text{ mol } \\
    \begin{aligned}
    &\text{O}_2/4 \text{ mol } \text{P} \times 32.00 \text{ g } \text{O}_2/1 \text{ mol } \text{O}_2 \\
    &\times 100. \text{ g } \text{air}/23 \text{ g } \text{O}_2 = 520 \text{ g } \text{air}
    \end{aligned}
24. 5.00 \text{ metric tons coke} \times 85.5\% \\
    \begin{aligned}
    &\text{C}/100.0\% \text{ coke} \times 1.00 \times 10^{6} \text{ g/1 metric ton} \\
    &\times 44.01 \text{ g } \text{CO}_2/1 \text{ mol } \text{CO}_2 \times 1 \text{ mol } \\
    &\text{C}/12.01 \text{ g } \text{C} \times 1 \text{ mol } \text{CO}_2/1 \text{ mol } \text{C} \\
    &\times 1 \text{ metric ton}/1.00 \times 10^{6} \text{ g} = 15.7 \text{ metric tons } \text{CO}_2
    \end{aligned}
25. 100 mL \text{CS}_2 \times 1.26 g \text{CS}_2/1 mL \text{CS}_2 \times \\
    \begin{aligned}
    &1 \text{ mol } \text{CS}_2/76.15 g \text{CS}_2 \times 2 \text{ mol } \text{SO}_2/1 \text{ mol } \text{CS}_2 \\
    &\times 22.4 L \text{SO}_2/1 \text{ mol } \text{SO}_2 = \\
    &74.1 L \text{SO}_2 74.01 L \text{SO}_2
    \end{aligned}
22. 910 g \text{Ca}_3\text{P}_2 \times 1 \text{ mol } \text{Ca}_3\text{P}_2/182.18 g \\
    \begin{aligned}
    &\text{Ca}_3\text{P}_2/2 \text{ mol } \text{PH}_3/1 \text{ mol Ca}_3\text{P}_2 \\
    &\times 33.99 \text{ g } \text{PH}_3/1 \text{ mol } \text{PH}_3 \\
    &\times 1 \text{ L } \text{PH}_3/1.517 \text{ g } \text{PH}_3 \\
    &= 220 \text{ L } \text{PH}_3
    \end{aligned}

Concept Review: Limiting Reactants and Percentage Yield

1. excess
2. limiting, product
3. limiting
4. stoichiometric
5. limiting
6. excess
7. percentage
8. actual; theoretical
9. actual
10. actual
11. 3.00 g Mg \times (1 \text{ mol Mg}/24.30 g Mg) = \\
    0.123 \text{ mol Mg} \\
    2.20 g \text{O}_2 \times (1 \text{ mol } \text{O}_2/32.00 \text{ g } \text{O}_2) = \\
    0.0688 \text{ mol } \text{O}_2 \\
    0.0688 \text{ mol } \text{O}_2 \times (2 \text{ mol Mg}/1 \text{ mol } \text{O}_2) = \\
    0.138 \text{ mol Mg needed.} \\
    \text{Mg is limiting.}
    0.123 \text{ mol Mg} \times (2 \text{ mol } \text{MgO}/2 \text{ mol Mg}) \\
    \times (40.30 \text{ g } \text{MgO}/1 \text{ mol } \text{MgO}) = 4.96 \text{ g } \text{MgO}
12. \(23 \text{ g } \text{C}_2\text{H}_5\text{OH} \times (1 \text{ mol } \text{C}_2\text{H}_5\text{OH}/46.08 \text{ g } \text{C}_2\text{H}_5\text{OH}) = 0.50 \text{ mol } \text{C}_2\text{H}_5\text{OH}\)
\(32 \text{ g } \text{O}_2 \times (1 \text{ mol } \text{O}_2/32.00 \text{ g } \text{O}_2) = 1.0 \text{ mol } \text{O}_2\)
1.0 mol \(\text{O}_2 \times (1 \text{ mol } \text{C}_2\text{H}_5\text{OH}/3 \text{ mol } \text{O}_2) = 0.33 \text{ mol } \text{C}_2\text{H}_5\text{OH} \text{ needed}\)
\(\text{O}_2 \) is limiting.
1.0 mol \(\text{O}_2 \times (2 \text{ mol } \text{CO}_2/3 \text{ mol } \text{O}_2) \times (44.01 \text{ g } \text{CO}_2/1 \text{ mol } \text{CO}_2) = 29 \text{ g } \text{CO}_2\)

13. \(154 \text{ g } \text{Ag} \times (1 \text{ mol } \text{Ag}/107.87 \text{ g } \text{Ag}) = 1.43 \text{ mol } \text{Ag}\)
\(189 \text{ g } \text{HNO}_3 \times (1 \text{ mol } \text{HNO}_3/63.02 \text{ g } \text{HNO}_3) = 3.00 \text{ mol } \text{HNO}_3\)
3.00 mol \(\text{HNO}_3 \times (3 \text{ mol } \text{Ag}/4 \text{ mol } \text{HNO}_3) = 2.25 \text{ mol } \text{Ag} \text{ needed}\)
\(\text{Ag} \) is limiting.
1.43 mol \(\text{Ag} \times (3 \text{ mol } \text{AgNO}_3/3 \text{ mol } \text{Ag}) \times (169.88 \text{ g } \text{AgNO}_3/1 \text{ mol } \text{AgNO}_3) = 243 \text{ g } \text{AgNO}_3\)

14. \(1.34 \text{ g } \text{Ag} \times (1 \text{ mol } \text{Ag}/107.87 \text{ g } \text{Ag}) \times (3 \text{ mol } \text{AgNO}_3/3 \text{ mol } \text{Ag}) \times (169.88 \text{ g } \text{AgNO}_3/1 \text{ mol } \text{AgNO}_3) = 2.11 \text{ g } \text{AgNO}_3\)
percentage yield = (actual yield/theoretical yield) \(\times 100\)
\((2.10 \text{ g } \text{AgNO}_3 \text{ actual yield}/2.11 \text{ g } \text{AgNO}_3 \text{ theoretical yield}) \times 100 = 95.3\%\)

15. \(5.552 \text{ g } \text{Pb(NO}_3)_2 \times (1 \text{ mol } \text{Pb(NO}_3)_2/331.2 \text{ g } \text{Pb(NO}_3)_2) \times (1 \text{ mol } \text{PbCrO}_4/1 \text{ mol } \text{Pb(NO}_3)_2) \times (323.2 \text{ g } \text{PbCrO}_4/1 \text{ mol } \text{PbCrO}_4) = 2.11 \text{ g } \text{PbCrO}_4\)
percentage yield = (actual yield/theoretical yield) \(\times 100\) = \(5.096 \text{ g } \text{PbCrO}_4/5.418 \text{ g } \text{PbCrO}_4 \times 100 = 94.06\%\)

16. \(20.0 \text{ g } \text{Mg} \times (1 \text{ mol } \text{Mg}/24.30 \text{ g } \text{Mg}) \times (2 \text{ mol } \text{MgO}/2 \text{ mol } \text{Mg}) \times (40.30 \text{ g } \text{MgO}/1 \text{ mol } \text{MgO}) \times (97.9\% \text{ percentage yield}/100\% \text{ theoretical yield}) = 32.5 \text{ g } \text{MgO}\)

17. \(10.0 \text{ g } \text{FeS} \times (1 \text{ mol } \text{FeS}/87.92 \text{ g } \text{FeS}) \times (2 \text{ mol } \text{Fe}_2\text{O}_3/4 \text{ mol } \text{FeS}) \times (159.70 \text{ g } \text{Fe}_2\text{O}_3/1 \text{ mol } \text{Fe}_2\text{O}_3) = 9.08 \text{ g } \text{Fe}_2\text{O}_3\)
theoretical yield
\(9.08 \text{ g } \text{Fe}_2\text{O}_3 \times (88.1\% \text{ percentage yield}/100\% \text{ theoretical yield}) = 8.00 \text{ g } \text{Fe}_2\text{O}_3\)

18. \(175.0 \text{ g } \text{Cl}_2 \times (1 \text{ mol } \text{Cl}_2/70.90 \text{ g } \text{Cl}_2) \times (1 \text{ mol } \text{CCl}_4/4 \text{ mol } \text{Cl}_2) \times (153.81 \text{ g } \text{CCl}_4/1 \text{ mol } \text{CCl}_4) \times (75.4\% \text{ actual yield}/100\% \text{ theoretical yield}) = 71.6 \text{ g } \text{CCl}_4\)

Concept Review:
Stoichiometry and Cars

6. If there is too much oxygen and not enough gasoline, the engine will stall. If, on the other hand, gasoline is in excess and there is not enough oxygen, lack of oxygen may prevent the mixture from igniting.

7. \(68.0 \text{ L } \text{N}_2 \times (0.916 \text{ g } \text{N}_2/1 \text{ L } \text{N}_2) \times (1 \text{ mol } \text{N}_2/28.02 \text{ g } \text{N}_2) \times (2 \text{ mol } \text{NaN}_3/3 \text{ mol } \text{N}_2) \times (65.02 \text{ g } \text{NaN}_3/1 \text{ mol } \text{NaN}_3) = 96.4 \text{ g } \text{NaN}_3\)

8. \(375 \text{ mL } \text{C}_8\text{H}_18 \times (0.692 \text{ g } \text{C}_8\text{H}_18/1 \text{ mL } \text{C}_8\text{H}_18) \times (1 \text{ mol } \text{C}_8\text{H}_18/114.26 \text{ g } \text{C}_8\text{H}_18) \times (25 \text{ mol } \text{O}_2/2 \text{ mol } \text{C}_8\text{H}_18) \times (32.00 \text{ g } \text{O}_2/1 \text{ mol } \text{O}_2) \times (1 \text{ L } \text{O}_2/1.33 \text{ g } \text{O}_2) = 2.97 \times 10^3 \text{ g } \text{O}_2\)

Additional Problems

STOICHIOMETRY

1. 15.0 mol (NH_4)_2SO_4
2. a. 51 g Al
   b. 101 g Fe
   c. 1.83 mol Fe_2O_3
3. 0.303 g H_2
4. H_2SO_4 + 2KOH → K_2SO_4 + 2H_2O; 1.11 g H_2SO_4
5. a. H_3PO_4 + 2NH_3 → (NH_4)_2HPO_4
   b. 0.293 mol (NH_4)_2HPO_4
   c. 970 kg NH_3
6. a. 90.0 mol ZnCO_3; 60.0 mol C_6H_8O_7
   b. 13.5 kg H_2O; 33.0 kg CO_2