Section 7.2: Mass Relationships in Chemical Reactions

Tutorial 1 Practice, page 323–324

1. (a) Given: $m_{CaCO_3} = 0.50\text{ g}$

Required: mass of hydrochloric acid, m_{HCl}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

$CaCO_3(s)$ + $2\ HCl(aq) \rightarrow CO_2(g) + H_2O(l) + CaCl_2(aq)$

0.50 g m_{HCl}

100.09 g/mol 36.46 g/mol

Step 2. Convert mass of calcium carbonate to amount of calcium carbonate.

$$n_{CaCO_3} = 0.50\ \cancel{g} \times \frac{1\text{ mol}_{CaCO_3}}{100.09\ \cancel{g}}$$

$$n_{CaCO_3} = 0.004\ 996\text{ mol}\ \ \text{[two extra digits carried]}$$

Step 3. Convert amount of calcium carbonate to amount of hydrochloric acid.

$$n_{HCl} = 0.004\ 996\ \cancel{\text{mol}_{CaCO_3}} \times \frac{2\text{ mol}_{HCl}}{1\ \cancel{\text{mol}_{CaCO_3}}}$$

$$n_{HCl} = 0.009\ 992\text{ mol}\ \ \text{[two extra digits carried]}$$

Step 4. Convert amount of hydrochloric acid to mass of hydrochloric acid.

$$m_{HCl} = (0.009\ 992\ \cancel{\text{mol}})\left(\frac{36.46\text{ g}}{1\ \cancel{\text{mol}}}\right)$$

$$m_{HCl} = 0.36\text{ g}$$

Statement: 0.50 g of calcium carbonate will neutralize 0.36 g of hydrochloric acid.

(b) Given: $m_{CaCO_3} = 0.50\text{ g}$; $n_{CaCO_3} = 0.004\ 996\text{ mol}$

Required: mass of calcium chloride, m_{CaCl_2}

Solution:

Step 1. List the given values, the required values, and the corresponding molar masses.

$CaCO_3(s) + 2\ HCl(aq) \rightarrow CO_2(g) + H_2O(l) + CaCl_2(aq)$

0.004 996 mol n_{CaCl_2}

0.50 g m_{CaCl_2}

100.09 g/mol 110.98 g/mol

Step 2. Convert amount of calcium carbonate to amount of calcium chloride.

$$n_{CaCl_2} = n_{CaCO_3}$$

$$n_{CaCl_2} = 0.004\ 996\text{ mol}$$

Step 3. Convert amount of calcium chloride to mass of calcium chloride.

$$m_{CaCl_2} = (0.004\ 996\ \cancel{mol})\left(\frac{110.98\ g}{1\ \cancel{mol}}\right)$$

$$m_{CaCl_2} = 0.55\ g$$

Statement: The mass of calcium chloride that will be produced is 0.55 g.

2. (a) Given: $m_{C_3H_8} = 8.8\ kg$

Required: mass of oxygen, m_{O_2}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

$C_3H_8(g)$ + $5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$
8.8 kg m_{O_2}
44.11 g/mol 32.00 g/mol

Step 2. Convert mass of propane to amount of propane.

$$n_{C_3H_8} = 8.8\ \cancel{kg} \times \frac{1000\ \cancel{g}}{1\ \cancel{kg}} \times \frac{1\ mol_{C_3H_8}}{44.11\ \cancel{g}}$$

$$n_{C_3H_8} = 199.5\ mol\ \text{[two extra digits carried]}$$

Step 3. Convert amount of propane to amount of oxygen.

$$n_{O_2} = 199.5\ \cancel{mol_{C_3H_8}} \times \frac{5\ mol_{O_2}}{1\ \cancel{mol_{C_3H_8}}}$$

$$n_{O_2} = 997.5\ mol\ \text{(two extra digits carried)}$$

Step 4. Convert amount of oxygen to mass of oxygen.

$$m_{O_2} = (997.5\ \cancel{mol})\left(\frac{32.00\ \cancel{g}}{1\ \cancel{mol}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right)$$

$$m_{O_2} = 32\ kg$$

Statement: The mass of oxygen required to burn 8.8 kg propane is 32 kg.

(b) Given: $m_{C_3H_8} = 8.8\ kg$; $n_{C_3H_8} = 199.5\ mol$

Required: mass of carbon dioxide, m_{CO_2}

Solution:

Step 1. List the given values, the required values, and the corresponding molar masses.

$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$
199.5 mol n_{CO_2}
8.8 kg m_{CO_2}
44.11 g/mol 44.01 g/mol

Step 2. Convert amount of propane to amount of carbon dioxide.

$$n_{CO_2} = 199.5\ \cancel{mol}_{C_3H_8} \times \frac{3\ mol_{CO_2}}{1\ \cancel{mol}_{C_3H_8}}$$

$$n_{CO_2} = 598.5\ mol$$

Step 3. Convert amount of carbon dioxide to mass of carbon dioxide.

$$m_{CO_2} = (598.5\ \cancel{mol})\left(\frac{44.01\ \cancel{g}}{1\ \cancel{mol}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right)$$

$$m_{CO_2} = 26\ kg$$

Statement: The mass of carbon dioxide that will be produced is 26 kg.

3. (a) 4 Na(s) + O_2(g) → 2 Na_2O(s)

(b) Given: $m_{Na} = 3.45\ g$

Required: mass of oxygen, m_{O_2}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

4 Na(s)	+	O_2(g) → 2 Na_2O(s)
3.45 g		m_{O_2}
22.99 g/mol		32.00 g/mol

Step 2. Convert mass of sodium to amount of sodium.

$$n_{Na} = 3.45\ \cancel{g} \times \frac{1\ mol_{Na}}{22.99\ \cancel{g}}$$

$n_{Na} = 0.150\ 07\ mol$ [two extra digits carried]

Step 3. Convert amount of sodium to amount of oxygen.

$$n_{O_2} = 0.15007\ \cancel{mol}_{Na} \times \frac{1\ mol_{O_2}}{4\ \cancel{mol}_{Na}}$$

$n_{O_2} = 0.037\ 518\ mol$ [two extra digits carried]

Step 4. Convert amount of oxygen to mass of oxygen.

$$m_{O_2} = (0.037\ 518\ \cancel{mol})\left(\frac{32.00\ g}{1\ \cancel{mol}}\right)$$

$$m_{O_2} = 1.20\ g$$

Statement: To react completely with 3.45 g of sodium, 1.20 g of oxygen is required.

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1. A balanced chemical equation is required before solving a stoichiometry problem because the coefficients of the equation give the mole ratio of the amounts of reactants and the amounts of products produced.

2. Combining stoichiometric amounts of ethanoic acid and sodium hydrogen carbonate would result in a reaction in which both reactants are used up completely. Since additional bubbling was observed when the student added more vinegar, some unreacted sodium hydrogen carbonate must have been present in the solution. Therefore, ethanoic acid and sodium hydrogen carbonate were not present in stoichiometric amounts initially.

3. From the balanced chemical equation, the ratio of the amount of aluminum to the amount of oxygen is 4:3.

Then 2.0 mol of aluminum, Al(s), and 1.5 mol of oxygen, O_2(g), are stoichiometric amounts because the ratio 2.0:1.5 equals 4:3.

Then 0.60 mol of aluminum, Al(s), and 0.45 mol of oxygen, O_2(g), are stoichiometric amounts because the ratio 0.60:0.45 equals 4:3.

So, 108 g of aluminum, Al(s), and 96 g of oxygen, O_2(g), are stoichiometric amounts because:

$$n_{\mathrm{Al}} = 108\ \cancel{\mathrm{g}} \times \frac{1\ \mathrm{mol}_{\mathrm{Al}}}{26.98\ \cancel{\mathrm{g}}} \qquad n_{\mathrm{O_2}} = 96\ \cancel{\mathrm{g}} \times \frac{1\ \mathrm{mol}_{\mathrm{O_2}}}{32.00\ \cancel{\mathrm{g}}}$$

$$n_{\mathrm{Al}} = 4.00\ \mathrm{mol} \qquad n_{\mathrm{O_2}} = 3.0\ \mathrm{mol}$$

The ratio of the amounts of these masses of aluminum and oxygen is 4:3.

4. (a) From the equation, 1 mol of lithium reacts with 1 mol of cobalt oxide. If the initial amounts of the reactants are equal, the amounts of lithium and cobalt oxide reacted are also equal. That means 80 % of the initial amount of cobalt oxide is converted, therefore, the percentage of cobalt oxide that remains is 20 %.

(b) The relative amounts of lithium and cobalt oxide remains to be 1:1 as the battery is recharged because the reverse reaction produces equal amounts of lithium and cobalt oxide.

5. (a) Given: $n_{\mathrm{Ca(OH)_2}} = 1.00\ \mathrm{g}$

Required: mass of calcium oxide, m_{CaO}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

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

1.00 g $\quad m_{\mathrm{CaO}}$

74.10 g/mol $\quad$ 56.08 g/mol

Step 2. Convert mass of calcium hydroxide to amount of calcium hydroxide.

$$n_{\mathrm{Ca(OH)_2}} = 1.00\ \cancel{\mathrm{g}} \times \frac{1\ \mathrm{mol}_{\mathrm{Ca(OH)_2}}}{74.10\ \cancel{\mathrm{g}}}$$

$n_{\mathrm{Ca(OH)_2}} = 0.013\ 495\ \mathrm{mol}$ [two extra digits carried]

Step 3. Convert amount of calcium hydroxide to amount of calcium oxide.

$n_{\mathrm{CaO}} = n_{\mathrm{Ca(OH)_2}}$

$n_{\mathrm{CaO}} = 0.013\ 495\ \mathrm{mol}$ [two extra digits carried]

Step 4. Convert amount of calcium oxide to mass of calcium oxide.

$$m_{CaO} = (0.013\ 495\ \cancel{mol})\left(\frac{56.08\ g}{1\ \cancel{mol}}\right)$$

$$m_{CaO} = 0.757\ g$$

Statement: The mass of calcium oxide that will be produced is 0.757 g.

(b) Given: $n_{Ca(OH)_2} = 1.00\ g$; $n_{Ca(OH)_2} = 0.013\ 495\ mol$

Required: mass of water, m_{H_2O}

Solution:

Step 1. List the given values, the required values, and the corresponding molar masses.

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

0.013 495 mol	n_{H_2O}
1.00 g	m_{H_2O}
74.10 g/mol	18.02 g/mol

Step 2. Convert amount of calcium hydroxide to amount of water.

$$n_{H_2O} = n_{Ca(OH)_2}$$

$$n_{H_2O} = 0.013\ 495\ mol$$

Step 3. Convert amount of water to mass of water.

$$m_{H_2O} = (0.013\ 495\ \cancel{mol})\left(\frac{18.02\ g}{1\ \cancel{mol}}\right)$$

$$m_{H_2O} = 0.243\ g$$

Statement: The mass of water expected is 0.243 g.

(c) Stoichiometry is not required to solve (b). When the masses of two of the three entities involved in a chemical reaction are known, the mass of the third entity can be calculated using the law of conservation of mass.

$$m_{Ca(OH)_2} = m_{CaO} + m_{H_2O}$$

$$1.00\ g = 0.757\ g + m_{H_2O}$$

$$m_{H_2O} = 1.00\ g - 0.757\ g$$

$$m_{H_2O} = 0.243\ g$$

(d) The answers to (a) and (b) illustrate the law of conservation of mass which states that the total mass of reactants is equal to the total mass of the products.

Total mass of reactants: $m_{Ca(OH)_2} = 1.00\ g$

Total mass of products: $m_{CaO} + m_{H_2O} = 0.757\ g + 0.243\ g = 1.00\ g$

(e) The prediction is incorrect because the mass of products cannot be greater than the mass of reactants. Although the amounts of the three chemicals are equal, their masses are not equal.

6. (a) The reaction involved is a single displacement reaction.
(b) Given: $m_{Cl_2} = 1.5\ \text{kg}$

Required: mass of iodine, m_{I_2}

Solution:
Step 1. List the given value, the required value, and the corresponding molar masses.
$Cl_2(g) + 2\ KI(aq) \rightarrow I_2(s) + 2\ KCl(aq)$
1.5 kg $\qquad$ m_{I_2}

70.90 g/mol $\qquad$ 253.80 g/mol
Step 2. Convert mass of chlorine to amount of chlorine.

$$n_{Cl_2} = 1.5\ \cancel{\text{kg}} \times \frac{1000\ \cancel{\text{g}}}{1\ \cancel{\text{kg}}} \times \frac{1\ \text{mol}_{Cl_2}}{70.90\ \cancel{\text{g}}}$$

$n_{Cl_2} = 21.16$ mol [two extra digits carried]
Step 3. Convert amount of chlorine to amount of iodine.
$n_{I_2} = n_{Cl_2}$

$n_{I_2} = 21.16\ \text{mol}$ (two extra digits carried)
Step 4. Convert amount of iodine to mass of iodine.

$$m_{I_2} = (21.16\ \cancel{\text{mol}})\left(\frac{253.80\ \text{g}}{1\ \cancel{\text{mol}}}\right)$$

$m_{I_2} = 5400$ g
Statement: The mass of iodine that can be produced from 1.5 kg of chlorine is 5400 g.
7. (a) $4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$
(b) Given: $n_{O_2} = 15\ \text{mol}$

Required: amount of iron, n_{Fe}; amount of iron(III) oxide, $n_{Fe_2O_3}$

Solution:
Step 1. List the given value and the required values.
$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$
n_{Fe} $\qquad$ 15 mol $\qquad$ $n_{Fe_2O_3}$

Step 2. Convert amount of oxygen to amounts of iron and iron(III) oxide.

$$n_{Fe} = 15\ \cancel{\text{mol}_{O_2}}\left(\frac{4\ \text{mol}_{Fe}}{3\ \cancel{\text{mol}_{O_2}}}\right) \qquad n_{Fe_2O_3} = 15\ \cancel{\text{mol}_{O_2}}\left(\frac{2\ \text{mol}_{Fe_2O_3}}{3\ \cancel{\text{mol}_{O_2}}}\right)$$

$n_{Fe} = 20$ mol $\qquad$ $n_{Fe_2O_3} = 10$ mol

Statement: So, 20 mol of iron reacts with 15 mol of oxygen to produce 10 mol of iron(III) oxide.

(c) Given: $m_{Fe_2O_3} = 4.60\ g$

Required: mass of iron, m_{Fe}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$

m_{Fe} 4.60 g

55.85 g/mol 159.70 g/mol

Step 2. Convert mass of iron(III) oxide to amount of iron(III) oxide.

$$n_{Fe_2O_3} = 4.60\ \cancel{g} \times \frac{1\ mol_{Fe_2O_3}}{159.70\ \cancel{g}}$$

$n_{Fe_2O_3} = 0.028\ 804$ mol [two extra digits carried]

Step 3. Convert amount of iron(III) oxide to amount of iron.

$$n_{Fe} = 0.028\ 804\ \cancel{mol_{Fe_2O_3}} \times \frac{4\ mol_{Fe}}{2\ \cancel{mol_{Fe_2O_3}}}$$

$n_{Fe} = 0.057\ 608$ mol [two extra digits carried]

Step 4. Convert amount of iron to mass of iron.

$$m_{Fe} = (0.057\ 608\ \cancel{mol})\left(\frac{55.85\ g}{1\ \cancel{mol}}\right)$$

$m_{Fe} = 3.22\ g$

Statement: The mass of iron reacted to produce 4.60 g of iron(III) oxide is 3.22 g.

(d) Since the total mass of product is 4.60 g, the total mass of iron and oxygen reacted is also 4.60 g, according to the law of conservation of mass.

(e) Stoichiometry is not required to solve (d) since the answer can be determined using the law of conservation of mass.

8. (a) Given: $m_{C_2H_6O} = 1.15\ g$

Required: mass of carbon dioxide, m_{CO_2}

Solution:

Step 1. Write a balanced chemical equation. List the given value, the required value, and the corresponding molar masses.

$C_2H_6O(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

1.15g m_{CO_2}

46.08 g/mol 44.01 g/mol

Step 2. Convert mass of ethanol to amount of ethanol.

$$n_{C_2H_6O} = 1.15\ \cancel{g} \times \frac{1\ mol_{C_2O_6H}}{46.08\ \cancel{g}}$$

$n_{C_2H_6O} = 0.024\ 957$ mol [two extra digits carried]

Step 3. Convert amount of ethanol to amount of carbon dioxide.

$$n_{CO_2} = 0.024\ 957\ \cancel{mol_{C_2H_6O}} \times \frac{2\ mol_{CO_2}}{1\ \cancel{mol_{C_2H_6O}}}$$

$n_{CO_2} = 0.049\ 914$ mol [two extra digits carried]

Step 4. Convert amount of carbon dioxide to mass of carbon dioxide.

$$m_{CO_2} = (0.049\ 914\ \cancel{mol})\left(\frac{44.01\ g}{1\ \cancel{mol}}\right)$$

$m_{CO_2} = 2.20$ g

Statement: The mass of carbon dioxide produced from the complete combustion of 1.15 g of ethanol is 2.20 g.

(b) Incomplete combustion results from an insufficient supply of oxygen. This process introduces pollutants like carbon monoxide and soot into the environment.

9. (a) $NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(g)$

(b) The reaction is a decomposition reaction.

(c) Given: $m_{NH_4NO_3} = 1.00$ g

Required: mass of dinitrogen monoxide, m_{N_2O}

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

$NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(g)$

1.00 g $\quad m_{N_2O}$

80.06 g/mol $\quad$ 44.02 g/mol

Step 2. Convert mass of ammonium nitrate to amount of ammonium nitrate.

$$n_{NH_4NO_3} = 1.00\ \cancel{g} \times \frac{1\ mol_{NH_4NO_3}}{80.06\ \cancel{g}}$$

$n_{NH_4NO_3} = 0.012\ 491$ mol [two extra digits carried]

Step 3. Convert amount of ammonium nitrate to amount of dinitrogen monoxide.

$n_{N_2O} = n_{NH_4NO_3}$

$n_{N_2O} = 0.012\ 491$ mol [two extra digits carried]

Step 4. Convert amount of dinitrogen monoxide to mass of dinitrogen monoxide.

$$m_{N_2O} = (0.012\ 491\ mol)\left(\frac{44.02\ g}{1\ mol}\right)$$

$m_{N_2O} = 0.550$ g

Statement: When 1.00 g of ammonium nitrate reacts, 0.550 g of dinitrogen monoxide will be produced.

10. Given: $m_{NH_3} = 425\text{ kg}$

Required: mass of nitric acid, m_{HNO_3}

Analysis: Use the equations to determine the mole ratio of ammonia to nitric acid in the process.
$4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$
amount of NH_3 to amount of NO = 4:4 = 1:1
$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$
amount of NO to amount of NO_2 = 2:2 = 1:1
Therefore, the amounts of NH_3 and NO_2 are in the ratio 1:1.
$3\ NO_2(g) + H_2O(g) \rightarrow 2\ HNO_3(aq) + NO(g)$
amount of NO_2 to amount of HNO_3 = 3:2
Therefore, the amounts of ammonia and nitric acid are also in the ratio 3:2.
Then, determine the mass of nitric acid produced from the mass of ammonia.

Solution:

Step 1. List the given value, the required value, and the corresponding molar masses.

3 mol $NH_3(g)$ →	2 mol $HNO_3(aq)$
425 kg	m_{HNO_3}
17.04 g/mol	63.02 g/mol

Step 2. Convert mass of ammonia to amount of ammonia.

$$n_{NH_3} = 425\ \cancel{kg} \times \frac{1000\ \cancel{g}}{1\ \cancel{kg}} \times \frac{1\ mol_{NH_3}}{17.04\ \cancel{g}}$$

$n_{NH_3} = 24\,941$ mol [two extra digits carried]

Step 3. Convert amount of ammonia to amount of nitric acid.

$$n_{HNO_3} = 24\,941\ \cancel{mol_{NH_3}} \times \frac{2\ mol_{HNO_3}}{3\ \cancel{mol_{NH_3}}}$$

$n_{HNO_3} = 16\,627$ mol [two extra digits carried]

Step 4. Convert amount of nitric acid to mass of nitric acid.

$$m_{HNO_3} = (16\,627\ \cancel{mol})\left(\frac{63.02\ \cancel{g}}{1\ \cancel{mol}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right)$$

$m_{HNO_3} = 1050$ kg

Statement: The mass of nitric acid that can be produced from 425 kg of ammonia is 1050 kg.