18. T
19. solvent
20. stoichiometry
21. balanced
22. amounts

## 2.10 EXTENSION EXERCISE

(Page 101)

### LIMITING AND EXCESSREAGENTS—ADDITIONAL PRACTICE

1. (a) $AgNO_{3(aq)} + KCl_{(aq)} \rightarrow AgCl_{(s)} + KNO_{3(aq)}$

$$n_{AgNO_3} = 5.10\ \cancel{g\ AgNO_3} \times \frac{1\ mol\ AgNO_3}{169.88\ \cancel{g\ AgNO_3}}$$

$$n_{AgNO_3} = 0.0300\ mol$$

$$n_{KCl} = 4.48\ \cancel{g\ KCl} \times \frac{1\ mol\ KCl}{74.55\ \cancel{g\ KCl}}$$

$$n_{KCl} = 0.0601\ mol$$

Therefore, $AgNO_{3(aq)}$ is the limiting reagent.

(b) $$m_{AgCl} = 0.0300\ \cancel{mol\ AgNO_3} \times \frac{1\ \cancel{mol\ AgCl}}{1\ \cancel{mol\ AgNO_3}} \times \frac{143.32\ g\ AgCl}{1\ \cancel{mol\ AgCl}}$$

$$m_{AgCl} = 4.3\ g\ AgCl$$

The mass of silver chloride formed is 4.3 g.

Before the reaction, there is 0.0601 mol potassium chloride. During the reaction, 0.0300 mol potassium chloride is consumed. The mole ratio is 1:1. Therefore, 0.0301 mol potassium chloride remain after the reaction.

$$m_{KCl} = 0.0301\ \cancel{mol\ KCl} \times \frac{74.55\ g\ KCl}{1\ \cancel{mol\ KCl}}$$

$$m_{KCl} = 2.24\ g\ KCl$$

Therefore, 2.24 g of potassium chloride remains unreacted.

2. (a) $4\ NH_{3(g)} + 5\ O_{2(g)} \rightarrow 4\ NO_{(g)} + 6\ H_2O_{(l)}$

(b)

| Balanced equation | $4\ NH_{3(g)}$ | + | $5\ O_{2(g)}$ | → | $4\ NO_{(g)}$ | + | $6\ H_2O_{(l)}$ |
|---|---|---|---|---|---|---|---|
| Before reaction | 4.00 mol | | 7.00 mol | | | | |
| Reaction according to balanced equation | 4.00 mol | | 5.00 mol | | | | |
| After reaction | 0 mol | | 2.00 mol | | | | |

Ammonia is the limiting reagent.

$n_{NH_3} = 4.00 \text{ mol } NH_3$

$M_{NO} = 30.01 \text{ g/mol } NO$

1 mol NO = 30.01 g NO
4 mol NO = 4 mol $NH_3$

$$m_{NO} = 4.00 \cancel{\text{mol } NH_3} \times \frac{4 \cancel{\text{mol NO}}}{4 \cancel{\text{mol } NH_3}} \times \frac{30.01 \text{ g NO}}{1 \cancel{\text{mol NO}}}$$

$$m_{NO} = 120 \text{ g NO}$$

The mass of nitrogen monoxide formed is 120 g.

(c) According to the reaction chart, 2.00 mol oxygen remains after the reaction.

$$m_{O_2} = 2.00 \cancel{\text{mol } O_2} \times \frac{32.00 \text{ g } O_2}{1 \cancel{\text{mol } O_2}}$$

$$m_{O_2} = 64.0 \text{ g } O_2$$

Therefore, 64.0 g of oxygen remains unreacted.

3. According to the balanced equation, 3 mol iodine is required to react with 2 mol aluminum. Before the reaction, there is 2.00 mol aluminum, but only 0.500 mol iodine. Therefore, iodine is the limiting reagent.

$$m_{AlI_3} = 0.500 \cancel{\text{mol } I_2} \times \frac{2 \cancel{\text{mol } AlI_3}}{3 \cancel{\text{mol } I_2}} \times \frac{407.68 \text{ g } AlI_3}{1 \cancel{\text{mol } AlI_3}}$$

$\frac{I}{Al} = \frac{3}{2} = \frac{0.5}{x}$ x = 

× 407

$$m_{AlI_3} = 136 \text{ g } AlI_3$$

The theoretical yield of aluminum iodide is 136 g.

4. (a) $N_{2(g)} + 2\,O_{2(g)} + 2\,NO_{2(g)}$

(b) According to the balanced equation, 1 mol nitrogen is required to react with 2 mol oxygen. Before the reaction, there is 0.200 mol nitrogen and 0.200 mol oxygen. Therefore, oxygen is the limiting reagent.

$$m_{NO_2} = 0.200 \cancel{\text{mol } O_2} \times \frac{2 \cancel{\text{mol } NO_2}}{2 \cancel{\text{mol } O_2}} \times \frac{46.01 \text{ g } NO_2}{1 \cancel{\text{mol } NO_2}}$$

$$m_{NO_2} = 9.20 \text{ g } NO_2$$

The theoretical yield of nitrogen dioxide is 9.20 g.

(c) Nitrogen is the limiting reagent.

$$n_{NO_2} = 2.00 \cancel{\text{mol } N_2} \times \frac{2 \text{ mol } NO_2}{1 \cancel{\text{mol } N_2}}$$

$$n_{NO_2} = 4.00 \text{ mol } NO_2$$

The amount of nitrogen dioxide produced is 4.00 mol.

5. (a) $2\,SO_{2(g)} + O_{2(g)} + 2\,H_2O_{(l)} \rightarrow 2\,H_2SO_{4(aq)}$

(b) According to the balanced equation, 2 mol sulfur dioxide reacts with 1 mol oxygen and 2 mol water. Before the reaction, there is 1.50 mol sulfur dioxide, 1.00 mol oxygen, and 2.00 mol water. Therefore, sulfur dioxide is the limiting reagent.

$$m_{H_2SO_4} = 1.50 \cancel{\text{mol } SO_2} \times \frac{2 \cancel{\text{mol } H_2SO_4}}{2 \cancel{\text{mol } SO_2}} \times \frac{98.08 \text{ g } H_2SO_4}{1 \cancel{\text{mol } H_2SO_4}}$$

$$m_{H_2SO_4} = 147 \text{ g } H_2SO_4$$

The theoretical yield of hydrogen sulfate is 147 g.

6. (a) $C_3H_{8(g)} + 5\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + 4\ H_2O_{(g)}$
(b) According to the balanced equation, 1 mol propane reacts with 5 mol oxygen. Before the reaction, there is 10.0 mol propane and 2.00 mol oxygen. Therefore, oxygen is the limiting reagent.

(c) $$m_{H_2O} = 2.00\ \cancel{\text{mol}\ O_2} \times \frac{4\ \cancel{\text{mol}\ H_2O}}{5\ \cancel{\text{mol}\ O_2}} \times \frac{18.02\ \text{g}\ H_2O}{1\ \cancel{\text{mol}\ H_2O}}$$

$$m_{H_2O} = 28.8\ \text{g}\ H_2O$$

Therefore, 28.8 g of water vapour is formed.

7. (a) $2\ Ag_{(s)} + Cu(NO_3)_{2(aq)} \rightarrow Cu_{(s)} + 2\ AgNO_{3(aq)}$
(b) According to the balanced equation, 2 mol silver reacts with 1 mol copper(II) nitrate. Before the reaction, there is 2.000 mol silver and 2.000 mol copper(II) nitrate. Therefore, silver is the limiting reagent.

(c) $$m_{Cu} = 2.000\ \cancel{\text{mol}\ Ag} \times \frac{1\ \cancel{\text{mol}\ Cu}}{2\ \cancel{\text{mol}\ Ag}} \times \frac{63.55\ \text{g}\ Cu}{1\ \cancel{\text{mol}\ Cu}}$$

$$m_{Cu} = 63.55\ \text{g}\ Cu$$

Therefore, 63.55 g of copper is formed.

## 2.11 ALTERNATIVE EXERCISE

**(Pages 104–105)**

### ACTIVITY: THE LIMITING REAGENT AND PERCENTAGE COMPOSITION OF A MIXTURE

**Observations**

**Part A**

| | Precipitate forms with $Ba(NO_3)_{2(aq)}$ (Yes/No) | Precipitate forms with $CuSO_{4(aq)}$ (Yes/No) |
|---|---|---|
| Test 1 | yes | — |
| Test 2 | — | no |

**Part B**

| | |
|---|---|
| Mass of filter paper + precipitate (step 12) | 2.35 g |
| Mass of filter paper (step 5) | 1.38 g |
| (a) Mass of precipitate | 0.97 g |

**Analysis**

(b) Since a precipitate formed when barium nitrate was added to the filtrate in test tube 1, but not when copper sulfate was added to the filtrate in test tube 2, barium nitrate is the limiting reagent.

(c) Since barium nitrate is the limiting reagent in this reaction, its amount (and mass) in the $Ba(NO_3)_{2(s)}/CuSO_{4(s)}$ mixture may be calculated using the mass of the barium sulfate precipitate formed in the reaction.

$$m_{Ba(NO_3)_2} = 0.97\ \cancel{\text{g}\ BaSO_4} \times \frac{1\ \cancel{\text{mol}\ BaSO_4}}{233.39\ \cancel{\text{g}\ BaSO_4}} \times \frac{1\ \cancel{\text{mol}\ Ba(NO_3)_2}}{1\ \cancel{\text{mol}\ BaSO_4}} \times \frac{261.35\ \text{g}\ Ba(NO_3)_2}{1\ \cancel{\text{mol}\ Ba(NO_3)_2}}$$

$$m_{Ba(NO_3)_2} = 1.1\ \text{g}\ Ba(NO_3)_2$$

$$\%\ Ba(NO_3)_2 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = \frac{1.1\ \text{g}}{2.01\ \text{g}} \times 100\%$$

$$\%\ Ba(NO_3)_2 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = 55\%$$

# Limiting Reagents + Percent Yield Worksheet

1) (a) $I_2O_5 + 5CO \rightarrow 5CO_2 + I_2$

| | $I_2O_5$ | $CO$ |
|---|---|---|
| | 80g | 28g |
| M | 333.8 g/mol | 28.01 g/mol |
| mol | 0.2397 | 0.9996 |

$\boxed{LR}$ $\frac{I_2O_5}{CO} = \frac{1}{5} = \frac{0.2397}{x}$ $x = 1.1985$ ∴ CO

$\boxed{Product}$ $\frac{CO}{I_2} = \frac{5}{1} = \frac{0.9996}{x}$ $x = 0.19992$ mol $I_2$

$\boxed{Mass}$ $m = n \times M$

$= 0.19992 \times (126.9 \times 2)$

$\boxed{= 50.7397\ g}$

(b) mass $= n \times M$

$= 0.160 \times (126.9 \times 2)$

$\boxed{= 40.608}$

% yield $= \frac{40.608}{50.7397} \times 100$

$\boxed{= 80.032\ \%}$

$I_2$

2) $Zn + S \rightarrow ZnS$

| | Zn | S |
|---|---|---|
| | 25g | 30g |
| mol | 0.3824 | 0.9357 |

$mass_{ZnS} = 0.3824 \times 97.44\ g/mol$

(b) $\boxed{ZnS = 37.26\ grams}$

(a) $\boxed{LR} \rightarrow Zn$

$\boxed{Product}$ $Zn/ZnS = \frac{1}{1}$ ZnS mol $= 0.3824$

(c) on back

2c) S
$0.9357\ mol - 0.3824\ mol$ used $\frac{S}{Zn} : \frac{1}{1} : \frac{x}{0.3824}$
$= .5533$ left over

mass $= 32.06\ g/mol \times 0.5533\ mol$
$= 17.74$ grams

3) $2Mg + O_2 \rightarrow 2MgO$
3g 2.2g
mol 0.1234 0.06875

LR $\frac{Mg}{O_2} = \frac{2}{1} = \frac{0.1234}{x}$ $x = 0.0617$ ∴ Mg is LR

$\boxed{\therefore O_2 \text{ is in excess}}$ $0.06875 - 0.0617 = \_\_\_\_ \times 32 g/mol$

Product $\frac{Mg}{MgO} = \frac{2}{2} = \frac{0.1234}{x\ 0.1234}$ $MgO = 0.1234$ mol

mass $= 0.1234 \times 40.31$
$\boxed{= 4.97 \text{ grams of } MgO}$

4) $2Al + 3S \rightarrow Al_2S_3$
5g 10g
mol 0.1853 0.3119

LR $\frac{Al}{S} = \frac{2}{3} = \frac{0.1853}{x}$ $x = 0.27795$ S needed
∴ Al is LR

Product $\frac{Al}{Al_2S_3} = \frac{2}{1} = \frac{0.1853}{x}$ $x = 0.09265$ mol

mass $= 0.09265 \times 150.05$
$\boxed{Al_2S_3 = 13.9\ g}$

5) $3Zn_{(s)} + 2MoO_3 \rightarrow Mo_2O_3 + 3ZnO$

$10g / 65.409$ $\quad$ $20g / 143.94$ $\quad$ ?

$\boxed{mol}$ 0.153 mol $\quad$ 0.139

$\boxed{LR.}$ $\frac{Zn}{MoO_3} = \frac{3}{2} = \frac{0.153}{x}$ $\quad x = 0.102$ $MoO_3$ needed

$\therefore$ Zn is LR

$\boxed{Product}$ $\frac{Zn}{ZnO} = \frac{3}{3} =$ $\quad ZnO = 0.153$ mol

mass = 0.153 × 81.407

= 12.4 g

6) $3AgNO_3 + FeCl_3 \rightarrow 3AgCl + Fe(NO_3)_3$

$25g / 169.88$ $\quad$ $45.0g / 162.197$

$\boxed{mol}$ 0.147 $\quad$ .27744

$\boxed{LR}$ $\frac{AgNO_3}{FeCl_3} = \frac{3}{1} = \frac{.147}{x}$ $\quad x = 0.049$ mol

$\boxed{\therefore AgNO_3 \text{ is LR}}$

$\boxed{Product}$ $\frac{AgCl}{AgNO_3} = \frac{3}{3} = \frac{x}{0.147}$ $\quad x = 0.147$

$\boxed{Mass}$ AgCl = 0.147 mol × 143.32 g/mol

$\boxed{= 21.07\ g}$

$\boxed{Excess}$ .27744 − 0.049 = .22844 mol

.22844 mol × 162.197 = $\boxed{37.05g}$

7) $1\,CaCO_3 + 1\,SO_2 \rightarrow 1\,CaSO_3$

255 g (100.08) 135 g ? (198 g Actual yield)

mol: 2.55 mol 2.107 mol

LR: 1:1 ∴ $SO_2$ is LR.

Product: 1:1 ∴ $CaSO_3$ = 2.107 mol

Mass: $CaSO_3$ = 2.107 × = $\boxed{253.13\,g}$

% yield = $\frac{198}{253.13} \times 100 = \boxed{78.22\%}$

8) $C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$

?g 153.846 g

actual yield = 100 g

% yield = 65% → .65

% yield = $\frac{act}{theo} \times 100$

① Theoretical yield = $\frac{\text{Actual}}{\text{yield \%}} = \frac{100g}{.65} = 153.846g$

Mole: $C_6H_5Cl = \frac{153.846\,mol}{112.56\,g/mol} = 1.3668\,mol$

Reagent: 1:1 ∴ mole of $C_6H_6$ = 1.3668 mol

mass of reagent: $C_6H_6$ = 1.3668 × 78.12 = $\boxed{106.77g}$

9) $C_7H_8 + 2KMnO_4 \rightarrow KC_7H_5O_2 + 2MnO_2 + KOH + H_2O$

$C_7H_8$: ?g

$KC_7H_5O_2$: 10g actual

%yield = 68%

$\boxed{\text{Theo yield}}$

$$\%\text{yield} = \frac{\text{actual}}{\text{theo}} \times 100$$

$$68\% = \frac{10g}{\text{theo}} \times 100$$

$$.68 = \frac{10g}{\text{theo}}$$

$$\text{theo} = \frac{10g}{.68} = 14.706\ g$$

$\boxed{\text{Mole product}}$ $KC_7H_5O_2$

$$\frac{14.706g}{160.2183} = 0.0918\ mol$$

$\boxed{\text{Mol reactant}}$ 1:1 ratio $\therefore C_7H_8 = 0.0918\ mol$

$\boxed{\text{Mass reactant}}$ $C_7H_8 = 0.0918\ mol \times 92.15\ g/mol$

$$\boxed{= 8.46\ \text{grams}}$$

10) $2NaOH + 2Al + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$

84.1g   51g   ?g

$\boxed{\text{mole}}$   2.103   1.89

$\boxed{\text{LR}}$   $\frac{NaOH}{Al} = \frac{1}{1} =$   ∴ Al is L.R.

$\boxed{\text{Product } H_2}$   $\frac{Al}{H_2} = \frac{2}{3} = \frac{1.89}{x}$   $x = 2.835$ mol

$\boxed{\text{Mass } H_2}$   mass $= 2.835 \times 2.016 = 5.71536$ g

| | Avail | | Used | 1:1 Ratio |
|---|---|---|---|---|
| $\boxed{\text{Excess Reagent}}$ NaOH = | 2.103 | − | 1.89 | |

= 0.213 mol

NaOH $= 39.908 \times 0.213$

$= 8.50$ g

11) $\boxed{1}(CH_3)_2NNH_2 + \boxed{2}N_2O_4 \rightarrow 4H_2O + 3N_2 + 2CO_2$

| | | |
|---|---|---|
| 150kg | 460kg | $\boxed{210.15 \text{ } H_2O}$ |
| 60 | 92 | 20.02 |
| 2.5 | 5 | 7.5 |

11 iii) $\frac{30\ kg}{x} \times 100 = 68\%$

$\frac{30}{x} = 0.68$

$x = 44.11765$ kg theo yield

$\frac{44.11765}{28.02} = 1.575$ kmol

$\frac{N_2}{N_2O_4} = \frac{3}{2} = \frac{1.575\ kmol}{x}$ $x = 1.05$ kmol of $N_2O_4$

mass of $N_2O_4$ = 1.05 kmol × 92 g/mol = $\boxed{96.57 \text{ kg of } N_2O_4}$

12) $2Mg + O_2 \rightarrow 2MgO$

$\frac{5\,g}{24.31\,g/mol}$ $\frac{5\,g}{32\,g/mol}$ ? g

0.20568 0.15625

$\frac{Mg}{O_2} = \frac{2}{1} = \frac{0.20568}{x}$ $x = 0.10284$ needed

$O_2$ is excess

$\frac{Mg}{MgO} = \frac{2}{2} \Rightarrow$ $MgO = 0.20568$ mol formed

mass MgO = 0.20568 × (16 + 24.31) = 8.29 g

$O_2$ 0.15625 − 0.10284 = 0.05341

mass $O_2$ → 0.05341 × 32 g/mol = 1.71 g