2.10 LIMITING AND EXCESS REAGENTS

PRACTICE

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Understanding Concepts

1. (a) $m_{H_2} = 10.0 \text{ g } H_2$

$N_{O_2} = 32.00 \text{ g } O_2$

Balanced equation	$2\ H_{2(g)}$ +	$O_{2(g)}$ →	$2\ H_2O_{(l)}$
Before reaction	10.0 g	32.00 g	0 g
Reaction according to balanced equation	2 mol 4.04 g	1 mol 32.00 g	2 mol
After reaction	5.96 g	0 g	? g

According to the chart, oxygen is the limiting reagent, and hydrogen is the excess reagent.

(b)

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

$$n_{O_2} = 1.000 \text{ mol } O_2$$

$$n_{H_2O} = 1.000\ \cancel{\text{mol } O_2} \times \frac{2 \text{ mol } H_2O}{1\ \cancel{\text{mol } O_2}}$$

$$n_{H_2O} = 2.000 \text{ mol } H_2O$$

$$m_{H_2O} = 2.000\ \cancel{\text{mol } H_2O} \times \frac{18.02 \text{ g } H_2O}{1\ \cancel{\text{mol } H_2O}}$$

$$m_{H_2O} = 36.04 \text{ g } H_2O$$

Therefore, 36.04 g of water is produced.

The combined calculation is as follows:

$$m_{H_2O} = 32.00\ \cancel{\text{g } O_2} \times \frac{1\ \cancel{\text{mol } O_2}}{32.00\ \cancel{\text{g } O_2}} \times \frac{2\ \cancel{\text{mol } H_2O}}{1\ \cancel{\text{mol } O_2}} \times \frac{18.02 \text{ g } H_2O}{1\ \cancel{\text{mol } H_2O}}$$

$$m_{H_2O} = 36.04 \text{ g } H_2O$$

Therefore, 36.04 g of water is produced.

2. $m_{CH_4} = 32.1 \text{ g } CH_4$

$m_{O_2} = 160.0 \text{ g } O_2$

Balanced equation	$2\ CH_{4(g)}$ +	$3\ O_{2(g)}$ →	$2\ CO_{(g)}$ +	$4\ H_2O_{(g)}$
Before reaction	32.1 g	160.0 g	0 g	0 g
Reaction according to balanced equation	2 mol (32.10 g)	3 mol (96.00 g)		
After reaction	0 g	64.0 g	?	

According to the chart, methane is the limiting reagent and oxygen is the excess reagent.

$$n_{CH_4} = 32.1\ \cancel{g\ CH_4} \times \frac{1\ mol\ CH_4}{16.05\ \cancel{g\ CH_4}}$$

$$n_{CH_4} = 2.00\ mol\ CH_4$$

$$n_{CO} = 2.00\ \cancel{mol\ CH_4} \times \frac{2\ mol\ CO}{2\ \cancel{mol\ CH_4}}$$

$$n_{CO} = 2.00\ mol\ CO$$

$$m_{CO} = 2.00\ \cancel{mol\ CO} \times \frac{28.01\ g\ CO}{1\ \cancel{mol\ CO}}$$

$$m_{CO} = 56.0\ g\ CO$$

Therefore, 56.0 g of carbon monoxide is produced during incomplete combustion.

The combined calculation is as follows:

$$m_{CO} = 32.1\ \cancel{g\ CH_4} \times \frac{1\ \cancel{mol\ CH_4}}{16.05\ \cancel{g\ CH_4}} \times \frac{2\ \cancel{mol\ CO}}{2\ \cancel{mol\ CH_4}} \times \frac{28.01\ g\ CO}{1\ \cancel{mol\ CO}}$$

$$m_{CO} = 56.0\ g\ CO$$

Therefore, 56.0 g of carbon monoxide is produced during incomplete combustion.

3. (a) $m_{SO_2} = 192.18\ g\ SO_2$

$m_{O_2} = 32.00\ g\ O_2$

Balanced equation	$2\ SO_{2(g)}$ +	$O_{2(g)}$ →	$2\ SO_{3(g)}$
Before reaction	192.18 g	32.00 g	0 g
Reaction according to balanced equation	2 mol (128.00 g)	1 mol (32.00 g)	
After reaction	64.18 g	0 g	?

According to the chart, oxygen is the limiting reagent and sulfur dioxide is the excess reagent.

(b)

$$n_{O_2} = 32.00\ \cancel{g\ O_2} \times \frac{1\ mol\ O_2}{32.00\ \cancel{g\ O_2}}$$

$$n_{O_2} = 1.000\ mol\ O_2$$

$$n_{SO_3} = 1.000\ \cancel{mol\ O_2} \times \frac{2\ mol\ SO_3}{1\ \cancel{mol\ O_2}}$$

$$n_{SO_3} = 2.00\ mol SO_3$$

Therefore, 2.00 mol sulfur trioxide is produced.

(c) $m_{SO_3} = 2.00 \cancel{\text{ mol } SO_3} \times \frac{80.06 \text{ g } SO_3}{1 \cancel{\text{ mol } SO_3}}$

$m_{SO_3} = 160.1 \text{ g } SO_3$

Therefore, 160.1 g of sulfur trioxide is produced.

4. $m_{P_4} = 123.88 \text{ g } P_4$

$m_{Cl_2} = 1.00 \text{ kg } Cl_2 \times \frac{1000 \text{ g } Cl_2}{1 \text{ kg } Cl_2}$

$m_{Cl_2} = 1.00 \times 10^3 \text{ g } Cl_2$

Balanced equation	$P_{4(s)}$ +	$10\ Cl_{2(g)}$ →	$4\ PCl_{5(s)}$
Before reaction	123.88 g	354.5 g	0 g
Reaction according to balanced equation	1mol (123.88 g)	10 mol (709.0 g)	
After reaction	0 g	354.5 g	?

$n_{P_4} = 123.88 \cancel{\text{ g } P_4} \times \frac{1 \text{ mol } P_4}{123.88 \cancel{\text{ g } P_4}}$

$n_{P_4} = 1.000 \text{ mol } P_4$

$n_{PCl_5} = 1.000 \cancel{\text{ mol } P_4} \times \frac{4 \text{ mol } PCl_5}{1 \cancel{\text{ mol } P_4}}$

$n_{PCl_5} = 4.000 \text{ mol } PCl_5$

$m_{PCl_5} = 4.000 \cancel{\text{ mol } PCl_5} \times \frac{208.22 \text{ g } PCl_5}{1 \cancel{\text{ mol } PCl_5}}$

$m_{PCl_5} = 832.9 \text{ g } PCl_5$

The mass of phosphorus pentachloride produced from the reaction is 832.9 g.

The combined calculation is as follows:

$m_{PCl_5} = 123.88 \cancel{\text{ g } P_4} \times \frac{1 \cancel{\text{ mol } P_4}}{123.88 \cancel{\text{ g } P_4}} \times \frac{4 \cancel{\text{ mol } PCl_5}}{1 \cancel{\text{ mol } P_4}} \times \frac{208.22 \text{ g } PCl_5}{1 \cancel{\text{ mol } PCl_5}}$

$m_{PCl_5} = 832.9 \text{ g } PCl_5$

The mass of phosphorus pentachloride produced from the reaction is 832.9 g.

SECTION 2.10 QUESTIONS

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Understanding Concepts

1. The excess reagent is the reactant that is not completely consumed in a chemical reaction. The limiting reagent is the reactant that is completely consumed in a chemical reaction. The limiting reagent limits the amount of product that can be formed.
2. No, there does not need to be a limiting reagent in a chemical reaction. If reactants are mixed in amounts equal to, or proportional to, the coefficients in the balanced reaction equation, then all reagents will be completely consumed.

3. Substance A must be the limiting reagent, and substance B must be in excess. All of substance A must react to determine the amount of product formed and, therefore, the initial amount of substance A. The only way to be sure that all of substance A has reacted is to use an excess of substance B.

4. (a) $m_{CH_4} = 6.4 \text{ g } CH_4$

$m_{O_2} = ?$

Balanced equation	$2\ CH_{4}\rightarrow_{(g)}$ +	$3\ O_{2(g)}$ →	$2\ CO_{(g)}$ +	$4\ H_2O_{(g)}$
Given mass (g)	6.4 g	?		
Molar mass (g/mol)	16.05 g/mol	32.00 g/mol	28.01 g/mol	

$$n_{CH_4} = 6.4 \cancel{\text{ g } CH_4} \times \frac{1 \text{ mol } CH_4}{16.05 \cancel{\text{ g } CH_4}}$$

$$n_{CH_4} = 0.40 \text{ mol } CH_4$$

$$n_{O_2} = 0.40 \cancel{\text{ mol } CH_4} \times \frac{3 \text{ mol } O_2}{2 \cancel{\text{ mol } CH_4}}$$

$$n_{O_2} = 0.60 \text{ mol } O_2$$

$$m_{O_2} = 0.60 \cancel{\text{ mol } O_2} \times \frac{32.00 \text{ g } O_2}{1 \cancel{\text{ mol } O_2}}$$

$$m_{O_2} = 19 \text{ g } O_2$$

The mass of oxygen required to react with 6.4 g of methane is 19 g.

The combined calculation is as follows:

$$m_{O_2} = 6.4 \cancel{\text{ g } CH_4} \times \frac{1 \cancel{\text{ mol } CH_4}}{16.05 \cancel{\text{ g } CH_4}} \times \frac{3 \cancel{\text{ mol } O_2}}{2 \cancel{\text{ mol } CH_4}} \times \frac{32.00 \text{ g } O_2}{1 \cancel{\text{ mol } O_2}}$$

$$m_{O_2} = 19 \text{ g } O_2$$

The mass of oxygen required to react with 6.4 g of methane is 19 g.

(b) $m_{CH_4} = 6.4 \text{ g } CH_4$

$m_{CO} = ?$

Balanced chemical equation	$2\ CH_{4(g)}$ +	$3\ O_{2(g)}$ →	$2\ CO_{(g)}$ +	$4\ H_2O_{(g)}$
Given mass (g)	6.4 g	?		
Molar mass (g/mol)	16.05 g/mol	32.00 g/mol	28.01 g/mol	

From (a):

$n_{CH_4} = 0.40 \text{ mol } CH_4$

$$n_{CO} = 0.40 \cancel{\text{ mol } CH_4} \times \frac{2 \text{ mol CO}}{2 \cancel{\text{ mol } CH_4}}$$

$n_{CO} = 0.40 \text{ mol CO}$

$$m_{CO} = 0.40 \cancel{\text{ mol CO}} \times \frac{28.01 \text{ g } \cancel{CO}}{\cancel{1} \text{ mol CO}}$$

$m_{CO} = 11 \text{ g CO}$

The mass of carbon monoxide formed is 11 g.

The combined calculation is as follows:

$$m_{CO} = 6.4 \cancel{\text{ g } CH_4} \times \frac{1 \cancel{\text{ mol } CH_4}}{16.05 \cancel{\text{ g } CH_4}} \times \frac{2 \cancel{\text{ mol CO}}}{2 \cancel{\text{ mol } CH_4}} \times \frac{28.01 \text{ g CO}}{1 \cancel{\text{ mol CO}}}$$

$m_{CO} = 11 \text{ g CO}$

The mass of carbon monoxide formed is 11 g.

5. $m_{Al} = 6.71 \text{ g Al}$

$m_{Al_2(SO_4)_3} = ?$

Balanced chemical equation	$2\ Al_{(s)}$	$+\quad 3\ H_2SO_{4(aq)}$	$\rightarrow\quad Al_2(SO_4)_{3(aq)}$	$+\quad 3\ H_{2(g)}$
Given mass (g)	6.71 g		?	
Molar mass (g/mol)	26.98 g/mol		342.14 g/mol	

$$n_{Al} = 6.71 \cancel{\text{ g Al}} \times \frac{1 \text{ mol Al}}{26.98 \cancel{\text{ g Al}}}$$

$n_{Al} = 0.2487 \text{ mol Al}$

$$n_{Al_2(SO_4)_3} = 0.2487 \cancel{\text{ mol Al}} \times \frac{1 \text{ mol } Al_2(SO_4)_3}{2 \cancel{\text{ mol Al}}}$$

$n_{Al_2(SO_4)_3} = 0.1244 \text{ mol } Al_2(SO_4)_3$

$$m_{Al_2(SO_4)_3} = 0.1244 \cancel{\text{ mol } Al_2(SO_4)_3} \times \frac{342.14 \text{ g } Al_2(SO_4)_3}{1 \cancel{\text{ mol } Al_2(SO_4)_3}}$$

$m_{Al_2(SO_4)_3} = 42.5 \text{ g } Al_2(SO_4)_3$

The mass of aluminum sulfate formed is 42.5 g.

The combined calculation is as follows:

$$m_{Al_2(SO_4)_3} = 6.71 \cancel{\text{ g Al}} \times \frac{1 \cancel{\text{ mol Al}}}{26.98 \cancel{\text{ g Al}}} \times \frac{1 \cancel{\text{ mol } Al_2(SO_4)_3}}{2 \cancel{\text{ mol Al}}} \times \frac{342.14 \text{ g } Al_2(SO_4)_3}{1 \cancel{\text{ mol } Al_2(SO_4)_3}}$$

$m_{Al_2(SO_4)_3} = 42.5 \text{ g } Al_2(SO_4)_3$

The mass of aluminum sulfate formed is 42.5 g.

6. $m_{Cu} = ?$

$m_{Cu_2O} = 286.2 \text{ g } Cu_2O$

$m_{Cu_2S} = 286.2 \text{ g } Cu_2S$

Balanced chemical equation	$2\ Cu_2O_{(s)}$ +	$Cu_2S_{(s)}$ $\rightarrow$	$6\ Cu_{(s)}$ +	$SO_{2(g)}$
Before reaction	286.2 g	286.2 g	0 g	0 g
Reaction according to balanced chemical equation	2 mol (286.20 g)	1 mol (159.16 g)	6 mol (381.30 g)	1 mol (64.06 g)
After reaction	0 g	127.0 g	?	

From the table, the limiting reagent is $Cu_2O_{(s)}$ and the excess reagent is $Cu_2S_{(s)}$.

$$n_{Cu_2O} = 286.2\ \cancel{\text{g } Cu_2O} \times \frac{1 \text{ mol } Cu_2O}{143.1\ \cancel{\text{g } Cu_2O}}$$

$$n_{Cu_2O} = 2.000 \text{ mol } Cu_2O$$

$$n_{Cu} = 2.000\ \cancel{\text{mol } Cu_2O} \times \frac{6 \text{ mol Cu}}{2\ \cancel{\text{mol } Cu_2O}}$$

$$n_{Cu} = 6.000 \text{ mol Cu}$$

$$m_{Cu} = 6.000 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1\ \cancel{\text{mol Cu}}}$$

$$m_{Cu} = 381.3 \text{ g Cu}$$

The mass of copper obtained from the reaction is 381.3 g.

The combined calculation is as follows:

$$m_{Cu} = 286.2\ \cancel{\text{g } Cu_2O} \times \frac{1\ \cancel{\text{mol } Cu_2O}}{143.1\ \cancel{\text{g } Cu_2O}} \times \frac{6\ \cancel{\text{mol Cu}}}{2\ \cancel{\text{mol } Cu_2O}} \times \frac{63.55 \text{ g Cu}}{1\ \cancel{\text{mol Cu}}}$$

$$m_{Cu} = 381.3 \text{ g Cu}$$

The mass of copper obtained from the reaction is 381.3 g.

2.11 INVESTIGATION: THE LIMITING REAGENT IN A CHEMICAL REACTION

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Prediction

(a) According to the stoichiometric method, 2.32 g of strontium sulfate precipitate will be produced from the reaction of 2.00 g of strontium chloride with excess copper(II) sulfate. The reaction equation is shown below.