

## Chapter 9 – Stoichiometry

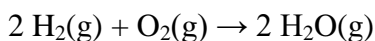
Chapter 9: 1, 3, 4, 6, 8 – 19, 22 – 32, 38, 43 – 46, 53, 55, 56

### Practice Problems

1. How many tricycle seats, wheels, and pedals are needed to make 288 tricycles?

Seats **288**                      wheels **864**                      pedals **576**

3. Interpret the equation for the formation of water from its elements in terms of (a) numbers of molecules, (b) numbers of moles, and (3) volumes of gases at STP.

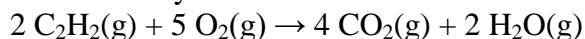


(a) # of molecules: Two molecules of hydrogen gas reacts with one molecule of oxygen gas to produce two molecules of water.

(b) # of moles: Two moles of hydrogen gas reacts with one mole of oxygen gas to yield two moles of water.

(c) Volumes of gases at STP: 44.8 L of hydrogen gas reacts with 22.4 L of oxygen gas to yield 44.8 L of water in the form of steam.

4. Balance the equation for the combustion of acetylene:



Then, interpret the equation in terms of (a) relative numbers of moles, (b) volumes of gases at STP, and (c) masses of reactants and products.

(a) 2 mol acetylene gas reacts with 5 mol of oxygen gas to produce 4 mol of carbon dioxide gas and 2 mol steam

(b) 44.8 L of acetylene gas reacts with 112 L oxygen gas to yield 89.6 L carbon dioxide gas and 44.8 L steam.

(c) 52.1 g of acetylene gas reacts with 160. g oxygen gas to produce 176 g carbon dioxide gas and 36.0 g steam.

### Section Review 9.1

6. Balance this equation:  $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g})$ .

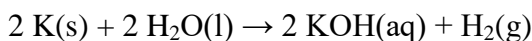
a. Interpret the equation in terms of numbers of molecules and moles.

One molecule (mole) of ethanol reacts with three molecules (moles) of oxygen gas to yield two molecules (moles) of carbon dioxide gas and three molecules (moles) of steam.

b. Show that the balanced equation obeys the law of conservation of mass.

46.0 g  $\text{C}_2\text{H}_5\text{OH}$  reacts with 96.0 g  $\text{O}_2$  to yield 88.0 g  $\text{CO}_2$  and 54.0 g  $\text{H}_2\text{O}$ .

8. Interpret the following equation in terms of (a) relative numbers of representative particles, (b) numbers of moles, and (c) masses of reactants and products.



(a) 2 K atoms + 2 H<sub>2</sub>O molecules yields 2 formula units of KOH and 1 molecule H<sub>2</sub>

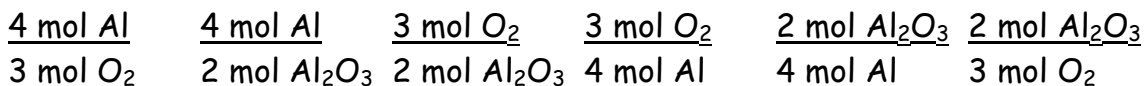
(b) 2 mol K and 2 mol H<sub>2</sub>O yields 2 mol KOH and 1 mol H<sub>2</sub>

(c) 78.2 g K and 36.0 g H<sub>2</sub>O produces 112.2 g KOH and 2.0 g H<sub>2</sub>

### Practice Problems – Mole-Mole Calculations

9. This equation shows the formation of aluminum oxide:  $4 \text{Al(s)} + 3 \text{O}_2\text{(g)} \rightarrow 2 \text{Al}_2\text{O}_3\text{(s)}$

a. write out the six mole ratios that can be derived from this equation.



b. How many moles of aluminum are needed to form 3.7 mol Al<sub>2</sub>O<sub>3</sub>?

$$(3.7 \text{ mol Al}_2\text{O}_3) \left( \frac{4 \text{ mol Al}}{2 \text{ mol Al}_2\text{O}_3} \right) = 7.4 \text{ mol Al}$$

10. According to the equation in Problem 9:

a. How many moles of oxygen are required to react completely with 14.8 mol Al?

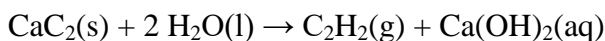
$$(14.8 \text{ Al}) \left( \frac{3 \text{ mol O}_2}{4 \text{ mol Al}} \right) = 11.1 \text{ mol O}_2$$

b. How many moles of Al<sub>2</sub>O<sub>3</sub> are formed when 0.78 mol O<sub>2</sub> reacts with aluminum?

$$(0.78 \text{ mol O}_2) \left( \frac{2 \text{ mol Al}_2\text{O}_3}{3 \text{ mol O}_2} \right) = 0.52 \text{ mol Al}_2\text{O}_3$$

### Practice Problems – Mass-Mass Calculations

11. Acetylene gas (C<sub>2</sub>H<sub>2</sub>) is produced by adding water to calcium carbide (CaC<sub>2</sub>).



How many grams of acetylene are produced by adding water to 5.00 g of CaC<sub>2</sub>?

$$(5.00 \text{ g CaC}_2) \left( \frac{1 \text{ mol CaC}_2}{64.1 \text{ g CaC}_2} \right) \left( \frac{1 \text{ mol C}_2\text{H}_2}{1 \text{ mol CaC}_2} \right) \left( \frac{26.0 \text{ g C}_2\text{H}_2}{1 \text{ mol C}_2\text{H}_2} \right) = 2.03 \text{ g C}_2\text{H}_2$$

12. Using the same equation from Problem #11, determine how many moles of CaC<sub>2</sub> are needed to react completely with 49.0 g H<sub>2</sub>O.

$$(49.0 \text{ g H}_2\text{O}) \left( \frac{1 \text{ mol H}_2\text{O}}{18.0 \text{ g H}_2\text{O}} \right) \left( \frac{1 \text{ mol CaC}_2}{2 \text{ mol H}_2\text{O}} \right) = 1.36 \text{ mol CaC}_2$$

### Practice Problems – Other Stoichiometric Calculations

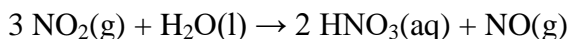
13. How many molecules of oxygen are produced by the decomposition of 6.54 g of potassium chlorate (KClO<sub>3</sub>)?



$$(6.54 \text{ g KClO}_3) \left( \frac{1 \text{ mol KClO}_3}{122.6 \text{ g KClO}_3} \right) \left( \frac{3 \text{ mol O}_2}{2 \text{ mol KClO}_3} \right) \left( \frac{6.02 \times 10^{23} \text{ molecules O}_2}{1 \text{ mol O}_2} \right) =$$

$$4.82 \times 10^{22} \text{ molecules O}_2$$

14. The last step in the production of nitric acid is the reaction of nitrogen dioxide with water:



How many grams of nitrogen dioxide must react with water to produce  $5.00 \times 10^{22}$  molecules of nitrogen monoxide?

$$(5.00 \times 10^{22} \text{ molecules NO}) \left( \frac{1 \text{ mol NO}}{6.02 \times 10^{23} \text{ molecules NO}} \right) \left( \frac{3 \text{ mol NO}_2}{1 \text{ mol NO}} \right) \left( \frac{46.0 \text{ g NO}_2}{1 \text{ mol NO}_2} \right) =$$

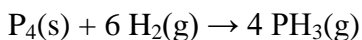
$$11.5 \text{ g NO}_2$$

15. The equation for the combustion of carbon monoxide is:  $2 \text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g})$

How many liters of oxygen are required to burn 3.86 L of carbon monoxide?

$$(3.86 \text{ L CO}) \left( \frac{1 \text{ L O}_2}{2 \text{ L CO}} \right) = 1.93 \text{ L O}_2$$

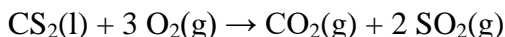
16. Phosphorus and hydrogen can be combined to form phosphine (PH<sub>3</sub>):



How many liters of phosphine are formed when 0.42 L of hydrogen reacts with phosphorus?

$$(0.42 \text{ L H}_2) \left( \frac{1 \text{ mol H}_2}{22.4 \text{ L H}_2} \right) \left( \frac{4 \text{ mol PH}_3}{6 \text{ mol H}_2} \right) \left( \frac{22.4 \text{ L PH}_3}{1 \text{ mol PH}_3} \right) = 0.28 \text{ L PH}_3$$

17. Consider this equation:



Calculate the volume of sulfur dioxide produced when 27.9 mL O<sub>2</sub> reacts with carbon disulfide.

$$(27.9 \text{ mL O}_2) \left( \frac{1 \text{ L O}_2}{1000 \text{ mL O}_2} \right) \left( \frac{1 \text{ mol O}_2}{22.4 \text{ L O}_2} \right) \left( \frac{2 \text{ mol SO}_2}{3 \text{ mol O}_2} \right) \left( \frac{22.4 \text{ L SO}_2}{1 \text{ mol SO}_2} \right) = 0.0186 \text{ L SO}_2$$

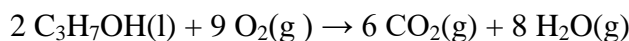
18. From the equation in Problem 17, calculate the number of deciliters of carbon dioxide produced when 0.38 L SO<sub>2</sub> is formed.

$$(0.38 \text{ L SO}_2) \left( \frac{1 \text{ mol SO}_2}{22.4 \text{ L SO}_2} \right) \left( \frac{1 \text{ mol CO}_2}{2 \text{ mol SO}_2} \right) \left( \frac{22.4 \text{ L CO}_2}{1 \text{ mol CO}_2} \right) \left( \frac{10 \text{ dL CO}_2}{1 \text{ L CO}_2} \right) = 1.9 \text{ dL CO}_2$$

First look at the mole ratio of the items you are being asked to compare and use them as **conversion factors**. For (a), you are comparing oxygen gas to isopropyl alcohol - so use that mole ratio to solve (a).

## Section Review 9.2

19. Isopropyl alcohol ( $C_3H_7OH$ ) burns in air according to this equation:



a. Calculate the moles of oxygen needed to react with 3.40 mol  $C_3H_7OH$ .

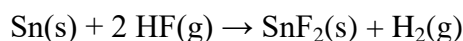
$$(3.40 \text{ mol } C_3H_7OH) \left( \frac{9 \text{ mol } O_2}{2 \text{ mol } C_3H_7OH} \right) = 15.3 \text{ mol } O_2$$

b. Find the moles of each product formed when 3.40 mol  $C_3H_7OH$  reacts with oxygen.

$$(3.40 \text{ mol } C_3H_7OH) \left( \frac{8 \text{ mol } H_2O}{2 \text{ mol } C_3H_7OH} \right) = 13.6 \text{ mol } H_2O$$

$$(3.40 \text{ mol } C_3H_7OH) \left( \frac{6 \text{ mol } CO_2}{2 \text{ mol } C_3H_7OH} \right) = 10.2 \text{ mol } CO_2$$

22. Tin(II) fluoride, formerly found in many kinds of toothpaste, is formed in this reaction:



a. How many liters of HF are needed to produce 9.40 L of  $H_2$  at STP?

$$(9.40 \text{ L } H_2) \left( \frac{1 \text{ mol } H_2}{22.4 \text{ L } H_2} \right) \left( \frac{2 \text{ mol } HF}{1 \text{ mol } H_2} \right) \left( \frac{22.4 \text{ L } HF}{1 \text{ mol } HF} \right) = 18.8 \text{ L } HF$$

b. How many molecules of  $H_2$  are produced by reaction of tin with 20.0 L HF at STP?

$$(20.0 \text{ L } HF) \left( \frac{1 \text{ mol } HF}{22.4 \text{ L } HF} \right) \left( \frac{1 \text{ mol } H_2}{2 \text{ mol } HF} \right) \left( \frac{6.02 \times 10^{23} \text{ molecules } H_2}{1 \text{ mol } H_2} \right) = 2.69 \times 10^{23} \text{ molecules } H_2$$

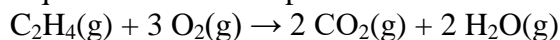
c. How many grams of  $SnF_2$  can be made by reacting  $7.42 \times 10^{24}$  molecules of HF with tin?

$$(7.42 \times 10^{24} \text{ molecules } HF) \left( \frac{1 \text{ mol } HF}{6.02 \times 10^{23} \text{ molecules } HF} \right) \left( \frac{1 \text{ mol } SnF_2}{2 \text{ mol } HF} \right) \left( \frac{156.7 \text{ g } SnF_2}{1 \text{ mol } SnF_2} \right) =$$

$$966 \text{ g } SnF_2$$

## Practice Problems – Limiting Reagent

23. The equation for the complete combustion of ethene ( $C_2H_4$ ) is:



If 2.70 mol  $C_2H_4$  is reacted with 6.30 mol  $O_2$ ,

a. identify the limiting reagent.

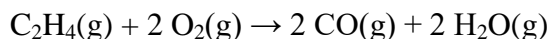
$$(2.70 \text{ mol } C_2H_4) \left( \frac{3 \text{ mol } O_2}{1 \text{ mol } C_2H_4} \right) = 8.1 \text{ mol } O_2$$

So, 8.1 mol  $O_2$  is needed to react with 2.70 mol of  $C_2H_4$ ;  
since there are only 6.30 mol of  $O_2$ , it is limiting.

b. calculate the moles of water produced.

$$(6.30 \text{ mol } O_2) \left( \frac{2 \text{ mol } H_2O}{3 \text{ mol } O_2} \right) = 4.20 \text{ mol } H_2O \text{ is produced}$$

24. The equation for the incomplete combustion of ethene (C<sub>2</sub>H<sub>4</sub>) is:



If 2.70 mol C<sub>2</sub>H<sub>4</sub> is reacted with 6.30 mol O<sub>2</sub>,

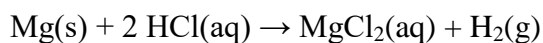
a. identify the limiting reagent.

$$(2.70 \text{ mol C}_2\text{H}_4) \left( \frac{2 \text{ mol O}_2}{1 \text{ mol C}_2\text{H}_4} \right) = 5.40 \text{ mol O}_2; \text{ since you need only } 5.40 \text{ mol O}_2 \text{ to react with } 2.70 \text{ mol C}_2\text{H}_4, \text{ and you are provided with } 6.30 \text{ mol O}_2; \\ \text{C}_2\text{H}_4 \text{ is the limiting reactant.}$$

b. calculate the moles of water produced.

$$2.70 \text{ mol C}_2\text{H}_4 \left( \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol C}_2\text{H}_4} \right) = 5.40 \text{ mol H}_2\text{O} \text{ is produced}$$

25. Hydrogen gas can be produced in the laboratory by the reaction of magnesium metal with hydrochloric acid.



a. identify the limiting reagent when 6.00 g HCl reacts with 5.00 g Mg.

$$(6.00 \text{ g HCl}) \left( \frac{1 \text{ mol HCl}}{36.46 \text{ g HCl}} \right) \left( \frac{1 \text{ mol Mg}}{2 \text{ mol HCl}} \right) \left( \frac{24.31 \text{ g Mg}}{1 \text{ mol Mg}} \right) = 2.00 \text{ g Mg}$$

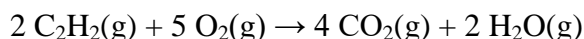
Since 6.00 HCl requires only 2.00 g Mg to react, the Mg (5.00 g) is in excess and HCl is the limiting reactant.

b. How many grams of hydrogen can be produced when 6.00 g HCl is added to 5.00 g Mg?

$$(6.00 \text{ g HCl}) \left( \frac{1 \text{ mol HCl}}{36.46 \text{ g HCl}} \right) \left( \frac{1 \text{ mol H}_2}{2 \text{ mol HCl}} \right) \left( \frac{2.02 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 0.166 \text{ g H}_2$$

Since HCl is the limiting reactant, we use that quantity to determine how many grams of H<sub>2</sub> will be produced.

26. Acetylene (C<sub>2</sub>H<sub>2</sub>) will burn in the presence of oxygen:



How many grams of water can be produced by the reaction of 2.40 mol C<sub>2</sub>H<sub>2</sub> with 7.4 mol O<sub>2</sub>?

First determine which of the reactants is limiting:

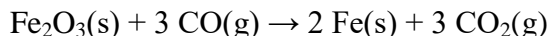
$$(2.40 \text{ mol C}_2\text{H}_2) \left( \frac{5 \text{ mol O}_2}{2 \text{ mol C}_2\text{H}_2} \right) = 6.0 \text{ mol O}_2$$

Since 2.40 mol C<sub>2</sub>H<sub>2</sub> reacts with exactly 6.0 mol O<sub>2</sub>, and we are provided a whopping 7.4 mol O<sub>2</sub>, the O<sub>2</sub> is in excess, and C<sub>2</sub>H<sub>2</sub> is limiting.

$$(2.40 \text{ mol C}_2\text{H}_2) \left( \frac{2 \text{ mol H}_2\text{O}}{2 \text{ mol C}_2\text{H}_2} \right) \left( \frac{18.0 \text{ mol H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right) = 43 \text{ g H}_2\text{O}$$

### Practice Problems – Percent Yield

27. When 84.8 g of iron(III) oxide reacts with an excess of carbon monoxide, 54.3 g of iron is produced according to the reaction:



**First**, calculate how much Fe is *theoretically* obtained.

**Second**, insert into equation:

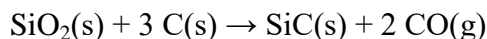
$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

What is the percent yield of this reaction?

$$(84.8 \text{ g Fe}_2\text{O}_3) \left( \frac{1 \text{ mol Fe}_2\text{O}_3}{159.7 \text{ g Fe}_2\text{O}_3} \right) \left( \frac{2 \text{ mol Fe}}{1 \text{ mol Fe}_2\text{O}_3} \right) \left( \frac{55.845 \text{ g Fe}}{1 \text{ mol Fe}} \right) = 59.3 \text{ g Fe theoretical yield}$$

$$\% \text{ yield} = \frac{54.3 \text{ g Fe}}{59.3 \text{ g Fe}} \times 100\% = 91.6\%$$

28. If 50.0 g of silicon dioxide is heated with an excess of carbon, 27.9 g of silicon carbide is produced.



What is the percent yield of this reaction?

$$(50.0 \text{ g SiO}_2) \left( \frac{1 \text{ mol SiO}_2}{60.1 \text{ g SiO}_2} \right) \left( \frac{1 \text{ mol SiC}}{1 \text{ mol SiO}_2} \right) \left( \frac{40.1 \text{ g SiC}}{1 \text{ mol SiC}} \right) = 33.36 \text{ g SiC, theoretical yield}$$

$$\% \text{ yield} = \left( \frac{27.9 \text{ g SiC}}{33.36 \text{ g SiC}} \right) (100\%) = 83.6\%$$

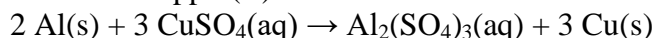
### Section Review 9.3

29. What is a limiting reagent? An excess reagent?

The limiting reagent is the one that is in short supply where the reaction is concerned; it is the one that determines the amount of product possible.

Excess reagent is the one not totally used up by the reaction.

30. What is the percent yield if 4.65 g of copper is produced when 1.87 g of aluminum reacts with an excess of copper(II) sulfate?



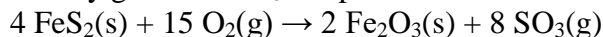
$$(1.87 \text{ g Al}) \left( \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \right) \left( \frac{3 \text{ mol Cu}}{2 \text{ mol Al}} \right) \left( \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} \right) = 6.607 \text{ g Cu, theoretically}$$

$$\% \text{ yield} = \left( \frac{4.65 \text{ g Cu}}{6.607 \text{ g Cu}} \right) (100\%) = 70.4\%$$

31. What is the difference between an actual yield and a theoretical yield? Which yield is larger for a given reaction? How are these values used to determine percent yield?

The actual yield is that which is obtained through actual experimentation; the theoretical yield is the value calculated from the balanced chemical reaction.

32. How many grams of SO<sub>3</sub> are produced when 20.0 g FeS<sub>2</sub> reacts with 16.0 g O<sub>2</sub> according to:



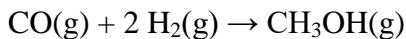
$$(20.0 \text{ g FeS}_2) \left( \frac{1 \text{ mol FeS}_2}{120. \text{g FeS}_2} \right) \left( \frac{15 \text{ mol O}_2}{4 \text{ mol FeS}_2} \right) \left( \frac{32.0 \text{ g O}_2}{1 \text{ mol O}_2} \right) = 20.0 \text{ g O}_2$$

by this we see that O<sub>2</sub> is limiting, since we have only 16.0 g available

$$(16.0 \text{ g O}_2) \left( \frac{1 \text{ mol O}_2}{32.0 \text{ g O}_2} \right) \left( \frac{8 \text{ mol SO}_3}{15 \text{ mol O}_2} \right) \left( \frac{80.1 \text{ g SO}_3}{1 \text{ mol SO}_3} \right) = 21.4 \text{ g SO}_3$$

## Chapter 9 Review

38. Methanol (CH<sub>3</sub>OH) is used in the production of many chemicals. Methanol is made by reacting carbon monoxide and hydrogen at a high temperature and pressure. 9.2



a. How many moles of each reactant are needed to produce  $3.60 \times 10^2$  g CH<sub>3</sub>OH?

$$(3.60 \times 10^2 \text{ g CH}_3\text{OH}) \left( \frac{1 \text{ mol CH}_3\text{OH}}{32.0 \text{ g CH}_3\text{OH}} \right) \left( \frac{1 \text{ mol CO}}{1 \text{ mol CH}_3\text{OH}} \right) = 11.3 \text{ mol CO}$$

$$(3.60 \times 10^2 \text{ g CH}_3\text{OH}) \left( \frac{1 \text{ mol CH}_3\text{OH}}{32.0 \text{ g CH}_3\text{OH}} \right) \left( \frac{2 \text{ mol H}_2}{1 \text{ mol CH}_3\text{OH}} \right) = 22.5 \text{ mol H}_2$$

b. Calculate the number of grams of each reactant needed to produce 4.00 mol CH<sub>3</sub>OH.

$$(4.00 \text{ mol CH}_3\text{OH}) \left( \frac{1 \text{ mol CO}}{1 \text{ mol CH}_3\text{OH}} \right) \left( \frac{28.0 \text{ g CO}}{1 \text{ mol CO}} \right) = 112 \text{ g CO}$$

$$(4.00 \text{ mol CH}_3\text{OH}) \left( \frac{2 \text{ mol H}_2}{1 \text{ mol CH}_3\text{OH}} \right) \left( \frac{2.02 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 16.2 \text{ g H}_2$$

c. How many grams of hydrogen are necessary to react with 2.85 mol CO?

43. Explain how you would identify a limiting reagent in a chemical reaction. 9.3

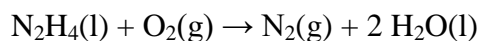
44. For each balanced equation, identify by *circling* the limiting reagent for the given combination of reactants. 9.3. *You may do your work on the back of this page.*

				# moles formed (#45)	excess (#46)		
a.	2 Al	+	3 Cl <sub>2</sub>	→	2 AlCl <sub>3</sub>		
	3.6 mol		5.3 mol			_____	_____
b.	2 H <sub>2</sub>	+	O <sub>2</sub>	→	2 H <sub>2</sub> O		
	6.4 mol		3.4 mol			_____	_____
c.	2 P <sub>2</sub> O <sub>5</sub>	+	6 H <sub>2</sub> O	→	4 H <sub>3</sub> PO <sub>4</sub>		
	0.48 mol		1.52 mol			_____	_____
d.	4 P	+	5 O <sub>2</sub>	→	2 P <sub>2</sub> O <sub>5</sub>		
	14.5 mol		18.0 mol			_____	_____

45. For each reaction in Problem 44, calculate the number of moles of product formed, and write next to the symbol for the products, as indicated above. 9.3

46. For each reaction in Problem 44, calculate the number of moles of excess reagent remaining after the reaction, and write as indicated above. 9.3

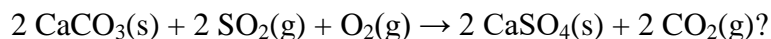
53. Hydrazine ( $\text{N}_2\text{H}_4$ ) is used as rocket fuel. It reacts with oxygen to form nitrogen and water.



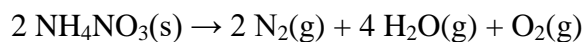
a. How many liters of  $\text{N}_2$  (at STP) form when 1.0 kg  $\text{N}_2\text{H}_4$  reacts with 1.0 kg  $\text{O}_2$ ?

b. How many grams of the excess reagent remain after the reaction?

55. If the reaction below proceeds with a 96.8 % yield, how many kilograms of  $\text{CaSO}_4$  are formed when 5.24 kg  $\text{SO}_2$  reacts with an excess of  $\text{CaCO}_3$  and  $\text{O}_2$ ?



56. Ammonium nitrate, marketed online as “Terrorists Choice,” will decompose explosively at high temperatures to form nitrogen, oxygen, and water vapor.



What is the total number of liters of gas formed when 228 g  $\text{NH}_4\text{NO}_3$  is decomposed? Assume STP.