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.

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$

(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:

$2\ C_2H_2(g) + 5\ O_2(g) \rightarrow 4\ CO_2(g) + 2\ H_2O(g)$

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.

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6. Balance this equation: $C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$.

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 C_2H_5OH reacts with 96.0 g O_2 to yield 88.0 g CO_2 and 54.0 g H_2O.

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.

$2\ K(s) + 2\ H_2O(l) \rightarrow 2\ KOH(aq) + H_2(g)$

(a) 2 K atoms + 2 H_2O molecules yields 2 formula units of KOH and 1 molecule H_2

(b) 2 mol K and 2 mol H_2O yields 2 mol KOH and 1 mol H_2

(c) 78.2 g K and 36.0 g H_2O produces 112.2 g KOH and 2.0 g H_2

Practice Problems – Mole-Mole Calculations

9. This equation shows the formation of aluminum oxide: $4\ Al(s) + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$

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

$$\frac{4 \text{ mol Al}}{3 \text{ mol } O_2} \quad \frac{4 \text{ mol Al}}{2 \text{ mol } Al_2O_3} \quad \frac{3 \text{ mol } O_2}{2 \text{ mol } Al_2O_3} \quad \frac{3 \text{ mol } O_2}{4 \text{ mol Al}} \quad \frac{2 \text{ mol } Al_2O_3}{4 \text{ mol Al}} \quad \frac{2 \text{ mol } Al_2O_3}{3 \text{ mol } O_2}$$

b. How many moles of aluminum are needed to form 3.7 mol Al_2O_3?

$$(3.7\ mol\ Al_2O_3)\left(\frac{4\ mol\ Al}{2\ mol\ Al_2O_3}\right) = 7.4\ mol\ Al$$

10. According to the equation in Problem 9:

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

$$(14.8\ Al)\left(\frac{3\ mol\ O_2}{4\ mol\ Al}\right) = 11.1\ mol\ O_2$$

b. How many moles of Al_2O_3 are formed when 0.78 mol O_2 reacts with aluminum?

$$(0.78\ mol\ O_2)\left(\frac{2\ mol\ Al_2O_3}{3\ mol\ O_2}\right) = 0.52\ mol\ Al_2O_3$$

Practice Problems – Mass-Mass Calculations

11. Acetylene gas (C_2H_2) is produced by adding water to calcium carbide (CaC_2).

$CaC_2(s) + 2\ H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$

How many grams of acetylene are produced by adding water to 5.00 g of CaC_2?

$$(5.00\ g\ CaC_2)\left(\frac{1\ mol\ CaC_2}{64.1\ g\ CaC_2}\right)\left(\frac{1\ mol\ C_2H_2}{1\ mol\ CaC_2}\right)\left(\frac{26.0\ g\ C_2H_2}{1\ mol\ C_2H_2}\right) = 2.03\ g\ C_2H_2$$

12. Using the same equation from Problem #11, determine how many moles of CaC_2 are needed to react completely with 49.0 g H_2O.

$$(49.0\ g\ H_2O)\left(\frac{1\ mol\ H_2O}{18.0\ g\ H_2O}\right)\left(\frac{1\ mol\ CaC_2}{2\ mol\ H_2O}\right) = 1.36\ mol\ CaC_2$$

Practice Problems – Other Stoichiometric Calculations

13. How many molecules of oxygen are produced by the decomposition of 6.54 g of potassium chlorate ($KClO_3$)?

$$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$$

$$(6.54\ g\ KClO_3)\left(\frac{1\ mol\ KClO_3}{122.6\ g\ KClO_3}\right)\left(\frac{3\ mol\ O_2}{2\ mol\ KClO_3}\right)\left(\frac{6.02\ x\ 10^{23} molecules\ O_2}{1\ mol\ O_2}\right) =$$

$$4.82\ x\ 10^{22}\ molecules\ O_2$$

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

$$3\ NO_2(g) + H_2O(l) \rightarrow 2\ HNO_3(aq) + NO(g)$$

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

$$(5.00\ x\ 10^{22}\ molecules\ NO)\left(\frac{1\ mol\ NO}{6.02\ x\ 10^{23} molecules\ NO}\right)\left(\frac{3\ mol\ NO_2}{1\ mol\ NO}\right)\left(\frac{46.0\ g\ NO_2}{1\ mol\ NO_2}\right) =$$

$$11.5\ g\ NO_2$$

15. The equation for the combustion of carbon monoxide is: $2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$

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

$$(3.86\ L\ CO)\left(\frac{1\ L\ O_2}{2\ L\ CO}\right) = 1.93\ L\ O_2$$

16. Phosphorus and hydrogen can be combined to form phosphine (PH_3):

$$P_4(s) + 6\ H_2(g) \rightarrow 4\ PH_3(g)$$

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

$$(0.42\ L\ H_2)\left(\frac{1\ mol\ H_2}{22.4\ L\ H_2}\right)\left(\frac{4\ mol\ PH_3}{6\ mol\ H_2}\right)\left(\frac{22.4\ L\ PH_3}{1\ mol\ PH_3}\right) = 0.28\ L\ PH_3$$

17. Consider this equation:

$$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$$

Calculate the volume of sulfur dioxide produced when 27.9 mL O_2 reacts with carbon disulfide.

$$(27.9\ mL\ O_2)\left(\frac{1\ L\ O_2}{1000\ mL\ O_2}\right)\left(\frac{1\ mol\ O_2}{22.4\ L\ O_2}\right)\left(\frac{2\ mol\ SO_2}{3\ mol\ O_2}\right)\left(\frac{22.4\ L\ SO_2}{1\ mol\ SO_2}\right) = 0.0186\ L\ SO_2$$

18. From the equation in Problem 17, calculate the number of deciliters of carbon dioxide produced when 0.38 L SO_2 is formed.

$$(0.38\ L\ SO_2)\left(\frac{1\ mol\ SO_2}{22.4\ L\ SO_2}\right)\left(\frac{1\ mol\ CO_2}{2\ mol\ SO_2}\right)\left(\frac{22.4\ L\ CO_2}{1\ mol\ CO_2}\right)\left(\frac{10\ dL\ CO_2}{1\ L\ CO_2}\right) = 1.9\ \ dL\ CO_2$$

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).

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

$2\ C_3H_7OH(l) + 9\ O_2(g) \rightarrow 6\ CO_2(g) + 8\ H_2O(g)$

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

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

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

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

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

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

$Sn(s) + 2\ HF(g) \rightarrow SnF_2(s) + H_2(g)$

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

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

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

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

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

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

$$966\ g\ SnF_2$$

Practice Problems – Limiting Reagent

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

$C_2H_4(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O(g)$

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2,

a. identify the limiting reagent.

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

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

b. calculate the moles of water produced.

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

24. The equation for the incomplete combustion of ethene (C_2H_4) is:

$C_2H_4(g) + 2\ O_2(g) \rightarrow 2\ CO(g) + 2\ H_2O(g)$

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2,

a. identify the limiting reagent.

$$(2.70\ mol\ C_2H_4)\left(\frac{2\ mol\ O_2}{1\ mol\ C_2H_4}\right) = 5.40\ mol\ O_2; since\ you\ need\ only\ 5.40\ mol\ O_2$$
$$to\ react\ with\ 2.70\ mol\ C_2H_4, and\ you\ are\ provided\ with\ 6.30\ mol\ O_2;$$
$$C_2H_4\ is\ the\ limiting\ reactant.$$

b. calculate the moles of water produced.

$$2.70\ mol\ C_2H_4)\ \left(\frac{2\ mol\ H_2O}{1\ mol\ C_2H_4}\right) = 5.40\ mol\ H_2O\ is\ produced$$

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

$Mg(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

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

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

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?

$$(6.00\ g\ HCl)\left(\frac{1\ mol\ HCl}{36.46\ g\ HCl}\right)\left(\frac{1\ mol\ H_2}{2\ mol\ HCl}\right)\left(\frac{2.02\ g\ H_2}{1\ mol\ H_2}\right) = 0.166\ g\ H_2$$

Since HCl is the limiting reactant, we use that quantity to determine how many grams of H_2 will be produced.

26. Acetylene (C_2H_2) will burn in the presence of oxygen:

$2\ C_2H_2(g) + 5\ O_2(g) \rightarrow 4\ CO_2(g) + 2\ H_2O(g)$

How many grams of water can be produced by the reaction of 2.40 mol C_2H_2 with 7.4 mol O_2?

First determine which of the reactants is limiting:

$$(2.40\ mol\ C_2H_2)\left(\frac{5\ mol\ O_2}{2\ mol\ C_2H_2}\right) = 6.0\ mol\ O_2$$

Since 2.40 mol C_2H_2 reacts with exactly 6.0 mol O_2, and we are provided a whopping 7.4 mol O_2, the O_2 is in excess, and C_2H_2 is limiting.

$$(2.40\ mol\ C_2H_2)\left(\frac{2\ mol\ H_2O}{2\ mol\ C_2H_2}\right)\left(\frac{18.0\ mol\ H_2O}{1\ mol\ H_2O}\right) = 43\ g\ H_2O$$

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:

$$\% \ yield = \frac{actual\ yield}{theoretical\ yield} x\ 100\%$$

$Fe_2O_3(s) + 3\ CO(g) \rightarrow 2\ Fe(s) + 3\ CO_2(g)$

What is the percent yield of this reaction?

$$(84.8\ g\ Fe_2O_3)\left(\frac{1\ mol\ Fe_2O_3}{159.7\ g\ Fe_2O_3}\right)\left(\frac{2\ molFe}{1\ mol\ Fe_2O_3}\right)\left(\frac{55.845\ g\ Fe}{1\ mol\ Fe}\right) = 59.3\ g\ Fe\ theoretical\ yield$$

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

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

$SiO_2(s) + 3\ C(s) \rightarrow SiC(s) + 2\ CO(g)$

What is the percent yield of this reaction?

$$(50.0\ g\ SiO_2)\left(\frac{1\ mol\ SiO_2}{60.1\ g\ SiO_2}\right)\left(\frac{1\ mol\ SiC}{1\ mol\ SiO_2}\right)\left(\frac{40.1\ g\ SiC}{1\ mol\ SiC}\right) = 33.36\ g\ SiC, theoretical\ yield$$

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

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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?

$2\ Al(s) + 3\ CuSO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3\ Cu(s)$

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

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

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_3 are produced when 20.0 g FeS_2 reacts with 16.0 g O_2 according to:

$4\ FeS_2(s) + 15\ O_2(g) \rightarrow 2\ Fe_2O_3(s) + 8\ SO_3(g)$

$$(20.0\ g\ FeS_2)\left(\frac{1\ mol\ FeS_2}{120.g\ FeS_2}\right)\left(\frac{15\ mol\ O_2}{4\ mol\ FeS_2}\right)\left(\frac{32.0\ g\ O_2}{1\ mol\ O_2}\right) = 20.0\ g\ O_2$$

$$by\ this\ we\ see\ that\ O_2\ is\ limiting, since\ we\ have\ only\ 16.0\ g\ available$$

$$(16.0\ g\ O_2)\left(\frac{1\ mol\ O_2}{32.0\ g\ O_2}\right)\left(\frac{8\ mol\ SO_3}{15\ mol\ O_2}\right)\left(\frac{80.1\ g\ SO_3}{1\ mol\ SO_3}\right) = 21.4\ g\ SO_3$$

Chapter 9 Review

38. Methanol (CH_3OH) 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

$CO(g) + 2\ H_2(g) \rightarrow CH_3OH(g)$

a. How many moles of each reactant are needed to produce 3.60×10^2 g CH_3OH?

$$(3.60\ x\ 10^2 g\ CH_3OH)\left(\frac{1\ mol\ CH_3OH}{32.0\ g\ CH_3OH}\right)\left(\frac{1\ mol\ CO}{1\ mol\ CH_3OH}\right) = 11.3\ mol\ CO$$

$$(3.60\ x\ 10^2 g\ CH_3OH)\left(\frac{1\ mol\ CH_3OH}{32.0\ g\ CH_3OH}\right)\left(\frac{2\ mol\ H_2}{1\ mol\ CH_3OH}\right) = 22.5\ mol\ H_2$$

b. Calculate the number of grams of each reactant needed to produce 4.00 mol CH_3OH.

$$(4.00\ mol\ CH_3OH)\left(\frac{1\ mol\ CO}{1\ mol\ CH_3OH}\right)\left(\frac{28.0\ g\ CO}{1\ mol\ CO}\right) = 112\ g\ CO$$

$$(4.00\ mol\ CH_3OH)\left(\frac{2\ mol\ H_2}{1\ mol\ CH_3OH}\right)\left(\frac{2.02\ g\ H_2}{1\ mol\ H_2}\right) = 16.2\ g\ H_2$$

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.	$2\ Al$ + 3.6 mol	$3\ Cl_2$ → 5.3 mol	$2\ AlCl_3$	___________	__________
b.	$2\ H_2$ + 6.4 mol	O_2 → 3.4 mol	$2\ H_2O$	___________	___________
c.	$2\ P_2O_5$ + 0.48 mol	$6\ H_2O$ → 1.52 mol	$4\ H_3PO_4$	___________	___________
d.	$4\ P$ + 14.5 mol	$5\ O_2$ → 18.0 mol	$2\ P_2O_5$	___________	___________

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 (N_2H_4) is used as rocket fuel. It reacts with oxygen to form nitrogen and water.

$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2\ H_2O(l)$

a. How many liters of N_2 (at STP) form when 1.0 kg N_2H_4 reacts with 1.0 kg 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 $CaSO_4$ are formed when 5.24 kg SO_2 reacts with an excess of $CaCO_3$ and O_2?

$2\ CaCO_3(s) + 2\ SO_2(g) + O_2(g) \rightarrow 2\ CaSO_4(s) + 2\ CO_2(g)$?

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

$2\ NH_4NO_3(s) \rightarrow 2\ N_2(g) + 4\ H_2O(g) + O_2(g)$

What is the total number of liters of gas formed when 228 g NH_4NO_3 is decomposed? Assume STP.