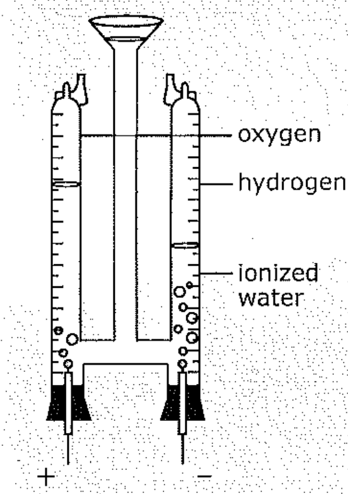
4.1 Writing and Balancing Chemical Equations — The Magic of Chemistry

Warm Up (p. 162)

Water may be broken down into its component elements, oxygen and hydrogen, by the application of electric current. This process is called electrolysis.



1. Use your knowledge of chemical nomenclature to write an equation showing the process occurring in the diagram. (Be sure to indicate hydrogen and oxygen as diatomic molecules.)

   $2H_2O \rightarrow 2H_2 + O_2$

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

2. Count the total number of atoms of hydrogen and oxygen before and after the change. Make any necessary changes to ensure that these are equal.
3. Make any necessary changes to indicate the states of the substances in your equation.
4. Include anything else you feel is necessary to help your equation fully describe what is happening during this process.

Quick Check (p. 163)

1. List three pieces of evidence of chemical change in the decomposition of mercury(II) oxide.
   color change (red → silver), evolution of gas (O_2) and ↑ solid mass.
   $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$
2. Convert the following from a word equation to a formula equation:
   Calcium oxide powder is combined with water to form calcium hydroxide solid.
   $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$
3. Convert the following from a formula equation to a word equation:
   $H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l)$
   carbonic acid decomposes to carbon dioxide gas and water

Quick Check (p. 165)

Circle the letter of the properly balanced equations:

(a) $Na(s) + Cl_2(g) \rightarrow NaCl_2(s)$ (incorrect formula created)

(b) $AgNO_3(aq) + KBr(aq) \rightarrow AgBr(s) + KNO_3(aq)$

(c) $H_2O(l) + SiCl_4(l) \rightarrow SiO_2(s) + 4\,HCl(g)$ (missing coefficient)

(d) $C_3H_8(g) + 5\,O_2(g) \rightarrow 3\,CO_2(g) + 4\,H_2O(l)$

(e) $3\,LiOH(aq) + Fe(IO_4)_3(aq) \rightarrow Fe(OH)_3(s) + 3\,LiIO_4(aq)$

Practice Problems — Balancing Formula Equations (p. 168)

1. Complete the following table to check the balancing of the sample equation above.

Atom	Reactant Side	Product Side
Na	8	8
O	20	20
H	8	8
Cr	4	4

2. Balance each of the following using the smallest possible whole number coefficients.
   (a) 2 $Al(s)$ + 3 $H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq)$ + 3 $H_2(g)$
   (b) $Mg_3N_2(s)$ + 6 $H_2O(l) \rightarrow$ 3 $Mg(OH)_2(s)$ + 2 $NH_3(g)$
   (c) 4 $NH_3(g)$ + 5 $O_2(g) \rightarrow$ 6 $H_2O(l)$ + 4 $NO(g)$

Practice Problems — Writing Balanced Formula Equations from Word Equations (p. 169)

Write balanced equations for each of the following, using the smallest possible whole number coefficients. Include appropriate phase indicators.

1. Solid iron and chlorine gas combine to form iron(III) chloride.
   $2\,Fe(s) + 3\,Cl_2(g) \rightarrow 2\,FeCl_3(aq)$
2. Aqueous solutions of ammonium phosphide and lead(II) bromate react to give a precipitate of lead(II) phosphide and aqueous ammonium bromate.
   $2\,(NH_4)_3P(aq) + 3\,Pb(BrO_3)_2 \rightarrow Pb_3P_2(s) + 6\,NH_4BrO_3(aq)$
3. Calcium metal reacts in an aqueous solution of nickel(III) sulphate to form calcium sulfate solution and nickel metal.
   $3\,Ca(s) + Ni_2(SO_4)_3(aq) \rightarrow 3\,CaSO_4(aq) + 2\,Ni(s)$

4.1 Activity: Building a Balanced Equation (p. 170)

Question

How can you represent the chemical reaction between nitrogen dioxide gas and water to form nitric acid and nitrogen monoxide?

Materials

You may use any of the following materials:

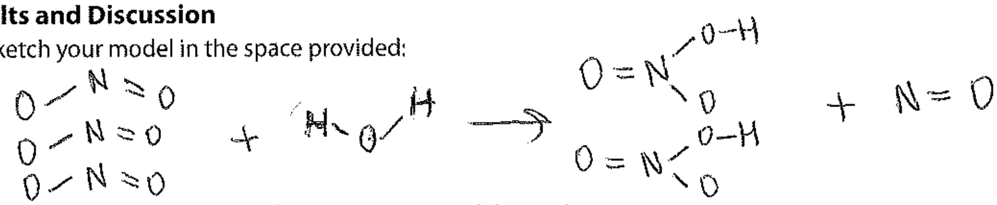
- a series of coins of different sizes representing nitrogen, oxygen, and hydrogen atoms
- modelling clay in different colours and sizes representing the required atoms
- a chemical model kit
- a series of drawings using different colours and sizes of images to represent the required atoms

Procedure

1. Use the materials you've selected to build a model of the balanced equation that represents the reaction in the question.
2. Compare your model with models done by one or more of your classmates.

Results and Discussion

1. Sketch your model in the space provided:



2. Make a table to check the balancing in your model equation:

$3NO_{2(g)} + H_2O_{(l)} \longrightarrow 2HNO_{3(aq)} + NO_{(g)}$

3. How many chemical bonds were broken during your reaction? Describe each of these bonds.

3 O–N single bonds broken
2 H–O single bonds "
3 N=O double bonds "
} 8 bonds broken, endothermic

4. How many chemical bonds were formed during your reaction? Describe each.

2 N=O bonds, 4 N–O bonds, 1 N=O bond, 2 O–H bonds ⇒ 9 bonds formed, exothermic

5. Were more bonds formed or broken? What might this mean for your reaction?

More bonds formed, exothermic rxn.

(Note: Circles with single bonds everywhere is certainly acceptable at this point)

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4.1 Review Questions (p. 171)

1. State two examples of chemical change from everyday life. What evidence indicates that these are chemical changes?

   For Example: Rusting – colour change
   Burning Wood – exothermic (heat released)

2. What chemical law requires us to balance chemical equations?

   Law of Conservation of Mass

   Who was responsible for formulating this law?

   Antoine Lavoisier

3. Write a word equation for each formula equation below:

   (a) $C(s) + O_2(g) \rightarrow CO_2(g)$ Solid carbon combines with oxygen gas to form carbon dioxide gas

   (b) $CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(g)$
   Methane gas combusts in oxygen gas to produce carbon dioxide gas and water vapor

   (c) $Cl_2(g) + 2\,KI(s) \rightarrow I_2(s) + 2\,KCl(s)$
   Chlorine gas reacts with solid potassium iodide. to form solid iodine and potassium chloride solid.

   (d) $HCl(aq) + NaOH(s) \rightarrow NaCl(aq) + H_2O(l)$
   hydrochloric acid neutralizes solid sodium hydroxide to form sodium chloride solution and water

   (e) $KF(s) \rightarrow K(s) + F_2(g)$
   solid potassium fluoride decomposes to form solid potassium and fluorine gas

4. Balance each of the following equations. (State indicators are not required.)

   (a) $CdF_2 + 2\,NaBr \rightarrow CdBr_2 + 2\,NaF$
   (b) $2\,Cr + 3\,F_2 \rightarrow 2\,CrF_3$
   (c) $Ca + 2\,H_2O \rightarrow Ca(OH)_2 + H_2$
   (d) $2\,Bi(NO_3)_3 + 3\,Na_2S \rightarrow Bi_2S_3 + 6\,NaNO_3$
   (e) $C_2H_5OH + 3\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O$
   (f) $16\,V + 5\,S_8 \rightarrow 8\,V_2S_5$
   (g) $2\,LiNO_3 + 10\,Li \rightarrow 6\,Li_2O + N_2$
   (h) $Ca_3(PO_4)_2 + 3\,H_2SO_4 \rightarrow 3\,CaSO_4 + 2\,H_3PO_4$
   (i) $2\,PH_3 + 4\,O_2 \rightarrow P_2O_5 + 3\,H_2O$
   (j) $3\,Ba + 2\,Ag_3PO_4 \rightarrow Ba_3(PO_4)_2 + 6\,Ag$
   (k) $Ca(ClO_3)_2 \rightarrow CaCl_2 + 3\,O_2$
   (l) $C_{12}H_{22}O_{11} + 12\,O_2 \rightarrow 12\,CO_2 + 11\,H_2O$
   (m) $Ca_2C + 4\,H_2O \rightarrow 2\,Ca(OH)_2 + CH_4$
   (n) $2\,NH_4Br + BaO \rightarrow 2\,NH_3 + BaBr_2 + H_2O$
   (o) $3\,LiAlH_4 + 4\,BF_3 \rightarrow 3\,LiF + 3\,AlF_3 + 2\,B_2H_6$

5. Write a balanced formula equation for each of the following (phase indicators should be included if possible):

(a) Titanium metal reacts with selenium to produce crystals of titanium(III) selenide.

$2Ti(s) + 3Se(s) \rightarrow Ti_2Se_3(s)$

(b) Phosphoric acid is neutralized with barium hydroxide to produce a precipitate of barium phosphate in water.

$2H_3PO_4(aq) + 3Ba(OH)_2(s) \rightarrow Ba_3(PO_4)_2(s) + 6H_2O(l)$

(c) Nitrogen gas reacts with lead(II) oxide powder to yield lead(II) nitride and oxygen gas.

$2N_2(g) + 6PbO(s) \rightarrow 2Pb_3N_2 + 3O_2(g)$

(d) Xenon hexafluoride crystals react with water to produce xenon trioxide powder and hydrofluoric acid.

$XeF_6(s) + 3H_2O(l) \rightarrow XeO_3(s) + 6HF$

(e) Aluminum carbide is reacted with water in the synthesis of methane gas. Aluminum hydroxide precipitate is also formed.

$Al_4C_3(s) + 12H_2O(l) \rightarrow 3CH_4(g) + 4Al(OH)_3(s)$

(f) Plants produce the simple sugar $C_6H_{12}O_6$ and oxygen gas from carbon dioxide and water during photosynthesis.

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$

(g) Ammonia gas (NH_3) is formed along with a precipitate of magnesium hydroxide from the reaction of magnesium nitride powder with water.

$Mg_3N_2(s) + 6H_2O(l) \rightarrow 2NH_3(g) + 3Mg(OH)_2(s)$

(h) Strong heating of copper(II) nitrate trihydrate produces copper(II) oxide, nitrogen dioxide, oxygen gas, and water.

$2Cu(NO_3)_2 \cdot 3H_2O \rightarrow 2CuO + 4NO_2(g) + O_2(g) + 6H_2O(l)$

6. Balancing Bonkers: Some equations are extremely difficult to balance even with the application of the balancing hints! Later on in your chemistry career, you will learn to balance some equations using the concepts of oxidation and reduction. This will be a major stress reducer when it comes to balancing. In the meantime, try to balance a few of these exhauster equations:

(a) $3Ag + 4HNO_3 \rightarrow NO + 3AgNO_3 + 2H_2O$
(b) $2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2$
(c) $10HNO_3 + 4Zn \rightarrow 4Zn(NO_3)_2 + 3H_2O + NH_4NO_3$
(d) $6H_2O + 4As + 3HClO_3 \rightarrow 4H_3AsO_3 + 3HClO$
(e) $3H_2SO_4 + H_2O_2 + 2KMnO_4 \rightarrow 2MnSO_4 + 3O_2 + 4H_2O + K_2SO_4$

Hint: You may want to come back to these once you've finished section 4.3.

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4.2 Classifying Chemical Changes and Predicting Products

Warm Up (p. 173)

Reaction Type	Reactants	Products
Synthesis (combination)	two substances	one substance
Decomposition	one substance	two substances
Single replacement	element + compound	new element + compound
Double replacement	two compounds	two new compounds
Neutralization	acid + base	salt + water
Combustion	organic compound + oxygen	carbon dioxide + water

Balance the following equations. Then use the table above to classify each as one of the major reaction types listed:

1. 2 $Na(s)$ + 2 $H_2O(l) \rightarrow$ 2 $NaOH(aq)$ + $H_2(g)$ Single Replacement
2. $Li_2O(s)$ + $H_2O(l) \rightarrow$ 2 $LiOH(aq)$ combination (synthesis)
3. 2 $C_6H_{14}(l)$ + 19 $O_2(g) \rightarrow$ 12 $CO_2(g)$ + 14 $H_2O(g)$ combustion
4. 2 $HCl(aq)$ + $Sr(OH)_2(aq) \rightarrow$ $SrCl_2(aq)$ + 2 $H_2O(l)$ Neutralization
5. 2 $AlBr_3(s) \rightarrow$ 2 $Al(s)$ + 3 $Br_2(l)$ Decomposition

Quick Check (p. 176)

Balance each of the following reactions and classify them as synthesis, decomposition or combustion.

1. $P_2O_5(g)$ + 3 $H_2O(l) \rightarrow$ 2 $H_3PO_4(aq)$ Combination (synthesis)
2. $CH_4(g)$ + 2 $O_2(g) \rightarrow$ $CO_2(g)$ + 2 $H_2O(g)$ Combustion
3. $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$ (bal) Decomposition

Practice Problems — Predicting Products of Reactions (p. 178)

First classify the equations, then determine the products and write a balanced formula equation for each of the following:

1. 2 $Fe_2O_3(s) \rightarrow$ 4Fe + 3O_2 Class: Decomposition
2. 2 $C_3H_7OH(l)$ + 9 $O_2(g) \rightarrow$ 6 CO_2 + 8 H_2O Class: Combustion
3. $Ag_2O(s)$ + $H_2O(l) \rightarrow$ 2 AgOH Class: Combination (syn)
4. $Pb(OH)_4(s) \rightarrow$ PbO_2 + H_2O (bal) Class: Decomposition

Quick Check (p. 179)

Use the series of chemical reactivity in Table 4.2.2 to determine whether each of the following single replacement reactions would proceed. Predict the products for those that do proceed and balance the equations.

1. 3 $Na(s)$ + $AlCl_3(aq) \rightarrow$ 3NaCl + Al

X $Cu(s)$ + $KBr(aq) \rightarrow$ no rxn.

3. $F_2(g)$ + 2 $LiI(aq) \rightarrow$ 2LiF + I_2

4. $Ca(s)$ + 2 $HOH(l) \rightarrow$ $Ca(OH)_2$ + H_2

Practice Problems — Predicting Products of Replacement Reactions (p. 182)

First classify the equations, then determine the products and write a balanced formula equation for each of the following:

1. $3HCl(aq) + Fe(OH)_3(s) \rightarrow FeCl_3 + 6H_2O$ Class: Neutralization
2. $Zn(s) + 2AgClO_3(aq) \rightarrow 2Ag + Zn(ClO_3)_2$ Class: Single Replacement
3. $(NH_4)_2S(aq) + 2CsOH(aq) \rightarrow Cs_2S + 2NH_3 + 2H_2O$ Class: Double Replacement
4. $8Cl_2(g) + 8Li_2S(aq) \rightarrow 16LiCl + S_8$ Class: Single Replacement

4.2 Activity: Identifying an Unknown Substance (p. 182–183)

Results and Discussion

1. Use the table below to record all information and answer the questions below.

Identity of Unknown	Balanced Equation	Explanation	
1) Cl_2	$Cl_{2(aq)} + 2NaBr_{(aq)} \rightarrow 2NaCl_{(aq)} + Br_{2(aq)}$	Chlorine replaces bromine, but iodine does NOT.	(Bromine is orange in elemental form.)
2) $MgCO_3$	$2HNO_{3(aq)} + MgCO_{3(s)} \rightarrow Mg(NO_3)_{(aq)} + H_2O_{(l)} + CO_{2(g)}$	bubbles indicate carbonic acid formed and decomposed → $CO_{2(g)}$	
3) $Pb(NO_3)_2$	$Pb(NO_3)_{2(aq)} + 2NaI_{(aq)} \rightarrow PbI_{2(s)} + 2NaNO_{3(aq)}$	PbI_2 precipitates. The other possible iodide (NaI) is soluble.	(all IA containing cmpds are)
4) $ZnCl_2$	$2Al_{(s)} + 3ZnCl_{2(aq)} \rightarrow 3Zn_{(s)} + 2AlCl_{3(aq)}$	Al replaces Zn^{2+} in compounds. It will not replace Ca^{2+}.	(see activity series)
5)			

2. Write a balanced chemical equation, including phase indicators for each of the confirming tests performed.

See Above

3. Explain why you decided on the unknown in each equation.

See Above

4. Design a test to distinguish between a fifth pair of unknown substances. Give the substances, the test and the expected observations in the provided spaces in the table above. Complete row #5 for your identified substance in the second table above. Many possible.

4.2 **Review Questions** (p. 184)

2 each

1. Balance each of the following reactions:

DR a) $CdF_2 + 2NaBr \rightarrow CdBr_2 (s) + 2NaF$
SR b) $Na_2SO_4 + 2Cu \rightarrow Cu_2SO_4 + 2Na$ (NO)
S c) $2Cr + 3F_2 \rightarrow 2CrF_3$
D d) $2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O$
SR e) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
DR f) $2Bi(NO_3)_3 + 3Na_2S \rightarrow Bi_2S_3 (s) + 6NaNO_3$
C g) $C_{25}H_{52} + 38O_2 \rightarrow 25CO_2 + 26H_2O$
SR h) $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$
D i) $2LiClO_3 \rightarrow 2LiCl + 3O_2$
S j) $2K + Cl_2 \rightarrow 2KCl$
SR k) $2Au + 3H_2S \rightarrow Au_2S_3 + 3H_2$ (NO)
S l) $16Nb + 5S_8 \rightarrow 8Nb_2S_5$
* S m) $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$
D n) $2HClO \rightarrow Cl_2O + H_2O$
N o) $H_3PO_4 + 3KOH \rightarrow K_3PO_4 + 3H_2O$
SR p) $4Rb + Sc_2(CrO_4)_3 \rightarrow 3Rb_2CrO_4 + 2Sc$
D q) $2V(OH)_5 \rightarrow V_2O_5 + 5H_2O$
D r) $2Ba_3P_2 \rightarrow 6Ba + P_4$
DR s) $K_2C_2O_4 + Ca(NO_3)_2 \rightarrow CaC_2O_4 (s) + 2KNO_3$
DR t) $BaCO_3 + 2HCl \rightarrow BaCl_2 + CO_2 + H_2O$

25

2. a) Classify each of the reactions in question 1 as synthesis, decomposition, combustion, single replacement, double replacement or neutralization.

b) Which of the single replacement reactions would *not* proceed spontaneously? b, k

c) Which of the double replacement reactions involve precipitate formation?

a, f, s

d) Indicate the precipitates with a (*s*).

3. Classify each of the following reactions, using the following key: S = Synthesis, D = Decompo- sition, C = Combustion, SR = Single Replace- ment, DR = Double Replacement, N = Neutral- ization. Complete the equations and balance them. Indicate any precipitates that form with a (*s*).

SR a) $2Rb + ZnF_2 \rightarrow 2RbF + Zn$
S b) $Sc_2O_3 + 3H_2O \rightarrow 2Sc(OH)_3$
DR c) $Pb(NO_3)_2 + 2NaCl \rightarrow PbCl_2 (s) + 2NaNO_3$
D d) $H_2CO_3 \rightarrow H_2O + CO_2$ bal
S e) $GeO_2 + 2SO_2 \rightarrow Ge(SO_3)_2$
DR f) $SrCO_3 + H_2S \rightarrow SrS (aq) + H_2O + CO_2$ bal
C g) $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$
SR h) $2Cs + NiCl_2 \rightarrow 2CsCl + Ni$
D i) $Zr(OH)_4 \rightarrow ZrO_2 + H_2O$ bal
SR j) $3Br_2 + 2InI_3 \rightarrow 2InBr_3 + 3I_2$
N k) $2H_3PO_4 + 3Ba(OH)_2 \rightarrow Ba_3(PO_4)_2 (s) + 6H_2O$
DR l) $2AgNO_3 + Ca(CH_3COO)_2 \rightarrow 2AgCH_3COO (s) + Ca(NO_3)_2$
C m) $C_3H_5OH + 4O_2 \rightarrow 3CO_2 + 3H_2O$
S n) $N_2O_5 + H_2O \rightarrow 2HNO_3$
DR o) $2AlCl_3 + 3Na_2CO_3 \rightarrow Al_2(CO_3)_3 (s) + 6NaCl$
DR p) $NH_4F + LiOH \rightarrow LiF + H_2O + NH_3$ bal
N q) $2HNO_3 + Sr(OH)_2 \rightarrow Sr(NO_3)_2 + 2H_2O$
SR r) $8F_2 + 8K_2S \rightarrow 16KF + S_8$
D s) $Mg(OH)_2 \rightarrow MgO + H_2O$ bal
S t) $6Na + N_2 \rightarrow 2Na_3N$

60

4. Classify each of the following chemical changes using the key from question 3. Write

balanced formula equations for each, including phase subscripts.

S a) A piece of magnesium ribbon on a stock shelf reacts with nitrogen gas in the air to form a black coating over time.

$$3\,Mg_{(s)} + N_{2(g)} \rightarrow Mg_3N_{2(s)}$$

N b) Phosphoric acid solution removes iron(III) hydroxide stains from an old bath tub.

$$H_3PO_{4(aq)} + Fe(OH)_{3(s)} \rightarrow FePO_{4(s)} + 3\,H_2O_{(l)}$$

C c) Butane gas is combusted in a disposable lighter.

$$2\,C_4H_{10(g)} + 13\,O_{2(g)} \rightarrow 8\,CO_{2(g)} + 10\,H_2O_{(g)}$$

SR d) A zinc strip placed in a solution of copper (II) sulphate becomes coated with brownish solid.

$$Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$$ bal

S e) Sulphur dioxide emitted from industrial plants combines with water vapour to form acid rain.

$$SO_{2(g)} + H_2O_{(g)} \rightarrow H_2SO_{3(aq)}$$ bal

DR f) Calcium carbonate in marble structures is eroded over time by nitric acid in acid rain.

$$CaCO_{3(s)} + 2\,HNO_{3(aq)} \rightarrow Ca(NO_3)_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

* SR g) Nickel (III) hydroxide reacts with a cadmium anode in a prototype rechargeable battery.

$$2\,Ni(OH)_{3(s)} + 3\,Cd_{(s)} \rightarrow 3\,Cd(OH)_{2(s)} + 2\,Ni_{(s)}$$

DR h) Solutions of gold(III) nitrate and sodium carbonate are combined.

$$2\,Au(NO_3)_{3(aq)} + 3\,Na_2CO_{3(aq)} \rightarrow Au_2(CO_3)_{3(s)} + 6\,NaNO_{3(aq)}$$

DR i) Potassium chromate solution indicates the endpoint in a potato chip analysis with a standard silver nitrate solution.

$$K_2CrO_{4(aq)} + 2\,AgNO_{3(aq)} \rightarrow Ag_2CrO_{4(s)} + 2\,KNO_{3(aq)}$$

C j) Methanol (CH_3OH) is combusted in race car engines.

$$2\,CH_3OH_{(l)} + 3\,O_{2(g)} \rightarrow 2\,CO_{2(g)} + 4\,H_2O_{(g)}$$

DR k) Baking soda (sodium hydrogen carbonate) ~~may~~ is used to neutralize a spill of hydrochloric acid. *

$$NaHCO_{3(aq)} + HCl_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)} + NaCl_{(aq)}$$ bal

DR l) A bright yellow pigment once used in paints is formed from the reaction of lead(II) nitrate and sodium iodide solutions. Why is this paint no longer used?

$$Pb(NO_3)_{2(aq)} + 2\,NaI_{(aq)} \rightarrow PbI_{2(s)} + 2\,NaNO_{3(aq)}$$

S m) Iron(III) oxide and water combine to form a basic compound often called rust.

$$Fe_2O_{3(s)} + 3\,H_2O_{(l)} \rightarrow 2\,Fe(OH)_{3(s)}$$

SR n) Dark silver sulphide tarnish may removed from knives and forks by placing them in contact with a piece of aluminum foil in a dilute ionic solution.

$$3\,Ag_2S_{(s)} + 2\,Al_{(s)} \rightarrow Al_2S_{3(s)} + 6\,Ag_{(s)}$$

DR o) A precipitate of barium oxalate forms in a solution of sodium nitrate following the combination of two solutions.

$$Na_2C_2O_{4(aq)} + Ba(NO_3)_{2(aq)} \rightarrow 2\,NaNO_{3(aq)} + BaC_2O_{4(s)}$$

SR p) A precipitate of barium sulphate and hydrogen gas are formed from the combination of a metal and an acid.

$$Ba_{(s)} + H_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + H_{2(g)}$$ bal

D q) $$2\,H_3PO_{4(aq)} \rightarrow P_2O_{5(g)} + 3\,H_2O_{(l)}$$

4.3 Another Way to Classify — Identifying Electron Transfer (Extension)

Warm Up (p. 187)

Complete and balance the following equations.

1. $2CsOH(s) \rightarrow Cs_2O + H_2O$
(2) $2Al(s) + 3F_2(g) \rightarrow 2AlF_3$
3. $H_2CO_3(aq) + 2KOH(aq) \rightarrow K_2CO_3 + 2H_2O$
(4) $2K(s) + Sr(OH)_2(aq) \rightarrow 2KOH + Sr$

Circle the numbers of the equations that involve a change in the oxidation number (charge) of one or more atoms during the reaction.

Quick Check (p. 187)

1. Decomposition
2. Synthesis (combination)
3. Neutralization
4. Single replacement

Practice Problems — Assigning Oxidation States (p. 190)

Assign the oxidation state of each atom in the following species:

1. H_2O +1 −2
2. Li_2O_2 +1 −1
3. $AgMnO_4$ +1 +7 −2
4. $K_2Cr_2O_7$ +1 +6 −2
5. AlH_3 +3 −1
6. NH_4^+ −3 +1
7. OF_2 +2 −1
8. $Ca(NO_3)_2$ +2 +5 −2
9. ClO_3^- +5 −2
10. $(N_2H_5)_2CO_3$ −2 +1 +4 −2

(p. 190) **Quick Check**

2e⁻ each

1. Write a balanced equation for the combination of magnesium metal with oxygen gas to synthesize a metal oxide.

$$\overset{0}{2Mg} + \overset{0}{O_2} \rightarrow 2\overset{+2}{Mg}\overset{-2}{O}$$

2. Indicate the oxidation state of each element over top of its symbol.
3. Use arrows to indicate the direction of electron transfer between the reactants.

Quick Check (p. 191)

1. (a) How many electrons did each magnesium atom lose in the previous Quick Check? 2
(b) How many electrons did each oxygen atom gain? 2
(c) Which species was oxidized? Mg
Which was reduced? O_2
2. (a) In Figure 4.3.1, how many electrons did each manganese(IV) ion gain? 2
(b) How many electrons did each chloride ion lose? 1
Did all the chloride ions lose electrons? no (2 of the Cl^- ions are spectators)

Practice Problems — Recognizing Oxidizing and Reducing Agents (p. 193)

Determine the oxidizing and reducing agent in each of the following reactions. Begin by clearly indicating the oxidation states of all elements in each equation.

O.A.: R.A.:

0 0 −4 +1

1. $Si(s) + 2\,H_2(g) \rightarrow SiH_4(g)$ — Si — H_2

0 +3 −1 0 +2 −1

2. $3\,Ca(s) + 2\,AlBr_3(aq) \rightarrow 2\,Al(s) + 3\,CaBr_2(aq)$ — Al^{3+} — Ca

+2 −2 +5 −2 +4 −2 0

3. $5\,CO(g) + I_2O_5(s) \rightarrow 5\,CO_2(g) + I_2(s)$ — I_2O_5 — CO

−3 +1 0 0

4. $2\,NH_3(g) \rightarrow N_2(g) + 3\,H_2(g)$ — NH_3 — NH_3

0 +1 −2 +2 −2 +1 0

5. $Mg(s) + 2\,H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$ — H_2O — Mg

4.3 Activity: Building a Table of Reduction Strengths (p. 194)

Question

Can you build a table of reduction strengths?

Background

It is possible to separate out the reduction and oxidation portions of a redox reaction and to represent them as half reactions. For example, the sample reaction from the previous page: $Zn(s) + 2\,HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$ may be broken into the following half reactions: $Zn \rightarrow Zn^{2+} + 2e^-$ (oxidation) and $2H^+ + 2e^- \rightarrow H_2$ (reduction). Notice that the chloride ion is not included in either reaction, as its oxidation state does not change.

An attempt to replace zinc with hydrogen in the following single replacement reaction: $H_2(g) + ZnCl_2(aq) \rightarrow 2HCl(aq) + Zn(s)$ is *unsuccessful* because H_2 gas is too weak as a reducing agent to be oxidized to H^+. Similarly Zn^{2+} is too weak as an oxidizing agent to be reduced to Zn. Comparing these two competing reactions shows us that H^+ ion is a stronger oxidizing agent than Zn^{2+}. Consider the following data:

Attempted Reaction	Result
1. A piece of zinc metal is placed in a solution of $CuCl_2$.	Brown coating results on the zinc.
2. A piece of copper metal is placed in a $ZnCl_2$ solution.	No reaction occurs.
3. Hydrogen gas is bubbled through a solution of $CuCl_2$.	Bits of brown metal form in an acid.
4. Copper metal is placed in a solution of HCl.	No reaction occurs.
5. Manganese metal is placed in a solution of $ZnCl_2$.	Black solid forms in pink $Mn^{2+}(aq)$.
6. Manganese metal is placed in a solution of $CaCl_2$.	No reaction occurs.
7. Calcium metal is placed in a solution of KCl.	No reaction occurs.
8. A coil of zinc is placed in $HCl_{(aq)}$.	Bubbles form as zinc disintegrates.

Procedure

1. Work with a partner or by yourself to design a table of reduction half reactions. Your table should be organized with the strongest oxidizing agent (the species most likely to be reduced) at the top. See the Results and Discussion section below for more ideas.
2. Compare your completed table with those of other groups.

Results and Discussion

1. Write a balanced equation for each attempted reaction (successful and *unsuccessful*) in the (data table above.) ?

1/ $Zn_{(s)} + CuCl_{2(aq)} \rightarrow Cu_{(s)} + ZnCl_{2(aq)}$

2/ $Cu_{(s)} + ZnCl_{2(aq)} \rightarrow Zn_{(s)} + CuCl_{2(aq)}$ N/R

3/ $H_{2(g)} + CuCl_{2(aq)} \rightarrow Cu_{(s)} + 2HCl_{(aq)}$

4/ $Cu_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + CuCl_{2(aq)}$ N/R

5/ $Mn_{(s)} + ZnCl_{2(aq)} \rightarrow Zn_{(s)} + MnCl_{2(aq)}$

6/ $Mn_{(s)} + CaCl_{2(aq)} \rightarrow Ca_{(s)} + MnCl_{2(aq)}$ N/R

7/ $Ca_{(s)} + 2KCl_{(aq)} \rightarrow 2K_{(s)} + CaCl_{2(aq)}$ N/R

8/ $Zn_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$

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2. Write a half reaction for the reduction process that would occur in each equation.

1/ $Cu^{2+} + 2e^- \rightarrow Cu$ (reacts with Zn)
2/ $Zn^{2+} + 2e^- \rightarrow Zn$ N/R with Cu
3/ $Cu^{2+} + 2e^- \rightarrow Cu$ (reacts with H_2)
4/ $2H^+ + 2e^- \rightarrow H_2$ N/R with Cu
5/ $Zn^{2+} + 2e^- \rightarrow Zn$ (reacts with Mn)
6/ $Ca^{2+} + 2e^- \rightarrow Ca$ N/R with Mn
7/ $K^+ + e^- \rightarrow K$ N/R with Ca
8/ $2H^+ + 2e^- \rightarrow H_2$ (reacts with Zn)

3. Use the result of each attempted reaction to help list the reductions from the most likely to the least likely to occur.

SOA → $Cu^{2+} + 2e^- \rightarrow Cu$
$2H^+ + 2e^- \rightarrow H_2$
$Zn^{2+} + 2e^- \rightarrow Zn$
$Mn^{2+} + 2e^- \rightarrow Mn$
$Ca^{2+} + 2e^- \rightarrow Ca$
$K^+ + e^- \rightarrow K$

4. Label the species at the top of your list as the "strongest oxidizing agent."

5. What role do metals always play in these reactions (oxidizing or reducing agent)?

Reducing Agent

6. Where would the strongest reducing agent be located?

Bottom, Right

4.3 **Review Questions** (p. 196)

1. Give the oxidation state for the underlined element in each of the following species:

a) $CaBr_2$ (+2) b) OF_2 (+2) c) $C_6H_{12}O_6$ (0) d) K_2O_2 (−1) e) $S_2O_3^{2-}$ (+2) f) BaH_2 (−1) g) ClO^- (+1) h) S_8 (0)

8

2. Complete and balance each of the following reactions. (States are not required.) Indicate which involve electron transfer.

✓ ET → a) $2Ca + O_2 \rightarrow 2CaO$ ✓✓

b) $CaO + H_2O \rightarrow Ca(OH)_2$ ✓✓ bal

10

✓ ET → c) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ ✓✓

d) $Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$ ✓✓

3. a) What is an oxidizing agent? Species that gets reduced. (O.N. ↓) (causes another species to be oxidize

b) What is a reducing agent? Species that gets oxidized. (O.N. ↑) (causes another to be reduced)

c) How would you expect electronegativity to be related to the strength of each?

↑EN → Stronger O.A. / Weaker R.A.

4. For each of the following reactions, indicate the species being oxidized and reduced and show the oxidation states above their symbols.

+5 −2   −1   0

a) $2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$ $KClO_3$ is oxidized and reduced. ✓ ✓

0   +1   +2   0

b) $Mg(s) + 2\ AgNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + 2\ Ag(s)$ Mg is oxidized ✓ Ag^+ is reduced ✓

0   0   +5 −2

c) $P_4(s) + 5\ O_2(g) \rightarrow 2\ P_2O_5(g)$ P_4 is oxidized ✓ O_2 is reduced ✓   8/8

−3 +5   +1

d) $NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(l)$ NH_4NO_3 is oxidized ✓ NH_4NO_3 is reduced ✓

5. In which chemical family would you expect to find

a) the most readily oxidized elements? Explain
Alkali metals (IA) – lose e⁻ easily (low EN)

b) the most readily reduced elements? Explain
Halogens (VII A) or 17 – gain e⁻ easily. (high EN)   4/4

6. Determine the oxidizing and reducing agent in each of the following reactions. Then indicate the number of electrons transferred by one atom of the reducing agent.

a. $2\ Pb(s) + O_2(g) \rightarrow 2\ PbO(s)$ OA: O_2 RA: Pb No e⁻: 2e⁻

b. $Pb(s) + 2\ Br_2(l) \rightarrow PbBr_4(s)$ OA: Br_2 RA: Pb No e⁻: 4e⁻

c. $2\ Al(s) + 6\ HCl(aq) \rightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$ OA: H^+ RA: Al No e⁻: 3e⁻

d. d) $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$ OA: O_2 RA: C_3H_8 No e⁻: $6\frac{2}{3}$ e⁻

7. Predict the products and write balanced equations for each of the following reactions. Include phase subscripts. Classify each equation according to the system learned in section 6.2. Then classify each again as redox or not.

S / Not → a) Sulphur dioxide gas reacts with solid calcium oxide.

$SO_{2(g)} + CaO_{(s)} \rightarrow CaSO_{3(s)}$ bal ✓✓

D / Redox → b) Solid potassium nitrate is heated to form solid potassium nitrite and a gas.

$2KNO_{3(s)} \rightarrow 2KNO_{2(s)} + O_{2(g)}$

N / Not → c) Strontium hydroxide solution reacts with nitric acid.

$Sr(OH)_{2(aq)} + 2HNO_{3(aq)} \rightarrow Sr(NO_3)_{2(aq)} + 2H_2O_{(l)}$

D / Not → d) Aluminum hydroxide solid is decomposed.

$2Al(OH)_{3(s)} \rightarrow Al_2O_{3(s)} + 3H_2O_{(l)}$ 32

SR / Redox → e) Chlorine gas is bubbled through a solution of cesium iodide.

$Cl_{2(g)} + 2CsI_{(aq)} \rightarrow 2CsCl_{(aq)} + I_{2(s)}$

S / Not → f) Tetraphosphorus decaoxide solid is reacted with water.

$P_4O_{10}(s) + \underline{6}\, H_2O(l) \rightarrow \underline{4}\, H_3PO_4(aq)$

S / Redox → g) Aluminum metal reacts with liquid bromine.

$\underline{2}\, Al(s) + \underline{3}\, Br_2(l) \rightarrow \underline{2}\, AlBr_3(s)$

SR / Redox → h) Zinc metal is placed in a solution of nickel(III) choride.

$\underline{3}\, Zn(s) + \underline{2}\, NiCl_3(aq) \rightarrow \underline{3}\, ZnCl_2(aq) + \underline{2}\, Ni(s)$

8 ~~7~~. Give an oxidation and a reduction half reaction for each of the following redox reactions:

a) $Sn(s) + 2\ AgNO_3(aq) \rightarrow Sn(NO_3)_2(aq) + 2\ Ag(s)$

ox: $Sn \rightarrow Sn^{2+} + 2e^-$

red: $Ag^+ + e^- \rightarrow Ag$

b) $F_2(g) + 2\ NaCl(s) \rightarrow 2\ NaF(s) + Cl_2(g)$

ox: $2Cl^- \rightarrow Cl_2 + 2e^-$

red: $F_2 + 2e^- \rightarrow 2F^-$

4.4 Energy Changes Associated with Chemical Change — Endothermicity and Exothermicity

Warm Up (p. 198)

Complete the following table by placing a checkmark in the appropriate energy-change column for each of the classifications of chemical change listed.

Reaction Type	Energy is Released	Energy is Absorbed
Most Synthesis (Combination) Reactions		✓
Most Decomposition Reactions		✓
Neutralization Reactions	✓	
Combustion Reactions	✓	

Quick Check (p. 199)

Examine each of the equations listed on the previous page. Consider the sign of the ΔH value and determine whether the reactants or products have more stored energy in each case. Put a checkmark under the side with more enthalpy.

Reaction	Reactants	Products
Dissolving potassium hydroxide	✓	
Combustion of propane	✓	
Melting ice		✓
Replacement of iron by aluminum	✓	
Formation of calcium hydroxide	✓	

Quick Check (p. 201)

Complete the right column in the following table by labelling each of the introductory reactions in this section as endothermic or exothermic.

Reaction	Endothermic or Exothermic
Dissolving potassium hydroxide	exothermic
Combustion of propane	exothermic
Melting ice	endothermic
Replacement of iron by aluminum	exothermic
Formation of calcium hydroxide	exothermic

Practice Problems — Representing Exothermic and Endothermic Changes (p. 203)

Given the following ΔH values, write a balanced thermochemical equation and an equation using ΔH notation with the smallest possible whole number coefficients for each of the following chemical changes:

1. $\Delta H_{combustion}$ of $C_2H_6(g) = -1428.5$ kJ/mol $2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 6H_2O_{(l)} + 4CO_{2(g)} + 2857 \frac{kJ}{mol}$

   $2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 6H_2O_{(l)} + 4CO_{2(g)}$ $\Delta H = -2857 \frac{kJ}{mol}$

2. $\Delta H_{decomposition}$ of $NH_3(g) = 46.1$ kJ/mol $2NH_{3(g)} + 92.2 \frac{kJ}{mol} \rightarrow N_{2(g)} + 3H_{2(g)}$

   $2NH_{3(g)} \rightarrow N_{2(g)} + 3H_{2(g)}$ $\Delta H = 92.2 \frac{kJ}{mol}$

3. $\Delta H_{formation}$ of $HBr(g) = -36.1$ kJ/mol $H_{2(g)} + Br_{2(g)} \rightarrow 2HBr_{(g)} + 72.2 \frac{kJ}{mol}$

   $H_{2(g)} + Br_{2(g)} \rightarrow 2HBr_{(g)}$ $\Delta H = -72.2 \frac{kJ}{mol}$

4.4 Activity: Designing a Household Product (p. 204)

The formation of iron(III) oxide, from iron powder and oxygen gas from the air is very exothermic and produces 826 kJ/mol of iron(III) oxide ore.

The dissolving of ammonium nitrate in water produces a solution of separated ammonium and nitrate ions. This physical change can be shown as

$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq) \quad \Delta H = 25.7$ kJ/mol

Procedure

1. Use the theoretical information provided above to design two useful products for treating athletic injuries. Present your designs in each of the following formats:
   - Describe each design in point form.
   - Provide a labeled diagram of each design.
2. Compare your designs with those of a classmate. Use your comparison to improve your designs.

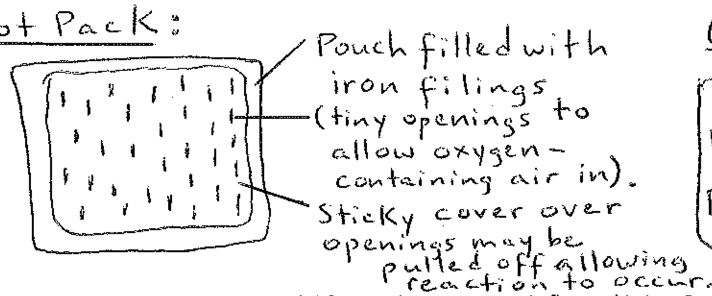
Results and Discussion

1. Write a balanced thermochemical equation using the smallest possible whole number coefficients to describe the chemical change used in each of your designs.

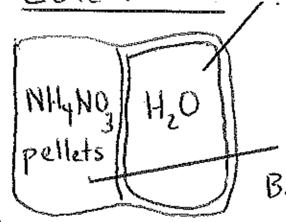
   ① $4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)} + 1643$ kJ/mol (Heat Pack)

   ② $NH_4NO_{3(s)} + 25.7$ kJ/mol $\rightarrow NH_4^+{}_{(aq)} + NO_3^-{}_{(aq)}$ (Cold Pack)

Hot Pack:



Cold Pac (p. 190)



Plastic pouch of H_2O encased in a second plastic pouch containing NH_4NO_3 pellets. Breaking inner pouch with pressure allows contents to mix.

2. Which of the two reactions is useful for cooling a warm, inflamed injury?

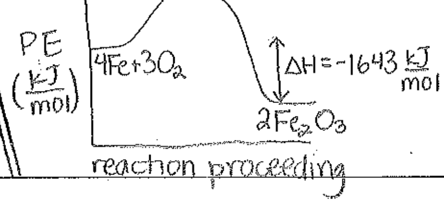
   ②

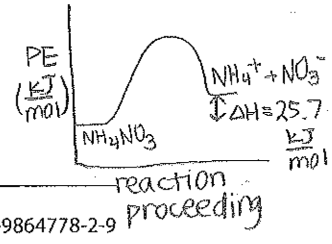
3. Which of the two reactions involves more bond breaking than bond forming?

   ②

4. Assume 240 g of ammonium nitrate are dissolved in the second design. How many kJ of energy are absorbed during this reaction?

$$240g\ NH_4NO_3 \times \frac{1\ mol\ NH_4NO_3}{80.0g\ NH_4NO_3} \times \frac{25.7\ kJ}{mol\ NH_4NO_3} = 77\ kJ$$





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4.4 Review Questions (p. 205)

1. Indicate whether each of the following changes is endothermic or exothermic:
   (a) Barbecuing a steak
   endothermic
   (b) Freezing a tray full of water to make ice
   exothermic
   (c) Neutralizing an acid spill with baking soda
   exothermic
   (d) Making a grilled cheese sandwich
   endothermic
   (e) Lighting a barbecue igniter
   endothermic
   (f) Condensing water on a mirror
   exothermic
2. Convert the following ΔH notation equations into thermochemical equations using the smallest whole number coefficients possible:
   (a) $\frac{1}{2}\ C_3H_8(g) \rightarrow \frac{1}{2}\ C_3H_8(l) \quad \Delta H = -175$ kJ/mol
   $C_3H_{8(g)} \rightarrow C_3H_{8(l)} + 350\ \frac{kJ}{mol}$
   (b) $Li(s) + \frac{1}{2}\ CaCl_2(aq) \rightarrow LiCl(aq) + \frac{1}{2}\ Ca(s) \quad \Delta H = -362$ kJ/mol
   $2Li_{(s)} + CaCl_{2(aq)} \rightarrow 2LiCl_{(aq)} + Ca_{(s)} + 724\ \frac{kJ}{mol}$
   (c) $2\ B(s) + 3\ H_2O(g) \rightarrow B_2H_6(g) + 3/2\ O_2(g) \quad \Delta H = 762$ kJ/mol
   $4B_{(s)} + 6H_2O_{(g)} + 1524\ \frac{kJ}{mol} \rightarrow 2B_2H_{6(g)} + 3O_{2(g)}$
   (d) $\frac{1}{2}\ P_4(s) + 3\ Cl_2(g) \rightarrow 2\ PCl_3(s) \quad \Delta H = -613$ kJ/mol
   $P_{4(s)} + 6Cl_{2(g)} \rightarrow 4PCl_{3(s)} + 1226\ \frac{kJ}{mol}$
   (e) $NH_3(g) + 3/2\ N_2O(g) \rightarrow 2\ N_2(g) + 3/2\ H_2O(l) \quad \Delta H = -505$ kJ/mol
   $2NH_{3(g)} + 3N_2O_{(g)} \rightarrow 4N_{2(g)} + 3H_2O_{(l)} + 1010\ \frac{kJ}{mol}$
   (f) $\frac{1}{2}\ Fe_3O_4(s) + \frac{1}{2}\ CO(g) \rightarrow 3/2\ FeO(s) + \frac{1}{2}\ CO_2(g) \quad \Delta H = 9$ kJ/mol
   $Fe_3O_{4(s)} + CO_{(g)} + 18\ \frac{kJ}{mol} \rightarrow 3FeO_{(s)} + CO_{2(g)}$
3. Convert the following thermochemical equations into ΔH notation using the smallest whole number coefficients possible.
   (a) $C(s) + 2\ H_2(g) + \frac{1}{2}\ O_2(g) \rightarrow CH_3OH(l) + 201$ kJ/mol
   $2C_{(s)} + 4H_{2(g)} + O_{2(g)} \rightarrow 2CH_3OH_{(l)} \quad \Delta H = -402\ \frac{kJ}{mol}$
   (b) $\frac{1}{2}\ Cu(s) + \frac{1}{2}\ H_2(g) + \frac{1}{2}\ O_2(g) \rightarrow \frac{1}{2}\ Cu(OH)_2(s) + 225$ kJ/mol
   $Cu_{(s)} + H_{2(g)} + O_{2(g)} \rightarrow Cu(OH)_{2(s)} \quad \Delta H = -450\ \frac{kJ}{mol}$
   (c) 389 kJ/mol $+ \frac{1}{2}\ Sb_4O_6(s) + 3\ C(s) \rightarrow 2\ Sb(s) + 3\ CO(g)$
   $Sb_4O_{6(s)} + 6C_{(s)} \rightarrow 4Sb_{(s)} + 6CO_{(g)} \quad \Delta H = 778\ \frac{kJ}{mol}$
   (d) 56 kJ/mol $+ NO_2(g) \rightarrow NO(g) + \frac{1}{2}\ O_2(g)$
   $2NO_{2(g)} \rightarrow 2NO_{(g)} + O_{2(g)} \quad \Delta H = 112\ \frac{kJ}{mol}$

(e) $PCl_3(g) + ½ O_2(g) \rightarrow Cl_3PO(g) + 286$ kJ/mol.

$2PCl_{3(g)} + O_{2(g)} \rightarrow 2Cl_3PO_{(g)}$ $\Delta H = -572 \frac{kJ}{mol}$

(f) $F_2(s) + ½ O_2(g) \rightarrow OF_2(g) + 22$ kJ/mol

$2F_{2(s)} + O_{2(g)} \rightarrow 2OF_{2(g)}$ $\Delta H = -44 \frac{kJ}{mol}$

4. Use the equations in question 3 to answer the following questions:

(a) How much energy would be released during the formation of 4 mol of methanol?

$\frac{4 \text{ mol } CH_3OH}{\text{mol rxn}} \times \frac{1 \text{ mol rxn}}{2 \text{ mol } CH_3OH} \times \frac{-402 \text{ kJ}}{1 \text{ mol rxn}} = 802 \frac{kJ}{\text{mol rxn}}$

(b) How many moles of nitrogen dioxide could be decomposed through the use of 168 kJ of energy?

$168 \text{ kJ} \times \frac{1 \text{ mol rxn}}{112 \text{ kJ}} \times \frac{2 \text{ mol } NO_2}{1 \text{ mol rxn}} = 3.00 \text{ mol } NO_2$

(c) Is more energy absorbed or released during the formation of Cl_3PO gas from PCl_3 and O_2 gas?

released (Exo)

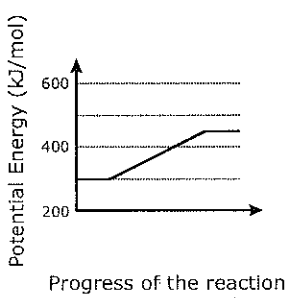
(d) What is the ΔH value for the decomposition of OF_2 gas into its elements?

$\Delta H_{decomposition \text{ of } OF_2} = 44 \text{ kJ/mol } OF_2$

(e) How much energy is required to decompose 1 mol of copper(II) hydroxide?

450. kJ/mol $Cu(OH)_2$

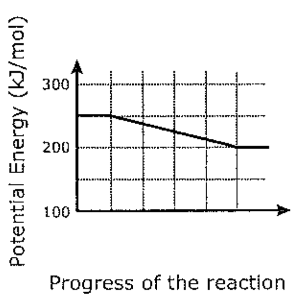
5. Does the following potential energy diagram represent an endothermic or an exothermic reaction? What is ΔH for this reaction?



$\Delta H = 150 \frac{kJ}{mol}$

endothermic

6. What is ΔH for this reaction?



$\Delta H = -50 \frac{kJ}{mol}$

exothermic

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4.5 Calculating with Chemical Change — Stoichiometry

Warm Up (p. 207)

1. Write a balanced equation for the reaction between chromium metal and hydrochloric acid to form chromium(III) chloride and a reactive gas.

   $2Cr_{(s)} + 6HCl_{(aq)} \rightarrow 2CrCl_{3(aq)} + 3H_{2(g)}$

2. If 2 mol of chromium metal completely reacted in an excess quantity of hydrochloric acid, how many moles of hydrogen gas would be formed?

   $2\text{ mol Cr} \times \frac{3\text{ mol }H_2}{2\text{ mol Cr}} = \boxed{3\text{ mol }H_2}$ From equation above as well.

3. How many moles of hydrogen gas would form if 4 mol of chromium metal were completely reacted in excess hydrochloric acid?

   $4\text{ mol Cr} \times \frac{3\text{ mol }H_2}{2\text{ mol Cr}} = \boxed{6\text{ mol }H_2}$ Double last value

Practice Problems — Moles of One Species ←→ Moles of Another Species (p. 208)

Calculate the moles of the requested species given the following information. Be sure to begin with a balanced chemical equation.

1. How many moles of ammonia ($NH_3(g)$) would be formed by the combination of 15.75 mol of nitrogen gas ($N_2(g)$) with a large excess of hydrogen gas ($H_2(g)$)?

   $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$ $15.75\text{ mol }N_2 \times \frac{2\text{ mol }NH_3}{1\text{ mol }N_2} = \boxed{31.50\text{ mol }NH_3}$

2. How many moles of water must be decomposed to form 9.45×10^{-5} mol of $O_2(g)$?

   $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$ $9.45 \times 10^{-5}\text{ mol }O_2 \times \frac{2\text{ mol }H_2O}{1\text{ mol }O_2} = \boxed{1.89 \times 10^{-4}\text{ mol }H_2O}$

3. How many moles of calcium metal would be required to replace 1.86 mol of silver from a solution of silver nitrate?

   $Ca_{(s)} + 2AgNO_{3(aq)} \rightarrow 2Ag_{(s)} + Ca(NO_3)_{2(aq)}$ $1.86\text{ mol Ag} \times \frac{1\text{ mol Ca}}{2\text{ mol Ag}} = \boxed{0.930\text{ mol Ca}}$

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Practice Problems — Mass of One Species ←→ Mass of Another Species (p. 210)

Show all work for each of the following questions. Begin with a balanced chemical equation if one is not provided. Be sure to include the formulas as part of your units in each step. Give your final answer with the correct number of significant figures.

1. The following reaction is exceptional in that a single reactant species is both oxidized and reduced:
   $2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$.
   What mass of oxygen gas would be formed by the decomposition of 45.65 g of $KClO_3$? (How should your answer compare to the mass of reactant? Does your answer make sense?)

$$45.65\text{g } KClO_3 \times \frac{1\text{ mol}}{122.6\text{ g}} \times \frac{3\text{ mol } O_2}{2\text{ mol}} \times \frac{32.0\text{g } O_2}{1\text{ mol } O_2} = \boxed{17.9\text{g}}$$

2. This *unbalanced* equation shows one possible set of products for the reaction of aluminum and nitric acid:
   $Al(s) + HNO_3(aq) \rightarrow Al(NO_3)_3(aq) + H_2(g)$.
   Use the balanced version of this equation to determine the mass of nitric acid required to form 170 kg of hydrogen gas.

$$170\text{kg} \times \frac{1\text{ mol } H_2}{0.0020\text{kg}} \times \frac{2\text{mol } HNO_3}{1\text{ mol } H_2} \times \frac{63.0\text{g } HNO_3}{1\text{ mol } HNO_3} = \boxed{1.1 \times 10^7\text{ g}}\ (\text{or } 11{,}000\text{kg})$$

3. Hydrogen gas can be used as a reducing agent in the production of pure boron from boron trichloride. How many moles of boron would form from the reduction of 500.0 g of boron trichloride with excess hydrogen gas?

   Equation: $2BCl_3 + 3H_2 \longrightarrow 2B + 6HCl$

$$500.0\text{g } BCl_3 \times \frac{1\text{ mol}}{117.3\text{g}} \times \frac{2\text{ mol B}}{2\text{ mol } BCl_3} = \boxed{4.263\text{ mol}}$$

4. Write a balanced chemical equation for the reaction between sodium metal and water.
   How many moles of hydrogen gas would form if 2 mol of sodium reacted with excess water? What volume would this gas occupy at STP conditions?

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$

$$2\text{mol Na} \times \frac{1\text{mol } H_2}{2\text{mol Na}} = \boxed{1\text{ mol } H_2} \quad 1\text{ mole of gas} = \boxed{22.4\text{L}}$$

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Quick Check (p. 211)

Use the balanced equation in Figure 4.5.3 to determine how many litres of carbon dioxide would form from the combustion of 10 L of propane gas.

$$10\text{ L } C_3H_8 \times \frac{3\text{ L } CO_2}{1\text{ L } C_3H_8} = \boxed{30\text{ L}}$$

Practice Problems — Calculations Involving Gas Volume (p. 213)

Show all work for each of the following questions. Begin with a balanced chemical equation if one is not provided. Be sure to include the formulas as part of your units in each step. Give your final answer with the correct number of significant figures.

1. The reaction, $2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$, occurs in the atmosphere when oxygen oxidizes the pollutant factory exhaust, sulphur dioxide. What volume of oxygen is required to oxidize the 2.41×10^7 L of sulphur dioxide released annually by a coal-based power plant at STP?

$$2.41 \times 10^7\text{ L } SO_2 \times \frac{1\text{ L } O_2}{2\text{ L } SO_2} = \boxed{1.21 \times 10^7\text{ L } O_2}$$

2. Consider the *unbalanced equation:* $NaOH(aq) + (NH_4)_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l) + NH_3(g)$. How many litres of ammonia, measured at STP, are formed by combining a solution containing 40.5 g of ammonium sulphate with a solution containing excess sodium hydroxide at STP?

$$2NaOH(aq) + (NH_4)_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2NH_3(g)$$

$$40.5\text{ g } (NH_4)_2SO_4 \times \frac{1\text{ mol}}{132.1\text{ g}} \times \frac{2\text{ mol } NH_3}{1\text{ mol } (NH_4)_2SO_4} \times \frac{22.4\text{ L } NH_3}{1\text{ mol } NH_3} = \boxed{13.7\text{ L}}$$

3. What mass of HCl must be contained in a solution added to an excess of zinc arsenide to obtain 17.5 L of arsine (AsH_3) gas at STP?

Equation: $6HCl + Zn_3As_2 \rightarrow 2AsH_3 + 3ZnCl_2$

$$17.5\text{ L} \times \frac{1\text{ mol } AsH_3}{22.4\text{ L } AsH_3} \times \frac{6\text{ mol HCl}}{2\text{ mol } AsH_3} \times \frac{36.5\text{ g HCl}}{1\text{ mol HCl}} = \boxed{85.5\text{ g}}$$

Quick Check (p. 214)

1. What is the concentration of a solution made by dissolving 117 g of sodium chloride in water to make a total volume of 1.5 L?

$$\frac{117\text{ g NaCl}}{1.5\text{ L}} \times \frac{1\text{ mol}}{58.5\text{ g}} = \boxed{1.3\text{ mol/L}}$$

2. Use the molarity of the solution from question 1 to determine the mass of NaCl in 250 mL.

$$250\text{ mL} \times \frac{10^{-3}\text{ L}}{1\text{ mL}} \times \frac{1.3\text{ mol}}{1\text{ L}} \times \frac{58.5\text{ g}}{1\text{ mol}} = 19.5 \rightarrow \boxed{20.\text{ g}}$$

3. What volume of a solution of this same molarity would contain 39.0 g of sodium chloride?

$$39.0\text{ g} \times \frac{1\text{ mol}}{58.5\text{ g}} \times \frac{1\text{ L}}{1.3\text{ mol}} = \boxed{0.50\text{ L}}$$

Practice Problems — Calculations Involving Solution Volumes (p. 215)

Show all work for each of the following questions. Begin with a balanced chemical equation if one is not provided. Be sure to include the formulas as part of your units in each step. Give your final answer with the correct number of significant figures.

1. The exothermic reaction $2\ K(s) + 2\ H_2O(l) \rightarrow 2\ KOH(aq) + H_2(g)$ often releases enough heat to ignite the hydrogen gas it produces. What mass of potassium metal would be required to produce 250 mL of a 0.45 mol/L solution of potassium hydroxide?

$$250\text{ mL} \times \frac{0.45\text{ mol KOH}}{1000\text{ mL}} \times \frac{2\text{ mol K}}{2\text{ mol KOH}} \times \frac{39.1\text{ g K}}{1\text{ mol K}} = \boxed{4.4\text{ g}}$$

2. What volume of 0.80 mol/L sodium iodide solution would completely react with 2.4×10^{24} molecules of chlorine gas?

Equation: $Cl_2 + 2NaI \rightarrow 2NaCl + I_2$

$$2.4\times10^{24}\text{ molecules } Cl_2 \times \frac{1\text{ mol } Cl_2}{6.02\times10^{23}\text{ molec}} \times \frac{2\text{ mol NaI}}{1\text{ mol } Cl_2} \times \frac{1\text{ L}}{0.80\text{ mol NaI}} = 9.97\text{ L} \rightarrow \boxed{10.\text{ L}}$$

3. How many litres of carbon dioxide gas would be formed at STP if 1.5 L of 1.75 M phosphoric acid were reacted with excess potassium carbonate solution? Be cautious, as this question requires the use of both molar volume and molarity as conversion factors.

Equation: $2H_3PO_4 + 3K_2CO_3 \rightarrow 2K_3PO_4 + 3H_2O + 3CO_2$

$$1.5\text{ L} \times \frac{1.75\text{ mol}}{1\text{ L}} \times \frac{3\text{ mol } CO_2}{2\text{ mol } H_3PO_4} \times \frac{22.4\text{ L } CO_2}{1\text{ mol } CO_2} = \boxed{88\text{ L}}$$

4.5 Activity: Stoichiometric Relationships of Hydrochloric Acid (p. 216)

Question

How can you measure the products of a reaction?

Background

Hydrochloric acid is the most commonly used acid in secondary school chemistry. It can be reacted with a variety of substances in several different types of chemical reactions. The products of such reactions may be separated and measured to study stoichiometric relationships in a variety of ways.

Example Only :—

Procedure

1. Use the theoretical information provided in the "Background" above to design two different experiments to isolate and measure a product of two different reactions, each consuming 750 mL of 1.0 M HCl. You must use a single and a double replacement reaction.
   - Describe each design in point-form.
   - Provide a labelled diagram of each design.

   A) Excess Zn in HCl, collect H_2 gas in STP conditions by water displacement.

   B) Excess $Pb(NO_3)_2$ in HCl, filter $PbCl_2$ ppt.
2. Compare your designs with those of a classmate. Use your comparison to improve your designs.

Results and Discussion

1. Write a balanced chemical equation for each reaction you selected.

A) $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2\,(aq)} + H_{2\,(g)}$

B) $Pb(NO_3)_{2\,(aq)} + 2HCl_{(aq)} \rightarrow PbCl_{2\,(s)} + 2HNO_{3\,(aq)}$

2. Calculate the quantity of product you would expect to measure in each experiment.

A) $750\,mL \times \frac{1.0\,mol\,HCl}{1000\,mL} \times \frac{1\,mol\,H_2}{2\,mol\,HCl} \times \frac{22.4\,L\,H_2}{1\,mol\,H_2} = 8.4\,L$

B) $750\,mL \times \frac{1.0\,mol\,HCl}{1000\,mL} \times \frac{1\,mol\,PbCl_2}{2\,mol\,HCl} \times \frac{278.2\,g\,PbCl_2}{1\,mol\,PbCl_2} = 104.3 \rightarrow 1.0 \times 10^2\,g$

3. Exchange your answers to questions 1 and 2 with the same classmate with whom you compared experimental designs. Beginning with the classmate's answers to question 2, calculate the volume of 1.0 mol/L HCl required to form the quantity of product he or she determined for each experiment. Your classmate should perform the same calculations with your question 2 answers.

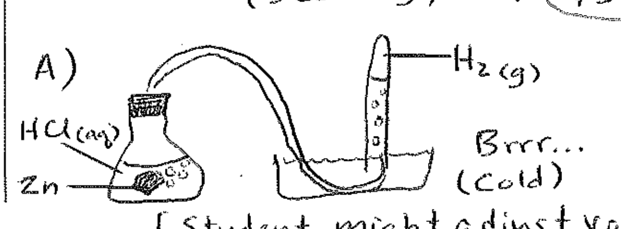
A) $8.4\,L\,H_2 \times \frac{1\,mol\,H_2}{22.4\,L} \times \frac{2\,mol\,HCl}{1\,mol\,H_2} \times \frac{1000\,mL}{1.0\,mol\,HCl} = 750\,mL$

B) $104.3\,g\,PbCl_2 \times \frac{1\,mol\,PbCl_2}{278.2\,g} \times \frac{2\,mol\,HCl}{1\,mol\,PbCl_2} \times \frac{1000\,mL}{1.0\,mol\,HCl} = 750\,mL$

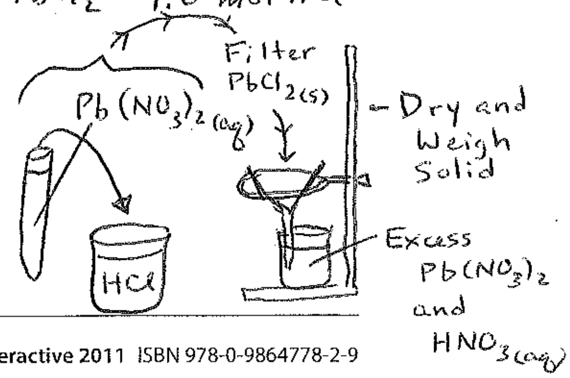
4. What answer should all students get for question 3?

(see #3) → 750 mL

A)



B)



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4.5 Review Questions (p. 217)

1\. a) $1.26 \text{ mol M} \times \frac{2 \text{ mol CuO}}{1 \text{ mol M}} = \boxed{2.52 \text{ mol CuO}}$ ✓✓

b) $1.5 \text{ Kg} \times \frac{10^3 \text{ g}}{1 \text{ Kg}} \times \frac{1 \text{ mol M}}{221.0 \text{ g}} \times \frac{2 \text{ mol CuO}}{1 \text{ mol M}} \times \frac{79.5 \text{ g}}{1 \text{ mol}} = \boxed{1100 \text{ g}}$ ✓✓

c) $706 \text{ g} \times \frac{1 \text{ mol}}{79.5 \text{ g CuO}} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol CuO}} \times \frac{22.4 \text{ L } CO_2}{1 \text{ mol } CO_2} = \boxed{99.5 \text{ L}}$ ✓✓

2\. a) $3160 \text{ g} \times \frac{1 \text{ mol } CH_3NO_2}{61.0 \text{ g}} \times \frac{2 \text{ mol } N_2}{4 \text{ mol } CH_3NO_2} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = \boxed{580. \text{ L}}$ ✓✓

b) $955 \text{ g} \times \frac{1 \text{ mol } N_2}{28.0 \text{ g}} \times \frac{4 \text{ mol } CH_3NO_2}{2 \text{ mol } N_2} \times \frac{61.0 \text{ g}}{1 \text{ mol}} = \boxed{4160 \text{ g}}$ ✓✓

c) $3.5 \times 10^{25} \text{ molec } N_2 \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molec}} \times \frac{6 \text{ mol } H_2O}{2 \text{ mol } N_2} \times \frac{18.0 \text{ g}}{1 \text{ mol}} = \boxed{3100 \text{ g}}$ ✓✓

3\. $10.0 \text{ mL} \times \frac{0.45 \text{ mol HCl}}{1000 \text{ mL}} \times \frac{1 \text{ mol Zn}}{2 \text{ mol HCl}} \times \frac{65.4 \text{ g}}{1 \text{ mol}} = \boxed{0.15 \text{ g}}$

4\. $12.2 \text{ g Na} \times \frac{1 \text{ mol Na}}{23.0 \text{ g Na}} \times \frac{124.7 \text{ KJ}}{4 \text{ mol Na}} = \boxed{16.5 \text{ KJ}}$ ✓✓

5\. $3.225 \text{ g} \times \frac{1 \text{ mol } H_2C_2O_4}{90.0 \text{ g}} \times \frac{2 \text{ mol } KMnO_4}{5 \text{ mol } H_2C_2O_4} \times \frac{1000 \text{ mL}}{0.250 \text{ mol}} =$ 57.3 mL

6\. $2Al + 3Cl_2 \rightarrow 2AlCl_3$ $\quad 4.56 \text{ Kg} \times \frac{1 \text{ mol}}{0.1335 \text{ Kg}} \times \frac{3 \text{ mol } Cl_2}{2 \text{ mol } AlCl_3} \times \frac{71.0 \text{ g}}{1 \text{ mol}} = \boxed{3640 \text{ g}}$ ✓

7\. $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$ $\quad 0.034 \text{ mol KOH} \times \frac{1 \text{ mol } H_2SO_4}{2 \text{ mol KOH}} = \boxed{0.017 \text{ mol}}$ ✓

8\. $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ ✓

$35.00 \text{ g } C_2H_5OH \times \frac{1 \text{ mol}}{46.0 \text{ g}} \times \frac{3 \text{ mol } H_2O}{1 \text{ mol } C_2H_5OH} \times \frac{18.0 \text{ g}}{1 \text{ mol}} = \boxed{41.1 \text{ g}}$ ✓✓

9\. $2HCl + FeS \rightarrow H_2S + FeCl_2$ ✓

$21.7 \text{ L} \times \frac{1 \text{ mol } H_2S}{22.4 \text{ L}} \times \frac{1 \text{ mol FeS}}{1 \text{ mol } H_2S} \times \frac{87.9 \text{ g}}{1 \text{ mol}} = \boxed{85.2 \text{ g}}$ ✓✓

10\. $CaCO_{3(s)} + 2HCl \rightarrow CaCl_2 + H_2O + CO_{2(g)}$ ✓

$15.0 \text{ g } CaCO_3 \times \frac{1 \text{ mol } CaCO_3}{100.1 \text{ g}} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } CaCO_3} \times \frac{44.0 \text{ g } CO_2}{1 \text{ mol } CO_2} = \boxed{6.59 \text{ g}}$ ✓✓

11\. $N_2 + 3H_2 \rightarrow 2NH_3$ ✓ $\quad 40.0 \text{ L } NH_3 \times \frac{3 \text{ L } H_2}{2 \text{ L } NH_3} = \boxed{60.0 \text{ L}}$ ✓✓

12\. $5.00 \text{ g } PbI_2 \times \frac{1 \text{ mol } PbI_2}{461.0 \text{ g}} \times \frac{46.5 \text{ KJ}}{1 \text{ mol } PbI_2} = \boxed{0.504 \text{ KJ}}$ ✓✓

13\. $2Zn + Sn(NO_3)_4 \rightarrow 2Zn(NO_3)_2 + Sn$ ✓ (Zn is the R.A.)

$27.5 \text{ g Sn} \times \frac{1 \text{ mol Sn}}{118.7 \text{ g Sn}} \times \frac{2 \text{ mol Zn}}{1 \text{ mol Sn}} \times \frac{65.3 \text{ g Zn}}{1 \text{ mol Zn}} = \boxed{30.3 \text{ g}}$ ✓✓

14\. $Ba(NO_3)_2 + K_2SO_4 \rightarrow BaSO_{4(s)} + 2KNO_3$ ✓

$6.5 \text{ mol } Ba(NO_3)_2 \times \frac{1 \text{ mol } BaSO_4}{1 \text{ mol } Ba(NO_3)_2} \times \frac{233.4 \text{ g}}{1 \text{ mol}} = \boxed{1500 \text{ g}}$ ✓✓

15\. See Q 10 (15) for EQN $\quad 12.2 \text{ L } CO_2 \times \frac{1 \text{ mol } CO_2}{22.4 \text{ L } CO_2} \times \frac{1 \text{ mol } CaCO_3}{1 \text{ mol } CO_2} \times \frac{100.1 \text{ g}}{1 \text{ mol}} = \boxed{54.5 \text{ g}}$ ✓✓

/3 16) $N_2O_4 \longrightarrow 2\,NO_2 \quad \Delta H = 56\ kJ/mol_{N_2O_4}$ ✓

$$1.25\,g\ NO_2 \times \frac{1\ mol\ NO_2}{46.0\,g\ NO_2} \times \frac{1\ mol\ N_2O_4}{2\ mol\ NO_2} \times \frac{56\ kJ}{1\ mol\ N_2O_4} = \boxed{0.76\ kJ}$$ ✓✓

/3 17) $2\,HBr + K_2CO_3 \longrightarrow 2\,KBr + H_2O + CO_2$ ✓

$$450\,mL \times \frac{0.500\ mol\ HBr}{1000\ mL} \times \frac{1\ mol\ K_2CO_3}{2\ mol\ HBr} \times \frac{138.2\ g}{1\ mol} = \boxed{16\ g}$$ ✓✓

18) $2\,CH_3COOH + Pb(NO_3)_2 \longrightarrow Pb(CH_3COO)_{2\,(s)} + 2\,HNO_3$ ✓

/3

$$8.64\,g \times \frac{1\ mol\ Pb(CH_3COO)_2}{325.2\ g} \times \frac{2\ mol\ CH_3COOH}{1\ mol\ Pb(CH_3COO)_2} \times \frac{1\ L}{2.5\ mol} = \boxed{0.021\ L}\ (21\,mL)$$ ✓✓

19) $3\,NaOH + H_3PO_4 \longrightarrow Na_3PO_4 + 3\,H_2O$ ✓

/3

$$25.0\,mL \times \frac{0.356\ mol\ H_3PO_4}{1000\ mL} \times \frac{3\ mol\ NaOH}{1\ mol\ H_3PO_4} \times \frac{1000\ mL}{0.610\ mol} = \boxed{43.8\,mL}$$ ✓✓

20) $Zn + 2\,HI \longrightarrow ZnI_2 + H_2$ ✓

/3

$$150\,mL \times \frac{0.185\ mol\ HI}{1000\ mL} \times \frac{1\ mol\ H_2}{2\ mol\ HI} \times \frac{22.4\ L\ H_2}{1\ mol\ H_2} = \boxed{0.31\ L}$$ ✓✓

4.6 Stoichiometry in the Real World — Excess/Limiting Amounts, Percentage Yield, and Impurities

Warm Up (p. 220)

Suppose you are working in an ice cream shop. A group of customers come in and they would like to order ice cream sundaes. The shop's computer page reads as follows for ice cream sundaes:

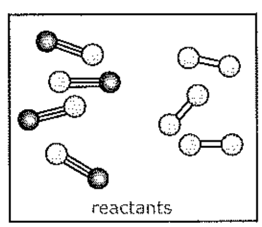
Sundae Ingredients in Stock	Number of Items	Sundae Recipe
Scoops vanilla ice cream	six scoops	one scoop vanilla ice cream
Chocolate syrup	200 mL	50 ml chocolate syrup
Super sweet red cherries	475 cherries	one cherry on top
		(Do NOT change the recipe)

1. What is the maximum number of sundaes you can make for customers? 4
2. What item *limits* the number of sundaes you can make? Chocolate Syrup
3. How much of each of the *excess* items will still be left as sundae stock?
   2 Scoops of ice cream
   471 cherries

Quick Check (p. 221)

Consider the following situation:

$2\ CO(g) + O_2(g) \longrightarrow 2\ CO_2(g)$



→ O=C=O
O=C=O
O=C=O
O=C=O
products

1. Which of the reactants is in excess? O_2
2. Sketch any remaining reactants and products to show what will be present once the reaction is complete.
   O=O
   excess O_2
3. How many CO_2 particles are formed? 4
4. How many excess reactant particles remain? 1

Practice Problems — Limiting and Excess Stoichiometry (p. 223)

1. 25.0 g each of zinc metal and HCl dissolved in aqueous solution are reacted together. What volume of hydrogen gas, measured at STP, is formed and what mass of excess reactant is left over?

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

$25.0\text{g}Zn \times \frac{1\text{mol}}{65.4\text{g}} \times \frac{1\text{mol}H_2}{1\text{mol}Zn} \times \frac{22.4\text{L}H_2}{1\text{mol}H_2} = 8.56\text{L}$ (Zn is in excess)

$25.0\text{g}HCl \times \frac{1\text{mol}}{36.5\text{g}} \times \frac{1\text{mol}H_2}{2\text{mol}HCl} \times \frac{22.4\text{L}}{1\text{mol}} =$ **7.67L**

$25.0\text{g}HCl \times \frac{1\text{mol}HCl}{36.5\text{g}HCl} \times \frac{1\text{mol}Zn}{2\text{mol}HCl} \times \frac{65.4\text{g}Zn}{1\text{mol}} =$ 22.4g Zn use

∴ 25.0 − 22.4 = **2.6g excess Zn**

2. An acid spill containing 12.0 g of pure sulphuric acid is neutralized by 80.0 g of sodium bicarbonate (baking soda). What volume of water is formed? What mass of excess reactant is left over? (Reminder: density of water = 1.00 g/mL) $2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O + 2CO_2$

excess → $80.0\,g \times \frac{1\,mol}{84.0\,g} \times \frac{2\,mol\,H_2O}{2\,mol\,NaHCO_3} \times \frac{18.0\,g\,H_2O}{1\,mol\,H_2O} \times \frac{1\,mL\,H_2O}{1.00\,g\,H_2O} = 17.1\,mL$

limiting → $12.0\,g \times \frac{1\,mol}{98.1\,g} \times \frac{2\,mol\,H_2O}{1\,mol\,H_2SO_4} \times \frac{18.0\,g\,H_2O}{1\,mol\,H_2O} \times \frac{1\,mL}{1.00\,g\,H_2O} = 4.40\,mL$

$12.0\,g\,H_2SO_4 \times \frac{1\,mol}{98.1\,g} \times \frac{2\,mol\,NaHCO_3}{1\,mol\,H_2SO_4} \times \frac{84.0\,g}{1\,mol} = 20.6\,g\,NaHCO_3$ used

∴ 80.0 − 20.6 = 59.4 g left

3. When ammonia is passed over hot calcium, calcium hydride and nitrogen gas are formed. What mass of calcium hydride results when 20.0 L of ammonia measured at STP and 150 g of calcium are reacted? What quantity of excess reactant remains? $2NH_3 + 3Ca \rightarrow 3CaH_2 + N_2$

$20.0\,L\,NH_3 \times \frac{1\,mol\,NH_3}{22.4\,L} \times \frac{3\,mol\,CaH_2}{2\,mol\,NH_3} \times \frac{42.1\,g}{1\,mol} = 56.4\,g$

excess → $150\,g\,Ca \times \frac{1\,mol}{40.1\,g} \times \frac{3\,mol\,CaH_2}{3\,mol\,Ca} \times \frac{42.1\,g}{1\,mol} = 157\,g$

$20.0\,L\,NH_3 \times \frac{1\,mol}{22.4\,L} \times \frac{3\,mol\,Ca}{2\,mol\,NH_3} \times \frac{40.1\,g}{1\,mol} = 53.7\,g$ Ca used

$150 - 53.7 = 96.3 \rightarrow 1.0 \times 10^2\,g$ left Ca

Quick Check (p. 224)

1. Determine the percentage purity of the following:
   (a) A 4.5 g piece of calcium contains only 3.8 g of pure calcium metal.

   $\frac{3.8\,g}{4.5\,g} \times 100\% = 84\%$

   (b) Pure phosphorus makes up 17.5 g of a sample of white phosphorus weighing 20.0 g.

   $\frac{17.5\,g}{20.0\,g} \times 100\% = 87.5\%$

2. What mass of pure potassium is contained in a 0.90 g piece of 90.0% pure potassium?

   $\frac{90.0}{100}(0.90\,g) = 0.81\,g$

Practice Problems — Percentage Purity (p. 226)

1. The thermite reaction is extremely exothermic, producing temperatures in excess of 2500°C. These high temperatures were used to weld iron tracks together during the early days of the railway. Thermite is a mixture of powdered aluminum and iron(III) oxide (rust) reacting as follows: $2\,Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2\,Fe(s)$. If 2.44 g of 95% pure aluminum is reacted, how many grams of aluminum oxide can be produced?

   $0.95(2.44\,g)\,Al \times \frac{1\,mol}{27.0\,g} \times \frac{1\,mol\,Al_2O_3}{2\,mol\,Al} \times \frac{102.0\,g}{1\,mol} = 4.4\,g$

2. How many grams of 73.0% pure iron(III) oxide are required to form 24.5 g of pure white hot iron metal in the thermite reaction? (Hint: Begin by determining the mass of *pure* oxide required.)

   $24.5\,g\,Fe \times \frac{1\,mol\,Fe}{55.8\,g} \times \frac{1\,mol\,Fe_2O_3}{2\,mol\,Fe} \times \frac{159.6\,g\,Fe_2O_3\,pure}{1\,mol\,Fe_2O_3} \times \frac{100\,impure}{73.0\,pure\,Fe_2O_3} = 48.0\,g$

3. When hydrochloric acid is added to 5.73 g of contaminated calcium carbonate, 2.49 g of carbon dioxide is obtained. Write a balanced equation and find the percentage purity of the calcium carbonate.

   $2HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$

   $2.49\,g\,CO_2 \times \frac{1\,mol\,CO_2}{44.0\,g} \times \frac{1\,mol\,CaCO_3}{1\,mol\,CO_2} \times \frac{100.1\,g}{1\,mol} = 5.66\,g$ pure ∴ $\frac{5.66\,g}{5.73\,g} \times 100\% = 98.9\%$

Practice Problems — Percentage Yield (p. 227)

1. A chunk of zinc metal reacts with an excess of hydrochloric acid solution. What is the percentage yield if a 7.23 g piece of zinc produces 2.16 L of hydrogen gas at STP? Begin with a balanced equation.

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

$7.23\,g\,Zn \times \frac{1\,mol}{65.4\,g} \times \frac{1\,mol\,H_2}{1\,mol\,Zn} \times \frac{22.4\,L\,H_2}{1\,mol\,H_2} = 2.48\,L \quad \therefore \frac{2.16\,L}{2.48\,L} \times 100\% = 87.2\%$

2. A solution containing 15.2 g of barium bromide is reacted with a solution containing excess sodium phosphate to form 9.5 g of precipitate. What is the percentage yield of the reaction? Begin with a balanced equation.

$3BaBr_2 + 2Na_3PO_4 \rightarrow Ba_3(PO_4)_{2(s)} + 6NaBr$

$15.2\,g\,BaBr_2 \times \frac{1\,mol}{297.1\,g} \times \frac{1\,mol\,Ba_3(PO_4)_2}{3\,mol\,BaBr_2} \times \frac{601.9\,g}{1\,mol} = 10.3\,g \quad \therefore \frac{9.5\,g}{10.3\,g} \times 100\% = 93\%$

3. Copper(II) oxide reacts with hydrogen gas to form water and copper metal. From this reaction, 3.6 g of copper metal was obtained with a yield of 32.5%. What mass of copper(II) oxide was reacted with the excess hydrogen gas? Begin with a balanced equation. $CuO + H_2 \rightarrow H_2O + Cu$ (bal)

yield of 100% would be $\frac{3.6\,g}{0.325} = 11\,g \quad 11\,g\,Cu \times \frac{1\,mol\,Cu}{63.5\,g} \times \frac{1\,mol\,CuO}{1\,mol\,Cu} \times \frac{79.5\,g\,CuO}{1\,mol\,CuO} = 14\,g$

4.6 Activity: Charting and Graphing Stoichiometry (p. 228)

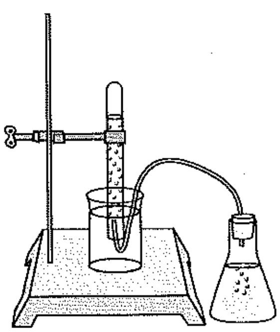
Question

What are some different ways to represent stoichiometric data?

Background

A student performs a single replacement reaction between pure magnesium metal and hydrochloric acid under two different conditions. The quantities involved are measured and recorded in tabular and graphic forms.

The reactions are performed in 250.0 mL of HCl(*aq*). The magnesium is weighed before and after the reactions are completed. The reactions are allowed to proceed for the same period of time in both trials. In both cases, once the reaction is completed, the volume of gas is measured under STP conditions.



Measured Items	Very Hot	Very Cold
Initial mass of Mg(*s*)	1.00 g	1.00 g
Final mass of Mg(*s*)	0.00 g	0.75 g
Volume of $H_2(g)$	? mL	? mL
Volume of HCl(*aq*)	250.0 mL	250 mL ← (250.0 mL)
Initial Concentration of HCl(*aq*)	1.00 mol/L	1.00 mol/L

Procedure

1. Complete the following tables for the reaction under very hot and very cold conditions. Include signs in the "change in number of moles row" to indicate an increase or decrease in the number of moles.

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

Reaction species	Mg(s)	HCl(*aq*)	$MgCl_2$(*aq*)	H_2(*g*)
Initial number of moles	0.0412	0.250	0	0
Change in number of moles	-0.0412	-0.0823	+0.0412	+0.0412
Final number of moles	0	0.168	0.0412	0.0412

$n_{Mg\ initial} = 1.00\ g \times \frac{1\ mol}{24.3\ g} = 0.0412\ mol$

$n_{HCl\ initial} = 0.250\ L \times \frac{1.00\ mol}{L} = 0.250\ mol$

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

Reaction species	Mg(s)	HCl(*aq*)	$MgCl_2$(*aq*)	H_2(*g*)
Initial number of moles	0.0412	0.250	0	0
Change in number of moles	-0.0103	-0.0206	+0.0103	+0.0103
Final number of moles	0.0309	0.229	0.0103	0.0103

$n_{Mg\ final\ (cold)} = 0.75\ g \times \frac{1\ mol}{24.3\ g} = 0.0309\ mol$ ← SF

Results and Discussion

1. What is the limiting reagent in the reaction under both conditions?

   Magnesium

2. What conditions are required to complete the reaction?

   Very Hot Temperature (in this time period).

3. What volume of hydrogen gas (measured at STP) is formed under very hot conditions? Under very cold conditions?

   HOT $0.0412\ mol \times \frac{22.4\ L}{1\ mol} = 0.923\ L$

   COLD $0.0103\ mol \times \frac{22.4\ L}{1\ mol} = 0.231\ L$

4. What is the percentage yield under very cold conditions?

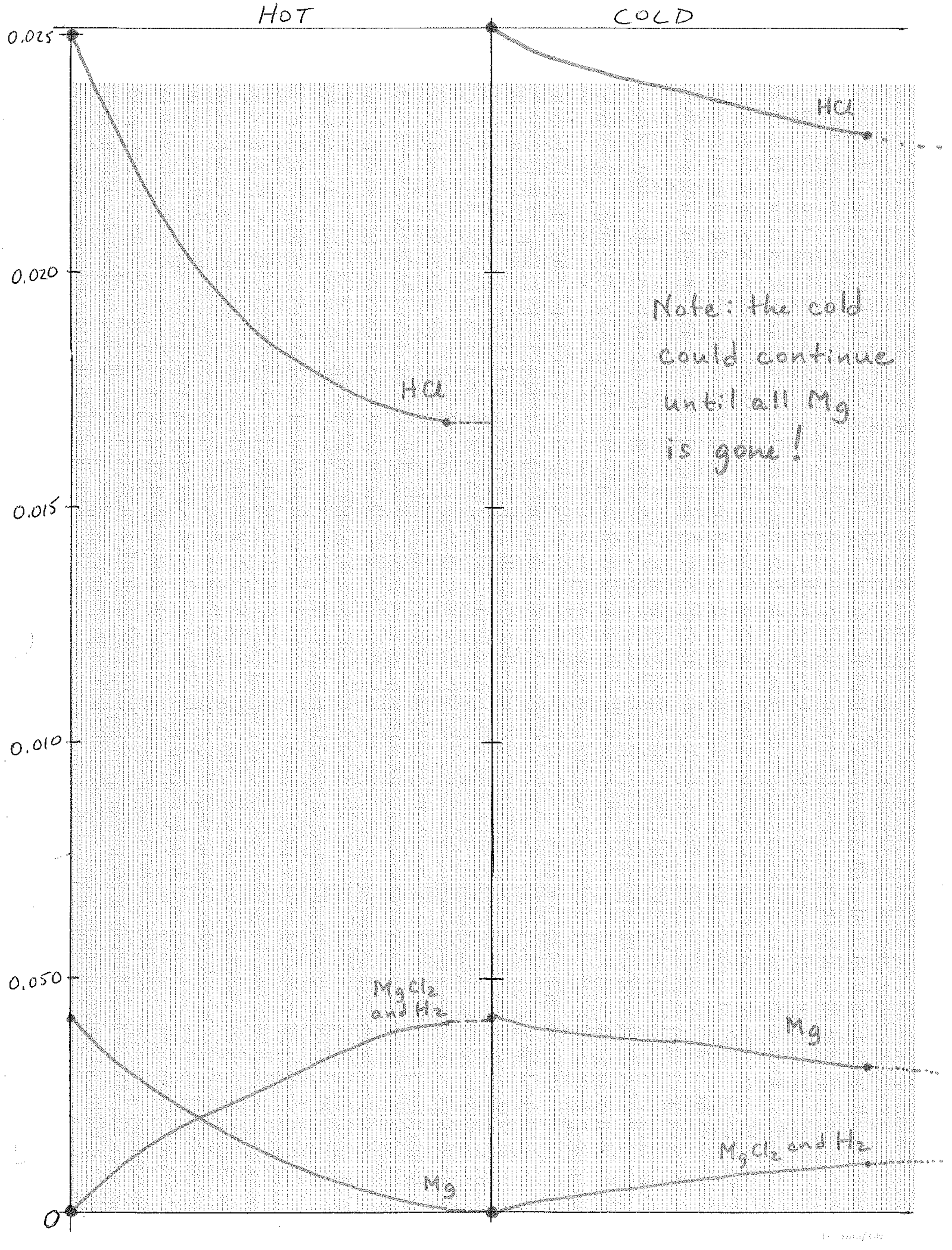
   $\frac{0.231\ L}{0.923\ L} \times 100\% = 25.0\%$ (Notice a quarter of the Mg only was used.)

5. What is the final concentration of magnesium chloride solution under very hot conditions? Under very cold conditions?

   HOT $\frac{0.0412\ mol}{0.2500\ L} = 0.165\ mol/L$

   COLD $\frac{0.0103\ mol}{0.2500\ L} = 0.0412\ mol/L$ $(\frac{1}{4}[MgCl_2]_{Hot})$

6. Using the graph "paper" below, sketch a graph to show the change in the number of moles of each species


HOT
COLD
0.025
0.020
0.015
0.010
0.050
0
HCl
HCl
Note: the cold could continue until all Mg is gone!
MgCl2 and H2
Mg
Mg
MgCl2 and H2

4.6 Review Questions (p. 230)

1. NO
   - Reactants may be impure
   - Rxn may not go 100% to completion.
   - One reactant may be in excess.

2. What are the reactants that are not completely consumed called?

   Excess

3. (obtained / expected) x 100%

4. Rarely. Need to apply % purity. (makes product mass smaller)

5. $\frac{0.132\ g}{100.132\ g} \times 100\% = 0.132\%$ (struck through)

6. $2NaN_3 \rightarrow 2Na + 3N_2$

   $0.85\ (NaN_3\ 120g) = 102g$ pure NaN_3

   $102g\ NaN_3 \times \frac{1\ mol\ NaN_3}{65.0g} \times \frac{3\ mol\ N_2}{2\ mol\ NaN_3} \times \frac{22.4L\ N_2}{1\ mol\ N_2} = 53L$

7. Limiting

   ↳ $4.22g \times \frac{1\ mol}{169.9g} \times \frac{3\ mol\ AgCl}{3\ mol\ AgNO_3} \times \frac{143.4g}{1\ mol} = 3.56\ g$

   Excess

   ↳ $7.73\ g\ AlCl_3 \times \frac{1\ mol}{133.59} \times \frac{3\ mol\ AgCl}{1\ mol\ AlCl_3} \times \frac{143.4g}{1\ mol} = 24.9g$ (struck through)

8. 100% yield would produce

   $\frac{8.00\ mol}{0.915} = 8.74\ mol$, so (struck through) $8.74\ mol\ GeF_3H \times \frac{1\ mol\ GeH_4}{4\ mol\ GeF_3H}$ = 2.19 mol

$S_8 + 12O_2 \rightarrow 8SO_3$

9. Excess

↳ $5.00g\ S_8 \times \frac{1 mol\ S_8}{256.8g} \times \frac{8\ mol\ SO_3}{1\ mol\ S_8} \times \frac{80.1g}{1\ mol} = 12.5g$

Limits

↳ $5.00g\ O_2 \times \frac{1 mol}{32.0g} \times \frac{8\ mol\ SO_3}{12\ mol\ O_2} \times \frac{80.1g}{1\ mol} = 8.34g$

10. Limiting

↳ $40.0g\ O_2 \times \frac{1 mol\ O_2}{32.0g} \times \frac{8\ mol\ SO_3}{12\ mol\ O_2} \times \frac{80.1g}{1\ mol} = 66.8g$

Excess

↳ $48.0g\ S_8 \times \frac{1 mol\ S_8}{256.8g} \times \frac{8\ mol\ SO_3}{1\ mol\ S_8} \times \frac{80.1g}{1\ mol} = 120.g$

$\%\ yield = \frac{63.2g}{66.75\ g} \times 100\% = 94.7\%$

11. $8.95g\ impure\ AgCl \times \frac{75.0g\ pure}{100g\ impure} \times \frac{1 mol\ AgCl}{143.4g} \times \frac{2\ mol\ AgNO_3}{2\ mol\ AgCl} \times \frac{1L}{0.105 mol} = 0.446L$

Equation : $2AgNO_3 + MgCl_2 \rightarrow 2AgCl(s) + Mg(NO_3)_2$

12. $Zn + 2AgNO_3 \rightarrow Zn(NO_3)_2 + 2Ag$

$\left(145.0 mL \times \frac{0.095\ mol\ AgNO_3}{1000\ mL} \times \frac{2 mol\ Ag}{2 mol\ AgNO_3} \times \frac{107.9g}{1 mol}\right) \times 0.97 = 1.4g$

13. Th yield $= 8.92g\ In_2O_3 \times \frac{1 mol}{277.6g} \times \frac{2\ mol\ In(OH)_3}{1\ mol\ In_2O_3} \times \frac{165.8g}{1 mol} = 10.7g$

$\therefore \frac{10.1g}{10.7g} \times 100\% = 94.8\%$

$In_2O_3 + 3H_2O \rightarrow 2In(OH)_3$

14. $2KCl + F_2 \rightarrow 2KF + Cl_2$ (at STP)

$39.8g \times \frac{84.0g\ Pure}{100g\ impure} \times \frac{1 mol\ KCl}{74.6g\ KCl} \times \frac{1 mol\ Cl_2}{2 mol\ KCl} \times \frac{22.4L}{1 mol} = 5.02L$

15. $2CuNO_3 + SrBr_2 \rightarrow 2CuBr(s) + Sr(NO_3)_2$

Excess

$\rightarrow$ $46.7g\ CuNO_3 \times \frac{1mol}{125.5g} \times \frac{2\ mol\ CuBr}{2\ mol\ CuNO_3} \times \frac{143.4g}{1mol} = 53.4g$

Limiting

$\rightarrow$ $30.8g\ SrBr_2 \times \frac{1\ mol}{247.4g} \times \frac{2\ mol\ CuBr}{1mol\ SrBr_2} \times \frac{143.4g}{1\ mol} = 35.7g$ ppt form

$CuNO_3$ in Excess

Used up

$\rightarrow$ $30.8g\ SrBr_2 \times \frac{1mol}{247.4g} \times \frac{2\ mol\ CuNO_3}{1mol\ SrBr_2} \times \frac{125.5g}{1\ mol} = 31.2g\ CuNO_3$

$\therefore$ 46.7 − 31.2 = 15.5g left over.

16. $20.0g\ Ca \times \frac{1mol}{40.1g} \times \frac{1mol\ H_2}{1mol\ Ca} \times \frac{22.4L}{1mol} = 11.2L$

$18.0mL \times \frac{1.00g}{1mL} \times \frac{1mol}{18.0g} \times \frac{1\ mol\ H_2}{2mol\ H_2O} \times \frac{22.4L}{1mol} = 11.2L$

Stoichiometric Amounts!! (ALL CONSUMED) $\therefore \frac{10.0L}{11.2L} \times 100\% = 89.5\%$ yield

17. $2AgNO_3 + CaCl_2 \rightarrow Ca(NO_3)_2 + 2AgCl(s)$

pure reacted = $4.41g\ AgCl \times \frac{1mol}{143.4g} \times \frac{1mol\ CaCl_2}{2mol\ AgCl} \times \frac{1000\ mL}{0.103\ mol} = 149mL$

Purity Was

$\therefore \frac{149mL}{250mL} \times 100\% = 59.7 \rightarrow 60\%$

18. $3Ag(s) + 4HNO_3(aq) \rightarrow 3AgNO_3(aq) + NO(g) + 2H_2O(l)$

$0.3295\ g\ AgCl \times \frac{1mol}{143.4g} \times \frac{1mol\ AgNO_3}{1mol\ AgCl} \times \frac{3\ mol\ Ag}{3\ mol\ AgNO_3} \times \frac{107.9g\ Ag\ pure}{1mol\ Ag} = 0.2479g$

Purity = $\frac{0.2479\ g}{0.7294\ g} \times 100\% = 33.99\%$