## CHE1031 Practice set 4: Stoichiometry of chemical reactions - KEY

*These are optional practice problems. It's up to you how to solve them and they don't need to be completed or passed in. As the answer key is posted with this problem set, you may find them useful in 'reverse engineering' HW problems or in studying for quizzes and exams.*
*Note that answers to quantitative problems are provided in blue.*

**4.1: Writing and balancing chemical equations**

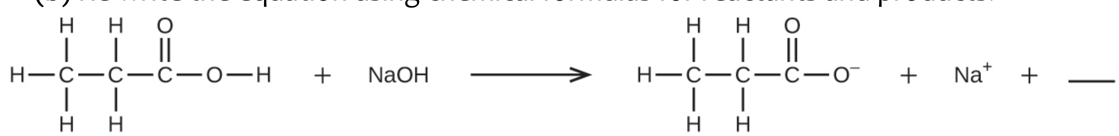
**1.** Balance the following equations:

(a) $P_4(s) + O_2(g) \longrightarrow P_4O_{10}(s)$
(b) $Pb(s) + H_2O(l) + O_2(g) \longrightarrow Pb(OH)_2(s)$
(c) $Sc_2O_3(s) + SO_3(l) \longrightarrow Sc_2(SO_4)_3(s)$
(d) $Ca_3(PO_4)_2(aq) + H_3(PO_4)(aq) \longrightarrow Ca(H_2PO_4)_2(aq)$
(e) $Al(s) + H_2(SO_4)(aq) \longrightarrow Al_2(SO_4)_3(s) + H_2(g)$
(f) $TiCl_4(s) + H_2O(g) \longrightarrow TiO_2(s) + HCl(g)$

(a) $\mathbf{4}Ag(s) + \mathbf{2}H_2S(g) + O_2(g) \longrightarrow \mathbf{2}Ag_2S(s) + \mathbf{2}H_2O(l)$
(b) $P_4(s) + \mathbf{5}O_2(g) \longrightarrow P_4O_{10}(s)$
(c) $\mathbf{2}Pb(s) + \mathbf{2}H_2O(l) + O_2(g) \longrightarrow \mathbf{2}Pb(OH)_2(s)$
(d) $\mathbf{3}Fe(s) + \mathbf{4}H_2O(l) \longrightarrow Fe_3O_4(s) + \mathbf{4}H_2(g)$
(e) $Sc_2O_3(s) + \mathbf{3}SO_3(l) \longrightarrow Sc_2(SO_4)_3(s)$
(f) $Ca_3(PO_4)_2(aq) + \mathbf{4}H_3(PO_4)(aq) \longrightarrow \mathbf{3}Ca(H_2PO_4)_2(aq)$
(g) $\mathbf{2}Al(s) + \mathbf{3}H_2(SO_4)(aq) \longrightarrow Al_2(SO_4)_3(s) + \mathbf{3}H_2(g)$
(h) $TiCl_4(s) + \mathbf{2}H_2O(g) \longrightarrow TiO_2(s) + \mathbf{4}HCl(g)$

**2.** This chemical reaction is missing a product.

(a) Fill in the blank with a single chemical formula for a covalent compound that balances the equation.
(b) Re-write the equation using chemical formulas for reactants and products.



$C_3H_6O_2 + Na(OH) \rightarrow C_3H_5O_2^{-1} + Na^{+1} + \underline{H_2O}$

**3.** Aqueous hydrogen fluoride (hydrofluoric acid) is used to etch glass and to analyze minerals for their silicon content. Hydrogen fluoride will also react with sand (silicon dioxide).

(a) Write an equation for the reaction of solid silicon dioxide with hydrofluoric acid to yield gaseous silicon tetrafluoride and liquid water.

(a) $SiO_2(s) + 4HF(aq) \rightarrow SiF_4(g) + 2H_2O(l)$

**4.2: Classifying chemical reactions**

**4.** Complete and balance this acid-base reaction: a solution of $Sr(OH)_2$ is added to a solution of $H(NO_3)$.

$Sr(OH)_2(aq) + 2HNO_3(aq) \rightarrow Sr(NO_3)_2(aq) + 2H_2O(l)$

**5.** Determine the oxidation numbers of the elements in the compounds listed. None of the oxygen-containing compounds are peroxides or superoxides.

(a) $H_2(SO_4)$
(b) $Ca(OH)_2$
(c) $Br(OH)$
(d) $Cl(NO_2)$
(e) $TiCl_4$
(f) $NaH$
(a) H +1, S +6, O -2
(b) Ca +2, O -2, H +1
(c) Br +1, O -2, H+1
(d) Cl +1, N +3, O -2
(e) Ti +4, Cl -1
(f) Na+1, H-1

**6.** Identify the atoms that are oxidized and reduced, the change in oxidation state for each, and the oxidizing and reducing agents in each of the following equations:

(a) $Mg(s) + NiCl_2(aq) \longrightarrow MgCl_2(aq) + Ni(s)$
(b) $PCl_3(l) + Cl_2(g) \longrightarrow PCl_5(s)$
(c) $C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(g)$
(d) $Zn(s) + H_2(SO_4)(aq) \longrightarrow Zn(SO_4)(aq) + H_2(g)$
(e) $2K_2S_2O_3(s) + I_2(s) \longrightarrow K_2S_4O_6(s) + 2KI(s)$
(f) $3Cu(s) + 8H(NO_3)(aq) \longrightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$

(a) $Mg(s) + NiCl_2(aq) \longrightarrow MgCl_2(aq) + Ni(s)$
0 +2/-1 +2/-1 0 — Mg ox (red agent); Ni red (ox agent)

(b) $PCl_3(l) + Cl_2(g) \longrightarrow PCl_5(s)$
+3/-1 0 +5/-1 — P ox (red agent); Cl red (ox agent)

(c) $C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(g)$
+2/-1 0 +4/-2 +1/-2 — C ox (red agent); O red (ox agent)

(d) $Zn(s) + H_2(SO_4)(aq) \longrightarrow Zn(SO_4)(aq) + H_2(g)$
0 +1/+6/-2 +2/+6/-2 0 — Zn ox (red agent); H red (ox agent)

(e) $2K_2S_2O_3(s) + I_2(s) \longrightarrow K_2S_4O_6(s) + 2KI(s)$
+1/+2/-2 0 +1/+5/2/-2 +1/-1 — S ox (red agent); I red (ox agent)

(f) $3Cu(s) + 8H(NO_3)(aq) \longrightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$
0 +1/+5/-2 +2/+5/-2 +2/-2 +1/-2
Cu ox (red agent); N red (ox agent)

**7.** Complete and balance the following oxidation-reduction reactions, which give the highest possible oxidation state for the oxidized atoms.

(a) $Al(s) + F_2(g) \longrightarrow$
(b) $Al(s) + CuBr_2(aq) \longrightarrow$ (single displacement)
(c) $P_4(s) + O_2(g) \longrightarrow$
(d) $Ca(s) + H_2O(l) \longrightarrow$ (products are a strong base and a diatomic gas)
(a) $2Al(s) + 3F_2(g) \longrightarrow 2AlF_3$
(b) $2Al(s) + 3CuBr_2(aq) \longrightarrow 3Cu + 2AlBr_3$
(c) $P_4(s) + O_2(g) \longrightarrow P_4O_2$
(d) $Ca(s) + 2H_2O(l) \longrightarrow Ca(OH)_2 + H_2$

**8.** Complete and balance the equations for the following <u>acid-base neutralization</u> reactions. If water is used as a solvent, write the reactants and products as aqueous ions. In some cases, there may be more than one correct answer, depending on the amounts of reactants used.

(a) $Mg(OH)_2(s) + H(ClO_4)(aq) \longrightarrow$
(b) $SO_3(g) + H_2O(l) \longrightarrow$ (assume an excess of water and that the product dissolves)
(c) $SrO(s) + H_2(SO_4)(l) \longrightarrow$

(a) $Mg(OH)_2(s) + 2H(ClO_4)(aq) \longrightarrow Mg(ClO_4)_2(aq) + 2H_2O(l)$
$Mg(OH)_2(s) + 2H^{+1} + \cancel{2(ClO_4)}^{-1} \longrightarrow Mg^{+2} + \cancel{2(ClO_4)}^{-1} + 2H_2O(l)$
(b) $SO_3(g) + H_2O(l) \longrightarrow H_2(SO_4)(aq)$
$SO_3(g) + H_2O(l) \longrightarrow 2H^{+1} + (SO_4)^{-2}$
(c) $SrO(s) + H_2(SO_4)(l) \longrightarrow H_2O(l) + Sr(SO_4)(s)$ [Sr(SO4) has very low solubility.]

**9.** Silver can be separated from gold because silver dissolves in nitric acid while gold does not. Is the dissolution of silver in nitric acid an <u>acid-base</u> reaction or an <u>oxidation-reduction</u> reaction? Explain your answer.

It's a redox reaction. Silver is not a base. Silver loses electrons while the hydrogen ion of the acid is reduced. $2Ag(s) + 2H(NO_3)(aq) \rightarrow 2Ag(NO_3)(aq) + H_2(g)$

**10.** Determine the <u>oxidation numbers</u> of the elements in the compounds listed.
(None of the oxygen-containing compounds are peroxides or superoxides.)

(a) $K(NO_2)$
(b) $In_2S_3$
(c) $P_4O_6$

(a) K+1, N +3, O -2
(b) In +3, S -2 (In is usually +3)
(c) P +3, O -2

**11.** Classify the following as <u>acid-base</u> reactions or <u>oxidation-reduction</u> reactions.
*Try assigning oxidation numbers.*

(a) $MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$
(b) $K_3P(s) + 2O_2(g) \longrightarrow K_3(PO_4)(s)$
(c) $3K(OH)(aq) + H_3(PO_4)(aq) \longrightarrow K_3(PO_4)(aq) + 3H_2O(l)$

(a) $MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$
+2/-2 +1/-1 +2/-1 +1/-2 acid-base
(b) $K_3P(s) + 2O_2(g) \longrightarrow K_3(PO_4)(s)$
+1/-3 0 +1/+5/-2 so redox
(c) $3K(OH)(aq) + H_3(PO_4)(aq) \longrightarrow K_3(PO_4)(aq) + 3H_2O(l)$
+1/-2/+1 +1/+5/-2 +1/+5/-2 +1/-2 so acid-base

**12.** Complete and balance each of the following half-reactions (steps 2–5 in half-reaction method):

(a) $Hg(l) + Br^{-1}(aq) \longrightarrow HgBr_4^{-2}(aq)$
(b) $ZnS(s) \longrightarrow Zn(s) + S^{-2}(aq)$
(c) $H_2(g) \longrightarrow H_3O^{+1}(aq)$ (in acidic solution)
(d) $Cl^{-1}(aq) \longrightarrow ClO_3^{-1}(aq)$ (in acidic solution)
(a) $Hg(l)$ + **4**$Br^{-1}(aq) \longrightarrow HgBr_4^{-2}(aq)$ + **2e-**
(b) $ZnS(s)$ + **2e-** $\longrightarrow Zn(s) + S^{-2}(aq)$
(c) $H_2(g)$ + **$H_2O$ + 2e-** $\longrightarrow H_3O^{+1}(aq)$ (in acidic solution) + **$H^{+1}$**
(d) $Cl^{-1}(aq)$ + 3$H_2O$ $\longrightarrow ClO_3^{-1}(aq)$ + **6$H^{+1}$** + **4e-** (in acidic solution)

**13.** Complete and balance each of these half-reactions:

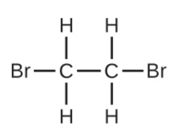
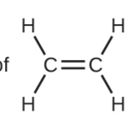
(a) $Cr^{+2}(aq) \longrightarrow Cr^{+3}(aq)$
(b) $NO_3^{-1}(aq) \longrightarrow HNO_2(aq)$ (in acidic solution)
(a) $Cr^{+2}(aq) \longrightarrow Cr^{+3}(aq)$ + **1e-**
(b) $NO_3^{-1}(aq)$ + **2$H^{+1}$ + 1e-** $\longrightarrow HNO_2(aq)$ (in acidic solution) + **$H_2O$**

**14.** In a common experiment in the general chemistry laboratory, magnesium metal is heated in air to produce MgO. MgO is a white solid, but in these experiments it often looks gray, due to small amounts of $Mg_3N_2$, a compound formed as some of the magnesium reacts with nitrogen. Write a balanced equation for each reaction.

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
$3Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$

## 4.3: Reaction stoichiometry

**15.** Write the balanced equation, then determine the information requested in each of the following:

(a) The number of moles and the mass of carbon dioxide formed by the combustion of 20.0 kg of carbon in an excess of oxygen.
(b) The number of moles and the mass of copper (II) carbonate needed to produce 1.500 kg of copper (II) oxide. ($CO_2$ is the other product.)
(c) The number of moles and the mass of  formed by the reaction of 12.85 g of  with an excess of $Br_2$.





Strategy for all: g → mol → mol → g

(a) $C + O_2 \rightarrow CO_2$

2.0 E4 g C | 1 mol C | 1 mol $CO_2$ = 1.67 E3 mol $CO_2$ | 43.99 g = 7.35 E4 g $CO_2$
| 12.01 g | 1 mol C | | 1 mol $CO_2$

(b) $Cu(CO_3) \rightarrow CuO + CO_2$

1500 g CuO | 1 mol CuO | 1 mol $Cu(CO_3)$ = 18.86 mol $Cu(CO_3)$ | 123.53 g = 2.330 E3 g
| 79.54 g | 1 mol CuO | | 1 mol $Cu(CO_3)$

(c) $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$

12.85 g | 1 mol $C_2H_4$ | 1 mol $C_2H_4Br_2$ = 0.458 mol | 187.86 g = 86.03 g
| 28.06 g | 1 mol $C_2H_4$ | | 1 mol $C_2H_4Br_2$

**16.** Carborundum is silicon carbide, SiC, a very hard material used as an abrasive on sandpaper and in other applications. It is prepared by the reaction of pure sand, $SiO_2$, with carbon at high temperature. Carbon monoxide, CO, is the other product of this reaction. Write the balanced equation for the reaction, and calculate how much $SiO_2$ is required to produce 3.00 kg of SiC.

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

g → mol → mol → 3.00 kg

$\frac{3.00\text{ E3 g}}{} \cdot \frac{1\text{ mol SiC}}{40.09\text{ g}} \cdot \frac{1\text{ mol } SiO_2}{1\text{ mol SiC}} \cdot \frac{60.00\text{ g}}{1\text{ mol } SiO_2}$ = 4489.89 g → 4.49 E3 g $SiO_2$

**17.** Automotive air bags inflate when a sample of sodium azide, $NaN_3$, is very rapidly decomposed.

$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$

What mass of sodium azide is required to produce 2.6 ft3 (73.6 L) of nitrogen gas with a density of 1.25 g/L?

$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$

g? 73.6 L @ 1.25 g/L

g ← mol ← mol ← g

$\frac{73.6\text{ L}}{} \cdot \frac{1.25\text{ g}}{1\text{ L}} \cdot \frac{1\text{ mol } N_2}{28.02\text{ g}} \cdot \frac{2\text{ mol } NaN_3}{3\text{ mol } N_2} \cdot \frac{65.02\text{ g}}{1\text{ mol } NaN_3}$ = 142 g $NaN_3$

**18.** In an accident, a solution containing 2.5 kg of nitric acid was spilled. Two kilograms of $Na_2(CO_3)$ was quickly spread on the area and $CO_2$ was released by the reaction. Was sufficient $Na_2(CO_3)$ used to neutralize all of the acid?

$2H(NO_3) + Na_2(CO_3) \rightarrow 2Na(NO_3) +$ ~~$H_2(CO_3)$~~ $+ H_2O + CO_2$

2.5 kg 2.0 kg

→ mol → mol → g

$\frac{2.5\text{ E3 g}}{} \cdot \frac{1\text{ mol } H(NO_3)}{62.99\text{ g}} \cdot \frac{1\text{ mol } Na_2(CO_3)}{2\text{ mol } H(NO_3)} \cdot \frac{105.96\text{ g}}{1\text{ mol } Na_2(CO_3)} \cdot \frac{1\text{ kg}}{1\text{E3 g}}$ = 2.10 kg so NO

## 4.4: Reaction yields

**19.** What is the limiting reactant when 1.50 g of lithium and 1.50 g of nitrogen combine to form lithium nitride, a component of advanced batteries, according to the following unbalanced equation?

$Li + N_2 \longrightarrow Li_3N$

$6Li + N_2 \longrightarrow 2Li_3N$

$\frac{1.50\text{ g}}{} \cdot \frac{1\text{ mol Li}}{6.94\text{ g}} \cdot \frac{2\text{ mol } Li_3N}{6\text{ mol Li}}$ = 0.0720 mol $Li_3N$ → lower yield, so Li is limiting

$\frac{1.50\text{ g}}{} \cdot \frac{1\text{ mol } N_2}{28.02\text{ g}} \cdot \frac{2\text{ mol } Li_3N}{1\text{ mol } N_2}$ = 0.107 mol $Li_3N$

**20.** How many molecules of $C_2H_4Cl_2$ can be prepared from 15 $C_2H_4$ molecules and 8 $Cl_2$ molecules?

$C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$ 8 molecules

15 8

**21.** Freon-12, $CCl_2F_2$, is prepared from $CCl_4$ by reaction with HF. The other product of this reaction is HCl. Outline the steps needed to determine the percent yield of a reaction that produces 12.5 g of $CCl_2F_2$ from 32.9 g of $CCl_4$. Freon-12 has been banned and is no longer used as a refrigerant because it catalyzes the decomposition of ozone and has a very long lifetime in the atmosphere. Determine the percent yield.

$CCl_4 + 2HF \rightarrow CCl_2F_2 + 2HCl$

32.9 g 12.5 g as % yield

g → mol → mol → g theoretical yield

$\frac{32.9\text{ g}}{} \cdot \frac{1\text{ mol }CCl_4}{153.81\text{g}} \cdot \frac{1\text{ mol }CCl_2F_2}{1\text{ mol }CCl_4} \cdot \frac{120.91\text{ g}}{1\text{ mol }CCl_2F_2} = 25.86\text{ g }CCl_2F_2$

% yield = (12.5 g/25.86 g)(100) = 48.34%

**22.** Toluene, $C_6H_5CH_3$, is oxidized by air under carefully controlled conditions to benzoic acid, $C_6H_5CO_2H$, which is used to prepare the food preservative sodium benzoate, $C_6H_5CO_2Na$. What is the percent yield of a reaction that converts 1.000 kg of toluene to 1.21 kg of benzoic acid?

$2C_6H_5CH_3 + 3O_2 \longrightarrow 2C_6H_5CO_2H + 2H_2O$

1.000 kg 1.21 kg

g → mol → mol → g → kg theoretical yield

$\frac{1.000\text{E3 g}}{} \cdot \frac{1\text{ mol toluene}}{92.15\text{ g}} \cdot \frac{2\text{ mol benzoic acid}}{2\text{ mol toluene}} \cdot \frac{122.11\text{ g}}{1\text{ mol benzoic acid}} \cdot \frac{1\text{ kg}}{1\text{E3 g}} = 1.325\text{ kg}$

% yield = (1.21 kg/1.325 kg)(100) = 91.3%

**4.5: Quantitative chemical analysis**

**23.** What volume of 0.0105-M HBr solution is required to titrate 125 mL of a 0.0100-M $Ca(OH)_2$ solution?

$Ca(OH)_2(aq) + 2HBr(aq) \longrightarrow CaBr_2(aq) + 2H_2O(l)$

125 mL X mL

0.0100 M 0.0105 M

$\frac{0.125\text{ L}}{} \cdot \frac{0.0100\text{ mol }Ca(OH)_2}{1\text{ L}} \cdot \frac{2\text{ mol HBr}}{1\text{ mol }Ca(OH)_2} \cdot \frac{1\text{ L}}{0.0105\text{ mol}} = 0.238\text{ L}$

**24.** What is the concentration of NaCl in a solution if titration of 15.00 mL of the solution with 0.2503 M $Ag(NO_3)$ requires 20.22 mL of the $Ag(NO_3)$ solution to reach the end point?

$Ag(NO_3)(aq) + NaCl(aq) \longrightarrow AgCl(s) + Na(NO_3)(aq)$

20.22 mL 15.00 mL

0.2503 M X M

$\frac{0.02022\text{ L}}{} \cdot \frac{0.2503\text{ mol }Ag(NO_3)}{1\text{ L}} \cdot \frac{1\text{ mol NaCl}}{1\text{ mol }Ag(NO_3)} \cdot \frac{1}{0.01500\text{ L}} = 0.3374\text{ M NaCl}$

**25.** A 0.025-g sample of a compound composed of boron and hydrogen, with a molecular mass of ~28 amu, burns spontaneously when exposed to air, producing 0.063 g of $B_2O_3$. What are the empirical and molecular formulas of the compound?

$B_xH_y + O_2 \rightarrow B_2O_3 + H_2O$

0.025 g     0.063 g

28 g/mol     69.59 g/mol

$\frac{0.025\text{ g} \quad 1\text{ mol}}{28\text{ g}} = 8.9\text{ E-4 mol}$     so 1:1 molar relationship     $B_2H_7$

$\frac{0.063\text{ g} \quad 1\text{ mol}}{69.59\text{ g}} = 9.1\text{ E-4 mol}$

**26.** The reaction of $WCl_6$ with Al at ~400 °C gives black crystals of a compound containing only tungsten and chlorine. A sample of this compound, when reduced with hydrogen, gives 0.2232 g of tungsten metal and hydrogen chloride, which is absorbed in water. Titration of the hydrochloric acid thus produced requires 46.2 mL of 0.1051 M Na(OH) to reach the end point. What is the empirical formula of the black tungsten chloride?

$WCl_6 + Al \rightarrow WCl_X$

$WCl_X + H_2 \rightarrow W + HCl$     $HCl + Na(OH) \rightarrow NaCl + H_2O$

0.2232 g (W)     46.2 mL, 0.1051 M (Na(OH))

$\frac{0.0462\text{ L} \quad 0.1051\text{ mol} \quad 1\text{ mol HCl}}{1\text{ L} \quad 1\text{ Na(OH)}} = 4.86\text{ E-3 mol HCl}$     $\frac{0.2232\text{ g} \quad 1\text{ mol W}}{183.84\text{ g}} = 1.214\text{ E-3 mol W}$

So, $\frac{4.86\text{ E-3 mol HCl}}{1.214\text{ E-3 mol W}} = 4:1$     So, $WCl_4$