Chemistry 2e
4: Stoichiometry of Chemical Reactions
4.1: Writing and Balancing Chemical Equations

1. What does it mean to say an equation is balanced? Why is it important for an equation to be balanced?

Solution
An equation is balanced when the same number of each element is represented on the reactant and product sides. Equations must be balanced to accurately reflect the law of conservation of matter.

3. Balance the following equations:

(a) $PCl_5(s) + H_2O(l) \longrightarrow POCl_3(l) + HCl(aq)$

(b) $Cu(s) + HNO_3(aq) \longrightarrow Cu(NO_3)_2(aq) + H_2O(l) + NO(g)$

(c) $H_2(g) + I_2(s) \longrightarrow HI(s)$

(d) $Fe(s) + O_2(g) \longrightarrow Fe_2O_3(s)$

(e) $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$

(f) $(NH_4)_2Cr_2O_7(s) \longrightarrow Cr_2O_3(s) + N_2(g) + H_2O(g)$

(g) $P_4(s) + Cl_2(g) \longrightarrow PCl_3(l)$

(h) $PtCl_4(s) \longrightarrow Pt(s) + Cl_2(g)$

Solution
(a) $PCl_5(s) + H_2O(l) \longrightarrow POCl_3(l) + 2HCl(aq)$; (b) $3Cu(s) + 8HNO_3(aq) \longrightarrow 3Cu(NO_3)_2(aq) + 4H_2O(l) + 2NO(g)$; (c) $H_2(g) + I_2(s) \longrightarrow 2HI(s)$; (d) $4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$; (e) $2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$; (f) $(NH_4)_2Cr_2O_7(s) \longrightarrow Cr_2O_3(s) + N_2(g) + 4H_2O(g)$; (g) $P_4(s) + 6Cl_2(g) \longrightarrow 4PCl_3(l)$; (h) $PtCl_4(s) \longrightarrow Pt(s) + 2Cl_2(g)$

5. Write a balanced molecular equation describing each of the following chemical reactions.
(a) Solid calcium carbonate is heated and decomposes to solid calcium oxide and carbon dioxide gas.
(b) Gaseous butane, C_4H_{10}, reacts with diatomic oxygen gas to yield gaseous carbon dioxide and water vapor.
(c) Aqueous solutions of magnesium chloride and sodium hydroxide react to produce solid magnesium hydroxide and aqueous sodium chloride.
(d) Water vapor reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.

Solution
(a) $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$; (b) $2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$; (c) $MgCl_2(aq) + 2NaOH(aq) \longrightarrow Mg(OH)_2(s) + 2NaCl(aq)$; (d) $2H_2O(g) + 2Na(s) \longrightarrow 2NaOH(s) + H_2(g)$

7. Colorful fireworks often involve the decomposition of barium nitrate and potassium chlorate

and the reaction of the metals magnesium, aluminum, and iron with oxygen.
(a) Write the formulas of barium nitrate and potassium chlorate.
(b) The decomposition of solid potassium chlorate leads to the formation of solid potassium chloride and diatomic oxygen gas. Write an equation for the reaction.
(c) The decomposition of solid barium nitrate leads to the formation of solid barium oxide, diatomic nitrogen gas, and diatomic oxygen gas. Write an equation for the reaction.
(d) Write separate equations for the reactions of the solid metals magnesium, aluminum, and iron with diatomic oxygen gas to yield the corresponding metal oxides.(Assume the iron oxide contains Fe^{3+} ions.)

Solution

(a) $Ba(NO_3)_2$, $KClO_3$; (b) $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$; (c)

$2Ba\left(NO_3\right)_2(s) \longrightarrow 2BaO(s) + 2N_2(g) + 5O_2(g)$;

$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$

(d) $4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$

$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$

9. 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 tetra fluoride and liquid water.
(b) The mineral fluorite (calcium fluoride) occurs extensively in Illinois. Solid calcium fluoride can also be prepared by the reaction of aqueous solutions of calcium chloride and sodium fluoride, yielding aqueous sodium chloride as the other product. Write complete and net ionic equations for this reaction.

Solution

(a) $4HF(aq) + SiO_2(s) \longrightarrow SiF_4(g) + 2\,H_2O(l)$; (b) complete ionic equation:

$2Na^+(aq) + 2F^-(aq) + Ca^{2+}(aq) + 2Cl^-(aq) \longrightarrow CaF_2(s) + 2Na^+(aq) + 2Cl^-(aq)$, net ionic equation: $2F^-(aq) + Ca^{2+}(aq) \longrightarrow CaF_2(s)$

11. From the balanced molecular equations, write the complete ionic and net ionic equations for the following:

(a) $K_2C_2O_4(aq) + Ba(OH)_2(aq) \longrightarrow 2KOH(aq) + BaC_2O_4(s)$

(b) $Pb(NO_3)_2(aq) + H_2SO_4(aq) \longrightarrow PbSO_4(s) + 2HNO_3(aq)$

(c) $CaCO_3(s) + H_2SO_4(aq) \longrightarrow CaSO_4(s) + CO_2(g) + H_2O(l)$

Solution

(a)

$$2K^+(aq) + C_2O_4{}^{2-}(aq) + Ba^{2+}(aq) + 2OH^-(aq) \longrightarrow 2K^+(aq) + 2OH^-(aq) + BaC_2O_4(s) \quad \text{(complete)}$$

$$Ba^{2+}(aq) + C_2O_4{}^{2-}(aq) \longrightarrow BaC_2O_4(s) \quad \text{(net)}$$

(b)

$$Pb^{2+}(aq) + 2NO_3^{-}(aq) + 2H^{+}(aq) + SO_4^{2-}(aq) \longrightarrow PbSO_4(s) + 2H^{+}(aq) + 2NO_3^{-}(aq) \quad \text{(complete)}$$

$$Pb^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow PbSO_4(s) \quad \text{(net)}$$

(c)

$$CaCO_3(s) + 2H^{+}(aq) + SO_4^{2-}(aq) \longrightarrow CaSO_4(s) + CO_2(g) + H_2O(l) \quad \text{(complete)}$$

$$CaCO_3(s) + 2H^{+}(aq) + SO_4^{2-}(aq) \longrightarrow CaSO_4(s) + CO_2(g) + H_2O(l) \quad \text{(net)}$$

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4.2: Classifying Chemical Reactions

13. Indicate what type, or types, of reaction each of the following represents:

(a) $Ca(s) + Br_2(l) \longrightarrow CaBr_2(s)$

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

(c) $C_6H_{12}(l) + 9O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(g)$

Solution

(a) oxidation-reduction (addition); (b) acid-base (neutralization); (c) oxidation-reduction (combustion)

15. 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 acid-base reaction or an oxidation-reduction reaction? Explain your answer.

Solution

An oxidation-reduction reaction, because the oxidation state of the silver changes during the reaction.

17. Determine the oxidation states of the elements in the compounds listed. None of the oxygen-containing compounds are peroxides or superoxides.

(a) H_3PO_4
(b) $Al(OH)_3$
(c) SeO_2
(d) KNO_2
(e) In_2S_3
(f) P_4O_6

Solution

(a) H +1, P +5, O –2; (b) Al +3, H +1, O –2; (c) Se +4, O –2; (d) K +1, N +3, O –2; (e) In +3, S –2; (f) P +3, O –2

19. Classify the following as acid-base reactions or oxidation-reduction reactions:

(a) $Na_2S(aq) + 2HCl(aq) \longrightarrow 2NaCl(aq) + H_2S(g)$

(b) $2Na(s) + 2HCl(aq) \longrightarrow 2NaCl(aq) + H_2(g)$

(c) $Mg(s) + Cl_2(g) \longrightarrow MgCl_2(s)$

(d) $MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$

(e) $K_3P(s) + 2O_2(g) \longrightarrow K_3PO_4(s)$

(f) $3KOH(aq) + H_3PO_4(aq) \longrightarrow K_3PO_4(aq) + 3H_2O(l)$

Solution

(a) acid-base; (b) oxidation-reduction: Na is oxidized, H^+ is reduced; (c) oxidation-reduction: Mg is oxidized, Cl_2 is reduced; (d) acid-base; (e) oxidation-reduction: P^{3-} is oxidized, O_2 is reduced; (f) acid-base

21. Complete and balance the following acid-base equations:

(a) HCl gas reacts with solid $Ca(OH)_2(s)$.
(b) A solution of $Sr(OH)_2$ is added to a solution of HNO_3.

Solution

(a) $2HCl(g) + Ca(OH)_2(s) \longrightarrow CaCl_2(s) + 2H_2O(l)$; (b) $Sr(OH)_2(aq) + 2HNO_3(aq) \longrightarrow Sr(NO_3)_2(aq) + 2H_2O(l)$

23. 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)

Solution

(a) $2Al(s) + 3F_2(g) \longrightarrow 2AlF_3(s)$; (b) $2Al(s) + 3CuBr_2(aq) \longrightarrow 3Cu(s) + 2AlBr_3(aq)$; (c) $P_4(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$; (d) $Ca(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$

25. Complete and balance the equations for the following acid-base neutralization 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) $Mg(OH)_2(s) + HClO_4(aq) \longrightarrow$

(b) $SO_3(g) + H_2O(l) \longrightarrow$ (assume an excess of water and that the product dissolves)

(c) $SrO(s) + H_2SO_4(l) \longrightarrow$

Solution

(a) $Mg(OH)_2(s) + 2HClO_4(aq) \longrightarrow Mg^{2+}(aq) + 2ClO_4^-(aq) + 2H_2O(l)$; (b) $SO_3(g) + 2H_2O(l) \longrightarrow H_3O^+(aq) + HSO_4^-(aq)$, (a solution of H_2SO_4; (c) $SrO(s) + H_2SO_4(l) \longrightarrow SrSO_4(s) + H_2O$

27. The military has experimented with lasers that produce very intense light when fluorine combines explosively with hydrogen. What is the balanced equation for this reaction?

Solution

$H_2(g) + F_2(g) \longrightarrow 2HF(g)$

29. Great Lakes Chemical Company produces bromine, Br_2, from bromide salts such as NaBr, in Arkansas brine by treating the brine with chlorine gas. Write a balanced equation for the reaction of NaBr with Cl_2.

Solution

$2NaBr(aq) + Cl_2(g) \longrightarrow 2NaCl(aq) + Br_2(l)$

31. Lithium hydroxide may be used to absorb carbon dioxide in enclosed environments, such as manned spacecraft and submarines. Write an equation for the reaction that involves 2 mol of LiOH per 1 mol of CO_2.(Hint: Water is one of the products.)

Solution

$2LiOH(aq) + CO_2(g) \longrightarrow Li_2CO_3(aq) + H_2O(l)$

33. Complete and balance the equations of the following reactions, each of which could be used to remove hydrogen sulfide from natural gas:

(a) $Ca(OH)_2(s) + H_2S(g) \longrightarrow$

(b) $Na_2CO_3(aq) + H_2S(g) \longrightarrow$

Solution

$Ca(OH)_2(s) + H_2S(g) \longrightarrow CaS(s) + 2H_2O(l)$; (b)

$Na_2CO_3(aq) + H_2S(g) \longrightarrow Na_2S(aq) + CO_2(g) + H_2O(l)$

35. Write balanced chemical equations for the reactions used to prepare each of the following compounds from the given starting material(s). In some cases, additional reactants may be required.

(a) solid ammonium nitrate from gaseous molecular nitrogen via a two-step process (first reduce the nitrogen to ammonia, then neutralize the ammonia with an appropriate acid)

(b) gaseous hydrogen bromide from liquid molecular bromine via a one-step redox reaction

(c) gaseous H_2S from solid Zn and S via a two-step process (first a redox reaction between the starting materials, then reaction of the product with a strong acid)

Solution

(a) step 1: $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$, step 2:

$NH_3(g) + HNO_3(aq) \longrightarrow NH_4NO_3(aq) \longrightarrow NH_4NO_3(s)$ (after drying); (b)

$H_2(g) + Br_2(l) \longrightarrow 2HBr(g)$; (c) $Zn(s) + S(s) \longrightarrow ZnS(s)$ and

$ZnS(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2S(g)$

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

(a) $Sn^{4+}(aq) \longrightarrow Sn^{2+}(aq)$

(b) $\left[Ag(NH_3)_2\right]^+(aq) \longrightarrow Ag(s) + NH_3(aq)$

(c) $Hg_2Cl_2(s) \longrightarrow Hg(l) + Cl^-(aq)$

(d) $H_2O(l) \longrightarrow O_2(g)$ (in acidic solution)

(e) $IO_3^-(aq) \longrightarrow I_2(s)$ (in basic solution)

(f) $SO_3^{2-}(aq) \longrightarrow SO_4^{2-}(aq)$ (in acidic solution)

(g) $MnO_4^-(aq) \longrightarrow Mn^{2+}(aq)$ (in acidic solution)

(h) $Cl^-(aq) \longrightarrow ClO_3^-(aq)$ (in basic solution)

Solution

(a) $\begin{array}{l} Sn^{4+}(aq) \longrightarrow Sn^{2+}(aq) \\ Sn^{4+}(aq) + 2e^- \longrightarrow Sn^{2+}(aq) \end{array}$; (b) $\begin{array}{l} \left[Ag(NH_3)_2\right]^+(aq) \longrightarrow Ag(s) + 2NH_3(aq) \\ \left[Ag(NH_3)_2\right]^+(aq) + e^- \longrightarrow Ag(s) + 2NH_3(aq) \end{array}$; (c)

$\begin{array}{l} Hg_2Cl_2(s) \longrightarrow Hg(l) + Cl^-(aq) \\ Hg_2Cl_2(s) \longrightarrow 2Hg(l) + 2Cl^-(aq) \\ Hg_2Cl_2(s) + 2e^- \longrightarrow 2Hg(l) + 2Cl^-(aq) \end{array}$; (d) $\begin{array}{l} 2H_2O(l) \longrightarrow O_2(g) \\ 2H_2O(l) \longrightarrow O_2(g) + 4H^+(aq) \\ 2H_2O(l) \longrightarrow O_2(g) + 4H^+(aq) + 4e^- \end{array}$; (e)

$IO_3^-(aq) \longrightarrow I_2(s)$

$2IO_3^-(aq) \longrightarrow I_2(s)$

$2IO_3^-(aq) \longrightarrow I_2(s) + 6H_2O(l)$

$12H^+(aq) + 2IO_3^-(aq) \longrightarrow I_2(s) + 6H_2O(l)$

$12H^+(aq) + \mathbf{12OH^-(aq)} + 2IO_3^-(aq) \longrightarrow I_2(s) + 6H_2O(l) + \mathbf{12OH^-(aq)}$; (f)

$12H_2O(l) + 2IO_3^-(aq) \longrightarrow I_2(s) + 6H_2O(l) + 12OH^-(aq)$

$6H_2O(l) + 2IO_3^-(aq) \longrightarrow I_2(s) + 12OH^-(aq)$

$6H_2O(l) + 2IO_3^-(aq) + 10e^- \longrightarrow I_2(s) + 12OH^-(aq)$

$SO_3^{2-}(aq) \longrightarrow SO_4^{2-}(aq)$

$H_2O(l) + SO_3^{2-}(aq) \longrightarrow SO_4^{2-}(aq)$; (g)

$H_2O(l) + SO_3^{2-}(aq) \longrightarrow SO_4^{2-}(aq) + 2H^+(aq)$

$H_2O(l) + SO_3^{2-}(aq) \longrightarrow SO_4^{2-}(aq) + 2H^+(aq) + 2e^-$

$MnO_4^-(aq) \longrightarrow Mn^{2+}(aq)$

$MnO_4^-(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$; (h)

$8H^+(aq) + MnO_4^-(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$

$8H^+(aq) + MnO_4^-(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$

$Cl^-(aq) \longrightarrow ClO_3^-(aq)$

$3H_2O(l) + Cl^-(aq) \longrightarrow ClO_3^-(aq)$

$3H_2O(l) + Cl^-(aq) \longrightarrow ClO_3^-(aq) + 6H^+(aq)$

$3H_2O(l) + Cl^-(aq) + \mathbf{6OH^-(aq)} \longrightarrow ClO_3^-(aq) + 6H^+(aq) + \mathbf{6OH^-(aq)}$

$3H_2O(l) + Cl^-(aq) + 6OH^-(aq) \longrightarrow ClO_3^-(aq) + 6H_2O(l)$

$Cl^-(aq) + 6OH^-(aq) \longrightarrow ClO_3^-(aq) + 3H_2O(l) + 6e^-$

39. Balance each of the following equations according to the half-reaction method:

(a) $Sn^{2+}(aq) + Cu^{2+}(aq) \longrightarrow Sn^{4+}(aq) + Cu^+(aq)$

(b) $H_2S(g) + Hg_2^{2+}(aq) \longrightarrow Hg(l) + S(s)$ (in acid)

(c) $CN^-(aq) + ClO_2(aq) \longrightarrow CNO^-(aq) + Cl^-(aq)$ (in acid)

(d) $Fe^{2+}(aq) + Ce^{4+}(aq) \longrightarrow Fe^{3+}(aq) + Ce^{3+}(aq)$

(e) $HBrO(aq) \longrightarrow Br^-(aq) + O_2(g)$ (in acid)

Solution

For an example of the fully worked out solution, see the solution to Exercise 37. (a)
$Sn^{2+}(aq) + 2Cu^{2+}(aq) \longrightarrow Sn^{4+}(aq) + 2Cu^+(aq)$; (b)
$H_2S(g) + Hg_2^{2+}(aq) + 2H_2O(l) \longrightarrow 2Hg(l) + S(s) + 2H_3O^+(aq)$; (c)
$5CN^-(aq) + 2ClO_2(aq) + 3H_2O(l) \longrightarrow 5CNO^-(aq) + 2Cl^-(aq) + 2H_3O^+(aq)$; (d)

$Fe^{2+}(aq) + Ce^{4+}(aq) \longrightarrow Fe^{3+}(aq) + Ce^{3+}(aq)$; (e)
$2HBrO(aq) + 2H_2O(l) \longrightarrow 2H_3O^+(aq) + 2Br^-(aq) + O_2(g)$

41. Balance each of the following equations according to the half-reaction method:
(a) $MnO_4^-(aq) + NO_2^-(aq) \longrightarrow MnO_2(s) + NO_3^-(aq)$ (in base)
(b) $MnO_4^{2-}(aq) \longrightarrow MnO_4^-(aq) + MnO_2(s)$ (in base)
(c) $Br_2(l) + SO_2(g) \longrightarrow Br^-(aq) + SO_4^{2-}(aq)$ (in acid)

Solution
For an example of the fully worked out solution, see the solution to Exercise 37. (a)
$2MnO_4^-(aq) + 3NO_2^-(aq) + H_2O(l) \longrightarrow 2MnO_2(s) + 3NO_3^-(aq) + 2OH^-(aq)$; (b)
$3MnO_4^{2-}(aq) + 2H_2O(l) \longrightarrow 2MnO_4^-(aq) + 4OH^-(aq) + MnO_2(s)$ (in base); (c)
$Br_2(l) + SO_2(g) + 2H_2O(l) \longrightarrow 4H^+(aq) + 2Br^-(aq) + SO_4^{2-}(aq)$

Chemistry 2e **4: Stoichiometry of Chemical Reactions** **4.3: Reaction Stoichiometry**

43. Determine the number of moles and the mass requested for each reaction in Exercise 42.

Solution

(a) The first step is to calculate the moles of sodium in 10.0 g.

$$\text{mol Na} = 10.0\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{22.989768\ \cancel{\text{g}}} = 0.435\ \text{mol}$$

From the balanced equation, 2 mol Na reacts with 1 mol Cl_2: therefore,

$$\text{mol } Cl_2 = \frac{\text{mol Na}}{2} = \frac{0.435\ \text{mol}}{2} = 0.217\ \text{mol}$$

g Cl_2 = mol × molar mass = 0.217 mol × 2 × 35.4527 g mol^{-1} = 15.4 g Cl_2,0.217 mol Cl_2, 15.4 g Cl_2;(b)

$$\text{mol HgO} = 1.252\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{216.59\ \cancel{\text{g HgO}}} = 0.005780\ \text{mol}$$

$$\text{mol } O_2 = 0.005780\ \cancel{\text{mol HgO}} \times \frac{1\ \text{mol } O_2}{2\ \cancel{\text{mol HgO}}} = 2.890 \times 10^{-3}\ \text{mol}$$; (c) From the balanced

$$\text{mass } O_2 = 2.890 \times 10^{-3}\ \cancel{\text{mol}} \times \frac{31.9998\ \text{g}}{1\ \cancel{\text{mol}}} = 9.248 \times 10^{-2}\ \text{g}$$

equation, 2 mol of $NaNO_3$ is required to produce 1 mol O_2.

mol $NaNO_3$ required = 2 mol O_2 = 2(4.00 mol)= 8.00 mol $NaNO_3$

g $NaNO_3$ = 8.00 mol $NaNO_3$ × 84.9947 g mol^{-1} $NaNO_3$ = 6.80 × 10^2 g $NaNO_3$; (d)

$$\text{mol } CO_2 = 20.0\ \cancel{\text{kg}} \times 100\ \frac{\cancel{\text{g}}}{\cancel{\text{kg}}} \times \frac{1\ \cancel{\text{mol C}}}{12.011\ \cancel{\text{g C}}} \times \frac{1\ \text{mol } CO_2}{1\ \cancel{\text{mol C}}} = 1665\ \text{mol } CO_2$$

;(e) Molar

$$\text{mass } CO_2 = 1665\ \cancel{\text{mol } CO_2} \times \frac{44.009\ \text{g } CO_2}{1\ \cancel{\text{mol } CO_2}} = 73.3\ \text{kg } CO_2$$

masses: CuO = 79.545 g mol^{-1}; $CuCO_3$ = 123.555 g mol^{-1}

$$\text{mol CuO} = 1500\ \text{g CuO} \times \frac{1\ \text{mol}}{79.545\ \text{g CuO}} = 18.86\ \text{mol}$$

1 molCuO = 1 mol CuO_3

$$\text{kg } CuCO_3 = 18.86\ \cancel{\text{mol } CuCO_3} \times \frac{123.555\ \cancel{\text{g}}}{\cancel{\text{mol } CuCO_3}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}} = 2.330\ \text{kg } CuCO_3$$; (f)

$$\text{mol } C_2H_4Br_2 = 12.85\ \cancel{\text{g } C_2H_4} \times \frac{1\ \cancel{\text{mol } C_2H_4}}{28.054\ \cancel{\text{g}}} \times \frac{1\ \text{mol } C_2H_4Br_2}{1\ \cancel{\text{mol } C_2H_4}} = 0.4580\ \text{mol } C_2H_4Br_2$$

$$\text{g } C_2H_4Br_2 = 0.4580\ \cancel{\text{mol } C_2H_4Br_2} \times \frac{187.862\ \text{g } C_2H_4Br_2}{1\ \cancel{\text{mol } C_2H_4Br_2}} = 86.05\ \text{g } C_2H_4Br_2$$

45. Determine the number of moles and the mass requested for each reaction in Exercise 44.

Solution

(a) $\text{mol Mg} = 5.00\ \cancel{\text{g HCl}} \times \frac{1\ \cancel{\text{mol HCl}}}{36.4606\ \cancel{\text{g}}} \times \frac{1\ \text{mol Mg}}{2\ \cancel{\text{mol HCl}}} = 0.0686\ \text{mol},$

$\text{g Mg} = 0.0686\ \cancel{\text{mol Mg}} \times \frac{24.305\ \text{g}}{1\ \cancel{\text{mol Mg}}} = 1.67\ \text{g};$

(b) $\text{mol } O_2 = 1.252\ \cancel{\text{g } Ag_2O} \times \frac{1\ \cancel{\text{mol } Ag_2O}}{231.7358\ \cancel{\text{g}}} \times \frac{1\ \text{mol } O_2}{2\ \cancel{\text{mol } Ag_2O}} = 2.701 \times 10^{-3},$

$\text{g } O_2 = 2.701 \times 10^{-3}\ \cancel{\text{mol } O_2} \times \frac{31.9988\ \text{g}}{1\ \cancel{\text{mol } O_2}} = 0.08644\ \text{g};$(c)

$\text{mol } MgCO_3 = 283\ \cancel{\text{g } CO_2} \times \frac{1\ \cancel{\text{mol } CO_2}}{44.010\ \cancel{\text{g}}} \times \frac{1\ \text{mol } MgCO_3}{1\ \cancel{\text{mol } CO_2}} = 6.43\ \text{mol},$

$\text{g } MgCO_3 = 6.43\ \cancel{\text{mol } MgCO_3} \times \frac{84.314\ \text{g}}{1\ \cancel{\text{mol } MgCO_3}} = 542\ \text{g};$

(d) $\text{mol } H_2O = 2.00 \times 10^4\ \cancel{\text{g } C_2H_4} \times \frac{1\ \cancel{\text{mol } C_2H_2}}{26.04\ \cancel{\text{g}}} \times \frac{1\ \text{mol } H_2O}{1\ \cancel{\text{mol } C_2H_2}} = 768\ \text{mol},$

$\text{g } H_2O = 768\ \cancel{\text{mol } H_2O} \times \frac{18.01528\ \cancel{\text{g}}}{1\ \cancel{\text{mol } H_2O}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}} = 13.8\ \text{kg}$

(e) $2.500\ \cancel{\text{kg BaO}} \times \frac{1000\ \cancel{\text{g BaO}}}{1\ \cancel{\text{kg BaO}}} \times \frac{1\ \cancel{\text{mol BaO}}}{153.326\ \cancel{\text{g BaO}}} \times \frac{2\ \text{mol } BaO_2}{2\ \cancel{\text{mol BaO}}} = 16.31\ \text{mol } BaO_2$

$16.31\ \cancel{\text{mol } BaO_2} \times \frac{169.326\ \text{g } BaO_2}{1\ \cancel{\text{mol } BaO_2}} = 2762\ \text{g } BaO_2$

(f) $9.55\ \cancel{\text{g } C_2H_6O} \times \frac{1\ \cancel{\text{mol } C_2H_6O}}{46.068\ \cancel{\text{g } C_2H_6O}} \times \frac{1\ \text{mol } C_2H_4}{1\ \cancel{\text{mol } C_2H_6O}} = 0.207\ \text{mol } C_2H_4$

$0.207\ \cancel{\text{mol } C_2H_4} \times \frac{28.053\ \text{g } C_2H_4}{1\ \cancel{\text{mol } C_2H_4}} = 5.81\ \text{g } C_2H_4$

47. Gallium chloride is formed by the reaction of 2.6 L of a 1.44 *M* solution of HCl according to the following equation: $2Ga + 6HCl \longrightarrow 2GaCl_3 + 3H_2$.

(a) Outline the steps necessary to determine the number of moles and mass of gallium chloride.
(b) Perform the calculations outlined.

Solution

(a) $\text{volume HCl solution} \longrightarrow \text{mol HCl} \longrightarrow \text{mol } GaCl_3$; (b)

$2.6\ \cancel{\text{L HCl}}\ ´\ \frac{1.44\ \cancel{\text{mol HCl}}}{1\ \cancel{\text{L HCl}}}\ ´\ \frac{2\ \cancel{\text{mol } GaCl_3}}{6\ \cancel{\text{mol HCl}}}\ ´\ \frac{176.1\ \text{g } GaCl_3}{1\ \cancel{\text{mol } GaCl_3}} = 2.2\ ´\ 10^2\ \text{g } GaCl_3$

49. Silver is often extracted from ores as $K[Ag(CN)_2]$ and then recovered by the reaction

$$2K\left[Ag(CN)_2\right](aq) + Zn(s) \longrightarrow 2Ag(s) + Zn(CN)_2(aq) + 2KCN(aq)$$

(a) How many molecules of $Zn(CN)_2$ are produced by the reaction of 35.27 g of $K[Ag(CN)_2]$?
(b) What mass of $Zn(CN)_2$ is produced?

Solution

The development requires the following:

$$\text{mass K}\left[\text{Ag}\left(\text{CN}\right)_2\right] \longrightarrow \text{mol K}\left[\text{Ag}\left(\text{CN}\right)_2\right] \longrightarrow \text{mol Zn}\left(\text{CN}\right)_2 \longrightarrow \text{molecules of Zn}\left(\text{CN}\right)_2 \;\; \text{g Zn}\left(\text{CN}\right)_2\;;$$

(a)

$$35.27 \;\cancel{\text{g K[Ag(CN)}_2]} \times \frac{1 \;\cancel{\text{mol K[Ag(CN)}_2]}}{199.002 \;\cancel{\text{g K[Ag(CN)}_2]}} \times \frac{1 \;\cancel{\text{mol Zn(CN)}_2}}{2 \;\cancel{\text{mol K[Ag(CN)}_2]}} \times \frac{6.022 \times 10^{23}}{1 \;\cancel{\text{mol Zn(CN)}_2}}$$

$$= 5.337 \times 10^{22} \text{ molecules}$$

(b)

$$5.337 \times 10^{22} \;\cancel{\text{molecules}} \times \frac{1 \;\cancel{\text{mol Zn(CN)}_2}}{6.022 \times 10^{23} \;\cancel{\text{molecules}}} \times \frac{117.43 \text{ g Zn(CN)}_2}{1 \;\cancel{\text{mol Zn(CN)}_2}} = 10.41 \text{ g Zn(CN)}_2$$

51. 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.

Solution

$SiO_2 + 3C \longrightarrow SiC + 2CO$. From the balanced equation, 1 mol of SiO_2 produces 1 mol of SiC. The unknown is the mass of SiO_2 required to produce 3.00 kg (3000 g) of SiC. To calculate the mass of SiO_2 required, determine the molar masses of SiO_2 and SiC. Then calculate the number of moles of SiC required, and through the mole relation of SiO_2 to SiC, find the mass of SiO_2 required. The conversions required are:

$$\text{g SiC} \longrightarrow \text{mol SiC} \longrightarrow \text{mol SiO}_2 \longrightarrow \text{g SiO}_2$$

Molar masses: SiO_2 = 60.0843 g mol^{-1}; SiC = 40.0955 g mol^{-1}

$$\text{mass SiO2} = 3000 \;\cancel{\text{g SiC}} \times \frac{1 \;\cancel{\text{mol SiC}}}{40.955 \;\cancel{\text{g SiC}}} \times \frac{1 \;\cancel{\text{mol SiO}_2}}{1 \;\cancel{\text{mol SiC}}} \times \frac{60.843 \text{ g SiO}_2}{1 \;\cancel{\text{mol SiO}_2}} = 4496 \text{ g SiO}_2$$

$$= 4.50 \text{ kg SiO}_2$$

53. Urea, $CO(NH_2)_2$, is manufactured on a large scale for use in producing urea-formaldehyde plastics and as a fertilizer. What is the maximum mass of urea that can be manufactured from the CO_2 produced by combustion of 1.00×10^3 kg of carbon followed by the reaction?

$$CO_2(g) + 2NH_3(g) \longrightarrow CO\left(NH_2\right)_2(s) + H_2O(l)$$

Solution

Molar mass urea = 12.011 + 15.9994 + 2(14.0067) + 4(1.0079) = 60.054 g mol^{-1}

$$1 \text{ mol C} \longrightarrow 1 \text{ mol CO}_2 \longrightarrow 1 \text{ mol urea}$$

$$\text{mass urea} = 1.00 \times 10^3 \;\cancel{\text{kg}} \times \frac{1000 \;\cancel{\text{g}}}{\cancel{\text{kg}}} \times \frac{1 \;\cancel{\text{mol C}}}{12.0 \;\cancel{\text{g C}}} \times \frac{1 \;\cancel{\text{mol urea}}}{1 \;\cancel{\text{mol C}}} \times \frac{60.054 \text{ g urea}}{1 \;\cancel{\text{mol urea}}}$$

$$= 5.00 \times 10^6 \text{ g or } 5.00 \times 10^3 \text{ kg}$$

55. A compact car gets 37.5 miles per gallon on the highway. If gasoline contains 84.2% carbonby mass and has a density of 0.8205 g/mL, determine the mass of carbon dioxide produced during a 500-mile trip (3.785 liters per gallon).

Solution

The balanced chemical equation is $C(s) + O_2(g) \longrightarrow CO_2(g)$

$$500\ \cancel{\text{miles}} \times \frac{1\ \cancel{\text{gallon}}}{37.5\ \cancel{\text{miles}}} \times \frac{3.785\ \cancel{\text{L}}}{1\ \cancel{\text{gallon}}} \times \frac{1000\ \cancel{\text{mL}}}{1\ \cancel{\text{L}}} \times \frac{0.8205\ \cancel{\text{g gas}}}{1\ \cancel{\text{mL}}\ \text{gas}} \times \frac{84.2\ \cancel{\text{g C}}}{100\ \cancel{\text{g gas}}}$$
$$\times \frac{1\ \cancel{\text{mol C}}}{12.01\ \cancel{\text{g C}}} \times \frac{1\ \cancel{\text{mol CO}_2}}{1\ \cancel{\text{mol C}}} \times \frac{44.01\ \text{g CO}_2}{1\ \cancel{\text{mol CO}_2}} = 1.28 \times 10^5\ \text{g CO}_2$$

57. What volume of a 0.2089 M KI solution contains enough KI to react exactly with the $Cu(NO_3)_2$ in 43.88 mL of a 0.3842 M solution of $Cu(NO_3)_2$?

$$2Cu(NO_3)_2 + 4KI \longrightarrow 2CuI + I_2 + 4KNO_3$$

Solution

Use molarity to convert. This solution involves the following steps:

1. Converting the volume of KI to moles of KI
2. Converting the moles of KI to moles of $Cu(NO_3)_2$
3. Converting the moles of $K \longrightarrow Cu(NO_3)_2$ to a volume of KI.$Cu(NO_3)_2$ solution

$$43.88\ \text{mL} \times \frac{1\ \text{L}}{1000\ \text{mL}} \times \frac{0.3842\ \cancel{\text{mol Cu(NO}_3)_2}}{1\ \text{L}} \times \frac{4\ \cancel{\text{mol KI}}}{2\ \cancel{\text{mol Cu(NO}_3)_2}} \times \frac{1\ \text{L KI}}{0.2089\ \cancel{\text{mol KI}}}$$

$= 161.4$ mL

All of these steps can be shown together, as follows:

$$\frac{43.88\ \text{mL Cu(NO}_3)_2}{1} \times \frac{0.3842\ \text{mol Cu(NO}_3)_2}{1000\ \text{mL Cu(NO}_3)_2} \times \frac{4\ \text{mol KI}}{2\ \text{mol Cu(NO}_3)_2} \times \frac{1000\ \text{mL KI}}{0.2089\ \text{mol KI}}$$

$= 161.4$ mL KI solution

59. The toxic pigment called white lead, $Pb_3(OH)_2(CO_3)_2$, has been replaced in white paints by rutile, TiO_2. How much rutile (g) can be prepared from 379 g of an ore that contains 88.3% ilmenite ($FeTiO_3$) by mass?

$$2FeTiO_3 + 4HCl + Cl_2 \longrightarrow 2FeCl_3 + 2TiO_2 + 2H_2O$$

Solution

Find from worked example, check your learning problem

$$\text{mass of ilmenite} = 379\ \cancel{\text{g ore}} \times \frac{0.883\ \text{g FeTiO}_3}{1\ \cancel{\text{g ore}}} = 334.6\ \text{g FeTiO}_3$$

$$\text{mass of rutile} = 334.6\ \cancel{\text{g FeTiO}_3} \times \frac{1\ \cancel{\text{mol FeTiO}_3}}{151.7\ \cancel{\text{g FeTiO}_3}} \times \frac{2\ \cancel{\text{mol TiO}_2}}{2\ \cancel{\text{mol FeTiO}_3}} \times \frac{79.88\ \text{g TiO}_2}{1\ \cancel{\text{mol TiO}_2}}$$
$$= 176\ \text{g TiO}_2$$

Chemistry 2e
4: Stoichiometry of Chemical Reactions

61. What is the limiting reactant in a reaction that produces sodium chloride from 8 g of sodium and 8 g of diatomic chlorine?

Solution

Write the balanced chemical equation and determine the number of moles of each reactant available.

The reaction is: $2Na + Cl_2 \longrightarrow 2NaCl$

$$\text{Moles of Na} = 8 \text{ g Na} \times \frac{1 \text{ mol}}{23.0 \text{ g}} = 0.3 \text{ mol Na}$$

$$\text{Moles of } Cl_2 = 8 \text{ g} \times \frac{1 \text{ mol}}{70.9 \text{ g}} = 0.1 \text{ mol } Cl_2$$

The stoichiometric ratio is 2 mol Na: 1 mol Cl_2; since the reactants are provided in a 0.3:0.1 or 3:1 ratio, Na is present in excess and Cl_2 is the limiting reactant.

63. A student isolated 25 g of a compound following a procedure that would theoretically yield 81 g. What was his percent yield?

$$\text{Percent yield} = \frac{25 \text{ g}}{81 \text{ g}} \times 100\% = 31\%$$

65. 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.

Solution

Write and balance the equation for the reaction: $CCl_4 + 2HF \longrightarrow CCl_2F_2 + 2HCl$. Molar masses: CCl_4 = 153.82 g/mol; CCl_2F_2 = 120.89 g/mol. The conversions required are $\text{g } CCl_4 \longrightarrow \text{mol } CCl_4 \longrightarrow \text{mol } CCl_2F_2 \longrightarrow \text{g } CCl_2F_2$. To find the percent yield, divide the 12.5 g of CCl_2F_2 by the theoretical mass, and multiply by 100%. For complete conversion,

$$\text{mass } CCl_2F_2 = 32.9 \cancel{\text{g } CCl_4} \times \frac{1 \cancel{\text{mol } CCl_4}}{153.82 \cancel{\text{g } CCl_4}} \times \frac{1 \cancel{\text{mol } CCl_2F_2}}{1 \cancel{\text{mol } CCl_4}} \times \frac{120.89 \text{ g } CCl_2F_2}{1 \cancel{\text{mol } CCl_2F_2}}$$

$$= 25.86 \text{ g } CCl_2F_2$$

$$\text{percent yield} = \frac{12.5 \text{ g}}{25.86 \text{ g}} \times 100\% = 48.3\%$$

67. 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?

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

Solution

$$1000\ \cancel{g\ C_6H_5CH_3} \times \frac{1\ \cancel{mol\ toluene}}{92.13\ \cancel{g\ C_6H_5CH_3}} \times \frac{1\ \cancel{mol\ benzoic\ acid}}{1\ \cancel{mol\ toluene}} \times \frac{122.1\ \cancel{g\ benzoic\ acid}}{1\ \cancel{mol\ benzoic\ acid}}$$
$$\times \frac{1\ kg}{1000\ \cancel{g\ benzoic\ acid}} = 1.325\ kg\ benzoic\ acid\ (theoretical\ yield)$$

$$\text{percent yield} = \frac{1.21\ kg}{1.325\ kg} \times 100\% = 91.3\%$$

69. Outline the steps needed to solve the following problem, then do the calculations. Ether, $(C_2H_5)_2O$, which was originally used as an anesthetic but has been replaced by safer and more effective medications, is prepared by the reaction of ethanol with sulfuric acid.

$$2C_2H_5OH + H_2SO_4 \longrightarrow (C_2H_5)_2O + H_2SO_4 \cdot H_2O$$

What is the percent yield of ether if 1.17 L (d = 0.7134 g/mL) is isolated from the reaction of 1.500 L of C_2H_5OH (d = 0.7894 g/mL)?

Solution

Convert mass of ethanol to moles of ethanol; relate the moles of ethanol to the moles of ether produced using the stoichiometry of the balanced equation. Convert moles of ether to grams; divide the actual grams of ether (determined through the density) by the theoretical mass to determine the percent yield.

$$d_{ether} = \frac{m}{V}$$

$$m = dV = 0.7134\ g\ mL^{-1} \times 1170\ mL = 834.7\ g$$

$$d_{ether} = \frac{m}{V}$$

$$m = dV = 0.7894\ g\ mL^{-1} \times 1500\ mL = 1184\ g$$

Mass ether = 1.184

$$\text{mass ether} = \cancel{g\ ethanol} \times \frac{1\ \cancel{mol\ ethanol}}{46.0688\ \cancel{g\ ethanol}} \times \frac{1\ \cancel{mol\ ether}}{2\ \cancel{mol\ ethanol}} \times \frac{74.1224\ g\ ether}{1\ \cancel{mol\ ether}}$$
$$= 0.9525\ g$$

$$\text{percent yield} = \frac{0.8347\ \cancel{g}}{0.9525\ \cancel{g}} \times 100\% = 87.6\%$$

71. Outline the steps needed to determine the limiting reactant when 0.50 g of Cr and 0.75 g of H_3PO_4 react according to the following chemical equation?

$$2Cr + 2H_3PO_4 \longrightarrow 2CrPO_4 + 3H_2$$

Determine the limiting reactant.

Solution

The conversion needed is $mol\ Cr \longrightarrow mol\ H_3PO_4$. Then compare the amount of Cr to the amount of acid present.

$$0.50\ mol\ Cr \times \frac{2\ mol\ H_3PO_4}{2\ mol\ Cr} = 0.50\ H_3PO_4$$

Thus, 0.25 mol H_3PO_4 is in excess, so Cr is the limiting reactant.

73. Uranium can be isolated from its ores by dissolving it as $UO_2(NO_3)_2$, then separating it as solid $UO_2(C_2O_4) \cdot 3H_2O$. Addition of 0.4031 g of sodium oxalate, $Na_2C_2O_4$, to a solution containing 1.481 g of uranyl nitrate, $UO_2(NO_2)_2$, yields 1.073 g of solid $UO_2(C_2O_4) \cdot 3H_2O$.

$$Na_2C_2O_4 + UO_2(NO_3)_2 + 3H_2O \longrightarrow UO_2(C_2O_4)\cdot 3H_2O + 2NaNO_3$$

Determine the limiting reactant and the percent yield of this reaction.

Solution

Using the balanced equation, determine which reactant quantity produces the smallest theoretical yield. This quantity represents the largest amount of product that can be produced. Then calculate the percent yield. The conversions for reaction 1 using the nitrate as limiting reactant are

$$\text{g } UO_2(NO_3)_2 \longrightarrow UO_2(NO_3)_2 + 3H_2O \longrightarrow UO_2(C_2O_4)\cdot 3H_2O \longrightarrow \text{g } UO_2(NO_3)_2\cdot 3H_2O.$$

The answer to this calculation should be compared with the answer from reaction 2 that uses sodium oxalate as the limiting reactant and requires the following conversions:

$$\text{g sodium oxalate} \longrightarrow \text{mol sodium oxalate} \longrightarrow \text{mol } UO_2(C_2O_4)\cdot 3H_2O \longrightarrow \text{g } UO_2(C_2O_4)\cdot 3H_2O$$

Molar masses: $UO_2(NO_3)_2$ = 394.04 g/mol
$Na_2C_2O_4$ = 134.00 g/mol
$UO_2(C_2O_4)\cdot 3H_2O$ = 412.09 g/mol

Reaction 1:

$$\text{mass (product)} = 1.48 \cancel{\text{ g } UO_2(NO_3)_2} \times \frac{1 \cancel{\text{ mol } UO_2(NO_3)_2}}{394.04 \cancel{\text{ g } UO_2(NO_3)_2}} \times \frac{1 \cancel{\text{ mol } UO_2(C_2O_4)\cdot 3H_2O}}{1 \cancel{\text{ mol } UO_2(NO_3)_2}} \times \frac{412.09 \text{ g } UO_2(C_2O_4)\cdot 3H_2O}{1 \cancel{\text{ mol } UO_2(C_2O_4)\cdot 3H_2O}} = 1.55 \text{ g } UO_2(C_2O_4)\cdot 3H_2O$$

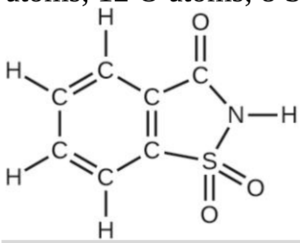
Reaction 2:

$$\text{mass (product)} = 0.403 \cancel{\text{ g } Na_2C_2O_4} \times \frac{1 \cancel{\text{ mol } Na_2C_2O_4}}{134.00 \cancel{\text{ g } Na_2C_2O_4}} \times \frac{1 \cancel{\text{ mol } UO_2(C_2O_4)\cdot 3H_2O}}{1 \cancel{\text{ mol } Na_2C_2O_4}} \times \frac{412.09 \text{ g } UO_2(C_2O_4)\cdot 3H_2O}{1 \cancel{\text{ mol } UO_2(C_2O_4)\cdot 3H_2O}} = 1.24 \text{ g } UO_2(C_2O_4)\cdot 3H_2O$$

Based on the two masses, the smaller mass is the limiting reactant. Thus, $Na_2C_2O_4$ is the limiting reactant. An amount of $UO_2(NO_3)_2$ is left unreacted.

$$\text{percent yield} = \frac{1.073 \cancel{\text{ g}}}{1.24 \cancel{\text{ g}}} \times 100 = 86.6\%$$

75. How many molecules of the sweetener saccharin can be prepared from 30 C atoms, 25 H atoms, 12 O atoms, 8 S atoms, and 14 N atoms?



Solution

Determine the number of atoms of each element in saccharin and then compare these numbers to the numbers of atoms available. The numbers of atoms in saccharin are seven C atoms, five H atoms, three O atoms, one S atom, and one N atom. Compare these to the numbers of atoms available. Divide each of the required number of atoms into the corresponding number of atoms available. These relationships are 30/7 C, 25/5 H, 12/3 O, 8/1 S, and 14/1 N. The smallest value is four for O, so only four molecules can be made.

77. Would you agree to buy 1 trillion (1,000,000,000,000) gold atoms for $5? Explain why or why not. Find the current price of gold at http://money.cnn.com/data/commodities/ ($1 \text{ troy ounce} = 31.1 \text{ g}$)

Solution

$$\text{mass Au} = \frac{1 \times 10^{12} \ \cancel{\text{atoms Au}}}{6.022 \times 10^{23} \ \cancel{\text{atoms mol}^{-1}}} \times 196.97 \text{ g } \cancel{\text{mol}^{-1}} = 3.27 \times 10^{-10} \text{ g}$$

This amount cannot be weighted by ordinary balances and is worthless.

Chemistry 2e
4: Stoichiometry of Chemical Reactions
4.5: Quantitative Chemical Analysis

79. Titration of a 20.0-mL sample of acid rain required 1.7 mL of 0.0811 *M* NaOH to reach the end point. If we assume that the acidity of the rain is due to the presence of sulfuric acid, what was the concentration of sulfuric acid in this sample of rain?

Solution

The balanced equation is

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

The steps to follow in solving this problem if we use volumes in milliliters are

$$\text{Volume NaOH} \longrightarrow \text{mmol NaOH} \longrightarrow \text{mmol } H_2SO_4 \longrightarrow \text{M } H_2SO_4$$

$$1.7 \cancel{\text{mL}} \times \frac{0.0811 \text{ mmol NaOH}}{\cancel{\text{mL}}} = 0.138 \text{ mmol NaOH}$$

$$\text{mmol } H_2SO_4 = 0.138 \cancel{\text{mmol NaOH}} \times \frac{1 \text{ mmol } H_2SO_4}{2 \cancel{\text{mmol NaOH}}} = 0.069 \text{ mmol}$$

$$M\ H_2SO_4 = \frac{0.069 \text{ mmol } H_2SO_4}{20.0 \text{ mL}} = 3.4 \times 10^{-3}\ M$$

81. In a common medical laboratory determination of the concentration of free chloride ion in blood serum, a serum sample is titrated with a $Hg(NO_3)_2$ solution.

$$2Cl^-(aq) + Hg(NO3)_2(aq) \longrightarrow 2NO_3^-(aq) + HgCl_2(s)$$

What is the Cl^- concentration in a 0.25-mL sample of normal serum that requires 1.46 mL of $8.25 \times 10^{-4} M$ $Hg(NO_3)_2(aq)$ to reach the end point?

Solution

In this exercise, the volume is left in units of milliliters and the number of moles is expressed in units of millimoles to compensate for the factor of 1000 difference between units. This technique is often useful in calculations. The steps involved in solving the problem are

$$\text{Volume } Hg(NO_3)_2 \longrightarrow \text{mmol } Hg(NO_3)_2 \longrightarrow \text{mmol } Cl^- \longrightarrow M\ Cl^-$$

$$\text{mmol } Hg(NO_3)_2 = 1.46 \cancel{\text{mL}} \times \left(8.25 \times 10^{-4} \text{ mmol}/\cancel{\text{mL}}\right) = 1.20 \times 10^{-3} \text{ mmol}$$

$$\text{mmol } Cl^- = [1.20 \times 10^{-3} \cancel{\text{mmol } Hg(NO_3)_2}] \times \frac{2 \text{ mmol } Cl^-}{1 \cancel{\text{mmol } Hg(NO_3)_2}} = 2.41 \times 10^{-3} \text{ mmol } Cl^-$$

$$M\ Cl^- = \frac{2.41 \times 10^{-3} \text{ mmol}}{0.25} = 9.6 \times 10^{-3}\ M$$

83. A sample of gallium bromide, $GaBr_3$, weighing 0.165 g was dissolved in water and treated with silver nitrate, $AgNO_3$, resulting in the precipitation of 0.299 g AgBr. Use these data to compute the % Ga (by mass) $GaBr_3$.

Solution

The reaction is $GaBr_3(aq) + 3AgNO_3(aq) \longrightarrow 3AgBr(s) + Ga(NO_3)_3(aq)$.

Begin by considering the definition of mass percentage:

$$\%Ga = \frac{\text{g Ga}}{\text{g } GaBr_3} \times 100\%$$

Computing this concentration will require the following approach:

$$\text{g AgBr} \longrightarrow \text{mol AgBr} \longrightarrow \text{mol Ga}(NO_3)_3 \longrightarrow \text{g Ga}$$

Using the provided data yields

$$\text{g Ga} = 0.299\ \text{g AgBr} \times \frac{1\ \text{mol}}{187.7722\ \text{g AgBr}} \times \frac{1\ \text{mol Ga}(NO_3)_3}{3\ \text{mol AgBr}} \times \frac{1\ \text{mol Ga}}{1\ \text{mol Ga}(NO_3)_3} \times \frac{69.723\ \text{g}}{1\ \text{mol Ga}} = 3.701 \times 10^{-2}\ \text{g}$$

Finally, the gallium mass percentage is calculated as

$$\%\text{Ga} = \frac{3.701 \times 10^{-2}\ \text{g Ga}}{0.165\ \text{g GaBr}_3} = 100\% = 22.4\%$$

85. 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.

Solution

Calculate the mass of B in the 0.063-gsample of B_2O_3. The difference of the mass of this boron and the 0.025-g sample of boron and hydrogen gives the mass of the hydrogen present. Determine the moles of B and H in the sample. Divide by the smaller number of moles to find the empirical formula. Divide the mass of the empirical formula into the assumed molecular mass of ~28 amu. That number multiplied by the subscripts of the empirical formula gives the molecular formula.

$$\text{mass of B in } B_2O_3 = \frac{2 \times 10.811\ \text{g mol}^{-1}\ \text{B}}{69.6202\ \text{g mol}^{-1}\ B_2O_3} \times 0.063\ \text{g}\ B_2O_3 = 0.0196\ \text{g}$$

$$\text{mass of H in } B_2O_3 = 0.025\ \text{g B \& H} - 0.0196\ \text{g B} = 0.0054\ \text{g H}$$

$$\text{mol B} = \frac{0.0196\ \text{g}}{10.811\ \text{g mol}^{-1}} = 0.00181\ \text{mol}$$

$$\text{mol H} = \frac{0.0054\ \text{g}}{1.00794\ \text{g mol}^{-1}} = 0.00535\ \text{mol}$$

$$\text{mole ratio: 1 B to } \frac{0.00535\ \text{mol H}}{0.00181\ \text{mol B}} = 2.96$$

Because of rounding errors, this calculation gives a ratio of 1:3. Therefore, the empirical formula is BH_3, which has a molecular mass of ~13.8 amu. Multiplication of this value by 2 gives 27.6 amu, a number of very close to the approximate mass. Consequently, the molecular formula is B_2H_6.

87. What volume of 0.600 *M* HCl is required to react completely with 2.50 g of sodium hydrogen carbonate?

$$NaHCO_3(aq) + HCl(aq) \longrightarrow NaCl(aq) + CO_2(g) + H_2O(l)$$

Solution

Convert the mass of $NaHCO_3$ to moles of Na_2CO_3, find the moles of HCl required to react with this number of moles of $NaHCO_3$, and find the volume of the solution of HCl that contains the required number of moles of HCl: 49.6 mL

89. What volume of a 0.3300-*M* solution of sodium hydroxide would be required to titrate 15.00 mL of 0.1500 *M* oxalic acid?

$$C_2O_4H_2(aq) + 2NaOH(aq) \longrightarrow Na_2C_2O_4(aq) + 2H_2O(l)$$

Solution

Find the number of moles of oxalic acid contained in 15.0 mL of its solution, find the moles of NaOH required to react with this number of moles of oxalic acid, and find the volume of the solution of NaOH that contains the required number of moles of NaOH: 13.64 mL

91. A sample of solid calcium hydroxide, $Ca(OH)_2$, is allowed to stand in water until a saturated solution is formed. A titration of 75.00 mL of this solution with 5.00×10^{-2} *M* HCl requires 36.6 mL of the acid to reach the end point.

$$Ca(OH)_2(aq) + 2HCl(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l)$$

What is the molarity?

Solution

$$\text{Volume HCl} \longrightarrow \text{mol HCl} \longrightarrow \text{mol Ca(OH)}_2 \longrightarrow \text{Concentration Ca(OH)2}$$

$$36.6\ \cancel{\text{mL HCl}} \times \frac{5.00 \times 10^{-2}\ \cancel{\text{mol HCl}}}{1000\ \cancel{\text{mL HCl}}} \times \frac{1\ \text{mol Ca(OH)}_2}{2\ \cancel{\text{mol HCl}}} \times \frac{1}{0.07500\ \text{L Ca(OH)}_2} = 0.0122\ M$$

93. How many milliliters of a 0.1500-*M* solution of KOH will be required to titrate 40.00 mL of a 0.0656-*M* solution of H_3PO_4?

$$H_3PO_4(aq) + 2KOH(aq) \longrightarrow K_2HPO_4(aq) + 2H_2O(l)$$

Solution

$$\text{Volume H}_3\text{PO}_4 \longrightarrow \text{mol KHP} \longrightarrow \text{mol NaOH} \longrightarrow \text{Concentration of NaOH}$$

$$40.00\ \cancel{\text{mL H}_3\text{PO}_4} \times \frac{0.0656\ \cancel{\text{mol H}_3\text{PO}_4}}{1000\ \cancel{\text{mL H}_3\text{PO}_4}} \times \frac{2\ \cancel{\text{mol KOH}}}{1\ \cancel{\text{mol H}_3\text{PO}_4}} \times \frac{1000\ \text{mL KOH}}{0.1500\ \cancel{\text{mol KOH}}}$$

$$= 34.99\ \text{mL KOH}$$

95. 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* NaOH to reach the end point. What is the empirical formula of the black tungsten chloride?

Solution

The general solution follows these steps:

$$\text{Volume(NaOH)} \longrightarrow \text{mol NaOH} \longrightarrow \text{mol HC1} \longrightarrow \text{mol Cl and Mass W} \longrightarrow \text{mol W}$$

For Cl:

$$\begin{aligned} 0.0462\ \text{L NaOH} \times 0.1051\ \text{M NaOH} &= 4.86 \times 10^{-3}\ \text{mol NaOH} \\ &= 4.86 \times 10^{-3}\ \text{mol HC1} \\ &= 4.86 \times 10^{-3}\ \text{mol Cl} \end{aligned}$$

For W:

$$\frac{0.2232\ \cancel{\text{g}}\ \text{W}}{183.85\ \cancel{\text{g}}\ \text{mol}^{-1}} = 1.214 \times 10^{-3}\ \text{mol W}$$

Then,

$$\frac{\text{mol Cl}}{\text{mol W}} = \frac{4.86 \times 10^{-3}\ \cancel{\text{mol}}}{1.214 \times 10^{-3}\ \cancel{\text{mol}}} = 4.00$$

The empirical formula is WCl_4.