Chapter 4: Stoichiometry of Chemical Equations

4.1 Writing and Balancing Chemical Equations

Question 22-1.

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.

Question 22-2.

Consider molecular, complete ionic, and net ionic equations.

(a) What is the difference between these types of equations?

(b) In what circumstance would the complete and net ionic equations for a reaction be identical?

Solution

(a) Molecular equations are written without regard to the dissociation of any ionic reactants or products, with all formulas represented as neutral substances. Complete ionic equations more realistically represent all dissolved ions.Net ionic equations represent only those dissolved ions that are chemically or physically changed by the reaction, omitting any spectator ions.
(b) If there are no spectator ions involved in a reaction, its complete and net ionic equations will be the same.

Question 22-3.

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) $PtCl_4(s) \longrightarrow Pt(s) + 2Cl_2(g)$

Question 22-4.

Balance the following equations:

(a) $Ag(s) + H_2S(g) + O_2(g) \longrightarrow Ag_2S(s) + H_2O(l)$

(b) $P_4(s) + O_2(g) \longrightarrow P_4O_{10}(s)$

(c) $Pb(s) + H_2O(l) + O_2(g) \longrightarrow Pb(OH)_2(s)$

(d) $Fe(s) + H_2O(l) \longrightarrow Fe_3O_4(s) + H_2(g)$

(e) $Sc_2O_3(s) + SO_3(l) \longrightarrow Sc_2(SO_4)_3(s)$

(f) $Ca_3(PO_4)_2(aq) + H_3PO_4(aq) \longrightarrow Ca(H_2PO_4)_2(aq)$

(g) $Al(s) + H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + H_2(g)$

(h) $TiCl_4(s) + H_2O(g) \longrightarrow TiO_2(s) + HCl(g)$

Solution

(a) $4Ag(s) + 2H_2S(g) + O_2(g) \longrightarrow 2Ag_2S(s) + 2H_2O(l)$; (b) $P_4(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$; (c) $2Pb(s) + 2H_2O(l) + O_2(g) \longrightarrow 2Pb(OH)_2(s)$; (d) $3Fe(s) + 4H_2O(l) \longrightarrow Fe_3O_4(s) + 4H_2(g)$; (e) $Sc_2O_3(s) + 3SO_3(l) \longrightarrow Sc_2(SO_4)_3(s)$; (f) $Ca_3(PO_4)_2(aq) + 4H_3PO_4(aq) \longrightarrow 3Ca(H_2PO_4)_2(aq)$; (g) $2Al(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$; (h) $TiCl_4(s) + 2H_2O(g) \longrightarrow TiO_2(s) + 4HCl(g)$]

Question 22-5.

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) $2H_2O(g) + 2Na(s) \longrightarrow 2NaOH(s) + H_2(g)$

Question 22-6.

Write a balanced equation describing each of the following chemical reactions.

(a) Solid potassium chlorate, $KClO_3$, decomposes to form solid potassium chloride and diatomic oxygen gas.

(b) Solid aluminum metal reacts with solid diatomic iodine to form solid Al_2I_6.

(c) When solid sodium chloride is added to aqueous sulfuric acid, hydrogen chloride gas and aqueous sodium sulfate are produced.

(d) Aqueous solutions of phosphoric acid and potassium hydroxide react to produce aqueous potassium dihydrogen phosphate and liquid water.

Solution

(a) $2KClO_3(s) \xrightarrow{\Delta} 2KCl(s) + 3O_2(g)$; (b) $2Al(s) + 3I_2(s) \longrightarrow Al_2I_6(s)$; (c) $2NaCl(s) + H_2SO_4(aq) \xrightarrow{\Delta} 2HCl(g) + Na_2SO_4(aq)$; (d) $H_3PO_4(aq) + KOH(aq) \longrightarrow KH_2PO_4(aq) + H_2O(l)$

Question 22-7.

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

(d)
$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$
$$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$
$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

Question 22-8.

Fill in the blank with a single chemical formula for a covalent compound that will balance the equation:

Solution

H_2O

Question 22-9.

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: $2F^-(aq) + Ca^{2+}(aq) \longrightarrow CaF_2(s)$

Question 22-10.

A novel process for obtaining magnesium from sea water involves several reactions. Write a balanced chemical equation for each step of the process.

(a) The first step is the decomposition of solid calcium carbonate from seashells to form solid calcium oxide and gaseous carbon dioxide.

(b) The second step is the formation of solid calcium hydroxide as the only product from the reaction of the solid calcium oxide with liquid water.

(c) Solid calcium hydroxide is then added to the seawater, reacting with dissolved magnesium chloride to yield solid magnesium hydroxide and aqueous calcium chloride.

(d) The solid magnesium hydroxide is added to a hydrochloric acid solution, producing dissolved magnesium chloride and liquid water.

(e) Finally, the magnesium chloride is melted and electrolyzed to yield liquid magnesium metal and diatomic chlorine gas.

Solution

(a) $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$; (b) $CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq)$; (c) $MgCl_2(aq) + Ca(OH)_2(aq) \longrightarrow Mg(OH)_2(s) + CaCl_2(aq)$; (d) $Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$; (e) $MgCl_2(l) \xrightarrow{\Delta} Mg(l) + Cl_2(g)$

Question 22-11.

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

4.2 Classifying Chemical Reactions

Question 23-1.

Use the following equations to answer the next five questions:

i. $H_2O(s) \longrightarrow H_2O(l)$

ii.

iii. $CH_3OH(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

iv. $Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$

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

v. $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

(a) Which equation describes a physical change?
(b) Which equation identifies the reactants and products of a combustion reaction?
(c) Which equation is not balanced?
(d) Which is a net ionic equation?

Solution

(a) i. The transition is from ice to liquid water. (b) iii. Combustion with oxygen generally produces both CO_2 and H_2O. (c) iii. The balanced equation is $2CH_3OH(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(g)$. (d) v. Only reacting ionic species are present.

Question 23-2.

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)

Question 23-3.

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

(a) $H_2O(g) + C(s) \longrightarrow CO(g) + H_2(g)$

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

(c) $Al(OH)_3(aq) + 3HCl(aq) \longrightarrow AlBr_3(aq) + 3H_2O(l)$

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

Solution

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

Question 23-4.

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.

Question 23-5.

Determine the oxidation states of the elements in the following compounds:

(a) NaI
(b) $GdCl_3$
(c) $LiNO_3$
(d) H_2Se
(e) Mg_2Si
(f) RbO_2, rubidium superoxide
(g) HF

Solution

(a) Na +1, I –1; (b) Gd +3, Cl –1; (c) Li +1, N +5, O –2; (d) H +1, Se –2; (e) Mg +2, Si –4; (f) Rb +1; $O -\frac{1}{2}$; (g) H +1, F –1

Question 23-6.

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

Question 23-7.

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

(a) H_2SO_4
(b) $Ca(OH)_2$
(c) BrOH
(d) $ClNO_2$
(e) $TiCl_4$
(f) NaH

Solution

(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

Question 23-8.

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

Question 23-9.

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) $Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$

(e) $2K_2S_2O_3(s) + I_2(s) \longrightarrow K_2S_4O_6(s) + 2KI(s)$

(f) $3Cu(s) + 8HNO_3(aq) \longrightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$

Solution

(a) Mg is oxidized from 0 to +2 and is the reducing agent, Ni is reduced from +2 to 0 and is the oxidizing agent; (b) P is oxidized from +3 to +5 and is the reducing agent, Cl is reduced from 0 to –1 and is the oxidizing agent; (c) C is oxidized from −2 to +4 and is the reducing agent, O is reduced from 0 to –2 and is the oxidizing agent; (d) Zn is oxidized from 0 to +2 and is the reducing agent, H is reduced from +1 to 0 and is the oxidizing agent; (e) S is oxidized from +2 to +2.5 and is the reducing agent, I_2 is reduced from 0 to –1 and is the oxidizing agent; (f) Cu is oxidized from O to +2, N is reduced from +5 to +2]

Question 23-10.

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

Question 23-11.

Complete and balance the following acid-base equations:

(a) A solution of $HClO_4$ is added to a solution of LiOH.

(b) Aqueous H_2SO_4 reacts with NaOH.

(c) $Ba(OH)_2$ reacts with HF gas.

Solution

(a) $HClO_4(aq) + LiOH(aq) \longrightarrow H_2O(l) + LiClO_4(aq)$; (b) $H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$; (c) $Ba(OH)_2(aq) + 2HF(g) \longrightarrow BaF_2(aq) + 2H_2O(l)$

Question 23-12.

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) $Ca(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$

Question 23-13.

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

(a) $K(s) + H_2O(l) \longrightarrow$

(b) $Ba(s) + HBr(aq) \longrightarrow$

(c) $Sn(s) + I_2(s) \longrightarrow$

Solution

(a) $2K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g)$; (b) $Ba(s) + 2HBr(aq) \longrightarrow BaBr_2(aq) + H_2(g)$; (c) $Sn(s) + 2I_2(s) \longrightarrow SnI_4(s)$

Question 23-14.

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) $SrO(s) + H_2SO_4(l) \longrightarrow SrSO_4(s) + H_2O$

Question 23-15.

When heated to 700–800 °C, diamonds, which are pure carbon, are oxidized by atmospheric oxygen. (They burn!) Write the balanced equation for this reaction.

Solution

$C(s) + O_2(g) \longrightarrow CO_2(g)$

Question 23-16.

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

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

Question 23-17.

Write the molecular, total ionic, and net ionic equations for the following reactions:

(a) $Ca(OH)_2(aq) + HC_2H_3O_2(aq) \longrightarrow$

(b) $H_3PO_4(aq) + CaCl_2(aq) \longrightarrow$

Solution

(a) $Ca(OH)_2(aq) + 2HC_2H_3O_2(aq) \longrightarrow Ca(C_2H_3O_2)_2(aq) + 2H_2O(l)$,

$Ca^{2+}(aq) + 2OH^-(aq) + 2HC_2H_3O_2(aq) \longrightarrow Ca^{2+}(aq) + 2C_2H_3O_2^-(aq) + 2H_2O(l)$,

$OH^-(aq) + HC_2H_3O_2(aq) \longrightarrow C_2H_3O_2^-(aq) + H_2O(l)$

(b) $2H_3PO_4(aq) + 3CaCl_2(aq) \longrightarrow Ca_3(PO_4)_2(s) + 6HCl(aq)$,

$2H_3PO_4(aq) + 3Ca^{2+}(aq) + 6Cl^-(aq) \longrightarrow Ca_3(PO_4)_2(s) + 6H^+(aq) + 6Cl^-(aq)$,

$2H_3PO_4(aq) + 3Ca^{2+}(aq) \longrightarrow Ca_3(PO_4)_2(s) + 6H^+(aq)$

Question 23-18.

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

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

Question 23-19.

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.

Solution

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

Question 23-20.

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

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

Question 23-21.

Calcium propionate is sometimes added to bread to retard spoilage. This compound can be prepared by the reaction of calcium carbonate, $CaCO_3$, with propionic acid, $C_2H_5CO_2H$, which has properties similar to those of acetic acid. Write the balanced equation for the formation of calcium propionate.

Solution

$CaCO_3(s) + 2C_2H_5CO_2H(aq) \longrightarrow Ca(C_2H_5CO_2)_2(aq) + CO_2(g) + H_2O(l)$

Question 23-22.

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)

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

Question 23-23.

Copper(II) sulfide is oxidized by molecular oxygen to produce gaseous sulfur trioxide and solid copper(II) oxide. The gaseous product then reacts with liquid water to produce liquid dihydrogen sulfate as the only product. Write the two equations that represent these reactions.

Solution

$CuS(s) + 2O_2(g) \longrightarrow SO_2(g) + CuO(s)$

$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(l)$

Question 23-24.

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

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

Question 23-25.

Calcium cyclamate $Ca(C_6H_{11}NHSO_3)_2$ is an artificial sweetener used in many countries around the world but is banned in the United States. It can be purified industrially by converting it to the barium salt through reaction of the acid $C_6H_{11}NHSO_3H$ with barium carbonate, treatment with sulfuric acid (barium sulfate is very insoluble), and then neutralization with calcium hydroxide. Write the balanced equations for these reactions.

Solution

$2C_6H_{11}NHSO_3H(aq) + BaCO_3(aq) \longrightarrow (C_6H_{11}NHSO_3)_2Ba(s) + H_2CO_3(aq)$

$(C_6H_{11}NHSO_3)_2Ba(s) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + 2C_6H_{11}NHSO_3H(aq)$

$2C_6H_{11}NHSO_3H(aq) + Ca(OH)_2(aq) \longrightarrow Ca(C_6H_{11}NHSO_3)_2(s) + 2H_2O(l)$

Question 23-26.

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

; (b)
$$\left[Ag(NH_3)_2\right]^+(aq) \longrightarrow Ag(s) + 2NH_3(aq)$$
$$\left[Ag(NH_3)_2\right]^+(aq) + e^- \longrightarrow Ag(s) + 2NH_3(aq)$$

; (c)
$$Hg_2Cl_2(s) \longrightarrow Hg(l) + Cl^-(aq)$$
$$Hg_2Cl_2(s) \longrightarrow 2Hg(l) + 2Cl^-(aq)$$
$$Hg_2Cl_2(s) + 2e^- \longrightarrow 2Hg(l) + 2Cl^-(aq)$$

; (d)
$$2H_2O(l) \longrightarrow O_2(g)$$
$$2H_2O(l) \longrightarrow O_2(g) + 4H^+(aq)$$
$$2H_2O(l) \longrightarrow O_2(g) + 4H^+(aq) + 4e^-$$

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

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

; (g)

$$MnO_4^-(aq) \longrightarrow Mn^{2+}(aq)$$
$$MnO_4^-(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$
; (h)
$$8H^+(aq) + MnO_4^-(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$
$$8H^+(aq) + MnO_4^-(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$
$$Cl^-(aq) \longrightarrow ClO_3^-(aq)$$
$$3H_2O(l) + Cl^-(aq) \longrightarrow ClO_3^-(aq)$$
$$3H_2O(l) + Cl^-(aq) \longrightarrow ClO_3^-(aq) + 6H^+(aq)$$
$$3H_2O(l) + Cl^-(aq) + \mathbf{6OH^-(aq)} \longrightarrow ClO_3^-(aq) + 6H^+(aq) + \mathbf{6OH^-(aq)}$$
$$3H_2O(l) + Cl^-(aq) + 6OH^-(aq) \longrightarrow ClO_3^-(aq) + 6H_2O(l)$$
$$Cl^-(aq) + 6OH^-(aq) \longrightarrow ClO_3^-(aq) + 3H_2O(l) + 6e^-$$

Question 23-27.

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

(a) $Cr^{2+}(aq) \longrightarrow Cr^{3+}(aq)$

(b) $Hg(l) + Br^-(aq) \longrightarrow HgBr_4^{2-}(aq)$

(c) $ZnS(s) \longrightarrow Zn(s) + S^{2-}(aq)$

(d) $H_2(g) \longrightarrow H_2O(l)$ (in basic solution)

(e) $H_2(g) \longrightarrow H_3O^+(aq)$ (in acidic solution)

(f) $NO_3^-(aq) \longrightarrow HNO_2(aq)$ (in acidic solution)

(g) $MnO_2(s) \longrightarrow MnO_4^-(aq)$ (in basic solution)

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

Solution

For an example of the fully worked out solution, see the solution to Exercise 37. (a) $Cr^{2+}(aq) \longrightarrow Cr^{3+}(aq) + e^-$; (b) $Hg(l) + 4Br^-(aq) \longrightarrow HgBr_4^{2-}(aq) + 2e^-$; (c) $ZnS(s) + 2e^- \longrightarrow Zn(s) + S^{2-}(aq)$; (d) $H_2(g) + 2OH^-(aq) \longrightarrow 2H_2O(l) + 2e^-$; (e) $H_2(g) + 2H_2O(l) \longrightarrow 2H_3O^+(aq) + 2e^-$; (f) $NO_3^-(aq) + 3H_3O^+(aq) + 2e^- \longrightarrow HNO_2(aq) + 4H_2O(l)$; (g) $MnO_2(s) + 4OH^-(aq) \longrightarrow MnO_4^-(aq) + 2H_2O(l) + 3e^-$; (h) $Cl^-(aq) + 3H_2O(l) \longrightarrow ClO_3^-(aq) + 6H_3O^+(aq) + 6e^-$

Question 23-28.

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) $2HBrO(aq) + 2H_2O(l) \longrightarrow 2H_3O^+(aq) + 2Br^-(aq) + O_2(g)$

Question 23-29.

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

(a) $Zn(s) + NO_3^-(aq) \longrightarrow Zn^{2+}(aq) + N_2(g)$ (in acid)

(b) $Zn(s) + NO_3^-(aq) \longrightarrow Zn^{2+}(aq) + NH_3(aq)$ (in base)

(c) $CuS(s) + NO_3^-(aq) \longrightarrow Cu^{2+}(aq) + S(s) + NO(g)$ (in acid)

(d) $NH_3(aq) + O_2(g) \longrightarrow NO_2(g)$ (gas phase)

(e) $H_2O_2(aq) + MnO_4^-(aq) \longrightarrow Mn^{2+}(aq) + O_2(g)$ (in acid)

(f) $NO_2(g) \longrightarrow NO_3^-(aq) + NO_2^-(aq)$ (in base)

(g) $Fe^{3+}(aq) + I^-(aq) \longrightarrow Fe^{2+}(aq) + I_2(aq)$

Solution

For an example of the fully worked out solution, see the solution to Exercise 37.

(a) $5Zn(s) + 12H_3O^+(aq) + 2NO_3^-(aq) \longrightarrow 5Zn^{2+}(aq) + N_2(g) + 18H_2O(l)$;

(b) $4Zn(s) + NO_3^-(aq) + 6H_2O(l) \longrightarrow 4Zn^{2+}(aq) + NH_3(aq) + 9OH^-(aq)$;

(c) $3CuS(s) + 8H_3O^+(aq) + 2NO_3^-(aq) \longrightarrow 3Cu^{2+}(aq) + 3S(s) + 2NO(g) + 12H_2O(l)$;

(d) $4NH_3(aq) + 7O_2(g) \longrightarrow 4NO_2(g) + 6H_2O(l)$;

(e) $5H_2O_2(aq) + 2MnO_4^-(aq) + 6H_3O^+(aq) \longrightarrow 2Mn^{2+}(aq) + 5O_2(g) + 14H_2O(l)$;

(f) $2NO_2(g) + 2OH^-(aq) \longrightarrow NO_3^-(aq) + NO_2^-(aq) + H_2O(l)$;

(g) $2Fe^{3+}(aq) + 2I^-(aq) \longrightarrow 2Fe^{2+}(aq) + I_2(aq)$

Question 23-30.

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) $Br_2(l) + SO_2(g) + 2H_2O(l) \longrightarrow 4H^+(aq) + 2Br^-(aq) + SO_4^{2-}(aq)$

4.3 Reaction Stoichiometry

Question 24-1.

Write the balanced equation, then outline the steps necessary to determine the information requested in each of the following:

(a) The number of moles and the mass of chlorine, Cl_2, required to react with 10.0 g of sodium metal, Na, to produce sodium chloride, NaCl.

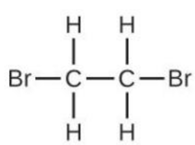
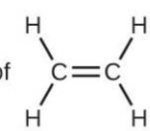
(b) The number of moles and the mass of oxygen formed by the decomposition of 1.252 g of mercury(II) oxide.

(c) The number of moles and the mass of sodium nitrate, $NaNO_3$, required to produce 128 g of oxygen. ($NaNO_2$ is the other product.)

(d) 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.

(e) 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.)

(f)

The number of moles and the mass of  formed by the reaction of 12.85 g of  with an excess of Br_2.

Solution

(a) $2Na + Cl_2 \longrightarrow 2NaCl$,

mass of Na $\longrightarrow$ moles of Na $\longrightarrow$ moles of Cl_2 $\longrightarrow$ mass of Cl_2; (b)

$2HgO \longrightarrow 2Hg + O_2$,

Mass of HgO $\longrightarrow$ Moles of HgO $\longrightarrow$ Moles of O_2 $\longrightarrow$ Mass of O_2; (c)

$2NaNO_3 \longrightarrow 2NaNO_2 + O_2$,

Mass of $NaNO_3$ $\longrightarrow$ Moles of $NaNO_3$ $\longrightarrow$ Moles of O_2 $\longrightarrow$ Mass of O_2; (d)

$C + O_2 \longrightarrow CO_2$, Mass of C $\longrightarrow$ Moles of C $\longrightarrow$ Moles of CO_2 $\longrightarrow$ Mass of CO_2;

(e) $CuCO_3 \longrightarrow CuO + CO_2$,

Mass of $CuCO_3$ $\longrightarrow$ Moles of $CuCO_3$ $\longrightarrow$ Moles of CuO $\longrightarrow$ Mass of CuO; (f)

$$C_2H_4 + Br_2 \longrightarrow C_2H_4Br_2,$$

$$\text{Mass of } C_2H_4 \longrightarrow \text{Moles of } C_2H_4 \longrightarrow \text{Moles of } C_2H_4Br_2 \longrightarrow \text{Mass of } C_2H_4Br_2$$

Question 24-2.

Determine the number of moles and the mass requested for each reaction in Exercise 1.

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)

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

$$\text{mol } O_2 = 0.005780 \cancel{\text{mol HgO}} \times \frac{1 \text{ mol } O_2}{2 \cancel{\text{mol HgO}}} = 2.890 \times 10^{-3} \text{ mol}$$

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

; (c) From the balanced 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)

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

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

;(e) Molar 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)

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

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

Question 24-3.

Write the balanced equation, then outline the steps necessary to determine the information requested in each of the following:

(a) The number of moles and the mass of Mg required to react with 5.00 g of HCl and produce $MgCl_2$ and H_2.

(b) The number of moles and the mass of oxygen formed by the decomposition of 1.252 g of silver oxide.

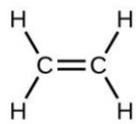
(c) The number of moles and the mass of magnesium carbonate, $MgCO_3$, required to produce 283 g of carbon dioxide. (MgO is the other product.)

(d) The number of moles and the mass of water formed by the combustion of 20.0 kg ofacetylene, C_2H_2, in an excess of oxygen.

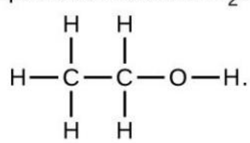
(e) The number of moles and the mass of barium peroxide, BaO_2, needed to produce 2.500 kg of barium oxide, BaO (O_2 is the other product.)

(f)

The number of moles and the mass of



required to react with H_2O to produce 9.55 g of



Solution

(a) $Mg + 2HCl \longrightarrow MgCl_2 + H_2$, $g\ HCl \longrightarrow mol\ HCl \longrightarrow mol\ Mg \longrightarrow g\ Mg$;

(b) $2Ag_2O \longrightarrow 4Ag + O_2$, $g\ Ag_2O \longrightarrow mol\ Ag_2O \longrightarrow mol\ O_2\ g\ O_2$;

(c) $MgCO_3 \longrightarrow CO_2 + MgO$, $g\ CO_2 \longrightarrow mol\ CO_2 \longrightarrow mol\ MgCO_3 \longrightarrow g\ MgCO_3$;

(d) $C_2H_2 + 5O_2 \longrightarrow 4CO_2 + 2H_2O$, $C_2H_2 \longrightarrow mol\ C_2H_2 \longrightarrow mol\ H_2O \longrightarrow g\ H_2O$;

(e) $2BaO_2 \longrightarrow 2BaO + O_2$,

$kg\ BaO \longrightarrow g\ BaO \longrightarrow mol\ BaO \longrightarrow mol\ BaO_2 \longrightarrow g\ BaO_2$; (f)

$C_2H_4 + H_2O \longrightarrow C_2H_6O$, $g\ C_2H_6O \longrightarrow mol\ C_2H_6O \longrightarrow mol\ C_2H_4 \longrightarrow g\ C_2H_4$

Question 24-4.

Determine the number of moles and the mass requested for each reaction in Exercise 3.

Solution

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

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

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

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

Question 24-5.

H_2 is produced by the reaction of 118.5 mL of a 0.8775-*M* solution of H_3PO_4 according to the following equation: $2Cr + 2H_3PO_4 \longrightarrow 3H_2 + 2CrPO_4$.

(a) Outline the steps necessary to determine the number of moles and mass of H_2.

(b) Perform the calculations outlined.

Solution

(a) volume of H_3PO_4 solution $\longrightarrow$ moles of H_3PO_4 $\longrightarrow$ moles of H_2 $\longrightarrow$ mass of H_2;

(b) multiply the volume in liters times the molarity to find the moles of H_3PO_4.

mol H_3PO_4 = 0.1185 L × 0.8775 *M* = 0.10398 mol

$$\text{mol } H_2 = 0.10398 \ \cancel{\text{mol } H_3PO_4} \times \frac{3 \text{ mol } H_2}{2 \ \cancel{\text{mol } H_3PO_4}} = 0.1560 \text{ mol}$$

$$\text{g } H_2 = 0.1560 \ \cancel{\text{mol } H_2} \times \frac{2.01588 \text{ g}}{1 \ \cancel{\text{mol } H_2}} = 0.3144 \text{ g}$$

Question 24-6.

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)

$$2.6\ \cancel{\text{L HCl}}\ \square\ \frac{1.44\ \cancel{\text{mol HCl}}}{1\ \cancel{\text{L HCl}}}\ \square\ \frac{2\ \cancel{\text{mol GaCl}_3}}{6\ \cancel{\text{mol HCl}}}\ \square\ \frac{176.1\ \text{g GaCl}_3}{1\ \cancel{\text{mol GaCl}_3}} = 2.2\ \square\ 10^2\ \text{g GaCl}_3$$

Question 24-7.

I_2 is produced by the reaction of 0.4235 mol of $CuCl_2$ according to the following equation:

$$2CuCl_2 + 4KI \longrightarrow 2CuI + 4KCl + I_2.$$

(a) How many molecules of I_2 are produced?

(b) What mass of I_2 is produced?

Solution

(a) The calculation requires the following conversions:

$$\text{mol CuCl}_2 \longrightarrow \text{mol I}_2 \longrightarrow \text{molecules of I}_2$$

$$\text{molecules of I}_2 = 0.4235\ \cancel{\text{mol CuCl}_2} \times \frac{1\ \cancel{\text{mol I}_2}}{2\ \cancel{\text{mol CuCl}_2}} \times \frac{6.022 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol I}_2}}$$

$$= 1.275 \times 10^{23}\ \text{molecules of I}_2$$

; (b) There are two possible ways to approach the problem.

Approach 1: Start with the number of moles. Since $2\ \text{mol CuCl}_2 \longrightarrow 1\ \text{mol I}_2$

$$0.4235\ \cancel{\text{mol CuCl}_2} \times \frac{1\ \text{mol I}_2}{2\ \cancel{\text{mol CuCl}_2}} = 0.21175\ \text{mol I}_2$$

$$0.21175\ \cancel{\text{mol I}_2} \times \frac{253.809\ \text{g}}{1\ \cancel{\text{mol I}_2}} = 53.74\ \text{g I}_2$$

Approach 2: Start with the number of molecules.

$$1.275 \times 10^{23}\ \cancel{\text{molecules I}_2} \times \frac{253.809\ \text{g}}{6.022 \times 10^{23}\ \cancel{\text{molecules I}_2}} = 53.74\ \text{g I}_2$$

Question 24-8.

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:

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

;

(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)

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

Question 24-9.

What mass of silver oxide, Ag_2O, is required toproduce 25.0 g of silver sulfadiazine, $AgC_{10}H_9N_4SO_2$, from the reaction of silver oxide and sulfadiazine?

$$2C_{10}H_{10}N_4SO_2 + Ag_2O \longrightarrow 2AgC_{10}H_9N_4SO_2 + H_2O$$

Solution

The following conversions are needed:

$$\text{g AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2 \longrightarrow \text{mol AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2 \longrightarrow \text{mol Ag}_2\text{O} \longrightarrow \text{g Ag}_2\text{O}$$

$$\text{mass Ag}_2\text{O} = 25.0 \ \cancel{\text{g AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2} \times \frac{1 \ \cancel{\text{mol AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2}}{357.141 \ \cancel{\text{g AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2}} \times \frac{1 \ \cancel{\text{mol Ag}_2\text{O}}}{2 \ \cancel{\text{mol AgC}_{10}\text{H}_9\text{N}_4\text{SO}_2}}$$
$$\times \frac{231.735 \text{ g Ag}_2\text{O}}{1 \ \cancel{\text{mol Ag}_2\text{O}}} = 8.11 \text{ g}$$

Question 24-10.

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}

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

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

Question 24-11.

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 ft^3 (73.6 L) of nitrogen gas with a density of 1.25 g/L?

Solution

$$\text{volume N}_2 \longrightarrow \text{mass N}_2 \longrightarrow \text{mol N}_2 \longrightarrow \text{mol NaN}_3 \longrightarrow \text{mass NaN}_3$$

$$368\ \cancel{\text{L}} \times \frac{1.25\ \cancel{\text{g}}}{\cancel{\text{L}}} \times \frac{1\ \cancel{\text{mol N}_2}}{28.02\ \cancel{\text{g}}} \times \frac{2\ \cancel{\text{mol NaN}_3}}{3\ \cancel{\text{mol N}_2}} \times \frac{65.02\ \text{g}}{1\ \cancel{\text{mol NaN}_3}} = 712\ \text{g}$$

Question 24-12.

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?

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

Solution

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

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

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

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

Question 24-13.

In an accident, a solution containing 2.5 kg of nitric acid was spilled. Two kilograms of Na_2CO_3 was quickly spread on the area and CO_2 was released by the reaction. Was sufficient Na_2CO_3 used to neutralize all of the acid?

Solution

The reaction is $Na_2CO_3 + 2HNO_3 \longrightarrow 2Na^+ + 2NO_3^- + 2CO_2 + H_2O$

Calculate the mass of Na_2CO_3 required for complete reaction of nitric acid using the process

$$\text{mass of acid} \longrightarrow \text{mol of acid} \longrightarrow \text{mol of Na}_2\text{CO}_3 \longrightarrow \text{mass of Na}_2\text{CO}_3$$

$$\text{mass of Na}_2\text{CO}_3 = 2.5\ \text{kg} \times 1000\ \cancel{\text{g}}\ \text{kg}^{-1} \times \frac{1\ \cancel{\text{mol HNO}_3}}{63.0\ \cancel{\text{g}}} \times \frac{1\ \cancel{\text{mol Na}_2\text{CO}_3}}{2\ \cancel{\text{mol HNO}_3}} \times \frac{106.0\ \text{g}}{\cancel{\text{mol Na}_2\text{CO}_3}}$$

$$= 2.1 \times 10^3\ \text{g} = 2.1\ \text{kg}$$

No, 2.1 kg is required.

Question 24-14.

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 $C(s) + O_2(g) \longrightarrow CO_2(g)$

$$500 \cancel{\text{miles}} \times \frac{1 \cancel{\text{gallon}}}{37.5 \cancel{\text{miles}}} \times \frac{3.785 \cancel{\text{L}}}{1 \cancel{\text{gallon}}} \times \frac{1000 \cancel{\text{mL}}}{1 \cancel{\text{L}}} \times \frac{0.8205 \cancel{\text{g gas}}}{1 \cancel{\text{mL}} \text{ gas}} \times \frac{84.2 \cancel{\text{g C}}}{100 \cancel{\text{g gas}}}$$

$$\times \frac{1 \cancel{\text{mol C}}}{12.01 \cancel{\text{g C}}} \times \frac{1 \cancel{\text{mol CO}_2}}{1 \cancel{\text{mol C}}} \times \frac{44.01 \text{ g CO}_2}{1 \cancel{\text{mol CO}_2}} = 1.28 \times 10^5 \text{ g CO}_2$$

Question 24-15.

What volume of a 0.750 M solution of hydrochloric acid, a solution of HCl, can be prepared from the HCl produced by the reaction of 25.0 g of NaCl with an excess of sulfuric acid?

$$NaCl(s) + H_2SO_4(l) \longrightarrow HCl(g) + NaHSO_4(s)$$

Solution

$$\text{mass NaCl} \longrightarrow \text{mol NaCl} \longrightarrow \text{mol HCl} \longrightarrow \text{Volume HCl}$$

$$25.0 \cancel{\text{g NaCl}} \times \frac{1 \cancel{\text{mol NaCl}}}{58.44 \cancel{\text{g NaCl}}} \times \frac{1 \cancel{\text{mol HCl}}}{1 \cancel{\text{mol NaCl}}} \times \frac{1 \text{ L HCl}}{0.750 \cancel{\text{mol HCl}}} = 0.570 \text{ L HCl}$$

Question 24-16.

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

Question 24-17.

A mordant is a substance that combines with a dye to produce a stable fixed color in a dyed fabric. Calcium acetate is used as a mordant. It is prepared by the reaction of acetic acid with calcium hydroxide.

$$2CH_3CO_2H + Ca(OH)_2 \longrightarrow Ca(CH_3CO_2)_2 + 2H_2O$$

What mass of $Ca(OH)_2$ is required to react with the acetic acid in 25.0 mL of a solution having a density of 1.065 g/mL and containing 58.0% acetic acid by mass?

Solution

$$\text{Volume of solution} \longrightarrow \text{mass solution} \longrightarrow \text{mass acetic acid} \longrightarrow \text{moles of acetic acid} \longrightarrow \text{moles Ca(OH)}_2 \longrightarrow \text{mass Ca(OH)}_2$$

The last step is to determine the mass of $Ca(OH)_2$ from the moles:

$$25.0 \text{ mL} \times \frac{1.065 \cancel{\text{ g solution}}}{1 \text{ mL}} \times \frac{58.0 \text{ g acetic acid}}{100 \cancel{\text{ g solution}}} \times \frac{1 \text{ mol CH}_3\text{COOH}}{60.05 \text{ g CH}_3\text{COOH}} \times \frac{1 \text{ mol Ca(OH)}_2}{2 \text{ mol CH}_3\text{COOH}} \times \frac{74.093 \text{ g Ca(OH)}_2}{1 \text{ mol}} = 9.53 \text{ g}$$

Question 24-18.

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

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

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

4.4 Reaction Yields

Question 25-1.

The following quantities are placed in a container: 1.5×10^{24} atoms of hydrogen, 1.0 mol of sulfur, and 88.0 g of diatomic oxygen.

(a) What is the total mass in grams for the collection of all three elements?
(b) What is the total number of moles of atoms for the three elements?
(c) If the mixture of the three elements formed a compound with molecules that contain two hydrogen atoms, one sulfur atom, and four oxygen atoms, which substance is consumed first?
(d) How many atoms of each remaining element would remain unreacted in the change described in (c)?

Solution

(a) Convert each quantity to grams.

For H: $\dfrac{1.5 \times 10^{24} \text{ atoms}}{6.022 \times 10^{23} \text{ atoms mol}^{-1}} \times 1.0079 \text{ g mol}^{-1} \text{ H} = 2.5 \text{ g}$

For S: $1.0 \text{ mol S} \times \dfrac{32.06 \text{ g S}}{1 \text{ mol S}} = 32 \text{ g S}$

Total mass = 2.5 g H + 32 g S + 88 g O_2 = 122 g

(b) Convert each quantity to moles.

For H: $\dfrac{1.5 \times 10^{24} \text{ atoms}}{6.022 \times 10^{23} \text{ atoms mol}^{-1}} = 2.5 \text{ mol H}$

For S: 1.0 mol S

For O_2: $88.0 \cancel{\text{ g } O_2} \times \dfrac{1 \cancel{\text{ mol } O_2}}{31.9988 \cancel{\text{ g } O_2}} \times \dfrac{2 \text{ mol O}}{1 \cancel{\text{ mol } O_2}} = 5.5 \text{ mol O}$

Total number of moles = 2.5 + 1.0 + 5.5 = 9.0 mol

(c) The moles of each element present are given in (b). The ratio is 2.5 H: 1.0 S: 11.0 O. The ratio in the compound is 2H: 1 S: 4 O. Comparing these two ratios shows that both H and O are provided in greater-than-stoichiometric amounts. For each mole of S, the compound requires 2 moles of H (2.5 are provided) and 4 moles of O (11.0 mol are provided). Sulfur, therefore, is the limiting reagent.

(d) H remaining = 2.5 mol – 2.0 mol = 0.5 mol H or 3.0×10^{23} H atoms; O atoms remaining = 11.0 mol – 4.0 mol = 7 mol O or 4.2×10^{24} O atoms

Question 25-2.

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: $2\text{Na} + \text{Cl}_2 \longrightarrow 2\text{NaCl}$

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

$$\text{Moles of Cl}_2 = 8 \text{ g} \times \frac{1 \text{ mol}}{70.9 \text{ g}} = 0.1 \text{ mol Cl}_2$$

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.

Question 25-3.

Which of the postulates of Dalton's atomic theory explains why we can calculate a theoretical yield for a chemical reaction?

Solution

In a given compound, the number of atoms of each type always has the same ratio. Atoms are neither created nor destroyed during a chemical change.

Question 25-4.

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

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

Question 25-5.

A sample of 0.53 g of carbon dioxide was obtained by heating 1.31 g of calcium carbonate. What is the percent yield for this reaction?

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(s)$$

Solution

Begin by calculating the mass of CO_2 that can be produced from 1.31 g of $CaCO_3$, assuming that all of the CO_2 can be recovered. The conversion is

$\text{g } CaCO_3 \longrightarrow \text{mol } CaCO_3 \longrightarrow \text{mol } CO_2 \longrightarrow \text{g } CO_2$. This procedure gives the theoretical mass. Then divide the actual yield by the theoretical yield and multiply the result by 100% to obtain the percentage yield. Molar masses: $CaCO_3$ = 100.09 g/mol; CO_2 = 44.010 g/mol. For complete conversion,

$$\text{Mass } CO_2 = 1.31\text{ g } CaCO_3 \times \frac{1\text{ mol } CaCO_3}{100.09\text{ g } CaCO_3} \times \frac{1\text{ mol } CO_2}{1\text{ mol } CaCO_3} \times \frac{44.010\text{ g } CO_2}{1\text{ mol } CO_2}$$

$$= 0.576\text{ g } CO_2 \text{ (theoretical yield)}$$

Question 25-6.

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,

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

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

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

Question 25-7.

Citric acid, $C_6H_8O_7$, a component of jams, jellies, and fruity soft drinks, is prepared industrially via fermentation of sucrose by the mold *Aspergillus niger*. The equation representing this reaction is

$$C_{12}H_{22}O_{11} + H_2O + 3O_2 \longrightarrow 2C_6H_8O_7 + 4H_2O$$

What mass of citric acid is produced from exactly 1 metric ton (1.000×10^3 kg) of sucrose if the yield is 92.30%?

Solution

Calculate the mass of citric acid by assuming 100% yield. The expected value is 92.30% of this amount. $C_{12}H_{22}O_{11} + H_2O + 3O_2 \longrightarrow 2C_6H_8O_7 + 4H_2O$

1 mol 2 mol

1.000×10^3 kg 100% yield?

Formula masses: $C_{12}H_{22}O_{11}$ = 342.30 g/mol; $C_6H_8O_7$ = 192.12 g/mol. Once the ratio of masses is established, the formula masses are independent of units; thus, mass either in grams or kilograms can be used, as long as the units are used consistently. One mole of $C_{12}H_{22}O_{11}$ (342.30 g), produces two moles of $C_6H_8O_7$: 2 × 192.12 g = 384.24. Using kilogram values, 342.30 kg of $C_{12}H_{22}O_{11}$ produces 2 × 192.12 kg of citric acid, or 384.24 kg.

For 100% yield,

$$\text{mass of } C_6H_8O_7 = 1.000 \times 10^3 \text{ kg sucrose} \times \frac{1 \text{ mol kg sucrose}}{342.30 \text{ kg sucrose}} \times \frac{2 \text{ mol-kg citric acid}}{1 \text{ mol-kg sucrose}} \times \frac{192.12 \text{ kg citric acid}}{\text{mol-kg citric acid}} = 1122 \text{ kg citric acid}$$

For 92.302% yield, mass of $C_6H_8O_7$ = 1122 kg × 0.9230 = 1036 kg

Question 25-8.

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

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

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

Question 25-9.

In a laboratory experiment, the reaction of 3.0 mol of H_2 with 2.0 mol of I_2 produced 1.0 mol of HI. Determine the theoretical yield in grams and the percent yield for this reaction.

Solution

$$H_2 + I_2 \longrightarrow 2HI$$

Because the balanced equation shows that H_2 and I_2 react on a 1:1 molar ratio, the I_2 in this problem is limiting.

$$2.0 \text{ mol } I_2 \times \frac{2 \text{ mol HI}}{1 \text{ mol } I_2} = 4.0 \text{ mol HI (theoretical yield)}$$

$$4.0 \text{ mol HI} \times \frac{127.9 \text{ g}}{\text{mol HI}} = 5.1 \times 10^2 \text{ HI}$$

$$\text{percent yield} = \frac{1.0 \text{ mol}}{4.0 \text{ mol}} \times 100\% = 25\%$$

Question 25-10.

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.

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

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

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

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

Mass ether = 1.184

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

$$= 0.9525 \text{ g}$$

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

Question 25-11.

Outline the steps needed to determine the limiting reactant when 30.0 g of propane, C_3H_8, is burned with 75.0 g of oxygen. Determine the limiting reactant.

Solution

Determine the moles of CO_2 produced by 30.0 g of propane. Determine the moles of CO_2 produced by 75.0 g of oxygen. The limiting reagent is the one that produces the smaller amount of CO_2.

$$30.0\ g\ C_3H_8 \times \frac{1\ mol\ C_3H_8}{44.097\ g\ C_3H_8} \times \frac{5\ mol\ O_2}{1\ mol\ C_3H_8} = 3.40\ mol\ O_2$$

$$75.0\ g\ O_2 \times \frac{1\ mol\ O_2}{31.9988\ g\ O_2} = 2.34\ mol\ O_2$$

Only 2.34 mol O_2 is available. As 3.40 mol of O_2 are required to burn the propane, O_2 is limiting the reaction.

Question 25-12.

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.

Question 25-13.

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?

$$Li + N_2 \longrightarrow Li_3N$$

Solution

Balance the equation. Then determine the number of moles of each component and compare with the mole requirement of the balanced equation.

$$6Li + N_2 \longrightarrow 2Li_3N$$

$$mol\ Li = 1.50\ g\ Li \times \frac{1\ mol\ Li}{6.941\ g\ Li} = 0.216\ mol\ Li$$

$$mol\ N_2 = 1.50\ g\ N_2 \times \frac{1\ mol\ N_2}{14.01348\ g\ N_2} = 0.107\ mol\ N_2$$

The ratio is six Li atoms to 1 mol N_2, the amount of Li is less than six times the number of moles of N_2; thus, Li is the limiting reagent.

Question 25-14.

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.

$$\text{percent yield} = \frac{1.073\ \cancel{\text{g}}}{1.24\ \cancel{\text{g}}} \times 100 = 86.56\%$$

Question 25-15.

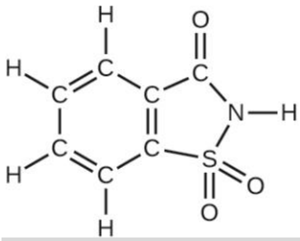
How many molecules of $C_2H_4Cl_2$ can be prepared from 15 C_2H_4 molecules and 8 Cl_2 molecules?

Solution

Since multiplication of $C_2H_4Cl_2$ by eight gives the most Cl that can be accommodated consistent with the amount of Cl present, only eight C_2H_4 molecules are needed. Therefore, C_2H_4 is in excess and Cl_2 is the limiting reagent.

Question 25-16.

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.

Question 25-17.

The phosphorus pentoxide used to produce phosphoric acid for cola soft drinks is prepared by burning phosphorus in oxygen.

(a) What is the limiting reactant when 0.200 mol of P_4and0.200 mol of O_2 react according to $P_4 + 5O_2 \longrightarrow P_4O_{10}$

(b) Calculate the percent yield if 10.0 g of P_4O_{10} is isolated from the reaction.

Solution

(a) The stoichiometry of this reaction requires 1 mole P_4 for each 5 moles of O_2, or an oxygen-to-phosphorus ratio of 5:1. The reactants are provided in equimolar amounts, 0.200 moles each, or an oxygen-to-phosphorus ratio of 1:1. Oxygen is provided in a less-than-stoichiometric amount and is the limiting reactant.

(b) 0.200 mol O_2 will produce $\frac{1}{5} \times 0.200$ mol of P_4O_{10}. The molar mass of P_4O_{10} is (4 × 30.97376) + (10 × 15.9994) = 283.889 g/mol. Then $\frac{1}{5} \times 0.200 \times 283.889 \text{ g/mol} = 11.4 \text{ g}$.

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{10.0 \text{ g}}{11.4 \text{ g}} \times 100\% = 87.7\%$$

Question 25-18.

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 troy ounce = 31.1 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.

4.5 Quantitative Chemical Analysis

Question 26-1.

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

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

Solution

$$\text{Volume } Ca(OH)_2 \times M\ Ca(OH)_2 \longrightarrow \text{mol } Ca(OH)_2 \longrightarrow \text{mol HBr} \longrightarrow \text{volume HBr}$$

0.0100 *M* $Ca(OH)_2$ × 0.125 L $Ca(OH)_2$ = 1.25×10^{-3} mol $Ca(OH)_2$

$$1.25 \times 10^{-3} \text{ mol } Ca(OH)_2 \times \frac{2 \text{ mol HBr}}{1 \text{ mol } Ca(OH)_2} = 2.50 \times 10^{-3} \text{ mol HBr}$$

$$\text{volume HBr} = \frac{2.50 \times 10^{-3} \text{ mol HBr}}{1.05 \times 10^{-2} \text{ mol L}^{-1}} = 0.238 \text{ L or } 238 \text{ mL}$$

Question 26-2.

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

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

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

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

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

Question 26-3.

What is the concentration of NaCl in a solution if titration of 15.00 mL of the solution with 0.2503 *M* $AgNO_3$ requires 20.22 mL of the $AgNO_3$ solution to reach the end point?

$$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$$

Solution

The end point in the reaction occurs when all available $AgNO_3$ has reacted with the minimum NaCl added. From the balanced equation, $AgNO_3$ and NaCl react on a 1:1 molar basis. Thus, the moles of NaCl in 15.00 mL equal the moles of $AgNO_3$ present:

$$\text{mol } AgNO_3 = 0.250\ M \times 20.22 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.005055 \text{ mol}$$

Therefore, in 15.00 mL, there are 0.005055 mol NaCl. Thus,

$$M\ \text{NaCl} = \frac{0.005055\ \text{mol}}{0.01500\ \text{L}} = 0.3370\ \text{M}$$

Question 26-4.

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

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

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

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

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

Question 26-5.

Potatoes can be peeled commercially by soaking them in a 3-*M* to 6-*M* solution of sodium hydroxide, then removing the loosened skins by spraying them with water. Does a sodium hydroxide solution have a suitable concentration if titration of 12.00 mL of the solution requires 30.6 mL of 1.65 *M* HCI to reach the end point?

Solution

The reaction is

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$1.65\ \text{mol L}^{-1} \times 0.0306\ \text{L} = 5.05 \times 10^{-2}\ \text{mol HCl} = 5.05 \times 10^{-2}\ \text{mol NaOH}$$

$$M\ \text{NaOH} = \frac{5.05 \times 10^{-2}\ \text{mol NaOH}}{0.01200\ \text{L}} = 4.21\ M$$

Yes, the concentration of NaOH falls in the suitable range of 3 M to 6 M.

Question 26-6.

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:

$$\%\text{Ga} = \frac{\text{g Ga}}{\text{g GaBr}_3} \times 100\%$$

Computing this concentration will require the following approach:

$$\text{g AgBr} \longrightarrow \text{mol AgBr} \longrightarrow \text{mol Ga}\left(\text{NO}_3\right)_3 \longrightarrow \text{g Ga}$$

Using the provided data yields

$$\text{g Ga} = 0.299\ \cancel{\text{g AgBr}} \times \frac{1\ \cancel{\text{mol}}}{187.7722\ \cancel{\text{g AgBr}}} \times \frac{1\ \cancel{\text{mol Ga(NO}_3)_3}}{3\ \cancel{\text{mol AgBr}}} \times \frac{1\ \cancel{\text{mol Ga}}}{1\ \cancel{\text{mol Ga(NO}_3)_3}}$$

$$\times \frac{69.723\ \text{g}}{1\ \cancel{\text{mol Ga}}} = 3.701 \times 10^{-2}\ \text{g}$$

Finally, the gallium mass percentage is calculated as

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

Question 26-7.

The principal component of mothballs is naphthalene, a compound with a molecular mass of about 130 amu, containing only carbon and hydrogen. A 3.000-mg sample of naphthalene burns to give 10.3 mg of CO_2. Determine its empirical and molecular formulas.

Solution

$$10.3\ \cancel{\text{mg CO}_2} \times \frac{12.0\ \text{mg C}}{44.0\ \cancel{\text{mg CO}_2}} = 2.81\ \text{mg C}$$

3.00 mg – 2.81 mg = 0.19 mg H

$$2.81\ \cancel{\text{mg C}} \times \frac{1\ \text{mmol C}}{1.01\ \cancel{\text{mg C}}} = 0.234\ \text{mmol C}$$

$$0.19\ \cancel{\text{mg H}} \times \frac{1\ \text{mmol}}{1.01\ \cancel{\text{mg H}}} = 0.188\ \text{mmol H}$$

Find the mole ratios and then the lowest common denominator.

$$\frac{0.234}{0.188} = 1.24 \qquad 1.24 \times 4 = 4.96$$

$$\frac{0.188}{0.188} = 1.00 \qquad 1.00 \times 4 = 4.00$$

Empirical formula: C_5H_4

Empirical mass of C_5H_4: 64.1

Molecular mass = (empirical mass)(n)

$$n = \frac{\text{molecular mass}}{\text{empirical mass}} = \frac{130}{64.1} \approx 2$$

Molecular formula: (2)(C_5H_4) $C_{10}H_8$

Question 26-8.

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.

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

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

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

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

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

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.

Question 26-9.

Sodium bicarbonate (baking soda), $NaHCO_3$, can be purified by dissolving it in hot water (60 °C), filtering to remove insoluble impurities, cooling to 0 °C to precipitate solid $NaHCO_3$, and then filtering to remove the solid, leaving soluble impurities in solution. Any $NaHCO_3$ that remains in solution is not recovered. The solubility of $NaHCO_3$ in hot water of 60 °C is 164 g L. Its solubility in cold water of 0 °C is 69 g/L. What is the percent yield of $NaHCO_3$ when it is purified by this method?

Solution

Use 1 L as a basis for calculation: 164 – 69 = 95 g solid $NaHCO_3$

$$\text{percent yield} = \frac{95 \not{\text{g}}}{1641 \not{\text{g}}} \times 100 = 58\%$$

Question 26-10.

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

Question 26-11.

What volume of 0.08892 *M* HNO_3 is required to react completely with 0.2352 g of potassium hydrogen phosphate?

$$2HNO_3(aq) + K_2HPO_4(aq) \longrightarrow H_3PO_4(aq) + 2KNO_{3(aq)}$$

Solution

The outline of three steps is as follows:

1. Convert the grams of potassium hydrogen phosphate to moles of K_2HPO_4 present; use potassium hydrogen phosphate.
2. Convert the balanced equation to convert moles of potassium hydrogen phosphate to moles of HNO_3; then use nitric acid.
3. Convert the given moles of HNO_3 to calculate the volume needed in milliliters of nitric acid.

$$0.2352\text{ g }K_2HPO_4 \times \frac{1\text{ mol }K_2HPO_4}{174.20\text{ g}} \times \frac{2\text{ mol }HNO_3}{1\text{ mol }K_2HPO_4} \times \frac{1\text{ L}}{0.08892\text{ mol }HNO_3} = 30.37\text{ mL}$$

All these steps can be combined into a single calculation:

$$\frac{0.2352\text{ g }K_2HPO_4}{1} \times \frac{1\text{ mol }K_2HPO_4}{174.20\text{ g}} \times \frac{2\text{ mol }NHO_3}{1\text{ mol }K_2HPO_4} \times \frac{1000\text{ mL }HNO_3}{0.08892\text{ mol }HNO_3} = 30.37\text{ mL }HNO_3$$

Question 26-12.

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

Question 26-13.

What volume of a 0.00945-*M* solution of potassium hydroxide would be required to titrate 50.00 mL of a sample of acid rain with a H_2SO_4concentration of 1.23×10^{-4} *M*.

$$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$$

Solution

$$\text{mass KOH} \longrightarrow \text{mol KOH} \longrightarrow \text{mol }H_2SO_4 \longrightarrow \text{M }H_2SO_4 \longrightarrow \text{volume }H_2SO_4$$

$$\text{mol KOH} = 24.74 \cancel{\text{g}}\text{ KOH} \times \frac{1 \cancel{\text{mol KOH}}}{39.0983 \cancel{\text{g}}} \times \frac{1\text{ mol }H_2SO_4}{2 \cancel{\text{mol KOH}}} = 0.031638\text{ mol}$$

$$\text{volume }H_2SO_4 = \frac{0.031638\text{ mol}}{0.3446\text{ M}} = 0.09181\text{ L}$$

Question 26-14.

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?

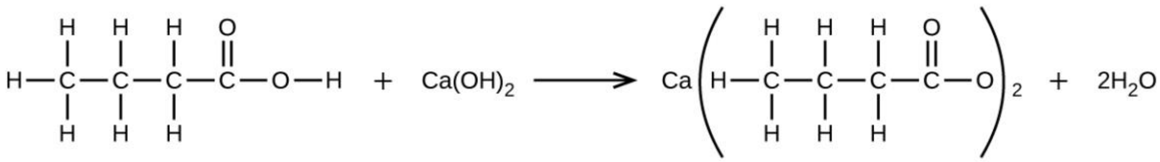
Solution

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

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

Question 26-15.

What mass of $Ca(OH)_2$ will react with 25.0 g of propionic acid to form the preservative calcium propionate according to the equation?



Solution

Determine the molar mass of $Ca(OH)_2$ and propionic acid.

Molar mass of $Ca(OH)_2$ = 74.093 g/mol

Molar mass of propionic acid = 88.106 g/mol

$$\text{mass of Ca(OH)}_2 = 25.0\ \cancel{\text{g P.A.}} \times \frac{1\ \cancel{\text{mol P.A.}}}{88.106\ \cancel{\text{g P.A.}}} \times \frac{1\ \cancel{\text{mol Ca(OH)}_2}}{\cancel{\text{mol P.A.}}} \times \frac{74.093\ \text{g}}{\cancel{\text{mol Ca(OH)}_2}}$$

$$= 21.0\ \text{g}$$

Question 26-16.

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

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

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

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

Question 26-17.

Potassium hydrogen phthalate, $KHC_8H_4O_4$, or KHP, is used in many laboratories, including general chemistry laboratories, to standardize solutions of base. KHP is one of only a few stable solid acids that can be dried by warming and weighed. A 0.3420-g sample of $KHC_8H_4O_4$ reacts with 35.73 mL of a NaOH solution in a titration. What is the molar concentration of the NaOH?

$$KHC_8H_4O_4(aq) + NaOH(aq) \longrightarrow KNaC_8H_4O_4(aq) + H_2O(aq)$$

Solution

$$\text{mass KHP} \longrightarrow \text{mol KHP} \longrightarrow \text{mol NaOH} \longrightarrow \text{Concentration of NaOH}$$

$$0.3420\ \cancel{\text{g KHP}} \times \frac{1\ \cancel{\text{mol KHP}}}{204.223\ \cancel{\text{g KHP}}} \times \frac{1\ \text{mol NaOH}}{1\ \cancel{\text{mol KHP}}} \times \frac{1}{0.03573\ \text{L}} = 4.687 \times 10^{-2}\ M$$

Question 26-18.

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:

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

For Cl:

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

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.