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Some of the answers below may differ in format but have the same value as your result. Please check with your instructor if a specific format is desired.

Chapter 2

2-1. Define

Answers:

(a) molar mass.

The molar mass is the mass in grams of one mole of a chemical species.

(c) millimolar mass.

The *millimolar mass* is the mass in grams of one millimole of a chemical species.

2-3. Give two examples of units derived from the fundamental base SI units.

Solution:

$$\text{The liter: } 1\text{ L} = \frac{1000\text{ mL}}{1\text{ L}} \times \frac{1\text{ cm}^3}{\text{mL}} \times \left(\frac{\text{m}}{100\text{ cm}}\right)^3 = 10^{-3}\text{ m}^3$$

$$\text{Molar concentration: } 1\text{ M} = \frac{1\text{ mol}}{\text{L}} \times \frac{\text{L}}{10^{-3}\text{ m}^3} = \frac{1\text{ mol}}{10^{-3}\text{ m}^3}$$

2-4. Simplify the following quantities using a unit with an appropriate prefix:

Solutions:

(a) 5.8×10^8 Hz.

$$5.8\times10^8\text{ Hz}\times\frac{\text{MHz}}{10^6\text{ Hz}} = 580\text{ MHz}$$

(c) 9.31×10^7 µmol.

$$9.31\times10^7\ \mu\text{mol}\times\frac{\text{mol}}{10^6\ \mu\text{mol}} = 93.1\text{ mol}$$

(e) 3.96×10^6 nm.

$$3.96\times10^6\text{ nm}\times\frac{\text{mm}}{10^6\text{ nm}} = 3.96\text{ mm}$$

2-5. Why is 1 g no longer exactly 1 mole of unified atomic mass units?

Answer:
The dalton is defined as 1/12 the mass of a neutral ^{12}C atom. With the redefinition of SI base units in 2019, the definition of the dalton remained the same. However, the definition of the mole and the kilogram changed in such a way that the molar mass unit is no longer exactly 1 g/mol.

2-7. Find the number of Na^+ ions in 2.75 g of Na_3PO_4?

Solution:

$$2.75 \text{ g } Na_3PO_4 \times \frac{1 \text{ mol } Na_3PO_4}{163.94 \text{ g}} \times \frac{3 \text{ mol } Na^+}{\text{mol } Na_3PO_4} \times \frac{6.022\times10^{23} \text{ } Na^+}{\text{mol } Na^+} = 3.03\times10^{22} \text{ } Na^+$$

2-9. Find the amount of the indicated element (in moles) in

Solutions:

(a) 5.32 g of B_2O_3.

$$5.32 \text{ g } B_2O_3 \times \frac{2 \text{ mol B}}{\text{mol } B_2O_3} \times \frac{\text{mol } B_2O_3}{69.62 \text{ g } B_2O_3} = 0.153 \text{ mol B}$$

(b) 195.7 mg of $Na_2B_4O_7 \cdot 10H_2O$.

$$195.7 \text{ mg } Na_2B_4O_7 \cdot 10H_2O \times \frac{\text{g}}{1000 \text{ mg}} \times \frac{7 \text{ mol O}}{\text{mol } Na_2B_4O_7 \cdot 10H_2O}$$

$$\times \frac{\text{mol } Na_2B_4O_7 \cdot 10H_2O}{381.37 \text{ g}} = 3.59\times10^{-3} \text{ mol O} = 3.59 \text{ mmol}$$

(c) 4.96 g of Mn_3O_4.

$$4.96 \text{ g } Mn_3O_4 \times \frac{\text{mol } Mn_3O_4}{228.81 \text{ g } Mn_3O_4} \times \frac{3 \text{ mol Mn}}{\text{mol } Mn_3O_4} = 6.50\times10^{-2} \text{ mol Mn}$$

(d) 333 mg of CaC_2O_4.

$$333 \text{ mg } CaC_2O_4 \times \frac{\text{g}}{1000 \text{ mg}} \times \frac{\text{mol } CaC_2O_4}{128.10 \text{ g } CaC_2O_4} \times \frac{2 \text{ mol C}}{\text{mol } CaC_2O_4} = 5.20\times10^{-3} \text{ mol C}$$

$$= 5.20 \text{ mmol}$$

2-11. Find the number of millimoles of solute in

Solutions:

(a) 2.00 L of 0.0449 M_{KMnO_4}.

$$\frac{0.0449 \text{ mol } KMnO_4}{\text{L}} \times \frac{1000 \text{ mmol}}{\text{mol}} \times 2.00 \text{ L} = 89.8 \text{ mmol } KMnO_4$$

(b) 750 mL of 5.35×10^{-3} M KSCN.

$$\frac{5.35\times10^{-3}\text{ M KSCN}}{\text{L}}\times\frac{1000\text{ mmol}}{\text{mol}}\times\frac{\text{L}}{1000\text{ mL}}\times750\text{ mL}=4.01\text{ mmol KSCN}$$

(c) 3.50 L of a solution that contains 6.23 ppm of $CuSO_4$.

$$\frac{6.23\text{ mg CuSO}_4}{\text{L}}\times\frac{\text{g}}{1000\text{ mg}}\times\frac{\text{mol CuSO}_4}{159.61\text{ g CuSO}_4}\times\frac{1000\text{ mmol}}{\text{mol}}\times3.50\text{ L}=0.137\text{ mmol CuSO}_4$$

(d) 250 mL of 0.414 mM KCl.

$$\frac{0.414\text{ mmol KCl}}{\text{L}}\times\frac{1\text{ L}}{1000\text{ mL}}\times250\text{ mL}=0.104\text{ mmol KCl}$$

2-13. What is the mass in milligrams of

Solutions:

(a) 0.367 mol of HNO_3?

$$0.367\text{ mol HNO}_3\times\frac{63.01\text{ g HNO}_3}{\text{mol HNO}_3}\times\frac{1000\text{ mg}}{\text{g}}=2.31\times10^{4}\text{ mg HNO}_3$$

(b) 245 mmol of MgO?

$$245\text{ mmol MgO}\times\frac{\text{mol}}{1000\text{ mmol}}\times\frac{40.30\text{ g MgO}}{\text{mol MgO}}\times\frac{1000\text{ mg}}{\text{g}}=9.87\times10^{3}\text{ mg MgO}$$

(c) 12.5 mol of NH_4NO_3?

$$12.5\text{ mol NH}_4\text{NO}_3\times\frac{80.04\text{ g NH}_4\text{NO}_3}{\text{mol NH}_4\text{NO}_3}\times\frac{1000\text{ mg}}{\text{g}}=1.00\times10^{6}\text{ mg NH}_4\text{NO}_3$$

(d) 4.95 mol of $(NH_4)_2e(NO_3)_6$ (548.23 g/mol)?

$$4.95\text{ mol (NH}_4)_2\text{Ce(NO}_3)_6\times\frac{548.23\text{ g (NH}_4)_2\text{Ce(NO}_3)_6}{\text{mol (NH}_4)_2\text{Ce(NO}_3)_6}\times\frac{1000\text{ mg}}{\text{g}}$$
$$=2.71\times10^{6}\text{ mg (NH}_4)_2\text{Ce(NO}_3)_6$$

2-15. What is the mass in milligrams of solute in

Solutions:

(a) 16.0 mL of 0.350 M sucrose (342 g/mol)?

$$\frac{0.350\text{ mol sucrose}}{\text{L}}\times\frac{\text{L}}{1000\text{ mL}}\times\frac{342\text{ g sucrose}}{\text{mol sucrose}}\times\frac{1000\text{ mg}}{\text{g}}$$
$$\times16.0\text{ mL}=1.92\times10^{3}\text{ mg sucrose}$$

(b) 1.92 L of 3.76×10^{-3} M H_2O_2 ?

$$\frac{3.76\times10^{-3}\ \text{mol}\ H_2O_2}{\text{L}}\times\frac{34.02\ \text{g}\ H_2O_2}{\text{mol}\ H_2O_2}\times\frac{1000\ \text{mg}}{\text{g}}\times1.92\ \text{L}=246\ \text{mg}\ H_2O_2$$

2-16. What is the mass in grams of solute in

Solutions:

(a) 250 mL of 0.264 M H_2O_2 ?

$$\frac{0.264\ \text{mol}\ H_2O_2}{\text{L}}\times\frac{\text{L}}{1000\ \text{mL}}\times\frac{34.02\ \text{g}\ H_2O_2}{\text{mol}\ H_2O_2}\times250\ \text{mL}=2.25\ \text{g}\ H_2O_2$$

(b) 37.0 mL of 5.75×10^{-4} M benzoic acid (122 g/mol)?

$$\frac{5.75\times10^{-4}\ \text{mol benzoic acid}}{\text{L}}\times\frac{\text{L}}{1000\ \text{mL}}\times\frac{122\ \text{g benzoic acid}}{\text{mol benzoic acid}}$$
$$\times\ 37.0\ \text{mL}=2.60\times10^{-3}\ \text{g benzoic acid}$$

2-17. Calculate the p-value for each of the listed ions in the following:

Solutions:

(a) Na^+, Cl^-, and OH^- in a solution that is 0.0635 M in NaCl and 0.0403 M in NaOH.

$$\text{pNa}=-\log(0.0635+0.0403)=-\log(0.1038)=0.9838$$
$$\text{pCl}=-\log(0.0635)=1.197$$
$$\text{pOH}=-\log(0.0403)=1.395$$

(c) H^+, Cl^-, and Zn^{2+} in a solution that is 0.400 M in HCl and 0.100 M in $ZnCl_2$.

$$\text{pH}=-\log(0.400)=0.398$$
$$\text{pCl}=-\log(0.400+2\times0.100)=-\log(0.600)=0.222$$
$$\text{pZn}=-\log(0.100)=1.00$$

(e) K^+, OH^-, and $Fe(CN)_6^{\ 4-}$ in a solution that is 1.62×10^{-7} M in $K_4Fe(CN)_6$ and 5.12×10^{-7} M in KOH.

$$\text{pK}=-\log(4\times1.62\times10^{-7}+5.12\times10^{-7})=-\log(1.16\times10^{-6})=5.94$$
$$\text{pOH}=-\log(5.12\times10^{-7})=6.291$$
$$\text{pFe(CN)}_6=-\log(1.62\times10^{-7})=6.790$$

2-18. Calculate the molar H_3O^+ ion concentration of a solution that has a pH of

Solutions:

(a) 3.73.

pH = 3.73, $\log[H_3O^+] = -3.73$, $[H_3O^+] = 1.9 \times 10^{-4}$ M
as in part (a)

(c) 0.59.

$[H_3O^+] = 0.26$ M

(e) 7.62.

$[H_3O^+] = 2.4 \times 10^{-8}$ M

(g) −0.76.

$[H_3O^+] = 5.8$ M

2-19. Calculate the p-functions for each ion in a solution that is

Solutions:

(a) 0.0200 M in NaBr.

pNa = pBr = –log(0.0200) = 1.699

(c) 4.5×10^{-3} M in $Ba(OH)_2$.

pBa = $-\log(4.5 \times 10^{-3}) = 2.35$; pOH = $-\log(2 \times 4.5 \times 10^{-3}) = 2.05$

(e) 7.2×10^{-3} M in $CaCl_2$ and 8.2×10^{-3} M in $BaCl_2$.

pCa = $-\log(7.2 \times 10^{-3}) = 2.14$; pBa = $-\log(8.2 \times 10^{-3}) = 2.09$
pCl = $-\log(2 \times 7.2 \times 10^{-3} + 2 \times 8.2 \times 10^{-3}) = -\log(0.0308) = 1.51$

2-20. Convert the following p-functions to molar concentrations:

Solutions:

(a) pH = 1.102.

pH = 1.102; $\log[H_3O^+] = -1.102$; $[H_3O^+] = 0.0791$ M

(c) pBr = 7.77.

pBr = 7.77; $\log[Br^-] = -7.77$; $[Br^-] = 1.70 \times 10^{-8}$ M

(e) pLi = 12.35.

pLi = 12.35; $\log[Li^+] = -12.35$; $[Li^+] = 4.5 \times 10^{-13}$ M

(g) pMn = 0.135.

pMn = 0.135; log[Mn^{2+}] = −0.135; [Mn^{2+}] = 0.733 M

2-21. Seawater contains an average of 1.08×10^3 ppm of Na^+ and 270 ppm of SO_4^{2-}. Calculate

Solutions:

(a) the molar concentrations of Na^+ and SO_4^{2-} given that the average density of seawater is 1.02 g/mL.

$$1.08\times10^3\ \text{ppm}\ \ Na^+ \times \frac{1}{10^6\ \text{ppm}} \times \frac{1.02\ \text{g}}{\text{mL}} \times \frac{1000\ \text{mL}}{\text{L}} \times \frac{\text{mol Na}^+}{22.99\ \text{g}} = 4.79\times10^{-2}\ \text{M Na}^+$$

$$270\ \text{ppm}\ SO_4^{2-} \times \frac{1}{10^6\ \text{ppm}} \times \frac{1.02\ \text{g}}{\text{mL}} \times \frac{1000\ \text{mL}}{\text{L}} \times \frac{\text{mol } SO_4^{2-}}{96.06\ \text{g}} = 2.87\times10^{-3}\ \text{M } SO_4^{2-}$$

(b) the pNa and pSO_4 for seawater.

$$\text{pNa} = -\log(4.79\times10^{-2}) = 1.320$$

$$pSO_4 = -\log(2.87\times10^{-3}) = 2.543$$

2-23. A solution was prepared by dissolving 5.76 g of $KCl \cdot MgCl_2 \cdot 6H_2O$ (277.85 g/mol) in sufficient water to give 2.000 L. Calculate

Solutions:

(a) the molar analytical concentration of $KCl \cdot MgCl_2$ in this solution.

$$\frac{5.76\ \text{g KCl}\cdot MgCl_2\cdot 6H_2O}{2.00\ \text{L}} \times \frac{\text{mol KCl}\cdot MgCl_2\cdot 6H_2O}{277.85\ \text{g}} = 1.04\times10^{-2}\ \text{M KCl}\cdot MgCl_2\cdot 6H_2O$$

(b) the molar concentration of Mg^{2+}.

There is 1 mole of Mg^{2+} per mole of $KCl \cdot MgCl_2$, so the molar concentration of Mg^{2+} is the same as the molar concentration of $KCl \cdot MgCl_2$ or 1.04×10^{-2} M.

(c) the molar concentration of Cl^-.

$$1.04\times10^{-2}\ \text{M KCl}\cdot MgCl_2\cdot 6H_2O \times \frac{3\ \text{mol Cl}^-}{\text{mol KCl}\cdot MgCl_2\cdot 6H_2O} = 3.12\times10^{-2}\ \text{M Cl}^-$$

(d) the weight/volume percentage of $KCl \cdot MgCl_2 \cdot 6H_2O$.

$$\frac{5.76\ \text{g KCl}\cdot MgCl_2\cdot 6H_2O}{2.00\ \text{L}} \times \frac{\text{L}}{1000\ \text{mL}} \times 100\% = 0.288\%\ (\text{w/v})$$

(e) the number of millimoles of Cl^- in 25.0 mL of this solution.

$$\frac{3.12\times10^{-2}\ \text{mol Cl}^-}{\text{L}} \times \frac{\text{L}}{1000\ \text{mL}} \times \frac{1000\ \text{mmol}}{\text{mol}} \times 25\ \text{mL} = 7.8\times10^{-1}\ \text{mmol Cl}^-$$

(f) ppm K^+.

$$1.04\times10^{-2}\ \text{M KCl}\cdot\text{MgCl}_2\cdot6\text{H}_2\text{O}\times\frac{1\ \text{mol K}^+}{1\text{mol KCl}\cdot\text{MgCl}_2\cdot6\text{H}_2\text{O}}\times\frac{39.10\ \text{g K}^+}{\text{mol K}^+}\times\frac{1000\ \text{mg}}{\text{g}}$$

$$=\frac{407\ \text{mg}}{\text{L}}=407\ \text{ppm K}^+$$

(g) pMg for the solution.

$$\text{pMg} = -\log(1.04\times10^{-2}) = 1.983$$

(h) pCl for the solution.

$$\text{pCl} = -\log(3.12\times10^{-2}) = 1.506$$

2-25. A 5.85% (w/w) $Fe(NO_3)_3$ (241.86 g/mol) solution has a density of 1.059 g/mL. Calculate

Solutions:

(a) the molar analytical concentration of $Fe(NO_3)_3$ in this solution.

$$5.85\%\ \text{Fe(NO}_3)_3=\frac{5.85\ \text{g Fe(NO}_3)_3}{\text{g solution}}\times\frac{1}{100}\times\frac{1.059\ \text{g}}{\text{mL}}\times\frac{1000\ \text{mL}}{\text{L}}\times\frac{\text{mol Fe(NO}_3)_3}{241.86\ \text{g}}$$

$$=2.56\times10^{-1}\ \text{M Fe(NO}_3)_3=0.256\ \text{M}$$

(b) the molar NO_3^- concentration in the solution.

$$2.56\times10^{-1}\ \text{M}\ \ \text{Fe(NO}_3)_3=\frac{2.56\times10^{-1}\ \text{mol Fe(NO}_3)_3}{\text{L}}\times\frac{3\ \text{mol NO}_3^-}{\text{mol Fe(NO}_3)_3}=7.68\times10^{-1}\ \text{M NO}_3^-$$

(c) the mass in grams of $Fe(NO_3)_3$ contained in each liter of this solution.

$$\frac{2.56\times10^{-1}\ \text{mol Fe(NO}_3)_3}{\text{L}}\times\frac{241.86\ \text{g Fe(NO}_3)_3}{\text{mol}}\times\text{L}=6.20\times10^{1}\ \text{g Fe(NO}_3)_3=62.0\ \text{g}$$

2-27. Describe the preparation of

Solutions:

(a) 500 mL of 5.25% (w/v) aqueous ethanol (C_2H_5OH, 46.1 g/mol).

$$\frac{5.25\ \text{g C}_2\text{H}_5\text{OH}}{\text{mL soln}}\times\frac{1}{100}\times500\ \text{mL soln}=26.3\ \text{g C}_2\text{H}_5\text{OH}$$

Weigh 26.3 g ethanol and add enough water to give a final volume of 500 mL.

(b) 500 g of 5.25% (w/w) aqueous ethanol.

$$5.25\%\ \text{(w/w) C}_2\text{H}_5\text{OH}=\frac{5.25\ \text{g C}_2\text{H}_5\text{OH}}{\text{g soln}}\times\frac{1}{100}\times500\ \text{g soln}=2.63\times10^{1}\ \text{g C}_2\text{H}_5\text{OH}$$

$$500\ \text{g soln}=26.3\ \text{g C}_2\text{H}_5\text{OH}+x\ \text{g water}$$

$$x \text{ g water} = 500 \text{ g soln} - 26.3 \text{ g } C_2H_5OH = 473.7 \text{ g water}$$

Mix 26.3 g ethanol with 473.7 g water.

(c) 500 mL of 5.25% (v/v) aqueous ethanol.

$$5.25\% \text{ (v/v) } C_2H_5OH = \frac{5.25 \text{ mL } C_2H_5OH}{100 \text{ mL soln}}$$

$$\frac{5.25 \text{ mL } C_2H_5OH}{100 \text{ mL soln}} \times 500 \text{ mL soln} = 26.3 \text{ mL } C_2H_5OH$$

Dilute 26.3 mL ethanol with enough water to give a final volume of 500 mL.

2-29. Describe the preparation of 500 mL of 3.00 M H_3PO_4 from the commercial reagent that is 86% H_3PO_4 (w/w) and has a specific gravity of 1.71.

Solution:

$$\frac{3.00 \text{ mol } H_3PO_4}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 500 \text{ mL} = 1.50 \text{ mol } H_3PO_4$$

$$\frac{86 \text{ g } H_3PO_4}{\text{g reagent}} \times \frac{1}{100} \times \frac{1.71 \text{ g reagent}}{\text{g water}} \times \frac{\text{g water}}{\text{mL}} \times \frac{1000 \text{ mL}}{\text{L}} \times \frac{\text{mol } H_3PO_4}{98.0 \text{ g}} = \frac{1.50 \times 10^{1} \text{ mol } H_3PO_4}{\text{L}}$$

$$\text{volume 86\% (w/w) } H_3PO_4 \text{ required} = 1.50 \text{ mol } H_3PO_4 \times \frac{\text{L}}{1.50 \times 10^{1} \text{ mol } H_3PO_4}$$

$$= 1.00 \times 10^{-1} \text{ L}$$

Dilute 100 mL to 500 mL with water.

2-31. Describe the preparation of

Solutions:

(a) 500 mL of 0.1000 M $AgNO_3$ from the solid reagent.

$$0.1000 \text{ M } AgNO_3 = \frac{0.1000 \text{ mol } AgNO_3}{\text{L}}$$

$$= \frac{0.1000 \text{ mol } AgNO_3}{\text{L}} \times \frac{169.87 \text{ g } AgNO_3}{\text{mol}} \times \frac{\text{L}}{1000 \text{ mL}} \times 500 \text{ mL}$$

$$= 8.49 \text{ g } AgNO_3$$

Dissolve 8.49 g $AgNO_3$ in enough water to give a final volume of 500 mL.

(b) 1.00 L of 0.1000 M HCl, starting with a 6.00 M solution of the reagent.

$$\frac{0.1000 \text{ mol HCl}}{\text{L}} \times 1 \text{ L} = 0.1000 \text{ mol HCl}$$

$$0.1000 \text{ mol HCl} \times \frac{\text{L}}{6.00 \text{ mol HCl}} = 1.67 \times 10^{-2} \text{ L HCl}$$

Take 167 mL of the 6.00 M HCl and dilute to 1.00 L using water.

(c) 250 mL of a solution that is 0.0810 M in K^+, starting with solid $K_4Fe(CN)_6$.

$$\frac{0.0810\text{ mol K}^+}{\text{L}}\times\frac{\text{L}}{1000\text{ mL}}\times 250\text{ mL} = 2.025\times10^{-2}\text{ mol K}^+$$

$$2.025\times10^{-2}\text{ mol K}^+\times\frac{\text{mol K}_4\text{Fe(CN)}_6}{4\text{ mol K}^+}\times\frac{368.35\text{ g K}_4\text{Fe(CN)}_6}{\text{mol}} = 1.86\text{ g K}_4\text{Fe(CN)}_6$$

Dissolve 1.86 g $K_4Fe(CN)_6$ in enough water to give a final volume of 250 mL.

(d) 500 mL of 3.00% (w/v) aqueous $BaCl_2$ from a 0.400 M $BaCl_2$ solution.

$$\frac{3.00\text{ g BaCl}_2}{\text{mL soln}}\times\frac{1}{100}\times 500\text{ mL} = 1.5\times10^{1}\text{ g BaCl}_2$$

$$1.5\times10^{1}\text{ g BaCl}_2\times\frac{\text{mol BaCl}_2}{208.23\text{ g}}\times\frac{\text{L}}{0.400\text{ mol BaCl}_2} = 1.80\times10^{-1}\text{ L}$$

Take 180 mL of the 0.400 M $BaCl_2$ solution and dilute to 500 mL using water.

(e) 2.00 L of 0.120 M $HClO_4$ from the commercial reagent [71.0% $HClO_4$ (w/w), sp gr 1.67].

$$\frac{0.120\text{ mol HClO}_4}{\text{L}}\times 2.00\text{ L} = 0.240\text{ mol HClO}_4$$

$$\frac{71\text{ g HClO}_4}{100\text{ g reagent}}\times\frac{1.67\text{ g reagent}}{\text{g water}}\times\frac{\text{g water}}{\text{mL}}\times\frac{1000\text{ mL}}{\text{L}}\times\frac{\text{mol HClO}_4}{100.46\text{ g}} = \frac{1.18\times10^{1}\text{ mol HClO}_4}{\text{L}}$$

$$\text{volume 71\% (w/w) HClO}_4\text{ required} = 0.240\text{ mol HClO}_4 = \frac{\text{L}}{1.18\times10^{1}\text{ mol HClO}_4}$$

$$= 2.03\times10^{-2}\text{ L}$$

Take 20.3 mL of the concentrated reagent and dilute to 2.00 L using water.

(f) 1.00 L of a solution that is 60.0 ppm in Na^+, starting with solid Na_2SO_4.

$$60\text{ ppm Na}^+ = \frac{60\text{ mg Na}^+}{\text{L soln}}$$

$$\frac{60\text{ mg Na}^+}{\text{L soln}}\times 1.00\text{ L} = 60\text{ mg Na}^+$$

$$60\text{ mg Na}^+\times\frac{\text{g}}{1000\text{ mg}}\times\frac{\text{mol Na}^+}{22.99\text{ g}} = 2.61\times10^{-3}\text{ mol Na}^+$$

$$2.61\times10^{-3}\text{ mol Na}^+\times\frac{\text{mol Na}_2\text{SO}_4}{2\text{ mol Na}^+}\times\frac{142.04\text{ g Na}_2\text{SO}_4}{\text{mol}} = 0.19\text{ g Na}_2\text{SO}_4$$

Dissolve 0.19 g Na_2SO_4 in enough water to give a final volume of 1.00 L.

2-33. What mass of solid $La(IO_3)_3$ (663.6 g/mol) is formed when 50.0 mL of 0.250 M La^{3+} is mixed with 75.0 mL of 0.302 M IO_3^-?

Solution:

$$\frac{0.250\ \text{mol}\ La^{3+}}{\text{L}}\times\frac{\text{L}}{1000\ \text{mL}}\times 50.0\ \text{mL} = 1.25\times10^{-2}\ \text{mol}\ La^{3+}$$

$$0.302\ \text{M}\ IO_3^- = \frac{0.302\ \text{mol}\ IO_3^-}{\text{L}}\times\frac{\text{L}}{1000\ \text{mL}}\times 75.0\ \text{mL} = 2.27\times10^{-2}\ \text{mol}\ IO_3^-$$

Because each mole of $La(IO_3)_3$ requires three moles IO_3^-, IO_3^- is the limiting reagent. Thus,

$$2.27\times10^{-2}\ \text{mol}\ IO_3^-\times\frac{\text{mol}\ La(IO_3)_3}{3\ \text{mol}\ IO_3^-}\times\frac{663.6\ \text{g}\ La(IO_3)_3}{\text{mol}} = 5.01\ \text{g}\ La(IO_3)_3\ \text{formed}$$

2-35. Exactly 0.118 g of pure Na_2CO_3 is dissolved in 100.0 mL of 0.0731 M HCl.

Solutions:

(a) What mass in grams of CO_2 is evolved?

A balanced chemical equation can be written as:
$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2(g)$$

$$0.1180\ \text{g}\ Na_2CO_3\times\frac{\text{mol}\ Na_2CO_3}{105.99\ \text{g}} = 1.113\times10^{-3}\ \text{mol}\ Na_2CO_3$$

$$\frac{0.0731\ \text{mol}\ HCl}{\text{L}}\times\frac{\text{L}}{1000\ \text{mL}}\times 100.0\ \text{mL} = 7.31\times10^{-3}\ \text{mol}\ HCl$$

Because one mole of CO_2 is evolved for every mole Na_2CO_3 reacted, Na_2CO_3 is the limiting reagent. Thus,

$$1.113\times10^{-3}\ \text{mol}\ Na_2CO_3\times\frac{\text{mol}\ CO_2}{\text{mol}\ Na_2CO_3}\times\frac{44.00\ \text{g}\ CO_2}{\text{mol}} = 4.897\times10^{-2}\ \text{g}\ CO_2\ \text{evolved}$$

(b) What is the molar concentration of the excess reactant (HCl or Na_2CO_3)?

$$\text{amnt HCl left} = 7.31\times10^{-3}\ \text{mol} - (2\times1.113\times10^{-3}\ \text{mol}) = 5.08\times10^{-3}\ \text{mol}$$

$$\frac{5.08\times10^{-3}\ \text{mol HCl}}{100.0\ \text{mL}}\times\frac{1000\ \text{mL}}{\text{L}} = 5.08\times10^{-2}\ \text{M HCl}$$

2-37. Exactly 75.00 mL of a 0.3132 M solution of Na_2SO_3 is treated with 150.0 mL of 0.4025 M $HClO_4$ and boiled to remove the SO_2 formed.

Solutions:

(a) What is the mass in grams of SO_2 that is evolved?

A balanced chemical equation can be written as:

$Na_2SO_3 + 2HClO_4 \rightarrow 2NaClO_4 + H_2O + SO_2(g)$

$$0.3132\text{ M Na}_2\text{SO}_3 = \frac{0.3132\text{ mol Na}_2\text{SO}_3}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times 75\text{ mL} = 2.3\times10^{-2}\text{ mol Na}_2\text{SO}_3$$

$$0.4025\text{ M HClO}_4 = \frac{0.4025\text{ mol HClO}_4}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times 150.0\text{ mL}$$
$$= 6.038\times10^{-2}\text{ mol HClO}_4$$

Because one mole SO_2 is evolved per mole Na_2SO_3, Na_2SO_3 is the limiting reagent. Thus,

$$2.3\times10^{-2}\text{ mol Na}_2\text{SO}_3 \times \frac{\text{mol SO}_2}{\text{mol Na}_2\text{SO}_3} \times \frac{64.06\text{ g SO}_2}{\text{mol}} = 1.5\text{ g SO}_2\text{ evolved}$$

(b) What is the concentration of the unreacted reagent (Na_2SO_3 or $HClO_4$) after the reaction is complete?

$$\text{mol HClO}_4\text{ unreacted} = 6.038\times10^{-2}\text{ mol} - (2\times2.3\times10^{-2}) = 1.4\times10^{-2}\text{ mol}$$

$$\frac{1.4\times10^{-2}\text{ mol HClO}_4}{225\text{ mL}} \times \frac{1000\text{ mL}}{\text{L}} = 6.4\times10^{-2}\text{ M HClO}_4 = 0.064\text{ M}$$

2-39. What volume of 0.01000 M $AgNO_3$ is required to precipitate all of the I^- in 150 mL of a solution that contains 22.50 ppt KI?

Solution:
A balanced chemical equation can be written as:

$AgNO_3 + KI \rightarrow AgI(s) + KNO_3$

$$22.50\text{ ppt KI} \times \frac{1}{10^3\text{ ppt}} \times \frac{\text{g}}{\text{mL}} \times 150\text{ mL} \times \frac{\text{mol KI}}{166.0\text{ g}} = 2.03\times10^{-2}\text{ mol KI}$$

$$2.03\times10^{-2}\text{ mol KI} \times \frac{\text{mol AgNO}_3}{\text{mol KI}} \times \frac{\text{L}}{0.0100\text{ mol AgNO}_3} = 2.03\text{ L AgNO}_3$$

2.03 L of 0.0100 M $AgNO_3$ would be required to precipitate I^- as AgI.

Solution and Answer Guide

Solution and Answer Guide: Skoog et al., *Fundamentals of Analytical Chemistry*, 10e, © 2022, 978-0-357-45039-0, Chapter 2: Calculations Used in Analytical Chemistry

Chapter 2

2-1. Define

Answers:

***(a)** molar mass.

The molar mass is the mass in grams of one mole of a chemical species.

(b) millimole.

The *millimole* is an amount of a chemical species, such as an atom, an ion, a molecule or an electron. There are

$$6.02\times10^{23}\,\frac{\text{particles}}{\text{mole}}\times10^{-3}\,\frac{\text{mole}}{\text{millimole}}=6.02\times10^{20}\,\frac{\text{particles}}{\text{millimole}}$$

***(c)** millimolar mass.

The *millimolar mass* is the mass in grams of one millimole of a chemical species.

(d) parts per billion.

Parts per billion, c_{ppb}, is a term expressing the concentration of dilute solutions.

Thus,

$$c_{ppb}=\frac{\text{mass of solute}}{\text{mass of solution}}\times10^{9}\ \text{ppb}$$

The units of mass in the numerator and the denominator must be the same.

2-2. What is the difference between molar species concentration and molar analytical concentration?

Answer:
The molar species concentration is number of moles of that species contained in one liter of solution. The molar analytical concentration is the total number of moles of a solute in 1 liter of the solution, regardless of the solute's chemical state.

*Answers and solutions are provided in the Student Solutions Manual for questions and problems marked with an asterisk.

***2-3.** Give two examples of units derived from the fundamental base SI units.

Solution:

The liter: $1\ \text{L} = \dfrac{1000\ \text{mL}}{1\ \text{L}} \times \dfrac{1\ \text{cm}^3}{\text{mL}} \times \left(\dfrac{\text{m}}{100\ \text{cm}}\right)^3 = 10^{-3}\ \text{m}^3$

Molar concentration: $1\ \text{M} = \dfrac{1\ \text{mol}}{\text{L}} \times \dfrac{\text{L}}{10^{-3}\ \text{m}^3} = \dfrac{1\ \text{mol}}{10^{-3}\ \text{m}^3}$

2-4. Simplify the following quantities using a unit with an appropriate prefix:

Solutions:

***(a)** 5.8×10^8 Hz.

$$5.8\times10^{8}\ \text{Hz}\times\frac{\text{MHz}}{10^{6}\ \text{Hz}} = 580\ \text{MHz}$$

(b) 4.37×10^{-7} g

$$4.37\times10^{-7}\ \text{g}\times\frac{10^{9}\ \text{ng}}{\text{g}} = 437\ \text{ng}$$

***(c)** 9.31×10^7 µmol.

$$9.31\times10^{7}\ \mu\text{mol}\times\frac{\text{mol}}{10^{6}\ \mu\text{mol}} = 93.1\ \text{mol}$$

(d) 8.3×10^{10} s.

$$8.3\times10^{10}\ \text{s}\times\frac{\text{Gs}}{10^{9}\ \text{s}} = 83\ \text{Gs}$$

***(e)** 3.96×10^{6} nm.

$$3.96\times10^{6}\ \text{nm}\times\frac{\text{mm}}{10^{6}\ \text{nm}} = 3.96\ \text{mm}$$

(f) 53,000 g.

$$53{,}000\ \text{g}\times\frac{\text{kg}}{1000\ \text{g}} = 53\ \text{kg}$$

***2-5.** Why is 1 g no longer exactly 1 mole of unified atomic mass units?

Answer:
The dalton is defined as 1/12 the mass of a neutral ^{12}C atom. With the redefinition of SI base units in 2019, the definition of the dalton remained the same. However, the definition of the mole and the kilogram changed in such a way that the molar mass unit is no longer exactly 1 g/mol.

2-6. How did the definition of the mole change with the 2019 redefinition of SI base units?

Answer:
Avogadro's constant is now an exact number, $6.02214076 \times 10^{23}$. One mole contains exactly that number of elementary entities, atoms, molecules, ions electrons, etc. In the earlier definition one mole was the mass in grams of Avogadro's number of entities.

***2-7.** Find the number of Na^+ ions in 2.75 g of Na_3PO_4?

Solution:

$$2.75\text{ g Na}_3\text{PO}_4 \times \frac{1\text{ mol Na}_3\text{PO}_4}{163.94\text{ g}} \times \frac{3\text{ mol Na}^+}{\text{mol Na}_3\text{PO}_4} \times \frac{6.022\times10^{23}\text{ Na}^+}{\text{mol Na}^+} = 3.03\times10^{22}\text{ Na}^+$$

2-8. Find the number of K^+ ions in 1.43 mol of K_2HPO_4?

Solution:

$$1.43\text{ mol K}_2\text{HPO}_4 \times \frac{2\text{ mol K}^+}{\text{mol K}_2\text{HPO}_4} \times \frac{6.022\times10^{23}\text{ K}^+}{\text{mol K}^+} = 1.72\times10^{24}\text{ K}^+$$

***2-9.** Find the amount of the indicated element (in moles) in

Solutions:

(a) 5.32 g of B_2O_3.

$$5.32\text{ g B}_2\text{O}_3 \times \frac{2\text{ mol B}}{\text{mol B}_2\text{O}_3} \times \frac{\text{mol B}_2\text{O}_3}{69.62\text{ g B}_2\text{O}_3} = 0.153\text{ mol B}$$

(b) 195.7 mg of $Na_2B_4O_7 \cdot 10H_2O$.

$$195.7\text{ mg Na}_2\text{B}_4\text{O}_7\cdot10\text{H}_2\text{O} \times \frac{\text{g}}{1000\text{ mg}} \times \frac{7\text{ mol O}}{\text{mol Na}_2\text{B}_4\text{O}_7\cdot10\text{H}_2\text{O}}$$
$$\times \frac{\text{mol Na}_2\text{B}_4\text{O}_7\cdot10\text{H}_2\text{O}}{381.37\text{ g}} = 3.59\times10^{-3}\text{ mol O} = 3.59\text{ mmol}$$

(c) 4.96 g of Mn_3O_4.

$$4.96\text{ g Mn}_3\text{O}_4 \times \frac{\text{mol Mn}_3\text{O}_4}{228.81\text{ g Mn}_3\text{O}_4} \times \frac{3\text{ mol Mn}}{\text{mol Mn}_3\text{O}_4} = 6.50\times10^{-2}\text{ mol Mn}$$

(d) 333 mg of CaC_2O_4.

$$333\text{ mg CaC}_2\text{O}_4 \times \frac{\text{g}}{1000\text{ mg}} \times \frac{\text{mol CaC}_2\text{O}_4}{128.10\text{ g CaC}_2\text{O}_4} \times \frac{2\text{ mol C}}{\text{mol CaC}_2\text{O}_4} = 5.20\times10^{-3}\text{ mol C}$$
$$= 5.20\text{ mmol}$$

2-10. Find the amount in millimoles of the indicated species in

Solutions:

(a) 12.92 g of $NaHCO_3$.

$$12.92\text{ g NaHCO}_3 \times \frac{\text{mol NaHCO}_3}{84.01\text{ g NaHCO}_3} \times \frac{1000\text{ mmol}}{\text{mol}} \times \frac{3\text{ mol O}}{\text{mol NaHCO}_3} = 461.4\text{ mmol O}$$

(b) 57 mg of $MgNH_4PO_4$.

$$57\text{ mg MgNH}_4\text{PO}_4 \times \frac{\text{g}}{1000\text{ mg}} \times \frac{\text{mol MgNH}_4\text{PO}_4}{137.32\text{ g MgNH}_4\text{PO}_4} \times \frac{1000\text{ mmol}}{\text{mol}} \times \frac{1\text{ mol Mg}}{\text{mol MgNH}_4\text{PO}_4}$$
$$= 0.42\text{ mmol Mg}$$

(c) 850 mg of P_2O_5.

$$850\text{ mg P}_2\text{O}_5 \times \frac{\text{g}}{1000\text{ mg}} \times \frac{\text{mol P}_2\text{O}_5}{141.94\text{ g P}_2\text{O}_5} \times \frac{1000\text{ mmol}}{\text{mol}} \times \frac{2\text{ mol P}}{\text{mol P}_2\text{O}_5} = 11.98\text{ mmol P}$$

(d) 40.0 g of CO_2.

$$40.0\text{ g CO}_2 \times \frac{\text{mol CO}_2}{44.01\text{ g CO}_2} \times \frac{1000\text{ mmol}}{\text{mol}} \times \frac{1\text{ mol C}}{\text{mol CO}_2} = 909\text{ mmol C}$$

***2-11.** Find the number of millimoles of solute in

Solutions:

(a) 2.00 L of 0.0449 M $KMnO_4$.

$$\frac{0.0449\text{ mol KMnO}_4}{\text{L}} \times \frac{1000\text{ mmol}}{\text{mol}} \times 2.00\text{ L} = 89.8\text{ mmol KMnO}_4$$

(b) 750 mL of 5.35×10^{-3} M KSCN.

$$\frac{5.35 \times 10^{-3}\text{ M KSCN}}{\text{L}} \times \frac{1000\text{ mmol}}{\text{mol}} \times \frac{\text{L}}{1000\text{ mL}} \times 750\text{ mL} = 4.01\text{ mmol KSCN}$$

(c) 3.50 L of a solution that contains 6.23 ppm of $CuSO_4$.

$$\frac{6.23\text{ mg CuSO}_4}{\text{L}} \times \frac{\text{g}}{1000\text{ mg}} \times \frac{\text{mol CuSO}_4}{159.61\text{ g CuSO}_4} \times \frac{1000\text{ mmol}}{\text{mol}} \times 3.50\text{ L} = 0.137\text{ mmol CuSO}_4$$

(d) 250 mL of 0.414 mM KCl.

$$\frac{0.414\text{ mmol KCl}}{\text{L}} \times \frac{1\text{ L}}{1000\text{ mL}} \times 250\text{ mL} = 0.104\text{ mmol KCl}$$

2-12. Find the number of millimoles of solute in

Solutions:

(a) 386 mL of 0.210 M $HClO_4$.

$$\frac{0.210\text{ mol }HClO_4}{L}\times\frac{1000\text{ mmol}}{\text{mol}}\times\frac{L}{1000\text{ mL}}\times 386\text{ mL}=81.1\text{ mmol }HClO_4$$

(b) 25.0 L of 8.05×10^{-3} M K_2CrO_4.

$$\frac{8.05\times10^{-3}\text{ mol }K_2CrO_4}{L}\times\frac{1000\text{ mmol}}{\text{mol}}\times 25.0\text{ L}=201\text{ mmol }K_2CrO_4$$

(c) 4.50 L of an aqueous solution that contains 6.95 ppm of $AgNO_3$.

$$\frac{6.95\text{ mg }AgNO_3}{L}\times\frac{g}{1000\text{ mg}}\times\frac{\text{mol }AgNO_3}{169.87\text{ g }AgNO_3}\times\frac{1000\text{ mmol}}{\text{mol}}\times 4.50\text{ L}=0.184\text{ mmol }AgNO_3$$

(d) 537 mL of 0.0200 M KOH.

$$\frac{0.0200\text{ mol KOH}}{L}\times\frac{1000\text{ mmol}}{\text{mol}}\times\frac{L}{1000\text{ mL}}\times 537\text{ mL}=10.7\text{ mmol KOH}$$

***2-13.** What is the mass in milligrams of

Solutions:

(a) 0.367 mol of HNO_3?

$$0.367\text{ mol }HNO_3\times\frac{63.01\text{ g }HNO_3}{\text{mol }HNO_3}\times\frac{1000\text{ mg}}{g}=2.31\times10^4\text{ mg }HNO_3$$

(b) 245 mmol of MgO?

$$245\text{ mmol MgO}\times\frac{\text{mol}}{1000\text{ mmol}}\times\frac{40.30\text{ g MgO}}{\text{mol MgO}}\times\frac{1000\text{ mg}}{g}=9.87\times10^3\text{ mg MgO}$$

(c) 12.5 mol of NH_4NO_3?

$$12.5\text{ mol }NH_4NO_3\times\frac{80.04\text{ g }NH_4NO_3}{\text{mol }NH_4NO_3}\times\frac{1000\text{ mg}}{g}=1.00\times10^6\text{ mg }NH_4NO_3$$

(d) 4.95 mol of $(NH_4)_2e(NO_3)_6$ (548.23 g/mol)?

$$4.95\text{ mol }(NH_4)_2Ce(NO_3)_6\times\frac{548.23\text{ g }(NH_4)_2Ce(NO_3)_6}{\text{mol }(NH_4)_2Ce(NO_3)_6}\times\frac{1000\text{ mg}}{g}$$
$$=2.71\times10^6\text{ mg }(NH_4)_2Ce(NO_3)_6$$

2-14. What is the mass in grams of

Solutions:

(a) 2.25 mol of KBr?

$$2.25 \text{ mol KBr} \times \frac{119.0 \text{ g KBr}}{\text{mol KBr}} = 268 \text{ g KBr}$$

(b) 15.5 mmol of PbO?

$$15.5 \text{ mmol PbO} \times \frac{\text{mol}}{1000 \text{ mmol}} \times \frac{223.20 \text{ g PbO}}{\text{mol PbO}} = 3.46 \text{ g PbO}$$

(c) 5.04 mol of $CaSO_4$?

$$5.04 \text{ mol } CaSO_4 \times \frac{136.13 \text{ g } CaSO_4}{\text{mol } CaSO_4} = 686 \text{ g } CaSO_4$$

(d) 10.9 mmol of $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$?

$$10.9 \text{ mmol } Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O \times \frac{\text{mol}}{1000 \text{ mmol}} \times \frac{392.13 \text{ g } Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O}{\text{mol } Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O}$$
$$= 4.27 \text{ g } Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$$

2-15. What is the mass in milligrams of solute in

Solutions:

***(a)** 16.0 mL of 0.350 M sucrose (342 g/mol)?

$$\frac{0.350 \text{ mol sucrose}}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times \frac{342 \text{ g sucrose}}{\text{mol sucrose}} \times \frac{1000 \text{ mg}}{\text{g}}$$
$$\times 16.0 \text{ mL} = 1.92 \times 10^3 \text{ mg sucrose}$$

***(b)** 1.92 L of 3.76×10^{-3} M H_2O_2?

$$\frac{3.76 \times 10^{-3} \text{ mol } H_2O_2}{\text{L}} \times \frac{34.02 \text{ g } H_2O_2}{\text{mol } H_2O_2} \times \frac{1000 \text{ mg}}{\text{g}} \times 1.92 \text{ L} = 246 \text{ mg } H_2O_2$$

(c) 356 mL of a solution that contains 2.96 ppm of $Pb(NO_3)_2$?

$$\frac{2.96 \text{ mg } Pb(NO_3)_2}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 356 \text{ mL} = 1.05 \text{ mg } Pb(NO_3)_2$$

(d) 5.75 mL of 0.0819 M KNO_3?

$$\frac{0.0819 \text{ mol } KNO_3}{\text{L}} \times \frac{101.10 \text{ g } KNO_3}{\text{mol}} \times \frac{1000 \text{ mg}}{\text{g}} \times \frac{\text{L}}{1000 \text{ mL}} \times 5.75 \text{ mL} = 47.6 \text{ mg } KNO_3$$

2-16. What is the mass in grams of solute in

Solutions:

***(a)** 250 mL of 0.264 M H_2O_2?

$$\frac{0.264\text{ mol }H_2O_2}{L}\times\frac{L}{1000\text{ mL}}\times\frac{34.02\text{ g }H_2O_2}{\text{mol }H_2O_2}\times 250\text{ mL}=2.25\text{ g }H_2O_2$$

***(b)** 37.0 mL of 5.75×10^{-4} M benzoic acid (122 g/mol)?

$$\frac{5.75\times10^{-4}\text{ mol benzoic acid}}{L}\times\frac{L}{1000\text{ mL}}\times\frac{122\text{ g benzoic acid}}{\text{mol benzoic acid}}$$
$$\times\ 37.0\text{ mL}=2.60\times10^{-3}\text{ g benzoic acid}$$

(c) 2.50 L of a solution that contains 37.2 ppm of $SnCl_2$?

$$\frac{37.2\text{ mg }SnCl_2}{L}\times\frac{g}{1000\text{ mg}}\times 2.50\text{ L}=0.093\text{ g }SnCl_2$$

(d) 11.7 mL of 0.0225 M $KBrO_3$?

$$\frac{0.0225\text{ mol }KBrO_3}{L}\times\frac{L}{1000\text{ mL}}\times\frac{167\text{ g }KBrO_3}{\text{mol }KBrO_3}\times 11.7\text{ mL}=4.40\times10^{-2}\text{ g }KBrO_3$$

2-17. Calculate the p-value for each of the listed ions in the following:

Solutions:

***(a)** Na^+, Cl^-, and OH^- in a solution that is 0.0635 M in NaCl and 0.0403 M in NaOH.

$$pNa=-\log(0.0635+0.0403)=-\log(0.1038)=0.9838$$
$$pCl=-\log(0.0635)=1.197$$
$$pOH=-\log(0.0403)=1.395$$

(b) Ba^{2+}, Mn^{2+}, and Cl^- in a solution that is 4.65×10^{-3} M in $BaCl_2$ and 2.54 M in $MnCl_2$.

$$pBa=-\log(4.65\times10^{-3})=2.333$$
$$pMn=-\log(2.54)=-0.405$$
$$pCl=-\log(2\times4.65\times10^{-3}+2\times2.54)=-\log(5.089)=-0.707$$

***(c)** H^+, Cl^-, and Zn^{2+} in a solution that is 0.400 M in HCl and 0.100 M in $ZnCl_2$.

$$pH=-\log(0.400)=0.398$$
$$pCl=-\log(0.400+2\times0.100)=-\log(0.600)=0.222$$
$$pZn=-\log(0.100)=1.00$$

(d) Cu^{2+}, Zn^{2+}, and NO_3^- in a solution that is 5.78×10^{-2} M in $Cu(NO_3)_2$ and 0.204 M in $Zn(NO_3)_2$.

$$pCu = -\log(5.78 \times 10^{-2}) = 1.238$$

$$pZn = -\log(0.204) = 0.690$$

$$pNO_3 = -\log(2 \times 0.0578 + 2 \times 0.204) = -\log(0.5236) = 0.281$$

***(e)** K^+, OH^-, and $Fe(CN)_6^{4-}$ in a solution that is 1.62×10^{-7} M in $K_4Fe(CN)_6$ and 5.12×10^{-7} M in KOH.

$$pK = -\log(4 \times 1.62 \times 10^{-7} + 5.12 \times 10^{-7}) = -\log(1.16 \times 10^{-6}) = 5.94$$

$$pOH = -\log(5.12 \times 10^{-7}) = 6.291$$

$$pFe(CN)_6 = -\log(1.62 \times 10^{-7}) = 6.790$$

(f) H^+, Ba^{2+}, and ClO_4^- M in a solution that is 2.35×10^{-4} M in $Ba(ClO_4)_2$ and 4.75×10^{-4} M in $HClO_4$.

$$pH = -\log(4.75 \times 10^{-4}) = 3.32$$

$$pBa = -\log(2.35 \times 10^{-4}) = 3.63$$

$$pClO_4 = -\log(2 \times 2.35 \times 10^{-4} + 4.75 \times 10^{-4}) = -\log(9.45 \times 10^{-4}) = 3.02$$

2-18. Calculate the molar H_3O^+ ion concentration of a solution that has a pH of

Solutions:

***(a)** 3.73.

pH = 3.73, $\log[H_3O^+] = -3.73$, $[H_3O^+] = 1.9 \times 10^{-4}$ M
as in part (a)

(b) 3.28.

$[H_3O^+] = 5.3 \times 10^{-4}$ M

***(c)** 0.59.

$[H_3O^+] = 0.26$ M

(d) 11.29.

$[H_3O^+] = 5.1 \times 10^{-12}$ M

***(e)** 7.62.

$[H_3O^+] = 2.4 \times 10^{-8}$ M

(f) 5.19.

$[H_3O^+] = 6.5 \times 10^{-6}$ M

***(g)** −0.76.

$[H_3O^+] = 5.8$ M

(h) −0.42.

$[H_3O^+] = 2.6$ M

2-19. Calculate the p-functions for each ion in a solution that is

Solutions:

***(a)** 0.0200 M in NaBr.

pNa = pBr = –log(0.0200) = 1.699

(b) 0.0300 M in $BaBr_2$.

pBa = –log(0.0300) = 1.523; pBr = –log(2 × 0.0300) = 1.222

***(c)** 4.5×10^{-3} M in $Ba(OH)_2$.

pBa = –log(4.5×10^{-3}) = 2.35; pOH = –log($2 \times 4.5 \times 10^{-3}$) = 2.05

(d) 0.020 M in HCl and 0.010 M in NaCl.

pH = –log(0.020) = 1.70; pNa = –log(0.010) = 2.00
pCl = –log(0.020 + 0.010) = –log(0.030) = 1.52

***(e)** 7.2×10^{-3} M in $CaCl_2$ and 8.2×10^{-3} M in $BaCl_2$.

pCa = –log(7.2×10^{-3}) = 2.14; pBa = –log(8.2×10^{-3}) = 2.09
pCl = –log($2 \times 7.2 \times 10^{-3} + 2 \times 8.2 \times 10^{-3}$) = –log(0.0308) = 1.51

(f) 2.8×10^{-8} M in $Zn(NO_3)_2$ and 6.6×10^{-7} M $Cd(NO_3)_2$.

pZn = –log(2.8×10^{-8}) = 7.55; pCd = –log(6.6×10^{-7}) = 6.18
pNO_3 = –log($2 \times 2.8 \times 10^{-8} + 2 \times 6.6 \times 10^{-7}$) = 5.86

2-20. Convert the following p-functions to molar concentrations:

Solutions:

***(a)** pH = 1.102.

pH = 1.102; $\log[H_3O^+] = -1.102$; $[H_3O^+] = 0.0791$ M

(b) $pOH = 0.0057.$

$pOH = 0.0057; \log[OH^-] = -0.0057; [OH^-] = 0.99$ M

***(c)** $pBr = 7.77.$

$pBr = 7.77; \log[Br^-] = -7.77; [Br^-] = 1.70 \times 10^{-8}$ M

(d) $pCa = -0.221.$

$pCa = -0.221; \log[Ca^{2+}] = 0.221; [Ca^{2+}] = 1.66$ M

***(e)** $pLi = 12.35.$

$pLi = 12.35; \log[Li^+] = -12.35; [Li^+] = 4.5 \times 10^{-13}$ M

(f) $pNO_3 = 0.054.$

$pNO_3 = 0.054; \log[NO_3^-] = -0.054; [NO_3^-] = 0.88$ M

***(g)** $pMn = 0.135.$

$pMn = 0.135; \log[Mn^{2+}] = -0.135; [Mn^{2+}] = 0.733$ M

(h) $pCl = 8.92.$

$pCl = 8.92; \log[Cl^-] = -8.92; [Cl^-] = 1.20 \times 10^{-9}$ M

***2-21.** Seawater contains an average of 1.08×10^3 ppm of Na^+ and 270 ppm of SO_4^{2-}. Calculate

Solutions:

(a) the molar concentrations of Na^+ and SO_4^{2-} given that the average density of seawater is 1.02 g/mL.

$$1.08\times10^3 \text{ ppm } Na^+ \times \frac{1}{10^6 \text{ ppm}} \times \frac{1.02 \text{ g}}{\text{mL}} \times \frac{1000 \text{ mL}}{\text{L}} \times \frac{\text{mol } Na^+}{22.99 \text{ g}} = 4.79\times10^{-2} \text{ M } Na^+$$

$$270 \text{ ppm } SO_4^{2-} \times \frac{1}{10^6 \text{ ppm}} \times \frac{1.02 \text{ g}}{\text{mL}} \times \frac{1000 \text{ mL}}{\text{L}} \times \frac{\text{mol } SO_4^{2-}}{96.06 \text{ g}} = 2.87\times10^{-3} \text{ M } SO_4^{2-}$$

(b) the pNa and pSO_4 for seawater.

$pNa = -\log(4.79\times10^{-2}) = 1.320$

$pSO_4 = -\log(2.87\times10^{-3}) = 2.543$

2-22. Average human blood contains 300 nmoles of hemoglobin(Hb) per liter of plasma and 2.2 mmol per liter of whole blood. Calculate

Solutions:

(a) the molar concentration in each of these media.

300 nmol/L = 300×10^{-9} mol/L or 300 nM in plasma

2.2 mmol/L = 2.2×10^{-3} mol/L or 2.2 mM in whole blood

(b) pHb in plasma in human serum.

pHb in plasma = $-\log(300 \times 10^{-9}) = 6.52$

pHb in blood = $-\log(2.2 \times 10^{-3}) = 2.66$

***2-23.** A solution was prepared by dissolving 5.76 g of $KCl \cdot MgCl_2 \cdot 6H_2O$ (277.85 g/mol) in sufficient water to give 2.000 L. Calculate

Solutions:

(a) the molar analytical concentration of $KCl \cdot MgCl_2$ in this solution.

$$\frac{5.76\text{ g KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}}{2.00\text{ L}} \times \frac{\text{mol KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}}{277.85\text{ g}} = 1.04 \times 10^{-2}\text{ M KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}$$

(b) the molar concentration of Mg^{2+}.

There is 1 mole of Mg^{2+} per mole of $KCl \cdot MgCl_2$, so the molar concentration of Mg^{2+} is the same as the molar concentration of $KCl \cdot MgCl_2$ or 1.04×10^{-2} M.

(c) the molar concentration of Cl^-.

$$1.04 \times 10^{-2}\text{ M KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O} \times \frac{3\text{ mol Cl}^-}{\text{mol KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}} = 3.12 \times 10^{-2}\text{ M Cl}^-$$

(d) the weight/volume percentage of $KCl \cdot MgCl_2 \cdot 6H_2O$.

$$\frac{5.76\text{ g KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}}{2.00\text{ L}} \times \frac{\text{L}}{1000\text{ mL}} \times 100\% = 0.288\%\text{ (w/v)}$$

(e) the number of millimoles of Cl^- in 25.0 mL of this solution.

$$\frac{3.12 \times 10^{-2}\text{ mol Cl}^-}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times \frac{1000\text{ mmol}}{\text{mol}} \times 25\text{ mL} = 7.8 \times 10^{-1}\text{ mmol Cl}^-$$

(f) ppm K^+.

$$1.04 \times 10^{-2}\text{ M KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O} \times \frac{1\text{ mol K}^+}{1\text{mol KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}} \times \frac{39.10\text{ g K}^+}{\text{mol K}^+} \times \frac{1000\text{ mg}}{\text{g}}$$

$$= \frac{407\text{ mg}}{\text{L}} = 407\text{ ppm K}^+$$

(g) pMg for the solution.

$pMg = -\log(1.04 \times 10^{-2}) = 1.983$

(h) pCl for the solution.

$pCl = -\log(3.12 \times 10^{-2}) = 1.506$

2-24. A solution was prepared by dissolving 875 mg of $K_3Fe(CN)_6$ (329.2 g/mol) in sufficient water to give 750 mL. Calculate

Solutions:

(a) the molar analytical concentration of $K_3Fe(CN)_6$.

$$\frac{875\text{ mg }K_3Fe(CN)_6}{750\text{ mL}} = \frac{875\text{ g }K_3Fe(CN)_6}{750\text{ L}} \times \frac{\text{mol }K_3Fe(CN)_6}{329.2\text{ g}} = 3.54 \times 10^{-3}\text{ M }K_3Fe(CN)_6$$

(b) the molar concentration of K^+.

$$3.54 \times 10^{-3}\text{ M}K_3Fe(CN)_6 \times \frac{3\text{ mol}K^+}{\text{mol }K_3Fe(CN)_6} = 1.06 \times 10^{-2}\text{ M }K^+$$

(c) the molar concentration of $Fe(CN)_6^{3-}$.

$$3.54 \times 10^{-3}\text{ M }K_3Fe(CN)_6 \times \frac{\text{mol }Fe(CN)_6^{3-}}{\text{mol }K_3Fe(CN)_6} = 3.54 \times 10^{-3}\text{ M }Fe(CN)_6^{3-}$$

(d) the weight/volume percentage of $K_3Fe(CN)_6$.

$$\frac{875\text{ mg }K_3Fe(CN)_6}{750\text{ mL}} \times \frac{\text{g}}{1000\text{ mg}} \times 100\% = 0.117\%\text{ (w/v)}$$

(e) the number of millimoles of K^+ in 50.0 mL of this solution.

$$\frac{1.06 \times 10^{-3}\text{ mol }K^+}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times \frac{1000\text{ mmol }K^+}{\text{mol }K^+} \times 50\text{ mL} = 5.3 \times 10^{-2}\text{ mmol }K^+$$

(f) the concentration of $Fe(CN)_6^{3-}$ in ppm.

$$\frac{3.54 \times 10^{-3}\text{ mol }K_3Fe(CN)_6}{\text{L}} \times \frac{\text{mol }Fe(CN)_6^{3-}}{\text{mol }K_3Fe(CN)_6} \times \frac{211.95\text{ g }Fe(CN)_6^{3-}}{\text{mol }Fe(CN)_6^{3-}}$$
$$\times \frac{1000\text{ mg}}{\text{g}} = \frac{750\text{ mg}}{\text{L}}\ Fe(CN)_6^{3-} = 750\text{ ppm }Fe(CN)_6^{3-}$$

(g) pK for the solution.

$pK = -\log(1.06 \times 10^{-2}) = 1.975$

(h) $pFe(CN)_6$ for the solution.

$pFe(CN)_6 = -\log(3.54 \times 10^{-3}) = 2.451$

***2-25.** A 5.85% (w/w) $Fe(NO_3)_3$ (241.86 g/mol) solution has a density of 1.059 g/mL. Calculate

Solutions:

(a) the molar analytical concentration of $Fe(NO_3)_3$ in this solution.

$$5.85\%\ Fe(NO_3)_3 = \frac{5.85\text{ g }Fe(NO_3)_3}{\text{g solution}} \times \frac{1}{100} \times \frac{1.059\text{ g}}{\text{mL}} \times \frac{1000\text{ mL}}{\text{L}} \times \frac{\text{mol }Fe(NO_3)_3}{241.86\text{ g}}$$
$$= 2.56 \times 10^{-1}\text{ M }Fe(NO_3)_3 = 0.256\text{ M}$$

(b) the molar NO_3^- concentration in the solution.

$$2.56 \times 10^{-1}\text{ M } Fe(NO_3)_3 = \frac{2.56 \times 10^{-1}\text{ mol }Fe(NO_3)_3}{\text{L}} \times \frac{3\text{ mol }NO_3^-}{\text{mol }Fe(NO_3)_3} = 7.68 \times 10^{-1}\text{ M }NO_3^-$$

(c) the mass in grams of $Fe(NO_3)_3$ contained in each liter of this solution.

$$\frac{2.56 \times 10^{-1}\text{ mol }Fe(NO_3)_3}{\text{L}} \times \frac{241.86\text{ g }Fe(NO_3)_3}{\text{mol}} \times \text{L} = 6.20 \times 10^{1}\text{ g }Fe(NO_3)_3 = 62.0\text{ g}$$

2-26. A 11.4% (w/w) $NiCl_2$ (129.61 g/mol) solution has a density of 1.149 g/mL. Calculate

Solutions:

(a) the molar concentration of $NiCl_2$ in this solution.

$$11.4\%\ NiCl_2 = \frac{11.4\text{ g }NiCl_2}{\text{g solution}} \times \frac{1}{100} \times \frac{1.149\text{ g}}{\text{mL}} \times \frac{1000\text{ mL}}{\text{L}} \times \frac{\text{mol }NiCl_2}{129.61\text{ g}} = 1.01\text{ M }NiCl_2$$

(b) the molar Cl^- concentration of the solution.

$$1.01\text{ M }NiCl_2 = \frac{1.01\text{ mol }NiCl_2}{\text{L}} \times \frac{2\text{ mol }Cl^-}{\text{mol }NiCl_2} = 2.02\text{ M }Cl^-$$

(c) the mass in grams of $NiCl_2$ contained in each liter of this solution.

$$\frac{1.01\text{ mol }NiCl_2}{\text{L}} \times \frac{129.61\text{ g }NiCl_2}{\text{mol}} \times \text{L} = 131\text{ g }NiCl_2$$

***2-27.** Describe the preparation of

Solutions:

(a) 500 mL of 5.25% (w/v) aqueous ethanol (C_2H_5OH, 46.1 g/mol).

$$\frac{5.25\ \text{g}\ C_2H_5OH}{\text{mL soln}} \times \frac{1}{100} \times 500\ \text{mL soln} = 26.3\ \text{g}\ C_2H_5OH$$

Weigh 26.3 g ethanol and add enough water to give a final volume of 500 mL.

(b) 500 g of 5.25% (w/w) aqueous ethanol.

$$5.25\%\ (\text{w/w})\ C_2H_5OH = \frac{5.25\ \text{g}\ C_2H_5OH}{\text{g soln}} \times \frac{1}{100} \times 500\ \text{g soln} = 2.63 \times 10^1\ \text{g}\ C_2H_5OH$$

$$500\ \text{g soln} = 26.3\ \text{g}\ C_2H_5OH + x\ \text{g water}$$

$$x\ \text{g water} = 500\ \text{g soln} - 26.3\ \text{g}\ C_2H_5OH = 473.7\ \text{g water}$$

Mix 26.3 g ethanol with 473.7 g water.

(c) 500 mL of 5.25% (v/v) aqueous ethanol.

$$5.25\%\ (\text{v/v})\ C_2H_5OH = \frac{5.25\ \text{mL}\ C_2H_5OH}{100\ \text{mL soln}}$$

$$\frac{5.25\ \text{mL}\ C_2H_5OH}{100\ \text{mL soln}} \times 500\ \text{mL soln} = 26.3\ \text{mL}\ C_2H_5OH$$

Dilute 26.3 mL ethanol with enough water to give a final volume of 500 mL.

2-28. Describe the preparation of

Solutions:

(a) 1.50 L of 21.0% (w/v) aqueous glycerol ($C_3H_8O_3$, 92.1 g/mol).

$$\frac{21.0\ \text{g}\ C_3H_8O_3}{\text{mL soln}} \times \frac{1}{100} \times \frac{1000\ \text{mL}}{\text{L}} \times 1.50\ \text{L soln} = 3.15 \times 10^2\ \text{g}\ C_3H_8O_3$$

Weigh 315 g glycerol and add enough water to give a final volume of 1.50 L.

(b) 1.50 kg of 21.0% (w/w) aqueous glycerol.

$$21.0\%\ (\text{w/w})\ C_3H_8O_3 = \frac{21.0\ \text{g}\ C_3H_8O_3}{\text{g soln}} \times \frac{1}{100} \times \frac{1000\ \text{g}}{\text{kg}} \times 1.50\ \text{kg soln} = 3.15 \times 10^2\ \text{g}\ C_3H_8O_3$$

$$1.50\ \text{kg soln} = 0.315\ \text{kg}\ C_3H_8O_3 + x\ \text{kg water}$$

$$x\ \text{kg water} = 1.50\ \text{kg soln} - 0.315\ \text{kg}\ C_3H_8O_3 = 1.185\ \text{kg water}$$

Mix 315 g glycerol with 1.185 kg water.

(c) 1.50 L of 21.0% (v/v) aqueous glycerol.

$$21.0\%\ (\text{v/v})\ C_3H_8O_3 = \frac{21.0\ \text{mL}\ C_3H_8O_3}{\text{mL soln}} \times \frac{1}{100} \times \frac{1000\ \text{mL}}{\text{L}} \times 1.50\ \text{L soln} = 3.15 \times 10^2\ \text{mL}\ C_3H_8O_3$$

Dilute 315 mL glycerol with enough water to give a final volume of 1.50 L.

***2-29.** Describe the preparation of 500 mL of 3.00 M H_3PO_4 from the commercial reagent that is 86% H_3PO_4 (w/w) and has a specific gravity of 1.71.

Solution:

$$\frac{3.00\ \text{mol}\ H_3PO_4}{\text{L}} \times \frac{\text{L}}{1000\ \text{mL}} \times 500\ \text{mL} = 1.50\ \text{mol}\ H_3PO_4$$

$$\frac{86\ \text{g}\ H_3PO_4}{\text{g reagent}} \times \frac{1}{100} \times \frac{1.71\ \text{g reagent}}{\text{g water}} \times \frac{\text{g water}}{\text{mL}} \times \frac{1000\ \text{mL}}{\text{L}} \times \frac{\text{mol}\ H_3PO_4}{98.0\ \text{g}} = \frac{1.50 \times 10^1\ \text{mol}\ H_3PO_4}{\text{L}}$$

$$\text{volume 86\% (w/w)}\ H_3PO_4\ \text{required} = 1.50\ \text{mol}\ H_3PO_4 \times \frac{\text{L}}{1.50 \times 10^1\ \text{mol}\ H_3PO_4}$$

$$= 1.00 \times 10^{-1}\ \text{L}$$

Dilute 100 mL to 500 mL with water.

2-30. Describe the preparation of 750 mL of 3.00 M HNO_3 from the commercial reagent that is 70.5% HNO_3 (w/w) and has a specific gravity of 1.42.

Solution:

$$\frac{3.00\ \text{mol}\ HNO_3}{\text{L}} \times \frac{\text{L}}{1000\ \text{mL}} \times 750\ \text{mL} = 2.25\ \text{mol}\ HNO_3$$

$$\frac{70.5\ \text{g}\ HNO_3}{\text{g reagent}} \times \frac{1}{100} \times \frac{1.42\ \text{g reagent}}{\text{g water}} \times \frac{\text{g water}}{\text{mL}} \times \frac{1000\ \text{mL}}{\text{L}} \times \frac{\text{mol}\ HNO_3}{63.0\ \text{g}} = \frac{15.9\ \text{mol}\ HNO_3}{\text{L}}$$

Volume HNO_3 required = 0.142 L

Dilute 142 mL of the commercial reagent to 750 mL using water.

***2-31.** Describe the preparation of

Solutions:

(a) 500 mL of 0.1000 M $AgNO_3$ from the solid reagent.

$$0.1000\ \text{M}\ AgNO_3 = \frac{0.1000\ \text{mol}\ AgNO_3}{\text{L}}$$

$$= \frac{0.1000\ \text{mol}\ AgNO_3}{\text{L}} \times \frac{169.87\ \text{g}\ AgNO_3}{\text{mol}} \times \frac{\text{L}}{1000\ \text{mL}} \times 500\ \text{mL}$$

$$= 8.49\ \text{g}\ AgNO_3$$

Dissolve 8.49 g $AgNO_3$ in enough water to give a final volume of 500 mL.

(b) 1.00 L of 0.1000 M HCl, starting with a 6.00 M solution of the reagent.

$$\frac{0.1000\text{ mol HCl}}{\text{L}}\times 1\text{ L} = 0.1000\text{ mol HCl}$$

$$0.1000\text{ mol HCl}\times\frac{\text{L}}{6.00\text{ mol HCl}} = 1.67\times10^{-2}\text{ L HCl}$$

Take 167 mL of the 6.00 M HCl and dilute to 1.00 L using water.

(c) 250 mL of a solution that is 0.0810 M in K^+, starting with solid $K_4Fe(CN)_6$.

$$\frac{0.0810\text{ mol K}^+}{\text{L}}\times\frac{\text{L}}{1000\text{ mL}}\times 250\text{ mL} = 2.025\times10^{-2}\text{ mol K}^+$$

$$2.025\times10^{-2}\text{ mol K}^+\times\frac{\text{mol K}_4\text{Fe(CN)}_6}{4\text{ mol K}^+}\times\frac{368.35\text{ g K}_4\text{Fe(CN)}_6}{\text{mol}} = 1.86\text{ g K}_4\text{Fe(CN)}_6$$

Dissolve 1.86 g $K_4Fe(CN)_6$ in enough water to give a final volume of 250 mL.

(d) 500 mL of 3.00% (w/v) aqueous $BaCl_2$ from a 0.400 M $BaCl_2$ solution.

$$\frac{3.00\text{ g BaCl}_2}{\text{mL soln}}\times\frac{1}{100}\times 500\text{ mL} = 1.5\times10^{1}\text{ g BaCl}_2$$

$$1.5\times10^{1}\text{ g BaCl}_2\times\frac{\text{mol BaCl}_2}{208.23\text{ g}}\times\frac{\text{L}}{0.400\text{ mol BaCl}_2} = 1.80\times10^{-1}\text{ L}$$

Take 180 mL of the 0.400 M $BaCl_2$ solution and dilute to 500 mL using water.

(e) 2.00 L of 0.120 M $HClO_4$ from the commercial reagent [71.0% $HClO_4$ (w/w), sp gr 1.67].

$$\frac{0.120\text{ mol HClO}_4}{\text{L}}\times 2.00\text{ L} = 0.240\text{ mol HClO}_4$$

$$\frac{71\text{ g HClO}_4}{100\text{ g reagent}}\times\frac{1.67\text{ g reagent}}{\text{g water}}\times\frac{\text{g water}}{\text{mL}}\times\frac{1000\text{ mL}}{\text{L}}\times\frac{\text{mol HClO}_4}{100.46\text{ g}} = \frac{1.18\times10^{1}\text{ mol HClO}_4}{\text{L}}$$

$$\text{volume 71\% (w/w) HClO}_4\text{ required} = 0.240\text{ mol HClO}_4 = \frac{\text{L}}{1.18\times10^{1}\text{ mol HClO}_4}$$

$$= 2.03\times10^{-2}\text{ L}$$

Take 20.3 mL of the concentrated reagent and dilute to 2.00 L using water.

(f) 1.00 L of a solution that is 60.0 ppm in Na^+, starting with solid Na_2SO_4.

$$60\text{ ppm Na}^+ = \frac{60\text{ mg Na}^+}{\text{L soln}}$$

$$\frac{60\text{ mg Na}^+}{\text{L soln}}\times 1.00\text{ L} = 60\text{ mg Na}^+$$

$$60\text{ mg Na}^+ \times \frac{\text{g}}{1000\text{ mg}} \times \frac{\text{mol Na}^+}{22.99\text{ g}} = 2.61\times10^{-3}\text{ mol Na}^+$$

$$2.61\times10^{-3}\text{ mol Na}^+ \times \frac{\text{mol Na}_2\text{SO}_4}{2\text{ mol Na}^+} \times \frac{142.04\text{ g Na}_2\text{SO}_4}{\text{mol}} = 0.19\text{ g Na}_2\text{SO}_4$$

Dissolve 0.19 g Na_2SO_4 in enough water to give a final volume of 1.00 L.

2-32. Describe the preparation of

Solutions:

(a) 2.50 L of 0.0250 M $KMnO_4$ from the solid reagent.

$$\frac{0.0250\text{ mol KMnO}_4}{\text{L}} \times 2.50\text{ L} \times \frac{158.03\text{ g KMnO}_4}{\text{mol}} = 9.877\text{ g KMnO}_4$$

Dissolve 9.9 g $KMnO_4$ in enough water to give a final volume of 2.50 L.

(b) 4.00 L of 0.250 M $HClO_4$, starting with an 8.00 M solution of the reagent.

$$\frac{0.250\text{ mol HClO}_4}{\text{L}} \times 4.00\text{ L} = 1.00\text{ mol HClO}_4$$

$$1.00\text{ mol HClO}_4 \times \frac{\text{L}}{8.00\text{ mol reagent}} = 1.25\times10^{-1}\text{ L reagent}$$

Take 125 mL of the 8.00 M reagent and dilute a final of volume of 4.00 L using water.

(c) 500 mL of a solution that is 0.0200 M in I^-, starting with MgI_2.

$$\frac{0.0200\text{ mol I}^-}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times 500\text{ mL} = 1.00\times10^{-2}\text{ mol I}^-$$

$$1.00\times10^{-2}\text{ mol I}^- \times \frac{\text{mol MgI}_2}{2\text{ mol I}^-} \times \frac{278.11\text{ g MgI}_2}{\text{mol}} = 1.39\text{ g MgI}_2$$

Dissolve 1.39 g MgI_2 in enough water to give a final volume of 500 mL.

(d) 200 mL of 1.00% (w/v) aqueous $CuSO_4$ from a 0.365 M $CuSO_4$ solution.

$$1.00\%\text{ (w/v) CuSO}_4 = \frac{1.00\text{ g CuSO}_4}{100\text{ mL soln}}$$

$$\frac{1.00\text{ g CuSO}_4}{100\text{ mL soln}} \times 200\text{ mL} = 2.00\text{ g CuSO}_4$$

$$2.00\text{ g CuSO}_4 \times \frac{\text{mol CuSO}_4}{159.60\text{ g}} \times \frac{\text{L}}{0.365\text{ mol CuSO}_4} = 3.43\times10^{-2}\text{ L}$$

Take 34.3 mL of the 0.365 M $CuSO_4$ and dilute to a final volume of 200 mL using water.

(e) 1.50 L of 0.300 M NaOH from the concentrated commercial reagent [50% NaOH (w/w), sp gr 1.525].

$$\frac{0.300 \text{ mol NaOH}}{\text{L}} \times 1.50 \text{ L} = 0.450 \text{ mol NaOH}$$

$$50\% \text{ (w/w) NaOH} = \frac{50 \text{ g NaOH}}{100 \text{ g reagent}}$$

$$\frac{50 \text{ g NaOH}}{100 \text{ g reagent}} \times \frac{1.525 \text{ g reagent}}{\text{g water}} \times \frac{\text{g water}}{\text{mL}} \times \frac{1000 \text{ mL}}{\text{L}} \times \frac{\text{mol NaOH}}{40.00 \text{ g}}$$
$$= \frac{1.9 \times 10^1 \text{ mol NaOH}}{\text{L}}$$

$$\text{volume 50\% (w/w) NaOH required} = 0.450 \text{ mol NaOH} \times \frac{\text{L}}{1.9 \times 10^1 \text{ mol NaOH}}$$
$$= 2.4 \times 10^{-2} \text{ L}$$

Take 24 mL of the concentrated reagent and dilute to a final volume of 1.50 L using water.

(f) 1.50 L of a solution that is 15.0 ppm in K^+, starting with solid $K_4Fe(CN)_6$.

$$15.0 \text{ ppm } K^+ = \frac{15 \text{ mg } K^+}{\text{L soln}}$$

$$\frac{15 \text{ mg } K^+}{\text{L soln}} \times 1.50 \text{ L} = 2.25 \times 10^1 \text{ mg } K^+$$

$$2.25 \times 10^1 \text{ mg } K^+ \times \frac{\text{g}}{1000 \text{ mg}} \times \frac{\text{mol } K^+}{39.10 \text{ g}} = 5.75 \times 10^{-4} \text{ mol } K^+$$

$$5.75 \times 10^{-4} \text{ mol } K^+ \times \frac{\text{mol } K_4Fe(CN)_6}{4 \text{ mol } K^+} \times \frac{368.35 \text{ g } K_4Fe(CN)_6}{\text{mol}} = 5.30 \times 10^{-2} \text{ g } K_4Fe(CN)_6$$

Dissolve 53.0 mg $K_4Fe(CN)_6$ in enough water to give a final volume of 1.50 L.

***2-33.** What mass of solid $La(IO_3)_3$ (663.6 g/mol) is formed when 50.0 mL of 0.250 M La^{3+} is mixed with 75.0 mL of 0.302 M IO_3^-?

Solution:

$$\frac{0.250 \text{ mol } La^{3+}}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 50.0 \text{ mL} = 1.25 \times 10^{-2} \text{ mol } La^{3+}$$

$$0.302 \text{ M } IO_3^- = \frac{0.302 \text{ mol } IO_3^-}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 75.0 \text{ mL} = 2.27 \times 10^{-2} \text{ mol } IO_3^-$$

Because each mole of $La(IO_3)_3$ requires three moles IO_3^-, IO_3^- is the limiting reagent. Thus,

$$2.27 \times 10^{-2} \text{ mol } IO_3^- \times \frac{\text{mol } La(IO_3)_3}{3 \text{ mol } IO_3^-} \times \frac{663.6 \text{ g } La(IO_3)_3}{\text{mol}} = 5.01 \text{ g } La(IO_3)_3 \text{ formed}$$

2-34. What mass of solid $PbCl_2$ (278.10 g/mol) is formed when 200 mL of 0.125 M Pb^{2+} is mixed with 400 mL of 0.175 M Cl^-?

Solution:

$$\frac{0.125 \text{ mol Pb}^{2+}}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 200 \text{ mL} = 2.50 \times 10^{-2} \text{ mol Pb}^{2+}$$

$$\frac{0.175 \text{ mol Cl}^-}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 400 \text{ mL} = 7.00 \times 10^{-2} \text{ mol Cl}^-$$

Because each mole of $PbCl_2$ requires two moles Cl^-, Pb^{2+} is the limiting reagent. Thus,

$$2.50 \times 10^{-2} \text{ mol Pb}^{2+} \times \frac{\text{mol PbCl}_2}{\text{mol Pb}^{2+}} \times \frac{278.10 \text{ g PbCl}_2}{\text{mol}} = 6.95 \text{ g PbCl}_2 \text{ formed}$$

***2-35.** Exactly 0.118 g of pure Na_2CO_3 is dissolved in 100.0 mL of 0.0731 M HCl.

Solutions:

(a) What mass in grams of CO_2 is evolved?

A balanced chemical equation can be written as:

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2(g)$$

$$0.1180 \text{ g Na}_2\text{CO}_3 \times \frac{\text{mol Na}_2\text{CO}_3}{105.99 \text{ g}} = 1.113 \times 10^{-3} \text{ mol Na}_2\text{CO}_3$$

$$\frac{0.0731 \text{ mol HCl}}{\text{L}} \times \frac{\text{L}}{1000 \text{ mL}} \times 100.0 \text{ mL} = 7.31 \times 10^{-3} \text{ mol HCl}$$

Because one mole of CO_2 is evolved for every mole Na_2CO_3 reacted, Na_2CO_3 is the limiting reagent. Thus,

$$1.113 \times 10^{-3} \text{ mol Na}_2\text{CO}_3 \times \frac{\text{mol CO}_2}{\text{mol Na}_2\text{CO}_3} \times \frac{44.00 \text{ g CO}_2}{\text{mol}} = 4.897 \times 10^{-2} \text{ g CO}_2 \text{ evolved}$$

(b) What is the molar concentration of the excess reactant (HCl or Na_2CO_3)?

$$\text{amnt HCl left} = 7.31 \times 10^{-3} \text{ mol} - (2 \times 1.113 \times 10^{-3} \text{ mol}) = 5.08 \times 10^{-3} \text{ mol}$$

$$\frac{5.08 \times 10^{-3} \text{ mol HCl}}{100.0 \text{ mL}} \times \frac{1000 \text{ mL}}{\text{L}} = 5.08 \times 10^{-2} \text{ M HCl}$$

2-36. Exactly 25.0 mL of a 0.3757 M solution of Na_3PO_4 is mixed with 100.00 mL of 0.5151 M $HgNO_3$.

Solutions:

(a) What mass of solid Hg_3PO_4 is formed?

A balanced chemical equation can be written as

$$Na_3PO_4 + 3HgNO_3 \rightarrow 3NaNO_3 + Hg_3PO_4$$

$$\frac{0.3757 \text{ mol } Na_3PO_4}{L} \times \frac{L}{1000 \text{ mL}} \times 25.0 \text{ mL} = 9.39 \times 10^{-3} \text{ mol } Na_3PO_4$$

$$\frac{0.5151 \text{ mol } HgNO_3}{L} \times \frac{L}{1000 \text{ mL}} \times 100.0 \text{ mL} = 5.151 \times 10^{-2} \text{ mol } HgNO_3$$

The limiting reagent is Na_3PO_4. Thus,

$$9.39 \times 10^{-3} \text{ mol } Na_3PO_4 \times \frac{\text{mol } Hg_3PO_4}{\text{mol } Na_3PO_4} \times \frac{696.74 \text{ g } Hg_3PO_4}{\text{mol}} = 6.54 \text{ g } Hg_3PO_4 \text{ formed}$$

(b) What is the molar concentration of the unreacted species (Na_3PO_4 or $HgNO_3$) after the reaction is complete?

$$\text{mol } HgNO_3 \text{ unreacted} = 5.151 \times 10^{-2} \text{ mol} - (3 \times 9.39 \times 10^{-3} \text{ mol}) = 2.33 \times 10^{-2} \text{ mol}$$

$$\frac{2.33 \times 10^{-2} \text{ mol } HgNO_3}{125.0 \text{ mL}} \times \frac{1000 \text{ mL}}{L} = 1.87 \times 10^{-1} \text{ M } HgNO_3$$

***2-37.** Exactly 75.00 mL of a 0.3132 M solution of Na_2SO_3 is treated with 150.0 mL of 0.4025 M $HClO_4$ and boiled to remove the SO_2 formed.

Solution:

(a) What is the mass in grams of SO_2 that is evolved?

A balanced chemical equation can be written as:

$$Na_2SO_3 + 2HClO_4 \rightarrow 2NaClO_4 + H_2O + SO_2(g)$$

$$0.3132 \text{ M } Na_2SO_3 = \frac{0.3132 \text{ mol } Na_2SO_3}{L} \times \frac{L}{1000 \text{ mL}} \times 75 \text{ mL} = 2.3 \times 10^{-2} \text{ mol } Na_2SO_3$$

$$0.4025 \text{ M } HClO_4 = \frac{0.4025 \text{ mol } HClO_4}{L} \times \frac{L}{1000 \text{ mL}} \times 150.0 \text{ mL}$$
$$= 6.038 \times 10^{-2} \text{ mol } HClO_4$$

Because one mole SO_2 is evolved per mole Na_2SO_3, Na_2SO_3 is the limiting reagent. Thus,

$$2.3 \times 10^{-2} \text{ mol } Na_2SO_3 \times \frac{\text{mol } SO_2}{\text{mol } Na_2SO_3} \times \frac{64.06 \text{ g } SO_2}{\text{mol}} = 1.5 \text{ g } SO_2 \text{ evolved}$$

(b) What is the concentration of the unreacted reagent (Na_2SO_3 or $HClO_4$) after the reaction is complete?

$$\text{mol } HClO_4 \text{ unreacted} = 6.038 \times 10^{-2} \text{ mol} - (2 \times 2.3 \times 10^{-2}) = 1.4 \times 10^{-2} \text{ mol}$$

$$\frac{1.4 \times 10^{-2} \text{ mol } HClO_4}{225 \text{ mL}} \times \frac{1000 \text{ mL}}{L} = 6.4 \times 10^{-2} \text{ M } HClO_4 = 0.064 \text{ M}$$

2-38. What mass of $MgNH_4PO_4$ precipitates when 200.0 mL of a 1.000% (w/v) solution of $MgCl_2$ is treated with 40.0 mL of 0.1753 M Na_3PO_4 and an excess of NH_4^+? What is the molar concentration of the excess reagent (Na_3PO_4 or $MgCl_2$) after the precipitation is complete?

Solution:
A balanced chemical equation can be written as:

$$MgCl_2 + Na_3PO_4 + NH_4^+ \rightarrow MgNH_4PO_4(s) + 3Na^+ + 2Cl^-$$

$$\frac{1.000\text{ g }MgCl_2}{100\text{ mL}} \times 200.0\text{ mL} \times \frac{\text{mol }MgCl_2}{95.21\text{ g}} = 2.101\times10^{-2}\text{ mol }MgCl_2$$

$$\frac{0.1753\text{ mol }Na_3PO_4}{\text{L}} \times \frac{\text{L}}{1000\text{ mL}} \times 40.0\text{ mL} = 7.01\times10^{-3}\text{ mol }Na_3PO_4.$$

Na_3PO_4 is the limiting reagent. Thus,

$$\text{amnt }MgCl_2\text{ unreacted} = (2.101\times10^{-2} - 7.01\times10^{-3}) = 1.40\times10^{-2}\text{ mol}$$

$$\frac{1.40\times10^{-2}\text{ mol }MgCl_2}{240.0\text{ mL}} \times \frac{1000\text{ mL}}{\text{L}} = 5.83\times10^{-2}\text{ M }MgCl_2$$

***2-39.** What volume of 0.01000 M $AgNO_3$ is required to precipitate all of the I^- in 150 mL of a solution that contains 22.50 ppt KI?

Solution:
A balanced chemical equation can be written as:

$$AgNO_3 + KI \rightarrow AgI(s) + KNO_3$$

$$22.50\text{ ppt KI} \times \frac{1}{10^3\text{ ppt}} \times \frac{\text{g}}{\text{mL}} \times 150\text{ mL} \times \frac{\text{mol KI}}{166.0\text{ g}} = 2.03\times10^{-2}\text{ mol KI}$$

$$2.03\times10^{-2}\text{ mol KI} \times \frac{\text{mol }AgNO_3}{\text{mol KI}} \times \frac{\text{L}}{0.0100\text{ mol }AgNO_3} = 2.03\text{ L }AgNO_3$$

2.03 L of 0.0100 M $AgNO_3$ would be required to precipitate I^- as AgI.

2-40. Exactly 750.0 mL of a solution that contains 500.0 ppm of $Ba(NO_3)_2$ is mixed with 200.0 mL of a solution that was 0.04100 M in $Al_2(SO_4)_3$.

Solutions:

(a) What mass of solid $BaSO_4$ is formed?

A balanced chemical equation can be written as

$$3Ba(NO_3)_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + 2Al^{+3} + 6NO_3^-$$

$$500\text{ ppm }Ba(NO_3)_2 \times \frac{1}{10^6\text{ ppm}} \times \frac{\text{g}}{\text{mL}} \times 750.0\text{ mL} \times \frac{\text{mol }Ba(NO_3)_2}{261.34\text{ g}} = 1.43\times10^{-3}\text{ mol }Ba(NO_3)_2$$

For $Al_2(SO_4)_3$

$$\frac{0.0410 \text{ mol } Al_2(SO_4)_3}{L} \times \frac{L}{1000 \text{ mL}} \times 200.0 \text{ mL} = 8.20 \times 10^{-3} \text{ mol } Al_2(SO_4)_3$$

$Ba(NO_3)_2$ is the limiting reagent. Thus,

$$1.43 \times 10^{-3} \text{ mol } Ba(NO_3)_2 \times \frac{3 \text{ mol } BaSO_4}{3 \text{ mol } Ba(NO_3)_2} \times \frac{233.39 \text{ g } BaSO_4}{\text{mol}} = 3.34 \times 10^{-1} \text{ g } BaSO_4 \text{ formed}$$

(b) What is the molar concentration of the unreacted reagent [$Al_2(SO_4)_3$ or $Ba(NO_3)_2$]?

Since 3 moles of $Ba(NO_3)_2$ react with 1 mole of $Al_2(SO_4)_3$,

$$\text{amnt } Al_2(SO_4)_3 \text{ unreacted} = 8.20 \times 10^{-3} \text{ mol} - (1/3 \times 1.43 \times 10^{-3} \text{ mol}) = 7.72 \times 10^{-3} \text{ mol}$$

$$\frac{7.72 \times 10^{-3} \text{ mol } Al_2(SO_4)_3}{950.0 \text{ mL}} \times \frac{1000 \text{ mL}}{L} = 8.13 \times 10^{-3} \text{ M } Al_2(SO_4)_3$$