CONVERSION BETWEEN CONCENTRATION UNITS

A concentrated solution of aqueous ammonia is 28.0% w/w NH₃ and has a density of 0.899 g/mL. What is the molar concentration of NH₃ in this solution?

**SOLUTION**

\[
\frac{28.0 \text{ g NH}_3}{100 \text{ g solution}} \times \frac{0.899 \text{ g solution}}{\text{mL solution}} \times \frac{1 \text{ mole NH}_3}{17.04 \text{ g NH}_3} \times \frac{1000 \text{ mL}}{\text{liter}} = 14.8 \text{ M}
\]

CONVERSION BETWEEN CONCENTRATION UNITS

The maximum allowed concentration of chloride in a municipal drinking water supply is \(2.50 \times 10^2\) ppm Cl⁻. When the supply of water exceeds this limit, it often has a distinctive salty taste. What is this concentration in moles Cl⁻/liter?

**SOLUTION**

\[
\frac{2.50 \times 10^2 \text{ mg Cl}^-}{\text{L}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ mole Cl}^-}{35.453 \text{ g Cl}^-} = 7.05 \times 10^{-3} \text{ M}
\]

p FUNCTION

What is pNa for a solution of \(1.76 \times 10^{-3}\) M Na₃PO₄?

**SOLUTION**

Since each mole of Na₃PO₄ contains three moles of Na⁺, the concentration of Na⁺ is

\[
[\text{Na}^+] = \frac{3 \text{ mol Na}^+}{\text{mol Na}_3\text{PO}_4} \times 1.76 \times 10^{-3} \text{ M} = 5.28 \times 10^{-3} \text{ M}
\]

and pNa is

\[
p\text{Na} = -\log[\text{Na}^+] = -\log(5.28 \times 10^{-3}) = 2.277
\]

p FUNCTION

What is the [H⁺] in a solution that has a pH of 5.16?

**SOLUTION**

The concentration of H⁺ is

\[
p\text{H} = -\log[H^+] = 5.16
\]

\[
\log[H^+] = -5.16
\]

\[
[H^+] = \text{antilog}(-5.16) = 10^{-5.16} = 6.9 \times 10^{-6} \text{ M}
\]
STOICHIOMETRIC CALCULATIONS

\[ 2\text{Fe}^{2+}(aq) + \text{H}_2\text{C}_2\text{O}_4(aq) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{Fe}^{2+}(aq) + 2\text{CO}_2(g) + 2\text{H}_2\text{O}^+(aq) \]  

The amount of oxalic acid in a sample of rhubarb was determined by reacting with Fe\(^{2+}\) as outlined in reaction 2.2. In a typical analysis, the oxalic acid in 10.62 g of rhubarb was extracted with a suitable solvent. The complete oxidation of the oxalic acid to CO\(_2\) required 36.44 mL of 0.0130 M Fe\(^{2+}\). What is the weight percent of oxalic acid in the sample of rhubarb?

**SOLUTION**

We begin by calculating the moles of Fe\(^{2+}\) used in the reaction

\[
\frac{0.0130 \text{ mol Fe}^{2+}}{L} \times 0.03644 \text{ L} = 4.737 \times 10^{-4} \text{ mol Fe}^{2+} 
\]

The moles of oxalic acid reacting with the Fe\(^{2+}\), therefore, is

\[4.737 \times 10^{-4} \text{ mol Fe}^{2+} \times \frac{1 \text{ mol C}_2\text{H}_2\text{O}_4}{2 \text{ mol Fe}^{2+}} = 2.369 \times 10^{-4} \text{ mol C}_2\text{H}_2\text{O}_4 \]

Converting moles of oxalic acid to grams of oxalic acid

\[2.369 \times 10^{-4} \text{ mol C}_2\text{H}_2\text{O}_4 \times \frac{90.03 \text{ g C}_2\text{H}_2\text{O}_4}{\text{mol C}_2\text{H}_2\text{O}_4} = 2.132 \times 10^{-2} \text{ g oxalic acid} \]

and converting to weight percent gives the concentration of oxalic acid in the sample of rhubarb as

\[
\frac{2.132 \times 10^{-2} \text{ g C}_2\text{H}_2\text{O}_4}{10.62 \text{ g rhubarb}} \times 100 = 0.201\% \text{ w/w C}_2\text{H}_2\text{O}_4 
\]

**SOLUTION USING CONSERVATION PRINCIPLES (CHARGE, MASS, etc.)**

Conservation of electrons for this redox reaction requires that

\[ \text{moles Fe}^{2+} = 2 \times \text{moles H}_2\text{C}_2\text{O}_4 \]

which can be transformed by writing moles as the product of molarity and volume or as grams per formula weight.

\[
M_{\text{Fe}^{2+}} \times V_{\text{Fe}^{2+}} = \frac{2 \times g \text{ H}_2\text{C}_2\text{O}_4}{FW \text{ H}_2\text{C}_2\text{O}_4}
\]

Solving for \( g \text{ H}_2\text{C}_2\text{O}_4 \) gives

\[
\frac{M_{\text{Fe}^{2+}} \times V_{\text{Fe}^{2+}} \times FW \text{ H}_2\text{C}_2\text{O}_4}{2} = \frac{(0.0130 \text{ M})(0.03644 \text{ L})(90.03 \text{ g/mole})}{2}
\]

\[= 2.132 \times 10^{-2} \text{ g H}_2\text{C}_2\text{O}_4 \]

and the weight percent oxalic acid is

\[
\frac{2.132 \times 10^{-2} \text{ g C}_2\text{H}_2\text{O}_4}{10.62 \text{ g rhubarb}} \times 100 = 0.201\% \text{ w/w C}_2\text{H}_2\text{O}_4 
\]
One quantitative analytical method for tetraethylthiuram disulfide, \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) (Antabuse), requires oxidizing the sulfur to \( \text{SO}_2 \), and bubbling the resulting \( \text{SO}_2 \) through \( \text{H}_2\text{O}_2 \) to produce \( \text{H}_2\text{SO}_4 \). The \( \text{H}_2\text{SO}_4 \) is then reacted with NaOH according to the reaction

\[
\text{H}_2\text{SO}_4(aq) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l)
\]

Using appropriate conservation principles, derive an equation relating the moles of \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) to the moles of NaOH. What is the weight percent \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) in a sample of Antabuse if the \( \text{H}_2\text{SO}_4 \) produced from a 0.4613-g portion reacts with 54.85 mL of 0.02500 M NaOH?

**SOLUTION**

The unbalanced reactions converting \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) to \( \text{H}_2\text{SO}_4 \) are

\[
\begin{align*}
\text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} & \rightarrow \text{SO}_2 \\
\text{SO}_2 & \rightarrow \text{H}_2\text{SO}_4
\end{align*}
\]

Using a conservation of mass we have

\[
4 \times \text{moles C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} = \text{moles SO}_2 = \text{moles H}_2\text{SO}_4
\]

A conservation of protons for the reaction of \( \text{H}_2\text{SO}_4 \) with NaOH gives

\[
2 \times \text{moles H}_2\text{SO}_4 = \text{moles of NaOH}
\]

Combining the two conservation equations gives the following stoichiometric equation between \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) and NaOH

\[
8 \times \text{moles C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} = \text{moles NaOH}
\]

Now we are ready to finish the problem. Making appropriate substitutions for moles of \( \text{C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) and moles of NaOH gives

\[
\frac{8 \times \text{g C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4}}{\text{FW C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4}} = \text{M}_{\text{NaOH}} \times \text{V}_{\text{NaOH}}
\]

Solving for \( \text{g C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} \) gives

\[
\text{g C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4} = \frac{1}{8} \times \text{M}_{\text{NaOH}} \times \text{V}_{\text{NaOH}} \times \text{FW C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4}
\]

\[
\frac{1}{8} \times (0.02500 \text{ M})(0.03485 \text{ L})(296.54 \text{ g/mol}) = 0.032295 \text{ g C}_{10}\text{H}_{20}\text{N}_{2}\text{S}_{4}
\]
(c) The concentration of this solution is only approximate, so volumes do not need to be measured exactly. The necessary volume of glacial acetic acid is

$$\frac{4 \text{ mL CH}_3\text{COOH}}{100 \text{ mL}} \times 2000 \text{ mL} = 80 \text{ mL CH}_3\text{COOH}$$

To prepare the solution we use a graduated cylinder to transfer 80 mL of glacial acetic acid to a container that holds approximately 2 L, and we then add sufficient water to bring the solution to the desired volume.

Describe how you would prepare the following three solutions: (a) 500 mL of approximately 0.20 M NaOH using solid NaOH; (b) 1 L of 150.0 ppm Cu$^{2+}$ using Cu metal; and (c) 2 L of 4% w/v acetic acid using concentrated glacial acetic acid.

**SOLUTION**

(a) Since the concentration only needs to be known to two significant figures, the mass of NaOH and volume of solution do not need to be measured exactly. The desired mass of NaOH is

$$\frac{0.20 \text{ mol}}{1 \text{ L}} \times 40.0 \text{ g mol}^{-1} \times 0.50 \text{ L} = 4.0 \text{ g}$$

To prepare the solution we place 4.0 g of NaOH, weighed to the nearest tenth of a gram, in a bottle or beaker and add approximately 500 mL of water.

(b) Since the concentration of Cu$^{2+}$ needs to be exact, the mass of Cu metal and the final solution volume must be measured exactly. The desired mass of Cu metal is

$$\frac{150.0 \text{ mg}}{1 \text{ L}} \times 1.000 \text{ L} = 150.0 \text{ mg} = 0.1500 \text{ g}$$

To prepare the solution we measure out exactly 0.1500 g of Cu into a small beaker. To dissolve the Cu we add a small portion of concentrated HNO$_3$ and gently heat until it completely dissolves. The resulting solution is poured into a 1-L volumetric flask. The beaker is rinsed repeatedly with small portions of water, which are added to the volumetric flask. This process, which is called a quantitative transfer, ensures that the Cu$^{2+}$ is completely transferred to the volumetric flask. Finally, additional water is added to the volumetric flask's calibration mark.

8

A laboratory procedure calls for 250 mL of an approximately 0.10 M solution of NH$_3$. Describe how you would prepare this solution using a stock solution of concentrated NH$_3$ (14.8 M).

**SOLUTION**

Substituting known volumes in equation 2.4

$$14.8 \text{ M} \times V_o = 0.10 \text{ M} \times 0.25 \text{ L}$$

and solving for $V_o$ gives $1.69 \times 10^{-3}$ L, or 1.7 mL. Since we are trying to make a solution that is approximately 0.10 M NH$_3$, we can measure the appropriate amount of concentrated NH$_3$ using a graduated cylinder, transfer the NH$_3$ to a beaker, and add sufficient water to bring the total solution volume to approximately 250 mL.
7. An analyst wishes to add 256 mg of Cl\(^-\) to a reaction mixture. How many milliliters of 0.217 M BaCl\(_2\) should be added?

8. A solution of 0.10 M SO\(_4^{2-}\) is available. What is the normality of this solution when used in the following reactions?
   a. Pb\(^{2+}\)(aq) + SO\(_4^{2-}\)(aq) \rightleftharpoons PbSO\(_4\)(s)
   b. HCl(aq) + SO\(_4^{2-}\)(aq) \rightleftharpoons HSO\(_4^-\)(aq) + Cl^-\)(aq)
   c. SO\(_4^{2-}\) + 4H\(_3\)O\(^+\)(aq) + 2e\(^-\) \rightleftharpoons H\(_2\)SO\(_3\)(aq) + 5H\(_2\)O(l)

9. The concentration of lead in an industrial waste stream is 0.28 ppm. What is its molar concentration?

10. Commercially available concentrated hydrochloric acid is 37.0% w/w HCl. Its density is 1.18 g/mL. Using this information calculate (a) the molarity of concentrated HCl, and (b) the mass and volume (in milliliters) of solution containing 0.315 mol of HCl.

11. The density of concentrated ammonia, which is 28.0% w/w NH\(_3\), is 0.899 g/mL. What volume of this reagent should be diluted to 1.0 \times 10^3 mL to make a solution that is 0.036 M in NH\(_3\)?

12. A 250.0-mL aqueous solution contains 45.1 \mu g of a pesticide. Express the pesticide’s concentration in weight percent, parts per million, and parts per billion.

13. A city’s water supply is fluoridated by adding NaF. The desired concentration of F\(^-\) is 1.6 ppm. How many milligrams of NaF should be added per gallon of treated water if the water supply already is 0.2 ppm in F\(^-\)?

14. What is the pH of a solution for which the concentration of H\(^+\) is 6.92 \times 10^-6 M? What is the [H\(^+\)] in a solution whose pH is 8.923?
16. Calculate the molarity of a potassium dichromate solution prepared by placing 9.67 g of K₂Cr₂O₇ in a 100-mL volumetric flask, dissolving, and diluting to the calibration mark.

17. For each of the following, explain how you would prepare 1.0 L of a solution that is 0.10 M in K⁺. Repeat for concentrations of 1.0 × 10⁻² ppm K⁺ and 1.0% w/v K⁺.
   a. KCl
   b. K₂SO₄
   c. K₃Fe(CN)₆

20. What is the molar concentration of NO₃⁻ in a solution prepared by mixing 50.0 mL of 0.050 M KNO₃ with 40.0 mL of 0.075 M NaNO₃? What is pNO₃ for the mixture?

21. What is the molar concentration of Cl⁻ in a solution prepared by mixing 25.0 mL of 0.025 M NaCl with 35.0 mL of 0.050 M BaCl₂? What is pCl for the mixture?

22. To determine the concentration of ethanol in cognac a 5.00-mL sample of cognac is diluted to 0.500 L. Analysis of the diluted cognac gives an ethanol concentration of 0.0844 M. What is the molar concentration of ethanol in the undiluted cognac?