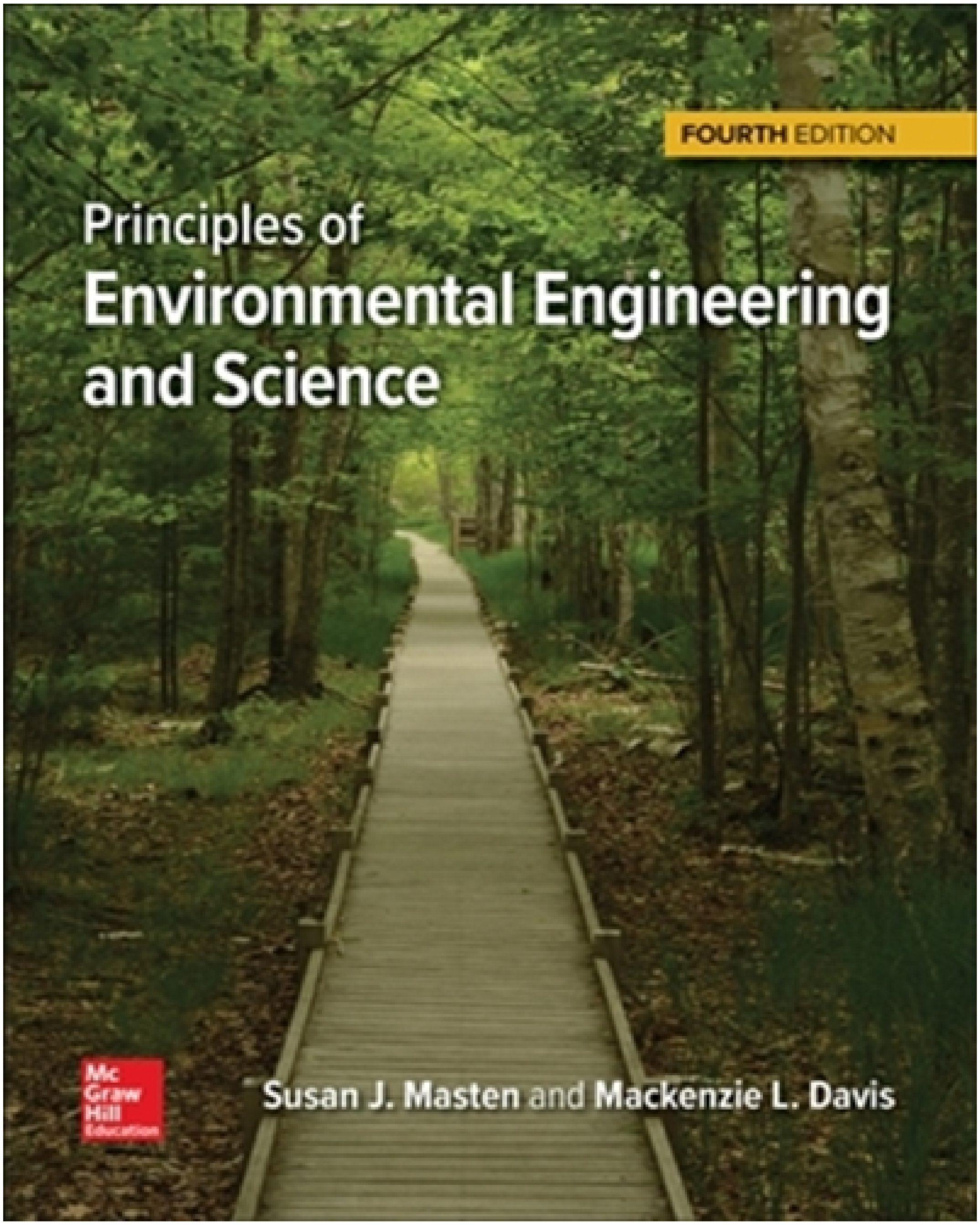
Solutions for Principles of Environmental Engineering and Science 4th Edition by Davis



Solutions

CHAPTER 2
SOLUTIONS

2-1 Name element, given atomic symbol

Given: Periodic table

Solution:

a. Pb = Lead
b. C = Carbon
c. Ca = Calcium
d. Zn = Zinc
e. O = Oxygen
f. H = Hydrogen
g. Mg = Mercury
h. S = Sulfur
i. N = Nitrogen
j. Cl = Chlorine
k. Mg = Magnesium
l. P = Phosphorus

2-2 Identify isotope

Given: Number of protons and neutrons for atoms A, B, C and D

Solution:

a. Isotopes have the same number of protons but different number of neutrons. Thus, Atom C is the isotope of atom A

b. The mass number is the sum of the protons and neutrons. Atom A has a mass number of 28. None of the other atoms have the same mass number.

2-3 Calculate the atomic weight of boron

Given: Isotopic mass and fractional abundance

Solution:

a. Atomic weight is the sum of products of isotopic mass and fractional abundance

$$(10.013)(0.1978) + (11.009)(0.8022) = 10.812 \text{ atomic mass units}$$

2-4 Identify element

Given: Periodic table

Solution:

a. The number of protons determines the atomic number. This element has 17 protons so its atomic number is 17. From the table inside the front cover the element with an atomic number of 17 is chlorine.

2-5 Concentration of sodium bicarbonate

Given: 45.000 g of sodium bicarbonate in 1.00 L of water.

Solution:

a. The resulting concentration of the solution is 45 g · L^{-1}. Converting this to mg · L^{-1}

$$(45 \text{ g} \cdot \text{L}^{-1})(1000 \text{ mg} \cdot \text{g}^{-1}) = 45{,}000 \text{ mg} \cdot \text{L}^{-1}$$

b. To find the molarity, the molecular weight of $NaHCO_3$ must be found

$$\begin{aligned} \text{Na} &= 22.99 \times 1 = 22.99 \\ \text{H} &= 1.008 \times 1 = 1.008 \\ \text{C} &= 12.01 \times 1 = 12.01 \\ \underline{3\text{O}} &\underline{= 16.00 \times 3 = 48.00} \\ &\Sigma = 84.01 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$

Then, the molarity

$$(45 \text{ g} \cdot \text{L}^{-1})(1 \text{ mol}/84 \text{ g}) = 0.536 \text{ M}$$

c. The equivalent weight of $NaHCO_3$ is its GMW divided by the number of hydrogen ions transferred. In this case n = 1 because Na^+ is replaced by 1 H. Thus normality (N) is n*M, and in this case n = 1

$$(0.536 \text{ M})(1) = 0.536 \text{ M}$$

d. Change to units of mg · L^{-1} as $CaCO_3$, using Eqn 2-87

$$45{,}000\text{mg} \cdot \text{L}^{-1}\left(\frac{50\text{mg} \cdot \text{L}^{-1}\text{as} \cdot \text{CaCO}_3}{84\text{mg} \cdot \text{L}^{-1}\text{as} \cdot \text{NaCO}_3}\right) = 26{,}785\text{mg} \cdot \text{L}^{-1}$$

or 2.68×10^4 mg · L^{-1} as $CaCO_3$

2-6 Balance the equation

Given: 5 reaction equations as shown below

Solution:

a. $CaCl_2 + Na_2CO_3 = CaCO_3 + NaCl$

Elements	Reactants	Products
Ca	1	1
Cl	2	1
Na	2	1
C	1	1
O	3	3

Note that we are short 1 Na, so multiply product NaCl by 2

Elements	Reactants	Products
Ca	1	1
Cl	2	2
Na	2	2
C	1	1
O	3	3

This yields the balanced equation:

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2\ NaCl$$

b. $C_6H_{12}O_6 + O_2 = CO_2 + H_2O$

Elements	Reactants	Products
C	6	1
H	12	2
O	8	3

Note that we are short 5 C, 10 H and 5 O. Multiply product CO_2 by 6 and H_2O by 6. This balances C and H on each side, and leaves a difference of 10 O. Multiply the reactant O_2 to balance equation:

$$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$$

Elements	Reactants	Products
C	6	6
H	12	12
O	18	18

c. $NO_2 + H_2O = HNO_3 + NO$

Elements	Reactants	Products
N	1	2
H	2	1

O	3	4

Note that H is short 1, therefore multiply the product HNO_3 by 2. This causes N to be out of balance, and the reactant NO_2 should be multiplied by 3.
$3\ NO_2 + H_2O = 2\ HNO_3 + NO$

Elements	Reactants	Products
N	3	3
H	2	2
O	7	7

d. $C_4H_{10} + O_2 = CO_2 + H_2O$

Elements	Reactants	Products
C	4	1
H	10	2
O	2	3

Note that H is out of balance, but in order to keep the number of O even, we must multiply the product H_2O by 10. As a result, the reactant C_4H_{10} must be multiplied by 2.

$2\ C_4H_{10} + O_2 = CO_2 + 10\ H_2O$

Elements	Reactants	Products
C	8	1
H	20	20
O	2	12

However, the reaction is still not balanced. CO_2 must be multiplied by 8 to maintain an equal number of C. As a result, O is left unbalanced. Multiply O_2 by 13.

$2\ C_4H_{10} + 13\ O_2 = 8\ CO_2 + 10\ H_2O$

Elements	Reactants	Products
C	8	8
H	20	20
O	26	26

e. $Al(OH)_2 = Al^{2+} + OH^-$

Elements	Reactants	Products
Al	1	1
O	2	1
H	2	1

Note that Al is in balance, however we are missing an OH group. Multiply the product OH^- by 2.

$Al(OH)_2 = Al^{2+} + 2\ OH^-$

Elements	Reactants	Products
Al	1	1
O	2	2
H	2	2

2-7 Concentration of magnesium hydroxide

Given: 10.00 g $Mg(OH)_2$, 1 L water, $pH_1 = 7$, assuming temperature is 25° C and ionic strength is negligible

Solution:

Note that the molecular weight of $Mg(OH)_2 = 58.526\ g \cdot mol^{-1}$. A 10.00 g sample is:

$$10\ g\ Mg(OH)_2\ X\ (58.526\ g \cdot mol^{-1})^{-1} = 0.17\ mol$$

Since there is 1 mol Mg per 1 mol $Mg(OH)_2$ and this is dissolved in 1 L water, it follows that

$$[Mg^{2+}] = 0.17\ M$$

Using the solubility equilibrium reaction from Table 2-1

$$Mg(OH)_2 \leftrightarrow Mg^{2+} = 2OH^- \quad pKsp = 11.25$$

$$[Mg^{2+}][OH^-]^2 = 10^{-11.25}$$

Know the pH is 7, so pOH is also 7 and

$$[OH^-] = 10^{-7}$$

Substituting

$$[Mg^{2+}](10^{-7})^2 = 10^{-11.25}$$

$$[Mg^{2+}] = 562.34\ M$$

Since only added enough magnesium hydroxide to have 0.17 M, the concentration will be 0.17 M

2-8 Concentration of magnesium with ionic strength

Given: Problem 2-7 and ionic strength of 0.01M and 0.5M

Solution:

a. Assuming equilibrium and using the solubility equilibrium reactions from Table 2-1

$$\mathrm{Mg(OH)_2} \leftrightarrow \mathrm{Mg^{2+}} = 2\mathrm{OH^-}$$

b. For 0.01 M ionic strength using Eqn 2-34

$$\log\gamma_{\mathrm{Mg}} = -0.5(2)^2\left(\frac{\sqrt{0.01}}{1+\sqrt{0.01}} - 0.2(0.5)\right)$$

$$\gamma_{\mathrm{Mg}} = 0.664$$

$$\log\gamma_{\mathrm{OH}} = -0.5(1)^2\left(\frac{\sqrt{0.01}}{1+\sqrt{0.01}} - 0.2(0.5)\right)$$

$$\gamma_{\mathrm{OH}} = 0.9027$$

c. Using Eqn 2-33

$$\gamma_{\mathrm{Mg}}\left[\mathrm{Mg^{2+}}\right]\gamma_{\mathrm{OH}}\left[\mathrm{OH^-}\right]^2 = 10^{-11.25}$$

Solving for [$\mathrm{Mg^{2+}}$] and substituting

$$\left[\mathrm{Mg^{2+}}\right] = \frac{10^{-11.25}}{\left(10^{-7}\right)^2(0.9027)(0.664)} = 938.18\mathrm{M}$$

Since only enough magnesium hydroxide was added to give a concentration of 0.17 M, the final concentration will be 0.17M

d. Using a similar approach for an ionic strength of 0.5M, find that the max possible magnesium concentration is 3438 M. However, since only enough magnesium for a final concentration of 0.17 M was added, 0.17 M will be the final concentration.

2-9 Concentration of ferric phosphate

Given: 2.4 g ferric phosphate added to 1.0 L water, initial phosphate = 1.0 mg · $\mathrm{L^{-1}}$.

Solution:

a. Calculate molar concentration of initial phosphate concentration. GMW PO_4 = 94.974.

$$(1\ \text{mg} \cdot L^{-1})(10^{-3}\ \text{g} \cdot \text{mg}^{-1})(1/94.974\ \text{g} \cdot \text{mol}^{-1}) = 1.053 \times 10^{-5}\ \text{M}$$

b. Tabulation of charge for the equation $FePO_4 \leftrightarrow Fe^{3+} + PO_4^{3-}$, $pK_s = 21.9$

	Fe^{3+}	PO_4^{3-}
initial		1.053×10^{-5}
equilibrium	s	$s + 1.053 \times 10^{-5}$

c. The equilibrium equation is

$$[Fe^{3+}][PO_4] = K_s = 10^{-21.9}$$

substituting

$$(s)(s + 1.053 \times 10^{-5}) = 10^{-21.9}$$

$$s^2 + 1.053 \times 10^{-5}(s) - 10^{-21.9} = 0$$

d. Solving the quadratic equation

$$s = \frac{(-1.053 \times 10^{-5}) \pm \sqrt{(1.053 \times 10^{-5})^2 - 4(1)(-10^{-21.9})}}{2(1)}$$

$$s = [Fe^{3+}] = 1.20 \times 10^{-17}\ \text{M}$$

2-10 Final concentration of calcium carbonate

Given: Supersaturated with Ca^{2+} and CO_3^{2-} at concentration of 1.35×10^{-3} M each

Solution:

a. Solubility expression for calcium carbonate from Table 2-1

$$[Ca^{2+}][CO_3^{2-}] = 10^{-8.34}$$

b. Amount removed given by s

$$10^{-8.34} = [1.35 \times 10^{-3} - s][1.35 \times 10^{-3} - s\ ]$$

$$4.57 \times 10^{-9} = 1.82 \times 10^{-6} - 2.70 \times 10^{-3}s + s^2$$

$$s^2 - 2.7 \times 10^{-3}s + 1.815 \times 10^{-6} = 0$$

c. Solving the quadratic equation

$$s = \frac{\left(-2.70\times10^{-3}\right)\pm\sqrt{\left(2.70\times10^{-5}\right)^2-4(1)\left(1.815\times10^{-6}\right)}}{2(1)}$$

$s = [Ca^{2+}] = [CO_3^{2-}] = 1.266 \text{ x } 10^{-3}$ M

2-11 pH calculations

Given: $[H^+] = 10^{-5}$ M, assuming temperature = 25 $^{\circ}$C

Solution:

a. Using Eqn 2-38

$pH = -\log [H^+] = -\log 10^{-5} = 5$

b. Solving Eqn 2-40 for pOH

$pOH = 14 - pH = 14 - 5 = 9$

2-12 pH of HCl solution

Given: 200 mg of HCl in 1.00 L

Solution:

a. Calculate molarity

GMW of HCL = 36.45

$$\left(\frac{200\text{mg}}{\text{L}}\right)\left(10^{-3}\,\frac{\text{g}}{\text{mg}}\right)\left(\frac{1\text{mol}}{36.45\text{g}}\right) = 5.487\times10^{-3}\text{ M of HCl}$$

b. Moles of H^+ on ionization

$HCl \leftrightarrow H^+ + Cl^-$

so 1 mole HCl = 1 mole H^+

$[H^+] = 5.487 \text{ x } 10^{-3}$ M

c. Using Eqn 2-38

$\text{pH} = -\log(5.487 \times 10^{-3}) = 2.26$

2-13 Acetic acid and acetate concentration

Given: 11.1 g CH_3COONa in 1.0 L, final pH = 5.25.

Solution:

a. Concentration of acetic acid

$$\begin{array}{lr} & (12.01)(2) = 24.02 \\ & (1.008)(3) = 3.024 \\ & (16)(2) \quad = 32 \\ + & \underline{(22.99)(1) = 22.99} \\ & 82.034\ \text{g} \cdot \text{mol}^{-1} \end{array}$$

$$\frac{11.1\text{g} \cdot \text{L}^{-1}}{82.03\text{g} \cdot \text{mol}^{-1}} = 0.135\text{M}$$

b. By equation

$[CH_3COO^-] + [CH_3COOH] = 0.135$ M

or by shorthand,

$[A^-] + [HA] = 0.135$ M, and from Table 2-3 find $pK_a = 4.75$

c. Using Eqn 2-46

$$\frac{[H^+] \cdot [A^-]}{[HA]} = 10^{-4.75}$$

substituting,

$$\frac{[10^{-5.25}] \cdot [A^-]}{0.135 - [A^-]} = 10^{-4.75}$$

d. Solving for $[A^-]$

$[10^{-5.25}][A^-] = 10^{-4.75}(0.135 - [A^-])$

$[10^{-5.25}][A^-] = 2.40 \times 10^{-6} - 10^{-4.75}[A^-]$

$2.34 \times 10^{-5}[A^-] = 2.40 \times 10^{-6}$

$[A^-] = 0.102$ M

and thus, [HA] = (0.135 – 0.102) = 0.033 M

2-14 Trichloroethylene concentration

Given: 55 gal drum with 25 gal of mixture of solvent, Trichloroethylene measured in gas = 0.00301 atm, $H_c = 0.00985 \text{ mol} \cdot \text{m}^{-3} \cdot \text{atm}^{-1}$.

Solution:

a. Using Eqn 2-49

$C_{aq} = K_H{}^{'}P_{gas}$

$C_{aq} = (0.00985 \text{ mol} \cdot \text{m}^{-3} \cdot \text{atm}^{-1})(0.00301 \text{ atm}) = 2.965 \text{ x } 10\text{-}05 \text{ mol} \cdot \text{m}^{-3}$

in units of $\text{mol} \cdot \text{L}^{-1}$

$(2.965 \text{ x } 10^{-5} \text{ mol} \cdot \text{m}^{-3})(10^{-3} \text{ L} \cdot \text{m}^{-3}) = 2.96 \text{ x } 10^{-8} \text{ mol} \cdot \text{L}^{-1}$

2-15 Chemical decay to read $0.14 \text{ mg} \cdot \text{L}^{-1}$

Given: 1st order kinetics, rate of 0.2 d^{-1}, initial concentration = $100 \text{ mg} \cdot \text{L}^{-1}$.

Solution:

a. Time to read $0.14 \text{ mg} \cdot \text{L}^{-1}$ by 1st order kinetics

$$\ln\frac{C}{C_0} = -kt$$

$$\ln\frac{0.14}{100} = -(0.2)t$$

-6.57 = -0.2t

t = 32.85 or 32.9 d

2-16 Reaeration of pond to read $6.5 \text{ mg} \cdot \text{L}^{-1}$

Given: 1st order kinetics, rate of 0.034 d^{-1}, initial oxygen = $2.5 \text{ mg} \cdot \text{L}^{-1}$.

Solution:

a. Time to reach 6.5 mg · L^{-1} by 1st order kinetics using Eqn 2-64(a)

$$\ln\left(\frac{C_s - C_t}{C_s - C_0}\right) = -kt$$

Find value of C_s = 10.15 mg · L^{-1} from Appendix A and substitute into equation

$$\ln\left(\frac{10.15 - 6.5}{10.15 - 2.5}\right) = -(0.034)t$$

-0.73998 = -0.034(t)

t = 21.76 or 22 d

2-17 Hypochlorous acid decay to 0.05 mg · L^{-1}

Given: 1st order kinetics, rate = 0.21 d^{-1}, initial = 3.65 mg · L^{-1}.

Solution:

a. Time to read 0.05 mg · L^{-1}

$$\ln\frac{C}{C_0} = -kt$$

$$\ln\frac{0.05}{3.65} = -(0.12)t$$

- 4.29 = - (0.12)t

t = 35.75 or 35.8 d

2-18 Show that 1 g · mL^{-1} = 1000 kg · m^{-3}

Given: Conversion factors inside back cover

Solution:

$$\left(\frac{1\text{g}}{\text{mL}}\right)\left(\frac{0.001\text{kg}}{\text{g}}\right)\left(\frac{1000\text{mL}}{\text{L}}\right)\left(\frac{1000\text{L}}{\text{m}^3}\right) = \left(\frac{1000\text{kg}}{\text{m}^3}\right)$$

2-19 Show that 4.50% = 45.0 kg · m^{-3}

Given: % by weight in water

Solution:

a. Assume density of water = 1000 kg $\cdot$ m^{-3}

b. Calculate % by weight

0.045 x 1000 kg $\cdot$ m^{-3} = 45.0 kg $\cdot$ m^{-3}

2-20 Show that 1 mg $\cdot$ L^{-1} = 1 g $\cdot$ m^{-3}

Given: Conversion factors inside back cover

Solution:

$$\left(\frac{1\text{mg}}{\text{mL}}\right)\left(\frac{0.001\text{g}}{\text{mg}}\right)\left(\frac{1000\text{mL}}{\text{L}}\right)\left(\frac{1000\text{L}}{\text{m}^3}\right)=\left(\frac{1\text{g}}{\text{m}^3}\right)$$

2-21 Molarity and Normality

Given: Concentrations in mg $\cdot$ L^{-1}

Solution: Molecular Weights are on inside of front cover. In each case:

$$\text{Molarity}=\frac{\text{mg}\cdot\text{L}^{-1}\text{of}\cdot\text{species}}{(1000\text{mg}\cdot\text{g}^{-1})(\text{MW})}$$

Normality = (molarity)(n)

a. HCl

$$\text{Molarity}=\frac{200}{(1000)(36.4609)}=0.005485\text{M}$$

Normality = (0.005485)(1) = 0.005485 N

b. H_2SO_4

$$\text{Molarity}=\frac{150}{(1000)(98.07)}=0.001529\text{M}$$

Normality = (0.001529)(2) = 0.003059 N

c. $Ca(HCO_3)_2$

$$\text{Molarity} = \frac{100}{(1000)(162.1122)} = 0.0006168\text{M}$$

Normality = (0.0006169)(2) = 0.001234 N

d. H_3PO_4

$$\text{Molarity} = \frac{70}{(1000)(97.9951)} = 0.000714$$

Normality = (0.000714)(3) = 0.00214 N

2-22 Molarity and Normality

Given: concentrations in $\mu g \cdot L^{-1}$

Solution:

a. HNO_3

Converting micrograms to milligrams

$$80\mu g \cdot L^{-1}\left(\frac{1mg}{1000\mu g}\right) = 0.08mg \cdot L^{-1}$$

$$\text{Molarity} = \frac{0.08}{(1000)(63.015)} = 1.3\times10^{-6}\,\text{M}$$

Normality = $(1.3 \text{ x } 10^{-6}$ M)(1) = $1.3 \text{ x } 10^{-6}$ N

b. $CaCO_3$

$$135\mu g \cdot L^{-1}\left(\frac{1mg}{1000\mu g}\right) = 0.135mg \cdot L^{-1}$$

$$\text{Molarity} = \frac{0.135}{(1000)(100.09)} = 1.3\times10^{-6}\,\text{M}$$

Normality = $(1.3 \text{ x } 10^{-6}$ M)(2) = $2.7 \text{ x } 10^{-6}$ N

c. $Cr(OH)_3$

$$10 \mu g \cdot L^{-1}\left(\frac{1 mg}{1000 \mu g}\right) = 0.01 mg \cdot L^{-1}$$

$$\text{Molarity} = \frac{0.01}{(1000)(103.02)} = 1.0 \times 10^{-7} M$$

Normality = $(1.0 \text{ x } 10^{-7}$ M)(3) = $3 \text{ x } 10^{-7}$ N

d.$Ca(OH)_2$

$$1000 \mu g \cdot L^{-1}\left(\frac{1 mg}{1000 \mu g}\right) = 1.0 mg \cdot L^{-1}$$

$$\text{Molarity} = \frac{1.0}{(1000)(74.096)} = 1.35 \times 10^{-5} M$$

Normality = $(1.35 \text{ x } 10^{-5}$ M)(2) = $2.7 \text{ x } 10^{-5}$ N

2-23 Converting to mg · L^{-1}

Given: Molarity and normality

Solution:

a. Ca (n = 2 since charge is +2)

$$(0.01000 N)\left(\frac{40.08 g}{2 eq}\right)(1000 mg \cdot g^{-1}) = 200.4 mg \cdot L^{-1}$$

b. HCO_3 (n = 1 since charge is -1)

(1.000 M)(61.016 g · M^{-1})(1000 mg · g^{-1}) = 61.020 mg · L^{-1}

c. H_2SO_4 (n = 2)

$$(0.02000 N)\left(\frac{98.07 g}{2 eq}\right)(1000 mg \cdot g^{-1}) = 980.7 mg \cdot L^{-1}$$

d. SO_4

(0.02000 M)(96.054 g · $mole^{-1}$)(1000 mg · g^{-1}) = 1,921 mg · L^{-1}

2-24 Converting to µg · L^{-1}

Given: Molarity and normality

Solution:

a. H_2CO_3 (n = 2)

$(0.05\ N)(62.01\ g \cdot eq^{-1})(1/2)(1{,}000{,}000\ \mu g \cdot g^{-1}) = 1.6 \times 10^{6}\ \mu g \cdot L^{-1}$

b. $CHCl_3$

$(0.0010\ M)(119.37\ g \cdot mole^{-1})(1{,}000{,}000\ \mu g \cdot g^{-1}) = 1.2 \times 10^{5}\ \mu g \cdot L^{-1}$

c. $Ca(OH)_2$ (n = 2)

$(0.03\ N)(74.096\ g \cdot eq^{-1})(1/2)(1{,}000{,}000\ \mu g \cdot g^{-1}) = 1.1 \times 10^{6}\ \mu g \cdot L^{-1}$

d. CO_3

$(0.0080\ M)(60.011\ g \cdot mole^{-1})(1{,}000{,}000\ \mu g \cdot g^{-1}) = 4.8 \times 10^{5}\ \mu g \cdot L^{-1}$

2-25 Solubility of Mg in $mg \cdot L^{-1}$

Given: Solution 0.001000 M in OH

Solution: From Table 2-1 pK = 10.74 for $Mg(OH)_2$

$K_s = 10^{-10.74} = 1.82 \times 10^{-11}$

$K_s = [Mg][OH]^2$

$$[Mg] = \frac{1.82 \times 10^{-11}}{[0.001]^2} = 1.82 \times 10^{-5}\ M$$

$Mg = (1.82 \times 10^{-5}\ M)(24.305 \times 10^{3}\ mg \cdot mol^{-1})$

$Mg = 0.4423\ mg \cdot L^{-1}$

2-26 pH to precipitate iron

Given: Groundwater has 1.800 $mg \cdot L^{-1}$ Fe and desired concentration is 0.30 $mg \cdot L^{-1}$

Solution: From Table 2-1 $pK_s = 38.57$ for $Fe(OH)_3$

$K_s = 10^{-38.57} = 2.69 \times 10^{-39}$

$$[\text{Fe}] = \frac{0.30\,\text{mg}\cdot\text{L}^{-1}}{(55.847\,\text{g}\cdot\text{mol}^{-1})(1000\,\text{mg}\cdot\text{g}^{-1})} = 5.37\times10^{-6}\,\text{M}$$

$K_s = [Fe][OH]^3$

$$[\text{OH}] = \left(\frac{2.69\times10^{-39}}{5.37\times10^{-6}}\right)^{1/3}$$

$[OH] = (5.01x\ 10^{-33})^{1/3} = 7.94 \text{ x } 10^{-12}$ M

pOH = -log (7.94 x 10^{-12})

pOH = 11.10 and pH = 14.00 - 11.10 = 2.90

2-27 Calcium remaining in solution

Given: Saturated solution of $CaCO_3$ and addition of 5.00 x 10^{-3} M of Na_2CO_3

Solution: This solution requires the solution of quadratic equation.

a. Begin with the equilibrium reaction (Table 2-1)

$CaCO_3 = Ca^{2+} + CO_3$

b. Write the equilibrium expression using K_s from Table 2-1

$K_{so} = [Ca^{2+}][SO_4^{2-}] = 10^{-4.58} = 2.63 \text{ x } 10^{-5}$

c. Calculate the molar concentration of Ca and SO_4^{2-} at equilibrium

$[Ca^{2+}] = [SO_4^{2-}] = (2.63 \text{ x } 10^{-5})^{1/2} = 5.13 \text{ x } 10^{-3}$

d. Set up quadratic equation where x = amount of Ca that will be removed from solution.

$[Ca^{2+}] = 5.13 \text{ x } 10^{-3} - x$

$[SO_4^{2-}] = 5.13 \text{ x } 10^{-3} + 0.005 – x = 0.0101286 - x$

$K_s = (5.13 \text{ x } 10^{-3} - x)(0.0101286 - x) = 2.63 \text{ x } 10^{-5}$

$x^2 - 0.0152586\ (x) + 2.56597 \text{ x } 10^{-5} = 0$

e. Solving the quadratic we get roots of

$x = 1.333 \text{ x } 10^{-2}$ and $x = 1.924 \text{ x } 10^{-3}$

Since 1.333 x 10^{-2} is greater than what we started with, we select the root x = 1.924 x 10^{-3}

f. The amount of Ca remaining is then

$$[Ca] = 5.13 \text{ x } 10^{-3} - 1.924 \text{ x } 10^{-3} = 3.206 \text{ x } 10^{-3} \text{ M}$$

2-28 Fluoride solubility

Given: Solubility product of CaF_2 = 3 x 10^{-11}, F = 1.0 mg · L^{-1} and Ca = 200 mg · L^{-1}

Solution:

a. Convert Ca and F to moles · L^{-1}

$$[Ca] = \frac{200 \text{mg} \cdot L^{-1}}{(40.08 \text{g} \cdot \text{mol}^{-1})(1000 \text{mg} \cdot \text{g}^{-1})} = 4.99 \times 10^{-5} \text{M}$$

$$[F] = \frac{1.0 \text{mg} \cdot L^{-1}}{(18.998 \text{g} \cdot \text{mol}^{-1})(1000 \text{mg} \cdot \text{g}^{-1})} = 5.26 \times 10^{-5} \text{M}$$

b. Calculate solubility of F with 200 mg · L^{-1} of Ca in solution.

$$K_s = [Ca][F]^2$$

$$K_s = [4.99 \text{ x } 10^{-3}][F]^2 = 3.00 \text{ x } 10^{-11}$$

$$[F] = \left(\frac{3.00 \times 10^{-11}}{4.99 \times 10^{-3}}\right)^{1/2} = 7.75 \times 10^{-5} \text{M}$$

c. Since 7.75 x 10^{-5} is greater than 5.26 x 10^{-5}, the 1.0 mg · L^{-1} of F will be soluble.

2-29 Amount of base to neutralize acid

Given: Acid concentrations in Example 2-11

Solution:

a. The reaction is

$$H_2SO_4 + 2 \text{ NaOH} = Na_2SO_4 + 2 H_2O$$

Therefore two moles of NaOH are required to neutralize each mole of H_2SO_4 .

Assuming one liter:

$$\frac{100.0\text{mg}}{98.07\text{mg}\cdot\text{mmol}^{-1}}=\frac{x}{2\left(39.997\text{mg}\cdot\text{mmol}^{-1}\right)}$$

$x = (1.0197)(2)(39.997)$

$x = 81.5683$ or 81.6 mg

2-30 Neutralize finished softened water

Given: pH is 10.74; normality of H_2SO_4 is 0.02000

Solution:

a. Assume only OH is present. Then

pOH = 14.00 - 10.74 = 3.26

$[OH] = 10^{-3.26} = 5.50 \times 10^{-4}$ moles · L^{-1}

b. Since n = 1 for OH the normality = molarity. Then since

N x mL = N x mL

We can say

$(5.50 \times 10^{-4})(1000 \text{ mL}) = (0.02000)(\text{mL acid})$

c. Solving for (mL acid)

mL acid = 27.477 or 27.5 mL

2-31 Neutralize finished water with HCl

Given: Problem 2-30

Solution: Since the normality is exactly the same as in Problem 2-30 the form of the acid is irrelevant and the answer is the same as in Problem 2-30, i.e. 27.5 mL

2-32 pH of water containing carbonic acid

Given: 0.6580 mg · L^{-1} H_2CO_3; assume $H^+ = HCO_3$

Solution:

a. From Table 2-3, $pK_a = 6.35$ for H_2CO_3

b. Convert mg · L^{-1} to moles · L^{-1}

$$\frac{0.6580\text{mg}}{\left(62.024\text{g}\cdot\text{mol}^{-1}\right)\left(1000\text{mg}\cdot\text{g}^{-1}\right)} = 1.061\times10^{-5}\,\text{M}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+]\cdot[HCO_3]}{[H_2CO_3]} = 10^{-6.35} = 4.467\times10^{-7}$$

d. Substitute carbonic acid concentration

$$K_a = \frac{[H^+]\cdot[HCO_3]}{[1.061\times10^{-5}]} = 10^{-6.35} = 4.467\times10^{-7}$$

e. Assuming $[H^+] = [HCO_3]$

$[H^+]^2 = 4.739 \text{ x } 10^{-12}$

$[H^+] = 2.177 \text{ x } 10^{-6}$

$pH = -\log(2.177\text{x}10^{-6}) = 5.66$

2-33 pH of water containing hypochlorous acid

Given: 0.5000 mg · L^{-1} HOCl; assume equilibrium

Solution:

a. From Table 2-3, $pK_a = 7.54$ for HOCl

b. Convert mg · L^{-1} to moles · L^{-1}

$$\frac{0.5000\text{mg}}{\left(52.45\text{g}\cdot\text{mol}^{-1}\right)\left(1000\text{mg}\cdot\text{g}^{-1}\right)} = 9.53\times10^{-6}\,\text{M}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+]\cdot[OCl^-]}{[HOCl]} = 10^{-7.54} = 2.884\times10^{-8}$$

d. Substitute hypochlorous acid concentration

$$K_a = \frac{[H^+]\cdot[OCl^-]}{[9.53\times10^{-6}]} = 2.884\times10^{-8}$$

e. Assuming $[H^+] = [OCl^-]$

$[H^+]^2 = 2.748 \text{ x } 10^{-13}$

$[H^+] = 5.24 \text{ x } 10^{-7}$

$\text{pH} = -\log(5.24 \text{ x } 10^{-7}) = 6.28$

2-34 OCl concentration

Given: Data in Problem 2-33 and pH = 7.00

Solution:

a. From Table 2-3, $pK_a = 7.54$ for HOCl.

b. Convert mg · L^{-1} to moles · L^{-1}

$$\frac{0.5000\text{mg}}{(36.46\text{g}\cdot\text{mol}^{-1})(1000\text{mg}\cdot\text{g}^{-1})} = 1.371\times10^{-5}\,\text{M}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+]\cdot[OCl^-]}{[HOCl]} = 10^{-7.54} = 2.884\times10^{-8}$$

d. With $[H^+] = 10^{-7}$ and hypochlorous acid concentration

$$K_a = \frac{[10^{-7}]\cdot[OCl^-]}{[1.371\times10^{-5}]} = 2.884\times10^{-8}$$

e. Solve for OCl

$[OCl^-] = 3.954 \text{ x } 10^{-6}$ moles · L^{-1}

f. Convert to mg · L^{-1}

$(3.954 \text{ x } 10^{-6}$ moles · $L^{-1})(51.452$ g · mole$^{-1})(1000$ mg · g$^{-1}) = 0.2034$ or 0.203 mg · L^{-1}

2-35 Converting from mg · L^{-1} to mg · L^{-1} as $CaCO_3$

Given: Concentrations in mg · L^{-1} as ion, E.W. of $CaCO_3$ = 50.04

Solution:

a. Ca (n = 2 because valence = 2)

$$\text{E.W.} = \frac{40.08}{2} = 20.04$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 83.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{20.04}\right) = 207.2515 \text{ or } 207.3$$

b. Mg (n = 2 because valence = 2)

$$\text{E.W.} = \frac{24.305}{2} = 12.1525$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 27.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{12.1525}\right) = 111.177 \text{ or } 111.2$$

c. CO_2 (n = 2 because H_2CO_3 has 2 hydrogens)

$$\text{E.W.} = \frac{44.01}{2} = 22.00$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 48.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{22.00}\right) = 109.178 \text{ or } 109.2$$

d. HCO_3 (n = 1 because valence = 1)

$$\text{E.W.} = \frac{61.02}{1} = 61.02$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 220.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{61.02}\right) = 180.413 \text{ or } 180.4$$

e. CO_3 (n = 2 because valence = 2)

$$\text{E.W.} = \frac{60.01}{2} = 30.00$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 15.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{30.00}\right) = 25.02 \text{ or } 25.02$$

2-36 Converting from mg · L^{-1} to mg · L^{-1} as $CaCO_3$

Given: Concentrations in mg/L as ion, E.W. of $CaCO_3$ = 50.04

Solution:

a. NH_4 (n = 1 because valence = 1)

$$\text{E.W.} = \frac{18.042}{1} = 18.042$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 200.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{18.042}\right) = 554.7$$

b. K (n = 1 since valence = 1)

$$\text{E.W.} = \frac{39.10}{1} = 39.10$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 280.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{39.10}\right) = 358.3$$

c. SO_4 (n = 2 because valence = 2)

$$\text{E.W.} = \frac{96.07}{2} = 48.035$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 123.45\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{48.035}\right) = 128.6$$

d. Ca (n = 2 because valence = 2)

$$\text{E.W.} = \frac{40.08}{2} = 20.04$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 85.05\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{20.04}\right) = 212.4$$

e. Na (n = 1 because valence = 1)

$$\text{E.W.} = \frac{22.9898}{1} = 22.9898$$

$$\text{mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 = 19.00\text{mg} \cdot \text{L}^{-1}\left(\frac{50.04}{22.9898}\right) = 9.143$$

2-37 Converting from mg · L^{-1} as CaCO$_3$ to mg · L^{-1}

Given: Concentrations in mg · L^{-1} as CaCO$_3$

Solution:

a. SO$_4$ (n = 2 because valence = 2)

$$\text{E.W.} = \frac{96.06}{2} = 48.03$$

$$\text{mg} \cdot \text{L}^{-1} = 100.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3\left(\frac{48.03}{50.04}\right) = 95.98$$

b. HCO$_3$ (n = 1 because valence = 1)

$$\text{E.W.} = \frac{61.016}{1} = 61.016$$

$$\text{mg} \cdot \text{L}^{-1} = 30.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3\left(\frac{61.016}{50.04}\right) = 36.58$$

c. Ca (n = 2 because valence = 2)

$$\text{E.W.} = \frac{40.08}{2} = 20.04$$

$$\text{mg} \cdot \text{L}^{-1} = 150.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3\left(\frac{20.04}{50.04}\right) = 60.07$$

d. H$_2$CO$_3$ (n = 2 because 2 H)

$$\text{E.W.} = \frac{62.03}{2} = 31.02$$

$$\text{mg} \cdot \text{L}^{-1} = 10.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3\left(\frac{31.02}{50.04}\right) = 6.198$$

e. Na (n = 1 because valence = 1)

$$\text{E.W.} = \frac{22.9898}{1} = 22.9898$$

$$\text{mg} \cdot \text{L}^{-1} = 150.0 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{22.9898}{50.04}\right) = 68.9143 \text{ or } 68.91$$

2-38 Converting from mg · L^{-1} as $CaCO_3$ to mg · L^{-1}

Given: Concentrations in mg · L^{-1} as $CaCO_3$

Solution:

a. CO_2 (n = 2 because H_2CO_3 has 2 H^+ replaceable)

$$\text{E.W.} = \frac{44.01}{2} = 22.00$$

$$\text{mg} \cdot \text{L}^{-1} = 10.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{22.00}{50.04}\right) = 4.3965 \text{ or } 4.397$$

b. $Ca(OH)_2$ (n = 2 because Ca requires 2 H^+ for replacement)

$$\text{E.W.} = \frac{74.09}{2} = 37.045$$

$$\text{mg} \cdot \text{L}^{-1} = 13.50 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{37.045}{50.04}\right) = 9.9942 \text{ or } 9.994$$

c. HPO_4 (n = 1 because 1 H)

$$\text{E.W.} = \frac{95.978}{1} = 95.978$$

$$\text{mg} \cdot \text{L}^{-1} = 481.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{95.978}{50.04}\right) = 922.6$$

d. H_2PO_4 (n = 2 because of 2 H)

$$\text{E.W.} = \frac{96.9872}{2} = 48.4936$$

$$\text{mg} \cdot \text{L}^{-1} = 81.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{48.4936}{50.04}\right) = 78.4968 \text{ or } 78.50$$

e. Cl (n = 1 because valence = 1)

$$\text{E.W.} = \frac{35.453}{1} = 35.453$$

$$\text{mg} \cdot \text{L}^{-1} = 40.00 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3 \left(\frac{35.453}{50.04}\right) = 28.3397 \text{ or } 28.34$$

2-39 Exact alkalinity

Given: HCO_3 = 0.6580 mg · L^{-1}; pH = 5.66; CO_3 = 0.00

Solution:

a. Convert HCO_3 to mg · L^{-1} as $CaCO_3$

$$0.6580 \left(\frac{50.04}{61.016}\right) = 0.53963 \text{ mg} \cdot \text{L}^{-1} \text{ as CaCO}_3$$

b. Convert pH to $[H^+]$

$$[H^+] = 10^{-5.66} = 2.188 \text{ x } 10^{-6} \text{ moles} \cdot \text{L}^{-1}$$

c. In mg · L^{-1}

$$\text{mg} \cdot \text{L}^{-1} = (2.1886 \text{ x } 10^{-6} \text{ M})(1.0079 \text{ x } 10^{3} \text{ mg} \cdot \text{mole}^{-1}) = 2.205 \text{ x } 10^{-3}$$

d. In mg · L^{-1} as $CaCO_3$

$$(2.205 \text{ x } 10^{-3})\left(\frac{50.04}{1.0079}\right) = 0.10948$$

e. Convert pH to OH

$$\text{pOH} = 14.00 - 5.66 = 8.34$$

$$[\text{OH}] = 10^{-8.34} = 4.571 \text{ x } 10^{-9} \text{ M}$$

f. In mg · L^{-1}

$$\text{mg} \cdot \text{L}^{-1} = (4.571 \text{ x } 10^{-9})(17.007 \text{ x } 10^{3} \text{ mg} \cdot \text{mole}^{-1}) = 7.774 \text{ x } 10^{-5}$$

g. In mg · L^{-1} as $CaCO_3$

$$7.774 \times 10^{-5}\left(\frac{50.04}{17.007}\right) = 2.287 \times 10^{-4}$$

h. Exact alkalinity (all in mg · L^{-1} as $CaCO_3$)

$$ALK = HCO_3 + CO_3 + OH - H$$

$$ALK = 0.53963 + 0 + 2.287 \times 10^{-4} - 0.10948$$

$$ALK = 0.4302 \text{ or } 0.43 \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$$

2-40 Calculate approximate alkalinity

Given: HCO_3 = 120 mg · L^{-1}; CO_3 = 15.00 mg · L^{-1}

Solution:

a. Convert to mg · L^{-1} as $CaCO_3$

HCO_3 (120 mg · L^{-1})(50.04/61.02) = 98.41

CO_3 (15.00 mg · L^{-1})(50.04/30.00) = 25.02

b. Calculate approximate alkalinity

$$ALK = 98.41 + 25.02 = 123.43 \text{ or } 123. \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$$

2-41 Exact alkalinity

Given: Problem 2-39; HCO_3 = 120 mg · L^{-1}; pH = 9.43; CO_3 = 15.00 mg · L^{-1}

Solution:

a. Convert HCO_3 to mg · L^{-1} as $CaCO_3$

$$120.0\left(\frac{50.04}{61.016}\right) = 98.41 \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$$

b. Convert CO_3 to mg · L^{-1} as $CaCO_3$

$$15.00\left(\frac{50.04}{30.004}\right) = 25.02 \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$$

c. Convert pH to H

$[H^+] = 10^{-9.43} = 3.715 \text{ x } 10^{-10} \text{ moles} \cdot L^{-1}$

d. In mg · L^{-1}

$\text{mg} \cdot L^{-1} = (3.715 \text{ x } 10^{-10} \text{ M})(1.0079 \text{ x } 10^{3} \text{ mg} \cdot \text{mole}^{-1}) = 3.745 \text{ x } 10^{-7}$

e. In mg · L^{-1} as $CaCO_3$

$$(3.745 \text{ x } 10^{-7})\left(\frac{50.04}{1.0079}\right) = 1.86 \text{ x } 10^{-5}$$

f. Convert pH to OH

pOH = 14.00 - 9.43 = 4.57

$[OH] = 10^{-4.57} = 2.692 \text{ x } 10^{-5} \text{ M}$

g. In mg · L^{-1}

$\text{mg} \cdot L^{-1} = (2.692 \text{ x } 10^{-5})(17.007 \text{ x } 10^{3} \text{ mg} \cdot \text{mole}^{-1}) = 0.4578$

h. In mg · L^{-1} as $CaCO_3$

$$0.4578\left(\frac{50.04}{17.007}\right) = 1.347$$

i. Exact alkalinity (all in mg · L^{-1} as $CaCO_3$)

$ALK = HCO_3 + CO_3 + OH - H$

$ALK = 98.41 + 25.02 + 1.347 - (1.86 \text{ x } 10^{-5})$

$ALK = 124.78 \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$

2-42 Calculate exact alkalinity

Given: Problem 2-39, pH = 11.03.

Solution:

a. From Problem 2-41,

$HCO_3 = 98.41 \text{ mg} \cdot L^{-1} \text{ as } CaCO_3$

$CO_3 = 25.02\ mg \cdot L^{-1}$ as $CaCO_3$

b. Convert pH to H

$[H^+] = 10^{-11.03} = 9.333 \times 10^{-12}\ mol \cdot L^{-1}$

c. In $mg \cdot L^{-1}$

$mg \cdot L^{-1} = (9.333 \times 10^{-12}\ M)(1.0079 \times 10^3\ mg \cdot mole^{-1}) = 9.406 \times 10^{-9}$

e. In $mg \cdot L^{-1}$ as $CaCO_3$

$$(9.406 \times 10^{-9})\left(\frac{50.04}{1.0079}\right) = 4.67 \times 10^{-7}$$

f. Convert pH to OH

$pOH = 14.00 – 11.03 = 2.97$

$[OH] = 10^{-2.97} = 1.072 \times 10^{-3}\ M$

g. In $mg \cdot L^{-1}$

$mg \cdot L^{-1} = (1.072 \times 10^{-3})(17.007 \times 10^3\ mg \cdot mole^{-1}) = 18.22$

h. In $mg \cdot L^{-1}$ as $CaCO_3$

$$18.22\left(\frac{50.04}{17.007}\right) = 53.62$$

i. Exact alkalinity (all in $mg \cdot L^{-1}$ as $CaCO_3$)

$ALK = HCO_3 + CO_3 + OH - H$

$ALK = 98.41 + 25.02 + 53.62 - (4.67 \times 10^{-7})$

$ALK = 177.05\ mg \cdot L^{-1}$ as $CaCO_3$

2-43 Determining pH from carbonate and bicarbonate

Given: $HCO_3 = 120.00$ and $CO_3 = 15.00\ mg \cdot L^{-1}$ as ion

Solution:

a. Convert HCO_3^- concentration to $mol \cdot L^{-1}$

GMW = 1 + 12+ 3(16) = 61

$$\frac{120.00\text{mg} \cdot \text{L}^{-1}}{61 \times 10^{3}\,\text{mg} \cdot \text{mol}^{-1}} = 0.001967\text{M}$$

b. Convert CO_3^{2-} concentration to mol · L^{-1}

GMW = 12 + 3(16) = 60

$$\frac{15.00\text{mg} \cdot \text{L}^{-1}}{60 \times 10^{3}\,\text{mg} \cdot \text{mol}^{-1}} = 2.5 \times 10^{-4}\,\text{M}$$

c. The equilibrium expression is

$$K_{a2} = \frac{\left[CO_3^{\,2-}\right] \cdot \left[H^+\right]}{\left[HCO_3^{\,-}\right]}$$

d. From Table 2-3, $K_{a2} = 10^{-10.33}$

e. Solve for $[H^+]$

$$\left[H^+\right] = \frac{K_{a2}\left[HCO_3^{\,-}\right]}{\left[CO_3^{\,2-}\right]}$$

$$\left[H^+\right] = \frac{10^{10.33}(0.001967)}{\left(2.50 \times 10^{-4}\right)}$$

$[H^+]$ = 3.680 x 10^{-10}

f. Solve for pH

pH = -log$[H^+]$

pH = -log(3.680 x 10^{-10}) = 9.43

2-44 Density of oxygen

Given: Temperature = 273.0 K, pressure = 98.0 kPa

Solution:

a. Assume 1 gram mole of oxygen

From inside front cover of book GMW of O = 15.9994

For O_2 = 2(15.999) = 31.9988 g · mol^{-1}

b. Calculate density, Eqn 2-92(a)

$$\rho = \left(\frac{1}{8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}}\right)\left(\frac{(98.0\text{kPa})(1\text{mol})(31.9988\text{g}\cdot\text{mol}^{-1})}{273\text{K}}\right)(1000\text{Pa}\cdot\text{kPa}^{-1})(10^{-3}\,\text{kg}\cdot\text{g}^{-1})$$

ρ = 1.382 kg · m^{-3}

2-45 Density of nitrogen

Given: Temperature = 298.0 K, pressure = 122.8 kPa

Solution:

a. Assume 1 gram mole of nitrogen

From inside front cover of book GMW of N =14.0067

For N_2 = 2(14.0067) = 28.0134 g · mol^{-1}

b. Calculate density, Eqn 2-92(a)

$$\rho = \left(\frac{1}{8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}}\right)\left(\frac{(122.8\text{kPa})(1\text{mol})(28.0134\text{g}\cdot\text{mol}^{-1})}{298\text{K}}\right)(1000\text{Pa}\cdot\text{kPa}^{-1})(10^{-3}\,\text{kg}\cdot\text{g}^{-1})$$

ρ = 1.39 kg · m^{-3}

2-46 Show one mole = 22.414 L at STP

Given: STP = 273.16 K, 101.325 kPa

Solution:

a. Solve Eqn 2-92(b) for V. Note that J = (N)(m) and that Pa = N · m^{-2} so that units are

$$V = \frac{(\text{mol})\left(\frac{\text{N}\cdot\text{m}}{\text{K}\cdot\text{mol}}\right)\text{K}}{\text{N}\cdot\text{m}^{-2}} = \text{m}^3$$

b. Using Eqn 2-92(b) with n = 1

$$V = \frac{(1\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(273.16\text{K})}{(101.325\text{kPa})(1000\text{Pa}\cdot\text{kPa}^{-1})}(1000\text{L}\cdot\text{m}^{-3})$$

V = 22.414 L

2-47 Volume occupied by 1 mole

Given: T = 25.0 °C, 101.325 kPa

Solution:

a. Solve Eqn 2-92(b) for V. Note that J = (N)(m) and that Pa = N · m^{-2} so that units are

$$V = \frac{(\text{mol})\left(\frac{\text{N}\cdot\text{m}}{\text{K}\cdot\text{mol}}\right)\text{K}}{\text{N}\cdot\text{m}^{-2}} = \text{m}^3$$

b. Using Eqn 2-92(b)with n = 1

$$V = \frac{(1\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(298.0\text{K})}{(101.325\text{kPa})(1000\text{Pa}\cdot\text{kPa}^{-1})}(1000\text{L}\cdot\text{m}^{-3})$$

V = 24.46 L

2-48 Partial pressures of oxygen and nitrogen

Given: STP, oxygen = 8.583 moles · m^{-3}, nitrogen = 15.93 moles · m^{-3}, 1.0 m^3 of air

Solution:

a. Solve Eqn 2-92(b) for P. Note that J = (N)(m) and that Pa = N · m^{-2} so that units are

$$P = \frac{(\text{mol})\left(\frac{\text{N}\cdot\text{m}}{\text{K}\cdot\text{mol}}\right)\text{K}}{\text{m}^3} = \text{N}\cdot\text{m}^{-2} = \text{Pa}$$

b. Partial pressure of oxygen Eqn 2-93(a)

$$P_{O2} = \frac{(8.563\text{mol}\cdot\text{m}^{-3})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(273.16\text{K})(10^{-3}\text{g}\cdot\text{kg}^{-1})}{1.0\text{m}^3}$$

P_{O2} = 19.45 kPa

c. Partial pressure of nitrogen Eqn 2-93(a)

$$P_{N2} = \frac{\left(15.93\text{mol}\cdot\text{m}^{-3}\right)\left(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}\right)\left(273.16\text{K}\right)\left(10^{-3}\text{g}\cdot\text{kg}^{-1}\right)}{1.0\text{m}^3}$$

P_{N2} = 36.18 kPa

2-49 Partial pressures of oxygen, nitrogen, carbon dioxide

Given: T = 25.0 °C, oxygen = 18.32 moles, nitrogen = 16.40 moles, carbon dioxide = 6.15 moles, 1.0 m^3 tank

Solution:

a. Solve Eqn 2-92(b) for P. Note that J = (N)(m) and that Pa = N · m^{-2} so that units are

$$P = \frac{(\text{mol})\left(\frac{\text{N}\cdot\text{m}}{\text{K}\cdot\text{mol}}\right)\text{K}}{\text{m}^3} = \text{N}\cdot\text{m}^{-2} = \text{Pa}$$

b. Convert temperature to K

T = 25.0 + 273 = 298 K

c. Partial pressure of oxygen Eqn 2-92(b)

$$P_{O2} = \frac{\left(18.32\text{mol}\cdot\text{m}^{-3}\right)\left(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}\right)\left(298.0\text{K}\right)\left(10^{-3}\text{g}\cdot\text{kg}^{-1}\right)}{1.0\text{m}^3}$$

P_{O2} = 45.39 kPa

d. Partial pressure of nitrogen Eqn 2-92(b)

$$P_{N2} = \frac{\left(16.40\text{mol}\cdot\text{m}^{-3}\right)\left(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}\right)\left(273.16\text{K}\right)\left(10^{-3}\text{g}\cdot\text{kg}^{-1}\right)}{1.0\text{m}^3}$$

P_{N2} = 40.63 kPa

e. Partial pressure of carbon dioxide Eqn 2-92(b)

$$P_{CO2} = \frac{\left(6.15\text{mol}\cdot\text{m}^{-3}\right)\left(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}\right)\left(298.0\text{K}\right)\left(10^{-3}\text{g}\cdot\text{kg}^{-1}\right)}{1.0\text{m}^3}$$

P_{CO2} = 15.2 kPa

2-50 Volume of carbon dioxide

Given: carbon dioxide = 5.2 kg, P = 152.0 kPa, T = 315.0 K

Solution:

a. Compute number of moles

GMW = 12.011 + 2(15.9994) = 44.0098

$$n = \frac{5200\text{g}}{44.00\text{g}\cdot\text{mol}^{-1}} = 118.18\text{mol}$$

b. Compute volume as in Problem 2-49 above

$$V = \frac{(118.18\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(315.0\text{K})}{(152.0\text{kPa})(1000\text{Pa}\cdot\text{kPa}^{-1})}(1000\text{L}\cdot\text{m}^{-3})$$

V = 2,036 L

2-51 Mass of oxygen

Given: volume = 5.0 m^3, P = 568.0 kPa, T. = 263.0 K

Solution:

a. Solve Eqn 2-92(b) for n

$$n = \frac{PV}{RT} = \frac{(568)(5.0)}{(8.314)(263.0)} = 1.2988$$

b. Compute mass

M_{O2} = (1.2988 moles)(31.9988 g · mole^{-1}) = 41.56 g

2-52 Partial pressure of H_2S

Given: 250 mg · L^{-1} of H_2S, T = 0 °C, P = 108.26 kPa

Solution:

a. Compute number of moles

GMW = 2(1.0079) + 32.06 = 34.07 g · mole^{-1}

$$n = \frac{250\text{mg}}{34.07\text{g}\cdot\text{mol}^{-1}} = 7.3366\times10^{-3}\text{mol}$$

b. Solve Eqn 2-92(b) for P (see Problem 2-51 above)

$$P_{H2S} = \frac{(7.3366\times10^{-3}\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(298.0\text{K})(10^{-3}\text{g}\cdot\text{kg}^{-1})}{1.0\text{L}}(1000\text{L}\cdot\text{m}^{-3})$$

P_{H2S} = 16.7 kPa

2-53 Partial pressures of CH_4, N_2, and CO_2

Given: 28 L volume, T = 300 K, 11 g methane, 1.5 g nitrogen, 16 g of carbon dioxide

Solution:

a. Compute moles of each gas

GMW_{CH4} = 12.011 + 4(1.0079) = 16.04 g · mole^{-1}

$$n = \frac{11\text{g}}{16.04\text{g}\cdot\text{mol}^{-1}} = 0.6856\text{mol}$$

GMW_{N2} = 2(14.0067) = 28.013 g · mole^{-1}

$$n = \frac{1.5\text{g}}{28.013\text{g}\cdot\text{mol}^{-1}} = 0.05355\text{mol}$$

GMW_{CO2} = 12.011 + 2(15.9994) = 44.01

$$n = \frac{16\text{g}}{44.01\text{g}\cdot\text{mol}^{-1}} = 0.3633\text{mol}$$

b. Compute partial pressures Eqn 2-92(b)

$$P_{CH4} = \frac{(0.6857\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(300.0\text{K})(10^{-3}\text{g}\cdot\text{kg}^{-1})}{28.0\text{L}}(1000\text{L}\cdot\text{m}^{-3})$$

P_{CH4} = 61.08 or 61 kPa

$$P_{N2} = \frac{(0.05355\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(300.0\text{K})(10^{-3}\text{g}\cdot\text{kg}^{-1})}{28.0\text{L}}(1000\text{L}\cdot\text{m}^{-3})$$

P_{N2} = 4.77 or 4.8 kPa

$$P_{CO2} = \frac{(0.3633\text{mol})(8.3143\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(300.0\text{K})(10^{-3}\text{g}\cdot\text{kg}^{-1})}{28.0\text{L}}(1000\text{L}\cdot\text{m}^{-3})$$

P_{CO2} = 32.36 or 32 kPa

2-54 Moles of gas present in Problem 2-53

Given: See Problem 2-53

Solution:

a. Compute moles of each gas
(Note: this is essentially a repetition of part of Problem 2-52 computed here with significant figures equal to that given)

GMW_{CH4} = 12.011 + 4(1.0079) = 16.04 g · mole^{-1}

$$n = \frac{11\text{g}}{16\text{g}\cdot\text{mol}^{-1}} = 0.688 \text{ or } 0.69 \text{ moles}$$

GMW_{N2} = 2(14.0067) = 28.013 g · mole^{-1}

$$n = \frac{1.5\text{g}}{28\text{g}\cdot\text{mol}^{-1}} = 0.05357 \text{ or } 0.054 \text{ moles}$$

GMW_{CO2} = 12.011 + 2(15.9994) = 44.01

$$n = \frac{16\text{g}}{44\text{g}\cdot\text{mol}^{-1}} = 0.364 \text{ or } 0.36 \text{ moles}$$

2-55 Gram molecular weight of air

Given: 22.414 L volume of air at STP, P_{O2} = 21.224 kPa, P_{N2} = 79.119 kPa, P_{Ar} =0.946 kPa, P_{CO2} = 0.036 kPa

Solution:

a. Compute number of moles of each gas

Oxygen

$$n = \frac{PV}{RT} = \frac{(21.224\text{kPa})(10^3\,\text{Pa}\cdot\text{kPa}^{-1})(22.414\text{L})(10^{-3}\,\text{m}^3\cdot\text{L}^{-1})}{(8.314)(273.15)}$$

n = 0.209469

Nitrogen

$$n = \frac{PV}{RT} = \frac{(79.119\text{kPa})(10^3\,\text{Pa}\cdot\text{kPa}^{-1})(22.414\text{L})(10^{-3}\,\text{m}^3\cdot\text{L}^{-1})}{(8.314)(273.15)}$$

n = 0.78086

Argon

$$n = \frac{PV}{RT} = \frac{(0.946\text{kPa})(10^3\,\text{Pa}\cdot\text{kPa}^{-1})(22.414\text{L})(10^{-3}\,\text{m}^3\cdot\text{L}^{-1})}{(8.314)(273.15)}$$

n = 0.009336

Carbon dioxide

$$n = \frac{PV}{RT} = \frac{(0.036\text{kPa})(10^3\,\text{Pa}\cdot\text{kPa}^{-1})(22.414\text{L})(10^{-3}\,\text{m}^3\cdot\text{L}^{-1})}{(8.314)(273.15)}$$

n = 0.000355

b. Compute mass of each gas

M_{O2} = (n)(M) = 0.209469(31.9988) = 6.703

M_{N2} = 0.78086(28.013) = 21.874

M_{Ar} = 0.009336(39.948) = 0.37296

M_{CO2} = 0.000355(44.0098) = 0.01562

c. Molecular weight of air

$M_{O2} + M_{N2} + M_{Ar} + M_{CO2}$ = 28.966 or 28.97 g · mole^{-1}

2-56 Micrograms · m^{-3} to ppm for SO_2

Given: 80 µg · m^{-3} of SO_2, T = 25 °C, P = 101.325 kPa

Solution:

a. Compute GMW of SO_2

GMW = 32.06 + 31.9988 = 64.058

b. Convert to ppm using Eqn 2-97

$$\text{ppm} = \frac{\left(\frac{80}{64.06}\right)(22.414)\left(\frac{298}{273}\right)\left(\frac{101.325}{101.325}\right)}{(1.0)(1000)}$$

ppm = 0.030555 or 0.031

2-57 ppm to $\mu g \cdot m^{-3}$ for NO_2

Given: 0.55 ppm of NO_2, T = 290 K, P = 100.0 kPa

Solution:

a. Compute GMW of NO_2

GMW = 14.0067 + 31.9988 = 46.0055

b. Convert to ppm using Eqn 2-97

$$M_p = \frac{(0.55)(1000)(46.0055)}{(22.414)\left(\frac{290}{273}\right)\left(\frac{101.325}{100}\right)}$$

M_p = 1048.82 or 1050 $\mu g \cdot m^{-3}$

2-58 Partition coefficient

Given: chemical concentration in soil= 100 $mg \cdot kg^{-1}$, chemical concentration in water = 250 $\mu g \cdot L^{-1}$.

Solution:

a. From Eqn 2-89

$$K_d = \frac{C_s}{C_w}$$

$$K_d = \frac{100\text{mg} \cdot \text{kg}^{-1}}{0.250\text{mg} \cdot \text{L}^{-1}} = 400\text{mg} \cdot \text{kg}^{-1} \cdot \text{mg}^{-1} \cdot \text{L}$$

2-59 Chemical concentration in soil

Given: Partition coefficicient = 12,500 (mg · kg^{-1} · mg^{-1} · L),
concentration in water = 105 μg · L^{-1}.

Solution:

a. From Eqn 2-89

$C_s = C_w K_d$

$C_s = (12500 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{mg}^{-1} \cdot \text{L})(0.105 \text{ mg} \cdot \text{L}^{-1})$

$C_s = 1312.5 \text{ mg} \cdot \text{kg}^{-1}$

2-60 Derivation of half-life

Given: First order reaction.

Solution:

a. For a first order reaction

$$\int_{C_O}^{C} \frac{dC}{dt} = -\int_0^t kC$$

$$\ln \frac{C}{C_O} = -kt$$

where $C = 0.5\, C_o$

$$\ln \frac{0.5C_O}{C_O} = -kt$$

ln 0.5 = -kt

-0.693 = -kt

$$t_{1/2} = \frac{0.693}{k}$$

CHAPTER 2
DISCUSSION QUESTIONS

2-1 pH of carbonated beverage

Given: carbonated beverage

Solution:

The pH will be below 7. This is an application of the carbonate buffer system. Since the beverage container is closed the addition of CO_2 forces the carbonate buffer system reaction to the right. Carbonic acid is formed. The dissociation results in an increase in hydrogen ion concentration and a lowering of the pH. See Equation 2-77 and Figure 2-12.

2-2 Molarity explanation

Given: Explain the concentration unit of molarity to a citizen at a hazardous waste site.

Solution;

Molarity is the number of moles per liter of solution. Each substance is composed of a particular number of atoms. Each atom has a particular atomic weight.
A mole is the sum of the atomic weights (called the molecular weight) of a substance.
Thus, the hazardous waste benzene has 6 atoms of carbon and 6 atoms of hydrogen.
Carbon has an atomic weight of 12 and hydrogen has an atomic weight of 1. The molecular weight of benzene is then

$(6)(12) + (6)(1) = 78$ g per mole

A 1 molar solution of benzene has 78 g of benzene in 1 liter of water.

2-3 Alkalinity and acid rain

Given: would a lake having a high or low alkalinity be more affected by acid rain with a pH of <4

Solution:

Alkalinity is a measure of buffer capacity. A high alkalinity lake would be less affected than a low alkalinity lake because it would be better able to resist change in pH.

2-4 Carbonated beverage pH

Given: an open can of carbonated beverage. Would the pH increase, decrease or remain the same?

Solution:

The pH would increase because the CO_2 would be released from solution and the carbonate buffer system would shift to the left resulting in a lower concentration of H^+ and thus a higher pH. (See Eqn. 2-77 and Figure 2-12)

2-5 Dissolution of kaolinite

Given: would the mineral kaolinite dissolve more in a water with a high or low pH

Solution:

Clays, including kaolinite, have a crystaline structure composed of silicon, aluminum, oxygen and hydrogen. They are formed by hydrolysis reactions of silicates. Thus, kaolinite will dissolve more in low pH than in high pH and liming of soil is a common practice to improve soil structure.

2-6 Gas sample concentration

Given: gas sample collected in a bag at 103.0 kPa is moved to a pressure of 100.0 kPa. Would SO_2 concentration increase, decrease or remain the same.

Solution:

The concentration would remain the same because concentrations in ppm in air are on a volume to volume ratio and the ratio remains constant in a flexible bag when the pressure is changed.

2-7 Equilibrium and steady-state

Given: What is the difference between chemical equilibrium and steady state?

Solution:

Equilibrium means that the concentrations of the reactants and the products have achieved a balance and will not change with time.

Steady-state means that the reaction continues to proceed at a constant rate.

FE EXAM FORMATTED PROBLEMS

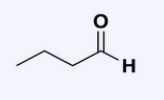
1. Which statement is correct?
    - ○ An atom may be separated into elements
    - **X An element can ~~only~~ be a gas or liquid *(it can also be a solid)***
    - ○ An element can be heterogeneous or homogeneous.
    - ○ A compound can be separated into its elements by physical means

2. Which of the following elements has the largest atomic radius?
    - ○ Mg
    - **X Be**
    - ○ Sr
    - ○ Ca
    - ○ Ba

3. Which of the following elements has the largest electronegativity?
    - **X F**
    - ○ O
    - ○ C
    - ○ Li
    - ○ B

4. An ion of an unknown element has an atomic number of 16 and contains 10 electrons. The ion is
    - ○ P^{3-}
    - ○ O^{2-}
    - ○ Si^{3-}
    - **X S^{6+}**
    - ○ F-

5. Which one of the following compounds is classified as an alkene?
    - ○ Ethanol
    - **X Ethylene**
    - ○ Butyne
    - ○ Butanal
    - ○ Butanone

6. The IUPAC name for the compound  is
    - **X Butanal**
    - ○ Butanol
    - ○ Butene
    - ○ Butane
    - ○ Butyne

7. Commercial phosphoric acid (H_3PO_4) is often supplied as a liquid containing 85 wt% (weight percent) solution. The density of the 85% solution is 1.685 g/mL at 20 °C.
Determine the concentration of this solutions in units of mg/L.

$$\left(\frac{85\ g\ H_3PO_4}{100\ g}\right)\left(\frac{1.685\ g}{mL}\right)(1000\ mL/L)\left(1000\frac{mg}{g}\right) = 1.43\ x\ 106\ mg/L$$

Determine the concentration of this solutions in units of molarity (M).

$$\left(\frac{85\ g\ H_3PO_4}{100\ g}\right)\left(\frac{1.685\ g}{mL}\right)(1000\ mL/L)\left(\frac{1}{97.994\ g/mol}\right) = 14.6\ mol/L$$

Determine the concentration of this solutions in units of normality (N).

$$\left(14.6\frac{mol}{L}\right)\left(2\frac{eq}{mol}\right) = 29.2\ N$$

Determine the concentration of this solutions in units of molarity (M).

○ 5.32
X 14.6
○ 19.4
○ 23.7

$$\left(\frac{85\ g\ H_3PO_4}{100\ g}\right)\left(\frac{1.685\ g}{mL}\right)(1000\ mL/L)\left(\frac{1}{97.994\ g/mol}\right) = 14.6\ g/mol$$

8. Determine the pH of 10 g/L NaOH solution

X 13.4
○ 1.6
○ 10.0
○ 4.0

$$(10\ g/L)\left(\frac{1\ mol}{39.998\ g}\right) = 0.25\text{ M}$$

NaOH is a strong acid so (OH^-) = 0.25 M

pH = - log (H^+)
pOH = - log (OH^-)

pOH = - log (0.25) = 0.602

At 25 oC and in dilute solution, pH + pOH = 14

∴ pH = 14-0.6 =13.4

9. A 20 ounce bottle of a popular sports drink contains 270 mg of sodium. How many moles of sodium does the drink contain?

   X 0.12 moles
   ○ 1.3 moles
   ○ 0.012 moles
   ○ 10.2 moles

$$\left(\frac{270\ mg}{bottle}\right)\left(\frac{g}{1000\ mg}\right)\left(\frac{mol}{22.99\ g}\right) = 0.012\ mol$$

10. Assuming that CO_2 behaves as an ideal gas, determine the pressure exerted by the 44 g CO_2 in a 1 L vessel at room temperature (21 °C).

   ○ 2.41 atm

   X 24.1 atm
   ○ 241. atm
   ○ 0.241 atm

PV=nRT

$$P = \left(\frac{nRT}{V}\right) = \left(\frac{(44\ g)\left(\frac{mol}{44.01\ g}\right)\left(0.082\frac{atm \cdot L}{mol \cdot K}\right)(21 + 273.15K)}{1\ L}\right) = 24.1\ atm$$