Chapter 3: Composition of Substances and Solutions

3.1 Formula mass and the Mole Concept

Question 17-1.

What is the total mass (amu) of carbon in each of the following molecules?

(a) CH_4
(b) $CHCl_3$
(c) $C_{12}H_{10}O_6$
(d) $CH_3CH_2CH_2CH_2CH_3$

Solution
(a) 1 × 12.01 amu = 12.01 amu; (b) 1 × 12.01 amu = 12.01 amu; (c) 12 × 12.01 amu = 144.12 amu; (d) 5 × 12.01 amu = 60.05 amu

Question 17-2.

What is the total mass of hydrogen in each of the molecules?

(a) CH_4
(b) $CHCl_3$
(c) $C_{12}H_{10}O_6$
(d) $CH_3CH_2CH_2CH_2CH_3$

Solution
(a) 4 × 1.008 amu = 4.032 amu; (b) 1 × 1.008 amu = 1.008 amu; (c) 10 × 1.008 amu = 10.080 (significant figures) amu; (d) 12 × 1.008 amu = 12.096 amu

Question 17-3.

Calculate the molecular or formula mass of each of the following:

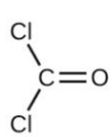
(a) P_4
(b) H_2O
(c) $Ca(NO_3)_2$
(d) CH_3CO_2H (acetic acid)
(e) $C_{12}H_{22}O_{11}$ (sucrose, cane sugar)

Solution
(a) 4 × 30.974 amu = 123.896 amu; (b) 2 × 1.008 amu + 15.999 amu = 18.015 amu; (c) 40.078 amu + 2 × 14.007 amu + 6 × 15.999 amu = 164.086 amu; (d) 2 × 12.011 amu + 4 × 1.008 amu + 2 × 15.999 amu = 60.052 amu; (e) 12 × 12.011 amu + 22 × 1.008 amu × 11 × 15.999 amu = 342.297 amu

Question 17-4.

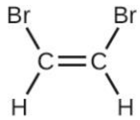
Determine the molecular mass of the following compounds:

(a)

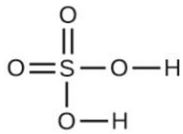


(b)

(c)



(d)



Solution

(a) Cl_2CO

$$\begin{aligned} 1C \times 12.011 &= 12.011 \text{ g mol}^{-1} \\ 1O \times 15.9994 &= 15.9994 \text{ g mol}^{-1} \\ 2Cl \times 35.4527 &= \underline{70.9054 \text{ g mol}^{-1}}\,; \\ &= 98.916 \text{ g mol}^{-1} \end{aligned}$$

(b) C_2H_2

$$\begin{aligned} 2C \times 12.011 &= 24.022 \text{ g mol}^{-1} \\ 2H \times 1.0079 &= \underline{2.0158 \text{ g mol}^{-1}}\;; \\ &= 26.038 \text{ g mol}^{-1} \end{aligned}$$

(c) $C_2H_2Br_2$

$$\begin{aligned} 2C \times 12.011 &= 24.022 \text{ g mol}^{-1} \\ 2H \times 1.0079 &= 2.0158 \text{ g mol}^{-1} \\ 4O \times 79.904 &= \underline{159.808 \text{ g mol}^{-1}}\,; \\ &= 185.846 \text{ g mol}^{-1} \end{aligned}$$

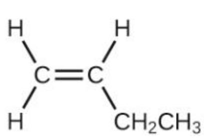
(d) H_2SO_4

$$\begin{aligned} 2H \times 1.0079 &= 2.0158 \text{ g mol}^{-1} \\ 1S \times 32.066 &= 32.066 \text{ g mol}^{-1} \\ 2Br \times 15.9994 &= \underline{63.9976 \text{ g mol}^{-1}} \\ &= 98.079 \text{ g mol}^{-1} \end{aligned}$$

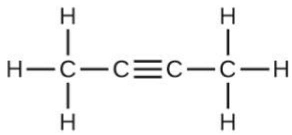
Question 17-5.

Determine the molecular mass of the following compounds:

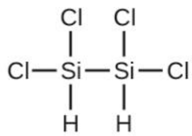
(a)



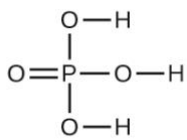
(b)



(c)



(d)



Solution

(a) C_4H_8

$$\begin{aligned} 4C \times 12.011 &= 48.044 \text{ amu} \\ 8H \times 1.0079 &= \underline{8.06352 \text{ amu}}; \\ &= 56.107 \text{ amu} \end{aligned}$$

(b) C_4H_6

$$\begin{aligned} 4C \times 12.011 &= 48.044 \text{ amu} \\ 6H \times 1.0079 &= \underline{6.0474 \text{ amu}}; \\ &= 54.091 \text{ amu} \end{aligned}$$

(c) $H_2Si_2Cl_4$

$$\begin{aligned} 2H \times 1.0079 &= 2.01558 \text{ amu} \\ 2Si \times 28.0855 &= 56.1710 \text{ amu} \\ 4Cl \times 35.4527 &= \underline{141.8108 \text{ amu}}; \\ &= 199.9976 \text{ amu} \end{aligned}$$

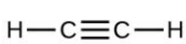
(d) H_3PO_4

$$\begin{aligned} 3H \times 1.0079 &= 3.0237 \text{ amu} \\ 1P \times 30.973762 &= 30.973762 \text{ amu} \\ 4O \times 15.9994 &= \underline{63.9976 \text{ amu}} \\ &= 97.9950 \text{ amu} \end{aligned}$$

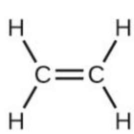
Question 17-6.

Which molecule has a molecular mass of 28.05 amu?

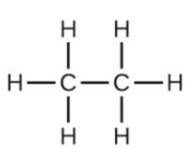
(a)



(b)



(c)



Solution
(b) 2 × 12.011 amu + 4 × 1.008 amu = 28.05 amu C_2H_4

Question 17-7.

Write a sentence that describes how to determine the number of moles of a compound in a known mass of the compound using its molecular formula.

Solution
Use the molecular formula to find the molar mass; to obtain the number of moles, divide the mass of compound by the molar mass of the compound expressed in grams.

Question 17-8.

Compare 1 mole of H_2, 1 mole of O_2, and 1 mole of F_2.
(a) Which has the largest number of molecules? Explain why.
(b) Which has the greatest mass? Explain why.

Solution
(a) All three have the same number of molecules, since a mole is defined as a specific number of particles. (b) F_2 has the largest molar mass, so it has the greatest mass of the three.

Question 17-9.

Which contains the greatest mass of oxygen: 0.75 mol of ethanol (C_2H_5OH), 0.60 mol of formic acid (HCO_2H), or 1.0 mol of water (H_2O)? Explain why.

Solution
Formic acid. Its formula has twice as many oxygen atoms as the other two compounds (one each). Therefore, 0.60 mol of formic acid would be equivalent to 1.20 mol of a compound containing a single oxygen atom.

Question 17-10.

Which contains the greatest number of moles of oxygen atoms: 1 mol of ethanol (C_2H_5OH), 1 mol of formic acid (HCO_2H), or 1 mol of water (H_2O)? Explain why.

Solution
One mole of formic acid. Formic acid has two moles of oxygen atoms per formula unit, whereas the other two compounds have only one mole of oxygen atoms per mole.

Question 17-11.

How are the molecular mass and the molar mass of a compound similar and how are they different?

Solution
The two masses have the same numerical value, but the units are different: The molecular mass is the mass of 1 molecule while the molar mass is the mass of 6.022×10^{23} molecules.

Question 17-12.

Calculate the molar mass of each of the following compounds:
(a) hydrogen fluoride, HF
(b) ammonia, NH_3

(c) nitric acid, HNO_3
(d) silver sulfate, Ag_2SO_4
(e) boric acid, $B(OH)_3$

Solution

(a) HF:

$$\begin{aligned} 1H &= 1 \times 1.00794 = 1.00794 \\ 1F &= 1 \times 18.9984 = \underline{18.9984} \quad ; \\ &= 20.0063 \text{ g} \end{aligned}$$

(b) NH_3:

$$\begin{aligned} 1N &= 1 \times 14.0067 = 14.0067 \\ 3H &= 3 \times 1.00794 = \underline{3.02382} \quad ; \\ &= 17.0305 \text{ g} \end{aligned}$$

(c) HNO_3:

$$\begin{aligned} 1N &= 1 \times 14.0067 = 14.0067 \\ 1H &= 1 \times 1.00794 = 1.00794 \\ 3O &= 3 \times 15.9994 = \underline{47.9982} \quad ; \\ &= 63.0128 \text{ g} \end{aligned}$$

(d) Ag_2SO_4

$$\begin{aligned} 2Ag &= 2 \times 107.8682 = 215.736 \\ 1S &= 1 \times 32.066 = 32.066 \\ 4O &= 4 \times 15.994 = \underline{63.976} \quad ; \\ & \quad 311.800 \text{ g} \end{aligned}$$

(e) $B(OH)_3$:

$$\begin{aligned} 1B &= 1 \times 10.81 = 10.81 \\ 3O &= 3 \times 15.9994 = 47.9982 \\ 3H &= 3 \times 1.00794 = \underline{3.02382} \\ &= 61.83 \text{ g} \end{aligned}$$

Question 17-13.

Calculate the molar mass of each of the following:

(a) S_8
(b) C_5H_{12}
(c) $Sc_2(SO_4)_3$
(d) CH_3COCH_3 (acetone)
(e) $C_6H_{12}O_6$ (glucose)

Solution

(a) S_8

$8S = 8 \times 32.06 = 256.48$ g/mol;

(b) C_5H_{12}

$5C = 5 \times 12.011 = 60.055 \text{ g mol}^{-1}$
$12H = 12 \times 1.00794 = \underline{12.09528 \text{ g mol}^{-1}}$;
$= 72.150 \text{ g mol}^{-1}$

(c) $Sc_2(SO_4)_3$

$2Sc = 2 \times 44.9559109 = 89.9118218 \text{ g mol}^{-1}$
$3S = 3 \times 32.066 = 96.198 \text{ g mol}^{-1}$
$12O = 12 \times 15.99943 = \underline{191.99316 \text{ g mol}^{-1}}$;
$= 378.103 \text{ g mol}^{-1}$

(d) CH_3COCH_3

$3C = 3 \times 12.011 = 36.033 \text{ g mol}^{-1}$
$1O = 1 \times 15.9994 = 15.9994 \text{ g mol}^{-1}$
$6H = 6 \times 1.00794 = \underline{6.04764 \text{ g mol}^{-1}}$;
$= 58.080 \text{ g mol}^{-1}$

(e) $C_6H_{12}O_6$

$6C = 6 \times 12.011 = 72.066 \text{ g mol}^{-1}$
$12H = 12 \times 1.00794 = 12.09528 \text{ g mol}^{-1}$
$6O = 6 \times 15.9994 = \underline{95.9964 \text{ g mol}^{-1}}$
$= 180.158 \text{ g mol}^{-1}$

Question 17-14.

Calculate the empirical or molecular formula mass and the molar mass of each of the following minerals:

(a) limestone, $CaCO_3$
(b) halite, NaCl
(c) beryl, $Be_3Al_2Si_6O_{18}$
(d) malachite, $Cu_2(OH)_2CO_3$
(e) turquoise, $CuAl_6(PO_4)_4(OH)_8(H_2O)_4$

Solution

(a) $CaCO_3$

$1Ca = 1 \times 40.078 = 40.078 \text{ g mol}^{-1}$
$1C = 1 \times 12.011 = 12.011 \text{ g mol}^{-1}$
$3O = 3 \times 15.9994 = \underline{47.9982 \text{ g mol}^{-1}}$;
$= 100.087 \text{ g mol}^{-1}$

(b) NaCl

$1Na = 1 \times 22.989768 = 22.989768 \text{ g mol}^{-1}$
$1Cl = 1 \times 35.4527 = \underline{35.4527 \text{ g mol}^{-1}}$;
$= 58.4425 \text{ g mol}^{-1}$

(c) $Be_3Al_2Si_6O_{18}$

$3Be = 3 \times 9.01218 = 27.03654 \text{ g mol}^{-1}$

$2Al = 2 \times 26.98154 = 53.96308 \text{ g mol}^{-1}$

$6Si = 6 \times 28.0855 = 168.513 \text{ g mol}^{-1}$;

$18O = 18 \times 15.9994 = \underline{287.9892 \text{ g mol}^{-1}}$

$= 537.502 \text{ g mol}^{-1}$

(d) $Cu_2(OH)_2CO_3$

$2C = 2 \times 63.546 = 127.092 \text{ g mol}^{-1}$

$5O = 5 \times 15.9994 = 79.997 \text{ g mol}^{-1}$

$2H = 2 \times 1.00794 = 2.01588 \text{ g mol}^{-1}$;

$1H = 1 \times 12.011 = \underline{12.011 \text{ g mol}^{-1}}$

$= 221.116 \text{ g mol}^{-1}$

(e) $CuAl_6(PO_4)_4(OH)_8(H_2O)_4$

$1Cu = 1 \times 63.546 = 63.546 \text{ g mol}^{-1}$

$6Al = 6 \times 26.98154 = 161.88924 \text{ g mol}^{-1}$

$4P = 4 \times 30.9737624 = 123.89505 \text{ g mol}^{-1}$

$28O = 28 \times 15.9994 = 447.9832 \text{ g mol}^{-1}$

$16H = 16 \times 1.00794 = \underline{16.12704 \text{ g mol}^{-1}}$

$= 813.441 \text{ g mol}^{-1}$

Question 17-15.

Calculate the molar mass of each of the following:

(a) the anesthetic halothane, $C_2HBrClF_3$
(b) the herbicide paraquat, $C_{12}H_{14}N_2Cl_2$
(c) caffeine, $C_8H_{10}N_4O_2$
(d) urea, $CO(NH_2)_2$
(e) a typical soap, $C_{17}H_{35}CO_2Na$

Solution

(a) $C_2HBrClF_3$

$2C = 2 \times 12.011 = 24.022 \text{ g mol}^{-1}$

$1H = 1 \times 1.00794 = 1.00794 \text{ g mol}^{-1}$

$1Br = 1 \times 79.904 = 79.904 \text{ g mol}^{-1}$

$1Cl = 1 \times 35.453 = 35.453 \text{ g mol}^{-1}$;

$3F = 3 \times 18.998403 = \underline{56.995209 \text{ g mol}^{-1}}$

$= 197.382 \text{ g mol}^{-1}$

(b) $C_{12}H_{14}N_2Cl_2$

$12C = 12 \times 12.011 = 144.132 \text{ g mol}^{-1}$
$14H = 14 \times 1.00794 = 14.111 \text{ g mol}^{-1}$
$2N = 2 \times 14.0067 = 28.0134 \text{ g mol}^{-1}$;
$2Cl = 2 \times 35.453 = \underline{70.906 \text{ g mol}^{-1}}$
$= 257.163 \text{ g mol}^{-1}$

(c) $C_8H_{10}N_4O_2$
$8C = 8 \times 12.011 = 96.088 \text{ g mol}^{-1}$
$10H = 10 \times 1.007 = 10.079 \text{ g mol}^{-1}$
$4N = 4 \times 14.0067 = 56.027 \text{ g mol}^{-1}$;
$2O = 2 \times 15.9994 = \underline{31.999 \text{ g mol}^{-1}}$
$= 194.193 \text{ g mol}^{-1}$

(d) $CO(NH_2)_2$
$1C = 1 \times 12.011 = 12.011 \text{ g mol}^{-1}$
$1O = 1 \times 15.9994 = 15.9994 \text{ g mol}^{-1}$
$2N = 2 \times 14.0067 = 28.0134 \text{ g mol}^{-1}$;
$4H = 4 \times 1.00794 = \underline{4.03176 \text{ g mol}^{-1}}$
$= 60.056 \text{ g mol}^{-1}$

(e) $C_{17}H_{35}CO_2Na$
$18C = 18 \times 12.011 = 216.198 \text{ g mol}^{-1}$
$35H = 35 \times 1.00794 = 35.2779 \text{ g mol}^{-1}$
$2O = 2 \times 15.9994 = 31.9988 \text{ g mol}^{-1}$
$1Na = 1 \times 22.98977 = \underline{22.98977 \text{ g mol}^{-1}}$
$= 306.464 \text{ g mol}^{-1}$

Question 17-16.

Determine the number of moles of compound and the number of moles of each type of atom in each of the following:

(a) 25.0 g of propylene, C_3H_6
(b) 3.06×10^{-3} g of the amino acid glycine, $C_2H_5NO_2$
(c) 25 lb of the herbicide Treflan, $C_{13}H_{16}N_2O_4F$ (1 lb = 454 g)
(d) 0.125 kg of the insecticide Paris Green, $Cu_4(AsO_3)_2(CH_3CO_2)_2$
(e) 325 mg of aspirin, $C_6H_4(CO_2H)(CO_2CH_3)$

Solution

(a) C_3H_6
$3C = 3 \times 12.011 = 36.033$
$6H = 6 \times 1.00794 = \underline{6.04764}$
molar mass $= 42.081 \text{ g mol}^{-1}$

$$\text{mol propylene} = \frac{25.0 \not{g}}{42.081 \not{g} \text{ mol}^{-1}} = 0.594 \text{ mol}$$

$3C = 3 \times 12.011 = 36.033$

$6H = 6 \times 1.00794 = \underline{6.04764}$

molar mass = 42.081 g mol^{-1}

$$\text{mol propylene} = \frac{25.0\ \cancel{g}}{42.081\ \cancel{g}\ \text{mol}^{-1}} = 0.594\ \text{mol}$$

1.78 mol C, 3.56 mol H;

(b) $C_2H_5NO_2$

$2C = 2 \times 12.011 = 24.022$

$5H = 5 \times 1.00794 = 5.0397$

$1N = 1 \times 14.0067 = 14.0067$

$2O = 2 \times 15.9994 = \underline{31.9988}$

molar mass = 75.067 g mol^{-1}

$$\text{mol glycine} = \frac{3.06 \times 10^{-3}\ \cancel{g}}{75.067\ \cancel{g}\ \text{mol}^{-1}} = 4.08 \times 10^{-5}\ \text{mol}$$

8.16×10^{-5} mol C and mol O, 2.04×10^{-4} mol H, 4.08×10^{-5} mol N;

(c) $C_{13}H_{16}N_2O_4F$

$13C = 13 \times 12.011 = 156.143$

$16H = 16 \times 1.00794 = 16.12704$

$2N = 2 \times 14.0067 = 28.0134$

$4O = 4 \times 15.9994 = 63.9976$

$1F = 1 \times 18.9984032 = \underline{18.9984032}$

molar mass = 283.270 g mol^{-1}

Convert lb to g: 25 lb × 454 lb^{-1} = 11,350 g

$$\text{mol Treflan} = \frac{11{,}380\ \cancel{g}}{283.270\ \cancel{g}\ \text{mol}^{-1}} = 40.20\ \text{mol}$$

5.2×10^2 mol C, 6.4×10^2 mol H, 80.2 mol N, 1.6×10^2 mol O, 40 mol F;

(d) $Cu_4(AsO_3)_2(CH_3CO_2)_2$

$4Cu = 4 \times 63.546 = 254.184$

$2As = 2 \times 74.92159 = 149.84318$

$10O = 10 \times 15.9994 = 159.9940$

$4C = 4 \times 12.011 = 48.044$

$6H = 6 \times 1.00794 = \underline{6.04764}$

molar mass = 618.113 g mol^{-1}

$$\text{mol Paris Green} = \frac{125\ \cancel{g}}{618.113\ \cancel{g}\ \text{mol}^{-1}} = 0.202\ \text{mol}$$

0.808 mol Cu and mol C, 0.404 mol As, 1.21 mol H, 2.02 mol O;

(e) $C_6H_4(CO_2H)(COCH_3)$

$9C = 9 \times 12.011 = 108.099$

$8H = 8 \times 1.00794 = 8.06352$

$4O = 4 \times 15.9994 = \underline{63.9976}$

$\text{molar mass} = 180.160 \text{ g mol}^{-1}$

$$\text{mol aspirin} = \frac{0.325 \cancel{\text{g}}}{180.160 \cancel{\text{g}} \text{ mol}^{-1}} = 1.80 \times 10^{-3} \text{ mol}$$

1.62×10^{-2} mol C, 1.44×10^{-2} mol H, 7.20×10^{-3} mol O

Question 17-17.

Determine the mass of each of the following:

(a) 0.0146 mol KOH
(b) 10.2 mol ethane, C_2H_6
(c) 1.6×10^{-3} mol Na_2SO_4
(d) 6.854×10^3 mol glucose, $C_6H_{12}O_6$
(e) 2.86 mol $Co(NH_3)_6Cl_3$

Solution

(a) KOH:

$1K = 1 \times 39.0983 = 39.0983$

$1O = 1 \times 15.9994 = 15.9994$

$1H = 1 \times 1.00794 = \underline{1.00794}$

$\text{molar mass} = 56.1056 \text{ g mol}^{-1}$

Mass = 0.0146 mol × 56.1056 g/mol = 0.819 g;

(b) C_2H_6

$2C = 2 \times 12.011 = 24.022$

$6H = 6 \times 1.00794 = \underline{6.04764}$

$\text{molar mass} = 30.070 \text{ g mol}^{-1}$

Mass = 10.2 mol × 30.070 g/mol = 307 g;

(c) Na_2SO_4:

$2Na = 2 \times 22.990 = 45.98$

$1S = 1 \times 32.066 = 32.066$

$4O = 4 \times 15.9994 = \underline{63.9976}$

$\text{molar mass} = 142.044 \text{ g mol}^{-1}$

Mass = 1.6×10^{-3} mol × 142.044 g/mol = 0.23 g;

(d) $C_6H_{12}O_6$

$6C = 6 \times 12.011 = 72.066$

$12H = 12 \times 1.00794 = 12.0953$

$6O = 6 \times 15.9994 = \underline{95.9964}$

$\text{molar mass} = 180.158 \text{ g mol}^{-1}$

Mass = 6.854×10^3 mol × 180.158 g/mol = 1.235×10^6 g (1235 kg);

(e) $Co(NH_3)_6Cl_3$

$Co = 1 \times 58.99320 = 58.99320$

$6N = 6 \times 14.0067 = 84.0402$

$18H = 18 \times 1.00794 = 18.1429$

$3Cl = 3 \times 35.4527 = \underline{106.358}$

$\text{molar mass} = 267.5344 \text{ g mol}^{-1}$

Mass = 2.86 mol × 267.5344 g/mol = 765 g

Question 17-18.

Determine the number of moles of the compound and determine the number of moles of each type of atom in each of the following:

(a) 2.12 g of potassium bromide, KBr
(b) 0.1488 g of phosphoric acid, H_3PO_4
(c) 23 kg of calcium carbonate, $CaCO_3$
(d) 78.452 g of aluminum sulfate, $Al_2(SO_4)_3$
(e) 0.1250 mg of caffeine, $C_8H_{10}N_4O_2$

Solution

(a) Molar mass of KBr:

$1K = 1 \times 39.0893 = 39.0893$

$1Br = 1 \times 79.904 = \underline{79.904}$

$= 118.9933 \text{ g mol}^{-1}$

$$\frac{2.12 \text{ g}}{118.9933 \text{ g mol}^{-1}} = 1.78 \times 10^{-2} \text{ mol KBr}$$

$1 \times 1.78 \times 10^{-2} = 1.78 \times 10^{-2}$ mol K ;
$1 \times 1.78 \times 10^{-2} = 1.78 \times 10^{-2}$ mol Br

(b) Molar mass of H_3PO_4

$1P = 1 \times 30.973762 = 30.973762$

$4O = 4 \times 15.9994 = 63.9976$

$3H = 3 \times 1.0079 = \underline{3.0237}$

$= 97.9951 \text{ g mol}^{-1}$

$$\frac{0.1488 \text{ g}}{97.9951 \text{ g mol}^{-1}} = 1.518 \times 10^{-3} \text{ mol } H_3PO_4$$

$3 \times 1.518 \times 10^{-3} = 4.555 \times 10^{-3}$ mol H
$1 \times 1.518 \times 10^{-3} = 1.518 \times 10^{-3}$ mol P ;
$4 \times 1.518 \times 10^{-3} = 6.073 \times 10^{-3}$ mol O

(c) Molar mass of $CaCO_3$

$1Ca = 1 \times 40.078 = 40.078$

$1C = 1 \times 12.011 = 12.011$

$3O = 3 \times 15.9994 = \underline{47.9982}$

$= 100.087 \text{ g mol}^{-1}$

$$\frac{2.3 \times 10^{4} \text{ g}}{100.087 \text{ g mol}^{-1}} = 2.3 \times 10^{2} \text{ mol } CaCO_3$$

$1 \times 2.3 \times 10^2$ mol = 2.3×10^2 mol Ca

$1 \times 2.3 \times 10^2$ mol = 2.3×10^2 mol C ;

$3 \times 2.3 \times 10^2$ mol = 6.9×10^2 mol O

(d) Molar mass of $Al_2(SO_4)_3$

$$\begin{aligned} 2Al &= 2 \times 26.981539 = 53.963078 \\ 3S &= 3 \times 32.066 = 96.198 \\ 12O &= 12 \times 15.9994 = \underline{191.9928} \\ &= 342.154 \text{ g mol}^{-1} \end{aligned}$$;

$$\frac{78.452 \cancel{\text{g}}}{315.172 \cancel{\text{g}} \text{ mol}^{-1}} = 0.22929 \text{ mol } Al_2(SO4)_3$$

$2 \times 0.22929 = 0.45858$ mol Al

$3 \times 0.22929 = 0.68787$ mol S

$12 \times 0.22929 = 2.75148$ mol O

(e) Molar mass of $C_8H_{10}N_4O_2$:

$$\begin{aligned} 8C &= 8 \times 12.011 = 96.088 \\ 10H &= 10 \times 1.00794 = 10.0794 \\ 4N &= 4 \times 14.0067 = 56.0268 \\ 2O &= 2 \times 15.9994 = \underline{31.9988} \\ &= 194.193 \text{ g mol}^{-1} \end{aligned}$$

$$\frac{0.1250 \cancel{\text{mg}}}{(194.193 \cancel{\text{g}} \text{ mol}^{-1} \times 1000 \cancel{\text{mg}} \cancel{\text{g}^{-1}})} = 6 \times 10^{-7} \text{ mol } C_8H_{10}N_4O_2$$

$8 \times 6.437 \times 10^{-7}$ mol $C_8H_{10}N_4O_2 = 5.150 \times 10^{-6}$ mol C

$10 \times 6.437 \times 10^{-7}$ mol $C_8H_{10}N_4O_2 = 6.437 \times 10^{-6}$ mol H

$4 \times 6.437 \times 10^{-7}$ mol $C_8H_{10}N_4O_2 = 2.575 \times 10^{-6}$ mol N

$2 \times 6.437 \times 10^{-7}$ mol $C_8H_{10}N_4O_2 = 1.287 \times 10^{-6}$ mol O

Question 17-19.

Determine the mass of each of the following:

(a) 2.345 mol LiCl

(b) 0.0872 mol acetylene, C_2H_2

(c) 3.3×10^{-2} mol Na_2CO_3

(d) 1.23×10^3 mol fructose, $C_6H_{12}O_6$

(e) 0.5758 mol $FeSO_4(H_2O)_7$

Solution

(a) molar mass $(LiCl) = 1 \times 6.941 + 1 \times 35.4527 = 42.394$ g mol^{-1}

mass = $2.345 \cancel{\text{mol}} \times 42.394 \text{ g } \cancel{\text{mol}^{-1}} = 99.41$ g ;

(b) molar mass $(C_2H_2) = 2 \times 12.011 + 2 \times 1.00794 = 26.038$ g mol^{-1}

mass = $0.0872 \cancel{\text{mol}} \times 26.038 \text{ g } \cancel{\text{mol}^{-1}} = 2.27$ g ;

(c) molar mass $(Na_2CO_3) = 2 \times 22.989768 + 1 \times 12.011 + 3 \times 15.9994 = 105.989$ g mol^{-1}

mass = $3.3 \times 10^{-2} \cancel{\text{mol}} \times 105.989 \text{ g } \cancel{\text{mol}^{-1}} = 3.5$ g ;

(d) molar mass ($C_6H_{12}O_6$) $= 6 \times 12.011 + 12 \times 1.00794 + 6 \times 15.9994 = 180.158 \text{ g mol}^{-1}$;
$\text{mass} = 1.23 \times 10^3 \ \cancel{\text{mol}} \times 180.158 \text{ g } \cancel{\text{mol}^{-1}} = 2.22 \times 10^5 \text{ g} = 222 \text{ kg}$

(e) $\text{molar mass } [FeSO_4(H_2O)_7] = 1 \times 55.847 + 1 \times 32.066 + 4 \times 15.999 + 7(2 \times 1.00794 + 15.9994) = 278.018 \text{ g mol}^{-1}$
$\text{mass} = 0.5758 \ \cancel{\text{mol}} \times 278.018 \text{ g } \cancel{\text{mol}^{-1}} = 160.1 \text{ g}$

Question 17-20.

The approximate minimum daily dietary requirement of the amino acid leucine, $C_6H_{13}NO_2$, is 1.1 g. What is this requirement in moles?

Solution

Molar mass = 6 × 12.011 + 13 × 1.00794 + 1 × 14.0067 + 2 × 15.9994 = 131.175 g/mol;

$$\text{mass} = \frac{1.1 \text{ g}}{131.175 \text{ g mol}^{-1}} = 8.4 \times 10^{-3} \text{ mol}$$

Question 17-21.

Determine the mass in grams of each of the following:

(a) 0.600 mol of oxygen atoms
(b) 0.600 mol of oxygen molecules, O_2
(c) 0.600 mol of ozone molecules, O_3

Solution

(a) 0.600 ~~mol~~ × 15.9994 g/~~mol~~ = 9.60 g; (b) 0.600 ~~mol~~ × 2 × 15.994 g/~~mol~~ = 19.2 g; (c) 0.600 ~~mol~~ × 3 × 15.994 g/~~mol~~ = 28.8 g

Question17- 22.

A 55-kg woman has 7.5×10^{-3} mol of hemoglobin (molar mass = 64,456 g/mol) in her blood. How many hemoglobin molecules is this? What is this quantity in grams?

Solution

7.5×10^{-3} mol × 6.022×10^{23} mol^{-1} = 4.5×10^{21} molecules; 7.5×10^{-3} mol × 64,456 g/mol = 4.8×10^2 g

Question 17-23.

Determine the number of atoms and the mass of zirconium, silicon, and oxygen found in 0.3384 mol of zircon, $ZrSiO_4$, a semiprecious stone.

Solution

Determine the number of moles of each component. From the moles, calculate the number of atoms and the mass of the elements involved. Zirconium: 0.3384 ~~mol~~ × 6.022×10^{23} ~~mol^{-1}~~ = 2.038×10^{23} atoms; 0.3384 ~~mol~~ × 91.224 g/~~mol~~ = 30.87 g; Silicon: 0.3384 ~~mol~~ × 6.022×10^{23} ~~mol^{-1}~~ = 2.038×10^{23} atoms; 0.3384 ~~mol~~ × 28.0855 g/~~mol~~ = 9.504 g; Oxygen: 4 × 0.3384 ~~mol~~ × 6.022×10^{23} ~~mol^{-1}~~ = 8.151×10^{23} atoms; 4 × 0.3384 ~~mol~~ × 15.9994 g/~~mol~~ = 21.66 g

Question 17-24.

Determine which of the following contains the greatest mass of hydrogen: 1 mol of CH_4, 0.6 mol of C_6H_6, or 0.4 mol of C_3H_8.

Solution

Multiply each amount of substance (mol) by the number of moles of hydrogen per mole of compound as shown in the compound formula. The result is the molar amount of H in the compound: the greater this molar amount, the greater the mass of H in the compound. CH_4: 1 × 4 = 4; C_6H_6: 0.6 × 6 = 2.4; C_3H_8: 0.4 × 8 = 3.2; 1 mol of CH_4 has the most mass of hydrogen.

Question 17-25.

Determine which of the following contains the greatest mass of aluminum: 122 g of $AlPO_4$, 266 g of Al_2Cl_6, or 225 g of Al_2S_3.

Solution

Determine the molar mass and, from the grams present, the moles of each substance. The compound with the greatest number of moles of Al has the greatest mass of Al.

Molar mass $AlPO_4$: 26.981539 + 30.973762 + 4(15.9994) = 121.9529 g/mol

Molar mass Al_2Cl_6: 2(26.981539) + 6(35.4527) = 266.6793 g/mol

Molar mass Al_2S_3: 2(26.981539) + 3(32.066) = 150.161 g/mol

$$AlPO_4: \frac{122\ \cancel{g}}{121.9529\ \cancel{g}\ mol^{-1}} = 1.000\ mol$$

mol Al = 1 × 1.000 mol = 1.000 mol, or 26.98 g Al

$$Al_2Cl_6: \frac{266\ g}{266.6793\ g\ mol^{-1}} = 0.997\ mol$$

mol Al = 2 × 0.997 mol = 1.994 mol, or 53.74 g Al

$$Al_2S_3: \frac{225\ \cancel{g}}{150.161\ \cancel{g}\ mol^{-1}} = 1.50\ mol$$

mol Al = 2 × 1.50 mol = 3.00 mol, or 80.94 g Al

The Al_2S_3 sample thus contains the greatest mass of Al.

Question 17-26.

Diamond is one form of elemental carbon. An engagement ring contains a diamond weighing 1.25 carats (1 carat = 200 mg). How many atoms are present in the diamond?

Solution

Determine the number of grams present in the diamond and from that the number of moles. From the number of moles, find the number of carbon atoms by multiplying by Avogadro's number:

$$1.25\ \cancel{carats} \times 200\ \cancel{mg}\ \cancel{carat}^{-1} \times \frac{1\ g}{1000\ \cancel{mg}} = 0.250\ g$$

$$\frac{0.250\ \cancel{g}}{12.011\ \cancel{g\ mol^{-1}}} \times 6.022 \times 10^{23}\ \cancel{mol^{-1}} = 1.25 \times 10^{22}\ atoms$$

Question 17-27.

The Cullinan diamond was the largest natural diamond ever found (January 25, 1905). It weighed 3104 carats (1 carat = 200 mg). How many carbon atoms were present in the stone?

Solution

Determine the number of grams present in the diamond and from that the number of moles. Find the number of carbon atoms by multiplying Avogadro's number by the number of moles:

$$\frac{3104 \ \cancel{\text{carats}} \times \frac{200 \ \cancel{\text{mg}}}{1 \ \cancel{\text{carat}}} \times \frac{1 \ \cancel{\text{g}}}{1000 \ \cancel{\text{mg}}}}{12.011 \ \cancel{\text{g}} \ \cancel{\text{mol}^{-1}}(6.022 \times 10^{23} \ \cancel{\text{mol}^{-1}})} = 3.113 \times 10^{25} \text{C atoms}$$

Question 17-28.

One 55-gram serving of a particular cereal supplies 270 mg of sodium, 11% of the recommended daily allowance. How many moles and atoms of sodium are in the recommended daily allowance?

Solution

Assume that the sodium mass of 270 mg is in an ionic form:

$$\frac{270 \text{ mg} \times 1 \text{ g}}{1000 \text{ mg}} = 0.270 \text{ g of Na}$$

Total sodium required $= \dfrac{0.270 \text{ g}}{0.11} = 2.4545 \text{ g}$ of ionic sodium. This amount is

$$\frac{2.4545 \ \cancel{\text{g}}}{22.989768 \ \cancel{\text{g}} \text{ mol}^{-1}} = 0.1068 \text{ mol Na}$$

0.1068 mol × 6.022 × 10^{23} mol^{-1} = 6.4 × 10^{22} atoms

Question 17-29.

A certain nut crunch cereal contains 11.0 grams of sugar (sucrose, $C_{12}H_{22}O_{11}$) per serving size of 60.0 grams. How many servings of this cereal must be eaten to consume 0.0278 moles of sugar?

Solution

Determine the molar mass of sugar. 12(12.011) + 22(1.00794) + 11(15.9994) = 342.300 g/mol;

Then 0.0278 mol × 342.300 g/mol = 9.52 g sugar. This 9.52 g of sugar represents $\dfrac{11.0}{60.0}$ of one serving or $\dfrac{60.0 \text{ g serving}}{11.0 \ \cancel{\text{g sugar}}} \times 9.52 \ \cancel{\text{g sugar}} = 51.9$ g cereal.

This amount is $\dfrac{51.9 \text{ g cereal}}{60.0 \text{ g serving}} = 0.865$ servings, or about 1 serving.

Question 17-30.

A tube of toothpaste contains 0.76 g of sodium monofluorophosphate (Na_2PO_3F) in 100 mL.

(a) What mass of fluorine atoms in mg was present?

(b) How many fluorine atoms were present?

Solution

Molar mass of Na_2PO_3F = 2(22.9898) + 1(18.9984) + 1(30.9738) + 3(15.9994) = 143.95 g/mol;

(a) $\text{mol Na}_2\text{PO}_3\text{F} = \dfrac{0.76 \text{ g}}{143.95 \text{ g mol}^{-1}} = 0.00528 \text{ mol}$. Since there is only one F atom in the formula, the number of moles of fluorine is also 5.28 × 10^{-3} mol.

Mass F = 5.28 × 10^{-3} mol × 18.9984 g/mol × 1000 mg/g = 1.0 × 10^{2} mg;

(b) $\text{atoms of F} = 100 \cancel{\text{mg}}\ \text{F} \times \frac{1 \cancel{\text{g}}}{1000 \cancel{\text{mg}}} \times \frac{1 \text{ mol F}}{18.9984 \cancel{\text{g}}\ \text{F}} \times 6.022 \times 10^{23} \text{ atoms mol}^{-1}$

$= 3.2 \times 10^{21} \text{ atoms F}$

Question 17-31.

Which of the following represents the least number of molecules?

(a) 20.0 g of H_2O (18.02 g/mol)
(b) 77.0 g of CH_4 (16.06 g/mol)
(c) 68.0 g of C_3H_6 (42.08 g/mol)
(d) 100.0 g of N_2O (44.02 g/mol)
(e) 84.0 g of HF (20.01 g/mol)

Solution

Calculate the number of moles of each species, then remember that 1 mole of anything = 6.022×10^{23} species. (a) 20.0 g = 1.11 mol H_2O; (b) 77.0 g CH_4 = 4.79 mol CH_4; (c) 68.0 g C_3H_6= 1.62 mol C_3H_6; (d) 100.0 g N_2O = 2.27 mol N_2O; (e) 84.0 g HF = 4.20 mol HF. Therefore, 20.0 g H_2O represents the least number of molecules since it has the least number of moles.

3.2 Determining Empirical and Molecular Formulas

Question 18-1.

What information is needed to determine the molecular formula of a compound from the empirical formula?

Solution

After determining the empirical formula, additional information such as the molar mass, or the moles of an element per mole of the compound, must be given.

Question 18-2.

Calculate the following to four significant figures:

(a) the percent composition of ammonia, NH_3
(b) the percent composition of photographic fixer solution (“hypo”), $Na_2S_2O_3$
(c) the percent of calcium ion in $Ca_3(PO_4)_2$

Solution

In each of these exercises asking for the percent composition, divide the molecular weight of the desired element or group of elements (the number of times it/they occur in the formula times the molecular weight of the desired element or elements) by the molecular weight of the compound.

(a)

$$\% \text{ N} = \frac{14.0067 \text{ g mol}^{-1} \times 100\%}{[3(1.007940 + 14.0067)] \text{ g mol}^{-1}} = \frac{14.0067 \text{ g mol}^{-1}}{17.0305 \text{ g mol}^{-1}} = 82.24\%$$

$$\% \text{ H} = \frac{3 \times 1.00794 \text{ g mol}^{-1}}{17.0305 \text{ g mol}^{-1}} \times 100\% = 17.76\%$$

;

$$\% \text{ Na} = \frac{2 \times 22.989768}{2 \times 22.989768 + 2 \times 32.066 + 3 \times 15.9994} \times 100\% = \frac{45.9795}{158.1097} \times 100 = 29.08\%$$

$$\% \text{ S} = \frac{64.132}{158.1097} \times 100\% = 40.56\%$$

$$\% \text{ O} = \frac{47.9982}{158.1097} \times 100\% = 30.36\%$$

(b) ;

(c)

$$\% \text{ Ca}^{2+} = \frac{3 \times 40.078}{3 \times 40.078 + 2 \times 30.973762 + 8 \times 15.9994} \times 100\% = \frac{120.234}{310.1816} \times 100\% = 38.76\%$$

Question 18-3.

Determine the following to four significant figures:

(a) the percent composition of hydrazoic acid, HN_3

(b) the percent composition of TNT, $C_6H_2(CH_3)(NO_2)_3$

(c) the percent of SO_4^{2-} in $Al_2(SO_4)_3$

Solution

(a)

$$\% \text{ H} = \frac{1.008}{43.029} \times 100 = 2.34\%$$

$$\% \text{ N} = \frac{42.021}{43.029} \times 100 = 97.66\%$$

;

(b)

$$\% \text{ C} = \left(\frac{84.077}{227.132}\right) \times 100 = 37.01\% \text{ C}$$

$$\% \text{ H} = \left(\frac{5.040}{227.132}\right) \times 100 = 2.219\% \text{ H}$$

$$\% \text{ O} = \left(\frac{95.994}{227.132}\right) \times 100 = 42.26\% \text{ O}$$

$$\% \text{ N} = \left(\frac{42.021}{227.132}\right) \times 100 = 18.50\% \text{ N}$$

;

(c)

$$\% \text{ SO}_4^{2-} = \frac{3(32.066 + 4 \times 15.999) \times 100\%}{2 \times 26.982 + 3(32.066 + 4 \times 15.999)} = \frac{288.186 \times 100\%}{342.15} = 84.23\%$$

Question 18-4.

Determine the percent ammonia, NH_3, in $Co(NH_3)_6Cl_3$, to three significant figures.

Solution

$$\% \text{ NH}_3 = \frac{6(14.007 + 3 \times 1.008)}{58.933 + 6(14.007 + 3 \times 1.008) + 3(35.453)} \times 100\% = \frac{102.186}{267.478} \times 100\% = 38.2\%$$

Question 18-5.

Determine the percent water in $CuSO_4 \cdot 5H_2O$ to three significant figures.

Solution

$$\% \; H_2O = \frac{5(2 \times 1.008 + 15.999)}{63.546 + 32.066 + 4(15.999) + 5(2 \times 1.008 + 15.999)}$$

$$= \frac{90.075}{159.608 + 90.075} = \frac{90.075}{249.683} \times 100\% = 36.1\%$$

Question 18-6.

Determine the empirical formulas for compounds with the following percent compositions:

(a) 15.8% carbon and 84.2% sulfur

(b) 40.0% carbon, 6.7% hydrogen, and 53.3% oxygen

Solution

(a) The percent of an element in a compound indicates the percent by mass. The mass of an element in a 100.0-g sample of a compound is equal in grams to the percent of that element in the sample; hence, 100.0 g of the sample contains 15.8 g of C and 84.2 g of S. The relative number of moles of C and S atoms in the compound can be obtained by converting grams to moles as shown.

Step 1:

$$\text{C: } 15.8 \text{ g} \times \frac{1 \text{ mol}}{12.011 \text{ g}} = 1.315 \text{ mol}$$

$$\text{S: } 84.2 \text{ g} \times \frac{1 \text{ mol}}{32.066 \text{ g}} = 2.626 \text{ mol}$$

Step 2:

$$\text{C: } \frac{1.315 \text{ mol}}{1.315 \text{ mol}} = 1.000$$

$$\text{S: } \frac{2.626 \text{ mol}}{1.315 \text{ mol}} = 1.997$$

The empirical formula is CS_2.

(b) Step 1:

$$\text{C: } 40.0 \text{ g} \times \frac{1 \text{ mol}}{12.011 \text{ g}} = 3.330 \text{ mol}$$

$$\text{H: } 6.7 \text{ g} \times \frac{1 \text{ mol}}{1.00794 \text{ g}} = 6.647 \text{ mol}$$

$$\text{O: } 53.3 \text{ g} \times \frac{1 \text{ mol}}{15.9994 \text{ g}} = 3.331 \text{ mol}$$

Step 2:

C: $\frac{3.330 \text{ mol}}{3.330 \text{ mol}} = 1.0$

H: $\frac{6.647 \text{ mol}}{3.330 \text{ mol}} = 2$

O: $\frac{3.331 \text{ mol}}{3.330 \text{ mol}} = 1.0$

The empirical formula is CH_2O.

Question 18-7.

Determine the empirical formulas for compounds with the following percent compositions:

(a) 43.6% phosphorus and 56.4% oxygen

(b) 28.7% K, 1.5% H, 22.8% P, and 47.0% O

Solution

(a) Step 1:

P: $43.6 \cancel{\text{g}} \times \frac{1 \text{ mol}}{30.97376 \cancel{\text{g}}} = 1.4076 \text{ mol}$

O: $56.4 \cancel{\text{g}} \times \frac{1 \text{ mol}}{15.9994 \cancel{\text{g}}} = 3.525 \text{ mol}$

Step 2:

P: $\frac{1.4076 \cancel{\text{mol}}}{1.4076 \cancel{\text{mol}}} = 1.000 \qquad 1.0 \times 2 = 2.0$

O: $\frac{3.525 \cancel{\text{mol}}}{1.4076 \cancel{\text{mol}}} = 2.504 \qquad 2.5 \times 2 = 5.0$

The empirical formula is P_2O_5.

(b)

Step 1:

K: $28.7 \cancel{\text{g}} \times \frac{1 \text{ mol}}{39.0983 \cancel{\text{g}}} = 0.7340 \text{ mol}$

H: $1.5 \cancel{\text{g}} \times \frac{1 \text{ mol}}{1.00794 \cancel{\text{g}}} = 1.4882 \text{ mol}$

P: $22.8 \cancel{\text{g}} \times \frac{1 \text{ mol}}{30.9738 \cancel{\text{g}}} = 0.7361 \text{ mol}$

O: $47.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{15.9994 \cancel{\text{g}}} = 2.9376 \text{ mol}$

Step 2:

K: $\dfrac{0.7340\ \cancel{\text{mol}}}{0.7340\ \cancel{\text{mol}}} = 1.00$

H: $\dfrac{1.4882\ \cancel{\text{mol}}}{0.7340\ \cancel{\text{mol}}} = 2.03$

P: $\dfrac{0.7361\ \cancel{\text{mol}}}{0.7340\ \cancel{\text{mol}}} = 1.00$

O: $\dfrac{2.9376\ \cancel{\text{mol}}}{0.7340\ \cancel{\text{mol}}} = 4.00$

The empirical formula is KH_2PO_4.

Question 18-8.

A compound of carbon and hydrogen contains 92.3% C and has a molar mass of 78.1 g/mol. What is its molecular formula?

Solution

To determine the empirical formula, a relationship between percent composition and atom composition must be established. The percent composition of each element in a compound can be found either by dividing its mass by the total mass of compound or by dividing the molar mass of that element as it appears in the formula (atomic mass times the number of times the element appears in the formula) by the formula mass of the compound. From this latter perspective, the percent composition of an element can be converted into a mass by assuming that we start with a 100-g sample. Then, multiplying the percentage times 100 g gives the mass in grams of that component. Division of each mass by its respective atomic mass gives the relative ratio of atoms in the formula. From the numbers so obtained, the whole-number ratio of elements in the compound can be found by dividing each ratio by the number representing the smallest ratio. Generally, this process can be done in two simple steps (a third step is needed if the ratios are not whole numbers).

Step 1: Divide each element's percentage (converted to grams) by its atomic mass:

C: $\dfrac{92.3\text{ g}}{12.011\text{ g mol}^{-1}} = 7.68\text{ mol}$

H: $\dfrac{7.7\text{ g}}{1.00794\text{ g mol}^{-1}} = 7.6\text{ mol}$

This operation established the relative ration of carbon to hydrogen in the formula.

Step 2: To establish a whole-number ratio of carbon to hydrogen, divide each factor by the smallest factor. In this case, both factors are essentially equal; thus the ration of atoms is 1 to 1:

C: $\dfrac{7.68}{7.6} = 1$

H: $\dfrac{7.6}{7.6} = 1$

The empirical formula is CH.

Since the molecular mass of the compound is 78.1 amu, some integer times the sum of the mass of 1C and 1H in atomic mass units (12.011 amu + 1.00794 amu = 13.019 amu) must be equal to 78.1 amu. To find this number, divide 78.1 amu by 13.019 amu:

$$\frac{78.1\text{ amu}}{13.019\text{ amu}} = 5.9989 \longrightarrow 6$$

The molecular formula is $(CH)_6 = C_6H_6$.

Question 18-9.

Dichloroethane, a compound that is often used for dry cleaning, contains carbon, hydrogen, and chlorine. It has a molar mass of 99 g/mol. Analysis of a sample shows that it contains 24.3% carbon and 4.1% hydrogen. What is its molecular formula?

Solution

The molecular formula is a whole-number multiple of the empirical formula, and the molecular mass is a whole-number multiple of the empirical mass. The solution sequence is to determine the empirical formula, the formula mass, and then the molecular formula.

Step 1:

$$\text{C}: \frac{24.3}{12.011} = 2.02 \text{ mol}$$

$$\text{H}: \frac{4.1}{1.0079} = 4.07 \text{ mol}$$

$$\text{Cl}: \frac{71.6}{35.453} = 2.02 \text{ mol}$$

Step 2:

$$\text{C}: \frac{2.02}{2.02} = 1.0$$

$$\text{H}: \frac{4.07}{2.02} = 2.0$$

$$\text{Cl}: \frac{2.02}{2.02} = 1.0$$

The empirical formula is CH_2Cl; the empirical formula mass is 49.5.

Molecular mass = (empirical formula mass) × (number of formula units)

99 = 49.5 × no. of formula units

Solve for the number of formula units: $\frac{99}{49.5} = 2$

Molecular formula: $2(CH_2Cl) = C_2H_4Cl_2$

Question 18-10.

Determine the empirical and molecular formula for chrysotile asbestos. Chrysotile has the following percent composition: 28.03% Mg, 21.60% Si, 1.16% H, and 49.21% O. The molar mass for chrysotile is 520.8 g/mol.

Solution

$$(28.03 \text{ g Mg})\left(\frac{1 \text{ mol Mg}}{24.30 \text{ g}}\right) = 1.153 \text{ mol Mg} \qquad \frac{1.153}{0.769} = 1.512 \text{ mol Mg}$$

$$(21.60 \text{ g Si})\left(\frac{1 \text{ mol Si}}{28.09 \text{ g Si}}\right) = 0.769 \text{ mol Si} \qquad \frac{0.769}{0.769} = 1.00 \text{ mol Si}$$

$$(1.16 \text{ g H})\left(\frac{1 \text{ mol H}}{1.01 \text{ g H}}\right) = 1.149 \text{ mol H} \qquad \frac{1.149}{0.769} = 1.49 \text{ mol H}$$

$$(49.21\text{ g O})\left(\frac{1\text{ mol O}}{16.00\text{ g O}}\right) = 3.076\text{ mol O} \qquad \frac{3.076}{0.769} = 4.00\text{ mol O}$$

(2)($Mg_{1.5}Si_1H_{1.5}O_4$) = $Mg_3Si_2H_3O_8$ (empirical formula), empirical mass of 260.1 g/unit

$$\frac{MM}{EM} = \frac{520.8}{260.1} = 2.00,$$ so (2)($Mg_3Si_2H_3O_8$) = $Mg_6Si_4H_6O_{16}$

Question 18-11.

Polymers are large molecules composed of simple units repeated many times. Thus, they often have relatively simple empirical formulas. Calculate the empirical formulas of the following polymers:

(a) Lucite (Plexiglas); 59.9% C, 8.06% H, 32.0% O
(b) Saran; 24.8% C, 2.0% H, 73.1% Cl
(c) polyethylene; 86% C, 14% H
(d) polystyrene; 92.3% C, 7.7% H
(e) Orlon; 67.9% C, 5.70% H, 26.4% N

Solution

(a)

Step 1:

$$\text{C: } 59.9\ \cancel{\text{g}} \times \frac{1\text{ mol}}{12.011\ \cancel{\text{g}}} = 4.99\text{ mol}$$

$$\text{H: } 8.06\ \cancel{\text{g}} \times \frac{1\text{ mol}}{1.00794\ \cancel{\text{g}}} = 8.00\text{ mol}$$

$$\text{O: } 32.0\ \cancel{\text{g}} \times \frac{1\text{ mol}}{15.9994\ \cancel{\text{g}}} = 2.00\text{ mol}$$

Step 2:

$$\text{C: } \frac{4.99}{2.00} = 2.5$$

$$\text{H: } \frac{8.00}{2.00} = 4.0$$

$$\text{O: } \frac{2.00}{2.00} = 1.0$$

Step 3:

C: 2.5 × 2 = 5.0
H: 4.0 × 2 = 8.0
O: 1.0 × 2 = 2.0

The empirical formula is $C_5H_8O_2$.

(b)

Step 1:

$$\text{C: } 24.8\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{12.011\ \cancel{\text{g}}} = 2.06\ \text{mol}$$

$$\text{H: } 2.0\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{1.00794\ \cancel{\text{g}}} = 2.0\ \text{mol}$$

$$\text{Cl: } 73.1\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{35.453\ \cancel{\text{g}}} = 2.06\ \text{mol}$$

Step 2:

$$\text{C: } \frac{2.06\ \cancel{\text{mol}}}{2.06\ \cancel{\text{mol}}} = 1$$

$$\text{H: } \frac{2.0\ \cancel{\text{mol}}}{2.06\ \cancel{\text{mol}}} = 1$$

$$\text{Cl: } \frac{2.06\ \cancel{\text{mol}}}{2.06\ \cancel{\text{mol}}} = 1$$

The empirical formula is CHCl.

(c)

Step 1:

$$\text{C: } \frac{86\ \cancel{\text{g}}}{12.011\ \cancel{\text{g}}\ \text{mol}^{-1}} = 7.2\ \text{mol}$$

$$\text{H: } \frac{14\ \cancel{\text{g}}}{1.00794\ \cancel{\text{g}}\ \text{mol}^{-1}} = 14\ \text{mol}$$

Step 2:

$$\text{C: } \frac{7.2\ \cancel{\text{mol}}}{7.2\ \cancel{\text{mol}}} = 1$$

$$\text{H: } \frac{14\ \text{mol}}{7.2\ \text{mol}} = 1.9 \approx 2$$

The empirical formula is CH_2.

(d)

Step 1:

$$\text{C: } 92.3\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{12.011\ \cancel{\text{g}}} = 7.68\ \text{mol}$$

$$\text{H: } 7.7\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{1.00794\ \cancel{\text{g}}} = 7.64\ \text{mol}$$

Step 2:

C: $\frac{7.68 \cancel{\text{mol}}}{7.64 \cancel{\text{mol}}} = 1$

H: $\frac{7.64 \text{ mol}}{7.64 \text{ mol}} = 1$

The empirical formula is CH.

(e)

Step 1:

C: $\frac{67.9 \cancel{\text{g}}}{12.011 \cancel{\text{g}} \text{ mol}^{-1}} = 5.65 \text{ mol}$

H: $\frac{5.70 \cancel{\text{g}}}{1.00794 \cancel{\text{g}} \text{ mol}^{-1}} = 5.66 \text{ mol}$

N: $\frac{26.4 \text{ g}}{14.0067 \text{ g mol}^{-1}} = 1.88 \text{ mol}$

Step 2:

C: $\frac{5.65 \cancel{\text{mol}}}{1.88 \cancel{\text{mol}}} = 3.01$

H: $\frac{5.66 \cancel{\text{mol}}}{1.88 \cancel{\text{mol}}} = 3.01$

N: $\frac{1.88 \cancel{\text{mol}}}{1.88 \cancel{\text{mol}}} = 1.00$

The empirical formula is C_3H_3N.

Question 18-12.

A major textile dye manufacturer developed a new yellow dye. The dye has a percent composition of 75.95% C, 17.72% N, and 6.33% H by mass with a molar mass of about 240 g/mol. Determine the molecular formula of the dye.

Solution

Assume 100.0 g; the percentages of the elements are then the same as their mass in grams. Divide each mass by the molar mass to find the number of moles.

Step 1:

$\frac{75.95 \cancel{\text{g}}}{12.011 \cancel{\text{g}} \text{ mol}^{-1}} = 6.323 \text{ mol C}$

$\frac{17.72 \cancel{\text{g}}}{14.0067 \cancel{\text{g}} \text{ mol}^{-1}} = 1.265 \text{ mol N}$

$\frac{6.33 \cancel{\text{g}}}{1.00794 \cancel{\text{g}} \text{ mol}^{-1}} = 6.28 \text{ mol H}$

Step 2: Divide each by the smallest number. The answers are 5C, 1N, and 5H. The empirical formula is C_5H_5N, which has a molar mass of 79.10 g/mol. To find the actual molecular formula, divide 240, the molar mass of the compound, by 79.10 to obtain 3. So the formula is three times the empirical formula, or $C_{15}H_{15}N_3$.

3.3 Molarity

Question 19-1.

Explain what changes and what stays the same when 1.00 L of a solution of NaCl is diluted to 1.80 L.

Solution

The mass and number of moles of NaCl stay the same. The volume of the solution and the concentration of NaCl change.

Question 19-2.

What information is needed to calculate the molarity of a sulfuric acid solution?

Solution

We need to know the number of moles of sulfuric acid dissolved in the solution and the volume of the solution.

Question 19-3.

A 200-mL sample and a 400-mL sample of a solution of salt have the same molarity. In what ways are the two samples identical? In what ways are these two samples different?

Solution

When a 200-mL and a 400-mL sample have the same concentration, both solutions have the same amount of salt per unit volume. The solutions are different in that the 400 mL solution contains twice as much salt.

Question 19-4.

Determine the molarity for each of the following solutions:

(a) 0.444 mol of $CoCl_2$ in 0.654 L of solution
(b) 98.0 g of phosphoric acid, H_3PO_4, in 1.00 L of solution
(c) 0.2074 g of calcium hydroxide, $Ca(OH)_2$, in 40.00 mL of solution
(d) 10.5 kg of $Na_2SO_4 \cdot 10H_2O$ in 18.60 L of solution
(e) 7.0×10^{-3} mol of I_2 in 100.0 mL of solution
(f) 1.8×10^4 mg of HCl in 0.075 L of solution

Solution

(a) $\frac{0.444 \text{ mol}}{0.654 \text{ L}} = 0.679 \text{ mol L}^{-1} = 0.679\ M$;

(b) First convert mass in grams to moles, and then substitute the proper terms into the definition.
Molar mass of H_3PO_4 = 97.995 g/mol

$$\text{mol (H}_3\text{PO}_4) = 98.0 \text{ g} \times \frac{1 \text{ mol}}{97.995 \text{ g}} = 1.00 \text{ mol}$$

$$M = \frac{1.00 \text{ mol}}{1.00 \text{ L}} = 1.00\ M;$$

(c) Molar mass $[Ca(OH)_2]$ = 74.09 g/mol

$$0.2074\ \cancel{g} \times \frac{1\text{ mol}}{74.09\ \cancel{g}} = 0.002799\text{ mol Ca(OH)}_2$$

$$\frac{0.002799\text{ mol}}{0.0400\text{ L}} = 0.06998\text{ mol L}^{-1} = 0.06998\ M\ ;$$

(d) Molar mass ($Na_2SO_4•10H_2O$) = 322.20 g/mol

$$10{,}500 \times \frac{1\text{ mol}}{322.20\text{ g}} = 32.6\text{ mol}$$

$$\frac{32.6\text{ mol}}{18.60\text{ L}} = 1.75\ M\ ;$$

(e) $$M = \frac{\text{millimoles solute}}{\text{volume of solution in milliliters}}$$

$$\frac{7.00\text{ mmol I}_2}{100\text{ mL}} = 0.070\ M\ ;$$

(f) Molar mass (HCl) = 36.46 g/mol

$$\text{mass (HCl)} = 1.8 \times 10^1\text{ g HCl} \times \frac{1\text{ mol}}{36.46\text{ g}} = 0.49\text{ mol HCl}$$

$$\frac{0.49\text{ mol HCl}}{0.075\text{ L}} = 6.6\ M$$

Question 19-5.

Determine the molarity of each of the following solutions:

(a) 1.457 mol KCl in 1.500 L of solution
(b) 0.515 g of H_2SO_4 in 1.00 L of solution
(c) 20.54 g of $Al(NO_3)_3$ in 1575 mL of solution
(d) 2.76 kg of $CuSO_4•5H_2O$ in 1.45 L of solution
(e) 0.005653 mol of Br_2 in 10.00 mL of solution
(f) 0.000889 g of glycine, $C_2H_5NO_2$, in 1.05 mL of solution

Solution

Make any conversions of units as necessary before setting up the problem and calculate the molar mass where necessary.

(a) $$\frac{1.457\text{ mol KCl}}{1.500\text{ L}} = 0.9713\ M\ ;$$

(b) $$\frac{\frac{0.515\ \cancel{g}}{98.079\ \cancel{g}\text{ mol}^{-1}}}{1.00\text{ L}} = 0.00525\ M\ ;$$

(c) $$\frac{\frac{20.54\ \cancel{g}}{213.00\ \cancel{g}\text{ mol}^{-1}}}{1.575\text{ L}} = 0.06123\ M\ ;$$

(d) $$\frac{\frac{2.76 \times 10^3\ \cancel{g}}{429.69\ \cancel{g}\text{ mol}^{-1}}}{1.45\text{ L}} = 7.62\ M\ ;$$

(e) $\frac{0.005653 \text{ mol}}{0.01000 \text{ L}} = 0.5653\ M$;

(f) $\frac{\frac{0.000889 \cancel{\text{g}}}{75.0675 \cancel{\text{g}} \text{ mol}^{-1}}}{0.00105 \text{ L}} = 0.0113\ M$

Question 19-6.

Consider this question: What is the mass of the solute in 0.500 L of 0.30 *M* glucose, $C_6H_{12}O_6$, used for intravenous injection?

(a) Outline the steps necessary to answer the question.

(b) Answer the question.

Solution

(a) determine the number of moles of glucose in 0.500 L of solution; determine the molar mass of glucose; determine the mass of glucose from the number of moles and its molar mass; (b) 0.500 L contains 0.30 $M \times 0.500$ L = 1.5×10^{-1} mol. Molar mass (glucose): 6 × 12.0011 g + 12 × 1.00794 g + 6 × 15.9994 g = 180.158 g, 1.5×10^{-1} ~~mol~~ × 180.158 g/~~mol~~ = 27 g.

Question 19-7.

Consider this question: What is the mass of solute in 200.0 L of a 1.556-*M* solution of KBr?

(a) Outline the steps necessary to answer the question.

(b) Answer the question.

Solution

(a) Determine the number of moles of KBr in 200.0 L of a 1.556-*M* solution. Determine the formula mass of KBr. Then determine the mass of KBr from the number of moles and its formula mass. (b) mol KBr = 200.0 L × 1.556 *M* = 311.2 mol

Mass (formula) = 39.0983 g/mol + 79.904 g/mol = 119.002 g/mol

Mass (KBr) = 311.2 mol × 119.002 g/mol = 3.703×10^4 g

Question 19-8.

Calculate the number of moles and the mass of the solute in each of the following solutions:

(a) 2.00 L of 18.5 *M* H_2SO_4, concentrated sulfuric acid

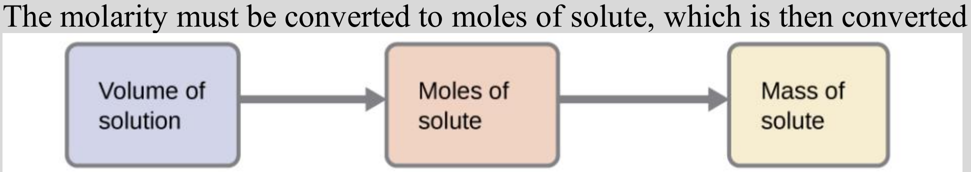
(b) 100.0 mL of 3.8×10^{-6} *M* NaCN, the minimum lethal concentration of sodium cyanide in blood serum

(c) 5.50 L of 13.3 *M* H_2CO, the formaldehyde used to “fix” tissue samples

(d) 325 mL of 1.8×10^{-6}*M* $FeSO_4$, the minimum concentration of iron sulfate detectable by taste in drinking water

Solution

The molarity must be converted to moles of solute, which is then converted to grams of solute:



$M = \frac{\text{mol}}{\text{liter}}$ or mol = $M \times$ liter

(a)

$$\text{mol } H_2SO_4 = 2.00\ \cancel{\text{L}} \times \frac{18.5 \text{ mol}}{\cancel{\text{L}}} = 37.0 \text{ mol } H_2SO_4$$

$$37.0\ \cancel{\text{mol } H_2SO_4} \times \frac{98.08 \text{ g } H_2SO_4}{1\ \cancel{\text{mol } H_2SO_4}} = 3.63 \times 10^3 \text{ g } H_2SO_4$$;

(b)

$$\text{mol NaCN} = 0.1000\ \cancel{\text{L}} \times \frac{3.8 \times 10^{-6} \text{ mol}}{\cancel{\text{L}}} = 3.8 \times 10^{-7} \text{ mol NaCN}$$

$$3.8 \times 10^{-7}\ \cancel{\text{mol NaCN}} \times \frac{49.01 \text{ g}}{1\ \cancel{\text{mol NaCN}}} = 1.9 \times 10^{-5} \text{ g NaCN}$$;

(c)

$$\text{mol } H_2CO = 5.50\ \cancel{\text{L}} \times \frac{13.3 \text{ mol}}{\cancel{\text{L}}} = 73.2 \text{ mol } H_2CO$$

$$73.2\ \cancel{\text{mol } H_2CO} \times \frac{30.026 \text{ g}}{1\ \cancel{\text{mol } H_2CO}} = 2198 \text{ g } H_2CO = 2.20 \text{ kg } H_2CO$$;

(d)

$$\text{mol } FeSO_4 = 0.325\ \cancel{\text{L}} \times \frac{1.8 \times 10^{-6} \text{ mol}}{\cancel{\text{L}}} = 5.9 \times 10^{-7} \text{ mol } FeSO_4$$

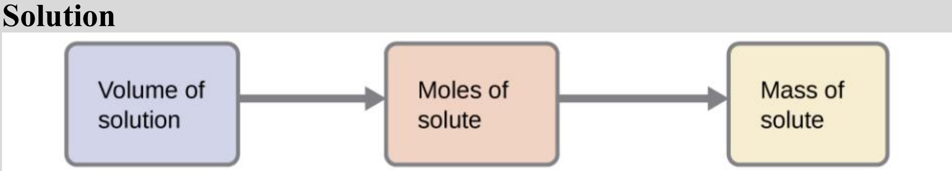
$$5.85 \times 10^{-7}\ \cancel{\text{mol } FeSO_4} \times \frac{151.9 \text{ g}}{1\ \cancel{\text{mol } FeSO_4}} = 8.9 \times 10^{-5} \text{ g } FeSO_4$$

Question 19-9.

Calculate the number of moles and the mass of the solute in each of the following solutions:

(a) 325 mL of $8.23 \times 10^{-5} M$ KI, a source of iodine in the diet
(b) 75.0 mL of $2.2 \times 10^{-5} M$ H_2SO_4, a sample of acid rain
(c) 0.2500 L of 0.1135 M K_2CrO_4, an analytical reagent used in iron assays
(d) 10.5 L of 3.716 M $(NH_4)_2SO_4$, a liquid fertilizer

Solution



M = mol/L or mol = M × L; convert mL to L to begin;

(a) mol KI = 0.325 L × $8.23 \times 10^{-5} M = 2.67 \times 10^{-5}$ mol KI

$$2.67 \times 10^{-5}\ \cancel{\text{mol KI}} \times \frac{166.0028 \text{ g}}{1\ \cancel{\text{mol KI}}} = 4.43 \times 10^{-3} \text{ g KI};$$

(b) mol H_2SO_4 = 0.0750 L × $2.2 \times 10^{-5} M = 1.6 \times 10^{-6}$mol H_2SO_4

$$1.6 \times 10^{-6}\ \cancel{\text{mol } H_2SO_4} \times \frac{98.079 \text{ g}}{1\ \cancel{\text{mol } H_2SO_4}} = 1.6 \times 10^{-6} \text{ g } H_2SO_4;$$

(c) mol K_2CrO_4 = 0.2500 L × 0.1135 M = 0.02838 mol K_2CrO_4

$$0.02838\ \cancel{\text{mol } K_2CrO_4} \times \frac{194.1903 \text{ g}}{1\ \cancel{\text{mol } K_2CrO_4}} = 5.511 \text{ g } K_2CrO_4;$$

(d) mol $(NH_4)_2SO_4$ = 10.5 L × 3.716 M = 39.0 mol $(NH_4)_2SO_4$

$$39.0\ \cancel{\text{mol } (NH_4)_2SO_4} \times \frac{132.141 \text{ g}}{\cancel{\text{mol } (NH_4)_2SO_4}} = 5.15 \times 10^3 \text{ g } (NH_4)_2SO_4$$

Question 19-10.

Consider this question: What is the molarity of $KMnO_4$ in a solution of 0.0908 g of $KMnO_4$ in 0.500 L of solution?

(a) Outline the steps necessary to answer the question.

(b) Answer the question.

Solution

(a) determine the molar mass of $KMnO_4$; determine the number of moles of $KMnO_4$ in the solution; from the number of moles and the volume of solution, determine the molarity; (b) Molar mass of $KMnO_4$ = 158.0264 g/mol

$$\text{mol KMnO}_4 = 0.0908 \ \cancel{\text{g KMnO}_4} \times \frac{1 \text{ mol}}{158.0264 \ \cancel{\text{g KMnO}_4}} = 5.746 \times 10^{-4} \text{ mol}$$

$$M \ \text{KMnO}_4 = \frac{5.746 \times 10^{-4} \text{ mol}}{0.500 \text{ L}} = 1.15 \times 10^{-3} \ M$$

Question 19-11.

Consider this question: What is the molarity of HCl if 35.23 mL of a solution of HCl contain 0.3366 g of HCl?

(a) Outline the steps necessary to answer the question.

(b) Answer the question.

Solution

(a) Determine the molar mass of HCl. Determine the number of moles of HCl in the solution. From the number of moles and the volume of solution, determine the molarity. (b) Molar mass of HCl = 36.4606

$$\text{mol HCl} = 0.3366 \ \cancel{\text{g HCl}} \times \frac{1 \text{ mol}}{36.4606 \ \cancel{\text{g HCl}}} = 9.232 \times 10^{-3} \text{ mol}$$

$$M \ \text{HCl} = \frac{9.232 \times 10^{-3} \text{ mol}}{0.03523 \text{ L}} = 0.2620 \ M$$

Question 19-12.

Calculate the molarity of each of the following solutions:

(a) 0.195 g of cholesterol, $C_{27}H_{46}O$, in 0.100 L of serum, the average concentration of cholesterol in human serum

(b) 4.25 g of NH_3 in 0.500 L of solution, the concentration of NH_3 in household ammonia

(c) 1.49 kg of isopropyl alcohol, C_3H_7OH, in 2.50 L of solution, the concentration of isopropyl alcohol in rubbing alcohol

(d) 0.029 g of I_2 in 0.100 L of solution, the solubility of I_2 in water at 20 °C

Solution

$$\text{(a) } M \ \text{C}_{27}\text{H}_{46}\text{O} = \frac{\text{mol}}{V} = \frac{\dfrac{0.195 \ \cancel{\text{g}} \ \text{C}_{27}\text{H}_{46}\text{O}}{386.660 \ \cancel{\text{g}} \ \text{mol}^{-1} \ \text{C}_{27}\text{H}_{46}\text{O}}}{0.100 \text{ L}} = 5.04 \times 10^{-3} \ M;$$

$$\text{(b) } M \text{ NH}_3 = \frac{\text{mol}}{V} = \frac{\dfrac{4.25 \cancel{\text{g}} \text{ NH}_3}{17.0304 \cancel{\text{g}} \text{ mol}^{-1} \text{ NH}_3}}{0.500 \text{ L}} = 0.499\ M;$$

$$\text{(c) } M \text{ C}_3\text{H}_7\text{OH} = \frac{\text{mol}}{V} = \frac{1.49 \cancel{\text{kg}} \text{ C}_3\text{H}_7\text{OH} \times \dfrac{1000 \cancel{\text{g}}}{1 \cancel{\text{kg}}} \times \dfrac{1 \text{ mol C}_3\text{H}_7\text{OH}}{60.096 \cancel{\text{g}}}}{2.50 \text{ L}} = 9.92\ M;$$

$$\text{(d) } M \text{ I}_2 = \frac{\text{mol}}{V} = \frac{\dfrac{0.029 \cancel{\text{g}} \text{ I}_2}{253.8090 \cancel{\text{g}} \text{ mol}^{-1} \text{ I}_2}}{0.100 \text{ L}} = 1.1 \times 10^{-3}\ M$$

Question 19-13.

Calculate the molarity of each of the following solutions:

(a) 293 g HCl in 666 mL of solution, a concentrated HCl solution

(b) 2.026 g $FeCl_3$ in 0.1250 L of a solution used as an unknown in general chemistry laboratories

(c) 0.001 mg Cd^{2+} in 0.100 L, the maximum permissible concentration of cadmium in drinking water

(d) 0.0079 g $C_7H_5SNO_3$ in one ounce (29.6 mL), the concentration of saccharin in a diet soft drink.

Solution

$$\text{(a) } M \text{ HCl} = \frac{\text{mol}}{V} = \frac{293 \cancel{\text{g HCl}} \times \dfrac{1 \text{ mol}}{36.4606 \cancel{\text{g HCl}}}}{0.666 \text{ L}} = 12.1\ M;$$

$$\text{(b) } M \text{ FeCl}_3 = \frac{\text{mol}}{V} = \frac{2.026 \cancel{\text{g FeCl}_3} \times \dfrac{1 \text{ mol}}{162.205 \cancel{\text{g FeCl}_3}}}{0.1250 \text{ L}} = 0.09992\ M;$$

$$\text{(c) } M \text{ Cd}^{2+} = \frac{\text{mol}}{V} = \frac{0.001 \cancel{\text{g Cd}}^{2+} \times \dfrac{0.001 \cancel{\text{g}}}{1 \cancel{\text{mg}}} \times \dfrac{1 \text{ mol}}{112.411 \cancel{\text{g Cd}}^{2+}}}{0.100 \text{ L}} = 9 \times 10^{-8}\ M;$$

$$\text{(d) } M \text{ C}_7\text{H}_5\text{SNO}_3 = \frac{\text{mol}}{V} = \frac{0.0079 \cancel{\text{g C}_7\text{H}_5\text{SNO}_3} \times \dfrac{1 \text{ mol}}{183.188 \cancel{\text{g C}_7\text{H}_5\text{SNO}_3}}}{0.0296 \text{ L}} = 1.5 \times 10^{-3}\ M$$

Question 19-14.

There is about 1.0 g of calcium, as Ca^{2+}, in 1.0 L of milk. What is the molarity of Ca^{2+} in milk?

Solution

$$M = \frac{\text{mol}}{V} = \frac{\dfrac{1.0 \cancel{\text{g}}}{40.08 \cancel{\text{g}} \text{ mol}^{-1}}}{1.0 \text{ L}} = 0.025\ M$$

Question 19-15.

What volume of a 1.00-*M* $Fe(NO_3)_3$ solution can be diluted to prepare 1.00 L of a solution with a concentration of 0.250 *M*?

Solution

$$V_1 = \frac{V_2 \times M_2}{M_2} = 1.00\ \text{L} \times \frac{0.250\ M}{1.00\ M} = 0.250\ \text{L}$$

Question 19-16.

If 0.1718 L of a 0.3556-*M* C_3H_7OH solution is diluted to a concentration of 0.1222 *M*, what is the volume of the resulting solution?

Solution

$$\frac{C_1V_1}{C_2} = V_2$$

$$\frac{\frac{0.3556\ \text{mol}}{\text{L}} \times 0.1718\ \text{L}}{\frac{0.1222\ \text{mol}}{\text{L}}} = V_2$$

$$0.5000\ \text{L} = V_2$$

Question 19-17.

If 4.12 L of a 0.850 *M*-H_3PO_4 solution is be diluted to a volume of 10.00 L, what is the concentration the resulting solution?

Solution

$$\frac{C_1V_1}{V_2} = C_2$$

$$\frac{\frac{0.850\ \text{mol}}{\text{L}} \times 4.12\ \text{L}}{10.00\ \text{L}} = C_2$$

$$0.350\ M = C_2$$

Question 19-18.

What volume of a 0.33-*M* $C_{12}H_{22}O_{11}$ solution can be diluted to prepare 25 mL of a solution with a concentration of 0.025 *M*?

Solution

$$V_1 = \frac{V_2 \times M_2}{M_2} = 25\ \text{mL} \times \frac{0.025\ M}{0.33\ M} = 1.9\ \text{mL}$$

Question 19-19.

What is the concentration of the NaCl solution that results when 0.150 L of a 0.556-*M* solution is allowed to evaporate until the volume is reduced to 0.105 L?

Solution

$$M_2 = \frac{V_1 \times M_1}{V_2} = 0.150\ \text{L} \times \frac{0.556\ M}{0.105\ \text{L}} = 0.794\ M$$

Question 19-20.

What is the molarity of the diluted solution when each of the following solutions is diluted to the given final volume?

(a) 1.00 L of a 0.250-*M* solution of $Fe(NO_3)_3$is diluted to a final volume of 2.00 L

(b) 0.5000 L of a 0.1222-*M* solution of C_3H_7OH is diluted to a final volume of 1.250 L

(c) 2.35 L of a 0.350-*M* solution of H_3PO_4 is diluted to a final volume of 4.00 L

(d) 22.50 mL of a 0.025-*M* solution of $C_{12}H_{22}O_{11}$ is diluted to 100.0 mL

Solution

(a) $C_2 = \frac{V_1 \times C_1}{V_2} = 1.00\ \cancel{\text{L}} \times \frac{0.250 M}{2.00\ \cancel{\text{L}}} = 0.125\ M$;

(b) $C_2 = \frac{V_1 \times C_1}{V_2} = 0.5000\ \cancel{\text{L}} \times \frac{0.1222\ M}{1.250\ \cancel{\text{L}}} = 0.04888\ M$;

(c) $C_2 = \frac{V_1 \times C_1}{V_2} = 2.35\ \cancel{\text{L}} \times \frac{0.350 M}{4.00\ \cancel{\text{L}}} = 0.206\ M$;

(d) $C_2 = \frac{V_1 \times C_1}{V_2} = 22.50\ \text{L} \times \frac{0.025\ M}{100\ \text{L}} = 0.0056\ M$

Question 19-21.

What is the final concentration of the solution produced when 225.5 mL of a 0.09988-*M* solution of Na_2CO_3 is allowed to evaporate until the solution volume is reduced to 45.00 mL?

Solution

$$C_2 = \frac{V_1 \times C_1}{V_2} = 225.5\ \cancel{\text{mL}} \times \frac{0.09988\ M}{45.00\ \cancel{\text{mL}}} = 0.5005$$

Question 19-22.

A 2.00-L bottle of a solution of concentrated HCl was purchased for the general chemistry laboratory. The solution contained 868.8 g of HCl. What is the molarity of the solution?

Solution

Determine the number of moles in 434.4 g of HCl: 1.00794 + 35.4527 = 36.4606 g/mol

$$\text{mol HCl} = \frac{434.4\ \cancel{\text{g}}}{36.4606\ \cancel{\text{g}}\ \text{mol}^{-1}} = 11.91\ \text{mol}$$

This HCl is present in 1.00 L, so the molarity is 11.9 *M*.

Question 19-23.

An experiment in a general chemistry laboratory calls for a 2.00-*M* solution of HCl. How many mL of 11.9 *M* HCl would be required to make 250 mL of 2.00 *M* HCl?

Solution

Use $C_1V_1 = C_2V_2$.

$$V_1 = \frac{250\ \text{mL} \times 2.00\ M}{11.9\ M} = 42.0\ \text{mL}$$

Question 19-24.

What volume of a 0.20-*M* K_2SO_4 solution contains 57 g of K_2SO_4?

Solution

$$57\ \text{g}\ K_2SO_4 \times \frac{1\ \text{mol}}{174.26\ \text{g}} \times \frac{1\ \text{L}}{0.20\ \text{mol}} = 1.6\ \text{L}$$

Question 19-25.

The US Environmental Protection Agency (EPA) places limits on the quantities of toxic substances that may be discharged into the sewer system. Limits have been established for a variety of substances, including hexavalent chromium, which is limited to 0.50 mg/L. If an industry is discharging hexavalent chromium as potassium dichromate ($K_2Cr_2O_7$), what is the maximum permissible molarity of that substance?

Solution

$$\frac{0.50\ \text{mg}}{\text{L}} \times \frac{1\ \text{g}}{1000\ \text{mg}} \times \frac{1\ \text{mol}}{294.1846\ \text{g}} = 1.7 \times 10^{-6}\ M$$

3.4 Other Units for Solution Concentrations

Question 20-1.

Consider this question: What mass of a concentrated solution of nitric acid (68.0% HNO_3 by mass) is needed to prepare 400.0 g of a 10.0% solution of HNO_3 by mass?

(a) Outline the steps necessary to answer the question.

(b) Answer the question.

Solution

(a) The dilution equation can be used, appropriately modified to accommodate mass-based concentration units:

$\%\text{mass}_1 \times \text{mass}_1 = \%\text{mass}_2 \times \text{mass}_2$

This equation can be rearranged to isolate mass_1 and the given quantities substituted into this equation.

(b) $$\text{mass}_1 = \frac{\%\text{mass}_2 \times \text{mass}_2}{\%\text{mass}_1} = \frac{10.0\ \% \times 400.0\ \text{g}}{68.0\ \%} = 58.8\ \text{g}$$

Question 20-2.

What mass of a 4.00% NaOH solution by mass contains 15.0 g of NaOH?

Solution

$$\text{mass (NaOH solution)} \times \frac{4.00\%}{100.0\%} = 15.0\ \text{g}$$

$$\text{mass (NaOH solution)} \times \frac{15.0\ \text{g}}{0.0400} = 375\ \text{g}$$

Question 20-3.

What mass of solid NaOH (97.0% NaOH by mass) is required to prepare 1.00 L of a 10.0% solution of NaOH by mass? The density of the 10.0% solution is 1.109 g/mL.

Solution

$$1000\ \cancel{cm^3} \times \frac{1.109\ g}{\cancel{cm^3}} = 1.11 \times 10^3\ g.$$

The mass of pure NaOH required is

$$\text{mass}\ (NaOH) = \frac{10.0\%}{100.0\%} \times 1.11 \times 10^3\ g = 1.11 \times 10^2\ g.$$

This mass of NaOH must come from the 97.0% solution:

$$\text{mass (NaOH solution)} \times \frac{97.0\%}{100.0\%} = 1.11 \times 10^2\ g$$

$$\text{mass (NaOH solution)} = \frac{1.11 \times 10^2\ g}{0.970} = 114\ g$$

Question 20-4.

What mass of HCl is contained in 45.0 mL of an aqueous HCl solution that has a density of 1.19 g cm^{-3} and contains 37.21% HCl by mass?

Solution

The solution contains 37.21% HCl by mass, and the remainder is water. Calculate the mass of the 45.0-mL sample, and then multiply by the percentage to obtain the mass of HCl. Since 1 cm^3 = 1 mL. Mass (sample) = 45.0 ~~mL~~ × 1.19 g/~~mL~~ = 53.55 g; Mass (HCl) = 53.55 g × 0.3721 = 19.9 g

Question 20-5.

The hardness of water (hardness count) is usually expressed in parts per million (by mass) of $CaCO_3$, which is equivalent to milligrams of $CaCO_3$ per liter of water. What is the molar concentration of Ca^{2+} ions in a water sample with a hardness count of 175 mg $CaCO_3$/L?

Solution

Since $CaCO_3$ contains 1 mol Ca^{2+} per mol of $CaCO_3$, the molar concentration of Ca^{2+} equals the molarity of $CaCO_3$:

$$M\ Ca^{2+} = \frac{\text{mol } CaCO_3}{L} = \frac{175\ \cancel{mg} \times \left(\frac{1\ mol}{100.0792\ \cancel{g}}\right) \times \left(\frac{1\ \cancel{g}}{1000\ \cancel{mg}}\right)}{1\ L} = 1.75 \times 10^{-3}\ M$$

Question 20-6.

The level of mercury in a stream was suspected to be above the minimum considered safe (1 part per billion by weight). An analysis indicated that the concentration was 0.68 parts per billion. Assume a density of 1.0 g/mL and calculate the molarity of mercury in the stream.

Solution

Convert 0.68 parts per billion to mass in grams:

$$\text{mass Hg} = \frac{0.68\ \cancel{g}\ Hg}{1 \times 10^9\ \cancel{g}\ \text{solution}} = 6.8 \times 10^{-10}\ \frac{g\ Hg}{g\ \text{solution}}$$

$$\text{mol Hg} = \frac{6.8 \times 10^{-10} \ \frac{\text{g Hg}}{\text{g solution}}}{200.59 \ \text{g mol}^{-1}} = 3.4 \times 10^{-12} \ \frac{\text{mol Hg}}{\text{g solution}}$$

$$\text{molarity of Hg} = \frac{3.4 \times 10^{-12} \ \text{mol Hg}}{\text{g solution}} \times \frac{1.0 \ \text{g solution}}{\text{mL solution}} \times \frac{1000 \ \text{mL}}{1 \ \text{L}} = 3.4 \times 10^{-9} \ M$$

Question 20-7.

In Canada and the United Kingdom, devices that measure blood glucose levels provide a reading in millimoles per liter. If a measurement of 5.3 m*M* is observed, what is the concentration of glucose ($C_6H_{12}O_6$) in mg/dL?

Solution

1 mg/dL = 0.01 g/L and 1 L = 10 dL

5.3 mmol/L × 180.158 mg/mmol = 9.5×10^2 mg/L

$$9.5 \times 10^2 \text{mg/L} \times \frac{1 \ \text{L}}{10 \ \text{dL}} = 95 \ \text{mg/dL}$$

Question 20-8.

A throat spray is 1.40% by mass phenol, C_6H_5OH, in water. If the solution has a density of 0.9956 g/mL, calculate the molarity of the solution.

Solution

Assume 1.000 L of solution. Then

1000 mL × 0.9956 g/mL = 995.6 g

995.6 g × 1.40% = 995.6 g × 0.0140 = 13.9 g.

The molar mass of phenol is:

6 × C = 6 × 12.011 = 72.066

6 × H = 6 × 1.00794 = 6.04764

1 × O = 1 × 15.9994 = 15.9994

94.113 g mol^{-1}

$$\text{mol phenol} = \frac{13.9 \ \text{g}}{94.113 \ \text{g mol}^{-1}} = 0.148 \ \text{mol};$$

Since this value is the number of moles in 1 L, the molarity is 0.148 *M*.

Question 20-9.

Copper(I) iodide (CuI)is often added to table salt as a dietary source of iodine. How many moles of CuI are contained in 1.00 lb (454 g) of table salt containing 0.0100% CuI by mass?

Solution

0.0100% of 454 g is (0.000100 × 454 g) = 0.0454 g;

Molar mass of CuI = 63.546 + 126.90447 = 190.450 g/mol;

$$\text{mol CuI} = \frac{0.0454 \ \text{g}}{190.450 \ \text{g mol}^{-1}} = 0.000238 \ \text{mol} = 2.38 \times 10^{-4} \ \text{mol}$$

Question 20-10.

A cough syrup contains 5.0% ethyl alcohol, C_2H_5OH, by mass. If the density of the solution is 0.9928 g/mL, determine the molarity of the alcohol in the cough syrup.

Solution

Assume that we start with 1000 mL of liquid. Then

$$\frac{0.9928\text{ g}}{\text{mL}^{-1}} \times 1000\text{ mL} = 992.8\text{ g};$$

992.8 g × 5.0% = 992.8 g × 0.050 = 49.64 g;

the molar mass of ethanol, C_2H_5OH, is:

2 × 12.011 + 6 × 1.00794 + 15.9994 = 46.069 g/mol;

$$\text{Mol ethanol} = \frac{49.64\text{ g}}{46.069\text{ g mol}^{-1}} = 1.1\text{ mol};$$

since this amount of ethanol is present in a 1 L solution, the molarity is 1.1 *M*.

Question 20-11.

D5W is a solution used as an intravenous fluid. It is a 5.0% by mass solution of dextrose ($C_6H_{12}O_6$) in water. If the density of D5W is 1.029 g/mL, calculate the molarity of dextrose in the solution.

Solution

The molar mass of $C_6H_{12}O_6$ is 6 × 12.011 + 12 × 1.00794 + 6 × 15.9994 = 180.2 g/mol. In 1.000 L, there are:

$$(1000\text{ mL} \times 1.029\text{ g mL}^{-1}) = 1029\text{ g}$$

$$\text{mol dextrose} = 1029\text{ g} \times 0.050 \times \frac{1\text{ mol}}{180.2\text{ g}} = 0.29\text{ mol } C_6H_{12}O_6.$$

Since we selected the volume to be 1.00 L, the molarity of dextrose is

$$\text{molarity} = \frac{\text{mol}}{\text{L}} = \frac{0.29\text{ mol}}{1.00\text{ L}} = 0.29\text{ mol}.$$

Question 20-12.

Find the molarity of a 40.0% by mass aqueous solution of sulfuric acid, H_2SO_4, for which the density is 1.3057 g/mL.

Solution

First, calculate the moles of sulfuric acid in a convenient, 100-g sample:

$$40.0\text{ g } H_2SO_4 \times \frac{1\text{ mol}}{98.0748\text{ g}} = 0.407833\text{ mol } H_2SO_4.$$

Next, use the given density to find the volume of a 100-g sample:

$$100\text{ g solution} \times \frac{1\text{ mL}}{1.3057\text{ g solution}} \times \frac{1\text{ L}}{1000\text{ mL}} = 0.076587\text{ L solution}.$$

Finally, use the calculated values to find the molarity:

$$\frac{0.407833\text{ mol } H_2SO_4}{0.076587\text{ L solution}} = 5.33\ M\ H_2SO_4.$$