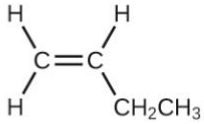
Chemistry 2e
3: Composition of Substances and Solutions
3.1: Formula Mass and the Mole Concept

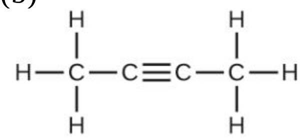
1. What is the total mass (amu) of carbon in each of the following molecules?
(a) CH_4
(b) $CHCl_3$
(c) $C_{12}H_{10}O_6$
(d) $CH_3CH_2CH_2CH_2CH_3$

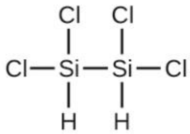
Solution
(a) 1 × 12.01 amu = 12.01 amu; (b) 1 × 12.01 amu = 12.01 amu; (c) 12 × 12.01 amu = 144.12 amu; (d) 5 × 12.01 amu = 60.05 amu

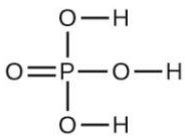
3. Calculate the molecular or formula mass of each of the following:
(a) P_4
(b) H_2O
(c) $Ca(NO_3)_2$
(d) CH_3CO_2H (acetic acid)
(e) $C_{12}H_{22}O_{11}$ (sucrose, cane sugar)

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

5. Determine the molecular mass of the following compounds:
(a)


(b)


(c)


(d)


Solution
(a) C_4H_8

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

(b) C_4H_6

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

(c) $H_2Si_2Cl_4$

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

(d) H_3PO_4

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

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.

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.

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.

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}

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

(c) $Sc_2(SO_4)_3$

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

(d) CH_3COCH_3

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

(e) $C_6H_{12}O_6$

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

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) $C_2HBrClF_3$

$$\begin{aligned} 2C &= 2 \times 12.011 = 24.022 \text{ g mol}^{-1} \\ 1H &= 1 \times 1.00794 = 1.00794 \text{ g mol}^{-1} \\ 1Br &= 1 \times 79.904 = 79.904 \text{ g mol}^{-1} \\ 1Cl &= 1 \times 35.453 = 35.453 \text{ g mol}^{-1} \\ 3F &= 3 \times 18.998403 = \underline{56.995209 \text{ g mol}^{-1}} \\ &= 197.382 \text{ g mol}^{-1} \end{aligned};$$

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

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

(c) $C_8H_{10}N_4O_2$

$$\begin{aligned} 8C &= 8 \times 12.011 = 96.088 \text{ g mol}^{-1} \\ 10H &= 10 \times 1.007 = 10.079 \text{ g mol}^{-1} \\ 4N &= 4 \times 14.0067 = 56.027 \text{ g mol}^{-1} \\ 2O &= 2 \times 15.9994 = \underline{31.999 \text{ g mol}^{-1}} \\ &= 194.193 \text{ g mol}^{-1} \end{aligned};$$

(d) $CO(NH_2)_2$

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

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

$2N = 2 \times 14.0067 = 28.0134\ g\ mol^{-1}$;

$4H = 4 \times 1.00794 = \underline{4.03176\ g\ mol^{-1}}$

$= 60.056\ g\ mol^{-1}$

(e) $C_{17}H_{35}CO_2Na$

$18C = 18 \times 12.011 = 216.198\ g\ mol^{-1}$

$35H = 35 \times 1.00794 = 35.2779\ g\ mol^{-1}$

$2O = 2 \times 15.9994 = 31.9988\ g\ mol^{-1}$

$1Na = 1 \times 22.98977 = \underline{22.98977\ g\ mol^{-1}}$

$= 306.464\ g\ mol^{-1}$

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:

$1K = 1 \times 39.0983 = 39.0983$

$1O = 1 \times 15.9994 = 15.9994$

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

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

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

(b) C_2H_6

$2C = 2 \times 12.011 = 24.022$

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

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

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

(c) Na_2SO_4:

$2Na = 2 \times 22.990 = 45.98$

$1S = 1 \times 32.066 = 32.066$

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

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

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

(d) $C_6H_{12}O_6$

$$\begin{aligned} 6C &= 6 \times 12.011 = 72.066 \\ 12H &= 12 \times 1.00794 = 12.0953 \\ 6O &= 6 \times 15.9994 = \underline{95.9964} \\ \text{molar mass} &= 180.158 \text{ g mol}^{-1} \end{aligned}$$

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

(e) $Co(NH_3)_6Cl_3$

$$\begin{aligned} Co &= 1 \times 58.99320 = 58.99320 \\ 6N &= 6 \times 14.0067 = 84.0402 \\ 18H &= 18 \times 1.00794 = 18.1429 \\ 3Cl &= 3 \times 35.4527 = \underline{106.358} \\ \text{molar mass} &= 267.5344 \text{ g mol}^{-1} \end{aligned}$$

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

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) $$\begin{aligned} &\text{molar mass } (\text{LiCl}) = 1 \times 6.941 + 1 \times 35.4527 = 42.394 \text{ g mol}^{-1} \\ &\text{mass} = 2.345 \cancel{\text{mol}} \times 42.394 \text{ g } \cancel{\text{mol}^{-1}} = 99.41 \text{ g} \end{aligned};$$

(b) $$\begin{aligned} &\text{molar mass } (C_2H_2) = 2 \times 12.011 + 2 \times 1.00794 = 26.038 \text{ g mol}^{-1} \\ &\text{mass} = 0.0872 \cancel{\text{mol}} \times 26.038 \text{ g } \cancel{\text{mol}^{-1}} = 2.27 \text{ g} \end{aligned};$$

(c) $$\begin{aligned} &\text{molar mass } (Na_2CO_3) = 2 \times 22.989768 + 1 \times 12.011 + 3 \times 15.9994 = 105.989 \text{ g mol}^{-1} \\ &\text{mass} = 3.3 \times 10^{-2} \cancel{\text{mol}} \times 105.989 \text{ g } \cancel{\text{mol}^{-1}} = 3.5 \text{ g} \end{aligned};$$

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

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

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

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: $0.3384\ \cancel{\text{mol}} \times 6.022 \times 10^{23}\ \cancel{\text{mol}^{-1}} = 2.038 \times 10^{23}$ atoms; $0.3384\ \cancel{\text{mol}} \times 91.224\ \text{g}/\cancel{\text{mol}} = 30.87$ g; Silicon: $0.3384\ \cancel{\text{mol}} \times 6.022 \times 10^{23}\ \cancel{\text{mol}^{-1}} = 2.038 \times 10^{23}$ atoms; $0.3384\ \cancel{\text{mol}} \times 28.0855\ \text{g}/\cancel{\text{mol}} = 9.504$ g; Oxygen: $4 \times 0.3384\ \cancel{\text{mol}} \times 6.022 \times 10^{23}\ \cancel{\text{mol}^{-1}} = 8.151 \times 10^{23}$ atoms; $4 \times 0.3384\ \cancel{\text{mol}} \times 15.9994\ \text{g}/\cancel{\text{mol}} = 21.66$ g

25. Determine which of the following contains the greatest mass of aluminum: 122 g of $AlPO_4$, 266 g of Al_2C1_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

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

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

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

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

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

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.

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:

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

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 $\frac{11.0}{60.0}$ of one serving or $\frac{60.0\ \text{g serving}}{11.0\ \cancel{\text{g sugar}}} \times 9.52\ \cancel{\text{g sugar}} = 51.9\ \text{g cereal}$.

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

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.

Chemistry 2e
3: Composition of Substances and Solutions
3.2: Determining Empirical and Molecular Formulas

33. 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)
$$\%\ N = \frac{14.0067\ g\ mol^{-1} \times 100\%}{[3(1.007940 + 14.0067)]\ g\ mol^{-1}} = \frac{14.0067\ g\ mol^{-1}}{17.0305\ g\ mol^{-1}} = 82.24\%;$$
$$\%\ H = \frac{3 \times 1.00794\ g\ mol^{-1}}{17.0305\ g\ mol^{-1}} \times 100\% = 17.76\%$$

(b)
$$\%\ Na = \frac{2 \times 22.989768}{2 \times 22.989768 + 2 \times 32.066 + 3 \times 15.9994} \times 100\% = \frac{45.9795}{158.1097} \times 100 = 29.08\%$$
$$\%\ S = \frac{64.132}{158.1097} \times 100\% = 40.56\%;$$
$$\%\ O = \frac{47.9982}{158.1097} \times 100\% = 30.36\%$$

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

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

Solution
$$\%\ NH_3 = \frac{6(14.007 + 3 \times 1.008)}{58.933 + 6(14.007 + 3 \times 1.008) + 3(35.453)} \times 100\% = \frac{102.186}{267.478} \times 100\% = 38.2\%$$

37. 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:
$$C:\ 15.8\ g \times \frac{1\ mol}{12.011\ g} = 1.315\ mol$$
$$S:\ 84.2\ g \times \frac{1\ mol}{32.066\ g} = 2.626\ mol$$

Step 2:

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

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

The empirical formula is CS_2.

(b) Step 1:

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

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

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.

39. 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: $\frac{92.3 \text{ g}}{12.011 \text{ g mol}^{-1}} = 7.68 \text{ mol}$

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

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: $\frac{7.68}{7.6} = 1$

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

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 $(CH)_6 = C_6H_6$.

41. 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

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

43. 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:

$$\frac{75.95 \not{g}}{12.011 \not{g} \text{ mol}^{-1}} = 6.323 \text{ mol C}$$

$$\frac{17.72 \not{g}}{14.0067 \not{g} \text{ mol}^{-1}} = 1.265 \text{ mol N}$$

$$\frac{6.33 \not{g}}{1.00794 \not{g} \text{ mol}^{-1}} = 6.28 \text{ mol H}$$

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 $C_{15}H_{15}N_3$.

Chemistry 2e
3: Composition of Substances and Solutions
3.3: Molarity

45. 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.

47. 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•$10H_2O$ 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

$$\text{mol }(H_3PO_4) = 98.0\text{ g} \times \frac{1\text{ mol}}{97.995\text{ g}} = 1.00\text{ mol}$$

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

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

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

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

(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

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

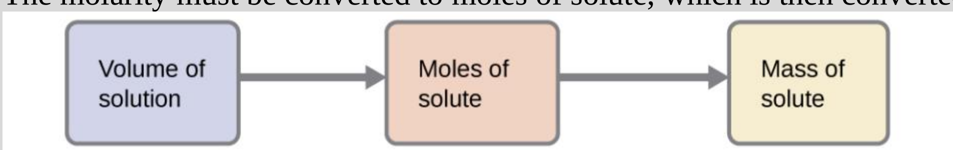
$$\frac{0.49\text{ mol HCl}}{0.075\text{ L}} = 6.6\ M$$

49. 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* × 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, $1.5 \times 10^{-1}\ \cancel{\text{mol}} \times 180.158\ \text{g}/\cancel{\text{mol}} = 27\ \text{g}$.

51. 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:



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

(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)
$$\text{mol } FeSO_4 = 0.325\ \cancel{\text{L}} \times \frac{1.8 \times 10^{-6}\ \text{mol}}{\cancel{\text{L}}} = 5.9 \times 10^{-7}\ \text{mol } FeSO_4$$
$$5.85 \times 10^{-7}\ \cancel{\text{mol } FeSO_4} \times \frac{151.9\ \text{g}}{1\ \cancel{\text{mol } FeSO_4}} = 8.9 \times 10^{-5}\ \text{g } FeSO_4$$

53. 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

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

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

55. 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

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

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

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

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

57. 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

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

59. 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

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

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

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

61. 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

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

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

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

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

65. 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*.

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

Solution

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

Chemistry 2e
3: Composition of Substances and Solutions
3.4: Other Units for Solution Concentrations

69. 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:
$\%mass_1 \times mass_1 = \%mass_2 \times mass_2$
This equation can be rearranged to isolate $mass_1$ and the given quantities substituted into this equation.

$$\text{(b)}\ \ mass_1 = \frac{\%mass_2 \times mass_2}{\%mass_1} = \frac{10.0\ \% \times 400.0\ \text{g}}{68.0\ \%} = 58.8\ \text{g}$$

71. 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

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

The mass of pure NaOH required is

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

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

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

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

73. 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 $CaCO_3$:

$$M\ \text{Ca}^{2+} = \frac{\text{mol CaCO}_3}{\text{L}} = \frac{175\ \cancel{\text{mg}} \times \left(\frac{1\ \text{mol}}{100.0792\ \cancel{\text{g}}}\right) \times \left(\frac{1\ \cancel{\text{g}}}{1000\ \cancel{\text{mg}}}\right)}{1\ \text{L}} = 1.75 \times 10^{-3}\ M$$

75. 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

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

77. 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;

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

79. 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:

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

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

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

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