$\text{density}_{He} = 0.179 \text{ g/L}$

The density of helium gas at STP is 0.179 g/L.

$$\text{density}_{N_2} = \frac{28.02 \text{ g}}{1 \cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{22.4 \text{ L}}$$

$\text{density}_{N_2} = 1.25 \text{ g/L}$

The density of nitrogen gas at STP is 1.25 g/L.

$$\text{density}_{O_2} = \frac{32.00 \text{ g}}{1 \cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{22.4 \text{ L}}$$

$\text{density}_{O_2} = 1.43 \text{ g/L}$

The density of oxygen gas at STP is 1.43 g/L.

$$\text{density}_{CO_2} = \frac{44.01 \text{ g}}{1 \cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{22.4 \text{ L}}$$

$\text{density}_{CO_2} = 1.96 \text{ g/L}$

The density of carbon dioxide gas at STP is 1.96 g/L.

Note : The molar volume of 22.4 L/mol at STP for gases is an approximation derived from a theoretical "ideal" gas system, rounded to three significant digits. See page 469 of the text (Did You Know?) for more precise values for some real gases.

Reflecting

6. Molar mass is a conversion factor that can be used to convert measured masses of substances into numerical amounts, in moles. This will be useful because the numbers in chemical reaction equations represent numerical values.

4.4 CALCULATIONS INVOLVING THE MOLE CONCEPT

PRACTICE

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Understanding Concepts

1. $m_{NaCl} = 2.5 \text{ g}$

$M_{NaCl} = 58.44 \text{ g/mol}$

$n_{NaCl} = ?$

$$n_{NaCl} = 2.5 \cancel{\text{g}} \times \frac{1 \text{ mol}}{58.44 \cancel{\text{g}}}$$

$$n_{NaCl} = 0.043 \text{ mol} = 43 \text{ mmol}$$

The amount of sodium chloride is 43 mmol.

2. $m_{C_6H_{12}O_6} = 1.0 \text{ kg}$

$M_{C_6H_{12}O_6} = 180.18 \text{ g/mol}$

$n_{C_6H_{12}O_6} = ?$

$$n_{C_6H_{12}O_6} = 1.0 \text{ k}\cancel{\text{g}} \times \frac{1 \text{ mol}}{180.18 \cancel{\text{g}}}$$

$$n_{C_6H_{12}O_6} = 0.056 \text{ kmol} = 5.6 \text{ mol}$$

The amount of glucose is 5.6 mol.

3. $m_{O_2} = 25.0 \text{ g}$

$M_{O_2} = 32.00 \text{ g/mol}$

$n_{O_2} = ?$

$$n_{O_2} = 25.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{32.00 \cancel{\text{g}}}$$

$$n_{O_2} = 0.781 \text{ mol}$$

The amount of oxygen is 0.781 mol (or 781 mmol).

4. (a) $m_C = 24.0 \text{ g}$

$M_C = 12.01 \text{ g/mol}$

$n_C = ?$

$$n_C = 24.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{12.01 \cancel{\text{g}}}$$

$$n_C = 2.00 \text{ mol}$$

The amount of carbon atoms in the compound is 2.00 mol.

$m_H = 6.0 \text{ g}$

$M_H = 1.01 \text{ g/mol}$

$n_H = ?$

$$n_H = 6.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{1.01 \cancel{\text{g}}}$$

$$n_H = 5.9 \text{ mol}$$

The amount of hydrogen atoms in the compound is 5.9 mol.

$m_O = 16.0 \text{ g}$

$M_O = 16.00 \text{ g/mol}$

$n_O = ?$

$$n_O = 16.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{16.00 \cancel{\text{g}}}$$

$$n_O = 1.00 \text{ mol}$$

The amount of oxygen atoms in the compound is 1.00 mol.

(b) The mole ratio of C:H:O is approximately 2:6:1.

(c) The likely formula for the compound then, is $C_2H_6O_{(l)}$.

PRACTICE

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Understanding Concepts

5. $n_{Mg(OH)_2} = 0.45 \text{ mol}$

$M_{Mg(OH)_2} = 58.33 \text{ g/mol}$

$m_{Mg(OH)_2} = ?$

$$m_{Mg(OH)_2} = 0.45 \cancel{\text{mol}} \times \frac{58.33 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{Mg(OH)_2} = 26 \text{ g}$$

The mass of magnesium hydroxide is 26 g.

6. $n_{NH_3} = 87 \text{ mmol}$

$M_{NH_3} = 17.04 \text{ g/mol}$

$m_{NH_3} = ?$

$$m_{NH_3} = 87\ \text{m}\cancel{\text{mol}} \times \frac{17.04\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$m_{NH_3} = 1.5 \times 10^3\ \text{mg} = 1.5\ \text{g}$$

The mass of ammonia is 1.5 g.

7. $n_{C_8H_6O_4} = 63.28$ mol

$M_{C_8H_6O_4} = 166.14$ g/mol

$m_{C_8H_6O_4} = ?$

$$m_{C_8H_6O_4} = 63.28\ \cancel{\text{mol}} \times \frac{166.14\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$m_{C_8H_6O_4} = 10.51 \times 10^3\ \text{g} = 10.51\ \text{kg}$$

The mass of 1,4-benzenediotic acid is 10.51 kg.

8. $n_{HC_9H_7O_4} = 1.0$ mmol

$M_{HC_9H_7O_4} = 180.17$ g/mol

$m_{HC_9H_7O_4} = ?$

$$m_{HC_9H_7O_4} = 1.0\ \text{m}\cancel{\text{mol}} \times \frac{180.17\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$m_{HC_9H_7O_4} = 1.8 \times 10^2\ \text{mg} = 0.18\ \text{g}$$

The mass of acetylsalicylic acid (Aspirin) is 0.18 g.

Try This Activity : Counting Atoms, Molecules, and Other Entities

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Calculate the evaporation rate (in molecules) of a drop of water:
mass of 50 drops of water = 1.95 g
mass of 1 drop of water = 1.95 g/50 = 0.039 g
time of 1 drop of water to evaporate = 65 min = 3.9×10^3 s

$$n_{H_2O} = 0.039\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{18.02\ \cancel{\text{g}}} = 0.00216\ \text{mol}$$

There is 0.00216 mol of H_2O molecules in every drop.

$$N_{H_2O} = 0.00216\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}} = 1.30 \times 10^{21}\ \text{molecules}$$

There are 1.30×10^{21} molecules of H_2O in every drop.

$$\text{evaporation rate} = \frac{1.30 \times 10^{21}\ \text{molecules}}{3.9 \times 10^3\ \text{s}}$$

$$\text{evaporation rate} = 3.34 \times 10^{17}\ \text{molecules/s}$$

Water molecules evaporate at the average rate of 3.34×10^{17} molecules/s.

Calculate the number of atoms and the value of each atom in a copper penny:
mass of 1 penny = 2.44 g

$$n_{Cu} = 2.44\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{63.55\ \cancel{\text{g}}} = .0384\ \text{mol}$$

$$N_{Cu} = .0384\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \cancel{\text{mol}}}$$
$$N_{Cu} = 2.31 \times 10^{22}\ \text{atoms}$$

There are 2.31×10^{22} atoms in a copper penny.

$$\text{value of a copper atom} = \frac{1 \text{ cent}}{2.31 \times 10^{22} \text{ atoms}}$$

$$\text{value of a copper atom} = 4.33 \times 10^{-23} \text{ cents}$$

Each copper atom in a penny has a value of 4.33×10^{-23} cents.

Measure into a graduated cylinder half a mole of sucrose molecules:
$M_{C12H22O11} = 337.34$ g/mol

$$\text{mass of half a mole of sucrose} = \frac{337.34 \text{ g}}{1 \cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{2}$$
$$= 168.67 \text{ g}$$

When poured into a graduated cylinder, the volume of sucrose = 185 mL.

Measure into a graduated cylinder the quantity of sugar that contains two moles of carbon atoms:

One mole of sucrose, $C_{12}H_{22}O_{11(s)}$, contains twelve moles of carbon atoms. Therefore, you would need one-sixth of a mole of sucrose to get two moles of carbon atoms.

$$\text{required mass of sucrose} = \frac{337.34 \text{ g}}{1 \cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{6}$$
$$= 56.22 \text{ g}$$

When poured into a graduated cylinder, the volume of sucrose = 60 mL.

Calculate the number of atoms needed to write your name in chalk:
initial mass of chalk = 14.23 g
final mass of chalk = 14.15 g
change in mass of chalk = 0.08 g
$M_{CaCO3} = 100.09$ g/mol
number of atoms in each formula unit = 5

$$n_{CaCO_3} = 0.08 \cancel{\text{g}} \times \frac{1 \text{ mol}}{100.09 \cancel{\text{g}}}$$
$$= 0.000799 \text{ mol}$$
$$N_{CaCO_3} = 0.000799 \cancel{\text{mol}} \times \frac{6.02 \times 10^{23} \text{ formula units}}{1 \cancel{\text{mol}}}$$
$$= 4.81 \times 10^{20} \text{ formula units}$$
$$\text{number of atoms} = 4.81 \times 10^{20} \cancel{\text{form unit}} \times \frac{5 \text{ atoms}}{1 \cancel{\text{form unit}}}$$
$$= 2.40 \times 10^{21} \text{ atoms}$$

The number of atoms needed to write my name in chalk is 2.40×10^{21}.

Calculate the number of sodium ions in a solution of 3.00 g of NaCl in 200 mL of water:
$m_{NaCl} = 3.00$ g
$M_{NaCl} = 58.44$ g/mol

$$N_{NaCl} = 3.00 \cancel{\text{g}} \times \frac{1 \cancel{\text{mol}}}{58.44 \cancel{\text{g}}} \times \frac{6.02 \times 10^{23} \text{ formula units}}{1 \cancel{\text{mol}}}$$
$$= 3.09 \times 10^{22} \text{ formula units}$$

Since there is one sodium ion in every NaCl formula unit, the number of sodium ions is 3.09×10^{22}.

Calculate the number of iron atoms in a nail:
$m_{nail} = 4.16$ g

$M_{Fe} = 55.85$ g/mol

$$N_{Fe} = 4.16 \cancel{\text{g}} \times \frac{1 \cancel{\text{mol}}}{55.85 \cancel{\text{g}}} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1 \cancel{\text{mol}}}$$
$$= 4.48 \times 10^{22}$$

There are 4.48×10^{22} atoms in the iron nail.

Calculate the number of years to span a mole of seconds:

Number of seconds in one year $= \frac{60 \text{ s}}{1 \cancel{\text{min}}} \times \frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \times \frac{24 \cancel{\text{h}}}{1 \cancel{\text{d}}} \times \frac{365 \cancel{\text{d}}}{1 \text{ a}}$

$= 3.15 \times 10^7$ s/a

Years in one mole of seconds $= \frac{6.02 \times 10^{23} \cancel{\text{s}}}{1 \text{ mol}} \times \frac{1 \text{ a}}{3.15 \times 10^7 \cancel{\text{s}}}$

$= 1.91 \times 10^{16}$ a/mol

It takes 1.91×10^{16} years to span a mole of seconds.

PRACTICE

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Understanding Concepts

9. (a) The molar mass of $H_2O_{(l)}$ is 18.01 g/mol.
   (b) The molar mass of $CO_{2(g)}$ is 44.01 g/mol.
   (c) The molar mass of $NaCl_{(s)}$ is 58.44 g/mol.
   (d) The molar mass of $C_{12}H_{22}O_{11(s)}$ is 342.34 g/mol.
   (e) The molar mass of $(NH_4)_2Cr_2O_{7(s)}$ is 252.10 g/mol.

   Note: Solutions for the rest of this course assume that students can correctly total a molar mass for a substance without showing work for the operation, unless specifically requested to do so. As a final example of the full work:

   1 mol $(NH_4)_2Cr_2O_7$ = 2 mol N + 8 mol H + 2 mol Cr + 7 mol O

   $M_{(NH_4)_2Cr_2O_7} = [(14.01 \times 2) + (1.01 \times 8) + (52.00 \times 2) + (16.00 \times 7)]$ g/mol

   $M_{(NH_4)_2Cr_2O_7} = 252.10$ g/mol

10. (a) $m_{C_{12}H_{22}O_{11}} = 10.00$ kg

   $M_{C_{12}H_{22}O_{11}} = 342.34$ g/mol

   $n_{C_{12}H_{22}O_{11}} = ?$

   $n_{C_{12}H_{22}O_{11}} = 10.00 \text{ k}\cancel{\text{g}} \times \frac{1 \text{ mol}}{342.34 \cancel{\text{g}}}$

   $n_{C_{12}H_{22}O_{11}} = 0.02921 \text{ kmol} = 29.21 \text{ mol}$

   The amount of sucrose is 29.21 mol.

   (b) $m_{NaCl} = 500$ g

   $M_{NaCl} = 58.44$ g/mol

   $n_{NaCl} = ?$

   $n_{NaCl} = 500 \cancel{\text{g}} \times \frac{1 \text{ mol}}{58.44 \cancel{\text{g}}}$

   $n_{NaCl} = 8.56$ mol

   The amount of pickling salt (sodium chloride) is 8.56 mol.

   (c) $m_{C_3H_8} = 40.0$ g

   $M_{C_3H_8} = 44.11$ g/mol

   $n_{C_3H_8} = ?$

   $n_{C_3H_8} = 40.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{44.11 \cancel{\text{g}}}$

   $n_{C_3H_8} = 0.907$ mol

The amount of propane is 0.907 mol (or 907 mmol).

(d) $m_{HC_9H_7O_4} = 325$ mg

$M_{HC_9H_7O_4} = 180.17$ g/mol

$n_{HC_9H_7O_4} = ?$

$$n_{HC_9H_7O_4} = 325 \text{ m}\cancel{\text{g}} \times \frac{1 \text{ mol}}{180.17 \cancel{\text{g}}}$$

$$n_{HC_9H_7O_4} = 1.80 \text{ mmol}$$

The amount of acetylsalicylic acid (Aspirin) is 1.80 mmol.

(e) Write $CH_3CHOHCH_3$ condensed to C_3H_8O for convenience.

$m_{C_3H_8O} = 150$ g

$M_{C_3H_8O} = 60.11$ g/mol

$n_{C_3H_8O} = ?$

$$n_{C_3H_8O} = 150 \cancel{\text{g}} \times \frac{1 \text{ mol}}{60.11 \cancel{\text{g}}}$$

$$n_{C_3H_8O} = 2.50 \text{ mol}$$

The amount of 2-propanol (rubbing alcohol) is 2.50 mol.

Note: The first printing of Chemistry 11 incorrectly gives the formula of 2-propanol as $CH_3CH_2OHCH_{3(l)}$. Using that formula would yield an answer of 2.45 mol.

11\. (a) $n_{NH_3} = 4.22$ mol

$M_{NH_3} = 17.04$ g/mol

$m_{NH_3} = ?$

$$m_{NH_3} = 4.22 \cancel{\text{mol}} \times \frac{17.04 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{NH_3} = 71.9 \text{ g}$$

The mass of ammonia is 71.9 g.

(b) $n_{NaOH} = 0.224$ mol

$M_{NaOH} = 40.00$ g/mol

$m_{NaOH} = ?$

$$m_{NaOH} = 0.224 \cancel{\text{mol}} \times \frac{40.00 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{NaOH} = 8.96 \text{ g}$$

The mass of sodium hydroxide is 8.96 g.

(c) $n_{H_2O} = 57.3$ mmol

$M_{H_2O} = 18.02$ g/mol

$m_{H_2O} = ?$

$$m_{H_2O} = 57.3 \text{ m}\cancel{\text{mol}} \times \frac{18.02 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{H_2O} = 1.03 \times 10^3 \text{ mg} = 1.03 \text{ g}$$

The mass of water is 1.03 g.

(d) $n_{KMnO_4} = 9.44$ kmol

$M_{KMnO_4} = 158.04$ g/mol

$m_{KMnO_4} = ?$

$$m_{KMnO_4} = 9.44 \text{ k}\cancel{\text{mol}} \times \frac{158.04 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{KMnO_4} = 1.49 \times 10^3 \text{ kg} = 1.49 \text{ Mg}$$

The mass of potassium permanganate is 1.49 Mg (or 1.49 t).

(e) $n_{(NH_4)_2SO_4} = 0.77 \text{ mol}$

$M_{(NH_4)_2SO_4} = 132.16 \text{ g/mol}$

$m_{(NH_4)_2SO_4} = ?$

$$m_{(NH_4)_2SO_4} = 0.77 \cancel{\text{mol}} \times \frac{132.16 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{(NH_4)_2SO_4} = 1.0 \times 10^2 \text{ g} = 0.10 \text{ kg}$$

The mass of ammonium sulfate is 0.10 kg.

12. (a) $n_{CO_2} = 15 \text{ mol}$

$N_A = 6.02 \times 10^{23} \text{ entities/mol}$

$N_{CO_2} = ?$

$$N_{CO_2} = 15 \cancel{\text{mol}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mol}}}$$

$$N_{CO_2} = 9.0 \times 10^{24} \text{ molecules}$$

There are 9.0×10^{24} molecules of carbon dioxide in the sample.

(b) $m_{NH_3} = 15 \text{ g}$

$M_{NH_3} = 17.04 \text{ g/mol}$

$N_A = 6.02 \times 10^{23} \text{ entities/mol}$

$N_{NH_3} = ?$

$$n_{NH_3} = 15 \cancel{\text{g}} \times \frac{1 \text{ mol}}{17.04 \cancel{\text{g}}}$$

$$n_{NH_3} = 0.88 \text{ mol}$$

$$N_{NH_3} = 0.88 \cancel{\text{mol}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mol}}}$$

$$N_{NH_3} = 5.3 \times 10^{23} \text{ molecules}$$

or

$$N_{NH_3} = 15 \cancel{\text{g}} \times \frac{1 \cancel{\text{mol}}}{17.04 \cancel{\text{g}}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mol}}}$$

$$N_{NH_3} = 5.3 \times 10^{23} \text{ molecules}$$

There are 5.3×10^{23} molecules of ammonia in the sample.

(c) $m_{HCl} = 15 \text{ g}$

$M_{HCl} = 36.46 \text{ g/mol}$

$N_A = 6.02 \times 10^{23} \text{ entities/mol}$

$N_{HCl} = ?$

$$n_{HCl} = 15 \cancel{\text{g}} \times \frac{1 \text{ mol}}{36.46 \cancel{\text{g}}}$$

$$n_{HCl} = 0.41 \text{ mol}$$

$$N_{HCl} = 0.41 \cancel{\text{mol}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mol}}}$$

$$N_{HCl} = 2.5 \times 10^{23} \text{ molecules}$$

or

$$N_{HCl} = 15\ \cancel{g} \times \frac{1\ \cancel{mol}}{36.46\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{mol}}$$

$$N_{HCl} = 2.5 \times 10^{23}\ \text{molecules}$$

There are 2.5×10^{23} molecules of hydrogen chloride in the sample.

(d) $m_{NaCl} = 15\ g$

$M_{NaCl} = 58.44\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_{NaCl} = ?$

$$n_{NaCl} = 15\ \cancel{g} \times \frac{1\ mol}{58.44\ \cancel{g}}$$

$$n_{NaCl} = 0.26\ mol$$

$$N_{NaCl} = 0.26\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{mol}}$$

$$N_{NaCl} = 1.5 \times 10^{23}\ \text{formula units}$$

or

$$N_{NaCl} = 15\ \cancel{g} \times \frac{1\ \cancel{mol}}{58.44\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{mol}}$$

$$N_{NaCl} = 1.5 \times 10^{23}\ \text{formula units}$$

There are 1.5×10^{23} formula units of sodium chloride in the sample.

13. (a) $M_{CO_2} = 44.01\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$m_{CO_2} = ?$

$$m_{CO_2} = \frac{44.01\ g}{1\ \cancel{mol}} \times \frac{1\ \cancel{mol}}{6.02 \times 10^{23}\ \text{molecules}}$$

$$m_{CO_2} = 7.31 \times 10^{-23}\ \text{g/molecule (on average)}$$

The average mass of a molecule in a sample of carbon dioxide from respiration is 7.31×10^{-23} g.

(b) $M_{C_6H_{12}O_6} = 180.18\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$m_{C_6H_{12}O_6} = ?$

$$m_{C_6H_{12}O_6} = \frac{180.18\ g}{1\ \cancel{mol}} \times \frac{1\ \cancel{mol}}{6.02 \times 10^{23}\ \text{molecules}}$$

$$m_{C_6H_{12}O_6} = 2.99 \times 10^{-22}\ \text{g/molecule (on average)}$$

The average mass of a molecule in a sample of glucose from photosynthesis is 2.99×10^{-22} g.

(c) $M_{O_2} = 32.00\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$m_{O_2} = ?$

$$m_{O_2} = \frac{32.00\ g}{1\ \cancel{mol}} \times \frac{1\ \cancel{mol}}{6.02 \times 10^{23}\ \text{molecules}}$$

$$m_{O_2} = 5.32 \times 10^{-23}\ \text{g/molecule (on average)}$$

The average mass of a molecule in a sample of oxygen from photosynthesis is 5.32×10^{-23} g.

14. $m_{H_2O} = 1.000\ \cancel{L} \times 1.00\ kg/\cancel{L} = 1.00\ kg$

$M_{H_2O} = 18.02\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_{H_2O} = ?$

Note: It is assumed that students by this point will automatically apply the 1.00 g/mL, 1.00 kg/L, and 1.00 Mg/m^3 (1.00 t/m^3) conversions for the mass–volume relationship of pure water.

$$n_{H_2O} = 1.00\ k\cancel{g} \times \frac{1\ mol}{18.02\ \cancel{g}}$$

$$n_{H_2O} = 0.0555\ kmol = 55.5\ mol$$

$$N_{H_2O} = 55.5\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$

$$N_{H_2O} = 3.34 \times 10^{25}\ molecules$$

or

$$N_{H_2O} = 1.00\ k\cancel{g} \times \frac{1\ \cancel{mol}}{18.02\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$

$$N_{H_2O} = 3.34 \times 10^{25}\ molecules$$

There are 3.34×10^{25} molecules of water in 1.000 L.

SECTION 4.4 QUESTIONS

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Understanding Concepts

1. (a) $n_{O_2} = 1.5\ mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_{O_2} = ?$

$$N_{O_2} = 1.5\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$

$$N_{O_2} = 9.0 \times 10^{23}\ molecules$$

There are 9.0×10^{23} molecules of oxygen in the sample.

(b) 2 atoms/molecule $\times$ 9.0×10^{23} molecules $= 1.8 \times 10^{24}$ atoms.

There are 1.8×10^{24} atoms of oxygen in the sample.

2. $m_{H_2C_6H_6O_6} = 90\ mg$

$M_{H_2C_6H_6O_6} = 176.14\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_{H_2C_6H_6O_6} = ?$

$$n_{H_2C_6H_6O_6} = 90\ m\cancel{g} \times \frac{1\ mol}{176.14\ \cancel{g}}$$

$$n_{H_2C_6H_6O_6} = 0.51\ mmol$$

$$N_{H_2C_6H_6O_6} = 0.51\ m\cancel{mol} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$

$$N_{H_2C_6H_6O_6} = 3.1 \times 10^{20}\ molecules$$

or

$$N_{H_2C_6H_6O_6} = 90\ \cancel{\text{mg}} \times \frac{1\ \cancel{\text{mol}}}{176.14\ \cancel{\text{g}}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}}$$

$$N_{H_2C_6H_6O_6} = 3.1 \times 10^{20}\ \text{molecules}$$

There are 3.1×10^{20} molecules of ascorbic acid in the tablet.

3. (a) $n_{Ca(IO_3)_2} = 1.00 \times 10^{-2}$ mol

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_I = ?$

$$N_{Ca(IO_3)_2} = 1.00 \times 10^{-2}\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}}$$

$$N_{Ca(IO_3)_2} = 6.02 \times 10^{21}\ \text{formula units}$$

$$N_I = 6.02 \times 10^{21}\ \text{formula units} \times \frac{2\ \text{atoms}}{\text{formula unit}}$$

$$N_I = 1.20 \times 10^{22}\ \text{atoms}$$

There are 1.20×10^{22} atoms of iodine in the sample.

(b) $n_{Ca(IO_3)_2} = 1.00 \times 10^{-2}$ mol

$M_{Ca(IO_3)_2} = 389.88$ g/mol

$m_{Ca(IO_3)_2} = ?$

$$m_{Ca(IO_3)_2} = 1.00 \times 10^{-2}\ \cancel{\text{mol}} \times \frac{389.88\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{Ca(IO_3)_2} = 3.90\ \text{g}$$

The mass of calcium iodate is 3.90 g.

4. $m_{H_2O} = 500$ g

$M_{H_2O} = 18.02$ g/mol

$n_{H_2O} = ?$

$$n_{H_2O} = 500\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{18.02\ \cancel{\text{g}}}$$

$$n_{H_2O} = 27.7\ \text{mol}$$

$m_{C_{12}H_{22}O_{11}} = 200$ g

$M_{C_{12}H_{22}O_{11}} = 342.34$ g/mol

$n_{C_{12}H_{22}O_{11}} = ?$

$$n_{C_{12}H_{22}O_{11}} = 200\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{342.34\ \cancel{\text{g}}}$$

$$n_{C_{12}H_{22}O_{11}} = 0.584\ \text{mol (or 584 mmol)}$$

$m_{HC_2H_3O_2} = 25$ g

$M_{HC_2H_3O_2} = 60.06$ g/mol

$n_{HC_2H_3O_2} = ?$

$$n_{HC_2H_3O_2} = 25\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{60.06\ \cancel{\text{g}}}$$

$$n_{HC_2H_3O_2} = 0.42\ \text{mol}$$

$m_{H_3C_6H_5O_7} = 15$ g

$M_{H_3C_6H_5O_7} = 192.14$ g/mol

$n_{H_3C_6H_5O_7} = ?$

$$n_{H_3C_6H_5O_7} = 15\ \cancel{g} \times \frac{1\ mol}{192.14\ \cancel{g}}$$
$$n_{H_3C_6H_5O_7} = 0.078\ mol\ (or\ 78\ mmol\ )$$

m_{NaCl} = 5 g

M_{NaCl} = 58.44 g/mol

n_{NaCl} = ?

$$n_{NaCl} = 5\ \cancel{g} \times \frac{1\ mol}{58.44\ \cancel{g}}$$
$$n_{NaCl} = 0.09\ mol$$

Converted to amounts, the recipe is: 27.7 mol water, 0.584 mol sugar, 0.42 mol vinegar, 0.078 mol citric acid, and 0.09 mol salt.

5. (a) $v_{C_2H_5OH}$ = 17 mL

$d_{C_2H_5OH}$ = 0.789 g/mL (density)

$M_{C_2H_5OH}$ = 46.08 g/mol

N_A = 6.02×10^{23} entities/mol

$N_{C_2H_5OH}$ = ?

$$m_{C_2H_5OH} = 17\ \cancel{mL} \times \frac{0.789\ g}{1\ \cancel{mL}}$$
$$m_{C_2H_5OH} = 13\ g$$
$$n_{C_2H_5OH} = 13\ \cancel{g} \times \frac{1\ mol}{46.08\ \cancel{g}}$$
$$n_{C_2H_5OH} = 0.29\ mol$$
$$N_{C_2H_5OH} = 0.29\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$
$$N_{C_2H_5OH} = 1.8 \times 10^{23}\ molecules$$

or

$$N_{C_2H_5OH} = 17\ \cancel{mL} \times \frac{0.789\ \cancel{g}}{1\ \cancel{mL}} \times \frac{1\ \cancel{mol}}{46.08\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$
$$N_{C_2H_5OH} = 1.8 \times 10^{23}\ molecules$$

There are 1.8×10^{23} molecules of ethanol in the beer.

(b) v_{Ni} = 0.72 cm^3

d_{Ni} = 8.90 g/cm^3 (density)

M_{Ni} = 58.69 g/mol

N_A = 6.02×10^{23} entities/mol

N_{Ni} = ?

$$m_{Ni} = 0.72\ \cancel{cm^3} \times \frac{8.90\ g}{\cancel{cm^3}}$$
$$m_{Ni} = 6.4\ g$$
$$n_{Ni} = 6.4\ \cancel{g} \times \frac{1\ mol}{58.69\ \cancel{g}}$$
$$n_{Ni} = 0.11\ mol$$

$$N_{Ni} = 0.11\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \cancel{mol}}$$

$$N_{Ni} = 6.6 \times 10^{22}\ \text{atoms}$$

or

$$N_{Ni} = 0.72\ \cancel{cm^3} \times \frac{8.90\ \cancel{g}}{\cancel{cm^3}} \times \frac{1\ \cancel{mol}}{58.69\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \cancel{mol}}$$

$$N_{Ni} = 6.6 \times 10^{22}\ \text{atoms}$$

There are 6.6×10^{22} atoms of nickel in the quarter.

(c) $m_{H_2O} = 100\ \cancel{mL} \times 1.00\ g/\cancel{mL} = 100\ g$

$M_{H_2O} = 18.02\ g/mol$

$N_A = 6.02 \times 10^{23}$ entities/mol

$N_{H_2O} = ?$

$$n_{H_2O} = 100\ \cancel{g} \times \frac{1\ \text{mol}}{18.02\ \cancel{g}}$$

$$n_{H_2O} = 5.55\ \text{mol}$$

$$N_{H_2O} = 5.55\ \cancel{mol} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{mol}}$$

$$N_{H_2O} = 3.34 \times 10^{24}\ \text{molecules}$$

or

$$N_{H_2O} = 100\ \cancel{g} \times \frac{1\ \cancel{mol}}{18.02\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{mol}}$$

$$N_{H_2O} = 3.34 \times 10^{24}\ \text{molecules}$$

There are 3.34×10^{24} molecules of water in 100 mL.

Applying Inquiry Skills

6. **Experimental Design**

A sample of silver nitrate is dissolved and completely reacted with copper metal. The ratio of amounts of silver product and copper reactant are determined from mass measurements.

Materials

- silver nitrate
- copper wire
- pure water
- 250-mL beaker
- stirring rod
- centigram balance
- paper towels

Procedure

1. Measure the mass of a piece of coiled copper wire to 0.01 g.
2. Dissolve the silver nitrate in about 150 mL of water in the beaker.
3. Place the copper wire in the solution and let stand until the reaction is complete.
4. Remove the silver from the surface of the copper wire, wipe the wire dry, and measure its final mass to 0.01 g.
5. Rinse the silver crystals in the beaker with water, and drain (decant) as much water as possible.
6. Place the wet silver on a piece of paper towel to dry.
7. When dry, measure the mass of the silver to 0.01 g.
8. Dispose of materials as instructed.

Evidence

mass of copper (initial) ________ g
mass of copper (final) ________ g
mass of silver ________ g

Analysis

The masses of silver and copper are divided by their molar masses to convert the quantities from masses to amounts. The ratio, amount of copper: amount of silver, is then calculated.

Making Connections

7. The primary point in any report should be that the concept of the mole is essential to converting the easily measurable quantity of substances (mass) into numerical amounts that are the numerical quantities represented by formulas and equations. Actual numbers are far too large for convenience, so the mole is defined so as to make these conversions quick and easy. It is, in fact, not necessary to know what the value of a mole is, numerically, to do predictive and descriptive work in chemistry — any more than one needs to know how many salt grains are in a shaker.

4.5 PERCENTAGE COMPOSITION

PRACTICE

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Understanding Concepts

1. $m_C = 7.2\text{ g}$

$m_H = 2.2\text{ g}$

$m_O = 17.6\text{ g}$

$m_{total} = 27.0\text{ g}$

$$\%\text{ C} = \frac{7.2\text{ }\cancel{g}}{27.0\text{ }\cancel{g}} \times 100\%$$

$$\%\text{ C} = 27\%$$

$$\%\text{ H} = \frac{2.2\text{ }\cancel{g}}{27.0\text{ }\cancel{g}} \times 100\%$$

$$\%\text{ H} = 8.1\%$$

$$\%\text{ O} = \frac{17.6\text{ }\cancel{g}}{27.0\text{ }\cancel{g}} \times 100\%$$

$$\%\text{ O} = 65.2\%$$

The percentage composition of the compound is 27% carbon atoms, 8.1% hydrogen atoms, and 65.2% oxygen atoms by mass.

2. (a) $m_O = (30.80 - 8.40)\text{ g} = 22.40\text{ g}$

(b) $m_C = 8.40\text{ g}$

$m_O = 22.40\text{ g}$

$m_{total} = 30.80\text{ g}\ (CO_{2(g)})$

$$\%\text{ C} = \frac{8.40\text{ }\cancel{g}}{30.80\text{ }\cancel{g}} \times 100\%$$

$$\%\text{ C} = 27.3\%$$

$$\%\text{ O} = \frac{22.40\text{ }\cancel{g}}{30.80\text{ }\cancel{g}} \times 100\%$$

$$\%\text{ O} = 72.7\%$$

The percentage composition of carbon dioxide is 27.3% carbon atoms and 72.7% oxygen atoms by mass.