### 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. $m_C = 7.2$ g

   $m_H = 2.2$ g

   $m_O = 17.6$ g

   $m_{total} = 27.0$ g

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

   $$\%\ C = 27\%$$

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

   $$\%\ H = 8.1\%$$

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

   $$\%\ O = 65.2\%$$

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

2. (a) $m_O = (30.80 - 8.40)$ g $= 22.40$ g

   (b) $m_C = 8.40$ g

   $m_O = 22.40$ g

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

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

   $$\%\ C = 27.3\%$$

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

   $$\%\ O = 72.7\%$$

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

3. a) $m_1 = 3.12$ g

$m_{Cu} = 2.50$ g

$m_O = (3.12 - 2.50)$ g $= 0.62$ g

$$\%\ Cu = \frac{2.50\ \cancel{g}}{3.12\ \cancel{g}} \times 100\%$$

$$\%\ Cu = 80.1\%$$

$$\%\ O = \frac{0.62\ \cancel{g}}{3.12\ \cancel{g}} \times 100\%$$

$$\%\ O = 20\%$$

The percentage composition of compound 1 is 80.1% copper atoms and 20% oxygen atoms by mass.

$m_2 = 1.62$ g

$m_{Cu} = 1.44$ g

$m_O = (1.62 - 1.44)$ g $= 0.18$ g

$$\%\ Cu = \frac{1.44\ \cancel{g}}{1.62\ \cancel{g}} \times 100\%$$

$$\%\ Cu = 88.9\%$$

$$\%\ O = \frac{0.18\ \cancel{g}}{1.62\ \cancel{g}} \times 100\%$$

$$\%\ O = 11\%$$

The percentage composition of compound 2 is 88.9% copper atoms and 11% oxygen atoms by mass.

(b) The two compounds cannot be the same substance, because the proportions of the elements are different.

## PRACTICE

**(Page 182)**

### Making Connections

4. (a) The total mass is 9.7 kg. Mass units cancel in percentage calculations.

| | |
|---|---|
| natural rubber is 1.8/9.7 ×100% | = 19% |
| carbon black is 2.3/9.7 ×100% | = 24% |
| steel cord is 0.5/9.7 ×100% | = 5% |
| polyester and nylon is 0.5/9.7 ×100% | = 5% |
| steel bead wire is 0.5/9.7 ×100% | = 5% |
| chemicals are 1.4/9.7 ×100% | = 14% |
| synthetic rubber is 2.7/9.7 ×100% | = 28% |

(b) From a Goodyear web site, the synthetic:natural rubber ratios of:

| | |
|---|---|
| Passenger car tires | 55%:45% |
| Light truck tires | 50%:50% |
| Racing car tires | 65%:35% |
| Earthmover tires | 20%:80% |

(c) Synthetic rubber gives more flexibility and traction, while natural rubber gives durability. Racing car tires must have superior traction, for example, but often don't even last for one race.

(d) Charles Goodyear discovered the process of vulcanizing rubber, which made it stable at higher temperatures. This made the rubber tire for vehicles possible, which has shaped the entire evolution of technological society.

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## Try This Activity : What Makes Popcorn Pop?

**(Page 182)**

| Popcorn Initial Mass (g) | | Final Mass (g) | Change in Mass (g) | Percentage Water (%) | Percentage of Popped Corn (%) |
|---|---|---|---|---|---|
| whole | 18.16 | 16.30 | 1.86 | 10.2 | ~90 |
| split crosswise | 15.34 | 13.90 | 1.45 | 9.45 | ~20 |
| split lengthwise | 15.04 | 13.54 | 1.50 | 9.97 | <1 |

(a) In general, the results seem to confirm that popcorn pops because the moisture inside the large part (endosperm) of the seed vaporizes, builds up the internal pressure, and suddenly breaks the hard outer coating (pericarp). The evidence of the popping percentage of the whole seeds versus the lengthwise-split seeds clearly illustrates this. The results for the crosswise-split seeds are inconclusive, perhaps because this splitting will, in some cases, include some of the endosperm and, in other cases, be restricted only to the bottom, germinating part of the seed.

## PRACTICE

**(Page 184)**

### Understanding Concepts

5. $m_{H} = 1.01\text{ u} \times 2 = 2.02\text{ u}$

$m_{S} = 32.06\text{ u} \times 1 = 32.06\text{ u}$

$m_{O} = 16.00\text{ u} \times 4 = 64.00\text{ u}$

$m_{H_2SO_{4(aq)}} = 98.08\text{ u}$

$$\%\text{ H} = \frac{2.02\ \cancel{\text{u}}}{98.08\ \cancel{\text{u}}} \times 100\%$$

$$\%\text{ H} = 2.06\%$$

$$\%\text{ S} = \frac{32.06\ \cancel{\text{u}}}{98.08\ \cancel{\text{u}}} \times 100\%$$

$$\%\text{ S} = 32.69\%$$

$$\%\text{ O} = \frac{64.00\ \cancel{\text{u}}}{98.08\ \cancel{\text{u}}} \times 100\%$$

$$\%\text{ O} = 65.25\%$$

The percentage composition of $H_2SO_{4(aq)}$ is 2.06% hydrogen atoms, 32.69% sulfur atoms, and 65.25% oxygen atoms by mass.

6. $m_{Mg^{2+}} = 24.31\text{ u} \times 1 = 24.31\text{ u}$

$m_{Mg(OH)_{2(s)}} = 58.33\text{ u}$

$$\%\text{ Mg}^{2+} = \frac{24.31\ \cancel{\text{u}}}{58.33\ \cancel{\text{u}}} \times 100\%$$

$$\%\text{ Mg}^{2+} = 41.68\%$$

The percentage, by mass, of magnesium ions in $Mg(OH)_{2(s)}$ is 41.68%.

7. $m_{Fe^{2+}} = 55.85\text{ u} \times 1 = 55.85\text{ u}$

$m_{O^{2-}} = 16.00\text{ u} \times 1 = 16.00\text{ u}$

$m_{FeO_{(s)}} = 71.85\text{ u}$

$$\%\text{ Fe}^{2+} = \frac{55.85\ \cancel{\text{u}}}{71.85\ \cancel{\text{u}}} \times 100\%$$

$$\%\text{ Fe}^{2+} = 77.73\%$$

$$\%\ O^{2-} = \frac{16.00\ \cancel{u}}{71.85\ \cancel{u}} \times 100\%$$

$$\%\ O^{2-} = 22.27\%$$

$m_{Fe^{3+}} = 55.85\ u \times 2 = 111.70\ u$

$m_{O^{2-}} = 16.00\ u \times 3 = 48.00\ u$

$m_{Fe_2O_{3(s)}} = 159.70\ u$

$$\%\ Fe^{3+} = \frac{111.70\ \cancel{u}}{159.70\ \cancel{u}} \times 100\%$$

$$\%\ Fe^{3+} = 69.94\%$$

$$\%\ O^{2-} = \frac{48.00\ \cancel{u}}{159.70\ \cancel{u}} \times 100\%$$

$$\%\ O^{2-} = 30.06\%$$

The percentage composition of $FeO_{(s)}$ is 77.73% iron(II) ions, 22.27% oxide ions by mass. The percentage composition of $Fe_2O_{3(s)}$ is 69.94% iron(III) ions, 30.06% oxide ions by mass.

8. $m_N = 14.01\ u \times 3 = 42.03\ u$

$m_{(NH_4)_3PO_4} = 149.12\ u$

$$\%\ N = \frac{42.03\ \cancel{u}}{149.12\ \cancel{u}} \times 100\%$$

$$\%\ N = 28.19\%$$

The percentage, by mass, of nitrogen atoms in $(NH_4)_3PO_{4(s)}$ is 28.19%.

## SECTION 4.5 QUESTIONS

**(Page 184)**

### Understanding Concepts

1. The percentage composition of a new compound can be used to establish the correct formula.
2. The total mass of the compound sample is (33.5 + 30.4) g = 63.9 g.

$$\%\ K^+ = \frac{33.5\ \cancel{g}}{63.9\ \cancel{g}} \times 100\% = 52.4\%$$

$$\%\ Cl^- = \frac{30.4\ \cancel{g}}{63.9\ \cancel{g}} \times 100\% = 47.6\%$$

The percentage composition of the compound is 52.4% potassium ions and 47.6% chloride ions by mass.

3. The total mass of the compound sample is (23.0 + 16.0 + 32.0) g = 71.0 g.

$$\%\ Na^+ = \frac{23.0\ \cancel{g}}{71.0\ \cancel{g}} \times 100\% = 32.4\%$$

$$\%\ S = \frac{16.0\ \cancel{g}}{71.0\ \cancel{g}} \times 100\% = 22.5\%$$

$$\%\ O = \frac{32.0\ \cancel{g}}{71.0\ \cancel{g}} \times 100\% = 45.1\%$$

The percentage composition of the compound is 32.4% sodium ions, 22.5% sulfur atoms, and 45.1% oxygen atoms by mass.

4. $m_N = 14.01\ u \times 2 = 28.02\ u$

$m_{NH_4NO_{3(s)}} = 80.06\ u$

$$\%\ N = \frac{28.02\ \cancel{u}}{80.06\ \cancel{u}} \times 100\%$$

$$\% \text{ N} = 35.00\%$$

$m_{\text{N}} = 14.01 \text{ u} \times 2 = 28.02 \text{ u}$

$m_{(NH_4)_2SO_{4(s)}} = 132.16 \text{ u}$

$$\% \text{ N} = \frac{28.02 \cancel{\text{u}}}{132.16 \cancel{\text{u}}} \times 100\%$$

$$\% \text{ N} = 21.20\%$$

The percentage by mass of nitrogen atoms in ammonium nitrate is 35.00%. In ammonium sulfate this percentage is 21.20%.

5. $m_{2H_2O} = 2[(1.01 \text{ u} \times 2) + 16.00 \text{ u}] = 36.04 \text{ u}$

$m_{CaSO_4 \cdot 2H_2O_{(s)}} = 172.18 \text{ u}$

$$\% \text{ H}_2\text{O} = \frac{36.04 \cancel{\text{u}}}{172.18 \cancel{\text{u}}} \times 100\%$$

$$\% \text{ H}_2\text{O} = 20.93\%$$

$m_{H_2O} = [(1.01 \text{ u} \times 2) + 16.00 \text{ u}] = 18.02 \text{ u}$

$m_{CaSO_4 \cdot H_2O_{(s)}} = 154.16 \text{ u}$

$$\% \text{ H}_2\text{O} = \frac{18.02 \cancel{\text{u}}}{154.16 \cancel{\text{u}}} \times 100\%$$

$$\% \text{ H}_2\text{O} = 11.69\%$$

The percentage by mass of water molecules in calcium sulfate dihydrate is 20.93%. In calcium sulfate monohydrate this percentage is 11.69%.

## Applying Inquiry Skills

6. (a) **Procedure**

1. Measure and record the mass of the empty crucible to 0.01 g.
2. Place the copper in the crucible and measure and record the total mass to 0.01 g.
3. Add excess sulfur to the crucible, and heat strongly in a fume hood until all the copper has reacted, and all the excess sulfur has burned off.
4. Allow the crucible and contents to cool, and measure and record the total mass to 0.01 g.

(b) **Analysis**

The masses of copper and of copper sulfide can be obtained by subtraction, and used to calculate the percent (by mass) of copper ions in the compound. Subtracting from 100 will give the mass percent of sulfide ions in this compound.

(c) **Evaluation**

The experimental design is judged to be adequate. It should easily provide dependable evidence from which to calculate the required answer to the question.

## Making Connections

7. (a) Percentage by mass is routinely used for home products like medications (0.05% oxymetazoline hydrochloride in a nasal spray) or cleaners (3% sodium hypochlorite when packed, in bleach). Foodstuffs almost never have mass percent data. Instead they list mass of each component per "serving size."
(b) Typical products that use a percentage other than mass include vinegar, which is typically 5 or 7% acetic acid by volume, and alcoholic beverages, which list alcohol (ethanol) as volume percent as well.