Skills to Develop

- To learn how the masses of moles of atoms and molecules are expressed.

Now that we have introduced the mole and practiced using it as a conversion factor, we ask the obvious question: why is the mole that particular number of things? Why is it \(6.022 \times 10^{23}\) and not \(1 \times 10^{23}\) or even \(1 \times 10^{20}\)?

The number in a mole, Avogadro's number, is related to the relative sizes of the atomic mass unit and gram mass units. Whereas one hydrogen atom has a mass of approximately 1 u, 1 mol of H atoms has a mass of approximately 1 gram. And whereas one sodium atom has an approximate mass of 23 u, 1 mol of Na atoms has an approximate mass of 23 grams.

One mole of a substance has the same mass in grams that one atom or molecule has in atomic mass units. The numbers in the periodic table that we identified as the atomic masses of the atoms not only tell us the mass of one atom in u but also tell us the mass of 1 mol of atoms in grams.

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**Example \(\PageIndex{1}\): Moles to Mass Conversion with Elements**

What is the mass of each quantity?

a. 1 mol of Al atoms
b. 2 mol of U atoms

**SOLUTION**

a. One mole of Al atoms has a mass in grams that is numerically equivalent to the atomic mass of aluminum. The periodic table shows that the atomic mass (rounded to two decimal points) of Al is 26.98, so 1 mol of Al atoms has a mass of 26.98 g.

b. According to the periodic table, 1 mol of U has a mass of 238.0 g, so the mass of 2 mol is twice that, or 476.0 g.

**Exercise \(\PageIndex{1}\): Moles to Mass Conversion with Elements**

What is the mass of each quantity?

a. 1 mol of Au atoms
b. 5 mol of Br atoms
Answer:

a. 197.0 g

b. 5 mol Br atoms x 79.90 g/mol = 399.5 g

The mole concept can be extended to masses of formula units and molecules as well. The mass of 1 mol of molecules (or formula units) in grams is numerically equivalent to the mass of one molecule (or formula unit) in atomic mass units. For example, a single molecule of O$_2$ has a mass of 32.00 u, and 1 mol of O$_2$ molecules has a mass of 32.00 g. As with atomic mass unit–based masses, to obtain the mass of 1 mol of a substance, we simply sum the masses of the individual atoms in the formula of that substance. The mass of 1 mol of a substance is referred to as its molar mass, whether the substance is an element, an ionic compound, or a covalent compound.

Example \(\PageIndex{2}\): Moles to Mass Conversion with Compounds

What is the mass of 1 mol of each substance?

1. NaCl
2. bilirubin (C$_{33}$H$_{36}$N$_4$O$_6$), the principal pigment present in bile (a liver secretion)

SOLUTION

1. Summing the molar masses of the atoms in the NaCl formula unit gives

<table>
<thead>
<tr>
<th>1 Na molar mass:</th>
<th>22.99 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cl molar mass:</td>
<td>35.45 g</td>
</tr>
<tr>
<td>Total:</td>
<td>58.44 g</td>
</tr>
</tbody>
</table>

The mass of 1 mol of NaCl is 58.44 g.

2. Multiplying the molar mass of each atom by the number of atoms of that type in bilirubin’s formula and adding the results, we get

<table>
<thead>
<tr>
<th>33 C molar mass:</th>
<th>33 × 12.01 g = 396.33 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 H molar mass:</td>
<td>36 × 1.01 = 36.36 g</td>
</tr>
<tr>
<td>4 N molar mass:</td>
<td>4 × 14.01 = 56.04 g</td>
</tr>
<tr>
<td>6 O molar mass:</td>
<td>6 × 16.00 = 96.00 g</td>
</tr>
</tbody>
</table>
The mass of 1 mol of bilirubin is 584.73 g.

Exercise 2: Moles to Mass Conversion with Compounds

What is the mass of 1 mol of each substance?

a. barium sulfate (BaSO\textsubscript{4}), used to take X rays of the gastrointestinal tract
b. adenosine (C\textsubscript{10}H\textsubscript{13}N\textsubscript{5}O\textsubscript{4}), a component of cell nuclei crucial for cell division

Answer:

a. 233.36 g

b. 267.28 g

Be careful when counting atoms. In formulas with polyatomic ions in parentheses, the subscript outside the parentheses is applied to every atom inside the parentheses. For example, the molar mass of \( \text{Ba(OH)}_2 \) requires the sum of 1 mass of Ba, 2 masses of O, and 2 masses of H:

- 1 Ba molar mass: \( 1 \times 137.3 \text{ g} = 137.3 \text{ g} \)
- 2 O molar mass: \( 2 \times 16.00 \text{ g} = 32.00 \text{ g} \)
- 2 H molar mass: \( 2 \times 1.01 \text{ g} = 2.02 \text{ g} \)

Total: \( 171.32 \text{ g} \)

Because molar mass is defined as the mass for 1 mol of a substance, we can refer to molar mass as grams per mole (g/mol). The division sign (/) implies “per,” and “1” is implied in the denominator. Thus, the molar mass of bilirubin can be expressed as 584.73 g/mol, which is read as “five hundred eighty four point seventy three grams per mole.”

Concept Review Exercises

1. How are molar masses of the elements determined?
2. How are molar masses of compounds determined?

Answers

1. Molar masses of the elements are the same numeric value as the masses of a single atom in atomic mass units but in units of grams instead.
2. Molar masses of compounds are calculated by adding the molar masses of their atoms.
Key Takeaway

- The mass of moles of atoms and molecules is expressed in units of grams.

Exercises

1. What is the molar mass of Si? What is the molar mass of U?
2. What is the molar mass of Mn? What is the molar mass of Mg?
3. What is the molar mass of FeCl₂? What is the molar mass of FeCl₃?
4. What is the molar mass of C₆H₆? What is the molar mass of C₆H₅CH₃?
5. What is the molar mass of (NH₄)₂S? What is the molar mass of Ca(OH)₂?
6. What is the molar mass of (NH₄)₃PO₄? What is the molar mass of Sr(HCO₃)₂?
7. Aspirin (C₉H₈O₄) is an analgesic (painkiller) and antipyretic (fever reducer). What is the molar mass of aspirin?
8. Ibuprofen (C₁₃H₁₈O₂) is an analgesic (painkiller). What is the molar mass of ibuprofen?
9. Morphine (C₁₇H₁₉NO₃) is a narcotic painkiller. What is the mass of 1 mol of morphine?
10. Heroin (C₂₁H₂₃NO₅) is a narcotic drug that is a derivative of morphine. What is the mass of 1 mol of heroin?

Answers

1. 28.09 g/mol; 238.0 g/mol
2. 54.94 g/mol; 24.31 g/mol
3. 126.75 g/mol; 162.20 g/mol
4. 78.12 g/mol; 92.15 g/mol
5. 68.16 g/mol; 74.10 g/mol
6. 149.12 g/mol; 209.66 g/mol
7. 180.17 g/mol
8. 206.31 g/mol
9. 285.37 g
10. 369.45 g