Molar Mass and The Periodic Table

Lecture five (Chapter two)

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What is the actual mass of a \(^{12}\text{C}\) atom?

Experimentally it is found to be: \(1.9927 \times 10^{-26}\) kg

This is a very inconvenient number so a new mass unit, the atomic mass unit (amu) has been defined.

The amu is defined as \(1/12\) of the mass of a \(^{12}\text{C}\) atom. An amu is also called a Dalton.

\[
1 \text{ amu} = \frac{1}{12} \times 1.9927 \times 10^{-26} \text{ kg} = 1.6605 \times 10^{-27} \text{ kg}
\]

The mass of a \(^{12}\text{C}\) atom is thus 12 amu exactly.

The mass of a \(^{13}\text{C}\) atom is 13.00335 amu from a mass spectroscopy experiment.

What is the mass of an average C atom?

\[
\begin{align*}
0.989 \times 12 \text{ amu} \\
+ 0.011 \times 13.003 \text{ amu}
\end{align*}
\]

\(12.011\) amu

\[
\begin{array}{cc}
\text{C} & \text{C} \\
6 & 6 \\
98.9\% & 1.1\%
\end{array}
\]

But this is a very small mass. Chemists seldom deal with single atoms. Instead they deal with atoms in gram quantities.

What is the conversion factor from amu to grams?

It is a special number called Avogadro’s Number.

\[
N = 6.022142 \times 10^{23}
\]
The Mole

• a unit of measurement, quantity of matter present
• Avogadro’s Number
  \[ 6.022 \times 10^{23} \text{ particles} \]
• Latin for “pile”

Molar Mass

The mass of one mole of any object is the mass of \( 6.02 \times 10^{23} \) objects.

The mass of one mole of \(^{12}\text{C}\) atoms is 12 grams exactly.

The mass of one mole of average C atoms is 12.01 grams, because the average includes the approximately 1% of \(^{13}\text{C}\) found in natural abundance. The molar mass of C as listed in the tables is 12.01 grams per mole.

Example

How many grams of Cu are there in 5.67 mol Cu?

\[
\text{#g Cu} = (5.67 \text{ mol})(63.546 \text{ g/mol})
\]
\[
= 360. \text{ g}
\]

Example

Calculate the number of boron atoms in 1.000 g sample of the element.

\[
\text{#B atoms} = (1.000 \text{ g})(1 \text{ mol} / 10.81 \text{ g})
\]
\[
\times (6.022 \times 10^{23} \text{ atoms/mol})
\]
\[
= 5.571 \times 10^{22} \text{ B atoms}
\]
Example

How many moles of Sulfur, S, are in 30.5g of S?

\[
\#\text{mol } S = \frac{30.5\text{g}}{32.06\text{g/mol}} \\
= 0.951 \text{ mol S}
\]

Example

What is the molar mass of methanol, CH\textsubscript{3}OH?

\[
\text{MM} = 1(\text{molar mass})_C + (3 + 1)(\text{molar mass})_H \\
+ 1(\text{molar mass})_O \\
= 1(12.011) + 4(1.00794) + 1(15.9994) \\
= 32.042 \text{ g/mol}
\]

Example

How many moles of carbon dioxide molecules are there in 6.45g of carbon dioxide?

\[
\text{MM} = 1(\text{molar mass})_C + 2(\text{molar mass})_O = 44.01 \text{ g/mol} \\
\#\text{mol } \text{CO}_2 = \frac{6.45\text{g}}{44.01\text{g/mol}} \\
= 0.147 \text{ mol}
\]

How many water molecules in a mole of water?

\[
6.02 \times 10^{23} \text{ molecules of } \text{H}_2\text{O}
\]

How many hydrogen atoms in a mole of water?

\[
6.02 \times 10^{23} \text{ molecules } \times \frac{2 \text{ H atoms}}{\text{molecule}} = 12.04 \times 10^{23} \text{ H atoms}
\]

\[
6.02 \times 10^{23} \text{ O atoms}
\]
**What is the molar mass of H$_2$O?**

2 x molar mass of H plus 1 x molar mass of O

2 x 1.01 g/mol + 16.00 g/mol = 18.02 g/mol

18.02 grams of water contains

One mole of water molecules
One mole of O atoms = 16.0 grams of O
Two moles of H atoms = 2.02 grams of H

**How many moles of H$_2$O in 1.00 kg?**

How many molecules of H$_2$O in 1.00 kg?

\[
1.00 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol}}{18.02 \text{ g}} = 55.5 \text{ mol}
\]

55.5 mol x \(\frac{6.02 \times 10^{23} \text{ molecules}}{\text{mol}}\) =

\(\frac{3.34 \times 10^{25} \text{ molecules}}{3.34 \times 10^{25} \text{ molecules}}\)

**What is the mass of a billion molecules of water?**

1 billion = \(10^9\)

\(10^9\) molecule x \(\frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}}\) x \(\frac{18.02 \text{ g}}{1 \text{ mol}}\) =

\(2.99 \times 10^{-14} \text{ grams} = .03 \text{ picograms}\)

**What percentage of the mass of water is the mass of the hydrogen?**

One mole of water has a mass of 18.02 grams
It contains 2 moles of H or 2.02 grams

\[
\frac{\frac{2.02 \text{ g}}{18.02 \text{ g}} = 0.112}{0.112 \times 100\% = 11.2\% \text{ H}}
\]

100.0\% - 11.2\% = 88.8 \% which must be the O

The Mass Percent Composition of Water is
11.2\% Hydrogen and 88.8\% Oxygen
Modern Periodic Table

**Moseley, Henry Gwyn Jeffreys**
1887–1915, English physicist.
- studied the relations among spectra of different elements.
- concluded that the **atomic number** is equal to the charge on the nucleus based on the x-ray spectra emitted by the element.
- explained discrepancies in Mendeleev’s Periodic Law.

<table>
<thead>
<tr>
<th>Periodic Table of the Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Periodic Table Image]</td>
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<table>
<thead>
<tr>
<th>Organization of Periodic Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>• period – horizontal row</td>
</tr>
<tr>
<td>• group – vertical column</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Family Names</th>
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<tbody>
<tr>
<td><strong>Group IA</strong></td>
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<tr>
<td><strong>Group IIA</strong></td>
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<tr>
<td><strong>Group VIIA</strong></td>
</tr>
<tr>
<td><strong>Group VIIIA</strong></td>
</tr>
<tr>
<td>transition metals</td>
</tr>
<tr>
<td>inner transition metals</td>
</tr>
<tr>
<td>• lanthanum series</td>
</tr>
<tr>
<td>• actinium series</td>
</tr>
</tbody>
</table>
Which sample contains the fewest atoms?

A. 10 g of C,  
B. 10 g of Ne,  
C. 10 g of F,  
D. 10 g of N,  
E. 10 g of O.

The correct answer is B.