4.8: Atomic Mass

Learning Objectives

- Explain what is meant by the atomic mass of an element.
- Calculate the atomic mass of an element from the masses and relative percentages of the isotopes of the element.

Since most elements have more than one naturally-occurring isotope that are already naturally premixed, we rarely need to worry about the mass of a specific isotope. Rather, we need to know the average mass of the atoms of an element. We call this mass the **atomic mass**.

Atomic Mass

The atomic mass of an element is defined as the average mass of all the naturally-occurring isotopes for that element. Atomic mass is typically reported in atomic mass units.

Calculating the Atomic Mass

Let's consider the element chlorine. Chlorine has two naturally occurring isotopes, ${}^{35}_{17}\text{Cl}$ and ${}^{37}_{17}\text{Cl}$. The mass and natural abundance of these two isotopes was obtained from https://www.webelements.com/chlorine/isotopes.html:

Table 4.8.1: Naturally Occurring Isotopes of Chlorine

Isotope	Mass (amu)	Natural Abundance
${}^{35}_{17}\text{Cl}$	34.969	75.78%
${}^{37}_{17}\text{Cl}$	36.966	24.22%

One of the first things we may notice is that the mass of one atom of ${}^{35}_{17}\text{Cl}$ is close to 35 amu and that the mass of ${}^{37}_{17}\text{Cl}$ is close to 37 amu. Remember that this is because the mass of each proton is about 1 amu and the mass of each neutron is about 1 amu, while each electron has a mass that is so small relative to the proton and neutron that their mass may generally be ignored.

In order to find the atomic mass for chlorine, it may be tempting to simply sum the masses of the two isotopes together and divide the result by 2. However, this does not take into consideration that ${}^{35}_{17}\text{Cl}$ has almost three times the natural abundance of ${}^{37}_{17}\text{Cl}$.

When the abundances are not equal, which will always be the case, an average is best accomplished by calculating what is called a **weighted average**, in which the fractional abundance of each naturally occurring isotope is multiplied by its mass and the resulting masses are summed together. We summarize this as follows:

$$\text{Atomic mass} = (\text{fractional abundance}_1)(\text{mass}_1) + (\text{fractional abundance}_2)(\text{mass}_2) + \cdots \tag{4.8.1}$$

Keep in mind that the fractional abundance represents $\frac{1}{100}$ of the percent abundance. Just like the percent natural abundances of isotopes should sum to 100%, the sum of fractional abundances of isotopes should sum to 1.

Table 4.8.2: Calculating the Atomic Mass of Chlorine

Isotope	Mass (amu)	Natural Abundance	Calculation	Mass (amu)
$^{35}_{17}\text{Cl}$	34.969	75.78%	$34.969 \text{ amu} \times 0.7578 =$	26.5$\underline{0}$0
$^{37}_{17}\text{Cl}$	36.966	24.22%	$36.966 \text{ amu} \times 0.2422 =$	8.95$\underline{3}$2
			atomic mass of chlorine =	35.4$\underline{5}$32

As we can see, the calculated atomic mass for chlorine is 35.45 amu. This matches the atomic mass listed on the Periodic Table for chlorine.

✅ Example 4.8.1: Boron Isotopes 1

Simply knowing that boron has two naturally occurring isotopes, $^{10}_{5}\text{B}$ and $^{11}_{5}\text{B}$, which of the two isotopes is more abundant?

Solution

According to the Periodic Table, the atomic mass of boron is 10.81 amu. Since the mass of one atom of $^{10}_{5}\text{B}$ would be approximately 10 amu and the mass of one atom of $^{11}_{5}\text{B}$ would be about 11 amu, we can conclude that the most abundant isotope is $^{11}_{5}\text{B}$, since the atomic mass is closer to the mass of $^{11}_{5}\text{B}$ than to $^{10}_{5}\text{B}$.

This is supported using natural abundance data available from https://www.webelements.com/boron/isotopes.html, which shows that 19.9% of boron atoms are $^{10}_{5}\text{B}$, while 80.1% are $^{11}_{5}\text{B}$.

✅ Example 4.8.2: Boron Isotopes 2

Given that the atomic mass of boron is 10.81 amu and that there are two naturally occurring isotopes of boron, $^{10}_{5}\text{B}$ and $^{11}_{5}\text{B}$, what is the percent natural abundance of each isotope?

Solution

As noted above, just like the percent natural abundances of isotopes should sum to 100%, the sum of fractional abundances of isotopes should sum to 1. Therefore, if we assume the fractional abundance of $^{10}_{5}B$ is x, then the fractional abundance of $^{11}_{5}B$ must be $1-x$. Summarizing the information into the table below shows we have enough information to calculate the value of x, hence the fractional abundance of each.

Isotope	Approximate Mass (amu)	Fractional Abundance	Mass (amu)
$^{10}_{5}B$	10.0	x	$10.0 \times (x)$
$^{11}_{5}B$	11.0	$1-x$	$11.0 \times (1-x)$
		atomic mass of boron =	10.81

At this point, we can solve for x:

$$10.0\,x + 11.0\,(1-x) = 10.81$$

$$10.0\,x + 11.0 - 11.0\,x = 10.81$$

$$-x = -0.2 \text{ or } x = 0.2$$

In other words, the fractional abundance of $^{10}_{5}B$ is x = 0.2 and the fractional abundance of $^{11}_{5}B$ is $1-x$ = $1-0.2$ = 0.8. Since a percentage is 100 times its fractional amount,

The natural abundance of $^{10}_{5}B$ is 100 × 0.2 = 20%

The natural abundance of $^{11}_{5}B$ is 100 × 0.8 = 80%

This compares very well to the natural abundance data available from https://www.webelements.com/boron/isotopes.html, which shows that 19.9% of boron atoms are $^{10}_{5}B$, while 80.1% are $^{11}_{5}B$.

✏️ Exercise 4.8.1

Neon has three naturally occurring isotopes. Using the data below, calculate the atomic mass of neon.

Table 4.8.3: Naturally Occurring Isotopes of Neon

Isotope	Mass (amu)	Natural Abundance	Calculation	Mass (amu)
$^{20}_{10}Ne$	19.992	90.48%		
$^{21}_{10}Ne$	20.994	0.27%		
$^{22}_{10}Ne$	21.991	9.25%		

Answer

20.18 amu

Summary

- An element's atomic mass is the weighted average of the masses of the isotopes of an element
- An element's atomic mass can be calculated provided the relative abundance of the element's naturally occurring isotopes and the masses of those isotopes are known.
- The periodic table is a convenient way to summarize information about the different elements. In addition to the element's symbol, most periodic tables will also contain the element's atomic number and the element's atomic mass.