1.5. Isotopes and Standard Atomic Notation

An **isotope** is an element that has a different number of neutrons in its nucleus. For example, sulfur has 4 isotopes, argon has three, chlorine has two, but beryllium and fluorine have only one.

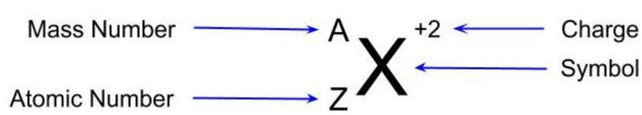
Protons: the number of protons in an atom's nucleus determines the identity of the atom. Change the number of protons to get a new element.

Neutrons: the number of neutrons in an atom's nucleus determines its nuclear stability. Change the number of neutrons to get a different isotope.

Electrons: the number and arrangement of the electrons around the nucleus determines the atom's physical and chemical properties.

Standard Atomic Notation

An **atomic notation** can be written for each isotope.



The **atomic number**, Z, is the number of protons in the nucleus of an atom. It determines the identity of that atom. Z = number of protons

The **mass number**, A, of an atom is the number of protons and neutrons in the nucleus of an atom. A = protons + neutrons

Practice 1: Determine the numbers of protons, electrons and neutrons from the atomic notation.

isotope	protons	electrons	neutrons
$^{56}_{26}Fe$	26	26	30
$^{56}_{26}Fe^{3+}$	26	23	30
$^{31}_{15}P$	15	15	16
$^{31}_{15}P^{3-}$	15	18	16
$^{36}_{18}Ar$	18	18	18
$^{38}_{18}Ar$	18	18	20
$^{40}_{18}Ar$	18	18	22

The more common naming system for isotopes gives the element name or symbol followed by a number that is the atomic mas number.

$$\text{Ar}-36\text{: } {}^{36}_{18}\text{Ar} \qquad \text{Ar}-38\text{: } {}^{38}_{18}\text{Ar} \qquad \text{Ar}-40\text{: } {}^{40}_{18}\text{Ar}$$

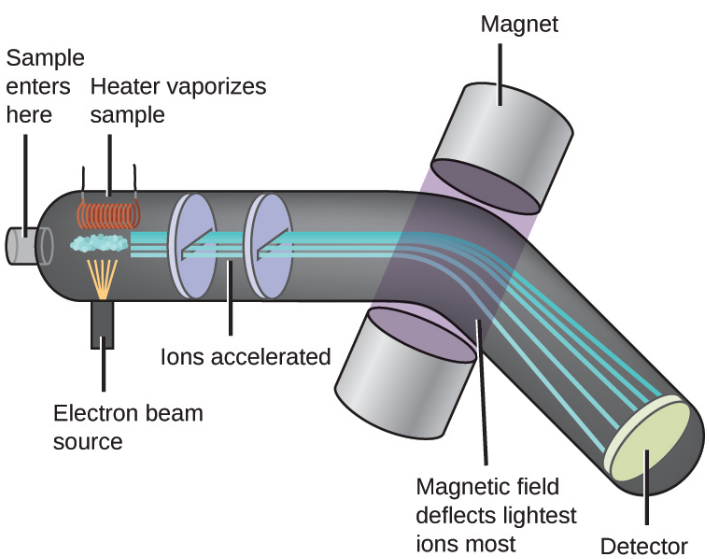
Uses of Isotopes

- Medical isotopes are used for:
  - treatment using radiation (radiotherapy).
  - imaging purposes (x-rays).
  - highlighting soft tissues that cannot be imaged by x-rays.
- The decay of isotopes can be used to work out the age of rocks and fossils.

Isotopes and the Average Atomic Mass (AAM)

Most elements have two or more naturally occurring isotopes. Therefore, a sample of most elements contains a mixture of the different isotopes of that element, with some of the isotopes being more common than others. For example, 99.985% of all hydrogen is the H-1 isotope (protium), 0.015% is H-2 (deuterium) and only a trace amount is H-3 (tritium). The proportion, or percent abundance, of the various isotopes is fairly constant for each element.

When charged particles are moving through a magnetic field In a mass spectrometer they get deflected from their original path based on their charge-to-mass (e/m) ratio. The greater the ratio, the more deflection occurs. For example when a beam of ionized neon gas (Ne), made up of three isotopes neon-20, neon-21, and neon-22, enters the magnetic field chamber the isotopes separate on their basis of their e/m ratios. The larger the e/m ratio, the more the isotope gets deflected.



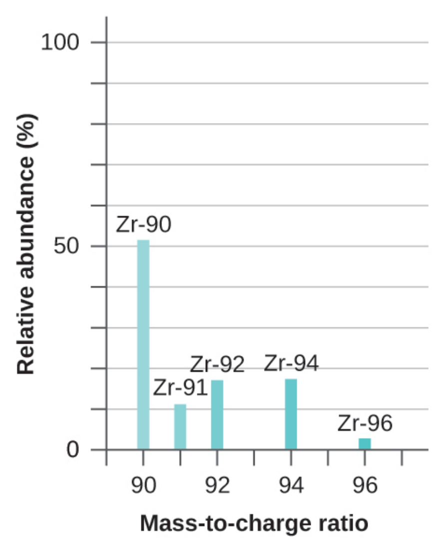


Image credit: Analysis of isotopes in a mass spectrometer by OpenStax Chemistry: Atoms First, CC BY 4.0

The **percent abundance** and the mass of each isotope are recorded from the mass spectrometer allows us to calculate the average atomic mass of the element. **The average atomic mass** is the weighed average of the masses of all of the isotopes of that element and can be found on the Periodic Table, in the top right hand corner for each element.

Average Atomic Mass (AAM)

$$\textbf{AAM} = (\textbf{Mass of Isotope 1} \times \textbf{\% abundance of Isotope 1}) + \\ + (\textbf{Mass of Isotope 2} \times \textbf{\% abundance of Isotope 2}) + ...$$

Calculating the Average Atomic Mass (AAM)

Chlorine has two naturally occurring isotopes, Cl-35 and Cl-37. 75.77% of all chlorine atoms are Cl-35, mass 34.9689 amu (atomic mass unit) and 24.23% of all chlorine atoms are Cl-37, mass 36.9659 amu. Calculate the average atomic mass (AAM) of chlorine.

$$\text{AAM} = (\text{Mass of Isotope Cl-35} \times \text{\% abundance}) + (\text{Mass of Isotope Cl-37} \times \text{\% abundance})$$

$$\text{AAM} = (34.9689\,\text{amu} \times 0.7577) + (36.9659\,\text{amu} \times 0.2423) = 35.4527\,\text{amu} = 35.45\,\text{amu}$$

Calculating the Percent Abundance

Chlorine has two naturally occurring isotopes. Calculate the percent abundances of chlorine-35 and chlorine-37 using the following data:

Atomic mass of chlorine = 35.45 amu

Mass of Cl-35 = 34.9689 amu

Mass of Cl-37 = 36.9659 amu

$$\text{AAM} = (\text{Mass of Isotope Cl-35} \times \text{\% abundance}) + (\text{Mass of Isotope Cl-37} \times \text{\% abundance})$$

Let the abundance of Cl-35 be x.

Let the abundance of Cl-37 be $1 - x$.

$$35.45 = 34.9689x + 36.9659(1 - x)$$

$$35.45 = 34.9689x + 36.9659 - 36.9659x$$

$$36.9659x - 34.9689x = 36.9659 - 35.45$$

$$1.997x = 1.5159$$

$$x = 0.759$$

% abundance Cl-35 is 76% and the % abundance Cl-37 is 100% - 76% = 24%.

Homework

Practice 2: Complete the table.

atomic notation	protons	electrons	neutrons
$^{9}_{4}Be$	4	4	5
$^{56}_{26}Fe^{2+}$	26	24	30
$^{14}_{7}N^{3-}$	7	10	7
$^{15}_{7}N$	7	7	8
$^{63}_{29}Cu^{2+}$	29	27	34
$^{65}_{29}Cu^{+}$	29	28	36
$^{35}_{17}Cl$	17	17	18
$^{37}_{17}Cl^{1-}$	17	18	20
$^{197}_{79}Au^{3+}$	79	76	118
$^{195}_{79}Au^{1+}$	79	78	116
$^{33}_{16}S$	16	16	17
$^{32}_{16}S^{2-}$	16	18	16
$^{74}_{33}As^{3+}$	33	30	41
$^{75}_{33}As$	33	33	42

Practice 3: Which isotope has the largest number of neutrons?

a. $^{285}_{112}Cn$ b. $^{286}_{113}Nh$ c. $^{290}_{115}Mc$ d. $^{294}_{117}Ts$ e. $^{294}_{118}Og$

Practice 4: Which isotope has the largest number of neutrons?

a. Ir-192 b. Ir-194 c. Pt-198 d. Hg-199 e. Au-197

Practice 5: Argon has three isotopes: Ar-36, Ar-38 and Ar-40. Given that the average atomic mass of naturally occurring argon is 39.95, which isotope is the most abundant?

Answer: Ar-40 is the most abundant since its mass is the closest to the average atomic mass

Practice 6: Find Average Atomic Mass of chromium. Masses and natural abundances of chromium isotopes are:

Isotope	Atomic Mass (amu)	Abundance (%)
Cr-50	49.946	4.35
Cr-52	51.941	83.79
Cr-53	52.941	9.50
Cr-54	53.939	2.37

$\text{AAM} = (49.946\,\text{u} \times 0.0435) + (51.941\,\text{u} \times 0.8379) + (52.941\,\text{u} \times 0.0950) + (53.939\,\text{u} \times 0.0237) = 52.00\,\text{u}$

Practice 7: Find Average Atomic Mass of silicon. Masses and natural abundances of silicon isotopes are:

Isotope	Atomic Mass (amu)	Abundance (%)
Si-28	27.977	92.23
Si-29	28.976	4.68
Si-30	29.974	3.09

$\text{AAM} = (27.977\,\text{u} \times 0.9223) + (28.976\,\text{u} \times 0.0468) + (29.974\,\text{u} \times 0.0309) = 28.09\,\text{u}$

Practice 8: Find the natural abundance of Lu-176. The average atomic mass of lutetium is 174.97 u. The atomic masses of lutetium isotopes are:

Isotope	Atomic Mass (amu)	Abundance (%)
Lu-175	174.94	1-x
Lu-176	175.94	x

$$\text{AAM} = (\text{Mass of Isotope Lu-175} \times \%\text{ abundance}) + (\text{Mass of Isotope Lu-176} \times \%\text{ abundance})$$

$$174.97 = 174.94(1-x) + 175.94x$$

$$174.97 = 174.94 - 174.94x + 175.94x$$

$$174.97 - 174.94 = -174.94x + 175.94x$$

$$0.03 = 1x$$

% abundance Lu-176 is 3% and the % abundance Lu-175 is 100% - 3% = 97%.