1.7. Nuclide Classifications

The total number of protons in the nucleus of an atom is called the *atomic number* of the atom and is given the symbol Z. The number of electrons in an electrically neutral atom is the same as the number of protons in the nucleus. The number of neutrons in a nucleus is known as the neutron number and is given the symbol N. The *mass number* of the nucleus is the total number of nucleons, that is, total number of protons and neutrons in the nucleus. The mass number is given the symbol A and can be found by sum of $Z + N = A$.

Each of the chemical elements has a unique atomic number because the atoms of different elements contain a different number of protons. The atomic number of an atom identifies the particular element.

Each type of atom that contains a unique combination of protons and neutrons is called a *nuclide*. Not all combinations of numbers of protons and neutrons are possible, but about 2500 specific nuclides with unique combinations of neutrons and protons have been identified. Each nuclide is denoted by the chemical symbol of the element with the atomic number written as a subscript and the mass number written as a superscript, as shown in Fig. 1.5. Because each element has a unique name, chemical symbol, and atomic number, only one of the three is necessary to identify the element. For this reason, nuclides can also be identified by either the chemical name or the chemical symbol followed by the mass number (for example, U-235 or uranium-235). Another common format is to use the abbreviation of the chemical element with the mass number superscripted (for example, ^{235}U).

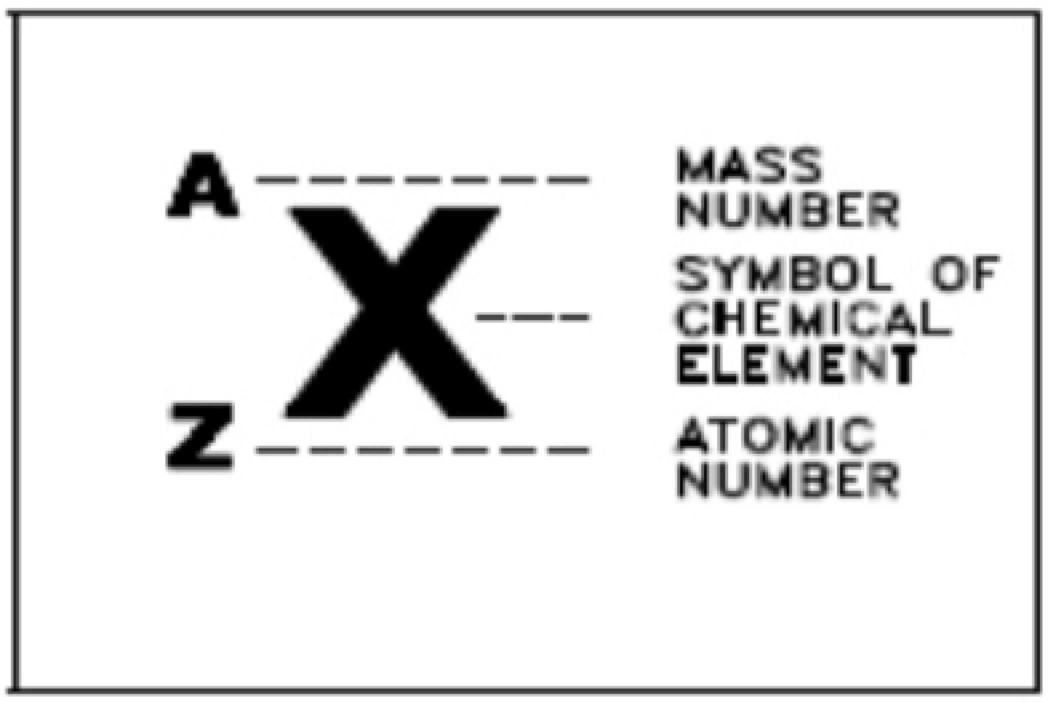

Figure 1.5. Nomenclature for identifying nuclides.

Example:

State the name of the element and the number of protons, electrons, and neutrons in the nuclides listed below:

$^{1}_{1}H$, $^{10}_{5}B$, $^{14}_{7}N$, $^{114}_{48}Cd$, $^{239}_{94}Pu$

Solution:

The name of the element can be found from the Periodic Table (refer to Chemistry Fundamentals Handbook) or the Chart of the Nuclides (to be discussed later). The number of protons and electrons is equal to Z. The number of neutrons is equal to A-Z.

Nuclide	*Element*	Pr*otons*	*Electrons*	*Neutrons*
$^{1}_{1}H$	*Hydrogen*	1	1	0
$^{10}_{5}B$	*Boron*	5	5	5
$^{14}_{7}N$	*Nitrogen*	7	7	7
$^{114}_{48}Cd$	*Cadmium*	48	48	66
$^{239}_{94}Pu$	*Plutonium*	94	94	145

1.7.1. Isotopes

Isotopes are nuclides that have the same atomic number and are therefore the same element, but differ in the number of neutrons. Most elements have a few stable isotopes and several unstable, radioactive isotopes. For example, oxygen has three stable isotopes that can be found in nature (oxygen-16, oxygen-17, and oxygen-18) and eight radioactive isotopes. Another example is hydrogen, which has two stable isotopes (hydrogen-1 and hydrogen-2) and a single radioactive isotope (hydrogen-3).

Different isotopes of the same element have essentially the same chemical properties. The isotopes of hydrogen are unique in that each of them is commonly referred to by a unique name instead of the common chemical element name. Hydrogen-1 is usually referred to as hydrogen. Hydrogen-2 is commonly called deuterium and symbolized ${}^{2}_{1}D$. Hydrogen-3 is commonly called tritium and symbolized ${}^{3}_{1}T$. It is convenient to use the symbols ${}^{2}_{1}H$ and ${}^{3}_{1}H$ for deuterium and tritium, respectively.

1.7.2. Isobars

Isobars are those nuclides that have the same mass number (A), but different numbers of protons and neutrons (Z & N). A special case is, when two isobars have proton and neutron numbers interchanged as in ${}^{A}_{Z}X_{A-Z}$ *and* ${}^{A}_{Z-1}Y_{A-Z+1}$, they are called *mirror nuclides*, *e.g.*,$\left({}^{15}_{8}O_{7}\ \ and\ \ {}^{15}_{7}N_{8}\right)$.

1.7.3. Isotones

Isotones are those nuclides that have the same number of neutrons (N), but different numbers of protons and mass numbers (Z & A).

1.8. Nuclear Radii and Densities

It is difficult to define exactly the size of an atom because the electron cloud, formed by the electrons moving in their various orbitals, does not have a distinct outer edge. A reasonable measure of atomic size can be the average distance of the outermost electron from the nucleus. Except for a few of the lightest atoms, the average atomic radii are approximately the same for all atoms, about 2×10^{-8} cm. Like the atom, the nucleus does not have a sharp spherical outer boundary.

Like any other object, the size and the shape of an object is to examine the radiation scattered from it (taking its photograph). To see the object and its details, the wavelength of the radiation must be smaller than the dimensions of the object; otherwise, the effects of diffraction will partially or completely obscure the image. For nuclei with a diameter of about *10 fm*, we require $\lambda \leq 10\ fm$. corresponding to $p \geq 100\ MeV/c$. The experimental access to obtain information on nuclei radii comes from scattering particles (e^-, p, $\pi^{\pm}$,…) off the atomic nucleus with appropriate energy. Electron scattering off nuclei is, for example, one of the most appropriate methods to deduce nuclear radii and charge distribution. Experiments have shown that the nucleus is a shaped like a sphere with a radius that depends on the atomic mass number of the atom with the central nuclear charge and/or matter density is nearly the same for all nuclei. Nucleons do not seem to congregate near the center of the nucleus, but instead have a fairly constant distribution out to the surface. Thus, the number of nucleons per unit nuclear volume is roughly constant.

$$Nucleon\ density = \frac{A}{\frac{4}{3}\pi R^3} = Constant \qquad 1.26$$

where: R= mean radius of the nucleus

A = atomic mass number

Calling R_0 an elementary radius for a nucleon in the nucleus, a most naïve estimate is given for the nuclear volume $V=4/3\pi R^3$;

$$V = 4/3\pi R_0^3 A \qquad 1.27$$

or $$R = R_0 A^{1/3} \qquad 1.28$$

This relation describes the variation of the *nuclear radius*, with a value of $R_0 \approx 1.2\ fm$ when deducing a 'charge' distributing radius, and a value of $R_0 \approx 1.4\ fm$ for the full 'matter' distributing radius. The values of the nuclear radii for some light, intermediate, and heavy nuclides are shown in Table 1.2.

The table clearly shows that the radius of a typical atom (e.g. 2 x 10^{-8} cm) is more than 25,000 times larger than the radius of the largest nucleus.

Table 1.2 calculated values for nuclear radii.

Nuclide	Radius of nucleus
${}^{1}_{1}H$	$1.25\times10^{-13}cm$
${}^{10}_{5}B$	$2.69\times10^{-13}cm$
${}^{56}_{26}Fe$	$4.78\times10^{-13}cm$
${}^{178}_{72}Hf$	$7.01\times10^{-13}cm$
${}^{238}_{92}U$	$7.74\times10^{-13}cm$
${}^{252}_{98}Cf$	$7.89\times10^{-13}cm$