17.3: Fundamental Concepts

It has been said that a picture is worth a thousand words. Similarly, understanding the symbols and units used to discuss nuclear physics allows us to communicate a lot of information in a compact notation. We are continuing the discussion of atoms but we are focusing on the nucleus, so our terminology is very specific.

Terminology

As you learned earlier, a particular atom on the periodic table of the elements is typically specified by one or more letters and several numbers:

$$^{A}_{Z}\mathrm{X}$$

Z is the *proton number,* A is the *atomic mass* and X is replaced by the letter(s) related to the name of the element. A neutral atom will also have Z electrons.

The value of Z determines the element and its placement on the periodic table: Z = 1 is hydrogen (H), while Z = 6 is carbon (C) and Z = 47 is silver (Ag).

Nuclear physics uses a very similar notation, but there are certain small but important differences. Nuclear physics generally doesn't involve the orbital electrons. That means the mass numbers used will be slightly different than the values on the periodic table. There is also a slightly different notation:

$$^{A}_{Z}\mathrm{X}_{N}$$

Z is the *proton number*, A is the *nucleon number*, N is the *neutron number*. Although the neutron number is important, it is often not explicitly stated. Since the nucleon number refers to the total number of protons and neutrons that make up the nucleus: A = Z + N, only two of the three values are needed. It is possible for atoms to have the same proton number, but different nucleon numbers. These are called *isotopes* of the element.

Example 17.3.1

Here are the symbolic representations of two silver isotopes.

$$\boxed{^{105}_{47}Ag}$$

$$\boxed{^{111}_{47}Ag}$$

Determine the neutron number for each.

Solution

Since A = Z + N, then N = A - Z: 105 - 47 = 58 and 111 - 47 = 64

Units and common physical constants

Because we will be dealing with very small objects, there is a system of units designed for this scale. After all, you wouldn't want to measure your height in fractions of a mile, or your weight in fractions of a ton. Similarly, the units of kilograms, meters and Joules are far too large for describing the nuclear world.

Mass

Nuclear masses are reported in terms of the *atomic mass unit*. This is abbreviated as *amu* or u. The amu is defined as 1/12 of the mass of a neutral Carbon 12 atom in its ground state. Since neutrons and protons have almost the same mass, we will say that a nucleon has a mass of approximately 1 u. This is incorrect, but it will give us a rough estimate of the true value.

- Proton mass: 1.00728 u
- Neutron mass: 1.00867 u
- Electron mass: 0.00054 u

In kilograms, $1\mathrm{u} = 1.6606 \times 10^{-27}\ \mathrm{kg}$.

Example 17.3.2

Convert the mass of the proton from atomic mass units to kilograms.

Solution

The proton mass is 1.00728 u.

1.00728 u $(1.6606 \times 10^{-27}\ \mathrm{kg/u})$ = 1.6727×10^{-27} kg

Energy

Nuclear energies are described in terms of the electron-Volt, abbreviated as eV. The electron-Volt is equal to the kinetic energy gained by an electron as it is accelerated through a potential difference of one Volt. 1 eV is equal to $1\mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{J}$.

Atomic energies are usually in the range of thousands of electron-Volts (10^3 eV, or kilo electron-Volts, keV), while nuclear energies are typically in the range of millions of electron-Volts (10^6 eV, or mega electron-Volts, MeV), about a thousand times larger.

Because Einstein was able to relate mass and energy by the equation E = mc^2, we will often express masses in terms of energy units. This may be confusing at first, but it helps make some of the calculations simpler. To convert between energy (in MeV) and mass (in u) the conversion factor is the square of the speed of light. In these units we have: $c^2 = 931.502\ \mathrm{MeV/u}$.

- Proton mass: 1.00728 u = 938.280 MeV/c^2
- Neutron mass: 1.00867 u = 938.573 MeV/c^2
- Electron mass: 0.00054 u = 0.511 MeV/c^2

Length

Typical atomic scales are measured in Angstroms. One Angstrom is 10^{-10} meters, but this is still too large for the nuclear scale. Typical lengths in nuclear physics are thousands of times smaller than the atom. Nuclear physics uses the femtometer (fm), also called the Fermi (F). 1 fm = 1 F = 10^{-15} meters.

Time

Events involving the nucleus can be almost instantaneous or they can span trillions of years (or more). Because of this wide range, many different time units are used.

Relevant constants

Physical constants that are regularly used in nuclear physics include:

- The speed of light in vacuum: c = 299, 792, 458 meters per second, often rounded to 3 x 10^8 m/s.
- The charge of the electron, and the proton: e = 1.602176487 x 10^{-19} Coulomb. Usually rounded to 1.602 x 10^{-19} C.
- The Planck constant: h = 6.62606896 × 10^{-34} Joule-seconds, or 6.626 × 10^{-34} J-s.
- Avogadro's Number: N_a = 6.022 x 10^{23} objects/mol.

Since nuclear physics overlaps with many different areas of science, there are a huge number of related variables. A good online reference is NIST, and this site also includes a tool to convert energy to different units.