CHAPTER 2

PERTINENT NUCLEAR PROPERTIES

2.1. Neutron - Proton Ratios

A nuclear species is characterized by its number of protons Z and number of neutrons N. There are thousands of combinations of N and Z that lead to nuclei that are sufficiently long-lived to be studied in the laboratory. The large number of possible combinations of neutrons and protons is to be compared with the only 100 or so elements characterized simply by Z.

Fig. 2.1 shows the distribution of the world nuclides plotted on the same axes as the *Chart of the Nuclides*. Most nuclei are unstable, i.e., radioactive. Generally, for each $A = N + Z$ there is only one or two combinations of (N, Z) sufficiently long-lived (or stable) to be naturally present on earth in significant quantities. These nuclei are the black squares in Fig. 2.1 that define the bottom of the *valley of stability*.

As the mass numbers become higher, the ratio of neutrons to protons in the nucleus becomes larger. For example, helium-4 (2 protons and 2 neutrons) and oxygen-16 (8 protons and 8 neutrons); this ratio is unity. While for indium-115 (49 protons and 66 neutrons), the ratio of neutrons to protons has increased to 1.35, and for uranium-238 (92 protons and 146 neutrons), the neutron to proton ratio is 1.59.

Generally speaking, when we examine the characteristics of stable nuclei, we find that for $A < 40$, the number of protons equals the number of neutrons ($N = Z$), as ^{40}Ca.

However, beyond $A = 40$, stable nuclei have $N \sim 1.7Z$, namely, neutrons far outnumber protons (see Fig. 2.1). This can be understood from the fact that, in larger nuclei, the charge density, and therefore the destabilizing effect of Coulomb repulsion, is smaller when there is a neutron excess.

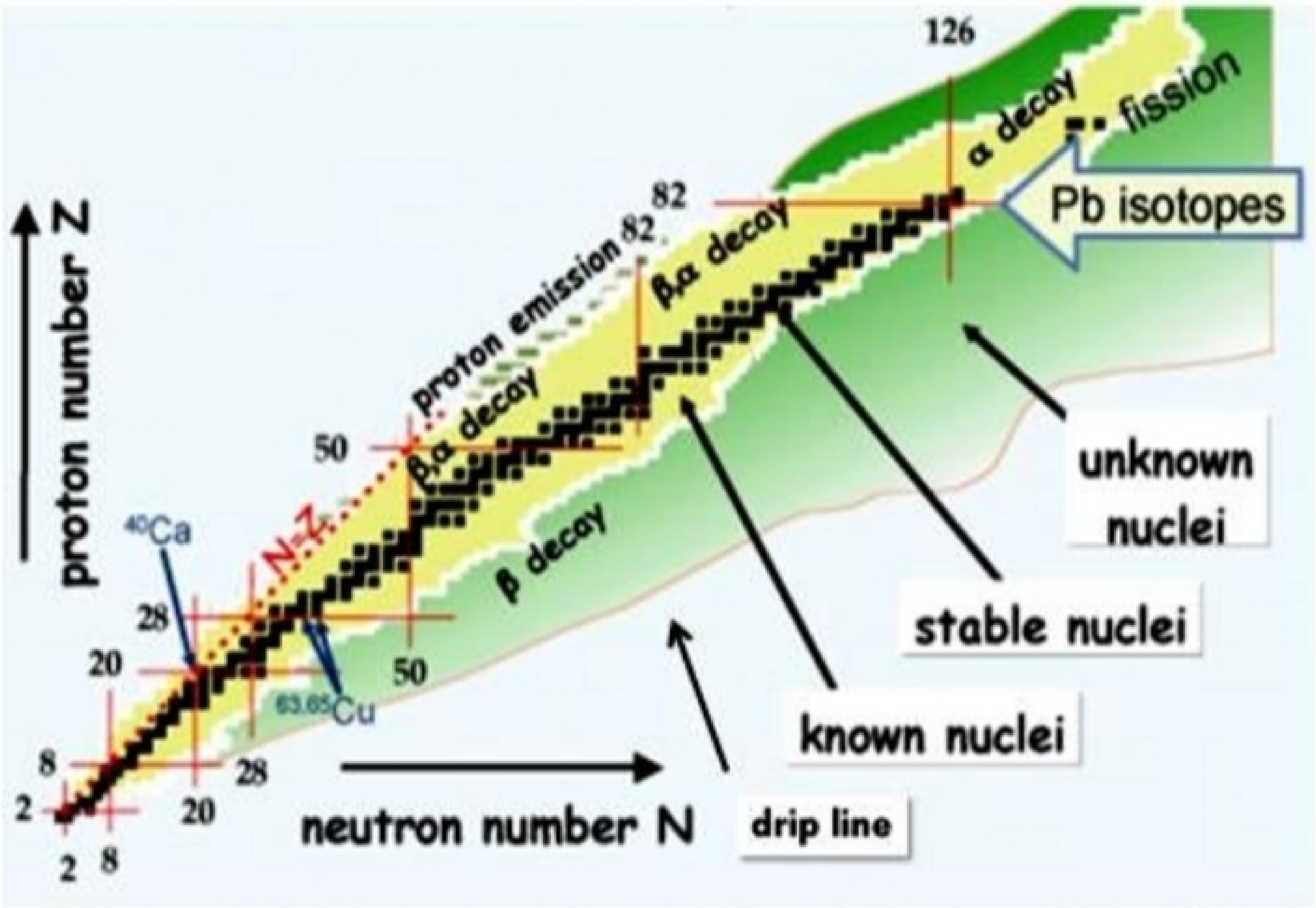

Figure 2.1. Neutron - Proton Plot of the world Nuclides.

Furthermore, a survey of the stable nuclei (see Table 2.1) reveals that even-even nuclei are the ones most abundant in nature. This again lends support to the strong-pairing hypothesis, namely that pairing of nucleons leads to nuclear stability.

In Fig. 2.1, the black squares are long-lived nuclei present on earth. Unbound combinations of (N, Z) lie outside the lines marked 'last proton/neutron unbound' which are predicted to be unbound. Most other nuclei are β-decay or α-decay to stable nuclei.

Table 2.1. Number of stable nuclei in nature.

N	Z	Number of stable nuclei
Even	Even	156
Even	Odd	48
Odd	Even	50
Odd	Odd	5

If a heavy nucleus were to split into two fragments, each fragment would form a nucleus that would have approximately the same neutron-to-proton ratio as the heavy nucleus. This high neutron-to-proton ratio places the fragments below and to the right of the stability curve displayed by Fig. 2.1. The instability caused by this excess of neutrons is generally rectified by successive beta emissions, each of which converts a neutron to a proton and moves the nucleus toward a more stable neutron-to-proton ratio.

2.2. Chart of the Nuclides

A tabulated chart called the *Chart of the Nuclides, National Nuclear Data Center,* http://www.nndc.bnl.gov/chart/, lists the world stable and unstable nuclides in addition to pertinent information about each one. Fig. 2.2 shows a small portion of a typical chart. This chart plots a box for each individual nuclide, with the number of protons (Z) on the vertical axis and the number of neutrons (N =A - Z) on the horizontal axis.