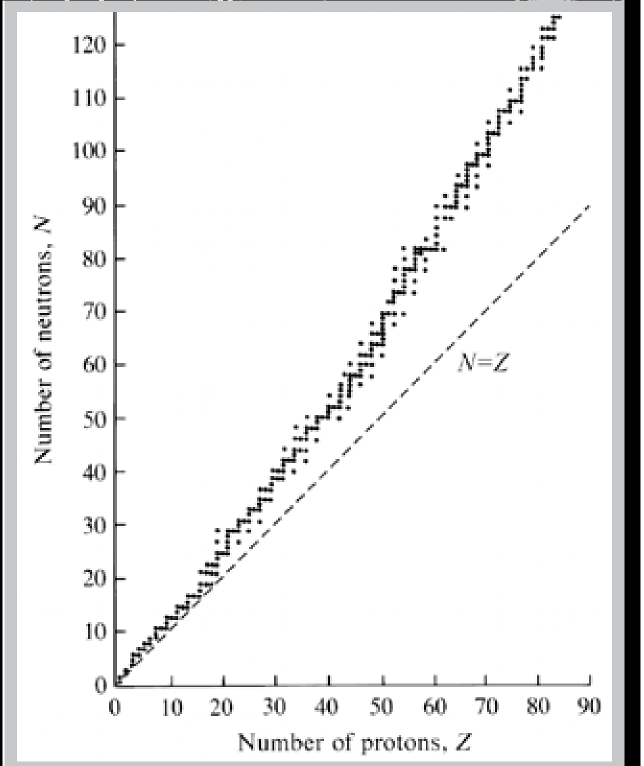
Nuclear Force and Binding Energy

You may recall that objects with the same electric charge repel one another. Protons within the nucleus are positively charged, yet they stay together in the nucleus rather than flying apart. This is due to the attractive **nuclear force** (more specifically, the *strong* nuclear force) that opposes the electric force that would otherwise push the protons apart. The nuclear force acts between pairs of nucleons, including both protons and neutrons. The nuclear force is also a very short-range force; it only acts across distances about the size of the nucleus and drops to zero at longer ranges.

If we took apart a nucleus and weighed each of the nucleons individually, we would find the sum of the individual nucleons' weights exceeds the weight of the original nucleus. How can this be? In everyday experience, a composite object weighs the same as the sum of the weights of its parts, but this principle does not carry over to the nucleus because of the large amount of potential energy it stores. According to Einstein's mass-energy equivalence relation $E = mc^2$, the energy required to keep the nucleus intact can be thought of as adding mass to the nucleus. We refer to this energy as **binding energy**. Binding energy can also be thought of as the energy required to separate a nucleus into its constituent protons and neutrons.

German-born American physicist Maria Goeppert Mayer. Mayer and Eugene Wigner proposed a "shell" model for nucleons similar to the orbital shells occupied by atomic electrons.

FIGURE 23



The nuclear "band of stability." Stable nuclei are represented as dots. Lighter nuclei have $N = Z$, whereas $N > Z$ for heavier nuclei.

As an example, consider a helium-4 nucleus, consisting of two protons and two neutrons bound together. The mass of the ^{4}He nucleus is 4.001506 u, the mass of a single proton is 1.007276 u, and the mass of a single neutron is 1.008665 u. The sum of the individual nucleon masses (2 protons and 2 neutrons) comes out to 4.031882 u, which is about 0.030376 u heavier than the known mass of ^{4}He. The binding energy corresponding to this difference in mass is about 28.3 MeV. This binding energy of over 7 MeV per nucleon is unusually high for a nucleus of this size. As we will see later, this property has important implications for the role of ^{4}He in radioactive decay.

Nuclear Stability

The binding energy of a nucleus provides an indication of how stable it is. As you can see in **FIGURE 22**, binding energy per nucleon peaks around A = 56, suggesting that elements in this region, such as iron and nickel, exhibit a great degree of stability, since it requires more energy on average to pull apart the nucleus, nucleon by nucleon. The binding energy slowly decreases with increasing atomic number for elements beyond A = 60, indicating that nucleons for these elements are less bound to one another. This fact can be attributed to the short-range