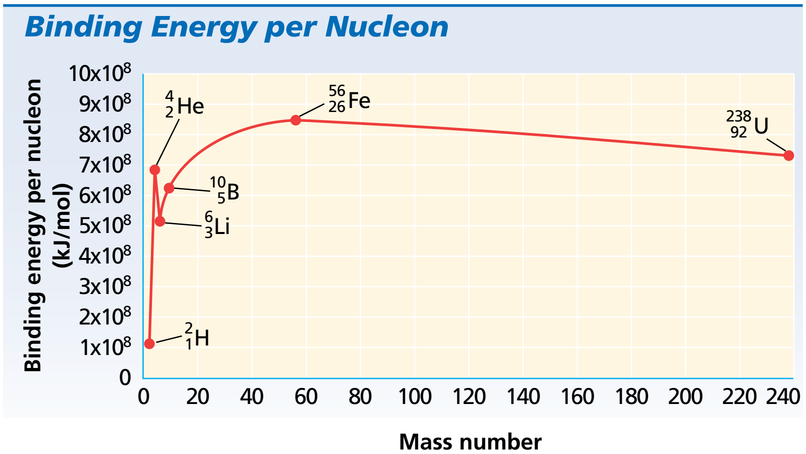
FIGURE 1 This graph shows the relationship between binding energy per nucleon and mass number. The binding energy per nucleon is a measure of the stability of a nucleus.



CROSS-DISCIPLINARY

Quarks

Many subatomic particles have been identified. Leptons and quarks are the elementary particles of matter. The electron is a lepton. Protons and neutrons are made of quarks. There are six types of quarks that differ in mass and charge. They are named *up, down, strange, charm, bottom,* and *top*. Protons consist of two *up* quarks and one *down* quark, and neutrons consist of two *down* quarks and one *up* quark. Although individual quarks have not been isolated, their existence explains the patterns of nuclear binding and decay.

The energy equivalent can now be calculated.

$$E = mc^2$$
$$E = (5.0441 \times 10^{-29}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2$$
$$= 4.54 \times 10^{-12}\ \text{kg}\cdot\text{m}^2/\text{s}^2 = 4.54 \times 10^{-12}\ \text{J}$$

This is the **nuclear binding energy,** *the energy released when a nucleus is formed from nucleons*. This energy can also be thought of as the amount of energy required to break apart the nucleus. Therefore, the nuclear binding energy is also a measure of the stability of a nucleus.

Binding Energy per Nucleon

The binding energy per nucleon is used to compare the stability of different nuclides, as shown in **Figure 1.** The *binding energy per nucleon* is the binding energy of the nucleus divided by the number of nucleons it contains. The higher the binding energy per nucleon, the more tightly the nucleons are held together. Elements with intermediate atomic masses have the greatest binding energies per nucleon and are therefore the most stable.

Nucleons and Nuclear Stability

Stable nuclides have certain characteristics. When the number of protons in stable nuclei is plotted against the number of neutrons, as shown in **Figure 2,** a belt-like graph is obtained. This stable nuclei cluster over a range of neutron-proton ratios is referred to as the *band of stability.* Among atoms having low atomic numbers, the most stable nuclei are those with a neutron-proton ratio of approximately 1:1. For example, $^{4}_{2}He$, a stable isotope of helium with two neutrons and two protons, has a neutron-proton ratio of 1:1. As the atomic number increases, the stable neutron-proton ratio increases to about 1.5:1. For example, $^{206}_{82}Pb$, with 124 neutrons and 82 protons, has a neutron-proton ratio of 1.51:1.

This trend can be explained by the relationship between the nuclear force and the electrostatic forces between protons. Protons in a nucleus repel all other protons through electrostatic repulsion, but the short