Thus the mass of ${}^4_2\mathrm{He}$ is measured to be $4.032980\,\mathrm{u} - 4.002603\,\mathrm{u} = 0.030377\,\mathrm{u}$ less than the masses of its constituents. Where has this lost mass gone?

It has, in fact, gone into energy of another kind (such as radiation, or kinetic energy, for example). The mass (or energy) difference in the case of ${}^4_2\mathrm{He}$, given in energy units, is $(0.030377\,\mathrm{u})(931.5\,\mathrm{MeV/u}) = 28.30\,\mathrm{MeV}$. This difference is referred to as the **total binding energy** of the nucleus. The total binding energy represents the amount of energy that must be put into a nucleus in order to break it apart into its constituents. If the mass of, say, a ${}^4_2\mathrm{He}$ nucleus were exactly equal to the mass of two neutrons plus two protons, the nucleus could fall apart without any input of energy. To be stable, the mass of a nucleus *must* be less than that of its constituent nucleons, so that energy input *is* needed to break it apart. Note that the binding energy is not something a nucleus has—it is energy it "lacks" relative to the total mass of its separate constituents.

Binding energy

[We saw in Chapter 27 that the binding energy of the one electron in the hydrogen atom is 13.6 eV; so the mass of a ${}^1_1\mathrm{H}$ atom is less than that of a single proton plus a single electron by $13.6\,\mathrm{eV}/c^2$. Compared to the total mass of the atom $(939\,\mathrm{MeV}/c^2)$, this is incredibly small, 1 part in 10^8. Also, the binding energies of nuclei are on the order of MeV, so the eV binding energies of electrons can be ignored.]

EXERCISE A Determine how much less the mass of the ${}^7_3\mathrm{Li}$ nucleus is compared to that of its constituents.

The **binding energy per nucleon** is defined as the total binding energy of a nucleus divided by A, the total number of nucleons. We calculated above that the binding energy of ${}^4_2\mathrm{He}$ is 28.3 MeV, so its binding energy per nucleon is $28.3\,\mathrm{MeV}/4 = 7.1\,\mathrm{MeV}$. Figure 30–1 shows the binding energy per nucleon as a function of A for stable nuclei. The curve rises as A increases and reaches a plateau at about 8.7 MeV per nucleon above $A \approx 40$. Beyond $A \approx 80$, the curve decreases slowly, indicating that larger nuclei are held together a little less tightly than those in the middle of the periodic table. We will see later that these characteristics allow the release of nuclear energy in the processes of fission and fusion.

Binding energy per nucleon

FIGURE 30–1 Binding energy per nucleon for the more stable nuclides as a function of mass number A.