EXAMPLE 30–4 **Binding energy for iron.** Calculate the total binding energy and the binding energy per nucleon for $^{56}_{26}\text{Fe}$, the most common stable isotope of iron.

APPROACH We subtract the mass of a $^{56}_{26}\text{Fe}$ atom from the total mass of 26 hydrogen atoms and 30 neutrons, all found in Appendix B. Then we convert mass units to energy units; finally we divide by $A = 56,$ the total number of nucleons.

SOLUTION $^{56}_{26}\text{Fe}$ has 26 protons and 30 neutrons whose separate masses are

$$\begin{aligned} 26m(^1_1\text{H}) = (26)(1.007825\,\text{u}) &= 26.20345\,\text{u (includes 26 electrons)} \\ 30m_\text{n} = (30)(1.008665\,\text{u}) &= \underline{30.25995\,\text{u}} \\ \text{sum} &= 56.46340\,\text{u.} \\ \text{Subtract mass of } ^{56}_{26}\text{Fe:} &= \underline{-55.93494\,\text{u}}\ \text{(Appendix B)} \\ \Delta m &= 0.52846\,\text{u.} \end{aligned}$$

The total binding energy is thus

$$(0.52846\,\text{u})(931.5\,\text{MeV/u}) = 492.26\,\text{MeV}$$

and the binding energy per nucleon is

$$\frac{492.26\,\text{MeV}}{56\text{ nucleons}} = 8.79\,\text{MeV}.$$

NOTE The binding energy per nucleon graph (Fig. 30–1) peaks just about here, for iron, so the iron nucleus (and its neighbors) is the most stable of nuclei.

EXERCISE B Determine the binding energy per nucleon for $^{16}_{8}\text{O}$.

EXAMPLE 30–5 **Binding energy of last neutron.** What is the binding energy of the last neutron in $^{13}_{6}\text{C}$?

APPROACH We subtract the mass of $^{13}_{6}\text{C}$ from the masses of the atom with one less neutron, $^{12}_{6}\text{C}$, and a free neutron.

SOLUTION Obtaining the masses from Appendix B, we have

$$\begin{aligned} \text{Mass } ^{12}_{6}\text{C} &= 12.000000\,\text{u} \\ \text{Mass } ^{1}_{0}\text{n} &= \underline{1.008665\,\text{u}} \\ \text{Total} &= 13.008665\,\text{u.} \\ \text{Subtract mass of } ^{13}_{6}\text{C:} & \quad \underline{-13.003355\,\text{u}} \\ \Delta m &= 0.005310\,\text{u} \end{aligned}$$

which in energy is $(931.5\,\text{MeV/u})(0.005310\,\text{u}) = 4.95\,\text{MeV}$. That is, it would require 4.95 MeV input of energy to remove one neutron from $^{13}_{6}\text{C}$.

Nuclear Forces

We can analyze nuclei not only from the point of view of energy, but also from the point of view of the forces that hold them together. We would not expect a collection of protons and neutrons to come together spontaneously, since protons are all positively charged and thus exert repulsive electric forces on each other. Indeed, the question arises as to how a nucleus stays together at all in view of the fact that the electric force between protons would tend to break it apart. Since stable nuclei *do* stay together, it is clear that another force must be acting. Because this new force is stronger than the electric force (which, in turn, is much stronger than gravity at the nuclear level), it is called the **strong nuclear force**. The strong nuclear force is an attractive force that acts between all nucleons—protons and neutrons alike. Thus protons attract each other via the strong nuclear force at the same time they repel each other via the electric force. Neutrons, since they are electrically neutral, only attract other neutrons or protons via the strong nuclear force.

Strong nuclear force