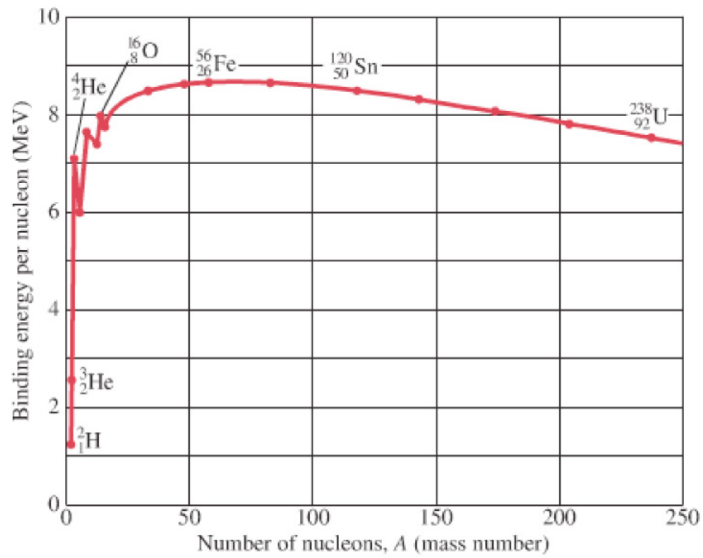

FIGURE 31–11 Average binding energy per nucleon as a function of mass number A for stable nuclei. Same as Fig. 30–1.

Nuclear Fusion; Stars

The process of building up nuclei by bringing together individual protons and neutrons, or building larger nuclei by combining small nuclei, is called **nuclear fusion**. A glance at Fig. 31–11 (same as Fig. 30–1) shows why small nuclei can combine to form larger ones with the release of energy: it is because the binding energy per nucleon is smaller for light nuclei than it is for those of increasing mass (up to about $A \approx 60$). It is believed that many of the elements in the universe were originally formed through the process of fusion (see Chapter 33), and that fusion is today continually taking place within the stars, including our Sun, producing the prodigious amounts of radiant energy they emit.

EXAMPLE 31–6 **Fusion energy release.** One of the simplest fusion reactions involves the production of deuterium, $^{2}_{1}\mathrm{H}$, from a neutron and a proton: $^{1}_{1}\mathrm{H} + \mathrm{n} \rightarrow {}^{2}_{1}\mathrm{H} + \gamma$. How much energy is released in this reaction?

APPROACH The energy released equals the difference in mass (times c^2) between the initial and final masses.

SOLUTION From Appendix B, the initial rest mass is

$$1.007825\,\mathrm{u} + 1.008665\,\mathrm{u} = 2.016490\,\mathrm{u},$$

and after the reaction the mass is that of the $^{2}_{1}\mathrm{H}$, namely 2.014102 u. The mass difference is

$$2.016490\,\mathrm{u} - 2.014102\,\mathrm{u} = 0.002388\,\mathrm{u},$$

so the energy released is

$$(\Delta m)c^2 = (0.002388\,\mathrm{u})(931.5\,\mathrm{MeV/u}) = 2.22\,\mathrm{MeV},$$

and it is carried off by the $^{2}_{1}\mathrm{H}$ nucleus and the γ ray.

The energy output of our Sun is believed to be due principally to the following sequence of fusion reactions:

Fusion reactions in the Sun (proton–proton cycle)

$$^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + e^{+} + \nu \qquad (0.42\,\mathrm{MeV}) \qquad \textbf{(31–6a)}$$

$$^{1}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \gamma \qquad (5.49\,\mathrm{MeV}) \qquad \textbf{(31–6b)}$$

$$^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \qquad (12.86\,\mathrm{MeV}) \qquad \textbf{(31–6c)}$$

where the energy released (Q-value) for each reaction is given in parentheses.