Alpha decay occurs because the strong nuclear force is unable to hold very large nuclei together. Because the nuclear force is a short-range force, it acts only between neighboring nucleons. But the electric force acts all the way across a large nucleus. For very large nuclei, the large Z means the repulsive electric force becomes so large (Coulomb's law) that the strong nuclear force is unable to hold the nucleus together.

Why the strong nuclear force cannot hold a nucleus together

We can express the instability in terms of energy (or mass): the mass of the parent nucleus is greater than the mass of the daughter nucleus plus the mass of the α particle. The mass difference appears as kinetic energy, which is carried away by the α particle and the recoiling daughter nucleus. The total energy released is called the **disintegration energy**, Q, or the ***Q*-value** of the decay. From conservation of energy,

$$M_{\mathrm{P}}c^2 = M_{\mathrm{D}}c^2 + m_{\alpha}c^2 + Q,$$

where $Q = \mathrm{KE}$ and M_{P}, M_{D}, and m_{α} are the masses of the parent, daughter, and α particle, respectively. Thus

$$Q = M_{\mathrm{P}}c^2 - \left(M_{\mathrm{D}} + m_{\alpha}\right)c^2. \qquad \textbf{(30–2)}$$

Q-value

If the parent had *less* mass than the daughter plus the α particle (so $Q < 0$), the decay could not occur spontaneously, for the conservation of energy law would be violated.

EXAMPLE 30–6 **Uranium decay energy release.** Calculate the disintegration energy when $^{232}_{92}\mathrm{U}$ (mass = 232.037146 u) decays to $^{228}_{90}\mathrm{Th}$ (228.028731 u) with the emission of an α particle. (As always, masses are for neutral atoms.)

APPROACH We use conservation of energy as expressed in Eq. 30–2. $^{232}_{92}\mathrm{U}$ is the parent, $^{228}_{90}\mathrm{Th}$ is the daughter.

SOLUTION Since the mass of the $^{4}_{2}\mathrm{He}$ is 4.002603 u (Appendix B), the total mass in the final state is

$$228.028731\ \mathrm{u} + 4.002603\ \mathrm{u} = 232.031334\ \mathrm{u}.$$

The mass lost when the $^{232}_{92}\mathrm{U}$ decays is

$$232.037146\ \mathrm{u} - 232.031334\ \mathrm{u} = 0.005812\ \mathrm{u}.$$

Since $1\ \mathrm{u} = 931.5\ \mathrm{MeV}$, the energy Q released is

$$Q = (0.005812\ \mathrm{u})(931.5\ \mathrm{MeV/u}) \approx 5.4\ \mathrm{MeV},$$

and this energy appears as kinetic energy of the α particle and the daughter nucleus.

NOTE Using conservation of momentum, it can be shown that the α particle emitted by a $^{232}_{92}\mathrm{U}$ nucleus at rest has a kinetic energy of about 5.3 MeV. Thus, the daughter nucleus—which recoils in the opposite direction from the emitted α particle—has about 0.1 MeV of kinetic energy. See the next Example and/or Problem 65.