Alpha decay can occur because according to quantum mechanics some nuclei have barriers that can be penetrated by the alpha particles (the tunneling process). This process is energetically more favorable for those nuclei having large excesses of neutrons. A nucleus can undergo **beta decay** in two ways. It can emit either an electron (e^-) and an antineutrino ($\bar{\nu}$) or a positron (e^+) and a neutrino (ν). In the **electron capture** process, the nucleus of an atom absorbs one of its own electrons (usually from the K shell) and emits a neutrino. In **gamma decay,** a nucleus in an excited state decays to its ground state and emits a gamma ray.

Nuclear reactions can occur when a target nucleus X is bombarded by a particle a, resulting in a nucleus Y and an outgoing particle b:

$$\mathrm{a + X \rightarrow Y + b} \quad \text{or} \quad \mathrm{X(a, b)Y} \qquad 30.24$$

The rest energy transformed to kinetic energy in such a reaction, called the **reaction energy** Q, is

$$Q = (M_a + M_X - M_Y - M_b)c^2 \qquad 30.25$$

A reaction for which Q is positive is called **exothermic.** A reaction for which Q is negative is called **endothermic.** The minimum kinetic energy of the incoming particle necessary for such a reaction to occur is called the **threshold energy.**

OBJECTIVE QUESTIONS

☐ denotes answer available in *Student Solutions Manual/Study Guide*

1. When $^{32}_{15}\mathrm{P}$ decays to $^{32}_{16}\mathrm{S}$, which of the following particles is emitted? (a) a proton (b) an alpha particle (c) an electron (d) a gamma ray (e) an antineutrino

2. Two samples of the same radioactive nuclide are prepared. Sample G has twice the initial activity of sample H. **(i)** How does the half-life of G compare with the half-life of H? (a) It is two times larger. (b) It is the same. (c) It is half as large. **(ii)** After each has passed through five half-lives, how do their activities compare? (a) G has more than twice the activity of H. (b) G has twice the activity of H. (c) G and H have the same activity. (d) G has lower activity than H.

3. If a radioactive nuclide $^A_Z\mathrm{X}$ decays by emitting a gamma ray, what happens? (a) The resulting nuclide has a different Z value. (b) The resulting nuclide has the same A and Z values. (c) The resulting nuclide has a different A value. (d) Both A and Z decrease by one. (e) None of those statements is correct.

4. Does a nucleus designated as $^{40}_{18}\mathrm{X}$ contain (a) 20 neutrons and 20 protons, (b) 22 protons and 18 neutrons, (c) 18 protons and 22 neutrons, (d) 18 protons and 40 neutrons, or (e) 40 protons and 18 neutrons?

5. In the decay $^{234}_{90}\mathrm{Th} \rightarrow {}^A_Z\mathrm{Ra} + {}^4_2\mathrm{He}$, identify the mass number and the atomic number of the Ra nucleus: (a) $A = 230$, $Z = 92$ (b) $A = 238$, $Z = 88$ (c) $A = 230$, $Z = 88$ (d) $A = 234$, $Z = 88$ (e) $A = 238$, $Z = 86$

6. When $^{144}_{60}\mathrm{Nd}$ decays to $^{140}_{58}\mathrm{Ce}$, identify the particle that is released. (a) a proton (b) an alpha particle (c) an electron (d) a neutron (e) a neutrino

7. When the $^{95}_{36}\mathrm{Kr}$ nucleus undergoes beta decay by emitting an electron and an antineutrino, does the daughter nucleus (Rb) contain (a) 58 neutrons and 37 protons, (b) 58 protons and 37 neutrons, (c) 54 neutrons and 41 protons, or (d) 55 neutrons and 40 protons?

8. What is the Q value for the reaction $^9\mathrm{Be} + \alpha \rightarrow {}^{12}\mathrm{C} + \mathrm{n}$? (a) 8.4 MeV (b) 7.3 MeV (c) 6.2 MeV (d) 5.7 MeV (e) 4.2 MeV

9. The half-life of radium-224 is about 3.6 days. What approximate fraction of a sample remains undecayed after two weeks? (a) $\frac{1}{2}$ (b) $\frac{1}{4}$ (c) $\frac{1}{8}$ (d) $\frac{1}{16}$ (e) $\frac{1}{32}$

10. A free neutron has a half-life of 614 s. It undergoes beta decay by emitting an electron. Can a free proton undergo a similar decay? (a) yes, the same decay (b) yes, but by emitting a positron (c) yes, but with a very different half-life (d) no

11. Which of the following quantities represents the reaction energy of a nuclear reaction? (a) (final mass − initial mass)$/c^2$ (b) (initial mass − final mass)$/c^2$ (c) (final mass − initial mass)c^2 (d) (initial mass − final mass)c^2 (e) none of those quantities

12. In the first nuclear weapon test carried out in New Mexico, the energy released was equivalent to approximately 17 kilotons of TNT. Estimate the mass decrease in the nuclear fuel representing the energy converted from rest energy into other forms in this event. *Note:* One ton of TNT has the energy equivalent of 4.2×10^9 J. (a) 1 μg (b) 1 mg (c) 1 g (d) 1 kg (e) 20 kg

CONCEPTUAL QUESTIONS

☐ denotes answer available in *Student Solutions Manual/Study Guide*

1. A student claims that a heavy form of hydrogen decays by alpha emission. How do you respond?

2. In beta decay, the energy of the electron or positron emitted from the nucleus lies somewhere in a relatively large range of possibilities. In alpha decay, however, the alpha-particle energy can only have discrete values. Explain this difference.

3. In Rutherford's experiment, assume an alpha particle is headed directly toward the nucleus of an atom. Why doesn't the alpha particle make physical contact with the nucleus?

4. Explain why nuclei that are well off the line of stability in Figure 30.4 tend to be unstable.