An α particle is a ${}^{4}_{2}\text{He}$ nucleus; a β particle is an electron or positron; and a γ ray is a high-energy photon. In β decay, a **neutrino** is also emitted. The transformation of the parent into the daughter nucleus is called **transmutation** of the elements. Radioactive decay occurs spontaneously only when the rest mass of the products is less than the mass of the parent nucleus. The loss in mass appears as kinetic energy of the products.

Nuclei are held together by the **strong nuclear force**. The **weak nuclear force** makes itself apparent in β decay. These two forces, plus the gravitational and electromagnetic forces, are the four known types of force.

Electric charge, linear and angular momentum, mass–energy, and **nucleon number** are **conserved** in all decays.

Radioactive decay is a statistical process. For a given type of radioactive nucleus, the number of nuclei that decay (ΔN) in a time Δt is proportional to the number N of parent nuclei present:

$$\Delta N = -\lambda N\,\Delta t; \tag{30–3a}$$

the minus sign means N *decreases* in time.

The proportionality constant λ is called the **decay constant** and is characteristic of the given nucleus. The number N of nuclei remaining after a time t decreases exponentially

$$N = N_0 e^{-\lambda t}, \tag{30–4}$$

as does the **activity**, $\Delta N/\Delta t$:

$$\frac{\Delta N}{\Delta t} = \left(\frac{\Delta N}{\Delta t}\right)_0 e^{-\lambda t}. \tag{30–5}$$

The **half-life**, $T_{\frac{1}{2}}$, is the time required for half the nuclei of a radioactive sample to decay. It is related to the decay constant by

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}. \tag{30–6}$$

Radioactive decay can be used to determine the age of certain objects.

[*Alpha decay occurs via a purely quantum mechanical process called **tunneling** through a barrier.]

[*Particle **detectors** include **Geiger counters**, **scintillators** with attached **photomultiplier tubes**, and **semiconductor detectors**. Detectors that can image particle tracks include photographic **emulsions, bubble chambers**, and today **wire drift chambers**.]

Questions

1. What do different isotopes of a given element have in common? How are they different?
2. What are the elements represented by the X in the following: (*a*) ${}^{232}_{92}\text{X}$; (*b*) ${}^{18}_{7}\text{X}$; (*c*) ${}^{1}_{1}\text{X}$; (*d*) ${}^{82}_{38}\text{X}$; (*e*) ${}^{247}_{97}\text{X}$?
3. How many protons and how many neutrons do each of the isotopes in Question 2 have?
4. Identify the element that has 88 nucleons and 50 neutrons.
5. Why are the atomic masses of many elements (see the periodic table) not close to whole numbers?
6. How do we know there is such a thing as the strong nuclear force?
7. What are the similarities and the differences between the strong nuclear force and the electric force?
8. What is the experimental evidence in favor of radioactivity being a nuclear process?
9. The isotope ${}^{64}_{29}\text{Cu}$ is unusual in that it can decay by γ, β^-, and β^+ emission. What is the resulting nuclide for each case?
10. A ${}^{238}_{92}\text{U}$ nucleus decays to a nucleus containing how many neutrons?
11. Describe, in as many ways as you can, the difference between α, β, and γ rays.
12. What element is formed by the radioactive decay of (*a*) ${}^{24}_{11}\text{Na}\ (\beta^-)$; (*b*) ${}^{22}_{11}\text{Na}\ (\beta^+)$; (*c*) ${}^{210}_{84}\text{Po}\ (\alpha)$? [*Hint*: see Appendix B.]
13. What element is formed by the decay of (*a*) ${}^{32}_{15}\text{P}\ (\beta^-)$; (*b*) ${}^{35}_{16}\text{S}\ (\beta^-)$; (*c*) ${}^{211}_{83}\text{Bi}\ (\alpha)$? [*Hint*: see Appendix B.]
14. Fill in the missing particle or nucleus:
    - (*a*) ${}^{45}_{20}\text{Ca} \rightarrow\ ? + e^- + \bar{\nu}$
    - (*b*) ${}^{58}_{29}\text{Cu} \rightarrow\ ? + \gamma$
    - (*c*) ${}^{46}_{24}\text{Cr} \rightarrow {}^{46}_{23}\text{V} +\ ?$
    - (*d*) ${}^{234}_{94}\text{Pu} \rightarrow\ ? + \alpha$
    - (*e*) ${}^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} +\ ?$
15. Immediately after a ${}^{238}_{92}\text{U}$ nucleus decays to ${}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$, the daughter thorium nucleus still has 92 electrons circling it. Since thorium normally holds only 90 electrons, what do you suppose happens to the two extra ones?
16. When a nucleus undergoes either β^- or β^+ decay, what happens to the energy levels of the atomic electrons? What is likely to happen to these electrons following the decay?
17. The alpha particles from a given alpha-emitting nuclide are generally monoenergetic; that is, they all have the same kinetic energy. But the beta particles from a beta-emitting nuclide have a spectrum of energies. Explain the difference between these two cases.
18. Do isotopes that undergo electron capture generally lie above or below the line of stability in Fig. 30–2?
19. Can hydrogen or deuterium emit an α particle? Explain.
20. Why are many artificially produced radioactive isotopes rare in nature?
21. An isotope has a half-life of one month. After two months, will a given sample of this isotope have completely decayed? If not, how much remains?
22. Why are none of the elements with $Z > 92$ stable?
23. A proton strikes a ${}^{6}_{3}\text{Li}$ nucleus. As a result, an α particle and another particle are released. What is the other particle?
24. Can ${}^{14}_{6}\text{C}$ dating be used to measure the age of stone walls and tablets of ancient civilizations? Explain.
25. In both internal conversion and β decay, an electron is emitted. How could you determine which decay process occurred?