Table 5
Properties of the Neutrino

The neutrino has zero electric charge.
The neutrino's mass was once believed to be zero; recent experiments suggest a very small nonzero mass (much smaller than the mass of the electron).
The neutrino interacts very weakly with matter and is therefore very difficult to detect.

The Greek letter *nu* (ν) is used to represent a neutrino. When a bar is drawn above the nu ($\overline{\nu}$), the particle is an antineutrino, or the antiparticle of a neutrino. The properties of the neutrino are summarized in **Table 5.** Note that the neutrino has no electric charge and that its mass is very small, perhaps even zero. As a result, the neutrino is difficult to detect experimentally.

With the neutrino, we can now describe the beta decay process of carbon-14 in a form that takes energy and momentum conservation into account, as follows:

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}e + \overline{\nu}$$

According to this expression, carbon-14 decays into a nitrogen nucleus, releasing an electron and an antineutrino in the process.

The decay of nitrogen-12 can also be rewritten, as follows:

$$^{12}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{0}_{1}e + \nu$$

Here we see that when $^{12}_{7}\mathrm{N}$ decays into $^{12}_{6}\mathrm{C}$, a positron and a neutrino are produced. To avoid confusing these two types of beta decay, keep in mind this simple rule: *In beta decay, an electron is always accompanied by an antineutrino and a positron is always accompanied by a neutrino.*

Did you know?

The word *neutrino* means "little neutral one." It was suggested by the physicist Enrico Fermi because the neutrino had to have zero electric charge and little or no mass.

High-energy photons are emitted in gamma decay

Very often, a nucleus that undergoes radioactive decay, either alpha or beta, is left in an excited energy state. The nucleus can then undergo a gamma decay in which one or more nucleons make transitions from a higher energy level to a lower energy level. In the process, one or more photons are emitted. Such photons, or *gamma rays,* have very high energy relative to the energy of visible light. The process of nuclear de-excitation, or gamma decay, is very similar to the emission of light by an atom, in which an electron makes a transition from a state of higher energy to a state of lower energy (as discussed in the chapter "Atomic Physics"). Note that in gamma decay, energy is emitted but the parts of the nucleus are left unchanged. Thus, both the atomic number and the mass number stay the same. Nonetheless, gamma decay is still considered to be a form of nuclear decay because it involves protons or neutrons in the nucleus.

Two common reasons for a nucleus being in an excited state are alpha and beta decay. The following sequence of events represents a typical situation in which gamma decay occurs:

$$^{12}_{5}\mathrm{B} \rightarrow {}^{12}_{6}\mathrm{C}^{*} + {}^{0}_{-1}e + \overline{\nu}$$
$$^{12}_{6}\mathrm{C}^{*} \rightarrow {}^{12}_{6}\mathrm{C} + \gamma$$

The first step is a beta decay in which $^{12}_{5}\mathrm{B}$ decays to $^{12}_{6}\mathrm{C}^{*}$. The asterisk indicates that the carbon nucleus is left in an excited state following the decay. The excited carbon nucleus then decays in the second step to the ground state by emitting a gamma ray.