does not occur, physicists hypothesized a new conservation law, the conservation of **baryon number**. (Baryon number is a generalization of nucleon number, which we saw earlier is conserved in nuclear reactions and decays.) All nucleons are defined to have baryon number $B = +1$, and all antinucleons (antiprotons, antineutrons) have $B = -1$. All other types of particles, such as photons, mesons, and electrons and other leptons, have $B = 0$. The reaction shown at the start of this paragraph does not conserve baryon number since the left side has $B = (+1) + (+1) = +2$, and the right has $B = (+1) + (+1) + (-1) = +1$. On the other hand, the following reaction does conserve $B$ and *does* occur if the incoming proton has sufficient energy:

*Baryon number*

$$\begin{aligned} \mathrm{p} + \mathrm{p} &\rightarrow \mathrm{p} + \mathrm{p} + \overline{\mathrm{p}} + \mathrm{p}, \\ B = +1 + 1 &= +1 + 1 - 1 + 1. \end{aligned}$$

As indicated, $B = +2$ on both sides of this equation. From these and other reactions, the **conservation of baryon number** has been established as a basic principle of physics.

*Conservation of baryon number*

Also useful are the conservation laws for the three **lepton numbers**, associated with weak interactions including decays. In ordinary $\beta$ decay, an electron or positron is emitted along with a neutrino or antineutrino. In a similar type of decay, a particle known as a "$\mu$" or mu meson, or **muon**, can be emitted instead of an electron. The muon (discovered in 1937) seems to be much like an electron, except its mass is 207 times larger $(106\,\mathrm{MeV}/c^2)$. The neutrino $(\nu_e)$ that accompanies an emitted electron is found to be different from the neutrino $(\nu_\mu)$ that accompanies an emitted muon. Each of these neutrinos has an antiparticle: $\bar{\nu}_e$ and $\bar{\nu}_\mu$. In ordinary $\beta$ decay we have, for example,

*Lepton numbers*

**CAUTION**

*The different types of neutrinos are not identical*

$$\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_e$$

but not $\mathrm{n} \nrightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_\mu$. To explain why these do not occur, the concept of **electron lepton number**, $L_e$, was invented. If the electron $(\mathrm{e}^-)$ and the electron neutrino $(\nu_e)$ are assigned $L_e = +1$, and $\mathrm{e}^+$ and $\bar{\nu}_e$ are assigned $L_e = -1$, whereas all other particles have $L_e = 0$, then all observed decays conserve $L_e$. For example, in $\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_e$, $L_e = 0$ initially, and $L_e = 0 + (+1) + (-1) = 0$ after the decay. Decays that do not conserve $L_e$, even though they would obey the other conservation laws, are not observed to occur.

*Lepton numbers conservation*

In a decay involving muons, such as

$$\pi^+ \rightarrow \mu^+ + \nu_\mu,$$

a second quantum number, **muon lepton number** $(L_\mu)$, is conserved. The $\mu^-$ and $\nu_\mu$ are assigned $L_\mu = +1$, and $\mu^+$ and $\bar{\nu}_\mu$ have $L_\mu = -1$, whereas other particles have $L_\mu = 0$. $L_\mu$ too is conserved in interactions and decays. Similar assignments can be made for the **tau lepton number**, $L_\tau$, associated with the $\tau$ lepton (discovered in 1976 with mass more than 3000 times the electron mass) and its neutrino, $\nu_\tau$.

Keep in mind that antiparticles have not only opposite electric charge from their particles, but also opposite $B$, $L_e$, $L_\mu$, and $L_\tau$. For example, a neutron has $B = +1$, an antineutron has $B = -1$ (and all the $L$'s are zero).

*Antiparticles have opposite Q, B, L*

**CONCEPTUAL EXAMPLE 32–4** **Lepton number in muon decay.** Which of the following decay schemes is possible for muon decay: *(a)* $\mu^- \rightarrow \mathrm{e}^- + \bar{\nu}_e$; *(b)* $\mu^- \rightarrow \mathrm{e}^- + \bar{\nu}_e + \nu_\mu$; *(c)* $\mu^- \rightarrow \mathrm{e}^- + \nu_e$? All of these particles have $L_\tau = 0$.

**RESPONSE** A $\mu^-$ has $L_\mu = +1$ and $L_e = 0$. This is the initial state, and the final state (after decay) must also have $L_\mu = +1$, $L_e = 0$. In *(a)*, the final state has $L_\mu = 0 + 0 = 0$, and $L_e = +1 - 1 = 0$; $L_\mu$ would not be conserved and indeed this decay is not observed to occur. The final state of *(b)* has $L_\mu = 0 + 0 + 1 = +1$ and $L_e = +1 - 1 + 0 = 0$, so both $L_\mu$ and $L_e$ are conserved. This is in fact the most common decay mode of the $\mu^-$. Finally, *(c)* does not occur because $L_e$ (= +2 in the final state) is not conserved, nor is $L_\mu$.