Section Summary

33.1 The Yukawa Particle and the Heisenberg Uncertainty Principle Revisited

- Yukawa's idea of virtual particle exchange as the carrier of forces is crucial, with virtual particles being formed in temporary violation of the conservation of mass-energy as allowed by the Heisenberg uncertainty principle.

33.2 The Four Basic Forces

- The four basic forces and their carrier particles are summarized in the Table 33.1.
- Feynman diagrams are graphs of time versus position and are highly useful pictorial representations of particle processes.
- The theory of electromagnetism on the particle scale is called quantum electrodynamics (QED).

33.3 Accelerators Create Matter from Energy

- A variety of particle accelerators have been used to explore the nature of subatomic particles and to test predictions of particle theories.
- Modern accelerators used in particle physics are either large synchrotrons or linear accelerators.
- The use of colliding beams makes much greater energy available for the creation of particles, and collisions between matter and antimatter allow a greater range of final products.

33.4 Particles, Patterns, and Conservation Laws

- All particles of matter have an antimatter counterpart that has the opposite charge and certain other quantum numbers as seen in Table 33.2. These matter-antimatter pairs are otherwise very similar but will annihilate when brought together. Known particles can be divided into three major groups—leptons, hadrons, and carrier particles (gauge bosons).
- Leptons do not feel the strong nuclear force and are further divided into three groups—electron family designated by electron family number L_e; muon family designated by muon family number L_μ; and tau family designated by tau family number L_τ. The family numbers are not universally conserved due to neutrino oscillations.
- Hadrons are particles that feel the strong nuclear force and are divided into baryons, with the baryon family number B being conserved, and mesons.

33.5 Quarks: Is That All There Is?

- Hadrons are thought to be composed of quarks, with baryons having three quarks and mesons having a quark and an antiquark.

- The characteristics of the six quarks and their antiquark counterparts are given in Table 33.3, and the quark compositions of certain hadrons are given in Table 33.4.
- Indirect evidence for quarks is very strong, explaining all known hadrons and their quantum numbers, such as strangeness, charm, topness, and bottomness.
- Quarks come in six flavors and three colors and occur only in combinations that produce white.
- Fundamental particles have no further substructure, not even a size beyond their de Broglie wavelength.
- There are three types of fundamental particles—leptons, quarks, and carrier particles. Each type is divided into three analogous families as indicated in Figure 33.20.

33.6 GUTs: The Unification of Forces

- Attempts to show unification of the four forces are called Grand Unified Theories (GUTs) and have been partially successful, with connections proven between EM and weak forces in electroweak theory.
- The strong force is carried by eight proposed particles called gluons, which are intimately connected to a quantum number called color—their governing theory is thus called quantum chromodynamics (QCD). Taken together, QCD and the electroweak theory are widely accepted as the Standard Model of particle physics.
- Unification of the strong force is expected at such high energies that it cannot be directly tested, but it may have observable consequences in the as-yet unobserved decay of the proton and topics to be discussed in the next chapter. Although unification of forces is generally anticipated, much remains to be done to prove its validity.