Antimatter

Startling discoveries made in the twentieth century have confirmed that electrons and other particles of matter have *antiparticles.* Antiparticles have the same mass as their corresponding particle but an opposite charge.

The discovery of antiparticles

The discovery of antiparticles began in the 1920s with work by the theoretical physicist Paul Adrien Maurice Dirac (1902–1984), who developed a version of quantum mechanics that incorporated Einstein's theory of special relativity. Dirac's theory was successful in many respects, but it had one major problem: its relativistic wave equation required solutions corresponding to negative energy states. This negative set of solutions suggested the existence of something like an electron but with an opposite charge, just as the negative energy states were opposite to an electron's typical energy states. At the time, there was no experimental evidence of such antiparticles.

In 1932, shortly after Dirac's theory was introduced, evidence of the antielectron was discovered by the American physicist Carl Anderson. The antielectron, also known as the *positron,* has the same mass as the electron but is positively charged. Anderson found the positron while examining tracks created by electronlike particles in a cloud chamber placed in a magnetic field. As described in the chapter "Magnetism," such a field will cause moving particles to follow curved paths. The direction in which a particle moves depends on whether its charge is positive or negative. Anderson noted that some of the tracks had deflections typical of an electron's mass, but in the opposite direction, corresponding to a positively charged particle.

Pair production and annihilation

Since Anderson's initial discovery, the positron has been observed in a number of experiments. In perhaps the most common process, a gamma ray with sufficiently high energy collides with a nucleus, creating an electron-positron pair. An example of this process, known as *pair production,* is shown in **Figure 1** on the next page. During pair production, the energy of the photon is completely converted into the rest energy and kinetic energy of the electron and the positron. Thus, pair production is a striking verification of the equivalence of mass (rest energy) and other forms of energy as predicted by Einstein's special theory of relativity. (This equivalence is discussed in the appendix feature "The Equivalence of Mass and Energy.")