## 32–3 Particles and Antiparticles

The positron, as we saw in Chapters 27 and 30, is basically a positive electron. That is, many of its properties are the same as for the electron, such as mass, but it has the opposite charge. Other quantum numbers that we discuss shortly are also reversed for antiparticles. The positron is said to be the **antiparticle** to the electron. After the positron was discovered in 1932, it was predicted that other particles also ought to have antiparticles. In 1955 the antiparticle to the proton was found, the **antiproton** ($\overline{\mathrm{p}}$), which carries a negative charge; see Fig. 32–10. (The bar over the p is used to indicate antiparticle.) Soon after, the antineutron ($\overline{\mathrm{n}}$) was found. All particles have antiparticles. But a few, like the photon and the $\pi^0$, do not have distinct antiparticles—we say that they are their own antiparticles.†

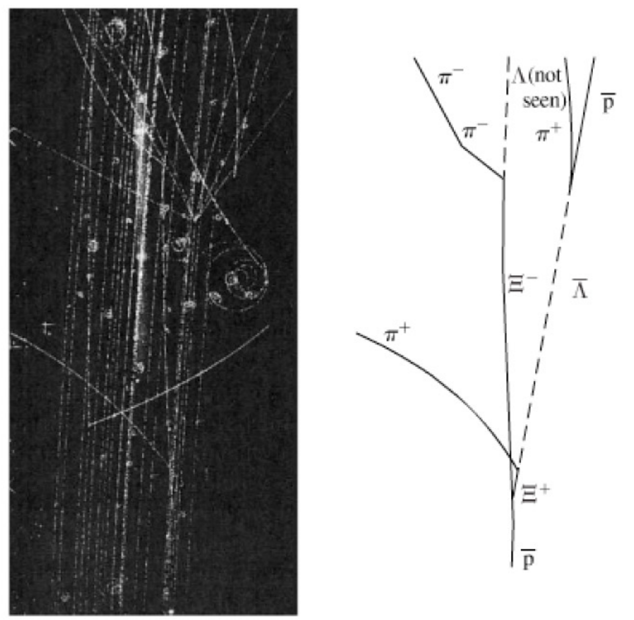


**FIGURE 32–10** Liquid-hydrogen bubble-chamber photograph of an antiproton ($\overline{\mathrm{p}}$) colliding with a proton at rest, producing a Xi–anti-Xi pair ($\overline{\mathrm{p}} + \mathrm{p} \rightarrow \Xi^- + \Xi^+$) that subsequently decay into other particles. The drawing indicates the assignment of particles to each track, which is based on how or if that particle decays, and on mass values estimated from measurement of momentum (curvature of track in magnetic field) and energy (thickness of track, for example). Neutral particle paths are shown by dashed lines since neutral particles produce no bubbles and hence no tracks.

Antiparticles are produced in nuclear reactions when there is sufficient energy available, and they do not live very long in the presence of matter. For example, a positron is stable when by itself; but if it encounters an electron, the two annihilate each other. The energy of their vanished mass, plus any kinetic energy they possessed, is converted into the energy of $\gamma$ rays or of other particles. Annihilation also occurs for all other particle–antiparticle pairs.

## 32–4 Particle Interactions and Conservation Laws

One of the important uses of high-energy accelerators is to study the interactions of elementary particles with each other. As a means of ordering this subnuclear world, the conservation laws are indispensable. The laws of conservation of energy, of momentum, of angular momentum, and of electric charge are found to hold precisely in all particle interactions.

A study of particle interactions has revealed a number of new conservation laws which (just like the old ones) are ordering principles: they help to explain why some reactions occur and others do not. For example, the following reaction has never been found to occur:

$$\mathrm{p} + \mathrm{n} \not\rightarrow \mathrm{p} + \mathrm{p} + \overline{\mathrm{p}}$$

even though charge, energy, and so on, are conserved ($\overline{\mathrm{p}}$ means an antiproton and $\not\rightarrow$ means the reaction does not occur). To understand why such a reaction

† Note, for example, that the opposite charge to $Q = 0$ is still zero.