Only a few of the hundreds of hadrons discovered are included in Table 32–2. Notice that the baryons Λ, Σ, Ξ, and Ω all decay to lighter-mass baryons, and eventually to a proton or neutron. All these processes conserve baryon number. Since there is no lighter particle than the proton with $B = +1$, if baryon number is strictly conserved, the proton itself cannot decay and is stable. (But see Section 32–11.)

The baryon and lepton numbers (B, L_e, L_μ, L_τ), as well as strangeness S (Section 32–8), as given in Table 32–2 are for particles; their antiparticles have opposite sign for these numbers.

32–7 Particle Stability and Resonances

Lifetime depends on which force is acting

Many particles listed in Table 32–2 are unstable. The lifetime of an unstable particle depends on which force is most active in causing the decay. When a stronger force influences a decay, that decay occurs more quickly. Decays caused by the weak force typically have lifetimes of 10^{-13} s or longer (W and Z are exceptions). Decays via the electromagnetic force have much shorter lifetimes, typically about 10^{-16} to 10^{-19} s, and normally involve a γ (photon). The unstable particles listed in Table 32–2 decay either via the weak or the electromagnetic interaction.

Very short-lived particles are inferred from their decay products

Many particles have been found that decay via the strong interaction, with very short lifetimes, typically about 10^{-23} s, and these are not listed in Table 32–2. Their lifetimes are so short they do not travel far enough to be detected before decaying. The existence of such short-lived particles is inferred from their decay products. Consider the first such particle discovered (by Fermi), using a beam of π^+ directed through a hydrogen target (protons) with varying amounts of energy. The number of interactions (π^+ scattered) plotted versus the pion's kinetic energy is shown in Fig. 32–11. The large number of interactions around 200 MeV led Fermi to conclude that the π^+ and proton combined momentarily to form a short-lived particle before coming apart again, or at least that they resonated together for a short time. Indeed, the large peak in Fig. 32–11 resembles a resonance curve (see Figs. 11–18 and 21–42), and this new "particle"—now called the Δ—is referred to as a **resonance**. Hundreds of other resonances have been found, and are regarded as excited states of lighter mass particles such as the nucleon.

Resonance

Uncertainty principle relates lifetime and mass width

The width of a resonance—in Fig. 32–11 the width of the Δ peak is on the order of 100 MeV—is an interesting application of the uncertainty principle. If a particle lives only 10^{-23} s, then its mass (i.e., its rest energy) will be uncertain by an amount $\Delta E \approx h/(2\pi\,\Delta t) \approx (6.6 \times 10^{-34}\,\mathrm{J\cdot s})/(6)(10^{-23}\,\mathrm{s}) \approx 10^{-11}\,\mathrm{J} \approx$ 100 MeV, which is what is observed. Actually, the lifetimes of $\approx 10^{-23}$ s for such resonances are inferred by the reverse process: from the measured width being ≈ 100 MeV.

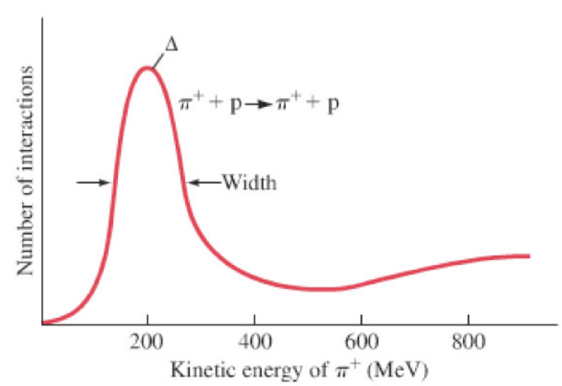

FIGURE 32–11 Number of π^+ particles scattered by a proton target as a function of the incident π^+ kinetic energy. The resonance shape represents the formation of a short-lived particle, the Δ, which has a charge in this case of $+2e$ (Δ^{++}).