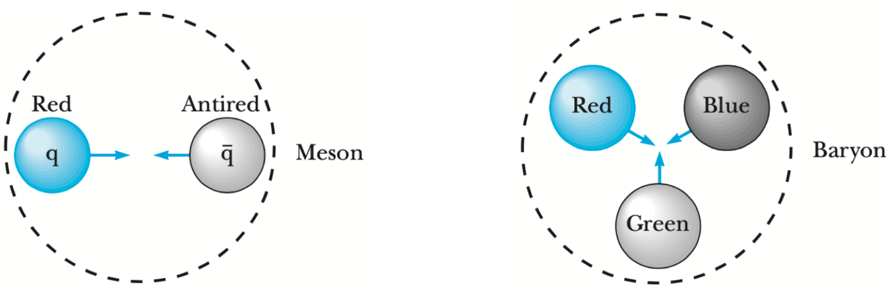
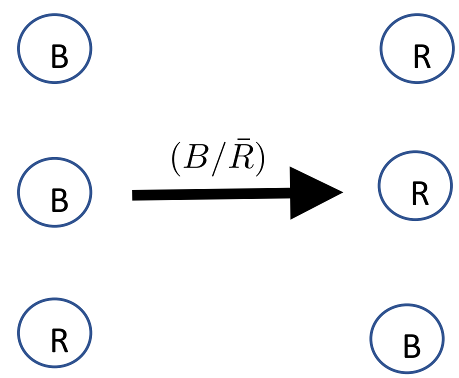
Cromodinamica cuantica

One example of a particle that violates the exclusion principle is the Ω^- (s s s) baryon, which contains three s quarks with parallel spins, giving it a total spin of $\frac{3}{2}$. Other examples of baryons that have identical quarks with parallel spins are the Δ^{++} (u u u) and the Δ^- (d d d). To resolve this problem, Moo-Young Han and Yoichiro Nambu suggested in 1965 that quarks possess a new property, called **color** or **color charge.**



(a) (b)



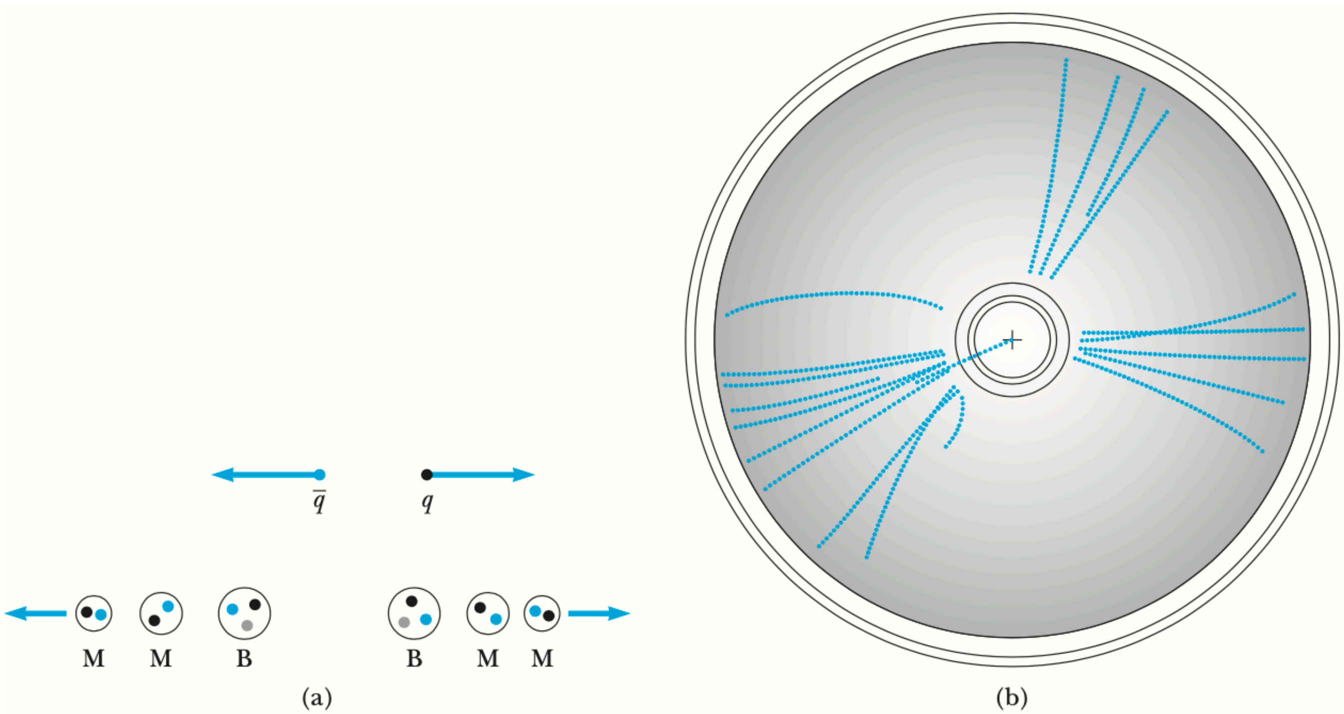
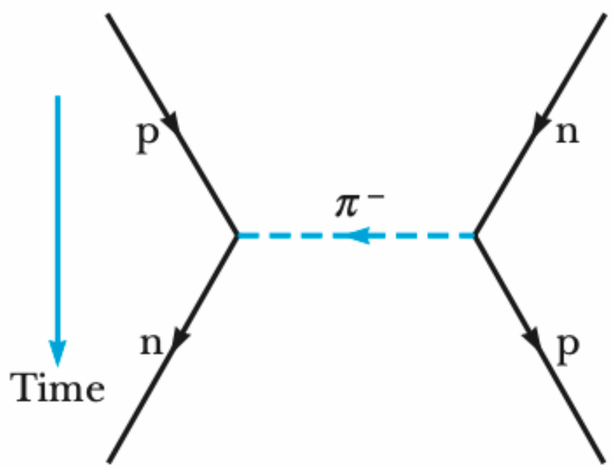
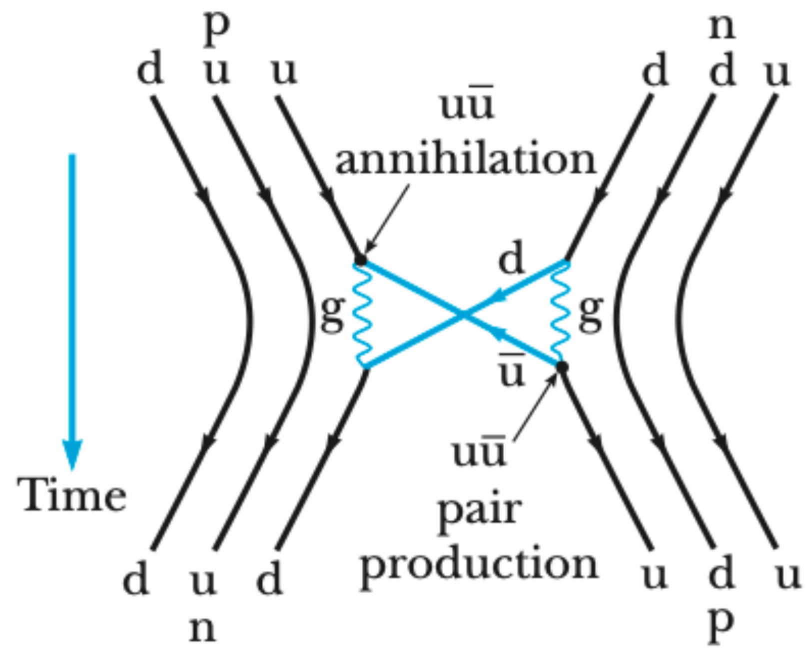


Figure 15.16 (a) As the quark–antiquark pair separates, the potential energy in the color field is transformed into additional $q\bar{q}$ pairs, which quickly condense into colorless mesons (M) and baryons (B). These separate as jets of hadrons. (b) Three jets of hadrons produced by a quark, an antiquark, and a gluon. This figure is from the JADE detector at the German laboratory DESY in Hamburg. (*Adapted from Gordon Kane,* The Particle Garden, *Figure 6.2, p. 100*)


p
n
π^-
n
p
Time

(a)


p
n
d u u
d d u
$u\bar{u}$
annihilation
d
g
g
$\bar{u}$
$u\bar{u}$
pair
production
Time
d u d
n
u d u
p

(b)

La interaccion debil no es simetrica bajo conjugacion de carga o reflexion especular

$$K^0 \longrightarrow \pi^- + e^+ + \nu_e$$

occurs much more frequently than

$$K^0 \longrightarrow \pi^+ + e^- + \bar{\nu}_e$$

In 1979 Sheldon Glashow, Abdus Salam, and Steven Weinberg won a Nobel prize for developing a theory that unifies the electromagnetic and weak interactions. This **electroweak theory** postulates that *the weak and electromagnetic interactions have the same strength at very high particle energies*. Thus the two interactions are viewed as two different manifestations of a single, unifying electroweak interaction.

The combination of the electroweak theory and QCD for the strong interaction is called **the Standard Model** in high-energy physics. It includes almost all the constituents of matter—six leptons, six quarks, and three forces and their field particles—but not the gravitational force at this time.

15.12 BEYOND THE STANDARD MODEL

Grand Unification Theory and Supersymmetry

Following the success of the electroweak theory, scientists attempted to combine it with QCD in a **grand unification theory,** or **GUT.** In this model, the next step is taken of merging the electroweak force with the strong color force to form a grand unified force. GUT considers leptons and quarks to be specific states of a single particle called a *leptoquark* and it is this identity that leads to the same number of flavors for leptons and quarks. Also, because leptons and quarks are states of the same particle, GUT predicts that quarks and leptons should be able to change into each other given sufficient time. Thus GUT predicts that quark-filled protons are unstable and will decay with a lifetime of about 10^{32} years to a positron, which is a lepton, and other nonbaryons. Attempts to detect such proton decays have so far been unsuccessful.

The search for unification has also led to another beautiful symmetry principle, **Supersymmetry (SUSY).** According to this principle the fundamental equations of nature are unchanged by the exchange of a fermion for a boson in these equations. SUSY suggests that every elementary particle has a **superpartner,** called a **sparticle,** although no sparticle has yet been observed. It is believed that supersymmetry is a broken symmetry (like the broken electroweak symmetry at low energies) and that the masses of the superpartners are too large to be produced in current accelerators. Continuing with the fun and whimsey in naming particles and their properties, superpartners are given the names *squarks* and *sleptons* (the boson superpartners of quarks and leptons) and *photinos, winos,* and *gluinos* (the fermion superpartners of the field bosons—photons, $W^{\pm}$ s, and gluons).

String Theory—A New Perspective

String theory is an effort to *unify* the four fundamental forces by modeling all particles as various vibrational modes of a single entity—an incredibly small string. The typical length of such a string is on the order of 10^{-35} m, called the **Planck length.** In string theory each quantized mode of vibration of the string corresponds to a different elementary particle in the Standard Model.

One of the complicating factors in string theory is that it requires space-time to have 10 dimensions. Despite the theoretical and conceptual difficulties in dealing with 10 dimensions, string theory holds promise *in incorporating gravity with the other forces*. Four of the 10 dimensions are visible to us—3 space dimensions and 1 time dimension—and the other 6 are said to be *compactified*. That is, the 6 dimensions are curled up so tightly that they are not visible in the macroscopic world.

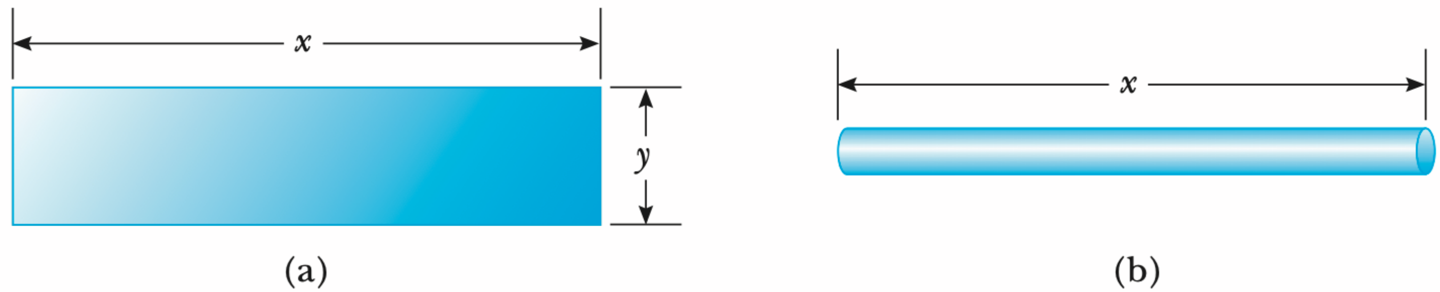
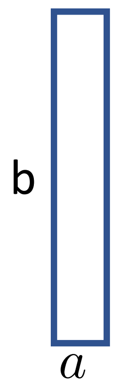


Figure 15.18 (a) A piece of paper is cut into a rectangular shape. As a rectangle, the shape has two dimensions. (b) The paper is rolled up into a soda straw. From far away, it appears to be one-dimensional. The curled-up second dimension is not visible when viewed from a distance large compared to the diameter of the straw.

Pozo infinito 2D



$$E_{n_x,n_y} = \frac{\hbar^2 \pi^2}{2m} \left(\left(\frac{n_x}{a} \right)^2 + \left(\frac{n_y}{b} \right)^2 \right)$$

Para a<<b la dimension x is indetectable