

TABLE 14.1 THE FOUR BASIC FORCES

Type	Range	Relative Strength	Characteristic Time	Typical Particles
Strong	1 fm	1	$<10^{-22}$ s	π , K, n, p
Electromagnetic	∞	10^{-2}	$10^{-14} - 10^{-20}$ s	e, μ , π , K, n, p
Weak	10^{-3} fm	10^{-7}	$10^{-8} - 10^{-13}$ s	All
Gravitational	∞	10^{-38}	Years	All

TABLE 14.2 THE FIELD PARTICLES

Force	Field Particle	Symbol	Charge (e)	Spin (\hbar)	Rest Energy (GeV)
Strong	Gluon	g	0	1	0
Electromagnetic	Photon	γ	0	1	0
Weak	Weak boson	W^+ , W^-	± 1	1	80.2
	Weak boson	Z^0	0	1	91.2
Gravitation	Graviton		0	2	0

TABLE 14.3 FAMILIES OF PARTICLES

Family	Structure	Interactions	Spin	Examples
Leptons	Fundamental	Weak, electromagnetic	Half integral	e, ν
Mesons	Composite	Weak, electromagnetic, strong	Integral	π , K
Baryons	Composite	Weak, electromagnetic, strong	Half integral	p, n
Field quanta	Fundamental	Weak, electromagnetic, strong	Integral	γ , W, Z

TABLE 14.4 THE LEPTON FAMILY

Particle	Antiparticle	Particle Charge (e)	Spin (\hbar)	Rest Energy (MeV)	Mean Life (s)	Typical Decay Products
e^-	e^+	-1	$\frac{1}{2}$	0.511	∞	—
ν_e	$\bar{\nu}_e$	0	$\frac{1}{2}$	<10 eV	∞	—
μ^-	μ^+	-1	$\frac{1}{2}$	105.7	2.2×10^{-6}	$e^- + \bar{\nu}_e + \nu_\mu$
ν_μ	$\bar{\nu}_\mu$	0	$\frac{1}{2}$	<0.3	∞	—
τ^-	τ^+	-1	$\frac{1}{2}$	1777	3.0×10^{-13}	$\mu^- + \bar{\nu}_\mu + \nu_\tau$
ν_τ	$\bar{\nu}_\tau$	0	$\frac{1}{2}$	<40	∞	—

TABLE 14.5 SOME SELECTED MESONS

Particle	Antiparticle	Charge ^a (e)	Spin (\hbar)	Strangeness ^a	Rest Energy (MeV)	Mean Life (s)	Typical Decay Products
π^+	π^-	+1	0	0	140	2.6×10^{-8}	$\mu^+ + \nu_\mu$
π^0	π^0	0	0	0	135	8.4×10^{-17}	$\gamma + \gamma$
K^+	K^-	+1	0	+1	494	1.2×10^{-8}	$\mu^+ + \nu_\mu$
K^0	\bar{K}^0	0	0	+1	498	0.9×10^{-10}	$\pi^+ + \pi^-$
η	η	0	0	0	547	8.0×10^{-19}	$\gamma + \gamma$
ρ^+	ρ^-	+1	1	0	769	4.5×10^{-24}	$\pi^+ + \pi^0$
η'	η'	0	0	0	958	2.2×10^{-21}	$\eta + \pi^+ + \pi^-$
D^+	D^-	+1	0	0	1869	1.1×10^{-12}	$K^- + \pi^+ + \pi^+$
ψ	ψ	0	1	0	3097	1.0×10^{-20}	$e^+ + e^-$
B^+	B^-	+1	0	0	5278	1.5×10^{-12}	$D^- + \pi^+ + \pi^+$
Y	Y	0	1	0	9460	1.3×10^{-20}	$e^+ + e^-$

^a The charge and strangeness are those of the particle. Values for the antiparticle have the opposite sign. The spin, rest energy, and mean life are the same for a particle and its antiparticle.

TABLE 14.6 SOME SELECTED BARYONS

Particle	Antiparticle	Charge ^a (e)	Spin (\hbar)	Strangeness ^a	Rest Energy (MeV)	Mean Life (s)	Typical Decay Products
p	\bar{p}	+1	$\frac{1}{2}$	0	938	∞	
n	\bar{n}	0	$\frac{1}{2}$	0	940	889	$p + e^- + \bar{\nu}_e$
Λ^0	$\bar{\Lambda}^0$	0	$\frac{1}{2}$	-1	1116	2.6×10^{-10}	$p + \pi^-$
Σ^+	$\bar{\Sigma}^+$	+1	$\frac{1}{2}$	-1	1189	0.8×10^{-10}	$p + \pi^0$
Σ^0	$\bar{\Sigma}^0$	0	$\frac{1}{2}$	-1	1192	7.4×10^{-20}	$\Lambda^0 + \gamma$
Σ^-	$\bar{\Sigma}^-$	-1	$\frac{1}{2}$	-1	1197	1.5×10^{-10}	$n + \pi^-$
Ξ^0	$\bar{\Xi}^0$	0	$\frac{1}{2}$	-2	1315	2.9×10^{-10}	$\Lambda^0 + \pi^0$
Ξ^-	$\bar{\Xi}^-$	-1	$\frac{1}{2}$	-2	1321	1.6×10^{-10}	$\Lambda^0 + \pi^-$
Δ^*	$\bar{\Delta}^*$	+2, +1, 0, -1	$\frac{3}{2}$	0	1232	6×10^{-24}	$p + \pi$
Σ^*	$\bar{\Sigma}^*$	+1, 0, -1	$\frac{3}{2}$	-1	1385	2×10^{-23}	$\Lambda^0 + \pi$
Ξ^*	$\bar{\Xi}^*$	-1, 0	$\frac{3}{2}$	-2	1530	6×10^{-23}	$\Xi + \pi$
Ω^-	$\bar{\Omega}^-$	-1	$\frac{3}{2}$	-3	1672	8.2×10^{-11}	$\Lambda^0 + K^-$

^aThe charge and strangeness are those of the particle. Values for the antiparticle have the opposite sign. The spin, rest energy, and mean life are the same for a particle and its antiparticle.

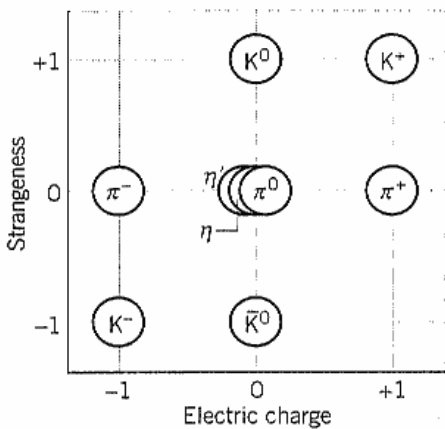


FIGURE 14.10 The relationship between electric charge and strangeness for the spin-0 mesons.

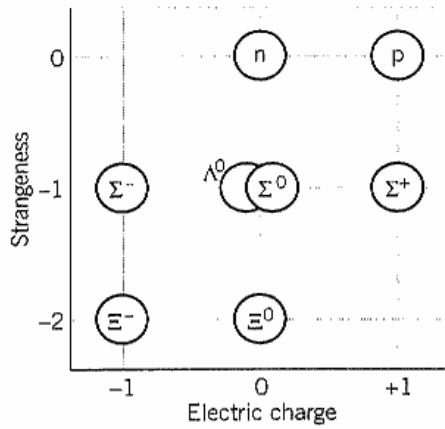


FIGURE 14.11 The relationship between electric charge and strangeness for the spin- $\frac{1}{2}$ baryons.

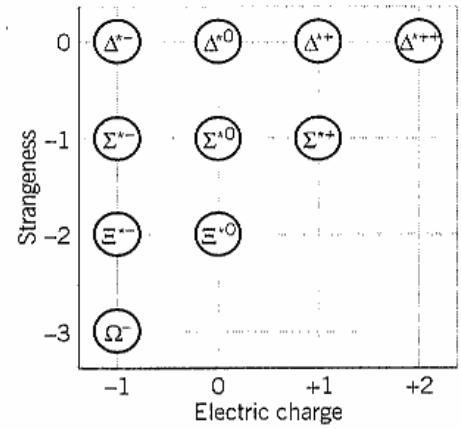


FIGURE 14.12 The relationship between electric charge and strangeness for the spin- $\frac{3}{2}$ baryons.

TABLE 14.7 PROPERTIES OF THE THREE ORIGINAL QUARKS

Name	Symbol	Charge (e)	Spin (\hbar)	Baryon Number	Strangeness	Antiquark
Up	u	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	0	\bar{u}
Down	d	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	0	\bar{d}
Strange	s	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	-1	\bar{s}

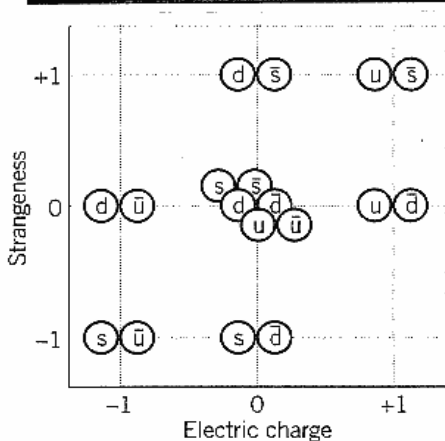


FIGURE 14.13 Spin-0 quark-antiquark combinations; compare with Figure 14.10.

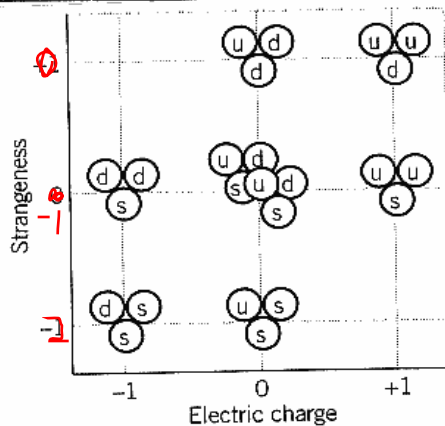


FIGURE 14.14 Spin- $\frac{1}{2}$ three-quark combinations; compare with Figure 14.11.

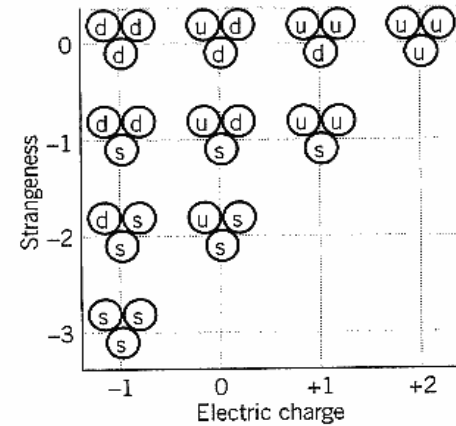


FIGURE 14.15 Spin- $\frac{3}{2}$ three-quark combinations; compare with Figure 14.12.

TABLE 14.10 PROPERTIES OF THE QUARKS

Type	Symbol	Antiparticle	Charge (e)	Spin (\hbar)	Baryon Number	Rest Energy ^a (MeV)	Properties			
							C	S	T	B
Up	u	\bar{u}	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	300	0	0	0	0
Down	d	\bar{d}	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	300	0	0	0	0
Charm	c	\bar{c}	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	1500	+1	0	0	0
Strange	s	\bar{s}	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	500	0	-1	0	0
Top	t	\bar{t}	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	180,000	0	0	+1	0
Bottom	b	\bar{b}	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	4700	0	0	0	-1

^a The rest energies are those of constituent quarks, which are bound in particles. The rest energies of free quarks are unknown.

TABLE 14.8 POSSIBLE QUARK-ANTIQUARK COMBINATIONS

Combination	Charge (e)	Spin (\hbar)	Baryon Number	Strangeness
$u\bar{u}$	0	0, 1	0	0
$u\bar{d}$	+1	0, 1	0	0
$u\bar{s}$	+1	0, 1	0	+1
$d\bar{u}$	-1	0, 1	0	0
$d\bar{d}$	0	0, 1	0	0
$d\bar{s}$	0	0, 1	0	+1
$s\bar{u}$	-1	0, 1	0	-1
$s\bar{d}$	0	0, 1	0	-1
$s\bar{s}$	0	0, 1	0	0

TABLE 14.9 POSSIBLE THREE-QUARK COMBINATIONS

Combination	Charge (e)	Spin (\hbar)	Baryon Number	Strangeness
uuu	+2	$\frac{3}{2}$	+1	0
uud	+1	$\frac{1}{2}, \frac{3}{2}$	+1	0
udd	0	$\frac{1}{2}, \frac{3}{2}$	+1	0
uus	+1	$\frac{1}{2}, \frac{3}{2}$	+1	-1
uss	0	$\frac{1}{2}, \frac{3}{2}$	+1	-2
uds	0	$\frac{1}{2}, \frac{3}{2}$	+1	-1
ddd	-1	$\frac{3}{2}$	+1	0
dds	-1	$\frac{1}{2}, \frac{3}{2}$	+1	-1
dss	-1	$\frac{1}{2}, \frac{3}{2}$	+1	-2
sss	-1	$\frac{3}{2}$	+1	-3

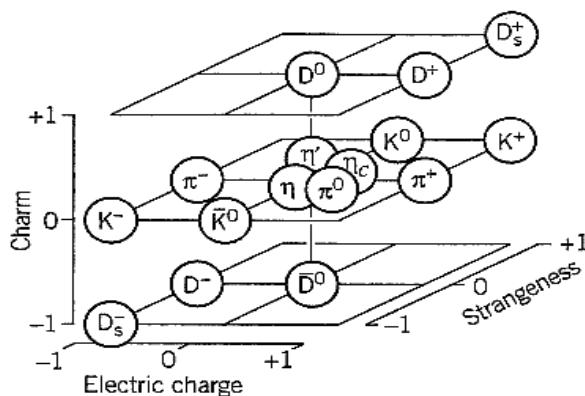


FIGURE 14.16 The relationship between electric charge, strangeness, and charm for the spin-0 mesons.