32–6 Particle Classification

In the decades following the discovery of the π meson in the late 1940s, hundreds of other subnuclear particles were discovered. One way of arranging the particles in categories is according to their interactions, since not all particles interact by means of all four of the forces known in nature (though all interact via gravity). Table 32–2 lists some of the more common particles classified in this way along with many of their properties. The particles listed are those that are stable, and many that are unstable. At the top of the Table are the **gauge bosons** (so-named after the theory that describes them, "gauge theory"), which include the gluons, the photon, and the W and Z particles; these are the particles that mediate the strong, electromagnetic, and weak interactions, respectively.

Gauge bosons

Next in Table 32–2 are the **leptons**, which are particles that do not interact via the strong force but do interact via the weak nuclear force. Leptons that carry electric charge also interact via the electromagnetic force. The leptons include the electron, the muon, and the tau, and three types of neutrino: the electron neutrino (ν_e), the muon neutrino (ν_μ), and the tau neutrino (ν_τ). Each has an antiparticle.

Leptons

The third category of particle in Table 32–2 is the **hadron**. Hadrons are those particles that interact via the strong nuclear force. Hence they are said to be **strongly interacting particles**. They also interact via the other forces, but the strong force predominates at short distances. The hadrons include the proton, neutron, pion, and a large number of other particles. They are divided into two subgroups: **baryons**, which are those particles that have baryon number $+1$ (or -1 in the case of their antiparticles); and **mesons**, which have baryon number $= 0$.

Hadrons

Baryons
Mesons

TABLE 32–2 Particles (stable under strong decay)[†]

Category	Forces involved	Particle name	Symbol	Anti-particle	Spin	Rest Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime (s)	Principal Decay Modes
							[antiparticles have opposite sign]			
Gauge bosons (force carriers)	g	Gluons	g	Self	1	0	0	0	0	0	0	Stable	
	em	Photon	γ	Self	1	0	0	0	0	0	0	Stable	
	w, em	W	W^+	W^-	1	80.41×10^3	0	0	0	0	0	3×10^{-25}	$e\nu_e, \mu\nu_\mu, \tau\nu_\tau$, hadrons
	w	Z	Z^0	Self	1	91.19×10^3	0	0	0	0	0	3×10^{-25}	$e^+e^-, \mu^+\mu^-, \tau^+\tau^-$, hadrons
Leptons	w, em[‡]	Electron	e^-	e^+	$\frac{1}{2}$	0.511	0	+1	0	0	0	Stable	
		Neutrino (e)	ν_e	$\bar{\nu}_e$	$\frac{1}{2}$	0 (<0.6 eV)[‡]	0	+1	0	0	0	Stable	
		Muon	μ^-	μ^+	$\frac{1}{2}$	105.7	0	0	+1	0	0	2.20×10^{-6}	$e^-\bar{\nu}_e\nu_\mu$
		Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	$\frac{1}{2}$	0 (<0.6 eV)[‡]	0	0	+1	0	0	Stable	
		Tau	τ^-	τ^+	$\frac{1}{2}$	1777	0	0	0	+1	0	2.91×10^{-13}	$\mu^-\bar{\nu}_\mu\nu_\tau, e^-\bar{\nu}_e\nu_\tau$, hadrons $+\nu_\tau$
		Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	$\frac{1}{2}$	0 (<0.6 eV)[‡]	0	0	0	+1	0	Stable	
Hadrons (selected)													
Mesons	s, em, w	Pion	π^+	π^-	0	139.6	0	0	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
			π^0	Self	0	135.0	0	0	0	0	0	0.84×10^{-16}	2γ
		Kaon	K^+	K^-	0	493.7	0	0	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu, \pi^+\pi^0$
			K_S^0	$\bar{K}_S^0$	0	497.7	0	0	0	0	+1	0.89×10^{-10}	$\pi^+\pi^-, 2\pi^0$
			K_L^0	$\bar{K}_L^0$	0	497.7	0	0	0	0	+1	5.17×10^{-8}	$\pi^\pm e^\mp \overset{(-)}{\nu_e}, \pi^\pm \mu^\mp \overset{(-)}{\nu_\mu}, 3\pi$
		Eta	η^0	Self	0	547.3	0	0	0	0	0	5×10^{-19}	$2\gamma, 3\pi^0, \pi^+\pi^-\pi^0$
		and others											
Baryons	s, em, w	Proton	p	$\bar{p}$	$\frac{1}{2}$	938.3	+1	0	0	0	0	Stable	
		Neutron	n	$\bar{n}$	$\frac{1}{2}$	939.6	+1	0	0	0	0	887	$pe^-\bar{\nu}_e$
		Lambda	Λ^0	$\bar{\Lambda}^0$	$\frac{1}{2}$	1115.7	+1	0	0	0	-1	2.63×10^{-10}	$p\pi^-, n\pi^0$
		Sigma	Σ^+	$\bar{\Sigma}^-$	$\frac{1}{2}$	1189.4	+1	0	0	0	-1	0.80×10^{-10}	$p\pi^0, n\pi^+$
			Σ^0	$\bar{\Sigma}^0$	$\frac{1}{2}$	1192.6	+1	0	0	0	-1	7.4×10^{-20}	$\Lambda^0\gamma$
			Σ^-	$\bar{\Sigma}^+$	$\frac{1}{2}$	1197.4	+1	0	0	0	-1	1.48×10^{-10}	$n\pi^-$
		Xi	Ξ^0	$\bar{\Xi}^0$	$\frac{1}{2}$	1314.9	+1	0	0	0	-2	2.90×10^{-10}	$\Lambda^0\pi^0$
			Ξ^-	$\bar{\Xi}^+$	$\frac{1}{2}$	1321.3	+1	0	0	0	-2	1.64×10^{-10}	$\Lambda^0\pi^-$
		Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5	+1	0	0	0	-3	0.82×10^{-10}	$\Xi^0\pi^-, \Lambda^0K^-, \Xi^-\pi^0$
		and others											

[†] See also Table 32–4 for particles with charm and bottomness.

[‡] Neutrinos partake only in the weak interaction. Experimental upper limits on neutrino masses are given in parentheses, as obtained from the WMAP survey (Chapter 33). Detection of neutrinos being transformed into one another suggests that at least one of the neutrinos has a nonzero mass greater than 0.05 eV.