

TABLE 32-4 Partial List of Heavy Hadrons, with Charm and Bottomness ($L_e = L_\mu = L_\tau = 0$)

Category	Particle	Anti-particle	Spin	Rest Mass (MeV/c ²)	Baryon			Lifetime (s)	Principal Decay Modes	
					Number B	Strangeness S	Charm c			
Mesons	D^+	D^-	0	1869.4	0	0	+1	0	10.6×10^{-13}	K + others, e + others
	D^0	\bar{D}^0	0	1864.6	0	0	+1	0	4.2×10^{-13}	K + others, μ or e + others
	D_s^+	D_s^-	0	1969	0	+1	+1	0	4.7×10^{-13}	K + others
	J/ψ (3097)	Self	1	3096.9	0	0	0	0	0.8×10^{-20}	Hadrons, e^+e^- , $\mu^+\mu^-$
	Υ (9460)	Self	1	9460.4	0	0	0	0	1.3×10^{-20}	Hadrons, $\mu^+\mu^-$, e^+e^- , $\tau^+\tau^-$
	B^-	B^+	0	5279	0	0	0	-1	1.5×10^{-12}	D^0 + others
	B^0	\bar{B}^0	0	5279	0	0	0	-1	1.5×10^{-12}	D^0 + others
Baryons	Λ_c^+	Λ_c^-	$\frac{1}{2}$	2285	+1	0	+1	0	2.0×10^{-13}	Hadrons (e.g., Λ + others)
	Σ_c^{++}	Σ_c^{--}	$\frac{1}{2}$	2453	+1	0	+1	0	?	$\Lambda_c^+ \pi^+$
	Σ_c^+	Σ_c^-	$\frac{1}{2}$	2454	+1	0	+1	0	?	$\Lambda_c^+ \pi^0$
	Σ_c^0	Σ_c^0	$\frac{1}{2}$	2452	+1	0	+1	0	?	$\Lambda_c^+ \pi^-$
	Λ_b^0	$\bar{\Lambda}_b^0$	$\frac{1}{2}$	5640	+1	0	0	-1	1.1×10^{-12}	$J/\psi \Lambda^0$, $pD^0 \pi^-$, $\Lambda_c^+ \pi^+ \pi^- \pi^-$

Today, the truly elementary particles are considered to be the six quarks, the six leptons, and the gauge bosons that carry the fundamental forces. See Table 32-5, where the quarks and leptons are arranged in three “generations.” Ordinary matter—atoms made of protons, neutrons, and electrons—is contained in the “first generation.” The others are thought to have existed in the very early universe, but are seen by us today only at powerful accelerators or in cosmic rays. All of the hundreds of hadrons can be accounted for by combinations of the six quarks and six antiquarks.

The elementary particles are quarks, leptons, gauge bosons

TABLE 32-5 The Elementary Particles[†] as Seen Today

Gauge bosons	Force	First generation	Second generation	Third generation
Gluons	Strong	Quarks	u, d	s, c
W^\pm, Z_0	Weak	Leptons	e, ν_e	μ, ν_μ
γ (photon)	EM			τ, ν_τ

[†]Note that the quarks and leptons are arranged into three generations each.

CONCEPTUAL EXAMPLE 32-7 Quark combinations. Find the baryon number, charge, and strangeness for the following quark combinations, and identify the hadron particle that is made up of these quark combinations: (a) udd, (b) $u\bar{u}$, (c) uss , (d) sdd , and (e) $b\bar{u}$.

RESPONSE We use Table 32-3 to get the properties of the quarks, then Table 32-2 or 32-4 to find the particle that has these properties.

(a) udd has

$$Q = +\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e = 0,$$

$$B = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1,$$

$$S = 0 + 0 + 0 = 0,$$

as well as $c = 0$, bottomness = 0, topness = 0. The only baryon ($B = +1$) that has $Q = 0$, $S = 0$, etc., is the neutron (Table 32-2).

(b) $u\bar{u}$ has $Q = \frac{2}{3}e - \frac{2}{3}e = 0$, $B = 0$, and all other quantum numbers = 0. Sounds like a π^0 ($d\bar{d}$ also gives a π^0 , and we say a π^0 is $u\bar{u} + d\bar{d}$).

(c) uss has $Q = 0$, $B = +1$, $S = -2$, others = 0. This is a Ξ^0 .

(d) sdd has $Q = -1$, $B = +1$, $S = -1$, so must be a Σ^- .

(e) $b\bar{u}$ has $Q = -1$, $B = 0$, $S = 0$, $c = 0$, bottomness = -1, topness = 0. This must be a B^- meson (Table 32-4).

EXERCISE B What is the quark composition of a K^- meson?