Formulas and Constants

Particle Data

Mass in MeV/c^2, lifetime in seconds, charge in units of the proton charge.

Leptons (spin 1/2)

Generation	Flavor	Charge	Mass*	Lifetime	Principal Decays
first	e (electron)	-1	0.510999	∞	–
	ν_e (e neutrino)	0	0	∞	–
second	μ (muon)	-1	105.659	2.19703×10^{-6}	$e\nu_\mu\overline{\nu}_e$
	ν_μ (μ neutrino)	0	0	∞	–
third	τ (tau)	-1	1776.99	2.91×10^{-13}	$e\nu_\tau\overline{\nu}_e$, $\mu\nu_\tau\overline{\nu}_\mu$, $\pi^-\nu_\tau$
	ν_τ (τ neutrino)	0	0	∞	–

*Neutrino masses are extremely small, and for most purposes can be taken to be zero; for details see Chapter 11.

Quarks (spin 1/2)

Generation	Flavor	Charge	Mass*
first	d (down)	$-1/3$	7
	u (up)	2/3	3
second	s (strange)	$-1/3$	120
	c (charm)	2/3	1200
third	b (bottom)	$-1/3$	4300
	t (top)	2/3	174000

*Light quark masses are imprecise and speculative; for effective masses in mesons and baryons, see Chapter 5.

Mediators (spin 1)

Force	Mediator	Charge	Mass*	Lifetime	Principal Decays
Strong	g (8 gluons)	0	0	∞	–
Electromagnetic	γ (photon)	0	0	∞	–
Weak	$W^\pm$ (charged)	±1	80,420	3.11×10^{-25}	$e^+\nu_e$, $\mu^+\nu_\mu$, $\tau^+\nu_\tau$, $cX \rightarrow$ hadrons
	Z^0 (neutral)	0	91,190	2.64×10^{-25}	e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $q\overline{q} \rightarrow$ hadrons

Baryons (spin 1/2)

Baryon	Quark Content	Charge	Mass	Lifetime	Principal Decays
$N\begin{cases}p\\n\end{cases}$	uud udd	1 0	938.272 939.565	∞ 885.7	– $pe\bar{\nu}_e$
Λ	uds	0	1115.68	2.63×10^{-10}	$p\pi^-, n\pi^0$
Σ^+	uus	1	1189.37	8.02×10^{-11}	$p\pi^0, n\pi^+$
Σ^0	uds	0	1192.64	7.4×10^{-20}	$\Lambda\gamma$
Σ^-	dds	−1	1197.45	1.48×10^{-10}	$n\pi^-$
Ξ^0	uss	0	1314.8	2.90×10^{-10}	$\Lambda\pi^0$
Ξ^-	dss	−1	1321.3	1.64×10^{-10}	$\Lambda\pi^-$
Λ_c^+	udc	1	2286.5	2.00×10^{-13}	$pK\pi$, $\Lambda\pi\pi$, $\Sigma\pi\pi$

Baryons (spin 3/2)

Baryon	Quark Content	Charge	Mass	Lifetime	Principal Decays
Δ	uuu, uud, udd, ddd	2,1,0,−1	1232	5.6×10^{-24}	$N\pi$
Σ^*	uus, uds, dds	1,0,−1	1385	1.8×10^{-23}	$\Lambda\pi$, $\Sigma\pi$
Ξ^*	uss, dss	0,−1	1533	6.9×10^{-23}	$\Xi\pi$
Ω^-	sss	−1	1672	8.2×10^{-11}	ΛK^-, $\Xi\pi$

Pseudoscalar Mesons (spin 0)

Meson	Quark Content	Charge	Mass	Lifetime	Principal Decays
$\pi^\pm$	$u\bar{d}$, $d\bar{u}$	1,−1	139.570	2.60×10^{-8}	$\mu\nu_\mu$
π^0	$(u\bar{u}-d\bar{d})/\sqrt{2}$	0	134.977	8.4×10^{-17}	$\gamma\gamma$
$K^\pm$	$u\bar{s}$, $s\bar{u}$	1,−1	493.68	1.24×10^{-8}	$\mu\nu_\mu$, $\pi\pi$, $\pi\pi\pi$
$K^0, \overline{K}^0$	$d\bar{s}$, $s\bar{d}$	0	497.65	$\begin{cases}K_S^0: 8.95\times10^{-11}\\K_L^0: 5.11\times10^{-8}\end{cases}$	$\pi\pi$ $\pi e\nu_e$, $\pi\mu\nu_\mu$, $\pi\pi\pi$
η	$(u\bar{u}+d\bar{d}-2s\bar{s})/\sqrt{6}$	0	547.51	5.1×10^{-19}	$\gamma\gamma$, $\pi\pi\pi$
η'	$(u\bar{u}+d\bar{d}+s\bar{s})/\sqrt{3}$	0	957.78	3.2×10^{-21}	$\eta\pi\pi$, $\rho\gamma$
$D^\pm$	$c\bar{d}$, $d\bar{c}$	1,−1	1869.3	1.04×10^{-12}	$K\pi\pi$, $K\mu\nu_\mu$, $Ke\nu_e$
$D^0, \overline{D}^0$	$c\bar{u}$, $u\bar{c}$	0	1864.5	4.1×10^{-13}	$K\pi\pi$, $Ke\nu_e$, $K\mu\nu_\mu$
$D_s^\pm$	$c\bar{s}$, $s\bar{c}$	1,−1	1968.2	5.0×10^{-13}	$\eta\rho$, $\phi\pi\pi$, $\phi\rho$
$B^\pm$	$u\bar{b}$, $b\bar{u}$	1,−1	5279.0	1.6×10^{-12}	$D^*\ell\nu_\ell$, $D\ell\nu_\ell$, $D^*\pi\pi\pi$
$B^0, \overline{B}^0$	$d\bar{b}$, $b\bar{d}$	0	5279.4	1.5×10^{-12}	$D^*\ell\nu_\ell$, $D\ell\nu_\ell$, $D^*\pi\pi$

Vector Mesons (spin 1)

Meson	Quark Content	Charge	Mass	Lifetime	Principal Decays
ρ	$u\bar{d}$, $(u\bar{u}-d\bar{d})/\sqrt{2}$, $d\bar{u}$	1,0,-1	775.5	4×10^{-24}	$\pi\pi$
K^*	$u\bar{s}$, $d\bar{s}$, $s\bar{d}$, $s\bar{u}$	1,0,-1	894	1×10^{-23}	$K\pi$
ω	$(u\bar{u}+d\bar{d})/\sqrt{2}$	0	782.6	8×10^{-23}	$\pi\pi\pi$, $\pi\gamma$
ψ	$c\bar{c}$	0	3097	7×10^{-21}	e^+e^-, $\mu^+\mu^-$, 5π, 7π
D^*	$c\bar{d}$, $c\bar{u}$, $u\bar{c}$, $d\bar{c}$	1,0,-1	2008	3×10^{-21}	$D\pi$, $D\gamma$
Υ	$b\bar{b}$	0	9460	1×10^{-20}	e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$

Spin 1/2

Pauli Matrices:

$$\sigma_x \equiv \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_y \equiv \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_z \equiv \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\sigma_i \sigma_j = \delta_{ij} + i\epsilon_{ijk}\sigma_k, \quad (\mathbf{a}\cdot\boldsymbol{\sigma})(\mathbf{b}\cdot\boldsymbol{\sigma}) = \mathbf{a}\cdot\mathbf{b} + i\boldsymbol{\sigma}\cdot(\mathbf{a}\times\mathbf{b})$$

$$\sigma_i^\dagger = \sigma_i = \sigma_i^{-1}, \qquad e^{i\boldsymbol{\theta}\cdot\boldsymbol{\sigma}} = \cos\theta + i(\hat{\theta}\cdot\boldsymbol{\sigma})\sin\theta$$

Dirac Matrices:

$$\gamma^0 \equiv \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad \sigma^i \equiv \begin{pmatrix} 0 & \sigma_i \\ -\sigma_i & 0 \end{pmatrix}, \quad \gamma^{0\dagger} = \gamma^0, \quad \gamma^{i\dagger} = -\gamma^i, \quad \gamma^0\gamma^{\mu\dagger}\gamma^0 = \gamma^\mu$$

$$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}, \quad g^{\mu\nu} = g_{\mu\nu} = \begin{Bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{Bmatrix}$$

$$\gamma^5 \equiv i\gamma^0\gamma^1\gamma^2\gamma^3 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \qquad \{\gamma^\mu, \gamma^5\} = 0, \quad (\gamma^5)^2 = 1$$

(For product rules and trace theorems see Appendix C.)

Dirac Equation:

$$i\hbar\gamma^\mu \partial_\mu \psi - mc\,\psi = 0$$

$$(\not{p} - mc)u = 0, \quad (\not{p} + mc)v = 0, \quad \overline{u}(\not{p} - mc) = 0, \quad \overline{v}(\not{p} + mc) = 0$$

$$\overline{\psi} \equiv \psi^\dagger\gamma^0, \quad \overline{\Gamma} \equiv \gamma^0\Gamma^\dagger\gamma^0, \quad \not{a} \equiv a_\mu\gamma^\mu$$

Feynman Rules

	External Lines		Propagators
Spin 0:	Nothing		$\dfrac{i}{q^2 - (mc)^2}$
Spin 1/2:	Incoming particle:	u	$\dfrac{i(\not{q} + mc)}{q^2 - (mc)^2}$
	Incoming antiparticle:	$\overline{v}$	
	Outgoing particle:	$\overline{u}$	
	Outgoing antiparticle:	v	

$$\text{Spin 1:} \quad \begin{cases} \text{Incoming:} & \epsilon_\mu \\ \text{Outgoing:} & \epsilon_\mu^* \end{cases} \qquad \begin{cases} \text{Massless:} & \dfrac{-ig_{\mu\nu}}{q^2} \\ \text{Massive:} & \dfrac{-i[g_{\mu\nu} - q_\mu q_\nu/(mc)^2]}{q^2 - (mc)^2} \end{cases}$$

(For vertex factors see Appendix D.)

Fundamental Constants

Planck's constant:	$\hbar$	=	1.05457×10^{-34} J s
		=	6.58212×10^{-22} MeV s
Speed of light:	c	=	2.99792×10^{8} m/s
Mass of electron:	m_e	=	9.10938×10^{-31}kg $= 0.510999$ MeV/c^2
Mass of proton:	m_p	=	1.67262×10^{-27}kg $= 938.272$ MeV/c^2
Electron charge (magnitude):	e	=	1.60218×10^{-19} C
		=	4.80320×10^{-10} esu
Fine structure constant:	α	=	$e^2/\hbar c = 1/137.036$
Bohr radius:	a	=	$\hbar^2/m_e e^2 = 5.29177 \times 10^{-11}$ m
Bohr energies:	E_n	=	$-m_e e^4/2\hbar^2 n^2 = -13.6057/n^2$ eV
Classical electron radius:	r_e	=	$e^2/m_e c^2 = 2.81794 \times 10^{-15}$ m
QED coupling constant:	g_e	=	$e\sqrt{4\pi/\hbar c} = 0.302822$
Weak coupling constants:	g_w	=	$g_e/\sin\theta_w = 0.6295$;
	g_z	=	$g_w/\cos\theta_w = 0.7180$
Weak mixing angle:	θ_w	=	28.76° $(\sin^2\theta_w = 0.2314)$
Strong coupling constant:	g_s	=	1.214

Conversion Factors

1 Å	=	0.1 nm $= 10^{-10}$ m
1 fm	=	10^{-15} m
1 barn	=	10^{-28} m^2
1 eV	=	1.60218×10^{-19} J
1 MeV/c^2	=	1.78266×10^{-30} kg
1 Coulomb	=	2.99792×10^{-9} esu