

APPENDIX A: PHYSICAL CONSTANTS

Summary of the physical constants and conversion factors used in this course:

Electron charge, $e = 1.602 \times 10^{-19}$ C

$\hbar c = 0.197$ GeV fm

$\hbar = 6.58 \times 10^{-25}$ GeV s

Fine structure constant, $\alpha = 1/137.04$

Bohr magneton, $\mu_B = 9.3 \times 10^{-24}$ JT⁻¹

Nuclear magneton, $\mu_N = 5.1 \times 10^{-27}$ JT⁻¹

1 eV = 1.602×10^{-19} J, 1 MeV = 10^6 eV, 1 GeV = 10^9 eV

1 fermi(fm) = 10^{-15} m

1 barn(b) = 10^{-28} m²

1 Curie(Ci) = 3.7×10^{10} decays s⁻¹

Atomic masses are often given in unified (or atomic) mass units:

1 unified mass unit(u) = Mass of an atom of ${}^1_6\text{C}/12$

1u = $1\text{g}/N_A = 1.66 \times 10^{-27}$ kg = 931.5 MeV/ c^2

APPENDIX B: PARTICLE PROPERTIES

From the *Review of Particle Physics*, C. Amsler *et al.*, Phys. Lett. **B667** 1 (2008)
<http://pdg.lbl.gov/>

Quarks (spin 1/2)			
Name	Flavour	Mass (GeV/ c^2)	Charge (e)
up	u	≈ 0.35	+2/3
down	d	$m_d \approx m_u$	-1/3
charm	c	1.5	+2/3
strange	s	0.5	-1/3
top	t	171.2(2.1)	+2/3
bottom	b	4.5	-1/3

Leptons (spin 1/2)					
Lepton	Charge	Mass (MeV/ c^2)	Mean life (s)	Lepton Decay Mode	Branching Fraction (%)
ν_e	0	$< 2 \text{ eV}/c^2$	stable		
ν_μ	0	< 0.19	stable		
ν_τ	0	< 18.2	stable		
e	± 1	0.511 ^a	stable		
μ	± 1	105.658 ^b	2.197×10^{-6} ^c	$e^- \bar{\nu}_e \nu_\mu$	≈ 100
τ	± 1	1776.8(2)	$291(1) \times 10^{-15}$	$\mu^- \bar{\nu}_\mu \nu_\tau$	17.36(5)
				$e^- \bar{\nu}_e \nu_\tau$	17.85(5)
				hadrons $+\nu_\tau$	≈ 65

^a The error on the e mass is $1.3 \times 10^{-8} \text{ MeV}/c^2$.

^b The error on the μ mass is $4 \times 10^{-6} \text{ MeV}/c^2$.

^c The error on the μ lifetime is $2 \times 10^{-11} \text{ s}$.

N.B. Numbers given in brackets correspond to the error in the last digit(s).

For example, $m_\tau = 1776.8(2) \text{ MeV}/c^2 \equiv (1776.8 \pm 0.2) \text{ MeV}/c^2$.

Gauge Bosons ($J^P = 1^-$)						
Force	Gauge Boson	Charge (e)	Mass (GeV/c^2)	Full Width (GeV)	Decay Mode	Branching Fraction (%)
E-M	γ	$< 5 \times 10^{-30}$	$< 10^{-18} \text{ eV}/c^2$	stable		
Weak (Charged)	W^\pm	± 1	80.40(3)	2.14(4)	$e\nu_e$	10.7(2)
					$\mu\nu_\mu$	10.6(2)
					$\tau\nu_\tau$	11.2(2)
					hadrons	67.6(3)
Weak (Neutral)	Z^0	0	91.188(2)	2.495(2)	ee	3.363(4)
					$\mu\mu$	3.366(7)
					$\tau\tau$	3.370(8)
					$\nu\nu$	20.00(6)
					hadrons	69.91(6)
Strong	g	0	0	stable		

Pseudoscalar Mesons ($J^P = 0^-$)					
Particle	Quark Content	Mass (MeV/ c^2)	Mean Life (s) or Width (keV)	Decay Mode	Branching Fraction (%)
π^\pm	$u\bar{d}, d\bar{u}$	139.5702(4)	$2.6033(5) \times 10^{-8}$ s	$\mu^- \bar{\nu}_\mu$	≈ 100
π^0	$(u\bar{u} - d\bar{d})/\sqrt{2}$	134.9766(6)	$8.4(6) \times 10^{-17}$ s	$\gamma\gamma$	98.80(3)
η	see note a	547.85(2)	1.30(7) keV	$\gamma\gamma$	39.3(2)
				$\pi^0\pi^0\pi^0$	32.6(2)
				$\pi^+\pi^-\pi^0$	22.7(3)
				$\pi^+\pi^-\gamma$	4.6(2)
η'	see note a	957.7(2)	0.20(2) MeV	$\pi^+\pi^-\eta$	45(2)
				$\rho^0\gamma$	29(1)
				$\pi^0\pi^0\eta$	21(1)
K^\pm	$u\bar{s}, s\bar{u}$	493.677(16)	$1.238(2) \times 10^{-8}$ s	$\mu^- \bar{\nu}_\mu$	63.5(1)
				$\pi^-\pi^0$	20.7(1)
				$\pi^+\pi^-\pi^-$	5.59(4)
				$\pi^0\mu^-\bar{\nu}_\mu$	3.35(4)
				$\pi^0e^-\bar{\nu}_e$	5.08(5)
K^0, \bar{K}^0	$d\bar{s}, s\bar{d}$	497.61(2)	$K_S^0: 0.8953(5) \times 10^{-10}$ s	$\pi^+\pi^-$	69.2(1)
			$K_L^0: 5.12(2) \times 10^{-8}$ s	$\pi^0\pi^0$	30.7(1)
				$\pi^0\pi^0\pi^0$	19.5(1)
				$\pi^+\pi^-\pi^0$	12.5(1)
				$\pi^\pm\mu^\mp\nu_\mu$	27.0(1)
				$\pi^\pm e^\mp\nu_e$	40.5(1)
D^\pm	$cd, d\bar{c}$	1869.3(4)	$1.040(7) \times 10^{-12}$ s	$e^- + \text{any}^b$	16.0(4)
				$K^- + \text{any}$	26(1)
				$K^+ + \text{any}$	5.9(8)
				$K^0 + \text{any}$	
				plus	
				$\bar{K}^0 + \text{any}$	61(5)
D^0, \bar{D}^0	$u\bar{c}, c\bar{u}$	1864.8(2)	$0.410(2) \times 10^{-12}$ s	$K^- + \text{any}^c$	55(3)
				$K^+ + \text{any}$	3.4(4)
				$e^+ + \text{any}$	6.5(2)
				$\mu^+ + \text{any}$	6.7(6)
				$\bar{K}^0 + \text{any}$	
				plus	
				$K^0 + \text{any}$	47(4)
D_s^\pm	$c\bar{s}, s\bar{c}$	1968.5(3)	$0.500(7) \times 10^{-12}$ s	seen	
B^\pm	$u\bar{b}, b\bar{u}$	5279.1(3)	$1.64(1) \times 10^{-12}$ s	many	
B^0, \bar{B}^0	$d\bar{b}, b\bar{d}$	5279.5(3)	$1.53(1) \times 10^{-12}$ s	many	
B_s^0, \bar{B}_s^0	$s\bar{b}, b\bar{s}$	5366.3(6)	$1.47(3) \times 10^{-12}$ s	many	
B_c^\pm	$c\bar{b}, b\bar{c}$	6276(4)	$0.46(18) \times 10^{-12}$ s	many	
η_c	$c\bar{c}$	2980(1)	27(3) MeV	hadrons	

^a η and η' are linear combinations of the quark state $(u\bar{u} + d\bar{d})/\sqrt{2}$ and $s\bar{s}$ (see lectures).

^b D^- decay modes; ^c D^0 decay modes.

Vector Mesons ($J^P = 1^-$)					
Particle	Quark Content	Mass (MeV/ c^2)	Full Width (MeV)	Decay Mode	Branching Fraction (%)
ρ^\pm	$u\bar{d}, d\bar{u}$	775.5(4)	149(1)	$\pi\pi$	100
ρ^0	$(u\bar{u} - d\bar{d})/\sqrt{2}$				
ω	$(u\bar{u} + d\bar{d})/\sqrt{2}$	782.6(1)	8.49(8)	$\pi^+\pi^-\pi^0$	89.2(7)
				$\pi^0\gamma$	8.9(2)
				$\pi^+\pi^-$	1.5(1)
ϕ	$s\bar{s}$	1019.46(2)	4.26(4)	K^+K^-	49.2(6)
				$K_L^0K_S^0$	34.0(5)
$K^{*\pm}$	$u\bar{s}, s\bar{u}$	891.7(3)	50.8(9)	$K\pi$	≈ 100
K^{*0}, \bar{K}^{*0}	$d\bar{s}, s\bar{d}$	896.0(3)	50.3(6)	$K\pi$	≈ 100
$D^{*\pm}$	$cd, d\bar{c}$	2010.3(2)	0.096(22)	$D^0\pi^{-a}$	67.7(5)
				$D^-\pi^0$	30.7(5)
D^{*0}, \bar{D}^{*0}	$u\bar{c}, c\bar{u}$	2007.0(2)	< 2.1	$D^0\pi^{0b}$	62(3)
				$D^0\gamma$	38(3)
$D_s^{*\pm}$	$c\bar{s}, s\bar{c}$	2112.3(5)	< 1.9	$D_s^\pm\gamma$	94(1)
				$D_s^\pm\pi^0$	6(1)
B^*	$u\bar{b}, b\bar{u}, d\bar{b}, b\bar{d}, s\bar{b}, b\bar{s}$	5325.1(5)		$B\gamma$ dominant	
J/ψ	$c\bar{c}$	3096.92(1)	93(2) keV	hadrons	87.7(5)
				e^+e^-	5.9(1)
				$\mu^+\mu^-$	5.9(1)
$\Upsilon(1s)$	$b\bar{b}$	9460.3(3)	54(1) keV	$\tau^+\tau^-$	2.6(1)
				e^+e^-	2.4(1)
				$\mu^+\mu^-$	2.48(5)

^a D^{*-} decay modes; ^b D^{*0} decay modes.

Baryons ($J^P = 1/2^+$)					
Particle	Quark Content	Mass (MeV/ c^2)	Mean Life (s) or Full Width (MeV)	Decay Mode	Branching Fraction (%)
p	uud	938.27203(8)	$> 2.1 \times 10^{29}$ years		
n	udd	939.56536(8)	885.7(8) s	$pe^- \bar{\nu}_e$	100
Λ^0	uds	1115.683(6)	$2.63(2) \times 10^{-10}$ s	$p\pi^-$	63.9(5)
				$n\pi^0$	35.8(5)
Σ^+	uus	1189.37(7)	$0.802(3) \times 10^{-10}$ s	$p\pi^0$	51.6(3)
				$n\pi^+$	48.3(3)
Σ^0	uds	1192.64(2)	$7.4(7) \times 10^{-20}$ s	$\Lambda^0\gamma$	100
Σ^-	dds	1197.45(3)	$1.48(1) \times 10^{-10}$ s	$n\pi^-$	99.848(5)
Ξ^0	uss	1314.8(2)	$2.90(9) \times 10^{-10}$ s	$\Lambda^0\pi^0$	99.52(1)
Ξ^-	dss	1321.7(1)	$1.64(2) \times 10^{-10}$ s	$\Lambda^0\pi^-$	99.89(4)
Λ_c^+	udc	2286.5(1)	$2.00(6) \times 10^{-13}$ s	many	
Λ_b	udb	5620(2)	$1.38(5) \times 10^{-12}$ s	many	
Baryons ($J^P = 3/2^+$)					
Δ	uuu, uud udd, ddd	≈ 1232	≈ 118 MeV	$N\pi$	> 99
Σ^*	uus, uds, dds	≈ 1385	≈ 36 MeV	$\Lambda^0\pi$	87(2)
				$\Sigma\pi$	12(2)
Ξ^*	uss, dss	≈ 1533	≈ 9 MeV	$\Xi\pi$	100
Ω^-	sss	1672.5(3)	$0.82(1) \times 10^{-10}$ s	$\Lambda^0 K^-$	67.8(7)
				$\Xi^0\pi^-$	23.6(7)
				$\Xi^-\pi^0$	8.6(4)