Appendix A

Physical constants and units

A.1 High-energy physics conversion constants and units

Table A.1. *High-energy physics conversion constants and units*

Quantity	Name	Value
Speed of light	c	299 792 458 m s^{-1}
Reduced Planck constant	$\hbar \equiv h/2\pi$	$1.054\,572\,66(63) \times 10^{-34}$ J s =
		$6.582\,122\,0(20) \times 10^{-23}$ MeV s
Conversion constants	$\hbar c$	197.327 053(59) MeV fm
	$(\hbar c)^2$	0.389 379 66(23) GeV^2 mbarn
Units where $\hbar = c = 1$	Mass, energy	1 eV = $1.602\,177\,33(49) \times 10^{-19}$ J
		1 GeV = 10^3 MeV = 10^6 keV = 10^9 eV
		1 erg = 10^{-7} J
		1 eV/c^2 = $1.782\,662\,70(54) \times 10^{-36}$ kg
	Length	1 GeV^{-1} = 0.197 327 053 fm =
		$0.197\,327\ldots \times 10^{-13}$ cm
		1 in = 0.0254 m 1 Å = 0.1 nm
	Lifetime	1 GeV^{-1} = $6\,582\,122\,0 \times 10^{-25}$ s
	Decay rate	1 GeV = $(1/6\,582\,122\,0) \times 10^{25}$ s^{-1}
	Cross-section	1 GeV^{-2} = $0.389\,379\,66(23) \times 10^6$ barn
		1 barn = 10^{-28} m^2 1 nb = 10^{-9} barn
	Others	0 °C = 273.15 K 1 G = 10^{-4} T
		kT at 300 K = $[38.681\,49(33)]^{-1}$ eV
		1 atmosphere = 760 torr = 101 325 Pa
		1 dyne = 10^{-5} N

A.2 High-energy physical constants

A complete list of physical constants is given in PDG [16]. Among them, we have:

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Table A.2. *Some high-energy physical constants*

Observable	Symbol	Value
Electron mass	m_e	$0.510\,999\,06(15)$ MeV$/c^2$ $= 9.109\,389\,7(54) \times 10^{-31}$ kg
Muon mass	m_μ	$105.658357(5)$ MeV$/c^2$
Tau mass	m_τ	1777.03^{+30}_{-26}MeV$/c^2$
Proton mass	m_p	$938.272\,31(28)$ MeV$/c^2$ $= 1836.152\,701(37)\, m_e$
Electron charge	e	$1.602\,177\,33(49) \times 10^{-19}$ C $= 4.803\,206\,8(15) \times 10^{-10}$ esu
Permittivity of free space	ϵ_0	$8.854\,187\,817\ldots \times 10^{-12}$ F m^{-1}
Fine structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	$1/137.035\,999\,58(52)$ at $q^2 = m_e^2$ $1/128$ at $q^2 = M_Z^2$
Electron anomaly	$a_e \equiv \frac{1}{2}(g_e - 2)$	$115\,965\,218\,84(43) \times 10^{-13}$
Muon anomaly	$a_\mu \equiv \frac{1}{2}(g_\mu - 2)$	$116\,592\,023(151) \times 10^{-11}$
Tau anomaly	$a_\tau \equiv \frac{1}{2}(g_\tau - 2)$	$0.004 \pm 0.027 \pm 0.023$
Electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$2.817\,940\,92(38) \times 10^{-15}$ m
Bohr radius ($m_{nucleus} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e c^2$ $= r_e\alpha^{-2}$	$0.529\,177\,249(24) \times 10^{-10}$ m
Electron Compton wavelength	$\lambda_e/2\pi = \hbar/m_e c$ $= r_e/\alpha$	$3.861\,593\,23(35) \times 10^{-13}$ m
Rydberg energy	$hcR_\infty = m_e c^2\alpha^2/2$	$13.605\,698\,1(40)$ eV
Thomson cross-section	$\sigma_T = 8\pi r_e^2/3$	$0.665\,246\,16(18)$ barn
Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\,382\,63(52) \times 10^{-11}$ MeV T^{-1}
Nuclear magneton	$\mu_B = e\hbar/2m_P$	$3.152\,451\,66(28) \times 10^{-14}$ MeV T^{-1}
Electron cyclotron freq./field	$\omega^e_{cycl}/B = e/m_e$	$1.758\,819\,62(53) \times 10^{11}$ rad s^{-1} T^{-1}
Fermi coupling constant	$G_F/(\hbar c)^2$	$1.166\,39(2) \times 10^{-5}$ GeV^{-2}
Weak mixing angle	$\sin^2\theta_W(M_Z)\ \overline{MS}$	$0.2315(4)$
$W^\pm$ boson mass	M_W	$80.33(15)$ GeV$/c^2$
Z^0 boson mass	M_Z	$91.187(7)$ GeV$/c^2$
Strong coupling constant	$\alpha_s(M_Z)$	$0.118(3)$

A.3 CKM weak mixing matrix

In the electroweak standard model $SU(2)_L \times U(1)$, where both quarks and leptons left-handed doublets and right-handed singlets, the quark mixing matrix can be represented as:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \tag{A.1}$$

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where from weak decays, the mixing matrix has the value:

$$\begin{pmatrix} 0.9745-0.9757 & 0.219-0.224 & 0.002-0.005 \\ 0.218-0.224 & 0.9736-0.9750 & 0.036-0.046 \\ 0.004-0.014 & 0.034-0.046 & 0.9989-0.9993 \end{pmatrix} \tag{A.2}$$

In the Wolfenstein parametrization:

$$\begin{aligned} V_{us} &\simeq \lambda\,, & V_{ub} &\simeq \lambda^3 A(\rho - i\eta) \\ V_{cb} &\simeq \lambda^2 A\,, & V_{td} &\simeq \lambda^3 A(1-\rho-i\eta) \end{aligned} \tag{A.3}$$

A.4 Some astrophysical constants

Table A.3. *Some astrophysical constants*

Observable	Symbol	Value
Newton gravitation constant	G_N	$6\,672\,59(85) \times 10^{-11}$ m^{3}kg^{-1}s^{-2}
Astronomical unit	AU	$1.495\,978\,706\,6(2) \times 10^{11}$ m
Tropical year(equinox to equinox)	yr	31 556 925.2 s
Age of the universe	t_0	15(5) Gyr
Planck mass	$\sqrt{\hbar c/G_N}$	$1.221\,047(79) \times 10^{19}$ GeV/c^2
parsec(1AU/1 arc sec)	pc	$3.085\,677\,580\,7(4) \times 10^{16} m = 3.262\ldots$ ly
light year	ly	$0.306\,6\ldots$ pc $= 0.9461\ldots \times 10^{16}$ m
Solar mass	$M_\odot$	$1.968\,92(25) \times 10^{30}$ kg
Solar luminosity	$L_\odot$	3.846×10^{26} W
Solar equatorial radius	$R_\odot$	76.96×10^{8} m
Earth mass	$M_\oplus$	$5.973\,70(76) \times 10^{24}$ kg
Earth equatorial radius	$R_\oplus$	$6.378\,140 \times 10^{6}$ m
Hubble constant	H_0	$100\,h_0$ km s^{-1}Mpc^{-1} = $h_0 \times (9.778\,13$ Gyr$)^{-1}$
Normalized Hubble constant	h_0	$0.5 \le h_0 \le 0.85$
Critical density of the universe	$\rho_c = 3H_0^2/8\pi G_N$	$2.775\,366\,27 \times 10^{11} h_0^2 M_\odot$Mpc^{-3}
Local halo density	$\rho_{\rm halo}$	$(2-13)10^{-25}$ g cm^{-3} $\approx$ $(0.1-0.7)$ GeV/c^2 cm^{-3}
Scaled cosmological constant	$\lambda_0 = \Lambda c^2/3H_0^2$	$-1 < \lambda_0 < 2$
Scale factor for cosmological constant	$c^2/3H_0^2$	2.853×10^{51}h$_0^2$ m^2

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