1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 2013 by P.J. Mohr (NIST). Mainly from the "CODATA Recommended Values of the Fundamental Physical Constants: 2010" by P.J. Mohr, B.N. Taylor, and D.B. Newell in Rev. Mod. Phys. **84**, 1527 (2012). The last group of constants (beginning with the Fermi coupling constant) comes from the Particle Data Group. The figures in parentheses after the values give the 1-standard-deviation uncertainties in the last digits; the corresponding fractional uncertainties in parts per 10^9 (ppb) are given in the last column. This set of constants (aside from the last group) is recommended for international use by CODATA (the Committee on Data for Science and Technology). The full 2010 CODATA set of constants may be found at `http://physics.nist.gov/constants`. See also P.J. Mohr and D.B. Newell, "Resource Letter FC-1: The Physics of Fundamental Constants," Am. J. Phys. **78**, 338 (2010).

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact[*]
Planck constant	h	6.626 069 57(29)$\times10^{-34}$ J s	44
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 726(47)$\times10^{-34}$ J s	44
		= 6.582 119 28(15)$\times10^{-22}$ MeV s	22
electron charge magnitude	e	1.602 176 565(35)$\times10^{-19}$ C = 4.803 204 50(11)$\times10^{-10}$ esu	22, 22
conversion constant	$\hbar c$	197.326 9718(44) MeV fm	22
conversion constant	$(\hbar c)^2$	0.389 379 338(17) GeV^2 mbarn	44
electron mass	m_e	0.510 998 928(11) MeV/c^2 = 9.109 382 91(40)$\times10^{-31}$ kg	22, 44
proton mass	m_p	938.272 046(21) MeV/c^2 = 1.672 621 777(74)$\times10^{-27}$ kg	22, 44
		= 1.007 276 466 812(90) u = 1836.152 672 45(75) m_e	0.089, 0.41
deuteron mass	m_d	1875.612 859(41) MeV/c^2	22
unified atomic mass unit (u)	(mass ^{12}C atom)/12 = (1 g)/(N_A mol)	931.494 061(21) MeV/c^2 = 1.660 538 921(73)$\times10^{-27}$ kg	22, 44
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 817 … $\times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi\times10^{-7}$ N A^{-2} = 12.566 370 614 … $\times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 5698(24)$\times10^{-3}$ = 1/137.035 999 074(44)[†]	0.32, 0.32
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 3267(27)$\times10^{-15}$ m	0.97
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 592 6800(25)$\times10^{-13}$ m	0.65
Bohr radius ($m_{\mathrm{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 210 92(17)$\times10^{-10}$ m	0.32
wavelength of 1 eV/c particle	$hc/(1\ \mathrm{eV})$	1.239 841 930(27)$\times10^{-6}$ m	22
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 692 53(30) eV	22
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 8734(13) barn	1.9
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 8066(38)$\times10^{-11}$ MeV T^{-1}	0.65
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 2605(22)$\times10^{-14}$ MeV T^{-1}	0.71
electron cyclotron freq./field	$\omega^e_{\mathrm{cycl}}/B = e/m_e$	1.758 820 088(39)$\times10^{11}$ rad s^{-1} T^{-1}	22
proton cyclotron freq./field	$\omega^p_{\mathrm{cycl}}/B = e/m_p$	9.578 833 58(21)$\times10^{7}$ rad s^{-1} T^{-1}	22
gravitational constant[‡]	G_N	6.673 84(80)$\times10^{-11}$ m^3 kg^{-1} s^{-2}	1.2×10^5
		= 6.708 37(80)$\times10^{-39}$ $\hbar c$ $(\mathrm{GeV}/c^2)^{-2}$	1.2×10^5
standard gravitational accel.	g_N	9.806 65 m s^{-2}	exact
Avogadro constant	N_A	6.022 141 29(27)$\times10^{23}$ mol^{-1}	44
Boltzmann constant	k	1.380 6488(13)$\times10^{-23}$ J K^{-1}	910
		= 8.617 3324(78)$\times10^{-5}$ eV K^{-1}	910
molar volume, ideal gas at STP	$N_A k(273.15\ \mathrm{K})/(101\ 325\ \mathrm{Pa})$	22.413 968(20)$\times10^{-3}$ m^3 mol^{-1}	910
Wien displacement law constant	$b = \lambda_{\mathrm{max}}T$	2.897 7721(26)$\times10^{-3}$ m K	910
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	5.670 373(21)$\times10^{-8}$ W m^{-2} K^{-4}	3600
Fermi coupling constant[**]	$G_F/(\hbar c)^3$	1.166 378 7(6)$\times10^{-5}$ GeV^{-2}	500
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\mathrm{MS}}$)	0.231 26(5)[††]	2.2×10^5
$W^\pm$ boson mass	m_W	80.385(15) GeV/c^2	1.9×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1185(6)	5.1×10^6

π = 3.141 592 653 589 793 238   e = 2.718 281 828 459 045 235 γ = 0.577 215 664 901 532 861

1 in ≡ 0.0254 m   1 G ≡ 10^{-4} T   1 eV = 1.602 176 565(35) $\times10^{-19}$ J kT at 300 K = $[38.681\ 731(35)]^{-1}$ eV
1 Å ≡ 0.1 nm   1 dyne ≡ 10^{-5} N   1 eV/c^2 = 1.782 661 845(39) $\times10^{-36}$ kg   0 °C ≡ 273.15 K
1 barn ≡ 10^{-28} m^2 1 erg ≡ 10^{-7} J   2.997 924 58 $\times10^{9}$ esu = 1 C   1 atmosphere ≡ 760 Torr ≡ 101 325 Pa

---

[*] The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

[†] At $Q^2 = 0$. At $Q^2 \approx m_W^2$ the value is $\sim 1/128$.

[‡] Absolute lab measurements of G_N have been made only on scales of about 1 cm to 1 m.

[**] See the discussion in Sec. 10, "Electroweak model and constraints on new physics."

[††] The corresponding $\sin^2\theta$ for the effective angle is 0.23155(5).

2. ASTROPHYSICAL CONSTANTS AND PARAMETERS

Table 2.1. Revised November 2013 by D.E. Groom (LBNL). The figures in parentheses after some values give the 1-σ uncertainties in the last digit(s). Physical constants are from Ref. 1. While every effort has been made to obtain the most accurate current values of the listed quantities, the table does not represent a critical review or adjustment of the constants, and is not intended as a primary reference.

The values and uncertainties for the cosmological parameters depend on the exact data sets, priors, and basis parameters used in the fit. Many of the derived parameters reported in this table have non-Gaussian likelihoods. Parameters may be highly correlated, so care must be taken in propagating errors. (But in multiplications by h^{-2} *etc.* in the table below, independent errors were assumed.) Unless otherwise specified, cosmological parameters are from six-parameter fits to a flat ΛCDM cosmology using CMB data alone: *Planck* temperature + WMAP polarization data + high-resolution data from ACT and SPT [2]. For more information see Ref. 3 and the original papers.

Quantity	Symbol, equation	Value	Reference, footnote
speed of light	c	$299\,792\,458$ m s^{-1}	exact[4]
Newtonian gravitational constant	G_N	$6.673\,8(8) \times 10^{-11}$ m^3 kg^{-1} s^{-2}	[1,5]
Planck mass	$\sqrt{\hbar c/G_N}$	$1.220\,93(7) \times 10^{19}$ GeV/c^2	[1]
		$= 2.176\,51(13) \times 10^{-8}$ kg	
Planck length	$\sqrt{\hbar G_N/c^3}$	$1.616\,20(10) \times 10^{-35}$ m	[1]
standard gravitational acceleration	g_N	$9.806\,65$ m s	exact[1]
jansky (flux density)	Jy	10^{-26} W m^{-2} Hz^{-1}	definition
tropical year (equinox to equinox) (2011)	yr	$31\,556\,925.2$ s $\approx \pi \times 10^7$ s	[6]
sidereal year (fixed star to fixed star) (2011)		$31\,558\,149.8$ s $\approx \pi \times 10^7$ s	[6]
mean sidereal day (2011) (time between vernal equinox transits)		$23^{\mathrm{h}}\,56^{\mathrm{m}}\,04\overset{\mathrm{s}}{.}090\,53$	[6]
astronomical unit	au	$149\,597\,870\,700$ m	exact [7]
parsec (1 au/1 arc sec)	pc	$3.085\,677\,581\,49 \times 10^{16}$ m $= 3.262\ldots$ ly	exact [8]
light year (deprecated unit)	ly	$0.306\,6\ldots$ pc $= 0.946\,053\ldots \times 10^{16}$ m	
Schwarzschild radius of the Sun	$2G_N M_\odot/c^2$	$2.953\,250\,077(2)$ km	[9]
Solar mass	$M_\odot$	$1.988\,5(2) \times 10^{30}$ kg	[10]
Solar equatorial radius	$R_\odot$	$6.9551(4) \times 10^8$ m	[11]
Solar luminosity	$L_\odot$	3.828×10^{26} W	[12]
Schwarzschild radius of the Earth	$2G_N M_\oplus/c^2$	$8.870\,055\,94(2)$ mm	[13]
Earth mass	$M_\oplus$	$5.972\,6(7) \times 10^{24}$ kg	[14]
Earth mean equatorial radius	$R_\oplus$	$6.378\,137 \times 10^6$ m	[6]
luminosity conversion (deprecated)	L	$3.02 \times 10^{28} \times 10^{-0.4\,M_{\mathrm{bol}}}$ W	[15]
		(M_{bol} = absolute bolometric magnitude = bolometric magnitude at 10 pc)	
flux conversion (deprecated)	$\mathscr{F}$	$2.52 \times 10^{-8} \times 10^{-0.4\,m_{\mathrm{bol}}}$ W m^{-2}	from above
		(m_{bol} = apparent bolometric magnitude)	
ABsolute monochromatic magnitude	AB	$-2.5\,\log_{10} f_\nu - 56.10$ (for f_ν in W m^{-2} Hz^{-1})	[16]
		$= -2.5\,\log_{10} f_\nu + 8.90$ (for f_ν in Jy)	
Solar angular velocity around the Galactic center	Θ_0/R_0	30.3 ± 0.9 km s^{-1} kpc^{-1}	[17]
Solar distance from Galactic center	R_0	$8.4(6)$ kpc	[17,18]
circular velocity at R_0	v_0 or Θ_0	$254(16)$ km s^{-1}	[17]
local disk density	ρ_{disk}	3–12 $\times 10^{-24}$ g cm^{-3} $\approx$ 2–7 GeV/c^2 cm^{-3}	[19]
local dark matter density	ρ_χ	canonical value 0.3 GeV/c^2 cm^{-3} within factor 2–3	[20]
escape velocity from Galaxy	v_{esc}	498 km/s $< v_{\mathrm{esc}} < 608$ km/s	[21]
present day CMB temperature	T_0	$2.7255(6)$ K	[22,23]
present day CMB dipole amplitude		$3.355(8)$ mK	[22,24]
Solar velocity with respect to CMB		$369(1)$ km/s towards $(\ell, b) = (263.99(14)^\circ, 48.26(3)^\circ)$	[22,24]
Local Group velocity with respect to CMB	v_{LG}	$627(22)$ km/s towards $(\ell, b) = (276(3)^\circ, 30(3)^\circ)$	[22,24]
entropy density/Boltzmann constant	s/k	$2\,891.2\ (T/2.7255)^3$ cm^{-3}	[25]
number density of CMB photons	n_γ	$410.7(T/2.7255)^3$ cm^{-3}	[25]
baryon-to-photon ratio	$\eta = n_{\mathrm{b}}/n_\gamma$	$6.05(7) \times 10^{-10}$ (CMB)	[26]
		$5.7 \times 10^{-10} \le \eta \le 6.7 \times 10^{-10}$ (95% CL)	[26]
present day Hubble expansion rate	H_0	$100\,h$ km s^{-1} Mpc^{-1} $= h \times (9.777\,752$ Gyr$)^{-1}$	[29]
scale factor for Hubble expansion rate	h	$0.673(12)$	[2,3]
Hubble length	c/H_0	$0.925\,0629 \times 10^{26}\,h^{-1}$ m $= 1.37(2) \times 10^{26}$ m	
scale factor for cosmological constant	$c^2/3H_0^2$	$2.85247 \times 10^{51}\,h^{-2}$ m^2 $= 6.3(2) \times 10^{51}$ m^2	
critical density of the Universe	$\rho_{\mathrm{crit}} = 3H_0^2/8\pi G_N$	$2.775\,366\,27 \times 10^{11}\,h^2\,M_\odot$Mpc^{-3}	
		$= 1.878\,47(23) \times 10^{-29}\,h^2$ g cm^{-3}	
		$= 1.053\,75(13) \times 10^{-5}\,h^2$ (GeV/c^2) cm^{-3}	
number density of baryons	n_{b}	$2.482(32) \times 10^{-7}$ cm^{-3}	[2,3,27,28]
		$(2.1 \times 10^{-7} < n_{\mathrm{b}} < 2.7 \times 10^{-7})$ cm^{-3} (95% CL)	$\eta \times n_\gamma$
baryon density of the Universe	$\Omega_{\mathrm{b}} = \rho_{\mathrm{b}}/\rho_{\mathrm{crit}}$	$^\ddagger\,0.02207(27)\,h^{-2} = {}^\dagger\,0.0499(22)$	[2,3]
cold dark matter density of the universe	$\Omega_{\mathrm{cdm}} = \rho_{\mathrm{cdm}}/\rho_{\mathrm{crit}}$	$^\ddagger\,0.1198(26)\,h^{-2} = {}^\dagger\,0.265(11)$	[2,3]
100 × approx to r_*/D_{A}	$100 \times \theta_{\mathrm{MC}}$	$^\ddagger\,1.0413(6)$	[2,3]
reionization optical depth	τ	$^\ddagger\,0.091^{+0.013}_{-0.014}$	[2,3]
scalar spectral index	n_{s}	$^\ddagger\,0.958(7)$	[2,3]
ln pwr primordial curvature pert. (k_0=0.05 Mpc^{-1})	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	$^\ddagger\,3.090(25)$	[2,3]

Quantity	**Symbol, equation**	**Value**	**Reference, footnote**
dark energy density of the ΛCDM Universe	Ω_Λ	$0.685^{+0.017}_{-0.016}$	[2,3]
pressureless matter density of the Universe	$\Omega_{\rm m} = \Omega_{\rm cdm} + \Omega_{\rm b}$	$0.315^{+0.016}_{-0.017}$ (From Ω_Λ and flatness constraint)	[2,3]
dark energy equation of state parameter	w	♯ $-1.10^{+0.08}_{-0.07}$ (*Planck*+WMAP+BAO+SN)	[32]
CMB radiation density of the Universe	$\Omega_\gamma = \rho_\gamma/\rho_{\rm c}$	$2.473 \times 10^{-5} (T/2.7255)^4\, h^{-2} = 5.46(19) \times 10^{-5}$	[25]
effective number of neutrinos	$N_{\rm eff}$	† 3.36 ± 0.34	[2]
sum of neutrino masses	$\sum m_\nu$	< 0.23 eV (95% CL; CMB+BAO) $\Rightarrow \Omega_\nu h^2 < 0.0025$	[2,30,31]
neutrino density of the Universe	Ω_ν	$< 0.0025\, h^{-2} \Rightarrow < 0.0055$ (95% CL; CMB+BAO)	[2,30,31]
curvature	$\Omega_{\rm tot} = \Omega_{\rm m} + \ldots + \Omega_\Lambda$	♯ $0.96^{+0.4}_{-0.5}$ (95%CL)	[2]
		♯ 1.000(7) (95% CL; CMB+BAO)	[2]
fluctuation amplitude at $8\, h^{-1}$ Mpc scale	σ_8	† 0.828 ± 0.012	[2,3]
running spectral index slope, $k_0 = 0.002$ Mpc^{-1}	$dn_{\rm s}/d\ln k$	♯ $-0.015(9)$	[2]
tensor-to-scalar field perturbations ratio, k_0=0.002 Mpc^{-1}	$r = T/S$	♯ < 0.11 at 95% CL; no running	[2,3]
redshift at decoupling	$z_{\rm dec}$	† 1090.2 ± 0.7	[2]
age at decoupling	t_*	† 3.72×10^5 yr	
sound horizon at decoupling	$r_s(z_*)$	† 147.5 ± 0.6 Mpc (*Planck* CMB)	[32]
redshift of matter-radiation equality	$z_{\rm eq}$	† 3360 ± 70	[2]
redshift at half reionization	$z_{\rm reion}$	† 11.1 ± 1.1	[2]
age at half reionization	$t_{\rm reion}$	† 462 Myr	
age of the Universe	t_0	† 13.81 ± 0.05 Gyr	[2]

‡ Parameter in six-parameter ΛCDM fit [2].

† Derived parameter in six-parameter ΛCDM fit [2].

♯ Extended model parameter [2].

References:

1. P.J. Mohr, B.N. Taylor, and D.B. Newell, J. Phys. Chem. Ref. Data 41, 043109, (2012); `physics.nist.gov/constants`.
2. P.A.R. Ade, *et al.*, (Planck Collab. 2013 XVI), `arXiv:1303.5076v1`.
3. O. Lahav and A.R. Liddle, "The Cosmological Parameters," in this *Review.*
4. B.W. Petley, Nature **303**, 373 (1983).
5. T. Quinn *et al.*, Phys. Rev. Lett. **111**, 101102 (2013). See especially Fig. 3.
6. *The Astronomical Almanac for the year 2011*, U.S. Government Printing Office, Washington, and The U.K. Hydrographic Office (2010).
7. Astronomical_Constants_2014.pdf, downloaded from `asa.usno.navy.mil/SecK/Constants.html`; also see `www.iau.org/static/resolutions/IAU2012_English.pdf`. The Gaussian gravitational constant k is now deleted from the system of astronomical constants .
8. The distance at which 1 au subtends 1 arc sec: 1 au divided by $\pi/648\,000$.
9. Product of $2/c^2$ and the observationally determined Solar mass parameter $G_N M_\odot$ [7](TDB time scale).
10. $G_N M_\odot$ [7] $\div$ G_N [1].
11. T. M. Brown and J. Christensen-Dalsgaard, Astrophys. J. **500**, L195 (1998) Many values for the Solar radius have been published, most of which are consistent with this result.
12. $4\pi\,(1 \text{ au})^2 \times (1361 \text{ W m}^{-2})$, assuming isotropic irradiance;
    G. Kopp and J.L. Lean, Geophys. Res. Lett. **38**, L01706 (2011) give $1360.8 \pm 0.6 \text{W m}^{-2}$, but given the scatter in the data we use the rounded value without quoting an error.
13. Product of $2/c^2$ and the geocentric gravitational constant $G_N M_\oplus$ [7](TDB time scale).
14. $G_N M_\oplus$ [7] $\div$ G_N [1].
15. E.W. Kolb and M.S. Turner, *The Early Universe*, Addison-Wesley (1990);
    The IAU (Commission 36) has recommended 3.055×10^{28} W for the zero point. Based on newer Solar measurements, the value and significance given in the table seems more appropriate.
16. J. B. Oke and J. E. Gunn, Astrophys. J. **266**, 713 (1983). Note that in the definition of AB the sign of the constant is wrong.
17. M.J. Reid, *et al.*, Astrophys. J. **700**, 137 (2009)
    Note that Θ_0/R_0 is better determined than either Θ_0 or R_0.
18. Z.M. Malkin, Astron. Rep. **57**, 128 (2013). 56 determinations of R_0 are given. The weighted mean of these unevaluated results is 8.0(4), with $\chi^2/dof = 1.2$.
19. G. Gilmore, R.F.G. Wyse, and K. Kuijken, Ann. Rev. Astron. Astrophys. **27**, 555 (1989).
20. Sampling of many references:
    M. Mori *et al.*, Phys. Lett. **B289**, 463 (1992);
    E.I. Gates *et al.*, Astrophys. J. **449**, L133 (1995);
    M. Kamionkowski and A.Kinkhabwala, Phys. Rev. **D57**, 325 (1998);
    M. Weber and W. de Boer, Astron. & Astrophys. **509**, A25 (2010);
    P. Salucci *et al.*, Astron. & Astrophys. **523**, A83 (2010);
    R. Catena and P. Ullio, JCAP **1008**, 004 (2010) conclude $\rho_{\rm DM}^{\rm local} = 0.39 \pm 0.03\,\text{GeV}\,\text{cm}^{-3}$.
21. M. C. Smith *et al.*, Mon. Not. R. Astr. Soc. **379**, 755 (2007) (`astro-ph/0611671`).
22. D. Scott and G.F. Smoot, "Cosmic Microwave Background," in this *Review.*
23. D. Fixsen, Astrophys. J. **707**, 916 (2009).
24. G. Hinshaw *et al.*, Astrophys. J. Suppl. in press, `arXiv:1212.5226`;
    D.J. Fixsen *et al.*, Astrophys. J. **473**, 576 (1996);
    A. Kogut *et al.*, Astrophys. J. **419**, 1 (1993).
25. $n_\gamma = \dfrac{2\zeta(3)}{\pi^2}\left(\dfrac{kT}{\hbar c}\right)^3$; $\rho_\gamma = \dfrac{\pi^2 kT}{15\,c^2}\left(\dfrac{kT}{\hbar c}\right)^3$; $s/k = \dfrac{2\cdot 43\cdot \pi^2}{11\cdot 45}\left(\dfrac{kT}{\hbar c}\right)^3$; $kT_0/\hbar c = 11.902(4)/\text{cm}$.
26. B.D. Fields, P. Molarto, and S. Sarkar, "Big-Bang Nucleosynthesis," in this *Review.*
27. $n_{\rm b}$ depends only upon the measured $\Omega_{\rm b} h^2$, the average baryon mass at the present epoch [28], and G_N:
    $n_{\rm b} = (\Omega_{\rm b} h^2) h^{-2} \rho_{\rm crit}/(0.93711\,\text{GeV}/c^2 \text{ per baryon})$.
28. G. Steigman, JCAP **0610**, 016, (2006).
29. Conversion using length of sidereal year.
30. $\Omega_\nu h^2 = \sum m_{\nu_j}/93.04\,\text{eV}$, where the sum is over all neutrino mass eigenstates. The lower limit follows from neutrino mixing results reported in this *Review* combined with the assumptions that there are three light neutrinos ($m_\nu < 45$ GeV/c^2) and that the lightest neutrino is substantially less massive than the others: $\Delta m^2_{32} = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2, so $\sum m_{\nu_j} \geq m_{\nu_3} \approx \sqrt{\Delta m^2_{32}} =$ 0.05 eV. (This becomes 0.10 eV if the mass hierarchy is inverted, with $m_{\nu_1} \approx m_{\nu_2} \gg m_{\nu_3}$.) Alternatively, if the limit obtained from tritium decay experiments ($m_\nu < 2\,\text{eV}$) is used for the upper limit, then $\Omega_\nu < 0.04$.
31. Astrophysical determinations of $\sum m_{\nu_j}$, reported in the Full Listings of this *Review* under "Sum of the neutrino masses," range from $< 0.17\,\text{eV}$ to $< 2.3\,\text{eV}$ in papers published since 2003.
32. M.J. Mortonson, D.H. Weinberg, and M. White, "Dark Energy," in this *Review.*

3. INTERNATIONAL SYSTEM OF UNITS (SI)

See "The International System of Units (SI)," NIST Special Publication **330**, B.N. Taylor, ed. (USGPO, Washington, DC, 1991); and "Guide for the Use of the International System of Units (SI)," NIST Special Publication **811**, 1995 edition, B.N. Taylor (USGPO, Washington, DC, 1995).

Physical quantity	**Name of unit**	**Symbol**
Base units		
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
Derived units with special names		
plane angle	radian	rad
solid angle	steradian	sr
frequency	hertz	Hz
energy	joule	J
force	newton	N
pressure	pascal	Pa
power	watt	W
electric charge	coulomb	C
electric potential	volt	V
electric resistance	ohm	Ω
electric conductance	siemens	S
electric capacitance	farad	F
magnetic flux	weber	Wb
inductance	henry	H
magnetic flux density	tesla	T
luminous flux	lumen	lm
illuminance	lux	lx
celsius temperature	degree celsius	°C
activity (of a radioactive source)*	becquerel	Bq
absorbed dose (of ionizing radiation)*	gray	Gy
dose equivalent*	sievert	Sv

*See our section 35, on "Radioactivity and radiation protection," p. 458.

SI prefixes

10^{24}	yotta	(Y)
10^{21}	zetta	(Z)
10^{18}	exa	(E)
10^{15}	peta	(P)
10^{12}	tera	(T)
10^{9}	giga	(G)
10^{6}	mega	(M)
10^{3}	kilo	(k)
10^{2}	hecto	(h)
10	deca	(da)
10^{-1}	deci	(d)
10^{-2}	centi	(c)
10^{-3}	milli	(m)
10^{-6}	micro	(μ)
10^{-9}	nano	(n)
10^{-12}	pico	(p)
10^{-15}	femto	(f)
10^{-18}	atto	(a)
10^{-21}	zepto	(z)
10^{-24}	yocto	(y)

4. PERIODIC TABLE OF THE ELEMENTS

Table 4.1. Revised 2011 by D.E. Groom (LBNL), and E. Bergren. Atomic weights of stable elements are adapted from the Commission on Isotopic Abundances and Atomic Weights, "Atomic Weights of the Elements 2007," `http://www.chem.qmul.ac.uk/iupac/AtWt/`. The atomic number (top left) is the number of protons in the nucleus. The atomic mass (bottom) of a stable elements is weighted by isotopic abundances in the Earth's surface. If the element has no stable isotope, the atomic mass (in parentheses) of the most stable isotope currently known is given. In this case the mass is from `http://www.nndc.bnl.gov/amdc/masstables/Ame2003/mass.mas03` and the longest-lived isotope is from `www.nndc.bnl.gov/ensdf/za_form.jsp`. The exceptions are Th, Pa, and U, which do have characteristic terrestrial compositions. Atomic masses are relative to the mass of ^{12}C, defined to be exactly 12 unified atomic mass units (u) (approx. g/mole). Relative isotopic abundances often vary considerably, both in natural and commercial samples; this is reflected in the number of significant figures given for the atomic mass. IUPAC does not accept the claims for elements 113, 115, 117, and 118 as conclusive at this time.

PERIODIC TABLE OF THE ELEMENTS

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminum 26.9815386	14 Si Silicon 28.0855	15 P Phosph. 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge German. 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.96	43 Tc Technet. (97.90722)	44 Ru Ruthen. 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Cesium 132.9054519	56 Ba Barium 137.327	57–71 Lantha-nides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.98243)	85 At Astatine (209.98715)	86 Rn Radon (222.01758)
87 Fr Francium (223.01974)	88 Ra Radium (226.02541)	89–103 Actinides	104 Rf Rutherford. (267.122)	105 Db Dubnium (268.125)	106 Sg Seaborg. (271.133)	107 Bh Bohrium (270.134)	108 Hs Hassium (269.134)	109 Mt Meitner. (276.151)	110 Ds Darmstadt. (281.162)	111 Rg Roentgen. (280.164)	112 Cn Copernicium (277)		114 Fl Flerovium (289)		116 Lv Livermorium (288)		

Lanthanide series	57 La Lanthan. 138.90547	58 Ce Cerium 140.116	59 Pr Praseodym. 140.90765	60 Nd Neodym. 144.242	61 Pm Prometh. (144.91275)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolin. 157.25	65 Tb Terbium 158.92535	66 Dy Dyspros. 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
Actinide series	89 Ac Actinium (227.02775)	90 Th Thorium 232.03806	91 Pa Protactin. 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237.04817)	94 Pu Plutonium (244.06420)	95 Am Americ. (243.06138)	96 Cm Curium (247.07035)	97 Bk Berkelium (247.07031)	98 Cf Californ. (251.07959)	99 Es Einstein. (252.0830)	100 Fm Fermium (257.09510)	101 Md Mendelev. (258.09843)	102 No Nobelium (259.1010)	103 Lr Lawrenc. (262.110)

5. ELECTRONIC STRUCTURE OF THE ELEMENTS

Table 5.1. Reviewed 2011 by J.E. Sansonetti (NIST). The electronic configurations and the ionization energies are from the NIST database, "Ground Levels and Ionization Energies for the Neutral Atoms," W.C. Martin, A. Musgrove, S. Kotochigova, and J.E. Sansonetti, `http://www.nist.gov/pml/data/ion_energy.cfm`. The electron configuration for, say, iron indicates an argon electronic core (see argon) plus six $3d$ electrons and two $4s$ electrons.

	Element		Electron configuration ($3d^5$ = five $3d$ electrons, *etc.*)		Ground state $^{2S+1}L_J$	Ionization energy (eV)
1	H	Hydrogen	$1s$		$^2S_{1/2}$	13.5984
2	He	Helium	$1s^2$		$^1S_0$	24.5874
3	Li	Lithium	(He) $2s$		$^2S_{1/2}$	5.3917
4	Be	Beryllium	(He) $2s^2$		$^1S_0$	9.3227
5	B	Boron	(He) $2s^2\ 2p$		$^2P_{1/2}$	8.2980
6	C	Carbon	(He) $2s^2\ 2p^2$		$^3P_0$	11.2603
7	N	Nitrogen	(He) $2s^2\ 2p^3$		$^4S_{3/2}$	14.5341
8	O	Oxygen	(He) $2s^2\ 2p^4$		$^3P_2$	13.6181
9	F	Fluorine	(He) $2s^2\ 2p^5$		$^2P_{3/2}$	17.4228
10	Ne	Neon	(He) $2s^2\ 2p^6$		$^1S_0$	21.5645
11	Na	Sodium	(Ne) $3s$		$^2S_{1/2}$	5.1391
12	Mg	Magnesium	(Ne) $3s^2$		$^1S_0$	7.6462
13	Al	Aluminum	(Ne) $3s^2\ 3p$		$^2P_{1/2}$	5.9858
14	Si	Silicon	(Ne) $3s^2\ 3p^2$		$^3P_0$	8.1517
15	P	Phosphorus	(Ne) $3s^2\ 3p^3$		$^4S_{3/2}$	10.4867
16	S	Sulfur	(Ne) $3s^2\ 3p^4$		$^3P_2$	10.3600
17	Cl	Chlorine	(Ne) $3s^2\ 3p^5$		$^2P_{3/2}$	12.9676
18	Ar	Argon	(Ne) $3s^2\ 3p^6$		$^1S_0$	15.7596
19	K	Potassium	(Ar) $4s$		$^2S_{1/2}$	4.3407
20	Ca	Calcium	(Ar) $4s^2$		$^1S_0$	6.1132
21	Sc	Scandium	(Ar) $3d\ 4s^2$	Transition elements	$^2D_{3/2}$	6.5615
22	Ti	Titanium	(Ar) $3d^2\ 4s^2$		$^3F_2$	6.8281
23	V	Vanadium	(Ar) $3d^3\ 4s^2$		$^4F_{3/2}$	6.7462
24	Cr	Chromium	(Ar) $3d^5\ 4s$		$^7S_3$	6.7665
25	Mn	Manganese	(Ar) $3d^5\ 4s^2$		$^6S_{5/2}$	7.4340
26	Fe	Iron	(Ar) $3d^6\ 4s^2$		$^5D_4$	7.9024
27	Co	Cobalt	(Ar) $3d^7\ 4s^2$		$^4F_{9/2}$	7.8810
28	Ni	Nickel	(Ar) $3d^8\ 4s^2$		$^3F_4$	7.6399
29	Cu	Copper	(Ar) $3d^{10}\ 4s$		$^2S_{1/2}$	7.7264
30	Zn	Zinc	(Ar) $3d^{10}\ 4s^2$		$^1S_0$	9.3942
31	Ga	Gallium	(Ar) $3d^{10}\ 4s^2\ 4p$		$^2P_{1/2}$	5.9993
32	Ge	Germanium	(Ar) $3d^{10}\ 4s^2\ 4p^2$		$^3P_0$	7.8994
33	As	Arsenic	(Ar) $3d^{10}\ 4s^2\ 4p^3$		$^4S_{3/2}$	9.7886
34	Se	Selenium	(Ar) $3d^{10}\ 4s^2\ 4p^4$		$^3P_2$	9.7524
35	Br	Bromine	(Ar) $3d^{10}\ 4s^2\ 4p^5$		$^2P_{3/2}$	11.8138
36	Kr	Krypton	(Ar) $3d^{10}\ 4s^2\ 4p^6$		$^1S_0$	13.9996
37	Rb	Rubidium	(Kr) $5s$		$^2S_{1/2}$	4.1771
38	Sr	Strontium	(Kr) $5s^2$		$^1S_0$	5.6949
39	Y	Yttrium	(Kr) $4d\ 5s^2$	Transition elements	$^2D_{3/2}$	6.2173
40	Zr	Zirconium	(Kr) $4d^2\ 5s^2$		$^3F_2$	6.6339
41	Nb	Niobium	(Kr) $4d^4\ 5s$		$^6D_{1/2}$	6.7589
42	Mo	Molybdenum	(Kr) $4d^5\ 5s$		$^7S_3$	7.0924
43	Tc	Technetium	(Kr) $4d^5\ 5s^2$		$^6S_{5/2}$	7.28
44	Ru	Ruthenium	(Kr) $4d^7\ 5s$		$^5F_5$	7.3605
45	Rh	Rhodium	(Kr) $4d^8\ 5s$		$^4F_{9/2}$	7.4589
46	Pd	Palladium	(Kr) $4d^{10}$		$^1S_0$	8.3369
47	Ag	Silver	(Kr) $4d^{10}\ 5s$		$^2S_{1/2}$	7.5762
48	Cd	Cadmium	(Kr) $4d^{10}\ 5s^2$		$^1S_0$	8.9938

49	In	Indium	(Kr) $4d^{10}5s^2$ $5p$		$^2P_{1/2}$	5.7864
50	Sn	Tin	(Kr) $4d^{10}5s^2$ $5p^2$		$^3P_0$	7.3439
51	Sb	Antimony	(Kr) $4d^{10}5s^2$ $5p^3$		$^4S_{3/2}$	8.6084
52	Te	Tellurium	(Kr) $4d^{10}5s^2$ $5p^4$		$^3P_2$	9.0096
53	I	Iodine	(Kr) $4d^{10}5s^2$ $5p^5$		$^2P_{3/2}$	10.4513
54	Xe	Xenon	(Kr) $4d^{10}5s^2$ $5p^6$		$^1S_0$	12.1298
55	Cs	Cesium	(Xe) $6s$		$^2S_{1/2}$	3.8939
56	Ba	Barium	(Xe) $6s^2$		$^1S_0$	5.2117
57	La	Lanthanum	(Xe) $5d$ $6s^2$		$^2D_{3/2}$	5.5769
58	Ce	Cerium	(Xe) $4f$ $5d$ $6s^2$		$^1G_4$	5.5387
59	Pr	Praseodymium	(Xe) $4f^3$ $6s^2$	Lanthanides	$^4I_{9/2}$	5.473
60	Nd	Neodymium	(Xe) $4f^4$ $6s^2$		$^5I_4$	5.5250
61	Pm	Promethium	(Xe) $4f^5$ $6s^2$		$^6H_{5/2}$	5.582
62	Sm	Samarium	(Xe) $4f^6$ $6s^2$		$^7F_0$	5.6437
63	Eu	Europium	(Xe) $4f^7$ $6s^2$		$^8S_{7/2}$	5.6704
64	Gd	Gadolinium	(Xe) $4f^7$ $5d$ $6s^2$		$^9D_2$	6.1498
65	Tb	Terbium	(Xe) $4f^9$ $6s^2$		$^6H_{15/2}$	5.8638
66	Dy	Dysprosium	(Xe) $4f^{10}$ $6s^2$		$^5I_8$	5.9389
67	Ho	Holmium	(Xe) $4f^{11}$ $6s^2$		$^4I_{15/2}$	6.0215
68	Er	Erbium	(Xe) $4f^{12}$ $6s^2$		$^3H_6$	6.1077
69	Tm	Thulium	(Xe) $4f^{13}$ $6s^2$		$^2F_{7/2}$	6.1843
70	Yb	Ytterbium	(Xe) $4f^{14}$ $6s^2$		$^1S_0$	6.2542
71	Lu	Lutetium	(Xe) $4f^{14}5d$ $6s^2$		$^2D_{3/2}$	5.4259
72	Hf	Hafnium	(Xe) $4f^{14}5d^2$ $6s^2$	Transition elements	$^3F_2$	6.8251
73	Ta	Tantalum	(Xe) $4f^{14}5d^3$ $6s^2$		$^4F_{3/2}$	7.5496
74	W	Tungsten	(Xe) $4f^{14}5d^4$ $6s^2$		$^5D_0$	7.8640
75	Re	Rhenium	(Xe) $4f^{14}5d^5$ $6s^2$		$^6S_{5/2}$	7.8335
76	Os	Osmium	(Xe) $4f^{14}5d^6$ $6s^2$		$^5D_4$	8.4382
77	Ir	Iridium	(Xe) $4f^{14}5d^7$ $6s^2$		$^4F_{9/2}$	8.9670
78	Pt	Platinum	(Xe) $4f^{14}5d^9$ $6s$		$^3D_3$	8.9588
79	Au	Gold	(Xe) $4f^{14}5d^{10}6s$		$^2S_{1/2}$	9.2255
80	Hg	Mercury	(Xe) $4f^{14}5d^{10}6s^2$		$^1S_0$	10.4375
81	Tl	Thallium	(Xe) $4f^{14}5d^{10}6s^2$ $6p$		$^2P_{1/2}$	6.1082
82	Pb	Lead	(Xe) $4f^{14}5d^{10}6s^2$ $6p^2$		$^3P_0$	7.4167
83	Bi	Bismuth	(Xe) $4f^{14}5d^{10}6s^2$ $6p^3$		$^4S_{3/2}$	7.2855
84	Po	Polonium	(Xe) $4f^{14}5d^{10}6s^2$ $6p^4$		$^3P_2$	8.414
85	At	Astatine	(Xe) $4f^{14}5d^{10}6s^2$ $6p^5$		$^2P_{3/2}$	
86	Rn	Radon	(Xe) $4f^{14}5d^{10}6s^2$ $6p^6$		$^1S_0$	10.7485
87	Fr	Francium	(Rn) $7s$		$^2S_{1/2}$	4.0727
88	Ra	Radium	(Rn) $7s^2$		$^1S_0$	5.2784
89	Ac	Actinium	(Rn) $6d$ $7s^2$		$^2D_{3/2}$	5.3807
90	Th	Thorium	(Rn) $6d^2$ $7s^2$		$^3F_2$	6.3067
91	Pa	Protactinium	(Rn) $5f^2$ $6d$ $7s^2$	Actinides	$^4K_{11/2}$*	5.89
92	U	Uranium	(Rn) $5f^3$ $6d$ $7s^2$		$^5L_6$*	6.1939
93	Np	Neptunium	(Rn) $5f^4$ $6d$ $7s^2$		$^6L_{11/2}$*	6.2657
94	Pu	Plutonium	(Rn) $5f^6$ $7s^2$		$^7F_0$	6.0260
95	Am	Americium	(Rn) $5f^7$ $7s^2$		$^8S_{7/2}$	5.9738
96	Cm	Curium	(Rn) $5f^7$ $6d$ $7s^2$		$^9D_2$	5.9914
97	Bk	Berkelium	(Rn) $5f^9$ $7s^2$		$^6H_{15/2}$	6.1979
98	Cf	Californium	(Rn) $5f^{10}$ $7s^2$		$^5I_8$	6.2817
99	Es	Einsteinium	(Rn) $5f^{11}$ $7s^2$		$^4I_{15/2}$	6.3676
100	Fm	Fermium	(Rn) $5f^{12}$ $7s^2$		$^3H_6$	6.50
101	Md	Mendelevium	(Rn) $5f^{13}$ $7s^2$		$^2F_{7/2}$	6.58
102	No	Nobelium	(Rn) $5f^{14}$ $7s^2$		$^1S_0$	6.65
103	Lr	Lawrencium	(Rn) $5f^{14}$ $7s^2$ $7p$?		$^2P_{1/2}$?	4.9?
104	Rf	Rutherfordium	(Rn) $5f^{14}6d^2$ $7s^2$?		$^3F_2$?	6.0?

* The usual LS coupling scheme does not apply for these three elements. See the introductory note to the NIST table from which this table is taken.

6. ATOMIC AND NUCLEAR PROPERTIES OF MATERIALS

Table 6.1 Abridged from `pdg.lbl.gov/AtomicNuclearProperties` by D. E. Groom (2007). See web pages for more detail about entries in this table including chemical formulae, and for several hundred other entries. Quantities in parentheses are for gases at 20° C and 1 atm, and square brackets indicate evaluation at 0° C and 1 atm. Boiling points are at 1 atm. Refractive indices n are evaluated at the sodium D line blend (589.2 nm); values $\gg$1 in brackets are for $(n-1)\times 10^6$ (gases).

Material	Z	A	$\langle Z/A \rangle$	Nucl.coll. length λ_T {g cm^{-2}}	Nucl.inter. length λ_I {g cm^{-2}}	Rad.len. X_0 {g cm^{-2}}	$dE/dx\|_{\min}$ { MeV g^{-1}cm^2}	Density {g cm^{-3}} ({gℓ^{-1}})	Melting point (K)	Boiling point (K)	Refract. index (@ Na D)
H_2	1	1.00794(7)	0.99212	42.8	52.0	63.04	(4.103)	0.071(0.084)	13.81	20.28	1.11[132.]
D_2	1	2.01410177803(8)	0.49650	51.3	71.8	125.97	(2.053)	0.169(0.168)	18.7	23.65	1.11[138.]
He	2	4.002602(2)	0.49967	51.8	71.0	94.32	(1.937)	0.125(0.166)		4.220	1.02[35.0]
Li	3	6.941(2)	0.43221	52.2	71.3	82.78	1.639	0.534	453.6	1615.	
Be	4	9.012182(3)	0.44384	55.3	77.8	65.19	1.595	1.848	1560.	2744.	
C diamond	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.725	3.520			2.42
C graphite	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.742	2.210			
N_2	7	14.0067(2)	0.49976	61.1	89.7	37.99	(1.825)	0.807(1.165)	63.15	77.29	1.20[298.]
O_2	8	15.9994(3)	0.50002	61.3	90.2	34.24	(1.801)	1.141(1.332)	54.36	90.20	1.22[271.]
F_2	9	18.9984032(5)	0.47372	65.0	97.4	32.93	(1.676)	1.507(1.580)	53.53	85.03	[195.]
Ne	10	20.1797(6)	0.49555	65.7	99.0	28.93	(1.724)	1.204(0.839)	24.56	27.07	1.09[67.1]
Al	13	26.9815386(8)	0.48181	69.7	107.2	24.01	1.615	2.699	933.5	2792.	
Si	14	28.0855(3)	0.49848	70.2	108.4	21.82	1.664	2.329	1687.	3538.	3.95
Cl_2	17	35.453(2)	0.47951	73.8	115.7	19.28	(1.630)	1.574(2.980)	171.6	239.1	[773.]
Ar	18	39.948(1)	0.45059	75.7	119.7	19.55	(1.519)	1.396(1.662)	83.81	87.26	1.23[281.]
Ti	22	47.867(1)	0.45961	78.8	126.2	16.16	1.477	4.540	1941.	3560.	
Fe	26	55.845(2)	0.46557	81.7	132.1	13.84	1.451	7.874	1811.	3134.	
Cu	29	63.546(3)	0.45636	84.2	137.3	12.86	1.403	8.960	1358.	2835.	
Ge	32	72.64(1)	0.44053	86.9	143.0	12.25	1.370	5.323	1211.	3106.	
Sn	50	118.710(7)	0.42119	98.2	166.7	8.82	1.263	7.310	505.1	2875.	
Xe	54	131.293(6)	0.41129	100.8	172.1	8.48	(1.255)	2.953(5.483)	161.4	165.1	1.39[701.]
W	74	183.84(1)	0.40252	110.4	191.9	6.76	1.145	19.300	3695.	5828.	
Pt	78	195.084(9)	0.39983	112.2	195.7	6.54	1.128	21.450	2042.	4098.	
Au	79	196.966569(4)	0.40108	112.5	196.3	6.46	1.134	19.320	1337.	3129.	
Pb	82	207.2(1)	0.39575	114.1	199.6	6.37	1.122	11.350	600.6	2022.	
U	92	[238.02891(3)]	0.38651	118.6	209.0	6.00	1.081	18.950	1408.	4404.	
Air (dry, 1 atm)			0.49919	61.3	90.1	36.62	(1.815)	(1.205)		78.80	[289]
Shielding concrete			0.50274	65.1	97.5	26.57	1.711	2.300			
Borosilicate glass (Pyrex)			0.49707	64.6	96.5	28.17	1.696	2.230			
Lead glass			0.42101	95.9	158.0	7.87	1.255	6.220			
Standard rock			0.50000	66.8	101.3	26.54	1.688	2.650			
Methane (CH_4)			0.62334	54.0	73.8	46.47	(2.417)	(0.667)	90.68	111.7	[444.]
Ethane (C_2H_6)			0.59861	55.0	75.9	45.66	(2.304)	(1.263)	90.36	184.5	
Propane (C_3H_8)			0.58962	55.3	76.7	45.37	(2.262)	0.493(1.868)	85.52	231.0	
Butane (C_4H_{10})			0.59497	55.5	77.1	45.23	(2.278)	(2.489)	134.9	272.6	
Octane (C_8H_{18})			0.57778	55.8	77.8	45.00	2.123	0.703	214.4	398.8	
Paraffin ($CH_3(CH_2)_{n\approx 23}CH_3$)			0.57275	56.0	78.3	44.85	2.088	0.930			
Nylon (type 6, 6/6)			0.54790	57.5	81.6	41.92	1.973	1.18			
Polycarbonate (Lexan)			0.52697	58.3	83.6	41.50	1.886	1.20			
Polyethylene ($[CH_2CH_2]_n$)			0.57034	56.1	78.5	44.77	2.079	0.89			
Polyethylene terephthalate (Mylar)			0.52037	58.9	84.9	39.95	1.848	1.40			
Polyimide film (Kapton)			0.51264	59.2	85.5	40.58	1.820	1.42			
Polymethylmethacrylate (acrylic)			0.53937	58.1	82.8	40.55	1.929	1.19			1.49
Polypropylene			0.55998	56.1	78.5	44.77	2.041	0.90			
Polystyrene ($[C_6H_5CHCH_2]_n$)			0.53768	57.5	81.7	43.79	1.936	1.06			1.59
Polytetrafluoroethylene (Teflon)			0.47992	63.5	94.4	34.84	1.671	2.20			
Polyvinyltoluene			0.54141	57.3	81.3	43.90	1.956	1.03			1.58
Aluminum oxide (sapphire)			0.49038	65.5	98.4	27.94	1.647	3.970	2327.	3273.	1.77
Barium flouride (BaF_2)			0.42207	90.8	149.0	9.91	1.303	4.893	1641.	2533.	1.47
Bismuth germanate (BGO)			0.42065	96.2	159.1	7.97	1.251	7.130	1317.		2.15
Carbon dioxide gas (CO_2)			0.49989	60.7	88.9	36.20	1.819	(1.842)			[449.]
Solid carbon dioxide (dry ice)			0.49989	60.7	88.9	36.20	1.787	1.563	Sublimes at 194.7 K		
Cesium iodide (CsI)			0.41569	100.6	171.5	8.39	1.243	4.510	894.2	1553.	1.79
Lithium fluoride (LiF)			0.46262	61.0	88.7	39.26	1.614	2.635	1121.	1946.	1.39
Lithium hydride (LiH)			0.50321	50.8	68.1	79.62	1.897	0.820	965.		
Lead tungstate ($PbWO_4$)			0.41315	100.6	168.3	7.39	1.229	8.300	1403.		2.20
Silicon dioxide (SiO_2, fused quartz)			0.49930	65.2	97.8	27.05	1.699	2.200	1986.	3223.	1.46
Sodium chloride (NaCl)			0.55509	71.2	110.1	21.91	1.847	2.170	1075.	1738.	1.54
Sodium iodide (NaI)			0.42697	93.1	154.6	9.49	1.305	3.667	933.2	1577.	1.77
Water (H_2O)			0.55509	58.5	83.3	36.08	1.992	1.000	273.1	373.1	1.33
Silica aerogel			0.50093	65.0	97.3	27.25	1.740	0.200	(0.03 H_2O, 0.97 SiO_2)		

Material	Dielectric constant ($\kappa = \epsilon/\epsilon_0$) () is ($\kappa$–1)×$10^6$ for gas	Young's modulus [10^6 psi]	Coeff. of thermal expansion [10^{-6}cm/cm-°C]	Specific heat [cal/g-°C]	Electrical resistivity [$\mu\Omega$cm(@°C)]	Thermal conductivity [cal/cm-°C-sec]
H_2	(253.9)	—	—	—	—	—
He	(64)	—	—	—	—	—
Li	—	—	56	0.86	8.55(0°)	0.17
Be	—	37	12.4	0.436	5.885(0°)	0.38
C	—	0.7	0.6–4.3	0.165	1375(0°)	0.057
N_2	(548.5)	—	—	—	—	—
O_2	(495)	—	—	—	—	—
Ne	(127)	—	—	—	—	—
Al	—	10	23.9	0.215	2.65(20°)	0.53
Si	11.9	16	2.8–7.3	0.162	—	0.20
Ar	(517)	—	—	—	—	—
Ti	—	16.8	8.5	0.126	50(0°)	—
Fe	—	28.5	11.7	0.11	9.71(20°)	0.18
Cu	—	16	16.5	0.092	1.67(20°)	0.94
Ge	16.0	—	5.75	0.073	—	0.14
Sn	—	6	20	0.052	11.5(20°)	0.16
Xe	—	—	—	—	—	—
W	—	50	4.4	0.032	5.5(20°)	0.48
Pt	—	21	8.9	0.032	9.83(0°)	0.17
Pb	—	2.6	29.3	0.038	20.65(20°)	0.083
U	—	—	36.1	0.028	29(20°)	0.064

7. ELECTROMAGNETIC RELATIONS

Revised September 2005 by H.G. Spieler (LBNL).

Quantity	Gaussian CGS	SI
Conversion factors: Charge: Potential: Magnetic field:	 $2.997\,924\,58 \times 10^9$ esu $(1/299.792\,458)$ statvolt (ergs/esu) 10^4 gauss $= 10^4$ dyne/esu	 $= 1$ C $= 1$ A s $= 1$ V $= 1$ J C^{-1} $= 1$ T $= 1$ N A^{-1}m^{-1}
	$\mathbf{F} = q\,(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B})$	$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
	$\nabla \cdot \mathbf{D} = 4\pi\rho$ $\nabla \times \mathbf{H} - \frac{1}{c}\frac{\partial \mathbf{D}}{\partial t} = \frac{4\pi}{c}\mathbf{J}$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} + \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = 0$	$\nabla \cdot \mathbf{D} = \rho$ $\nabla \times \mathbf{H} - \frac{\partial \mathbf{D}}{\partial t} = \mathbf{J}$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0$
Constitutive relations:	$\mathbf{D} = \mathbf{E} + 4\pi\mathbf{P}, \quad \mathbf{H} = \mathbf{B} - 4\pi\mathbf{M}$	$\mathbf{D} = \epsilon_0\mathbf{E} + \mathbf{P}, \quad \mathbf{H} = \mathbf{B}/\mu_0 - \mathbf{M}$
Linear media:	$\mathbf{D} = \epsilon\mathbf{E}, \quad \mathbf{H} = \mathbf{B}/\mu$ 1 1	$\mathbf{D} = \epsilon\mathbf{E}, \quad \mathbf{H} = \mathbf{B}/\mu$ $\epsilon_0 = 8.854\,187\ldots \times 10^{-12}$ F m^{-1} $\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}
	$\mathbf{E} = -\nabla V - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla \times \mathbf{A}$	$\mathbf{E} = -\nabla V - \frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla \times \mathbf{A}$
	$V = \sum\limits_{\text{charges}} \frac{q_i}{r_i} = \int \frac{\rho\,(\mathbf{r}')}{\lvert \mathbf{r} - \mathbf{r}' \rvert}\, d^3x'$ $\mathbf{A} = \frac{1}{c}\oint \frac{I\,\mathbf{d}\boldsymbol{\ell}}{\lvert \mathbf{r} - \mathbf{r}' \rvert} = \frac{1}{c}\int \frac{\mathbf{J}(\mathbf{r}')}{\lvert \mathbf{r} - \mathbf{r}' \rvert}\, d^3x'$	$V = \frac{1}{4\pi\epsilon_0} \sum\limits_{\text{charges}} \frac{q_i}{r_i} = \frac{1}{4\pi\epsilon_0}\int \frac{\rho\,(\mathbf{r}')}{\lvert \mathbf{r} - \mathbf{r}' \rvert}\, d^3x'$ $\mathbf{A} = \frac{\mu_0}{4\pi}\oint \frac{I\,\mathbf{d}\boldsymbol{\ell}}{\lvert \mathbf{r} - \mathbf{r}' \rvert} = \frac{\mu_0}{4\pi}\int \frac{\mathbf{J}(\mathbf{r}')}{\lvert \mathbf{r} - \mathbf{r}' \rvert}\, d^3x'$
	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$ $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \frac{1}{c}\mathbf{v} \times \mathbf{B})$ $\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$ $\mathbf{B}'_{\perp} = \gamma(\mathbf{B}_{\perp} - \frac{1}{c}\mathbf{v} \times \mathbf{E})$	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$ $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \mathbf{v} \times \mathbf{B})$ $\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$ $\mathbf{B}'_{\perp} = \gamma(\mathbf{B}_{\perp} - \frac{1}{c^2}\mathbf{v} \times \mathbf{E})$
$\frac{1}{4\pi\epsilon_0} = c^2 \times 10^{-7}$ N A^{-2} $= 8.987\,55\ldots \times 10^9$ m F^{-1} ; $\frac{\mu_0}{4\pi} = 10^{-7}$ N A^{-2} ; $c = \frac{1}{\sqrt{\mu_0\epsilon_0}} = 2.997\,924\ \ 58 \times 10^8$ m s^{-1}		

7.1. Impedances (SI units)

ρ = resistivity at room temperature in $10^{-8}\,\Omega$ m:

~ 1.7 for Cu $\quad\sim 5.5$ for W
~ 2.4 for Au $\quad\sim 73$ for SS 304
~ 2.8 for Al $\quad\sim 100$ for Nichrome
(Al alloys may have double the Al value.)

For alternating currents, instantaneous current I, voltage V, angular frequency ω:

$$V = V_0\, e^{j\omega t} = ZI \ . \tag{7.1}$$

Impedance of self-inductance L: $Z = j\omega L$.

Impedance of capacitance C: $Z = 1/j\omega C$.

Impedance of free space: $Z = \sqrt{\mu_0/\epsilon_0} = 376.7\ \Omega$.

High-frequency surface impedance of a good conductor:

$$Z = \frac{(1+j)\,\rho}{\delta}\ , \qquad \text{where } \delta = \text{skin depth} \ ; \tag{7.2}$$

$$\delta = \sqrt{\frac{\rho}{\pi\nu\mu}} \approx \frac{6.6\ \text{cm}}{\sqrt{\nu\,(\text{Hz})}} \quad \text{for Cu} \ . \tag{7.3}$$

7.2. Capacitors, inductors, and transmission Lines

The capacitance between two parallel plates of area A spaced by the distance d and enclosing a medium with the dielectric constant ε is

$$C = K\varepsilon A/d\,, \tag{7.4}$$

where the correction factor K depends on the extent of the fringing field. If the dielectric fills the capacitor volume without extending beyond the electrodes. the correction factor $K \approx 0.8$ for capacitors of typical geometry.

The inductance at high frequencies of a straight wire whose length ℓ is much greater than the wire diameter d is

$$L \approx 2.0 \left[\frac{\text{nH}}{\text{cm}}\right] \cdot \ell \left(\ln\left(\frac{4\ell}{d}\right) - 1\right) . \tag{7.5}$$

For very short wires, representative of vias in a printed circuit board, the inductance is

$$L(\text{in nH}) \approx \ell/d\,. \tag{7.6}$$

A transmission line is a pair of conductors with inductance L and capacitance C. The characteristic impedance $Z = \sqrt{L/C}$ and the phase velocity $v_p = 1/\sqrt{LC} = 1/\sqrt{\mu\varepsilon}$, which decreases with the inverse square root of the dielectric constant of the medium. Typical coaxial and ribbon cables have a propagation delay of about 5 ns/cm.

The impedance of a coaxial cable with outer diameter D and inner diameter d is

$$Z = 60\,\Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln\frac{D}{d}\,, \tag{7.7}$$

where the relative dielectric constant $\varepsilon_r = \varepsilon/\varepsilon_0$. A pair of parallel wires of diameter d and spacing $a > 2.5\,d$ has the impedance

$$Z = 120\,\Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln\frac{2a}{d}\,. \tag{7.8}$$

This yields the impedance of a wire at a spacing h above a ground plane,

$$Z = 60\,\Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln\frac{4h}{d}\,. \tag{7.9}$$

A common configuration utilizes a thin rectangular conductor above a ground plane with an intermediate dielectric (microstrip). Detailed calculations for this and other transmission line configurations are given by Gunston.*

7.3. Synchrotron radiation (CGS units)

For a particle of charge e, velocity $v = \beta c$, and energy $E = \gamma mc^2$, traveling in a circular orbit of radius R, the classical energy loss per revolution δE is

$$\delta E = \frac{4\pi}{3}\,\frac{e^2}{R}\,\beta^3\,\gamma^4 \ . \tag{7.10}$$

For high-energy electrons or positrons ($\beta \approx 1$), this becomes

$$\delta E\ (\text{in MeV}) \approx 0.0885\ [E(\text{in GeV})]^4/R(\text{in m}) \ . \tag{7.11}$$

For $\gamma \gg 1$, the energy radiated per revolution into the photon energy interval $d(\hbar\omega)$ is

$$dI = \frac{8\pi}{9}\alpha\,\gamma\,F(\omega/\omega_c)\,d(\hbar\omega) \ , \tag{7.12}$$

where $\alpha = e^2/\hbar c$ is the fine-structure constant and

$$\omega_c = \frac{3\gamma^3 c}{2R} \tag{7.13}$$

is the critical frequency. The normalized function $F(y)$ is

$$F(y) = \frac{9}{8\pi}\sqrt{3}\,y \int_y^\infty K_{5/3}\,(x)\ \ dx \ , \tag{7.14}$$

where $K_{5/3}\,(x)$ is a modified Bessel function of the third kind. For electrons or positrons,

$$\hbar\omega_c\,(\text{in keV}) \approx 2.22\ \ [E(\text{in GeV})]^3/R(\text{in m}) \ . \tag{7.15}$$

Fig. 7.1 shows $F(y)$ over the important range of y.

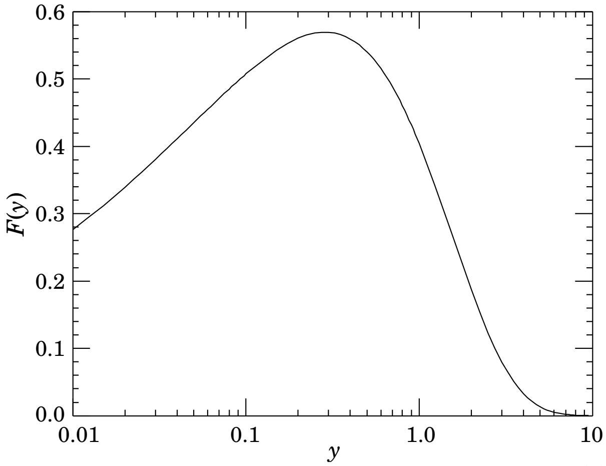

Figure 7.1: The normalized synchrotron radiation spectrum $F(y)$.

For $\gamma \gg 1$ and $\omega \ll \omega_c$,

$$\frac{dI}{d(\hbar\omega)} \approx 3.3\alpha\,(\omega R/c)^{1/3} \ , \tag{7.16}$$

whereas for

$$\gamma \gg 1 \text{ and } \omega \gtrsim 3\omega_c \ ,$$

$$\frac{dI}{d(\hbar\omega)} \approx \sqrt{\frac{3\pi}{2}}\,\alpha\,\gamma\left(\frac{\omega}{\omega_c}\right)^{1/2} e^{-\omega/\omega_c}\left[1 + \frac{55}{72}\frac{\omega_c}{\omega} + \ldots\right] \ . \tag{7.17}$$

The radiation is confined to angles $\lesssim 1/\gamma$ relative to the instantaneous direction of motion. For $\gamma \gg 1$, where Eq. (7.12) applies, the mean number of photons emitted per revolution is

$$N_\gamma = \frac{5\pi}{\sqrt{3}}\alpha\gamma \ , \tag{7.18}$$

and the mean energy per photon is

$$\langle\hbar\omega\rangle = \frac{8}{15\sqrt{3}}\hbar\omega_c \ . \tag{7.19}$$

When $\langle\hbar\omega\rangle \gtrsim \text{O}(E)$, quantum corrections are important.

---

* M.A.R. Gunston. Microwave Transmission Line Data, Noble Publishing Corp., Atlanta (1997) ISBN 1-884932-57-6, TK6565.T73G85.

See J.D. Jackson, *Classical Electrodynamics*, 3rd edition (John Wiley & Sons, New York, 1998) for more formulae and details. (Note that earlier editions had ω_c twice as large as Eq. (7.13).

8. NAMING SCHEME FOR HADRONS

Revised 2004 by M. Roos (University of Finland) and C.G. Wohl (LBNL).

8.1. Introduction

We introduced in the 1986 edition [1] a new naming scheme for the hadrons. Changes from older terminology affected mainly the heavier mesons made of the light (u, d, and s) quarks. Old and new names were listed alongside until 1994. Names also change from edition to edition because some characteristic like mass or spin changes. The Summary Tables give both the new and old names whenever a change occurred.

8.2. “Neutral-flavor” mesons ($S = C = B = T = 0$)

Table 8.1 shows the names for mesons having the strangeness and all heavy-flavor quantum numbers equal to zero. The scheme is designed for all ordinary non-exotic mesons, but it will work for many exotic types too, if needed.

Table 8.1: Symbols for mesons with the strangeness and all heavy-flavor quantum numbers equal to zero.

	$J^{PC} =$	0^{-+} 2^{-+} ⋮	1^{+-} 3^{+-} ⋮	1^{--} 2^{--} ⋮	0^{++} 1^{++} ⋮
$q\overline{q}$ content	$^{2S+1}L_J =$	$^1(L\,\text{even})_J$	$^1(L\,\text{odd})_J$	$^3(L\,\text{even})_J$	$^3(L\,\text{odd})_J$
$u\overline{d}, u\overline{u}-d\overline{d}, d\overline{u}$	$(I=1)$	π	b	ρ	a
$d\overline{d}+u\overline{u}$ and/or $s\overline{s}$	$(I=0)$	η, η'	h, h'	ω, ϕ	f, f'
$c\overline{c}$		η_c	h_c	$\psi^{\dagger}$	χ_c
$b\overline{b}$		η_b	h_b	Υ	χ_b
$t\overline{t}$		η_t	h_t	θ	χ_t

†The J/ψ remains the J/ψ.

First, we assign names to those states with quantum numbers compatible with being $q\overline{q}$ states. The rows of the Table give the possible $q\overline{q}$ content. The columns give the possible parity/charge-conjugation states,

$$PC = -+,\ +-,\ --,\ \text{and}\ ++\ ;$$

these combinations correspond one-to-one with the angular-momentum state $^{2S+1}L_J$ of the $q\overline{q}$ system being

$$^1(L\ \text{even})_J,\ ^1(L\ \text{odd})_J,\ ^3(L\ \text{even})_J,\ \text{or}\ ^3(L\ \text{odd})_J\ .$$

Here S, L, and J are the spin, orbital, and total angular momenta of the $q\overline{q}$ system. The quantum numbers are related by $P = (-1)^{L+1}$, $C = (-1)^{L+S}$, and G parity $= (-1)^{L+S+I}$, where of course the C quantum number is only relevant to neutral mesons.

The entries in the Table give the meson names. The spin J is added as a subscript except for pseudoscalar and vector mesons, and the mass is added in parentheses for mesons that decay strongly. However, for the lightest meson resonances, we omit the mass.

Measurements of the mass, quark content (where relevant), and quantum numbers I, J, P, and C (or G) of a meson thus fix its symbol. Conversely, these properties may be inferred unambiguously from the symbol.

If the main symbol cannot be assigned because the quantum numbers are unknown, X is used. Sometimes it is not known whether a meson is mainly the isospin-0 mix of $u\overline{u}$ and $d\overline{d}$ or is mainly $s\overline{s}$. A prime (or pair ω, ϕ) may be used to distinguish two such mixing states.

We follow custom and use spectroscopic names such as $\Upsilon(1S)$ as the primary name for most of those ψ, Υ, and χ states whose spectroscopic identity is known. We use the form $\Upsilon(9460)$ as an alternative, and as the primary name when the spectroscopic identity is not known.

Names are assigned for $t\overline{t}$ mesons, although the top quark is evidently so heavy that it is expected to decay too rapidly for bound states to form.

Gluonium states or other mesons that are not $q\overline{q}$ states are, if the quantum numbers are *not* exotic, to be named just as are the $q\overline{q}$ mesons. Such states will probably be difficult to distinguish from $q\overline{q}$ states and will likely mix with them, and we make no attempt to distinguish those “mostly gluonium” from those “mostly $q\overline{q}$.”

An “exotic” meson with J^{PC} quantum numbers that a $q\overline{q}$ system cannot have, namely $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, \cdots$, would use the same symbol as does an ordinary meson with all the same quantum numbers as the exotic meson except for the C parity. But then the J subscript may still distinguish it; for example, an isospin-0 1^{-+} meson could be denoted ω_1.

8.3. Mesons with nonzero S, C, B, and/or T

Since the strangeness or a heavy flavor of these mesons is nonzero, none of them are eigenstates of charge conjugation, and in each of them one of the quarks is heavier than the other. The rules are:

1. The main symbol is an upper-case italic letter indicating the heavier quark as follows:

   $$s \rightarrow \overline{K} \qquad c \rightarrow D \qquad b \rightarrow \overline{B} \qquad t \rightarrow T\ .$$

   We use the convention that *the flavor and the charge of a quark have the same sign.* Thus the strangeness of the s quark is negative, the charm of the c quark is positive, and the bottom of the b quark is negative. In addition, I_3 of the u and d quarks are positive and negative, respectively. The effect of this convention is as follows: *Any flavor carried by a charged meson has the same sign as its charge.* Thus the K^+, D^+, and B^+ have positive strangeness, charm, and bottom, respectively, and all have positive I_3. The D_s^+ has positive charm *and* strangeness. Furthermore, the $\Delta(\text{flavor}) = \Delta Q$ rule, best known for the kaons, applies to every flavor.
2. If the lighter quark is not a u or a d quark, its identity is given by a subscript. The D_s^+ is an example.
3. If the spin-parity is in the “normal” series, $J^P = 0^+, 1^-, 2^+, \cdots$, a superscript “*” is added.
4. The spin is added as a subscript except for pseudoscalar or vector mesons.

8.4. Ordinary (3-quark) baryons

The symbols N, Δ, Λ, Σ, Ξ, and Ω used for more than 30 years for the baryons made of light quarks (u, d, and s quarks) tell the isospin and quark content, and the same information is conveyed by the symbols used for the baryons containing one or more heavy quarks (c and b quarks). The rules are:

1. Baryons with *three* u and/or d quarks are N's (isospin 1/2) or Δ's (isospin 3/2).
2. Baryons with *two* u and/or d quarks are Λ's (isospin 0) or Σ's (isospin 1). If the third quark is a c, b, or t quark, its identity is given by a subscript.
3. Baryons with *one* u or d quark are Ξ's (isospin 1/2). One or two subscripts are used if one or both of the remaining quarks are heavy: thus Ξ_c, Ξ_{cc}, Ξ_b, *etc.**
4. Baryons with *no* u or d quarks are Ω's (isospin 0), and subscripts indicate any heavy-quark content.
5. A baryon that decays strongly has its mass as part of its name. Thus p, Σ^-, Ω^-, Λ_c^+, *etc.*, but $\Delta(1232)^0$, $\Sigma(1385)^-$, $\Xi_c(2645)^+$, *etc.*

In short, the number of u plus d quarks together with the isospin determine the main symbol, and subscripts indicate any content of heavy quarks. A Σ always has isospin 1, an Ω always has isospin 0, *etc.*

8.5. Exotic baryons

In 2003, several experiments reported finding a strangeness $S = +1$, charge $Q = +1$ baryon, and one experiment reported finding an $S = -2$, $Q = -2$ baryon. Baryons with such quantum numbers cannot be made from three quarks, and thus they are exotic. The $S = +1$ baryon, which once would have been called a Z, was quickly dubbed the $\Theta(1540)^+$, and we proposed to name the $S = -2$ baryon the $\Phi(1860)$. However, these "discoveries" were then completely ruled out by many experiments with far larger statistics: See our 2008 *Review* [2].

Footnote and Reference:

[*] Sometimes a prime is necessary to distinguish two Ξ_c's in the same SU(n) multiplet. See the "Note on Charmed Baryons" in the Charmed Baryon Listings.

1. Particle Data Group: M. Aguilar-Benitez *et al.,* Phys. Lett. **170B** (1986).
2. Particle Data Group: C. Amsler *et al.*, Phys. Lett. **B667**, 1 (2008).