CODATA RECOMMENDED VALUES OF THE FUNDAMENTAL PHYSICAL CONSTANTS: 2022

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An extensive list of constants is available on the NIST Physics Laboratory Web site physics.nist.gov/constants. For numerical values a number in parentheses, if present, is the one-standard-deviation uncertainty in the last two digits. For units with square brackets the full descriptions of $[\mathrm{m}]^{-1}$ and [m] are cycles per meter and meter per cycle, respectively. For the first radiation constant the full description of $[\mathrm{m}]^2$ is m^{-2} $(\mathrm{m/cycle})^4$.

Quantity	Symbol	Numerical value	Unit
speed of light in vacuum	c	299 792 458 (exact)	$\mathrm{m\ s^{-1}}$
Newtonian constant of gravitation	G	$6.674\,30(15) \times 10^{-11}$	$\mathrm{m^3\ kg^{-1}\ s^{-2}}$
Planck constant	h	$6.626\,070\,15 \times 10^{-34}$ (exact)	$\mathrm{J\ Hz^{-1}}$
in eV s		$4.135\,667\,696\ldots \times 10^{-15}$	$\mathrm{eV\ Hz^{-1}}$
	$\hbar$	$1.054\,571\,817\ldots \times 10^{-34}$	J s
in eV s		$6.582\,119\,569\ldots \times 10^{-16}$	eV s
elementary charge	e	$1.602\,176\,634 \times 10^{-19}$ (exact)	C
vacuum magnetic permeability $4\pi\alpha\hbar/e^2c$	μ_0	$1.256\,637\,061\,27(20) \times 10^{-6}$	$\mathrm{N\ A^{-2}}$
$\mu_0/(4\pi \times 10^{-7})$		0.999 999 999 87(16)	$\mathrm{N\ A^{-2}}$
vacuum electric permittivity $1/\mu_0 c^2$	ϵ_0	$8.854\,187\,8188(14) \times 10^{-12}$	$\mathrm{F\ m^{-1}}$
Josephson constant $2e/h$	K_J	$483\,597.848\,4\ldots \times 10^9$	$\mathrm{Hz\ V^{-1}}$
von Klitzing constant $\mu_0 c/2\alpha = 2\pi\hbar/e^2$	R_K	25 812.807 45 . . .	Ω
magnetic flux quantum $2\pi\hbar/(2e)$	Φ_0	$2.067\,833\,848\ldots \times 10^{-15}$	Wb
Bohr magneton $e\hbar/2m_\mathrm{e}$	μ_B	$9.274\,010\,0657(29) \times 10^{-24}$	$\mathrm{J\ T^{-1}}$
in eV $\mathrm{T^{-1}}$		$5.788\,381\,7982(18) \times 10^{-5}$	$\mathrm{eV\ T^{-1}}$
nuclear magneton $e\hbar/2m_\mathrm{p}$	μ_N	$5.050\,783\,7393(16) \times 10^{-27}$	$\mathrm{J\ T^{-1}}$
in eV $\mathrm{T^{-1}}$		$3.152\,451\,254\,17(98) \times 10^{-8}$	$\mathrm{eV\ T^{-1}}$
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,5643(11) \times 10^{-3}$	
inverse fine-structure constant	α^{-1}	137.035 999 177(21)	
Rydberg frequency $\alpha^2 m_\mathrm{e} c^2/2h = E_\mathrm{h}/2h$	cR_∞	$3.289\,841\,960\,2500(36) \times 10^{15}$	Hz
energy equivalent in eV		13.605 693 122 990(15)	eV
Rydberg constant	R_∞	10 973 731.568 157(12)	$[\mathrm{m^{-1}}]$
Bohr radius $\hbar/\alpha m_\mathrm{e} c = 4\pi\epsilon_0\hbar^2/m_\mathrm{e}e^2$	a_0	$5.291\,772\,105\,44(82) \times 10^{-11}$	m
Hartree energy $\alpha^2 m_\mathrm{e} c^2 = e^2/4\pi\epsilon_0 a_0 = 2(cR_\infty)h$	E_h	$4.359\,744\,722\,2060(48) \times 10^{-18}$	J
in eV		27.211 386 245 981(30)	eV
electron mass	m_e	$9.109\,383\,7139(28) \times 10^{-31}$	kg
in u		$5.485\,799\,090\,441(97) \times 10^{-4}$	u
energy equivalent in MeV	$m_\mathrm{e}c^2$	0.510 998 950 69(16)	MeV
electron-muon mass ratio	m_e/m_μ	$4.836\,331\,70(11) \times 10^{-3}$	
electron-proton mass ratio	$m_\mathrm{e}/m_\mathrm{p}$	$5.446\,170\,214\,889(94) \times 10^{-4}$	
electron charge to mass quotient	$-e/m_\mathrm{e}$	$-1.758\,820\,008\,38(55) \times 10^{11}$	$\mathrm{C\ kg^{-1}}$
reduced Compton wavelength $\hbar/m_\mathrm{e}c = \alpha a_0$	$\lambda\!\!\!^{-}_\mathrm{C}$	$3.861\,592\,6744(12) \times 10^{-13}$	m
Compton wavelength	λ_C	$2.426\,310\,235\,38(76) \times 10^{-12}$	[m]
classical electron radius $\alpha^2 a_0$	r_e	$2.817\,940\,3205(13) \times 10^{-15}$	m
Thomson cross section $(8\pi/3)r_\mathrm{e}^2$	σ_e	$6.652\,458\,7051(62) \times 10^{-29}$	$\mathrm{m^2}$
electron magnetic moment	μ_e	$-9.284\,764\,6917(29) \times 10^{-24}$	$\mathrm{J\ T^{-1}}$
to Bohr magneton ratio	$\mu_\mathrm{e}/\mu_\mathrm{B}$	−1.001 159 652 180 46(18)	
to nuclear magneton ratio	$\mu_\mathrm{e}/\mu_\mathrm{N}$	−1838.281 971 877(32)	
electron magnetic moment anomaly $\lvert\mu_\mathrm{e}\rvert/\mu_\mathrm{B} - 1$	a_e	$1.159\,652\,180\,46(18) \times 10^{-3}$	
electron g-factor $-2(1 + a_\mathrm{e})$	g_e	−2.002 319 304 360 92(36)	
electron-proton magnetic moment ratio	$\mu_\mathrm{e}/\mu_\mathrm{p}$	−658.210 687 89(19)	
muon mass in u	m_μ	0.113 428 9257(25)	u
energy equivalent in MeV	$m_\mu c^2$	105.658 3755(23)	MeV
muon-electron mass ratio	m_μ/m_e	206.768 2827(46)	
muon magnetic moment	μ_μ	$-4.490\,448\,30(10) \times 10^{-26}$	$\mathrm{J\ T^{-1}}$
to Bohr magneton ratio	μ_μ/μ_B	$-4.841\,970\,48(11) \times 10^{-3}$	
to nuclear magneton ratio	μ_μ/μ_N	−8.890 597 04(20)	
muon magnetic moment anomaly $\lvert\mu_\mu\rvert/(e\hbar/2m_\mu) - 1$	a_μ	$1.165\,920\,62(41) \times 10^{-3}$	

Quantity	Symbol	Numerical value	Unit
muon g-factor $-2(1 + a_\mu)$	g_μ	−2.002 331 841 23(82)	
muon-proton magnetic moment ratio	μ_μ/μ_p	−3.183 345 146(71)	
proton mass	m_p	$1.672\,621\,925\,95(52) \times 10^{-27}$	kg
in u		1.007 276 466 5789(83)	u
energy equivalent in MeV	$m_\mathrm{p}c^2$	938.272 089 43(29)	MeV
proton-electron mass ratio	$m_\mathrm{p}/m_\mathrm{e}$	1836.152 673 426(32)	
proton magnetic moment	μ_p	$1.410\,606\,795\,45(60) \times 10^{-26}$	$\mathrm{J\ T^{-1}}$
to nuclear magneton ratio	$\mu_\mathrm{p}/\mu_\mathrm{N}$	2.792 847 344 63(82)	
proton magnetic shielding correction $1-\mu'_\mathrm{p}/\mu_\mathrm{p}$ ($\mathrm{H_2O}$, sphere, 25 °C)	σ'_p	$2.567\,15(41) \times 10^{-5}$	
proton gyromagnetic ratio $2\mu_\mathrm{p}/\hbar$	γ_p	$2.675\,221\,8708(11) \times 10^8$	$\mathrm{s^{-1}\ T^{-1}}$
		42.577 478 461(18)	$\mathrm{MHz\ T^{-1}}$
shielded proton gyromagnetic ratio $2\mu'_\mathrm{p}/\hbar$ ($\mathrm{H_2O}$, sphere, 25 °C)	γ'_p	$2.675\,153\,194(11) \times 10^8$	$\mathrm{s^{-1}\ T^{-1}}$
		42.576 385 43(17)	$\mathrm{MHz\ T^{-1}}$
neutron mass in u	m_n	1.008 664 916 06(40)	u
energy equivalent in MeV	$m_\mathrm{n}c^2$	939.565 421 94(48)	MeV
neutron-proton mass ratio	$m_\mathrm{n}/m_\mathrm{p}$	1.001 378 419 46(40)	
neutron magnetic moment	μ_n	$-9.662\,3653(23) \times 10^{-27}$	$\mathrm{J\ T^{-1}}$
to nuclear magneton ratio	$\mu_\mathrm{n}/\mu_\mathrm{N}$	−1.913 042 76(45)	
deuteron mass in u	m_d	2.013 553 212 544(15)	u
energy equivalent in MeV	$m_\mathrm{d}c^2$	1875.612 945 00(58)	MeV
deuteron-proton mass ratio	$m_\mathrm{d}/m_\mathrm{p}$	1.999 007 501 2699(84)	
deuteron magnetic moment	μ_d	$4.330\,735\,087(11) \times 10^{-27}$	$\mathrm{J\ T^{-1}}$
to nuclear magneton ratio	$\mu_\mathrm{d}/\mu_\mathrm{N}$	0.857 438 2335(22)	
helion (^{3}He nucleus) mass in u	m_h	3.014 932 246 932(74)	u
energy equivalent in MeV	$m_\mathrm{h}c^2$	2808.391 611 12(88)	MeV
shielded helion magnetic moment (gas, sphere, 25 °C)	μ'_h	$-1.074\,553\,110\,35(93) \times 10^{-26}$	$\mathrm{J\ T^{-1}}$
to Bohr magneton ratio	$\mu'_\mathrm{h}/\mu_\mathrm{B}$	$-1.158\,671\,494\,57(94) \times 10^{-3}$	
to nuclear magneton ratio	$\mu'_\mathrm{h}/\mu_\mathrm{N}$	−2.127 497 7624(17)	
alpha particle mass in u	m_α	4.001 506 179 129(62)	u
energy equivalent in MeV	$m_\alpha c^2$	3727.379 4118(12)	MeV
Boltzmann constant	k	$1.380\,649 \times 10^{-23}$ (exact)	$\mathrm{J\ K^{-1}}$
Avogadro constant	N_A	$6.022\,140\,76 \times 10^{23}$ (exact)	$\mathrm{mol^{-1}}$
atomic mass constant $\frac{1}{12}m(^{12}\mathrm{C}) = 1$ u	m_u	$1.660\,539\,068\,92(52) \times 10^{-27}$	kg
energy equivalent in MeV	$m_\mathrm{u}c^2$	931.494 103 72(29)	MeV
Faraday constant $N_\mathrm{A}e$	F	96 485.332 12 . . .	$\mathrm{C\ mol^{-1}}$
molar gas constant $N_\mathrm{A}k$	R	8.314 462 618 . . .	$\mathrm{J\ mol^{-1}\ K^{-1}}$
in eV $\mathrm{K^{-1}}$		$8.617\,333\,262\ldots \times 10^{-5}$	$\mathrm{eV\ K^{-1}}$
molar volume of ideal gas RT/p (T = 273.15 K, p = 101.325 kPa)	V_m	$22.413\,969\,54\ldots \times 10^{-3}$	$\mathrm{m^3\ mol^{-1}}$
Stefan-Boltzmann constant $\pi^2k^4/60\hbar^3c^2$	σ	$5.670\,374\,419\ldots \times 10^{-8}$	$\mathrm{W\ m^{-2}\ K^{-4}}$
first radiation constant $2\pi hc^2$	c_1	$3.741\,771\,852\ldots \times 10^{-16}$	$[\mathrm{W\ m^2}]$
second radiation constant hc/k	c_2	$1.438\,776\,877\ldots \times 10^{-2}$	[m K]
Wien displacement law constant $b = \lambda_\mathrm{max}T = c_2/4.965\,114\,231\ldots$	b	$2.897\,771\,955\ldots \times 10^{-3}$	[m K]
Cu x unit: $\lambda(\mathrm{Cu\ K}\alpha_1)/1\,537.400$	$\mathrm{xu(Cu\ K}\alpha_1)$	$1.002\,076\,97(28) \times 10^{-13}$	m
Mo x unit: $\lambda(\mathrm{Mo\ K}\alpha_1)/707.831$	$\mathrm{xu(Mo\ K}\alpha_1)$	$1.002\,099\,52(53) \times 10^{-13}$	m

Energy equivalents

$[1\ \mathrm{m^{-1}}]c = 299\,792\,458$ Hz	$(1\ \mathrm{Hz})h/k = 4.799\,243\,073\ldots \times 10^{-11}$ K	$(1\ \mathrm{J}) = 6.241\,509\,074\ldots \times 10^{18}$ eV	$(1\ \mathrm{eV})/c^2 = 1.073\,544\,100\,83(33) \times 10^{-9}$ u
$[1\ \mathrm{m^{-1}}]hc/k = 1.438\,776\,877\ldots \times 10^{-2}$ K	$(1\ \mathrm{Hz})h = 4.135\,667\,696\ldots \times 10^{-15}$ eV	$(1\ \mathrm{eV}) = 1.602\,176\,634 \times 10^{-19}$ J	$(1\ \mathrm{kg}) = 6.022\,140\,7537(19) \times 10^{26}$ u
$[1\ \mathrm{m^{-1}}]hc = 1.239\,841\,984\ldots \times 10^{-6}$ eV	$(1\ \mathrm{K})k/hc = 69.503\,480\,04\ldots\ [\mathrm{m^{-1}}]$	$(1\ \mathrm{eV})/hc = 8.065\,543\,937\ldots \times 10^5\ [\mathrm{m^{-1}}]$	$(1\ \mathrm{u}) = 1.660\,539\,068\,92(52) \times 10^{-27}$ kg
$[1\ \mathrm{m^{-1}}]h/c = 1.331\,025\,048\,24(41) \times 10^{-15}$ u	$(1\ \mathrm{K})k/h = 2.083\,661\,912\ldots \times 10^{10}$ Hz	$(1\ \mathrm{eV})/h = 2.417\,989\,242\ldots \times 10^{14}$ Hz	$(1\ \mathrm{u})c/h = 7.513\,006\,6209(23) \times 10^{14}\ [\mathrm{m^{-1}}]$
$(1\ \mathrm{Hz})/c = 3.335\,640\,951\ldots \times 10^{-9}\ [\mathrm{m^{-1}}]$	$(1\ \mathrm{K})k = 8.617\,333\,262\ldots \times 10^{-5}$ eV	$(1\ \mathrm{eV})/k = 1.160\,451\,812\ldots \times 10^4$ K	$(1\ \mathrm{u})c^2 = 9.314\,941\,0372(29) \times 10^8$ eV

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