Fundamental Constants

Quantity	Symbol	Value(s)
Elementary charge	e	1.6022×10^{-19} C
Speed of light in vacuum	c	2.9979×10^{8} m/s
Permeability of vacuum	μ_0	$4\pi \times 10^{-7}$ N · A^{-2}
Permittivity of vacuum	ϵ_0	8.8542×10^{-12} F · m^{-1}
Gravitation constant	G	6.6726×10^{-11} N · m^2 · kg^{-2}
Planck constant	h	6.6261×10^{-34} J · s
		4.1357×10^{-15} eV · s
Avogadro constant	N_A	6.0221×10^{23} mol^{-1}
Boltzmann constant	k	1.3807×10^{-23} J · K^{-1}
Stefan-Boltzmann constant	σ	5.6705×10^{-8} W · m^{-2} · K^{-4}
Atomic mass unit	u	1.6605×10^{-27} kg
		931.49 MeV/c^2

Particle Masses

Particle	Mass in units of		
	kg	MeV/c^2	u
Electron	9.1094×10^{-31}	0.51100	5.4858×10^{-4}
Muon	1.8835×10^{-28}	105.66	0.11343
Proton	1.6726×10^{-27}	938.27	1.00728
Neutron	1.6749×10^{-27}	939.57	1.00866
Deuteron	3.3436×10^{-27}	1875.61	2.01355
α particle	6.6447×10^{-27}	3727.38	4.00151

Conversion Factors

1 yr = 3.156×10^{7} s
1 lightyear = 9.461×10^{15} m
1 cal = 4.186 J
1 MeV/c = 5.344×10^{-22} kg · m/s
1 eV = 1.6022×10^{-19} J
1 T = 10^{4} G
1 Ci = 3.7×10^{10} Bq
1 barn = 10^{-28} m^2
1 u = 1.66054×10^{-27} kg

Useful Combinations of Constants

$\hbar = h/2\pi = 1.0546 \times 10^{-34}\,\text{J} \cdot \text{s} = 6.5821 \times 10^{-16}\,\text{eV} \cdot \text{s}$

$hc = 1.9864 \times 10^{-25}\,\text{J} \cdot \text{m} = 1239.8\,\text{eV} \cdot \text{nm}$

$\hbar c = 3.1615 \times 10^{-26}\,\text{J} \cdot \text{m} = 197.33\,\text{eV} \cdot \text{nm}$

$$\frac{1}{4\pi\epsilon_0} = 8.9876 \times 10^{9}\,\text{N} \cdot \text{m}^2 \cdot \text{C}^{-2}$$

$$\text{Compton wavelength } \lambda_c = \frac{h}{m_e c} = 2.4263 \times 10^{-12}\,\text{m}$$

$$\frac{e^2}{4\pi\epsilon_0} = 2.3071 \times 10^{-28}\,\text{J} \cdot \text{m} = 1.4400 \times 10^{-9}\,\text{eV} \cdot \text{m}$$

$$\text{Fine structure constant } \alpha = \frac{e^2}{4\pi\epsilon_0 \hbar c} = 0.0072974 \approx \frac{1}{137}$$

$$\text{Bohr magneton } \mu_\text{B} = \frac{e\hbar}{2m_e} = 9.2740 \times 10^{-24}\,\text{J/T} = 5.7884 \times 10^{-5}\,\text{eV/T}$$

$$\text{Nuclear magneton } \mu_\text{N} = \frac{e\hbar}{2m_p} = 5.0508 \times 10^{-27}\,\text{J/T} = 3.1525 \times 10^{-8}\,\text{eV/T}$$

$$\text{Bohr radius } a_0 = \frac{4\pi\epsilon_0 \hbar^2}{m_e e^2} = 5.2918 \times 10^{-11}\,\text{m}$$

$$\text{Hydrogen ground state } E_0 = \frac{e^2}{8\pi\epsilon_0 a_0} = 13.606\,\text{eV} = 2.1799 \times 10^{-18}\,\text{J}$$

$$\text{Rydberg constant } \text{R}_\infty = \frac{\alpha^2 m_e c}{2h} = 1.09737 \times 10^{7}\,\text{m}^{-1}$$

$$\text{Hydrogen Rydberg } R_\text{H} = \frac{\mu}{m_e} R_\infty = 1.09678 \times 10^{7}\,\text{m}^{-1}$$

$$\text{Gas constant } R = N_\text{A} k = 8.3145\,\text{J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$$

$$\text{Magnetic flux quantum } \Phi_0 = \frac{h}{2e} = 2.0678 \times 10^{-15}\,\text{T} \cdot \text{m}^2$$

$$\text{Classical electron radius} = r_e = \alpha^2 a_0 = 2.8179 \times 10^{-15}\,\text{m}$$

$$kT = 2.5249 \times 10^{-2}\,\text{eV} \approx \frac{1}{40}\,\text{eV at } T = 293\,\text{K}$$

Note: The latest values of the fundamental constants can be found at the National Institute of Standards and Technology website at http://physics.nist.gov/cuu/Constants/index.html

APPENDIX 3

Mathematical Relations

Expansions

$$(1 \pm x)^n = 1 \pm nx + \frac{n(n-1)}{2!}x^2 \pm \frac{n(n-1)(n-2)}{3!}x^3 + \cdots \quad |x| < 1$$

$$(1 \pm x)^{\frac{1}{2}} = 1 \pm \tfrac{1}{2}x - \tfrac{1}{8}x^2 \pm \tfrac{1}{16}x^3 - \cdots \quad |x| < 1$$

$$(1 \pm x)^{-\frac{1}{2}} = 1 \mp \tfrac{1}{2}x + \tfrac{3}{8}x^2 \mp \tfrac{5}{16}x^3 + \cdots \quad |x| < 1$$

$$(1 \pm x)^{-1} = 1 \mp x + x^2 \mp x^3 + \cdots \quad |x| < 1$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \cdots$$

$$\tan x = x + \frac{x^3}{3!} + \frac{2}{15}x^5 + \cdots \quad |x| < \pi/2$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

Functions and Relations

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$

$$\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B$$

$$\sinh x = \frac{e^x - e^{-x}}{2}$$

$$\cosh x = \frac{e^x + e^{-x}}{2}$$

Cartesian form: $z = x + iy$

Complex conjugate: $z^* = x - iy$, $i = \sqrt{-1}$

Polar form: $z = |z|e^{i\theta}$

$$z^* = |z|e^{-i\theta}$$

$$zz^* = |z|^2 = x^2 + y^2$$

Real part of z: $\text{Re } z = \frac{1}{2}(z + z^*) = x$

Imaginary part of z: $\text{Im } z = -\frac{1}{2}(z - z^*) = y$

$$\sin x = \frac{e^{ix} - e^{-ix}}{2i}$$

$$\cos x = \frac{e^{ix} + e^{-ix}}{2}$$

$$e^{ix} = \cos x + i \sin x$$

Integrals

$$\int \sin^2 x\, dx = -\frac{1}{2}\cos x \sin x + \frac{1}{2}x = \frac{1}{2}x - \frac{1}{4}\sin 2x$$

$$\int x \sin^2 x\, dx = \frac{x^2}{4} - \frac{x \sin 2x}{4} - \frac{\cos 2x}{8}$$

$$\int x^2 \sin^2 x\, dx = \frac{x^3}{6} - \left(\frac{x^2}{4} - \frac{1}{8}\right)\sin 2x - \frac{x \cos 2x}{4}$$

$$\int_0^\infty e^{-x/\alpha}\, dx = \alpha$$

$$\int_0^\infty x e^{-x/\alpha}\, dx = \alpha^2$$

$$\int_0^\infty x^2 e^{-x/\alpha}\, dx = 2\alpha^3$$

$$\int_0^\infty x^n e^{-x/\alpha}\, dx = n!\alpha^{n+1}$$

$$\int_0^\infty e^{-ax^2}\, dx = \frac{\pi^{1/2}}{2a^{1/2}}, \quad \int_0^\infty x e^{-ax^2}\, dx = \frac{1}{2a}$$

$$\int_0^\infty x^2 e^{-ax^2}\, dx = \frac{\pi^{1/2}}{4a^{3/2}}, \quad \int_0^\infty x^3 e^{-ax^2}\, dx = \frac{1}{2a^2}$$

$$\int_0^\infty x^4 e^{-ax^2}\, dx = \frac{3\pi^{1/2}}{8a^{5/2}}, \quad \int_0^\infty x^5 e^{-ax^2}\, dx = \frac{1}{a^3}$$

$$\int e^{-x/a} = -ae^{-x/a}$$

$$\int xe^{-x/a} = -ae^{-x/a}\left[x + a\right]$$

$$\int x^2 e^{-x/a} = -ae^{-x/a}\left[x^2 + 2xa + 2a^2\right]$$

$$\int x^3 e^{-x/a} = -ae^{-x/a}\left[x^3 + 3x^2 a + 6xa^2 + 6a^3\right]$$

$$\int x^4 e^{-x/a} = -ae^{-x/a}\left[x^4 + 4x^3 a + 12x^2 a^2 + 24xa^3 + 24a^4\right]$$

$$\int x^5 e^{-x/a} = -ae^{-x/a}\left[x^5 + 5x^4 a + 20x^3 a^2 + 60x^2 a^3 + 120xa^4 + 120a^5\right]$$

$$\int x^6 e^{-x/a} = -ae^{-x/a}\left[x^6 + 6x^5 a + 30x^4 a^2 + 120x^3 a^3 + 360x^2 a^4 + 720xa^5 + 720a^6\right]$$

$$\int x^7 e^{-x/a} = -ae^{-x/a} \times \left[x^7 + 7x^6 a + 42x^5 a^2 + 210x^4 a^3 + 840x^3 a^4 + 2520x^2 a^5 + 5040xa^6 + 5040a^7\right]$$