One dimensional Dirac equation

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This worksheet explores solutions of the one dimensional Dirac equation for a free particle
Let $\psi_1(t,x)$ $\psi_2(t,x)$ be the two components of the wave function then we must make sure that the folowing two functions DE1 and DE2 are identically zero:

Planck's constant (h) $h := 6.6260755 \cdot 10^{-34} \cdot joule \cdot sec$

$$DE1(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_1(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_2(t,x) + m_0 \cdot c^2 \cdot \psi_1(t,x)\right)$$

Electromagnetic Constants

$$DE2(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_2(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_1(t,x) - m_0 \cdot c^2 \cdot \psi_2(t,x)\right)$$

Elementary charge $e := 1.60217733 \cdot 10^{-19} \cdot coul$

We check all proposed solutions of the Dirac equationn by numerically evaluating DE1 and DE2 for the function in question for random values of x and t.

Magnetic flux quantum $\Phi_0 := 2.06783461 \cdot 10^{-15} \cdot weber$

We can set the fundamental constants c: speed of light, h_ :planck's constant divided by 2π and m_0 the particle rest mas all equal to one.

Bohr magneton $9.2740154 \cdot 10^{-24} \cdot \frac{joule}{tesla}$

$m_0 := 1$ $c := 1$ $h\_ := 1$

Positive energy wave functions in terms of spatial wave vector k

Nuclear magneton $5.0507866 \cdot 10^{-27} \cdot \frac{joule}{tesla}$

Let $Ep(k) := \sqrt{(h\_ \cdot k \cdot c)^2 + m_0^2 \cdot c^4}$

Atomic Constants

Plane waves from left to right

Fine structure constant $\alpha := 7.29735308 \cdot 10^{-3}$

k must be positive $k := 2$

Rydberg constant $R := 10973731.534 \cdot m^{-1}$

k is positive

$$\Psi 1EpKp(k,t,x) := \sqrt{\frac{Ep(k) + m_0 \cdot c^2}{h\_}} \cdot \left[(\exp(i \cdot k \cdot x)) \cdot \exp\left(-i \cdot \frac{Ep(k)}{h\_} \cdot t\right) \right]$$

Bohr radius $a_0 := 0.529177249 \cdot 10^{-10} \cdot m$

Hartree energy $E_h := 4.3597482 \cdot 10^{-18} \cdot joule$

$$\Psi 2EpKp(k,t,x) := \sqrt{\frac{Ep(k) - m_0 \cdot c^2}{h\_}} \cdot \left[(\exp(i \cdot k \cdot x)) \cdot \exp\left(-i \cdot \frac{Ep(k)}{h\_} \cdot t\right) \right]$$

k is positive

Quantum of circulation $3.63694807 \cdot 10^{-4} \cdot \frac{m^2}{sec}$

As mentioned, we check these functions against the Dirac equation:

$\psi_1(t,x) := \Psi 1EpKp(k,t,x)$ $\psi_2(t,x) := \Psi 2EpKp(k,t,x)$

Electron

Electron mass $m_e := 9.1093897 \cdot 10^{-31} \cdot kg$

$$DE1(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_1(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_2(t,x) + m_0 \cdot c^2 \cdot \psi_1(t,x)\right)$$

Electron specific charge (electron charge to mass ratio) $-1.75881962 \cdot 10^{11} \cdot \frac{coul}{kg}$

$$DE2(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_2(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_1(t,x) - m_0 \cdot c^2 \cdot \psi_2(t,x)\right)$$

Electron Compton wavelength

$$DE1(3,2) = -4.263 \times 10^{-14} - 2.354i \times 10^{-14}$$

checks out

$2.42631058 \cdot 10^{-12} \cdot m$

Next, plane waves from right to left $k := -3$

Classical electron radius $r_e := 2.81794092 \cdot 10^{-15} \cdot m$

$$\Psi 1EpKn(k,t,x) := \sqrt{\frac{[illegible]}{h\_}} \cdot \left[(\exp(i \cdot k \cdot x)) \cdot \exp\left(-i \cdot \frac{Ep(k)}{h\_} \cdot t\right) \right]$$

Electron magnetic moment $928.47701 \cdot 10^{-26} \cdot \frac{joule}{tesla}$

$m_{\mu} = 1.884 \times 10^{-25}\,gm$

Proton

$\psi_1(t,x) := \Psi 1EpKn(k,t,x)$ $\quad \psi_2(t,x) := \Psi 2EpKn(k,t,x)$

$\psi_1(3,2) = -1.99 - 0.447i$

$\psi_2(3,2) = 1.435 + 0.323i$

Proton mass $\quad m_p := 1.6726231 \cdot 10^{-27} \cdot kg$

$$DE1(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_1(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_2(t,x) + m_0 \cdot c^2 \cdot \psi_1(t,x)\right)$$

Ratio of proton mass to electron mass $\quad 1836.152701$

$k = -3$

$$DE2(t,x) := i \cdot h\_ \cdot \frac{d}{dt}\psi_2(t,x) - \left(-i \cdot h\_ \cdot c \cdot \frac{d}{dx}\psi_1(t,x) - m_0 \cdot c^2 \cdot \psi_2(t,x)\right)$$

Proton Compton wavelength $\quad 1.32141002 \cdot 10^{-15} \cdot m$

$DE1(3,2) = -1.19 \times 10^{-13} - 6.661i \times 10^{-15}$

Proton magnetic moment $\quad 1.41060761 \cdot 10^{-26} \cdot \frac{joule}{tesla}$

Negative energy wave functions in terms of spatial wave vector k

Let

Proton gyromagnetic ratio

$$En(k) := -\sqrt{(h\_ \cdot k \cdot c)^2 + m_0{}^2 \cdot c^4}$$

$26751.5255 \cdot 10^4 \cdot \frac{rad}{sec \cdot tesla}$

Plane waves from right to left $\quad$ k must be negative $\quad k := -2$

Neutron

Neutron mass $\quad m_n := 1.6749286 \cdot 10^{-27} \cdot kg$

k is negative

$$\Psi 1EnKn(k,t,x) := \sqrt{\frac{En(k) + m_0 \cdot c^2}{h\_}} \cdot \left[(\exp(i \cdot k \cdot x)) \cdot \exp\left[\left(-i\,\frac{En(k)}{h\_}\right) \cdot t\right]\right]$$

Neutron Compton wavelength $\quad 1.31959110 \cdot 10^{-15} \cdot m$

$$\Psi 2EnKn(k,t,x) := \sqrt{\frac{En(k) - m_0 \cdot c^2}{h\_}} \cdot \left[(\exp(i \cdot k \cdot x)) \cdot \exp\left(-i \cdot \frac{En(k)}{h\_} \cdot t\right)\right]$$

k is negative

Physico-Chemical Constants

Avogadro constant $\quad N_A := 6.0221367 \cdot 10^{23} \cdot mole^{-1}$

Atomic mass constant $\quad AMU := 1.6605402 \cdot 10^{-27} \cdot kg$

$\psi_1(t,x) := \Psi 1EnKn(k,t,x)$ $\quad \psi_2(t,x) := \Psi 2EnKn(k,t,x)$

$x := 2$ $t := 3$

$$\frac{i\cdot h\_\cdot\frac{d}{dt}\psi_2(3,2) - \left(-i\cdot h\_\cdot c\cdot\frac{d}{dx}\psi_1(3,2) - m_0\cdot c^2\cdot\psi_2(3,2)\right)}{-3.798\times 10^{-34}\cdot\frac{1}{gm}} = 1.989\times 10^{33} + 4.299i\times 10^{33}\,gm$$

$$Re\left[\frac{i\cdot h\_\cdot\frac{d}{dt}\psi_2(3,2) - \left(-i\cdot h\_\cdot c\cdot\frac{d}{dx}\psi_1(3,2) - m_0\cdot c^2\cdot\psi_2(3,2)\right)}{-3.798\times 10^{-34}\cdot\frac{1}{gm}}\right] = 1.989\times 10^{33}\,gm$$

Boltzmann's constant

$DE1(3,2) = 2.109\times 10^{-14} + 4.086i\times 10^{-14}$

$$k_b := 1.380658\cdot 10^{-23}\cdot\frac{joule}{K}$$

checks out

Next, plane waves from right to left

$k := 3$

Molar volume of ideal gas at STP

$$22.41410\cdot\frac{liter}{mole}$$

$$\Psi1EnKp(k,t,x) := \sqrt{\frac{En(k) + m_0\cdot c^2}{h\_}}\cdot\left[(\exp(i\cdot k\cdot x))\cdot\exp\left(-i\cdot\frac{En(k)}{h\_}\cdot t\right)\right]$$

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k is positive

$$K := 1.3806580000000000000\cdot 10^{-23}\cdot\frac{joule}{k_b}$$

Stefan-Boltzmann constant

$$\sigma := 5.67051\cdot 10^{-8}\cdot\frac{watt}{m^2\cdot K^4}$$

k is positive

$$\Psi2EnKp(k,t,x) := -\sqrt{\frac{En(k) + m_0\cdot c^2}{h\_}}\cdot\left(\exp(i\cdot k\cdot x)\cdot\exp\left(-i\cdot\frac{En(k)}{h\_}\cdot t\right)\right)$$

( )Tφ +Φ. 21 Tφ 0. 4761 0 0 1. 216 72 277. 8898 Tμ ( )

First radiation constant

$$3.7417749\cdot 10^{-16}\cdot watt\cdot m^2$$

Second radiation constant

$$0.01438769\cdot m\cdot K$$

$\psi_1(t,x) := \Psi1EnKp(k,t,x)$ $\psi_2(t,x) := \Psi2EnKp(k,t,x)$

$\psi_1(3,2) = -0.323 - 1.435i$

$$DE1(t,x) := i\cdot h\_\cdot\frac{d}{dt}\psi_1(t,x) - \left(-i\cdot h\_\cdot c\cdot\frac{d}{dx}\psi_2(t,x) + m_0\cdot c^2\cdot\psi_1(t,x)\right)$$

$\psi_2(3,2) = 0.447 + 1.99i$

Data from CRC Handbook of Chemistry and Physics, 73nd edition, edited by David R. Lide, CRC Press (1992).

dt dx

$DE1(3,2) = 3.131\times 10^{-14} + 1.625i\times 10^{-13}$

$$\Psi 1dg(t,x) := \int_{0.00}^{20} \frac{\Psi 1EpKp'(k,t,x) - \Psi 1EnKp'(k,t,x)}{2\cdot Ep(k)}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{2}\right] dk - \int_{-20}^{0} \frac{\Psi 1EpKn'(k,t,x) - \Psi 1EnKn'(k,t,x)}{2\cdot En(k)}\cdot \exp$$

$$\Psi 2dg(t,x) := \int_{0.00}^{20} \frac{\Psi 2EpKp'(k,t,x) - \Psi 2EnKp'(k,t,x)}{2\cdot Ep(k)}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{2}\right] dk - \int_{-20}^{0} \frac{\Psi 2EpKn'(k,t,x) - \Psi 2EnKn'(k,t,x)}{2\cdot En(k)}\cdot$$

$$DE1(t,x) := i\cdot h\_\cdot \frac{d}{dt}\Psi 1dg(t,x) - \left(-i\cdot h\_\cdot c\cdot \frac{d}{dx}\Psi 2dg(t,x) + m_0\cdot c^2\cdot \Psi 1dg(t,x)\right)$$

$$DE2(t,x) := i\cdot h\_\cdot \frac{d}{dt}\Psi 2dg(t,x) - \left(-i\cdot h\_\cdot c\cdot \frac{d}{dx}\Psi 1dg(t,x) - m_0\cdot c^2\cdot \Psi 2dg(t,x)\right)$$

$DE1(3,2) = 8.105\times 10^{-15} +$ $DE2(3,2) = -1.107\times 10^{-16} - 1.277i\times 10^{-15}$

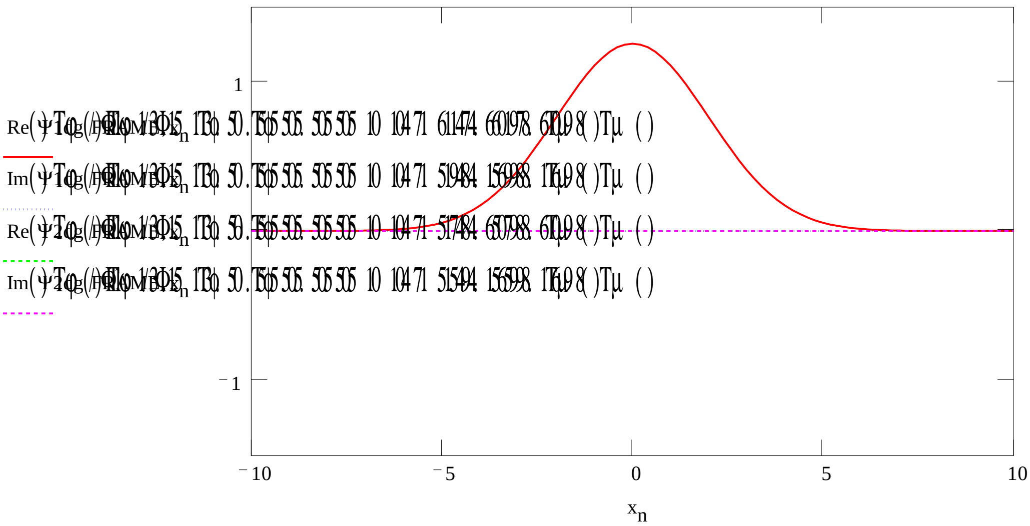
$\Psi 1dg(0,0) = 1.253$

t := FRAME

$x_n := -10, -9.8 .. 10$

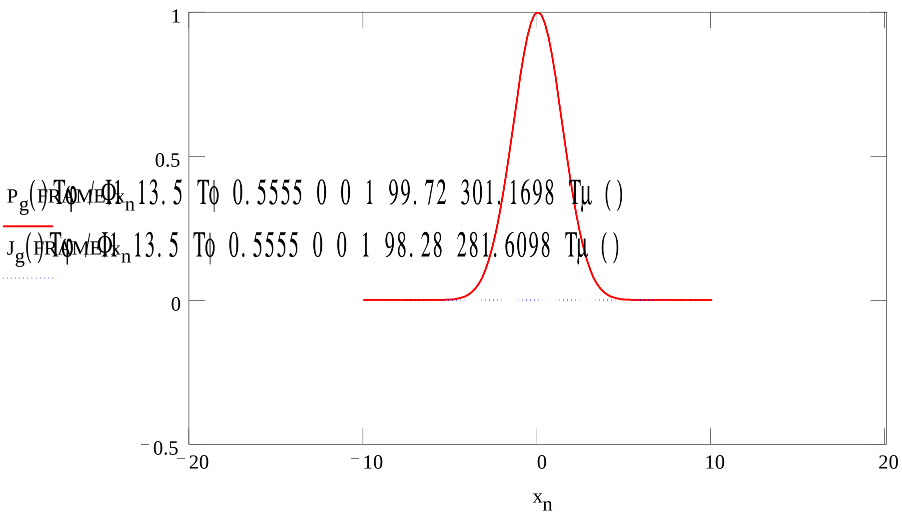
$\sigma = 2 \qquad t = 0$

Four equations plot



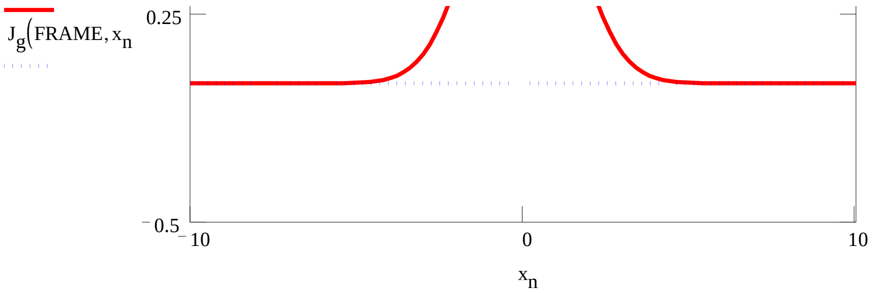
$$P_g(t,x) := \frac{\sigma^2}{2\cdot\pi}\cdot\left[\left(\left|\Psi1dg(t,x)\right|^2 + \left|\Psi2dg(t,x)\right|^2\right)\right] \qquad J_g(t,x) := c\cdot\left(\frac{\sigma^2}{2\cdot\pi}\right)\cdot\left(\overline{\Psi1dg(t,x)}\cdot\Psi2dg(t,x) + \Psi1dg(t,x)\cdot\overline{\Psi2dg(t,x)}\right)$$

$\sigma = 2 \qquad t = 0$



$\sigma := .2$

$$\Psi1dg(t,x) := \int_{0.}^{} \frac{\Psi1EpKp(k,t,x)}{2\cdot(Ep(k))}\cdot\exp\left[-\frac{(\sigma\cdot k)^2}{}\right] dk + \int_{-10}^{0} \frac{\Psi1EpKm(k,t,x)}{2\cdot(Ep(k))}\cdot\exp\left[-\frac{(\sigma\cdot k)^2}{}\right] dk$$



Wide Gaussian Wave Packets Positive Energy

$\sigma := 2$

$$\Psi1dg(t,x) := \int_{0.}^{5} \frac{\Psi1EpKp'(k,t,x)}{2\cdot(\pi)^{\frac{1}{4}}}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{4}\right] dk + \int_{-5}^{0} \frac{\Psi1EpKn'(k,t,x)}{2\cdot(\pi)^{\frac{1}{4}}}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{4}\right] dk$$

$$\Psi2dg(t,x) := \int_{0.00}^{5} \frac{\Psi2EpKp'(k,t,x)}{2\cdot(\pi)^{\frac{1}{4}}}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{4}\right] dk + \int_{-5}^{0} \frac{\Psi2EpKn'(k,t,x)}{2\cdot(\pi)^{\frac{1}{4}}}\cdot \exp\left[-\frac{(\sigma\cdot k)^2}{4}\right] dk$$

$$P_g(t,x) := \frac{2\cdot\sigma^2}{\pi}\cdot\left[\left(|\Psi1dg(t,x)|\right)^2 + \left(|\Psi2dg(t,x)|\right)^2\right]$$

$$J_g(t,x) := c\cdot\left(\frac{2\cdot\sigma^2}{\pi}\right)\cdot\left(\overline{\Psi1dg(t,x)}\cdot\Psi2dg(t,x) + \Psi1dg(t,x)\cdot\overline{\Psi2dg(t,x)}\right)$$

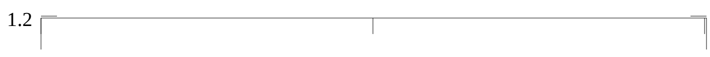
$$DE1(t,x) := i\cdot h\_\cdot\frac{d}{dt}\Psi1dg(t,x) - \left(-i\cdot h\_\cdot c\cdot\frac{d}{dx}\Psi2dg(t,x) + m_0\cdot c^2\cdot\Psi1dg(t,x)\right)$$

$$DE2(t,x) := i\cdot h\_\cdot\frac{d}{dt}\Psi2dg(t,x) - \left(-i\cdot h\_\cdot c\cdot\frac{d}{dx}\Psi1dg(t,x) - m_0\cdot c^2\cdot\Psi2dg(t,x)\right)$$

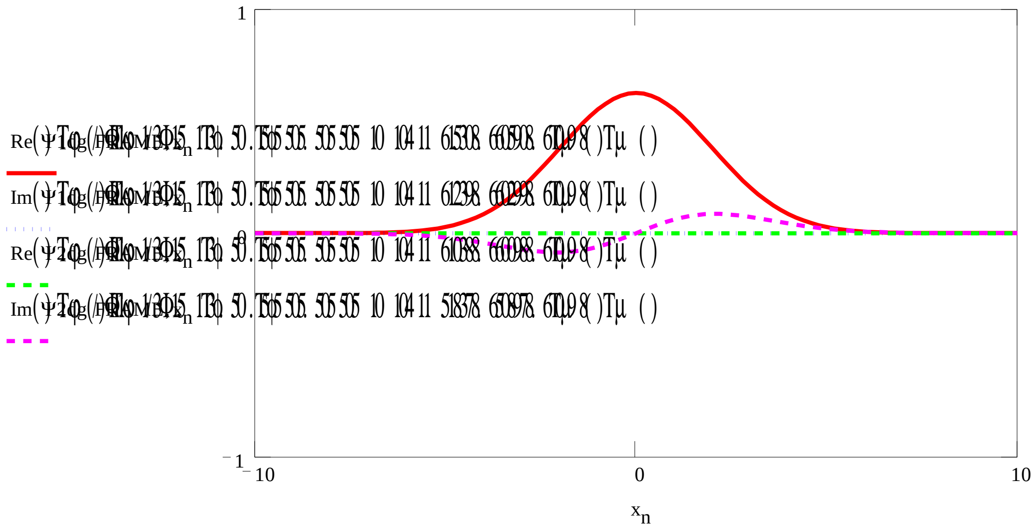
$DE2(3,2) = -1.867\times 10^{-15} - 7.494i\times 10^{-16}$

$DE1(3,2) = -1.277\times 10^{-15} - 5.135i\times 10^{-16}$

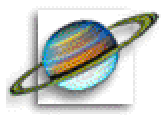
$\sigma = 2 \qquad t = 0$



$\sigma = 2 \qquad t = 0$



CHAPTER 6 ASTRONOMICAL & PHYSICAL CONSTANTS



6.2 Physical Constants

$K \equiv 1$

$mol \equiv 1$

$$G \equiv 6.672 \cdot 10 \cdot \frac{\quad}{kg \cdot sec^2}$$

Newtonian constant of gravitation:

$$h \equiv 6.62607 \cdot 10^{-34} \cdot joule \cdot sec$$

Planck constant:

$$\mu_0 \equiv 4 \cdot \pi \cdot 10^{-7} \cdot \frac{henry}{m}$$

Permeability of vacuum:

$$\mu_0 = 1.256637061 \times 10^{-6} \frac{henry}{m}$$

$$\varepsilon_0 \equiv \frac{1}{\mu_0 \cdot c^2}$$

Permittivity of vacuum:

$$\varepsilon_0 = 8.854187818 \times 10^{-12} \frac{farad}{m}$$

Electromagnetic Constants

$e \equiv 1.602177 \cdot 10^{-19} \cdot coul$

Elementary charge:

$$\mu_B = \frac{e \cdot h}{4 \cdot \pi \cdot m_e}$$

Bohr magneton:

$$\mu_B \equiv 9.27402 \cdot 10^{-24} \cdot \frac{joule}{tesla}$$

$$\mu_N = \frac{e \cdot h}{4 \cdot \pi \cdot m_p}$$

Nuclear magneton:

$$\mu_N \equiv 5.05079 \cdot 10^{-27} \cdot \frac{joule}{tesla}$$

Atomic Constants

$$\alpha = \frac{1}{2} \cdot \frac{\mu_0 \cdot c \cdot e^2}{h}$$

Fine-structure constant:

$$\alpha \equiv 7.297353 \cdot 10^{-3}$$

$$R_\alpha = \frac{1}{2} \cdot \frac{m_e \cdot c \cdot \alpha^2}{h}$$

Rydberg constant:

$$R_\alpha \equiv 10973731.5 \cdot \frac{1}{m}$$

$$a_0 = \frac{\alpha}{4 \cdot \pi \cdot R_\alpha}$$

Bohr radius:

$$a_0 \equiv 0.5291772 \cdot 10^{-10} \cdot m$$

Electron

$m_e \equiv 9.10939 \cdot 10^{-31} \cdot kg$

Electron mass:

$\lambda_C = \frac{h}{m_e \cdot c}$

Compton wavelength:

$\lambda_C \equiv 2.426310 \cdot 10^{-12} \cdot m$

$r_e = \alpha^2 \cdot a_0$

Classical electron radius:

$r_e \equiv 2.817941 \cdot 10^{-15} \cdot m$

$\sigma_e = \frac{8 \cdot \pi}{3} \cdot r_e^{\,2}$

Thomson cross section:

$\sigma_e \equiv 0.665246 \cdot 10^{-28} \cdot m^2$

$\mu_e \equiv 928.477 \cdot 10^{-26} \cdot \frac{joule}{tesla}$

Electron magnetic moment:

Proton

$m_p \equiv 1.67262 \cdot 10^{-27} \cdot kg$

Proton mass:

$\lambda_{Cp} = \frac{h}{m_p \cdot c}$

Proton Compton wavelength:

$\lambda_{Cp} \equiv 1.321410 \cdot 10^{-15} \cdot m$

$\mu_p \equiv 1.410607 \cdot 10^{-26} \cdot \frac{joule}{tesla}$

Proton magnetic moment:

Neutron

$m_n \equiv 1.674929 \cdot 10^{-27} \cdot kg$

Neutron mass

$\lambda_{Cn} = \frac{h}{m_n \cdot c}$

Neutron Compton wavelength:

$\lambda_{Cn} \equiv 1.319591 \cdot 10^{-15} \cdot m$

$\mu_n \equiv 0.966237 \cdot 10^{-26} \cdot \frac{joule}{tesla}$

Neutron magnetic moment

Physical-Chemical Constants

$N_A \equiv 6.022137 \cdot 10^{23} \cdot \frac{1}{mol}$

Avogadro constant

$m_u \equiv 1.66054 \cdot 10^{-27} \cdot kg$

Atomic mass constant, m(^{12}C)/12:

$F \equiv 96485.3 \cdot \frac{coul}{mol}$

Faraday constant:

$k_b \equiv 1.3807 \cdot 10^{-23} \cdot \frac{joule}{K}$

Boltzmann constant, R/N_A:

$\sigma = \frac{\pi^2}{60} \cdot \frac{k^4}{\left[\left(\frac{h}{2 \cdot \pi}\right)^3 \cdot c^2\right]}$

Stefan-Boltzmann constant:

$1.3807 \cdot 10^{-23} \cdot \frac{joule}{K} = 1.381 \times 10^{-16} erg$

$k_b = 1.381 \times 10^{-23} \frac{joule}{K}$

$\sigma = 5.671 \cdot 10^{-8} \frac{watt}{}$

Maintained Units and Standard Values

$eV \equiv 1.602177 \cdot 10^{-19} \cdot joule$

Electron volt:

$atm \equiv 101325 \cdot Pa$

Standard atmosphere:

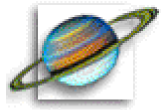
$g_n \equiv 9.80665 \cdot \frac{m}{sec^2}$

Standard acceleration of gravity:

$Angstrom \equiv 1.000015 \cdot 10^{-10} \cdot m$

Angstrom unit:

CHAPTER 6 ASTRONOMICAL & PHYSICAL CONSTANTS



6.1 Astronomical Constai

Introduction

This document provides a list of fundamenta
constants (the IAU (1976) system of astrono
properties of the major solar system bodies.
the Astronomical Almanac.

Physical constants are provided for

- The Sun
- The Moon
- The Earth
- The Planets

$$c \equiv 299792458 \cdot \frac{m}{sec}$$

Speed of light:

Primary Constants

$\tau_A \equiv 499.004782 \cdot sec$

Light-time for unit distance:

$a_e \equiv 6378140 \cdot m$

Equatorial radius for Earth:

$J_2 \equiv 0.00108263$

Dynamical form-factor for Earth:

$$GE \equiv 3.986005 \cdot 10^{14} \cdot \frac{m^3}{sec^2}$$

Geocentric gravitational constant:

$$G \equiv 6.672 \cdot 10^{-11} \cdot \frac{m^3}{kg \cdot sec^2}$$

Constant of gravitation:

$\mu \equiv 0.01230002$

Ratio of mass of Moon to Earth

General precession in longitude, per Julian century, at standard epoch 2000:

$\rho \equiv 5029.0966 \cdot arc\_sec$

Obliquity of the ecliptic, at standard epoch 2000:

$\varepsilon \equiv 23.4392911 \cdot deg$

Derived Constants

Constant of nutation, at standard epoch 2000:

$$N \equiv 9.2025 \cdot arc\_sec$$

$$A \equiv c \cdot \tau_A$$

Unit distance:

$$A = 1.4959787 \times 10^{11}\, m$$

$$\pi_S \equiv asin\left(\frac{a_e}{A}\right)$$

Solar parallax:

$$\pi_S = 8.794148\, arc\_sec$$

Constant of aberration, for standard epoch 2000:

$$\kappa \equiv 20.49552 \cdot arc\_sec$$

$$f \equiv 0.00335281$$

Flattening factor for the Earth:

$$GS \equiv A^3 \cdot \frac{k^2}{D^2}$$

Heliocentric gravitational constant:

$$GS = 1.32712439 \times 10^{20}\, \frac{m^3}{sec^2}$$

Ratio of mass of Sun to that of the Earth:

$$S\_E \equiv \frac{GS}{GE}$$

$$S\_E = 332946$$

Ratio of mass of Sun to that of Earth + Moon:

$$S\_E\_M \equiv \frac{S\_E}{1 + \mu}$$

$$S \equiv \frac{GS}{G}$$

Planetary masses (mass of Sun to mass of

$\mathrm{Saturn} \equiv 3498.5$

$\mathrm{Mercury} \equiv 6023600$

$\mathrm{Uranus} \equiv 22869$

$\mathrm{Venus} \equiv 408523.5$

$\mathrm{Neptune} \equiv 19314$

$\mathrm{Earth\_Moon} \equiv 328900.5$

$\mathrm{Pluto} \equiv 3000000$

$\mathrm{Mars} \equiv 3098710$

$\mathrm{Jupiter} \equiv 1047.355$

Sun, Earth, Moon, and Planets

Sun

$R_s \equiv 6.96 \cdot 10^{8} \cdot \mathrm{m}$

$M_S = 1.989 \times 10^{33}\,\mathrm{gm}$

Radius:

$\theta_s \equiv 959.63 \cdot \mathrm{arc\_sec}$

Semidiameter at mean distance:

$M_S \equiv 1.9891 \cdot 10^{30} \cdot \mathrm{kg}$

Mass:

$\rho_E \equiv 1.41 \cdot \frac{\mathrm{gm}}{\mathrm{cm}^3}$

Mean density:

$g_S \equiv 2.74 \cdot 10^{2} \cdot \frac{\mathrm{m}}{\mathrm{sec}^2}$

Surface gravity:

$i_S \equiv 7.25 \cdot \mathrm{deg}$

Inclination of solar equator to ecliptic:

$L = 75.77 + 1.40T$
degrees

$P = 26.90 + 5.2\sin^2\phi$ days

Period of synodic rotation

Earth

$R_e \equiv 6378140 \cdot m$

Equatorial radius:

$R_p \equiv 6356755 \cdot m$

Polar radius:

$M_E \equiv 5.9742 \cdot 10^{24} \cdot kg$

Mass of the Earth:

$\rho_E \equiv 5.52 \cdot \frac{gm}{cm^3}$

Mean density:

Normal gravity (ϕ = geodetic latitude):

g = 9.80621 - 0.02593cos 2ϕ + 0.00003cos

$\pi_S \equiv 8.794148 \cdot arc\_sec$

Solar parallax:

$AU \equiv 1.49597870 \cdot 10^{11} \cdot m$

1 astronomical unit of length (AU):

$e \equiv 0.016708617$

Mean eccentricity of the Earth's orbit:

$\varepsilon \equiv 23.4392911 \cdot deg$

Mean obliquity of the ecliptic:

$\xi \equiv 0.4704 \cdot \frac{arc\_sec}{yr}$

Annual rate of rotation of the ecliptic:

$d_S \equiv 1.0000010178 \cdot A$

Mean Earth-Sun distance:

$v_E \equiv 29.7859 \cdot \frac{km}{sec}$

Mean orbital speed:

sec

Mean centripetal acceleration:

Rotational period with respect to the fixed st

Moon

$R_M \equiv 1738 \cdot km$

Mean radius:

$\theta_m \equiv 15.543 \cdot arc\_min$

Semidiameter at mean distance:

$M_M \equiv 7.3483 \cdot 10^{22} \cdot kg$

Mass of Moon:

$\rho_M \equiv 3.34 \cdot \frac{gm}{cm^3}$

Mean density:

$g_M \equiv 1.62 \cdot \frac{m}{sec^2}$

Surface gravity:

$d_M \equiv 3.844 \cdot 10^5 \cdot km$

Mean distance of Moon from Earth:

Equatorial horizontal parallax at mean distance to Earth:

$\pi_M \equiv 3422.608 \cdot arc\_sec$

Mean eccentricity of the Moon's orbit about the Earth:

$e_M \equiv 0.05490$

$I_M \equiv 5.145396 \cdot deg$

Mean inclination of orbit to ecliptic:

Mean inclination of orbit to lunar equator:

$i_M \equiv 6.68 \cdot deg$

$\delta_{North} \equiv 29 \cdot deg$

Limits of geocentric declination:

$\delta_{South} \equiv 29 \cdot deg$

$v_M \equiv 1023 \cdot \frac{m}{sec}$

Mean orbital speed:

Planets (mean orbital elements are for J2

Eccentricity

Inclination (deg)

Mean Distance (AU)

Planet

0.205631

7.005

0.387098

Mercury

0.006772

3.394

0.723330

Venus

0.016709

0.000

1.000000

Earth

0.093401

1.850

1.523679

Mars

0.048495

1.303

5.202603

Jupiter

0.055509

2.489

9.554910

Saturn

0.046296

0.773

19.218446

Uranus

0.008988

30.110387

Neptune

0.249050

583.9214

0.615183

Venus

29.7859

0.999979

Earth

24.1309

779.9361

1.880711

Mars

13.0697

398.8840

11.856525

Jupiter

9.6724

378.0919

29.423519

Saturn

6.8352

369.6560

83.747407

Uranus

5.4778

367.4867

163.723045

Neptune

4.7490

366.7207

248.0208

Pluto

The sidereal period is the period of revolutic
respect to the fixed stars; the synodic perioc
between successive oppositions of a superi
successive inferior conjunctions of an inferic

Mean Density ($g\ cm^{-3}$)	Equatorial Radius (km)	Mass (10^{24} kg)	Planet
5.43	2439.7	0.3302	Mercury
5.24	6051.9	4.8690	Venus
5.515	6378.140	5.9742	Earth
3.34	1738	0.0735	*Moon*
3.94	3397	0.64191	Mars
1.33	71492	1898.8	Jupiter
0.70	60268	568.50	Saturn

1.30

25559

86.625

Uranus

1.76

24764

102.78

Neptune

1.1

1151

0.015

Pluto

Sidereal Rot. Period (Days)

Eq. Escape Velocity (km/s)

Eq. Surface Gravity (Earth = 1)

Planet

58.6462

4.3

0.387

Mercury

–243.01

10.3

0.879

Venus

0.99726968

11.2

1.000

Earth

27.32166

2.38

0.166