Constants and Conversions

Fundamental constants

Gravitational constant: $G = 6.67408 \times 10^{-8}\,\text{dyn cm}^2\,\text{g}^{-2}$
$= 6.67408 \times 10^{-8}\,\text{g}^{-1}\,\text{cm}^3\,\text{s}^{-2}$
$= 6.67408 \times 10^{-8}\,\text{erg cm g}^{-2}$
$= 2.960 \times 10^{-4} M_\odot^{-1}\,\text{AU}^3\,\text{days}^{-2}$
$= 1.327 \times 10^{11} M_\odot^{-1}\,\text{km}^3\,\text{s}^{-2}$

Speed of light: $c = 2.99792458 \times 10^{10}\,\text{cm s}^{-1}$

Planck's constant: $h = 2\pi\hbar = 6.6261 \times 10^{-27}\,\text{erg s}$
$= 4.136 \times 10^{-21}\,\text{MeV s}$
$\hbar = 1.0546 \times 10^{-27}\,\text{erg s} = 6.5827 \times 10^{-22}\,\text{MeV s}$
$\hbar c = 197.3\,\text{MeV fm} = 197.3 \times 10^{-13}\,\text{MeV cm}$

Electrical charge unit: $e = 4.8032068 \times 10^{-10}\,\text{esu}$
$= 4.8032068\,\text{erg}^{1/2}\text{cm}^{1/2}$
$= 4.8032068\,\text{g}^{1/2}\,\text{cm}^{3/2} s^{-1}$

Fine structure constant: $\alpha = (137.036)^{-1} = 0.0073$

Weak (Fermi) constant: $G_\text{F} = 8.958 \times 10^{-44}\,\text{MeV cm}^3$
$= 1.16637 \times 10^{-5}\,\text{GeV}^{-2}$ $[G_\text{F}/(\hbar c)^3;\ \hbar = c = 1]$

Mass of electron: $m_\text{e} = 9.1093898 \times 10^{-28}\,\text{g}$
$= 5.4858 \times 10^{-4}\,\text{amu}$
$= 0.5109991\,\text{MeV/c}^2$

Mass of proton: $m_\text{p} = 1.6726231 \times 10^{-24}\,\text{g}$
$= 1.00727647\,\text{amu}$
$= 938.27231\,\text{MeV/c}^2$

Mass of neutron: $m_\text{n} = 1.6749286 \times 10^{-24}\,\text{g}$
$= 1.0086649\,\text{amu}$
$= 939.56563\,\text{MeV/c}^2$

Atomic mass unit (amu) $= 1.6605390 \times 10^{-24}\,\text{g}$

Avogadro's constant: $N_\text{A} = 6.0221409 \times 10^{23}\,\text{mol}^{-1}$

Boltzmann's constant: $k = 1.38065 \times 10^{-16}\,\text{erg K}^{-1}$
$= 8.617389 \times 10^{-5}\,\text{eV K}^{-1}$

Ideal gas constant: $R_\text{gas} \equiv N_\text{A} k = 8.314511 \times 10^7\,\text{erg K}^{-1}\,\text{mole}^{-1}$

Stefan–Boltzmann constant: $\sigma = 5.67051 \times 10^{-5}\,\text{erg cm}^{-2}\,\text{K}^{-4}\,\text{s}^{-1}$

Radiation density constant: $a \equiv 4\sigma/c = 7.56591 \times 10^{-15}\,\text{erg cm}^{-3}\,\text{K}^{-4}$
$= 4.7222 \times 10^{-9}\,\text{MeV cm}^{-3}\text{K}^{-4}$

Planck mass: $M_\text{P} = 1.2 \times 10^{19}\,\text{GeV}/c^2$

Planck length: $\ell_\text{P} = 1.6 \times 10^{-33}\,\text{cm}$

Planck time: $t_\text{P} = 5.4 \times 10^{-44}\,\text{s}$

Planck temperature: $T_\text{P} = 1.4 \times 10^{32}\,\text{K}$

Solar quantities

Solar (photon) luminosity: $L_\odot = 3.828 \times 10^{33}$ erg/s

Solar absolute magnitude $M_\mathrm{v} = 4.83$

Solar bolometric magnitude $M^\odot_\mathrm{bol} = 4.74$

Solar mass: $M_\odot = 1.989 \times 10^{33}$ g

Effective surface temperature: $T^\mathrm{eff}_\odot = 5780\,\mathrm{K}$

Solar radius: $R_\odot = 6.96 \times 10^{10}$ cm

Central density: $\rho^\mathrm{core}_\odot \simeq 160\,\mathrm{g/cm^3}$

Central pressure: $P^\mathrm{core}_\odot \simeq 2.7 \times 10^{17}\,\mathrm{dyn\ cm^{-2}}$

Central temperature: $T^\mathrm{core}_\odot \simeq 1.6 \times 10^{7}\,\mathrm{K}$

Color indices: $B - V = 0.63 \qquad U - B = 0.13$

Solar constant: $1.36 \times 10^{6}\,\mathrm{erg\ cm^{-2}\ s^{-1}}$

General quantities

1 tropical year (yr) = $3.1556925 \times 10^{7}\,\mathrm{s} = 365.24219\,\mathrm{d}$

1 parsec (pc) = $3.0857 \times 10^{18}\,\mathrm{cm} = 206{,}265$ AU= 3.2616 ly

1 lightyear (ly) = 9.4605×10^{17} cm

1 astronomical unit (AU) = 1.49598×10^{13} cm

Energy per gram from H $\rightarrow$ He fusion = 6.3×10^{18} erg/g

Thomson scattering cross section: $\sigma_\mathrm{T} = 6.652 \times 10^{-25}\,\mathrm{cm^2}$

Mass of Earth $M_\oplus = 5.98 \times 10^{27}$ g

Radius of Earth $R_\oplus = 6.371 \times 10^{8}$ cm

Useful conversion factors

1 eV $= 1.60217733 \times 10^{-12}\,\mathrm{ergs} = 1.60217733 \times 10^{-19}\,\mathrm{J}$

1 J $= 10^{7}\,\mathrm{ergs} = 6.242 \times 10^{18}\,\mathrm{eV}$

1 amu $= 1.6605390 \times 10^{-24}$ g

1 fm $= 10^{-13}$ cm

0 K $= -273.16$ Celsius

1 atomic unit $(a_0) = 0.52918 \times 10^{-8}$ cm

1 atmosphere (atm) $= 1.013250 \times 10^{6}\,\mathrm{dyn\ cm^{-2}}$

1 Pascal (Pa) $= 1\,\mathrm{N\ m^{-2}} = 10\,\mathrm{dyn\ cm^{-2}}$

1 arcsec $= 1'' = 4.848 \times 10^{-6}\,\mathrm{rad} = 1/3600\,\mathrm{deg}$

1 Å $= 10^{-8}$ cm

1 barn (b) $= 10^{-24}\,\mathrm{cm^2}$

1 Newton (N) $= 10^{5}$ dyn

1 Watt (W) $= 1\,\mathrm{J\ s^{-1}} = 10^{7}\,\mathrm{erg\ s^{-1}}$

1 Gauss (G) = 10^{-4} Tesla (T)

$1\,\mathrm{g\,cm^{-3}} = 1000\,\mathrm{kg\,m^{-3}}$

Opacity units: $1\,\mathrm{m^2\ kg^{-1}} = 10\,\mathrm{cm^2\ g^{-1}}$

Geometrized Units

In gravitational physics it is useful to employ a natural set of units called *geometrized units* or $c = G = 1$ units that give both the speed of light and the gravitational constant unit value. Setting

$$1 = c = 2.9979 \times 10^{10}\,\mathrm{cm\ s^{-1}} \qquad 1 = G = 6.6741 \times 10^{-8}\,\mathrm{cm^3\ g^{-1}\ s^{-2}},$$

one may solve for standard units like seconds in terms of these new units. For example, from the first equation

$$1\,\mathrm{s} = 2.9979 \times 10^{10}\,\mathrm{cm},$$

and from the second

$$\begin{aligned} 1\,\mathrm{g} &= 6.6741 \times 10^{-8}\,\mathrm{cm^3\ s^{-2}} \\ &= 6.6741 \times 10^{-8}\,\mathrm{cm^3} \left(\frac{1}{2.9979 \times 10^{10}\,\mathrm{cm}} \right)^2 \\ &= 7.4261 \times 10^{-29}\,\mathrm{cm}. \end{aligned}$$

So both time and mass have the dimension of length in geometrized units. Likewise, from the preceding relations

$$\begin{aligned} 1\,\mathrm{erg} &= 1\,\mathrm{g\ cm^2\ s^{-2}} = 8.2627 \times 10^{-50}\,\mathrm{cm} \\ 1\,\mathrm{g\ cm^{-3}} &= 7.4261 \times 10^{-29}\,\mathrm{cm^{-2}} \\ 1 M_\odot &= 1.477\,\mathrm{km}, \end{aligned}$$

and so on. Velocity is dimensionless in these units (that is, v is measured in units of c). In geometrized units, all explicit instances of G and c are then dropped in the equations. When quantities need to be calculated in standard units, appropriate combinations of c and G must be reinserted to give the right standard units for each term.

Natural Units in Particle Physics

It is convenient in this context to define natural units where $\hbar = c = 1$. Using the notation $[a]$ to denote the dimension of a and using $[L]$, $[T]$ and $[M]$ to denote the dimensions of length, time, and mass, respectively, for the speed of light c,

$$[c] = [L][T]^{-1}.$$

Setting $c = 1$ then implies that $[L] = [T]$, and since $E^2 = \boldsymbol{p}^2 c^2 + M^2 c^4$,

$$[E] = [M] = [\boldsymbol{p}] = [\boldsymbol{k}],$$

where $\boldsymbol{p} = \hbar \boldsymbol{k}$. Furthermore, because

$$[\hbar] = [M][L]^2[T]^{-1}$$

one has

$$[M] = [L]^{-1} = [T]^{-1}$$

if $\hbar = c = 1$. These results then imply that $[M]$ may be chosen as the single independent dimension of our set of $\hbar = c = 1$ natural units. This dimension is commonly measured in MeV (10^6 eV) or GeV (10^9 eV). Useful conversions are

$$\hbar c = 197.3\,\text{MeV fm} \qquad 1\,\text{fm} = \frac{1}{197.3}\,\text{MeV}^{-1} = 5.068\,\text{GeV}^{-1}$$

$$1\,\text{fm}^{-1} = 197.3\,\text{MeV} \qquad 1\,\text{GeV} = 5.068\,\text{fm}^{-1}.$$

where 1 fm = 10^{-13} cm (one fermi or one femtometer).

Natural Units in Cosmology

In cosmology we often employ a set of $\hbar = c = k_\text{B} = 1$ natural units, where k_B is the Boltzmann constant. Then from $E = k_\text{B}T$ and $k_\text{B} = 8.617 \times 10^{-14}\,\text{GeV K}^{-1} = 1$,

$$1\,\text{GeV} = 1.2 \times 10^{13}\,\text{K},$$

where K denotes kelvins. From §12.6 we then have for the Planck mass, Planck energy, Planck temperature, Planck length, and Planck time in these natural units,

$$M_\text{P} = E_\text{P} = T_\text{P} = \ell_\text{P}^{-1} = t_\text{P}^{-1}.$$

To convert to standard units, note that from Eq. (12.16) the gravitational constant may be expressed as

$$G = \frac{1}{M_\text{P}^2},$$

where the Planck mass is

$$M_\text{P} = 1.2 \times 10^{19}\,\text{GeV}.$$

From Eqs. (12.17), (B.14), and (B.11), the corresponding Planck length is

$$\ell_\text{P} = \frac{1}{M_\text{P}} = 1.6 \times 10^{-33}\,\text{cm},$$

multiplying by c^{-1} gives the corresponding Planck time,

$$t_\text{P} = 5.4 \times 10^{-44}\,\text{s},$$

and from Eqs. (B.12) and (B.14) the Planck temperature is

$$T_\text{P} = 1.4 \times 10^{32}\,\text{K}.$$

Conversions between geometrized ($G = c = 1$) units and standard units

Quantity	Symbol	Geometrized unit	Standard unit	Conversion
Mass	M	$\mathscr{L}$	$\mathscr{M}$	GM/c^2
Length	L	$\mathscr{L}$	$\mathscr{L}$	L
Time	t	$\mathscr{L}$	$\mathscr{T}$	ct
Spacetime distance	s	$\mathscr{L}$	$\mathscr{L}$	s
Proper time	τ	$\mathscr{L}$	$\mathscr{T}$	$c\tau$
Energy	E	$\mathscr{L}$	$\mathscr{M}(\mathscr{L}/\mathscr{T})^2$	GE/c^4
Momentum	p	$\mathscr{L}$	$\mathscr{M}(\mathscr{L}/\mathscr{T})$	Gp/c^3
Angular momentum	J	$\mathscr{L}^2$	$\mathscr{M}(\mathscr{L}^2/\mathscr{T})$	GJ/c^3
Luminosity (power)	L	dimensionless	$\mathscr{M}(\mathscr{L}^2/\mathscr{T}^3)$	GL/c^5
Energy density	ε	$\mathscr{L}^{-2}$	$\mathscr{M}/(\mathscr{L}\mathscr{T}^2)$	$G\varepsilon/c^4$
Momentum density	π_i	$\mathscr{L}^{-2}$	$\mathscr{M}/(\mathscr{L}^2\mathscr{T})$	$G\pi_i/c^3$
Pressure	P	$\mathscr{L}^{-2}$	$\mathscr{M}/(\mathscr{L}\mathscr{T}^2)$	GP/c^4
Energy / unit mass	ε	dimensionless	$(\mathscr{L}/\mathscr{T})^2$	ε/c^2
Ang. mom. / unit mass	ℓ	$\mathscr{L}$	$\mathscr{L}^2/\mathscr{T}$	ℓ/c
Planck constant	$\hbar$	$\mathscr{L}^2$	$\mathscr{M}(\mathscr{L}^2/\mathscr{T})$	$G\hbar/c^3$

The standard unit of length is $\mathscr{L}$, the standard unit of mass is $\mathscr{M}$, and the standard unit of time is $\mathscr{T}$.
Geometrized to standard conversion: Replace quantities in column 2 with quantities in the last column.
Standard to geometrized conversion: Multiply by the factor of G and c appearing in the last column.