

# SFCalcSheet formula collection

## Preface

This is an index of formulas used internally by [SFCalcSheet](#), the science fiction calculation spreadsheet. Hopefully, and independent of whether you are a user of the spreadsheet, these formulas can help you with various worldbuilding and astronomy related tasks.

If you find a mistake in this document, don't hesitate and [file an issue](#) on GitHub. You can also contact the author on [Reddit](#), [Twitter](#) or on his [Discord server](#). Ideas, constructive feedback and praise are always appreciated.

## Star formulas

### Luminosity from absolute magnitude

$$\sqrt[5]{100}^{M_{Sun}-M}$$

$L$  = luminosity (Suns),  $M$  = absolute magnitude

### Absolute magnitude from luminosity

$$M = M_{Sun} - 2.5 \cdot \log_{10}(L)$$

$M$  = absolute magnitude,  $L$  = luminosity (Suns)

### Visible magnitude from absolute magnitude and distance

$$m = M - 5 + 5 \cdot \log_{10}(d)$$

$m$  = visible magnitude,  $M$  = absolute magnitude,  $d$  = distance (pc)

### Luminosity difference from absolute magnitudes

$$\Delta L = \sqrt[5]{100}^{(M_{Big}-M_{Small})}$$

$L$  = luminosity,  $M$  = absolute magnitude

### Luminosity from mass

$$L = m^{3.5}$$

$L$  = luminosity (Suns),  $m$  = mass (Suns)

### Radius from mass (stars less massive than the Sun)

$$r = m^{0.8}$$

$r$  = radius (Suns),  $m$  = mass (Suns)

### Radius from mass (stars as massive or more massive than the Sun)

$$r = m^{0.57}$$

$r$  = radius (Suns),  $m$  = mass (Suns)

### Surface temperature from mass

$$T_s = 5778 \cdot m^{0.54}$$

$T_s$  = surface temperature (K),  $m$  = mass (Suns)

5778 is the Sun's surface temperature in Kelvin.

### Inner rim of habitable zone

$$r_{inner} = \sqrt{\frac{L}{1.1}}$$

$r_{inner}$  = inner rim (AU),  $L$  = luminosity (Suns). This is a conservative formula resulting in a narrow HZ. Use the "habitable zone limits" formula for more flexibility.

### Outer rim of habitable zone

$$r_{h_{outer}} = \sqrt{\frac{L}{0.53}}$$

$r_{h_{outer}}$  = outer rim (AU),  $L$  = luminosity (Suns). This is a conservative formula resulting in a narrow HZ. Use the “habitable zone limits” formula for more flexibility.

### Main sequence life span from mass

$$l = 10^{10} \cdot \left(\frac{1}{m}\right)^{2.5}$$

$l$  = life span (years),  $m$  = mass (Suns)

### Luminosity relative to ZAMS (zero age main sequence)

$$L = 1 + 10^{-10} \cdot m^{2.5} \cdot t$$

$L$  = relative luminosity (ZAMS = 1),  $m$  = mass (Suns),  $t$  = age of star (years)

### Orbital period of binary orbit from distance and mass

$$T = 2\pi \cdot \sqrt{\frac{d^3}{G \cdot (m_1 + m_2)}}$$

$T$  = orbital period (s),  $d$  = separation of bodies' centers/sum of semi-major axes (m),  $G$  = gravitational constant,  $m_1$  and  $m_2$  = masses of orbiting bodies (kg)

### Barycenter of binary orbit

$$d_b = \frac{d}{1 + \frac{m_1}{m_2}}$$

$d_b$  = distance of barycenter to center of first body (m),  $d$  = distance between bodies' centers (m),  $m_1$  and  $m_2$  = masses of orbiting bodies (kg)

### Stellar wind mass loss

$$M_{Suns} = 10^{-12.76 + 1.3 \cdot \log_{10} L_{Suns}} \cdot 5754400000000$$

$M_{Suns}$  = mass loss (Sun = 1);  $L_{Suns}$  = luminosity of star (Suns)

### Stellar wind energy

$$E_{Suns} = M \cdot \left(\frac{T}{5778}\right)^4$$

$E_{Suns}$  = stellar wind energy (Sun = 1);  $M$  = stellar wind mass loss (Sun = 1);  $T$  = star surface temperature. 5778 is the Sun's surface temperature.

### Stellar wind energy at distance

$$E_d = \frac{E_{Suns}}{d^2}$$

$E_d$  = stellar wind energy at distance (Sun = 1);  $E_{Suns}$  = stellar wind energy;  $d$  = distance from star (AU)

## Planet formulas

### Radius from mass and density

$$r = \sqrt[3]{\frac{3m}{4\pi \cdot \rho}}$$

$r$  = radius (m),  $m$  = mass (kg),  $\rho$  = density (kg/m<sup>3</sup>)

### Gravitational acceleration from mass and radius

$$g = \frac{G \cdot m}{r^2}$$

$g$  = gravitational acceleration (m/s<sup>2</sup>),  $G$  = gravitational constant,  $m$  = body mass (kg),  $r$  = body radius (m)

### Escape velocity from mass and radius

$$v_e = \sqrt{\frac{2m \cdot G}{r}}$$

$v_e$  = escape velocity (m/s),  $G$  = gravitational constant,  $m$  = mass (kg),  $r$  = radius (m)

### Roche limit (rigid bodies) from densities

$$d = r_p \cdot 1.26 \cdot \sqrt[3]{\frac{\rho_p}{\rho_s}}$$

$d$  = Roche limit (m),  $r_p$  = planet radius (m),  $\rho_p$  = density of planet (kg/m<sup>3</sup>),  $\rho_s$  = density of satellite (kg/m<sup>3</sup>)

### Roche limit (fluid/loose bodies) from densities

$$d = r_p \cdot 2.44 \cdot \sqrt[3]{\frac{\rho_p}{\rho_s}}$$

$d$  = Roche limit (m),  $r_p$  = planet radius (m),  $\rho_p$  = density of planet (kg/m<sup>3</sup>),  $\rho_s$  = density of satellite (kg/m<sup>3</sup>)

### Orbital period from distance and mass

$$T = \sqrt{\frac{4\pi^2 \cdot d^3}{G \cdot m}}$$

$T$  = orbital period (s),  $d$  = semi-major axis (m),  $G$  = gravitational constant,  $m$  = mass of orbited body (kg)

### Hill sphere

$$r_h = d \cdot \sqrt[3]{\frac{m}{3m_o}}$$

$r_h$  = radius of Hill sphere (m),  $d$  = distance to orbited body (m),  $m$  = mass of body (kg),  $m_o$  = mass of orbited body (kg)

### Tidal force

$$F_t = G \cdot m \cdot \frac{2r}{d^3}$$

$F_t$  = tidal force (m/s<sup>2</sup>),  $G$  = gravitational constant,  $m$  = mass of causing body (kg),  $r$  = radius of affected body (m),  $d$  = distance between bodies (m)

### Habitable zone limits

$$d = \sqrt{\frac{L}{S_e}}$$

$d$  = distance of HZ limit to the star (AU),  $L$  = luminosity (Suns),  $S_e$  = normalized stellar flux (runaway greenhouse = 1.41; moist greenhouse = 1.107; 1st condensation = 0.53; maximum greenhouse = 0.356)

### Solar irradiance

$$R = L \cdot G_{SC} \cdot \left(\frac{1}{d}\right)^2$$

$R$  = irradiance (W/m<sup>2</sup>),  $L$  = luminosity of star (Suns),  $G_{SC}$  = solar constant (1,361 W/m<sup>2</sup>),  $d$  = distance of planet to star (AU)

### Effective temperature

$$T_e = \sqrt[4]{\frac{(1-A) \cdot L}{16\pi \cdot d^2 \cdot \sigma}}$$

$T_e$  = effective temperature (K),  $A$  = bond albedo of planet,  $L$  = luminosity of star (W),  $d$  = distance to star (m),  $\sigma$  = Stefan-Boltzmann constant

### Surface temperature

$$T_s = T_e \cdot \sqrt[4]{\frac{1}{1-\varepsilon}}$$

$T_s$  = surface temperature (K),  $T_e$  = effective temperature (K),  $\varepsilon$  = atmospheric absorption (0-1)

### Land area

$$A_l = 4\pi \cdot r^2 \cdot A_{lp}$$

$A_l$  = land area (km<sup>2</sup>),  $r$  = planet radius (km),  $A_{lp}$  = land percentage (0-1)

### Satellite formulas

#### Visual diameter

$$d_v = 2 \cdot \arcsin\left(\frac{r}{d}\right)$$

$d_v$  = visual diameter (rad),  $r$  = radius of satellite (km),  $d$  = distance to satellite (km)

#### Visual area from visual diameter

$$A_v = \pi \cdot \left(\frac{d_v}{2}\right)^2$$

$A_v$  = visual area (rad<sup>2</sup>),  $d_v$  = visual diameter (rad)

### Illuminance

$$E_v = \frac{A_v \cdot \left(\frac{A_b}{0.12}\right)}{48900}$$

$E_v$  = illuminance (full moons;  $\approx 0.25$  lux),  $A_v$  = visual area (rad<sup>2</sup>),  $A_b$  = bond albedo (0-1)

48900 is a shorthand for 1 divided by half the Moon's angular diameter (in radians) squared. 0.12 is the Moon's bond albedo.

## Compact object formulas

### Schwarzschild radius

$$r_s = \frac{2G \cdot m}{c^2}$$

$r_s$  = Schwarzschild radius (m),  $G$  = gravitational constant,  $m$  = mass (kg),  $c$  = speed of light (m/s)

### Black hole lifetime

$$t_l = m^3 \cdot \frac{5120 \cdot \pi \cdot G^2}{\hbar \cdot c^4}$$

$t_l$  = lifetime (s),  $m$  = mass (kg),  $G$  = gravitational constant,  $\hbar$  = Dirac constant,  $c$  = speed of light (m/s)

## Disaster formulas

### Impactor mass

$$m = \frac{4}{3} \cdot \pi \cdot \rho \cdot r^3$$

$m$  = impactor mass (kg),  $\rho$  = impactor density (kg/m<sup>3</sup>),  $r$  = impactor radius (m)

### Impactor kinetic energy

$$K = \frac{1}{2} \cdot m \cdot v^2$$

$K$  = impactor kinetic energy (J),  $m$  = impactor mass (kg),  $v$  = impactor velocity (m/s)

### Impact crater approximate size

$$d_c = \left( \frac{K}{(4.184 \cdot 10^{12})} \right)^{0.3} \cdot 46$$

$d_c$  = approximate crater diameter (m),  $K$  = impactor kinetic energy (J)

$4.184 \cdot 10^{12}$  is the explosion energy of 1 kt TNT in joules. 46 is the diameter of the crater left by the explosion of 1 kt TNT (in meters).

### Impact crater size lower bound

$$d_{c\text{lower}} = \frac{d_c}{3.48}$$

$d_{c\text{lower}}$  = crater diameter lower bound,  $d_c$  = approximate crater diameter

### Impact crater size upper bound

$$d_{c\text{upper}} = d_c \cdot 3.48$$

$d_{c\text{upper}}$  = crater diameter upper bound,  $d_c$  = approximate crater diameter

## Energy of matter/antimatter annihilation

$$E = mc^2$$

$E$  = released energy (J),  $m$  = total reaction mass (kg),  $c$  = speed of light (m/s)

### Bomb blast maximum fireball radius

$$r_{max} = E^{0.4} \cdot 39$$

$r_{max}$  = maximum fireball radius (m),  $E$  = bomb yield (kt TNT)

This is an intermediate formula between the approximate fireball radii of aerial and ground-based detonations. Use a multiplier of 33.5 for aerial and 44 for ground-based detonations.

### Bomb blast fireball duration

$$t = E^{0.45} \cdot 0.2$$

$t$  = fireball duration (s),  $E$  = bomb yield (kt TNT)

### Bomb blast crater diameter

$$d = E^{0.3} \cdot 46$$

$d$  = crater diameter (m),  $E$  = bomb yield (kt TNT)

### Bomb blast shockwave radius

$$r = E^{\frac{1}{5}} \cdot \Delta t^{\frac{2}{5}} \cdot \rho^{-\frac{1}{5}}$$

$r$  = shockwave radius (m),  $E$  = explosion energy (J),  $\Delta t$  = time since detonation (s),  $\rho$  = mass density of medium (kg/m<sup>3</sup>)

### Earthquake energy

$$E = 10^{4.4+1.5M}$$

$E$  = released energy (J),  $M$  = earthquake magnitude

## Travel formulas

### Time dilation (outside observer) / relativistic mass

$$\Delta t = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$t$  = time,  $v$  = velocity (m/s),  $c$  = speed of light (m/s)

### Uniform acceleration time

$$t_a = \frac{v_f - v_i}{a}$$

$t_a$  = acceleration time (s),  $v_f$  = final velocity (m/s),  $v_i$  = initial velocity (m/s),  $a$  = acceleration (m/s<sup>2</sup>)

### Uniform acceleration distance

$$d = \frac{(v_i + v_f) \cdot t_a}{2}$$

$d$  = distance (m),  $v_i$  = initial velocity (m/s),  $v_f$  = final velocity (m/s),  $t_a$  = acceleration time (s)