Appendix I
Constants

Constant	Symbol	Value
Universal constants		
Speed of light in vacuum	c	2.9979×10^{8} m s^{-1}
Universal gravitational constant	G	6.674×10^{-11} N m^2 kg^{-2}
		6.674×10^{-11} m^3 kg^{-1} s^{-2}
Planck constant	h	6.6261×10^{-34} J s
Electric constant	ε_0	8.8542×10^{-12} F m^{-1}
Magnetic constant	μ_0	1.2566×10^{-6} N A^{-2}
Thermal radiation		
Boltzmann constant	k	1.38065×10^{-23} J K^{-1}
Stefan-Boltzmann constant	σ	5.6704×10^{-8} J s^{-1} m^{-2} K^{-4}
Radiation density constant	a	7.5657×10^{-16} J m^{-3} K^{-4}
Wien wavelength displacement law constant	b	2.8978×10^{-3} m K
Atomic and nuclear		
Electron mass	m_e	9.1094×10^{-31} kg
Elementary charge	e	1.6022×10^{-19} C
Classical electron radius	r_e	2.8179×10^{-15} m
Thomson scattering cross section	σ_T	6.65246×10^{-29} m^2
Atomic mass unit	m_u = u	1.660539×10^{-27} kg
Proton mass	m_p	1.6726×10^{-27} kg
Neutron mass	m_n	1.6749×10^{-27} kg
Alpha particle mass	m_α	6.644656×10^{-27} kg
Bohr radius	a_0	5.2918×10^{-11} m
Rydberg constant	R_∞	10,973,731.5685 m^{-1}
Sun		
Mass of the Sun	$M_\odot$	1.989×10^{30} kg
Luminosity of Sun	$L_\odot$	3.828×10^{26} J s^{-1}
Radius of Sun	$R_\odot$	6.955×10^{8} m
Expanding universe		
Hubble constant	H_0	75 km s^{-1} Mpc^{-1}
Age of expanding Universe	t_0	13.7×10^{9} years

(continued)

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(continued)

Constant	Symbol	Value
Cosmic microwave background radiation		
Temperature	T_{CMB}	2.725 K
Photon density	N_{CMB}	4.10×10^{8} m^{-3}
Anisotropy	$\Delta T/T_{CMB}$	1.1×10^{-5}

The physical constants are accurate to the fourth decimal place. For greater accuracy with the latest values consult http://physics.nist.gov/cuu/constants/index.html

Appendix II
Units

Unit	Symbol	Value
Distance and length		
Ångström	Å	10^{-10} m
Meter	m	1 km = 10^3 m = 0.621371 mile 1 mile = 1.60934 km
Mean Earth-Sun distance	AU	1.49598×10^{11} m
Light-year	ly	9.460528×10^{15} m = 63,239.67 AU
Parsec	pc	3.08568×10^{16} m = 3.26164 light-years = 206,265 AU
Megaparsec	Mpc	10^6 pc
Angle		
Degree	°	$60' = 3600''$ $1^\circ = 0.0174532925$ radians $1'' = 4.8481368 \times 10^{-6}$ radians
(The symbol $'$ denotes minutes of arc, the symbol $''$ designates seconds of arc)		
Radian	rad	$2.06265 \times 10^5\ ''$ $57.2957795^\circ = 360^\circ/(2\pi)$
Pi	π	3.141592654
Time		
Solar day	day	24 h = 86,400 s
Sidereal day	sidereal day	23 h 56 m 04.09 s = 23.9344696 h
Year	tropical year	365.25 solar days = 3.15576×10^7 s
Energy, power, force, pressure		
Joule	J	10^7 erg
Electron-volt	ev	1.6018×10^{-19} J
Power	Watt	J s^{-1}
Force	N	kg m s^{-2}
Pressure	Pa	N m^{-2}

(continued)

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(continued)

Unit	Symbol	Value
Mass		
Kilogram	kg	1,000 g, 1 metric ton = 10^3 kg
Solar units		
Mass of the Sun	$M_\odot$	1.989×10^{30} kg
Luminosity of Sun	$L_\odot$	3.828×10^{26} J s^{-1}
Radius of Sun	$R_\odot$	6.955×10^8 m

Appendix III
Fundamental Equations

Angular resolution, θ_r, of a telescope of diameter, D_T, at a wavelength, λ:

$$\theta_r = \frac{\lambda}{D_T} \text{ radians} \tag{A-1}$$

where 1 radian = 2.06265×10^5 seconds of arc = 2.06265×10^5 ″.

Angular source extent, θ_{size}, of a celestial source of radius, R, located at a distance, D:

$$\theta_{size} = \frac{2R}{D} \text{radians}, \tag{A-2}$$

where 1 radian = 2.06265×10^5 seconds of arc = 2.06265×10^5 ″.

Wavelength, λ, **frequency**, v, and **speed of light**, c:

$$\lambda \times v = c, \tag{A-3}$$

where the speed of light $c = 2.9979 \times 10^8$ m s^{-1}.

Photon energy, E, of radiation at frequency v:

$$E = hv \tag{A-4}$$

where the Planck constant $h = 6.6261 \times 10^{-34}$ J s.

Stefan-Boltzmann law for luminosity, L, of thermal radiator with effective temperature T_{eff} and radius R:

$$L = 4\pi\sigma R^2 T_{eff}^4 \tag{A-5}$$

where $\pi = 3.14159$ and the Stefan-Boltzmann constant $\sigma = 5.6704 \times 10^{-8}$ J s^{-1} m^{-2} K^{-4}.

Apparent magnitude, absolute magnitude, and luminosity for a star. Any apparent magnitude, m, can be converted to absolute magnitude, M, through the simple formula:

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$$\text{absolute magnitude} = M = m + 5 - 5\log D, \tag{A-6}$$

where D is the distance in parsecs, and 1 parsec = 3.26164 light-years = 3.08568×10^{16} m. The absolute magnitude can be converted into a luminosity, L, using:

$$\log\left(\frac{L}{L_\odot}\right) = 0.4(M_\odot - M), \tag{A-7}$$

or

$$L = 10^{0.4(M_\odot - M)} L_\odot, \tag{A-8}$$

where the absolute magnitude of the Sun in the visual range of wavelengths, where it is most intense, is $M_\odot = +4.83$ and the absolute luminosity of the Sun is $L_\odot = 3.828 \times 10^{26}$ J s^{-1}. Notice that the symbol $M_\odot$ is used to denote both the absolute magnitude of the Sun, which is used here, and the mass of the Sun, used in other equations. The Sun has an apparent magnitude of $m_\odot = -26.74$.

Wien displacement law for wavelength λ_{max} of maximum intensity for a thermal radiator at temperature T:

$$\lambda_{max} = \frac{0.002898}{T} \text{meters}. \tag{A-9}$$

Radiant flux, f, or **apparent brightness**, of an object of luminosity L at distance D:

$$f = \frac{L}{4\pi D^2}. \tag{A-10}$$

Gravitational force, F_G, between two masses, M_1 and M_2 separated by a distance D between their centers:

$$F_G = \frac{GM_1M_2}{D^2}, \tag{A-11}$$

where the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}.

Kepler's third law for the orbital period P of a binary system of mass M_1 and M_2 separated by distance a:

$$P^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3 \tag{A-12}$$

where the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}.

Jeans mass, M_J, for a spherical gas cloud of radius, R, and temperature, T:

$$M_J = \frac{3kT}{Gm}R, \tag{A-13}$$

where the Boltzmann constant $k = 1.38065 \times 10^{-23}$ J K^{-1}, the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, and m is the gas particle mass. Gravitational collapse occurs if the cloud mass, M, is greater than the Jeans mass, M_J.

Escape velocity, V_{esc}, at a distance R from a mass M:

$$V_{esc} = \left(\frac{2GM}{R}\right)^{1/2}, \tag{A-14}$$

where the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}.

Doppler effect for a change $\Delta\lambda$ in the wavelength λ due to a radial velocity V_r of a source moving away from observer:

$$\frac{\Delta\lambda}{\lambda_{emitted}} = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{V_r}{c} \quad \text{for } V_r \ll c, \tag{A-15}$$

where the speed of light $c = 2.9979 \times 10^8$ m s^{-1}.

Parallax the annual parallax π_A, of a star at distance, D, is:

$$\pi_A = \text{AU/D radians}, \tag{A-16}$$

where 1 AU $= 1.49598 \times 10^{11}$ m and 1 radian $= 2.06265 \times 10^5$ s of arc. When the parallax is given in units of seconds of arc, then the distance, D, is given by:

$$D = \frac{1}{\pi_A} \text{ parsecs}, \tag{A-17}$$

where 1 parsec = 3.26164 light years = 206,265.8 AU.

Gravitational potential energy of a mass, M, with radius, R:

$$\text{Gravitational potential energy} = \frac{GM^2}{R}, \tag{A-18}$$

where the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}.

Kinetic energy of mass, m, moving at velocity, V:

$$\text{Kinetic energy} = \frac{1}{2}mV^2. \tag{A-19}$$

Thermal energy at temperature, T:

$$\text{Thermal energy} = \frac{3}{2}kT, \tag{A-20}$$

where the Boltzmann constant $k = 1.38065 \times 10^{-23}$ J K^{-1}.

Thermal velocity, $V_{thermal}$, of a particle of mass, m, at temperature, T:

$$V_{thermal} = \sqrt{\frac{3kT}{m}} = \left[\frac{3kT}{m}\right]^{1/2}, \tag{A-21}$$

where the Boltzmann constant $k = 1.38065 \times 10^{-23}$ J K^{-1}.

Gas pressure, P_G, of particles of number density, N, and temperature T:

$$P_G = NkT, \tag{A-22}$$

where the Boltzmann constant $k = 1.38065 \times 10^{-23}$ J K^{-1}.

Radiation pressure, P_r, for a temperature T:

$$P_r = \frac{aT^4}{3} \tag{A-23}$$

where the radiation constant $a = 7.5657 \times 10^{-16}$ J m^{-3} K^{-4}.

Magnetic pressure, P_B, of a magnetic field of strength, B:

$$P_B = \frac{B^2}{2\mu_0}, \tag{A-24}$$

where the magnetic constant $\mu_0 = 1.2566 \times 10^{-6}$ N A^{-2}.

Energy radiated, ΔE, **by a mass loss**, Δm, during nuclear reactions:

$$\Delta E = \Delta m\, c^2, \tag{A-25}$$

where the speed of light $c = 2.9979 \times 10^8$ m s^{-1}.

Schwarzschild radius, R_{sch}, of a mass, M, of radius R:

$$R_{\text{sch}} = \frac{2GM}{c^2} = 2.95 \times 10^3 \left(\frac{M}{M_\odot}\right) \text{m}, \tag{A-26}$$

where the universal gravitational constant $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2} and the Sun's mass $M_\odot = 1.989 \times 10^{30}$ kg.

Hubble law for the recession velocity V_r of a galaxy at a distance D:

$$V_r = H_0 \times D, \tag{A-27}$$

where the Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1} and 1 Mpc $= 3.08568 \times 10^{22}$ m.

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