PHYSICS 3150 Final Exam
Dec 8 2006
2 pages, 2 hours, 100% total

You are [redacted] Be complete but concise in your answers.

PART 1: Short-Answer questions. Complete 6 out of 7 (10% each, 60% total). Complete all parts of any question you attempt. The best 6 questions will be counted.

1. UR Notsirius is a star with a luminosity of 3.00 $L_\odot$ and a visual magnitude of V=4.75. The bolometric correction for its type is 0.08. Find its:
   a.) absolute visual magnitude
   b.) distance modulus
   c.) distance from the Earth in parsecs.
   d.) radiant flux at the distance of the Earth.

2. State Kirchhoff's laws of spectral line formation, and explain each in terms of physics.

3. a.) Explain why the edge or limb of the visible Sun is darker than the centre of the visible Sun.
   b.) Star A has a very bright centre compared to the brightness of its limb. Star B has a relatively more uniform brightness from centre to limb. What does this tell us about the temperature structure in the atmospheres of stars A and B?

4. a.) Why is observation of the strengths of Balmer lines in stellar spectra sometimes referred to as the "Balmer thermometer"? In other words, how do the Balmer lines allow one to roughly estimate the temperature of a star?
   b.) Explain why a very hot star and a very cool star may have similar Balmer line strengths.

5. a.) What is the primary source of energy of a star when it is on the main sequence, including its location in the star?
   b.) What happens for a star to leave the main sequence, in particular, in the core of the star?
   c.) What is the source of energy for a star after it leaves the main sequence, including its location in the star?
   d.) Why are the cores of some main sequence stars convective and some radiative?

6. a.) What is meant by the mean free path of a photon inside a star?
   b.) If a star has a central density of $1.62\times10^2\,\mathrm{g/cm^3}$ or $1.62\times10^5\,\mathrm{g/cm^3}$ and an opacity of $1.12\,\mathrm{cm^2/g}$ or $0.112\,\mathrm{m^2/kg}$ what is the mean free path of a photon in the center of the star?
   c.) Estimate the time it takes for a photon to travel from the center of a solar-type star to its surface, if the density and opacity are constant throughout.

7. a.) Show why thermal energy is classically insufficient for hydrogen atoms to overcome the Coulomb barrier and fuse in nuclear reactions in a star with a core temperature of $1.6\times10^7\,\mathrm{K}$. (The attractive strong nuclear force dominates Coulomb repulsion at approximately $1\times10^{-13}\,\mathrm{cm}$ or $1\times10^{-15}\,\mathrm{m}$)
   b.) Briefly, explain how the physics of quantum mechanics allows nuclear fusion to occur in cool main sequence dwarf stars.

PART 2: Long-Answer Questions: Complete both questions (20% each, 40% total)

8. The radial velocity curves and bolometric magnitude versus time graph for a binary star are attached. The period is 5.01 days. (Note that x-axis scales are not the same, and that there is a break in the time scale of the lower graph, to allow you to see the detail in the light curve minima.)

1 a.) What classes of binary star does this star belong to?

1 b.) We will assume that i=90° for this system. Why is this a reasonable assumption?

1 c.) We will assume that this system has circular orbits. Why is this a reasonable assumption?

7 d.) Find the masses of star A and star B.

4 e.) Find the radius of each star.

6 f.) Find the ratio of the surface fluxes, and then the temperatures, of the stars.

9. The core of the Sun has the following parameters: X=0.34, X_{CNO}=0.013, ρ=162 g/cm^3 $(1.62\times10^5 \text{g/cm}^3)$, T=15.8 million K.

4 a.) i.) What is the ratio of the energy generation rate for the CNO cycle to the energy generation rate for the pp chain in the core of the Sun?

4 ii.) If the fraction of CNO elements stayed constant, what mass fraction of hydrogen would be necessary in the core of the Sun for the CNO cycle and pp chain to have equal energy generation rates?

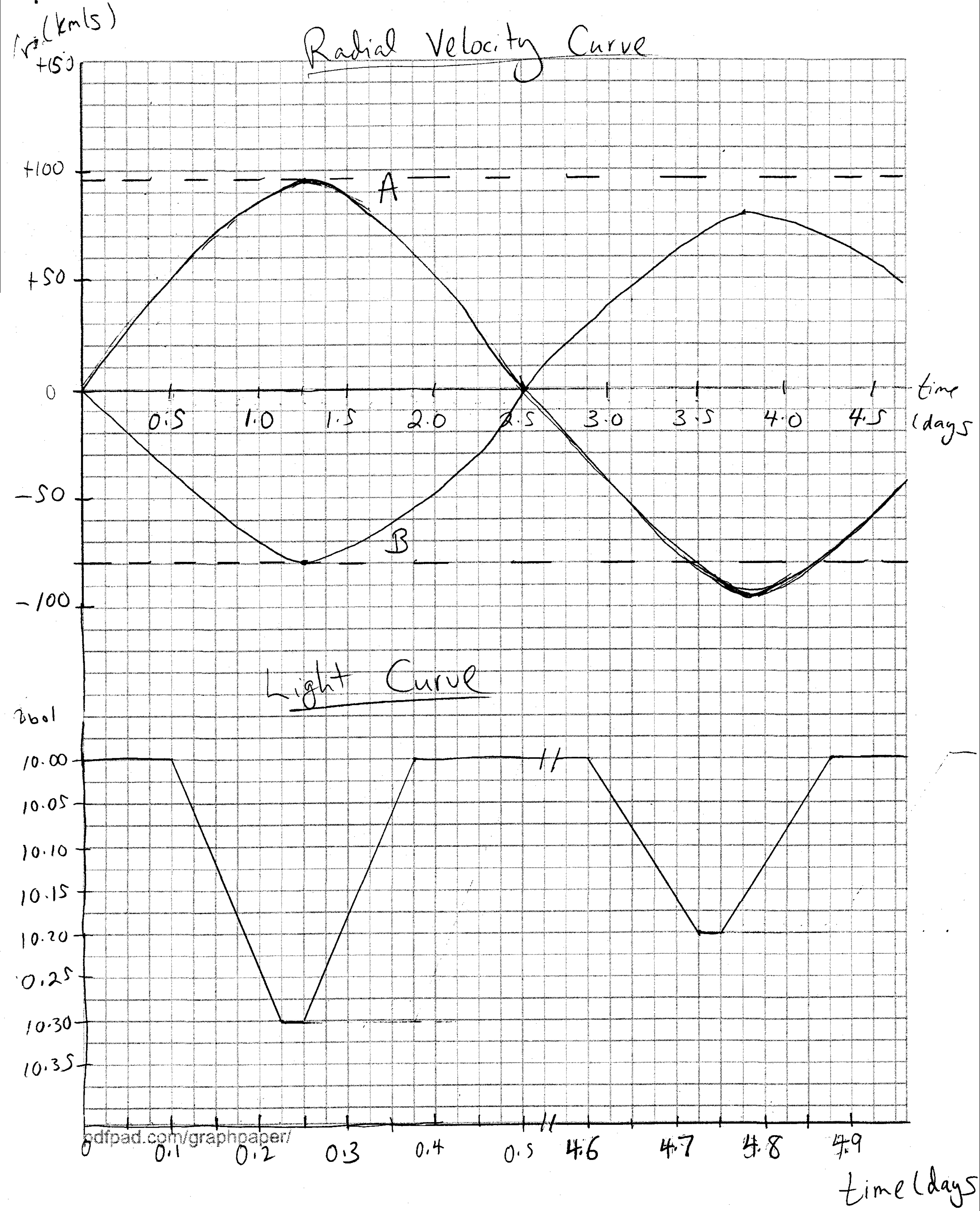
2 iii.) Is the situation in part ii. plausible? Namely, will the fraction of CNO elements stay constant and can the mass fraction of hydrogen reach the value you found?

b.) The triple alpha process involves the fusion of three hydrogen nuclei into one carbon nucleus.

1 i.) Why does this process occur in two steps, with an intermediate step of the production of a beryllium nucleus, instead of a single step?

3 ii.) How much energy is liberated in one complete triple alpha process? The masses of the nuclei are: He -- 4.002603 u, C -- 12.000000 u.

6 ii.) If a star has a core with the following parameters: M(core)=0.25 $M_\odot$ and Y=0.98. The star's total luminosity is 1000 $L_\odot$. How long could you expect the star to have the triple alpha process as its source of luminosity?



Radial Velocity Curve
v_r (km/s)
+150
+100
+50
0
-50
-100
A
B
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
time (days)
Light Curve
m_{bol}
10.00
10.05
10.10
10.15
10.20
10.25
10.30
10.35
0
0.1
0.2
0.3
0.4
0.5
4.6
4.7
4.8
4.9
time (days)
pdfpad.com/graphpaper/

Physics 3150 Final Exam: Equations

$$\frac{N_b}{N_a}=\frac{g_b}{g_a}e^{-(E_b-E_a)/kT} \qquad Z=g_1+\sum_{j=2}^{\infty} g_j e^{-(E_j-E_1)/kT}$$

$$\frac{N_{i+1}}{N_i}=\frac{2kTZ_{i+1}}{P_e Z_i}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi_i/kT}=\frac{2Z_{i+1}}{n_e Z_i}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi_i/kT}$$

$$m_1+m_2=\frac{P}{2\pi G}\frac{(v_{1r}+v_{2r})^3}{\sin^3 i} \qquad \frac{m_1}{m_2}=\frac{a_2}{a_1}=\frac{v_{2r}}{v_{1r}} \qquad P^2=\frac{4\pi^2}{G(m_1+m_2)}a^3$$

$$r_s=\frac{v}{2}(t_b-t_a),\ r_l=\frac{v}{2}(t_c-t_a) \qquad \frac{B_0-B_p}{B_0-B_s}=\left(\frac{T_s}{T_l}\right)^4=\left(\frac{F_{rs}}{F_{rl}}\right)$$

$$E_n=-13.6\,eV\frac{1}{n^2} \qquad \frac{1}{\lambda}=R_H\left(\frac{1}{m^2}-\frac{1}{n^2}\right) \qquad E_{photon}=h\nu=\frac{hc}{\lambda} \qquad \frac{\lambda_{obs}-\lambda_{rest}}{\lambda_{rest}}=\frac{v_r}{c}$$

$$B_\lambda(T)=\frac{2hc^2/\lambda^5}{e^{hc/\lambda kT}-1} \qquad L=4\pi R^2\sigma T_e^4 \qquad \lambda_{max}T=0.290\,cm\,K \qquad m_1-m_2=-2.5\log\left(\frac{F_1}{F_2}\right)$$

$$M_1-M_2=-2.5\log\left(\frac{L_1}{L_2}\right) \qquad m-M=5\log(d)-5 \qquad BC=m_{bol}-V=M_{bol}-M_V$$

$$E=mc^2 \qquad v_{mp}=\sqrt{2kT/m} \qquad v_{avg}=\sqrt{3kT/m} \qquad \tau_\lambda=\int_0^s \kappa_\lambda \rho\, ds \qquad l=\frac{1}{n\sigma}=\frac{1}{\kappa\rho}$$

$$\frac{dP}{dr}=-G\frac{M_r\rho}{r^2} \qquad \frac{dM_r}{dr}=4\pi r^2\rho \qquad \frac{dL^2}{dr}=4\pi r^2\rho\epsilon \qquad \frac{dT}{dr}=\frac{-3}{4ac}\frac{\bar{\kappa}\rho}{T^3}\frac{L_r}{4\pi r^2}$$

$$P=nkT \qquad \mu=\frac{\bar{m}}{m_H} \qquad P_{rad}=\frac{aT^4}{3} \qquad U_{elec}=\frac{kq_1q_2}{r^2}\ (SI)=\frac{q_1q_2}{r^2}\ (cgs)$$

$$F_{grav}=\frac{Gm_1m_2}{r^2} \qquad \epsilon_{pp}\approx\epsilon'_{o,pp}\rho X^2 T_6^4$$

$$\epsilon'_{o,pp}=1.05\times10^{-5}\,\mathrm{erg\,cm^3\,g^{-2}\,s^{-1}}=1.05\times10^{-12}\,\mathrm{W\,m^3\,kg^{-2}}$$

$$\epsilon_{CNO}\approx\epsilon'_{o,CNO}\rho X X_{CNO} T_6^{19.9}$$

$$\epsilon'_{o,pp}=8.24\times10^{-24}\,\mathrm{erg\,cm^3\,g^{-2}\,s^{-1}}=8.24\times10^{-31}\,\mathrm{W\,m^3\,kg^{-2}}$$

Appendix A

Astronomical and Physical Constants

Astronomical Constants		
Solar mass	1 $M_\odot$	= 1.989×10^{33} g
Solar luminosity	1 $L_\odot$	= 3.826×10^{33} ergs s^{-1}
Solar radius	1 $R_\odot$	= 6.9599×10^{10} cm
Solar effective temperature	$T_\odot$	= 5770 K
Earth mass	1 $M_\oplus$	= 5.974×10^{27} g
Earth radius	1 $R_\oplus$	= 6.378×10^{8} cm
Light year	1 ly	= 9.4605×10^{17} cm
Parsec	1 pc	= 3.0857×10^{18} cm
		= 3.2616 ly
Astronomical unit	1 AU	= 1.4960×10^{13} cm
Sidereal day		= $23^h\ 56^m\ 04.09054^s$
Solar day		= 86400 s
Sidereal year		= 3.155815×10^{7} s
Tropical year		= 3.155693×10^{7} s

Physical Constants		
Gravitational constant	G	$= 6.67259 \times 10^{-8}$ dyne cm^2 g^{-2}
Speed of light (exact)	c	$= 2.99792458 \times 10^{10}$ cm s^{-1}
Planck's constant	h	$= 6.6260755 \times 10^{-27}$ erg s
	$\hbar$	$\equiv h/2\pi$
		$= 1.05457266 \times 10^{-27}$ erg s
Boltzmann's constant	k	$= 1.380658 \times 10^{-16}$ erg K^{-1}
Stefan–Boltzmann constant	σ	$= 5.67051 \times 10^{-5}$ erg cm^{-2} s^{-1} K^{-4}
Radiation constant	a	$= 4\sigma/c$
		$= 7.56591 \times 10^{-15}$ erg cm^{-3} K^{-4}
Proton mass	m_p	$= 1.6726231 \times 10^{-24}$ g
Neutron mass	m_n	$= 1.674929 \times 10^{-24}$ g
Electron mass	m_e	$= 9.1093897 \times 10^{-28}$ g
Hydrogen mass	m_H	$= 1.673534 \times 10^{-24}$ g
Atomic mass unit	1 u	$= 1.6605402 \times 10^{-24}$ g
		$= 931.49432$ MeV/c^2
Coulomb law constant (cgs)	k_C	$\equiv 1$
(SI)		$= 8.9875518 \times 10^9$ N m^2 C^{-2}
Electric charge (cgs)	e	$= 4.803206 \times 10^{-10}$ esu
(SI)		$= 1.60217733 \times 10^{-19}$ C
Electron volt	1 eV	$= 1.60217733 \times 10^{-12}$ erg
Avagadro's number	N_A	$= 6.0221367 \times 10^{23}$ mole^{-1}
Gas constant	R	$= 8.314510 \times 10^7$ ergs mole^{-1} K^{-1}
Bohr radius	a_o	$= \hbar^2/m_e e^2$
		$= 5.29177249 \times 10^{-9}$ cm
Rydberg constant	R_H	$= \mu e^4/4\pi\hbar^3 c$
		$= 1.09677585 \times 10^5$ cm^{-1}

Suggested Readings

TECHNICAL

Cohen, E. Richard, and Taylor, Barry N., "The 1986 Adjustment of the Fundamental Physical Constants," *Reviews of Modern Physics*, *59*, 1121, 1987.

Lang, Kenneth R., *Astrophysical Data: Planets and Stars*, Springer-Verlag, New York, 1992.

APPENDIX

A Astronomical and Physical Constants

Astronomical Constants			
Solar mass	$1\ M_\odot$	$=$	1.9891×10^{30} kg
Solar irradiance	S	$=$	$1.365(2) \times 10^{3}$ W m^{-2}
Solar luminosity	$1\ L_\odot$	$=$	$3.839(5) \times 10^{26}$ W
Solar radius	$1\ R_\odot$	$=$	$6.95508(26) \times 10^{8}$ m
Solar effective temperature	$T_{e,\odot}$	$\equiv$	$L_\odot/(4\pi\sigma R_\odot^2)^{1/4}$
		$=$	5777(2) K
Solar absolute bolometric magnitdue	M_{bol}	$=$	4.74
Solar apparent bolometric magnitude	m_{bol}	$=$	-26.83
Solar apparent ultraviolet magnitude	U	$=$	-25.91
Solar apparent blue magnitude	B	$=$	-26.10
Solar apparent visual magnitude	V	$=$	-26.75
Solar bolometric correction	BC	$=$	-0.08
Earth mass	$1\ M_\oplus$	$=$	5.9736×10^{24} kg
Earth radius (equatorial)	$1\ R_\oplus$	$=$	6.378136×10^{6} m
Astronomical unit	1 AU	$=$	$1.4959787066 \times 10^{11}$ m
Light (Julian) year	1 ly	$=$	$9.460730472 \times 10^{15}$ m
Parsec	1 pc	$=$	206264.806 AU
		$=$	3.0856776×10^{16} m
		$=$	3.2615638 ly (Julian)
Sidereal day		$=$	$23^h56^m04.0905309^s$
Solar day		$=$	86400 s
Sidereal year		$=$	3.15581450×10^{7} s
		$=$	365.256308 d
Tropical year		$=$	$3.155692519 \times 10^{7}$ s
		$=$	365.2421897 d
Julian year		$\equiv$	3.1557600×10^{7} s
		$\equiv$	365.25 d
Gregorian year		$\equiv$	3.1556952×10^{7} s
		$\equiv$	365.2425 d

Note: Uncertainties in the last digits are indicated in parentheses. For instance, the solar radius, $1\ R_\odot$, has an uncertainty of $\pm 0.00026 \times 10^{8}$ m.

stants

Physical Constants

Gravitational constant	G	$=$	$6.673(10) \times 10^{-11}$ N m^2 kg^{-2}
Speed of light (exact)	c	$\equiv$	2.99792458×10^{8} m s^{-1}
Permeability of free space	μ_0	$\equiv$	$4\pi \times 10^{-7}$ N A^{-2}
Permittivity of free space	ϵ_0	$\equiv$	$1/\mu_0 c^2$
		$=$	$8.854187817\ldots \times 10^{-12}$ F m^{-1}
Electric charge	e	$=$	$1.602176462(63) \times 10^{-19}$ C
Electron volt	1 eV	$=$	$1.602176462(63) \times 10^{-19}$ J
Planck's constant	h	$=$	$6.62606876(52) \times 10^{-34}$ J s
		$=$	$4.13566727(16) \times 10^{-15}$ eV s
	$\hbar$	$\equiv$	$h/2\pi$
		$=$	$1.054571596(82) \times 10^{-34}$ J s
		$=$	$6.58211889(26) \times 10^{-16}$ eV s
Planck's constant × speed of light	hc	$=$	$1.23984186(16) \times 10^{3}$ eV nm
		$\simeq$	1240 eV nm
Boltzmann's constant	k	$=$	$1.3806503(24) \times 10^{-23}$ J K^{-1}
		$=$	$8.6173423(153) \times 10^{-5}$ eV K^{-1}
Stefan–Boltzmann constant	σ	$\equiv$	$2\pi^5 k^4/(15c^2h^3)$
		$=$	$5.670400(40) \times 10^{-8}$ W m^{-2} K^{-4}
Radiation constant	a	$=$	$4\sigma/c$
		$=$	$7.565767(54) \times 10^{-16}$ J m^{-3} K^{-4}
Atomic mass unit	1 u	$=$	$1.66053873(13) \times 10^{-27}$ kg
		$=$	$931.494013(37)$ MeV$/c^2$
Electron mass	m_e	$=$	$9.10938188(72) \times 10^{-31}$ kg
		$=$	$5.485799110(12) \times 10^{-4}$ u
Proton mass	m_p	$=$	$1.67262158(13) \times 10^{-27}$ kg
		$=$	$1.00727646688(13)$ u
Neutron mass	m_n	$=$	$1.67492716(13) \times 10^{-27}$ kg
		$=$	$1.00866491578(55)$ u
Hydrogen mass	m_H	$=$	$1.673532499(13) \times 10^{-27}$ kg
		$=$	$1.00782503214(35)$ u
Avogadro's number	N_A	$=$	$6.02214199(47) \times 10^{23}$ mol^{-1}
Gas constant	R	$=$	$8.314472(15)$ J mol^{-1} K^{-1}
Bohr radius	$a_{0,\infty}$	$\equiv$	$4\pi\epsilon_0\hbar^2/m_e e^2$
		$=$	$5.291772083(19) \times 10^{-11}$ m
	$a_{0,H}$	$\equiv$	$(m_e/\mu)a_{0,\infty}$
		$=$	$5.294654075(20) \times 10^{-11}$ m
Rydberg constant	R_∞	$\equiv$	$m_e e^4/64\pi^3\epsilon_0^2\hbar^3 c$
		$=$	$1.0973731568549(83) \times 10^{7}$ m^{-1}
	R_H	$\equiv$	$(\mu/m_e)R_\infty$
		$=$	$1.09677583(13) \times 10^{7}$ m^{-1}

Note: Uncertainties in the last digits are indicated in parentheses. For instance, the universal gravitational constant, G, has an uncertainty of $\pm 0.010 \times 10^{-11}$ N m^2 kg^{-2}.

SI to Miscellaneous Unit Conversions

Quantity	SI Unit	Misc. Unit	Conversion Factor (SI to Misc.)[d]
Distance	meter (m)	angstrom (Å)	10^{-10}
Distance	nanometer (nm)	angstrom (Å)	10^{-1}
Spectral flux density	W m^{-2} Hz^{-1}	jansky (Jy)	10^{-26}

[d] Multiply the SI unit by the conversion factor to obtain the equivalent micellaneous unit.

SI–cgs Electromagnetic Equation Conversions

Selected Equations of Electromagnetism	SI Version	cgs Version	Text Equation
Poynting Vector	$\langle S\rangle = \frac{1}{2\mu_0} E_0 B_0$	$\langle S\rangle = \frac{c}{8\pi} E_0 B_0$	(3.12)
Coulomb's Law	$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$	$F = \frac{q_1 q_2}{r^2}$	(5.9)
Lorentz Equation	$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$	$\mathbf{F} = q\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right)$	(11.2)
Magnetic pressure	$P = \frac{B^2}{2\mu_0}$	$P = \frac{B^2}{8\pi}$	(11.10)

APPENDIX

B

Unit Conversions

Quantity	SI Unit	cgs Unit	Conversion Factor[a]
		SI to cgs Unit Conversions	
Distance	meter (m)	centimeter (cm)	10^{-2}
Mass	kilogram (kg)	gram (g)	10^{-3}
Time	second (s)	second (s)	1
Current[b]	ampere (A)	esu s^{-1}	$3.335640952 \times 10^{-10}$
Charge[c]	coulomb (C; A s)	esu	$3.335640952 \times 10^{-10}$
Velocity	m s^{-1}	cm s^{-1}	10^{-2}
Acceleration	m s^{-2}	cm s^{-2}	10^{-2}
Linear momentum	kg m s^{-1}	g cm s^{-1}	10^{-5}
Angular momentum	kg m^2 s^{-1}	g cm^2 s^{-1}	10^{-7}
Force	newton (N; kg m s^{-2})	dyne (g cm s^{-2})	10^{-5}
Energy (work)	joule (J; N m)	erg (dyne cm)	10^{-7}
Power (luminosity)	watt (W; J s^{-1})	erg s^{-1}	10^{-7}
Pressure	pascal (Pa; N m^{-2})	dyne cm^{-2}	10^{-1}
Mass density	kg m^{-3}	g cm^{-3}	10^{3}
Charge density	C m^{-3}	esu cm^{-3}	$3.335640952 \times 10^{-4}$
Current density	A m^{-2}	esu s^{-1} cm^{-2}	$3.335640952 \times 10^{-6}$
Electric potential	volt (V; J C^{-1})	statvolt (erg esu^{-1})	$2.997924580 \times 10^{2}$
Electric field	V m^{-1}	statvolt cm^{-1}	$2.997924580 \times 10^{4}$
Magnetic field	tesla (T; N A^{-1} m^{-1})	gauss (G; dyne esu^{-1})	10^{-4}
Magnetic flux	weber (Wb; T m^2)	G cm^2	10^{-8}

[a]Multiply the SI unit by the conversion factor to obtain the equivalent cgs unit; e.g., 10^{-2} m = 1 cm.

[b]The ampere is the fundamental electromagnetic unit in the SI system.

[c]The esu (*electrostatic unit*) is the fundamental electromagnetic unit in the cgs system.