Definition of Standards and Fundamental and Derived Physical Constants*

APPENDIX A

The definition of primary standards is by agreement within the International Conference of Weights and Measures whose most recent general meeting was October, 1964 in Paris. Measured and derived values of the fundamental physical constants summarize hundreds of physical measurements made over the years by scientists in all parts of the world. They have been subjected to exhaustive statistical analysis and, with their accompanying error limits (which are given as three standard deviations), represent the best values to date (1963). For most problem work three significant figures suffice, and the "computational" (rounded) values may be used. The data presented are based largely on values given in the *National Bureau of Standards Technical News Bulletin*, Vol. 47, No. 10 (October 1963).

* See "A Pilgrim's Progress in Search of the Fundamental Constants," by J. W. M. Du Mond, *Physics Today*, October 1965.

Definition of Standards and Equivalents

Standard	Abbreviation	Equivalent
Meter	m	1,650,763.73 wavelengths in vacuo of the unperturbed transition $2p_{10}$—$5d_5$ in Kr^{86}
Kilogram	kg	mass of the international kilogram at Sèvres, France
Second	sec	9,192,631,770 vibrations of the unperturbed hyperfine transition 4,0—3,0 of the fundamental state $^2S_{1/2}$ in Cs^{133}[a]
Degree Kelvin	°K	defined in the thermodynamic scale by assigning 273.16 °K to the triple point of water
Unified atomic mass unit	amu	$\frac{1}{12}$ the mass of an atom of the C^{12} nuclide
Mole	mol	amount of substance containing the same number of atoms as 12 gm (exactly) of pure C^{12}
Standard acceleration of free fall	g_n	9.80665 meter/sec^2
Normal atmospheric pressure	atm	101,325 nt/meter^2
Thermochemical calorie	cal	4.1840 joules
Liter	l	0.001,000,028 meter^3
Inch	in.	0.0254 meter
Pound (avdp.)	lb	0.453,592,37 kg

[a] There is no measurable difference between this and the previous standard of time, 1/31,556,925.9747 of the tropical year at 12^h ET, 0 January 1900. For this reason and because even more accurate maser standards may soon be available, the Cs standard was adopted provisionally rather than "permanently."

Fundamental and Derived Constants

Name	Symbol	Computational Value	Best Experimental Value[b]
Speed of light	c	3.00×10^8 meters/sec	2.997925 ± 0.000003
Permeability constant	μ_0	1.26×10^{-6} henry/meter	$4\pi \times 10^{-7}$ exactly
Permittivity constant	ϵ_0	8.85×10^{-12} farad/meter	8.85418 ± 0.00002
Elementary charge	e	1.60×10^{-19} coul	1.60210 ± 0.00007
Avogadro constant	N_0	6.02×10^{23}/mole	6.02252 ± 0.00028
Electron rest mass	m_e	9.11×10^{-31} kg	9.1091 ± 0.0004
Proton rest mass	m_p	1.67×10^{-27} kg	1.67252 ± 0.00008
Neutron rest mass	m_n	1.67×10^{-27} kg	1.67482 ± 0.00008
Faraday constant	F	9.65×10^4 coul/mole	9.64870 ± 0.00016
Planck constant	h	6.63×10^{-34} joule sec	6.6256 ± 0.0005
Fine structure constant	α	7.30×10^{-3}	7.29720 ± 0.00010
Electron charge/mass ratio	e/m_e	1.76×10^{11} coul/kg	1.758796 ± 0.000019
Quantum/charge ratio	h/e	4.14×10^{-15} joule sec/coul	4.13556 ± 0.00012
Electron Compton wavelength	λ_C	2.43×10^{-12} meter	2.42621 ± 0.00006
Proton Compton wavelength	λ_{Cp}	1.32×10^{-15} meter	1.32140 ± 0.00004
Rydberg constant	R_∞	1.10×10^7/meter	1.0973731 ± 0.0000003
Bohr radius	a_0	5.29×10^{-11} meter	5.29167 ± 0.00007
Bohr magneton	μ_B	9.27×10^{-24} joule/tesla[a]	9.2732 ± 0.0006
Nuclear magneton	μ_N	5.05×10^{-27} joule/tesla[a]	5.0505 ± 0.0004
Proton magnetic moment	μ_p	1.41×10^{-26} joule/tesla[a]	1.41049 ± 0.00013
Universal gas constant	R	8.31 joule/°K mole	8.3143 ± 0.0012
Standard volume of ideal gas	—	2.24×10^{-2} meter^3/mole	2.24136 ± 0.00030
Boltzmann constant	k	1.38×10^{-23} joule/°K	1.38054 ± 0.00018
First radiation constant π 2 hc^2	c_1	3.74×10^{-16} watt/meter^2	3.7405 ± 0.0003
Second radiation constant hc/k	c_2	1.44×10^{-2} meter °K	1.43879 ± 0.00019
Wien displacement constant	b	2.90×10^{-3} meter °K	2.8978 ± 0.0004
Stefan-Boltzmann constant	σ	5.67×10^{-8} watt/meter^2 °K^4	5.6697 ± 0.0029
Gravitational constant	G	6.67×10^{-11} nt meter^2/kg^2	6.670 ± 0.015

[a] Tesla = weber/meter^2.
[b] Same units and power of ten as the computational value.

Miscellaneous Terrestrial Data

APPENDIX B

Standard atmosphere	1.013×10^5 nt/meter^2 14.70 lb/in^2 760.0 mm-Hg
Density of dry air at STP[a]	1.293 kg/meter^3 2.458×10^{-3} slug/ft^3
Speed of sound in dry air at STP	331.4 meters/sec 1089 ft/sec 742.5 miles/hr
Acceleration of gravity, g (standard value)[b]	9.80665 meters/sec^2 32.1740 ft/sec^2
Solar constant[c]	1340 watts/m^2 1.92 cal/cm^2-min
Mean total solar radiation	3.92×10^{26} watts
Equatorial radius of earth	6.378×10^6 meters 3963 miles
Polar radius of earth	6.357×10^6 meters 3950 miles
Volume of earth	1.087×10^{21} meter^3 3.838×10^{22} ft^3
Radius of sphere having same volume	6.371×10^6 meters 3959 miles 2.090×10^7 ft

Mean density of earth	5522 kg/meter^3
Mass of earth	5.983×10^{24} kg
Mean orbital speed of earth	29,770 meters/sec 18.50 miles/sec
Mean angular speed of rotation of earth	7.29×10^{-5} radians/sec
Earth's magnetic field, B (at Washington, D. C.)	5.7×10^{-5} tesla[d]
Earth's magnetic dipole moment	6.4×10^{21} amp-m^2

[a] STP = standard temperature and pressure = 0° C and 1 atm.

[b] This value, used for barometer corrections, legal weights, etc., was adopted by the International Committee on Weights and Measures in 1901. It approximates 45° latitude at sea level.

[c] The solar constant is the solar energy falling per unit time at normal incidence on unit area of the earth's surface.

[d] Tesla ≡ weber/meter^2.

The Solar System[a]

Planet	Mercury ☿	Venus ♀	Earth ⊕, ⊖, ♁	Mars ♂	Jupier ♃	Saturn ♄	Uranus ⛢, ♅	Neptune ♆	Pluto ♇
Mean diameter km	5,000	12,400	12,742	6,870	139,760	115,100	51,000	50,000	12,700?
Earth diameters	0.39	0.973	1.000	0.532	10.97	9.03	4.00	3.90	0.46
Volume (earth volumes)	0.06	0.92	1.00	0.15	1,318	736	64	39	0.10
Mass (earth masses)	0.04	0.82	1.00	0.11	318.3	95.3	14.7	17.3	1.0?
Density (earth densities)	0.69	0.89	1.00	0.70	0.24	0.13	0.23	0.29	?
Mean density gm/cm^3	3.8	4.86	5.52	3.96	1.33	0.71	1.26	1.6	?
Surface gravity (earth's)	0.27	0.86	1.00	0.37	2.64	1.17	0.92	1.44	?
Velocity of escape, km/sec	3.6	10.2	11.2	5.0	60	36	21	23	11?
Length of day (earth days)	58.6^d	30^d?	1^d	$1^d37^m23^s$	9^h55^m	10^h38^m	10.7^h	15.8^h	?

Planet	Mercury ☿	Venus ♀	Earth, ⊕, ⊖, ♁	Mars ♂	Jupiter ♃	Saturn ♄	Uranus ⛢, ♅	Neptune ♆	Pluto ♇
Period, siderial days	87.97	224.70	365.26	686.98	4,332.59	10,759.20	30,685.93	60,187.64	90,885
Inclination of equator to orbit	—	0°?	23°27′	25°12′	3°7′	26°45′	98.0°	29°	?
Oblateness	0.00	0.00	1/296	1/192	1/15.4	1/9.5	1/14	1/45	?
Atmosphere, main constituents	none	N_2, CO_2, A	N_2, O_2	N_2, CO_2, H_2O	CH_4, NH_3	CH_4, NH_3	CH_4, NH_3	CH_4, NH_3	none
Maximum surface temperature, °K	700	700	350	* 320	153	138	110?	90?	80?
Distance from Sun, 10^6 km	58	108	149	228	778	1426	2869	4495	5900

The Sun ⊙ 329,390 earth masses, mean density 1.42, mean diameter 1,390,600 km, surface gravity 28 (earth's).

The Moon ☽ 0.01228 earth masses, mean density 3.36, mean diameter 3,476 km, surface gravity 0.17 (earth's), distance from earth 38×10^4 km.

* Adapted from Payne-Gaposchkin and *Handbook of Chemistry and Physics.*

APPENDIX D

Periodic Table of the Elements

Atomic weights are expressed in *atomic mass units* (amu), one atom of the isotope C^{12} being defined to have a mass of (exactly) 12 amu. For unstable elements the mass number of the most stable or best known isotope is given in brackets.

Period	Series	I	II	III	IV	V	VI	VII	VIII	0
1	1	1 H 1.00797								2 He 4.0026
2	2	3 Li 6.939	4 Be 9.0122	5 B 10.811	6 C 12.01115	7 N 14.0067	8 O 15.9994	9 F 18.9984		10 Ne 20.183
3	3	11 Na 22.9898	12 Mg 24.312	13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453		18 A 39.948
4	4	19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847 27 Co 58.9332 28 Ni 58.71	
	5	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909		36 Kr 83.80
5	6	37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc [99]	44 Ru 101.07 45 Rh 102.905 46 Pd 106.4	
	7	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9044		54 Xe 131.30
6	8	55 Cs 132.905	56 Ba 137.34	57–71 Lanthanide series[a]	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2 77 Ir 192.2 78 Pt 195.09	
	9	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po [210]	85 At [210]		86 Rn [222]
7	10	87 Fr [223]	88 Ra [226]	89 Actinide series[b]						

[a] Lanthanide series:	57 La 138.91	58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm [145]	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97
[b] Actinide series:	89 Ac [227]	90 Th 232.038	91 Pa [231]	92 U 238.04	93 Np [237]	94 Pu [242]	95 Am [243]	96 Cm [245]	97 Bk [249]	98 Cf [249]	99 Es [254]	100 Fm [252]	101 Md [256]	102 [254]	103 Lw [257]

APPENDIX E

The Particles of Physics[a]

Family name	Particle name	Symbol	Mass	Spin	Strangeness[b]	Charge	Antiparticle[c]	No. of particles	Average[d] lifetime, seconds	Typical decay products
	Photon	γ (gamma ray)	0	1	0	0	Same particle	1	Infinite	—
Electron family	Electron	e^-	1	$\frac{1}{2}$	—	$-e$	e^+	2	Infinite	—
	Electron's neutrino	ν_e	0	$\frac{1}{2}$	—	0	$\bar{\nu}_e$	2	Infinite	—
Muon family	Muon	μ^-	206.77	$\frac{1}{2}$	—	$-e$	μ^+	2	2.212×10^{-6}	$e^- + \bar{\nu}_e + \nu_\mu$
	Muon's neutrino	ν_μ	0(?)	$\frac{1}{2}$	—	0	$\bar{\nu}_\mu$	2	Infinite	—
Mesons	Pion	π^+ π^0	273.2 264.2	0 0	0 0	$+e$ 0	π^- π^0	3	2.55×10^{-8} 1.9×10^{-16}	$\mu^+ + \nu_\mu$ $\gamma + \gamma$
	Kaon	K^+ K^0	966.6 974	0 0	+1 +1	$+e$ 0	$\overline{K^+}$ $\overline{K^0}$	4	1.22×10^{-8} 1.00×10^{-10} and 6×10^{-8}	$\pi^+ + \pi^0$ $\pi^+ + \pi^-$

Family name	Particle name	Symbol	Mass	Spin	Strangeness[b]	Charge	Antiparticle[c]	No. of particles	Average lifetime seconds	Typical decay products
Baryons	Nucleon	p^+ (proton)	1836.12	$\frac{1}{2}$	0	$+e$	$\overline{p^+}$	4	Infinite	
		n^0 (neutron)	1838.65	$\frac{1}{2}$	0	0	$\overline{n^0}$		1013	$p + e^- + \overline{\nu_e}$
	Lambda particle	Λ^0	2182.8	$\frac{1}{2}$	−1	0	$\overline{\Lambda^0}$	2	2.51×10^{-10}	$p + \pi^-$
	Sigma particle	Σ^+	2327.7	$\frac{1}{2}$	−1	$+e$	$\overline{\Sigma^+}$		8.1×10^{-11}	$n + \pi^+$
		Σ^-	2340.5	$\frac{1}{2}$	−1	$-e$	$\overline{\Sigma^-}$	6	1.6×10^{-10}	$n + \pi^-$
		Σ^0	2332	$\frac{1}{2}$	−1	0	$\overline{\Sigma^0}$		about 10^{-20}	$\Lambda^0 + \gamma$
	Xi particle	Ξ^-	2580	$\frac{1}{2}$	−2	$-e$	$\overline{\Xi^-}$	4	1.3×10^{-10}	$\Lambda^0 + \pi^-$
		Ξ^0	2570	$\frac{1}{2}$	−2	0	$\overline{\Xi^0}$		about 10^{-10}	$\Lambda^0 + \pi^0$

[a] Adapted and modified from *The World of Elementary Particles*, by Kenneth W. Ford.
[b] This is a "quantum number" whose assignment permits an understanding of the inter-relationships of the particles.
[c] Antiparticles have the same mass and spin as the particles but their charges and strangeness numbers are opposite in sign.
[d] The K^0 meson has two different lifetimes; all other particles have only one.

Symbols, Dimensions, and Units for Physical Quantities

APPENDIX F

All units and dimensions are in the mksq (rationalized) system. The primary units can be found by reading kilograms for M, meters for L, seconds for T, and coulombs for Q. The symbols are those used in the text.

In practice, Q is defined in terms of M, L, and T. However, the addition of Q to the traditional M, L, and T enables us to avoid the use of fractional exponents in dimensional considerations. The term 'rationalized' simply means that a factor $1/4\pi$ is separated out of Coulomb's law in order to remove the factor 4π that would otherwise appear in many other formulas in electricity.

Quantity	Symbol	Dimensions	Derived Units
Acceleration	**a**	LT^{-2}	meters/sec²
Angular acceleration	$\boldsymbol{\alpha}$	T^{-2}	radians/sec²
Angular displacement	θ	—	radian
Angular frequency and speed	ω	T^{-1}	radians/sec
Angular momentum	**L**	ML^2T^{-1}	kg-m²/sec
Angular velocity	$\boldsymbol{\omega}$	T^{-1}	radians/sec
Area	A, S	L^2	meter²
Displacement	**r**, **d**	L	meter

Quantity	Symbol	Dimensions	Derived Units
Energy, total	E	ML^2T^{-2}	joule
kinetic	K	ML^2T^{-2}	joule
potential	U	ML^2T^{-2}	joule
Force	$\mathbf{F}$	MLT^{-2}	newton
Frequency	ν	T^{-1}	hertz ≡ cycles/sec
Gravitational field strength	$\mathbf{g}$	LT^{-2}	nt/kg
Gravitational potential	V	L^2T^{-2}	joules/kg
Length	l	L	meter
Mass	m	M	kilogram
Mass density	ρ	ML^{-3}	kg/m^3
Momentum	$\mathbf{p}$	MLT^{-1}	kg-m/sec
Period	T	T	second
Power	P	ML^2T^{-3}	watt
Pressure	p	$ML^{-1}T^{-2}$	nt/m^2
Rotational inertia	I	ML^2	$kg\text{-}m^2$
Time	t	T	second
Torque	$\boldsymbol{\tau}$	ML^2T^{-2}	nt-m
Velocity	$\mathbf{v}$	LT^{-1}	meters/sec
Volume	V	L^3	$meter^3$
Wavelength	λ	L	meter
Work	W	ML^2T^{-2}	joule
Entropy	S	ML^2T^{-2}	joules/$K°$
Internal energy	U	ML^2T^{-2}	joule
Heat	Q	ML^2T^{-2}	joule
Temperature	T	—	Kelvin degree
Capacitance	C	$M^{-1}L^{-2}T^2Q^2$	farad
Charge	q	Q	coulomb
Conductivity	σ	$M^{-1}L^{-3}TQ^2$	$(\text{ohm-meter})^{-1}$
Current	i	$T^{-1}Q$	ampere
Current density	$\mathbf{j}$	$L^{-2}T^{-1}Q$	$amp/meter^2$
Electric dipole moment	$\mathbf{p}$	LQ	coul-meter
Electric displacement	$\mathbf{D}$	$M^{-2}Q$	$coul/meter^2$
Electric polarization	$\mathbf{P}$	$M^{-2}Q$	$coul\text{-}meter^2$
Electric field strength	$\mathbf{E}$	$MLT^{-2}Q^{-1}$	volts/meter
Electric flux	Φ_E	$ML^3T^{-2}Q^{-1}$	volt-meter
Electric potential	V	$ML^2T^{-2}Q^{-1}$	volt
Electromotive force	$\mathcal{E}$	$ML^2T^{-2}Q^{-1}$	volt
Inductance	L	ML^2Q^{-2}	henry
Magnetic dipole moment	$\boldsymbol{\mu}$	$L^2T^{-1}Q$	$amp\text{-}meter^2$
Magnetic field strength	$\mathbf{H}$	$L^{-1}T^{-1}Q$	amp-meter
Magnetic flux	Φ_B	$ML^2T^{-1}Q^{-1}$	weber = volt-sec
Magnetic induction	$\mathbf{B}$	$MT^{-1}Q^{-1}$	tesla ≡ $webers/meter^2$
Magnetization	$\mathbf{M}$	$L^{-1}T^{-1}Q$	amp/meter
Permeability	μ	MLQ^{-2}	henrys/meter
Permittivity	ϵ	$M^{-1}L^{-3}T^2Q^2$	farads/meter
Resistance	R	$ML^2T^{-1}Q^{-2}$	ohm
Resistivity	ρ	$ML^3T^{-1}Q^{-2}$	ohm-meter
Voltage	V	$ML^2T^{-2}Q^{-1}$	volt

Conversion Factors[a]

APPENDIX G

Conversion factors for common and not-so-common units may be read off directly from the tables below. For example, 1 degree = 2.778×10^{-3} revolutions, so $16.7° = 16.7 \times 2.778 \times 10^{-3}$ rev. The mks quantities are capitalized in each table.

PLANE ANGLE

	°	′	″	RADIAN	rev
1 degree =	1	60	3600	1.745×10^{-2}	2.778×10^{-3}
1 minute =	1.667×10^{-2}	1	60	2.909×10^{-4}	4.630×10^{-5}
1 second =	2.778×10^{-4}	1.667×10^{-2}	1	4.848×10^{-6}	7.716×10^{-7}
1 RADIAN =	57.30	3438	2.063×10^{5}	1	0.1592
1 revolution =	360	2.16×10^{4}	1.296×10^{6}	6.283	1

1 rev = 2π radians = 360°   1° = 60′ = 3600″

SOLID ANGLE

1 sphere = 4π steradians = 12.57 steradians

[a] Adapted in part from G. Shortley and D. Williams, *Elements of Physics*, Prentice-Hall, Englewood Cliffs, New Jersey, Second Edition, 1955.

LENGTH

	cm	METER	km	in.	ft	mile
1 centimeter =	1	10^{-2}	10^{-5}	0.3937	3.281 $\times 10^{-2}$	6.214 $\times 10^{-6}$
1 METER =	100	1	10^{-3}	39.37	3.281	6.214 $\times 10^{-4}$
1 kilometer =	10^5	1000	1	3.937 $\times 10^4$	3281	0.6214
1 inch =	2.540	2.540 $\times 10^{-2}$	2.540 $\times 10^{-5}$	1	8.333 $\times 10^{-2}$	1.578 $\times 10^{-5}$
1 foot =	30.48	0.3048	3.048 $\times 10^{-4}$	12	1	1.894 $\times 10^{-4}$
1 statute mile =	1.609 $\times 10^5$	1609	1.609	6.336 $\times 10^4$	5280	1

1 angstrom (A) = 10^{-10} meter
1 X-unit = 10^{-13} meter
1 micron = 10^{-6} meter
1 millimicron (mμ) = 10^{-9} meter
1 nautical mile = 1852 meters = 1.1508 statute miles = 6076.10 ft

1 light-year = 9.4600 $\times 10^{12}$ km
1 parsec = 3.084 $\times 10^{13}$ km
1 fathom = 6 ft

1 yard = 3 ft
1 rod = 16.5 ft
1 mil = 10^{-3} in.

AREA

	METER^2	cm^2	ft^2	in.^{2}	circ mil
1 SQUARE METER =	1	10^4	10.76	1550	1.974 $\times 10^9$
1 square centimeter =	10^{-4}	1	1.076 $\times 10^{-3}$	0.1550	1.974 $\times 10^5$
1 square foot =	9.290 $\times 10^{-2}$	929.0	1	144	1.833 $\times 10^8$
1 square inch =	6.452 $\times 10^{-4}$	6.452	6.944 $\times 10^{-3}$	1	1.273 $\times 10^6$
1 circular mill =	5.067 $\times 10^{-10}$	5.067 $\times 10^{-6}$	5.454 $\times 10^{-9}$	7.854 $\times 10^{-7}$	1

1 square mile = 27,878,400 ft^2 = 640 acres   1 acre = 43,560 ft^2
1 barn = 10^{-28} meter^2

VOLUME

	METER^3	cm^3	l	ft^3	in.^{3}
1 CUBIC METER =	1	10^6	1000	35.31	6.102 $\times 10^4$
1 cubic centimeter =	10^{-6}	1	1.000 $\times 10^{-3}$	3.531 $\times 10^{-5}$	6.102 $\times 10^{-2}$
1 liter =	1.000 $\times 10^{-3}$	1000	1	3.531 $\times 10^{-2}$	61.02
1 cubic foot =	2.832 $\times 10^{-2}$	2.832 $\times 10^4$	28.32	1	1728
1 cubic inch =	1.639 $\times 10^{-5}$	16.39	1.639 $\times 10^{-2}$	5.787 $\times 10^{-4}$	1

1 U. S. fluid gallon = 4 U. S. fluid quarts = 8 U. S. pints = 128 U. S. fluid ounces = 231 in.^{3}
1 British imperial gallon = the volume of 10 lb of water at 62° F = 277.42 in.^{3}
1 liter = the volume of 1 kg of water at its maximum density = 1000.028 cm^3

MASS

Note: Those quantities to the right of and below the heavy lines are not mass units at all but are often used as such. When we write, for example,

1 kg "=" 2.205 lb

this means that a kilogram is a *mass* that *weighs* 2.205 pounds. Clearly this "equivalence" is approximate (depending on the value of g) and is meaningful only for terrestrial measurements. Thus, care must be employed when using the factors in the shaded portion of the table.

	gm	KG	slug	amu	oz	lb	ton
1 gram =	1	0.001	6.852×10^{-5}	6.024×10^{23}	3.527×10^{-2}	2.205×10^{-3}	1.102×10^{-6}
1 KILOGRAM =	1000	1	6.852×10^{-2}	6.024×10^{26}	35.27	2.205	1.102×10^{-3}
1 slug =	1.459×10^{4}	14.59	1	8.789×10^{27}	514.8	32.17	1.609×10^{-2}
1 amu =	1.660×10^{-24}	1.660×10^{-27}	1.137×10^{-28}	1	5.855×10^{-26}	3.660×10^{-27}	1.829×10^{-30}
1 ounce (avoirdupois) =	28.35	2.835×10^{-2}	1.943×10^{-3}	1.708×10^{25}	1	6.250×10^{-2}	3.125×10^{-5}
1 pound (avoirdupois) =	453.6	0.4536	3.108×10^{-2}	2.732×10^{26}	16	1	0.0005
1 ton =	$9.072 \times 10^{+5}$	907.2	62.16	5.465×10^{29}	3.2×10^{4}	2000	1

DENSITY

Note: Those quantities to the right or below the heavy line are weight densities and, as such, are dimensionally different from mass densities. Care must be used. (See note for mass table.)

	slug/ft³	KG/METER³	gm/cm³	lb/ft³	lb/in.³
1 slug per ft³ =	1	515.4	0.5154	32.17	1.862×10^{-2}
1 KILOGRAM per METER³ =	1.940×10^{-3}	1	0.001	6.243×10^{-2}	3.613×10^{-5}
1 gram per cm³ =	1.940	1000	1	62.43	3.613×10^{-2}
1 pound per ft³ =	3.108×10^{-2}	16.02	1.602×10^{-2}	1	5.787×10^{-4}
1 pound per in.³ =	53.71	2.768×10^{4}	27.68	1728	1

TIME

	yr	day	hr	min	SEC
1 year =	1	365.2	8.766×10^{3}	5.259×10^{5}	3.156×10^{7}
1 day =	2.738×10^{-3}	1	24	1440	8.640×10^{4}
1 hour =	1.141×10^{-4}	4.167×10^{-2}	1	60	3600
1 minute =	1.901×10^{-6}	6.944×10^{-4}	1.667×10^{-2}	1	60
1 SECOND =	3.169×10^{-8}	1.157×10^{-5}	2.778×10^{-4}	1.667×10^{-2}	1

SPEED

	ft/sec	km/hr	METER/SEC	miles/hr	cm/sec	knot
1 foot per second =	1	1.097	0.3048	0.6818	30.48	0.5925
1 kilometer per hour =	0.9113	1	0.2778	0.6214	27.78	0.5400
1 METER per SECOND =	3.281	3.6	1	2.237	100	1.944
1 mile per hour =	1.467	1.609	0.4470	1	44.70	0.8689
1 centimeter per second =	3.281×10^{-2}	3.6×10^{-2}	0.01	2.237×10^{-2}	1	1.944×10^{-2}
1 knot =	1.688	1.852	0.5144	1.151	51.44	1

1 knot = 1 nautical mile/hr   1 mile/min = 88 ft/sec = 60 miles/hr

FORCE

Note: Those quantities to the right of and below the heavy lines are not force units at all but are often used as such, especially in chemistry. For instance, if we write

1 gram-force "=" 980.7 dynes,

we mean that a gram-*mass* experiences a *force* of 980.7 dynes in the earth's gravitational field. Thus, care must be employed when using the factors in the shaded portion of the table.

	dyne	NT	lb	pdl	gf	kgf
1 dyne =	1	10^{-5}	2.248×10^{-6}	7.233×10^{-5}	1.020×10^{-3}	1.020×10^{-6}
1 NEWTON =	10^5	1	0.2248	7.233	102.0	0.1020
1 pound =	4.448×10^5	4.448	1	32.17	453.6	0.4536
1 poundal =	1.383×10^4	0.1383	3.108×10^{-2}	1	14.10	1.410×10^{-2}
1 gram-force =	980.7	9.807×10^{-3}	2.205×10^{-3}	7.093×10^{-2}	1	0.001
1 kilogram-force =	9.807×10^5	9.807	2.205	70.93	1000	1

1 kgf = 9.80665 nt   1 lb = 32.17398 pdl

PRESSURE

	atm	dyne/cm²	inch of water	cm Hg	NT/METER²	lb/in.²	lb/ft²
1 atmosphere =	1	1.013×10^6	406.8	76	1.013×10^5	14.70	2116
1 dyne per cm² =	9.869×10^{-7}	1	4.015×10^{-4}	7.501×10^{-5}	0.1	1.450×10^{-5}	2.089×10^{-3}
1 inch of water at 4° C [a] =	2.458×10^{-3}	2491	1	0.1868	249.1	3.613×10^{-2}	5.202
1 centimeter of mercury at 0° C [a] =	1.316×10^{-2}	1.333×10^4	5.353	1	1333	0.1934	27.85
1 NEWTON per METER² =	9.869×10^{-6}	10	4.015×10^{-3}	7.501×10^{-4}	1	1.450×10^{-4}	2.089×10^{-2}
1 pound per in.² =	6.805×10^{-2}	6.895×10^4	27.68	5.171	6.895×10^3	1	144
1 pound per ft² =	4.725×10^{-4}	478.8	0.1922	3.591×10^{-2}	47.88	6.944×10^{-3}	1

ENERGY, WORK, HEAT

The electron volt (ev) is the kinetic energy an electron gains from being accelerated through the potential difference of one volt in an electric field. The Mev is the kinetic energy it gains from being accelerated through a million-volt potential difference.

The last two items in this table are not properly energy units but are included for convenience. They arise from the relativistic mass-energy equivalence formula $E = mc^2$ and represent the energy released if a kilogram or atomic mass unit (amu) is destroyed completely.

Again, care should be used when employing this table.

	Btu	erg	ft-lb	hp-hr	JOULES	cal	kw-hr	ev	Mev	kg	amu
1 British thermal unit =	1	1.055×10^{10}	777.9	3.929×10^{-4}	1055	252.0	2.930×10^{-4}	6.585×10^{21}	6.585×10^{15}	1.174×10^{-14}	7.074×10^{12}
1 erg =	9.481×10^{-11}	1	7.376×10^{-8}	3.725×10^{-14}	10^{-7}	2.389×10^{-8}	2.778×10^{-14}	6.242×10^{11}	6.242×10^{5}	1.113×10^{-24}	670.5
1 foot-pound =	1.285×10^{-3}	1.356×10^{7}	1	5.051×10^{-7}	1.356	0.3239	3.766×10^{-7}	8.464×10^{18}	8.464×10^{12}	1.509×10^{-17}	9.092×10^{9}
1 horsepower-hour =	2545	2.685×10^{13}	1.980×10^{6}	1	2.685×10^{6}	6.414×10^{5}	0.7457	1.676×10^{25}	1.676×10^{19}	2.988×10^{-11}	1.800×10^{16}
1 JOULE =	9.481×10^{-4}	10^{7}	0.7376	3.725×10^{-7}	1	0.2389	2.778×10^{-7}	6.242×10^{18}	6.242×10^{12}	1.113×10^{-17}	6.705×10^{9}
1 calorie =	3.968×10^{-3}	4.186×10^{7}	3.087	1.559×10^{-6}	4.186	1	1.163×10^{-6}	2.613×10^{19}	2.613×10^{13}	4.659×10^{-17}	2.807×10^{10}
1 kilowatt-hour =	3413	3.6×10^{13}	2.655×10^{6}	1.341	3.6×10^{6}	8.601×10^{5}	1	2.247×10^{25}	2.270×10^{19}	4.007×10^{-11}	2.414×10^{16}
1 electron volt =	1.519×10^{-22}	1.602×10^{-12}	1.182×10^{-19}	5.967×10^{-26}	1.602×10^{-19}	3.827×10^{-20}	4.450×10^{-26}	1	10^{-6}	1.783×10^{-36}	1.074×10^{-9}
1 million electron volts =	1.519×10^{-16}	1.602×10^{-6}	1.182×10^{-13}	5.967×10^{-20}	1.602×10^{-13}	3.827×10^{-14}	4.450×10^{-20}	10^{6}	1	1.783×10^{-30}	1.074×10^{-3}
1 kilogram =	8.521×10^{13}	8.987×10^{23}	6.629×10^{16}	3.348×10^{10}	8.987×10^{16}	2.147×10^{16}	2.497×10^{10}	5.610×10^{35}	5.610×10^{29}	1	6.025×10^{26}
1 atomic mass unit =	1.415×10^{-13}	1.492×10^{-3}	1.100×10^{-10}	5.553×10^{-17}	1.492×10^{-10}	3.564×10^{-11}	4.145×10^{-17}	9.31×10^{8}	931.0	1.660×10^{-27}	1

1 m-kgf = 9.807 joules   1 watt-sec = 1 joule = 1 nt-m   1 cm-dyne = 1 erg

POWER

	Btu/hr	ft-lb/min	ft-lb/sec	hp	cal/sec	kw	WATTS
1 British thermal unit per hour =	1	12.97	0.2161	3.929×10^{-4}	7.000×10^{-2}	2.930×10^{-4}	0.2930
1 foot-pound per minute =	7.713×10^{-2}	1	1.667×10^{-2}	3.030×10^{-5}	5.399×10^{-3}	2.260×10^{-5}	2.260×10^{-2}
1 foot-pound per second =	4.628	60	1	1.818×10^{-3}	0.3239	1.356×10^{-3}	1.356
1 horsepower =	2545	3.3×10^{4}	550	1	178.2	0.7457	745.7
1 calorie per second =	14.29	1.852×10^{2}	3.087	5.613×10^{-3}	1	4.186×10^{-3}	4.186
1 kilowatt =	3413	4.425×10^{4}	737.6	1.341	238.9	1	1000
1 WATT =	3.413	44.25	0.7376	1.341×10^{-3}	0.2389	0.001	1

ELECTRIC CHARGE

	abcoul	amp-hr	COUL	faraday	statcoul
1 abcoulomb (1 emu) =	1	2.778×10^{-3}	10	1.036×10^{-4}	2.998×10^{10}
1 ampere-hour =	360	1	3600	3.730×10^{-2}	1.079×10^{13}
1 COULOMB =	0.1	2.778×10^{-4}	1	1.036×10^{-5}	2.998×10^{9}
1 faraday =	9652	26.81	9.652×10^{4}	1	2.893×10^{14}
1 statcoulomb (1 esu) =	3.336×10^{-11}	9.266×10^{-14}	3.336×10^{-10}	3.456×10^{-15}	1

1 electronic charge = 1.602×10^{-19} coulomb

ELECTRIC CURRENT

	abamp	AMP	statamp
1 abampere (1 emu) =	1	10	2.998×10^{10}
1 AMPERE =	0.1	1	2.998×10^{9}
1 statampere (1 esu) =	3.336×10^{-11}	3.336×10^{-10}	1

ELECTRIC POTENTIAL, ELECTROMOTIVE FORCE

	abv	VOLTS	statv
1 abvolt (1 emu) =	1	10^{-8}	3.336×10^{-11}
1 VOLT =	10^{8}	1	3.336×10^{-3}
1 statvolt (1 esu) =	2.998×10^{10}	299.8	1

ELECTRIC RESISTANCE

	abohm	OHMS	statohm
1 abohm (1 emu) =	1	10^{-9}	1.113×10^{-21}
1 OHM =	10^{9}	1	1.113×10^{-12}
1 statohm (1 esu) =	8.987×10^{20}	8.987×10^{11}	1

ELECTRIC RESISTIVITY

	abohm-cm	μohm-cm	ohm-cm	statohm-cm	OHM-M	ohm-circ mil/ft
1 abohm-centimeter (1 emu) =	1	0.001	10^{-9}	1.113×10^{-21}	10^{-11}	6.015×10^{-3}
1 micro-ohm-centimeter =	1000	1	10^{-6}	1.113×10^{-18}	10^{-8}	6.015
1 ohm-centimeter =	10^{9}	10^{6}	1	1.113×10^{-12}	0.01	6.015×10^{6}
1 statohm-centimeter (1 esu) =	8.987×10^{20}	8.987×10^{17}	8.987×10^{11}	1	8.987×10^{9}	5.406×10^{18}
1 OHM-METER =	10^{11}	10^{8}	100	1.113×10^{-10}	1	6.015×10^{8}
1 ohm-circular mil per foot =	166.2	0.1662	1.662×10^{-7}	1.850×10^{-19}	1.662×10^{-9}	1

CAPACITANCE

	abf	FARADS	μf[a]	statf
1 abfarad (1 emu) =	1	10^{9}	10^{15}	8.987×10^{20}
1 FARAD =	10^{-9}	1	10^{6}	8.987×10^{11}
1 microfarad =	10^{-15}	10^{-6}	1	8.987×10^{5}
1 statfarad (1 esu) =	1.113×10^{-21}	1.113×10^{-12}	1.113×10^{-6}	1

[a] This unit is frequently abbreviated as mf.

INDUCTANCE

	abhenry	HENRYS	μh	mh	stathenry
1 abhenry (1 emu) =	1	10^{-9}	0.001	10^{-6}	1.113×10^{-21}
1 HENRY =	10^{9}	1	10^{6}	1000	1.113×10^{-12}
1 microhenry =	1000	10^{-6}	1	0.001	1.113×10^{-18}
1 millihenry =	10^{6}	0.001	1000	1	1.113×10^{-15}
1 stathenry (1 esu) =	8.987×10^{20}	8.987×10^{11}	8.987×10^{17}	8.987×10^{14}	1

MAGNETIC FLUX

	maxwell	kiloline	WEBER
1 maxwell (1 line or 1 emu) =	1	0.001	10^{-8}
1 kiloline =	1000	1	10^{-5}
1 WEBER =	10^{8}	10^{5}	1

1 esu = 299.8 webers

MAGNETIC INDUCTION B

	gauss	kiloline/in.^{2}	WEBER/ METER^2 = TESLA	milligauss	
1 gauss (line per cm^2) =	1	6.452×10^{-3}	10^{-4}	1000	10^5
1 kiloline per in.^{2} =	155.0	1	1.550×10^{-2}	1.550×10^5	1.550×10^7
1 WEBER per METER^2 = 1 TESLA =	10^4	64.52	1	10^7	10^9
1 milligauss =	0.001	6.452×10^{-6}	10^{-7}	1	100
1 gamma =	10^{-5}	6.452×10^{-8}	10^{-9}	0.01	1

1 esu = 2.998×10^6 webers/meter^2

MAGNETOMOTIVE FORCE

	abamp-turn	AMP-TURN	gilbert
1 abampere-turn =	1	10	12.57
1 AMPERE-TURN =	0.1	1	1.257
1 gilbert =	7.958×10^{-2}	0.7958	1

1 pragilbert = 4π amp-turn   1 esu = 2.655×10^{-11} amp-turn

MAGNETIC FIELD STRENGTH H

	abamp-turn/cm	amp-turn/cm	amp-turn/in.	AMP-TURN/ METER	oersted
1 abampere-turn per centimeter =	1	10	25.40	1000	12.57
1 ampere-turn per centimeter =	0.1	1	2.540	100	1.257
1 ampere-turn per inch =	3.937×10^{-2}	0.3937	1	39.37	0.4947
1 AMPERE-TURN per METER =	0.001	0.01	2.540×10^{-2}	1	1.257×10^{-2}
1 oersted =	7.958×10^{-2}	0.7958	2.021	79.58	1

1 oersted = 1 gilbert   1 esu = 2.655×10^{-9} amp-turn/meter

1 praoersted = 4π amp-turn/meter

Mathematical Symbols and the Greek Alphabet

APPENDIX H

Mathematical signs and symbols

$=$ equals
$\cong$ equals approximately
$\neq$ is not equal to
$\equiv$ is identical to, is defined as
$>$ is greater than ($\gg$ is much greater than)
$<$ is less than ($\ll$ is much less than)
$\geq$ is more than or equal to (or, is no less than)
$\leq$ is less than or equal to (or, is no more than)
$\pm$ plus or minus (e.g., $\sqrt{4} = \pm 2$)
$\propto$ is proportional to (e.g., Hooke's law: $F \propto x$, or $F = -kx$)
Σ the sum of
$\bar{x}$ the average value of x

The Greek alphabet

Alpha	A	α	Nu	N	ν
Beta	B	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	O	o
Delta	Δ	δ	Pi	Π	π
Epsilon	E	ϵ	Rho	P	ρ
Zeta	Z	ζ	Sigma	Σ	σ
Eta	H	η	Tau	T	τ
Theta	Θ	θ, ϑ	Upsilon	Υ	υ
Iota	I	ι	Phi	Φ	ϕ, φ
Kappa	K	κ	Chi	X	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	M	μ	Omega	Ω	ω

Mathematical Formulas

APPENDIX I

Quadratic formula

If $ax^2 + bx + c = 0$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

Trigonometric functions of angle θ

$\sin\theta = \dfrac{y}{r}$ $\cos\theta = \dfrac{x}{r}$

$\tan\theta = \dfrac{y}{x}$ $\cot\theta = \dfrac{x}{y}$

$\sec\theta = \dfrac{r}{x}$ $\csc\theta = \dfrac{r}{y}$

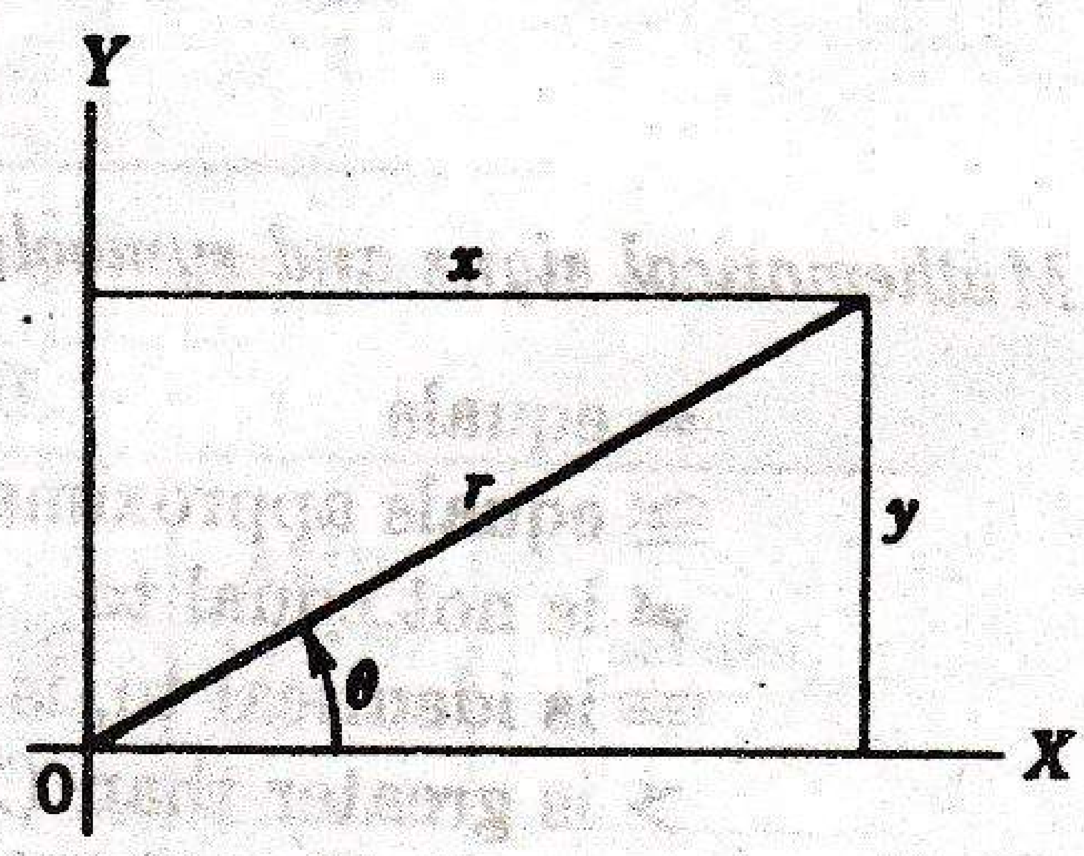

Fig. App. I

Pythagorean theorem

$$x^2 + y^2 = r^2$$

Trigonometric identities

$$\sin^2\theta + \cos^2\theta = 1 \qquad \sec^2\theta - \tan^2\theta = 1 \qquad \csc^2\theta - \cot^2\theta = 1$$

$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$$

$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$$

$$\tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha\tan\beta}$$

$$\sin 2\theta = 2\sin\theta\cos\theta$$

$$\cos 2\theta = \cos^2\theta - \sin^2\theta = 2\cos^2\theta - 1 = 1 - 2\sin^2\theta$$

$$\sin\theta = \frac{e^{i\theta} - e^{-i\theta}}{2i} \qquad \cos\theta = \frac{e^{i\theta} + e^{-i\theta}}{2}$$

$$e^{\pm i\theta} = \cos\theta \pm i\sin\theta$$

Taylor's series

$$f(x_0 + x) = f(x_0) + f'(x_0)x + f''(x_0)\frac{x^2}{2!} + f'''(x_0)\frac{x^3}{3!} + \cdots$$

Series expansions (these expansions converge for $-1 < x < 1$, except as noted)

$$\frac{1}{1+x} = 1 - x + x^2 - x^3 + \cdots$$

$$\sqrt{1+x} = 1 + \frac{x}{2} - \frac{x^2}{8} + \frac{x^3}{16} - \cdots$$

$$\frac{1}{\sqrt{1+x}} = 1 - \frac{x}{2} + \frac{3x^2}{8} - \frac{5x^3}{16} + \cdots$$

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \cdots \qquad (-\infty < x < \infty)$$

x in radians:

$$\sin x = x - \frac{x^3}{6} + \frac{x^5}{120} - \cdots \qquad (-\infty < x < \infty)$$

$$\cos x = 1 - \frac{x^2}{2} + \frac{x^4}{24} - \cdots \qquad (-\infty < x < \infty)$$

$$\tan x = x + \frac{x^3}{3} + \frac{2x^5}{15} + \cdots \qquad (-\pi/2 < x < \pi/2)$$

$$(x+y)^n = x^n + \frac{n}{1!}x^{n-1}y + \frac{n(n-1)}{2!}x^{n-2}y^2 + \cdots \qquad (x^2 > y^2)$$

Derivatives and indefinite integrals

In what follows, the letters u and v stand for any functions of x, and a and m are constants. To each of the integrals should be added an arbitrary constant of integration. *A Short Table of Integrals* by Peirce and Foster (Ginn and Co.) gives a more extensive tabulation.

1. $\frac{dx}{dx} = 1$
2. $\frac{d}{dx}(au) = a\frac{du}{dx}$
3. $\frac{d}{dx}(u+v) = \frac{du}{dx} + \frac{dv}{dx}$
4. $\frac{d}{dx}x^m = mx^{m-1}$
5. $\frac{d}{dx}\ln x = \frac{1}{x}$
6. $\frac{d}{dx}(uv) = u\frac{dv}{dx} + v\frac{du}{dx}$
7. $\frac{d}{dx}e^x = e^x$
8. $\frac{d}{dx}\sinh x = \cosh x$

1. $\int dx = x$
2. $\int au\,dx = a\int u\,dx$
3. $\int (u+v)\,dx = \int u\,dx + \int v\,dx$
4. $\int x^m\,dx = \frac{x^{m+1}}{m+1} \qquad (m \neq -1)$
5. $\int \frac{dx}{x} = \ln|x|$
6. $\int u\frac{dv}{dx}\,dx = uv - \int v\frac{du}{dx}\,dx$
7. $\int e^x\,dx = e^x$
8. $\int \cosh x\,dx = \sinh x$

9. $\frac{d}{dx}\cosh x = \sinh x$

10. $\frac{d}{dx}\arctan x = \frac{1}{1+x^2}$

11. $\frac{d}{dx}\arcsin x = \frac{1}{\sqrt{1-x^2}}$

12. $\frac{d}{dx}\operatorname{arcsec} x = \frac{1}{x\sqrt{x^2-1}}$

13. $\frac{d}{dx}\cos x = -\sin x$

14. $\frac{d}{dx}\sin x = \cos x$

15. $\frac{d}{dx}\tan x = \sec^2 x$

16. $\frac{d}{dx}\cot x = -\csc^2 x$

17. $\frac{d}{dx}\sec x = \tan x \sec x$

18. $\frac{d}{dx}\csc x = -\cot x \csc x$

9. $\int \sinh x\, dx = \cosh x$

10. $\int \frac{dx}{1+x^2} = \arctan x$

11. $\int \frac{dx}{\sqrt{1-x^2}} = \arcsin x$

12. $\int \frac{dx}{x\sqrt{x^2-1}} = \operatorname{arcsec} x$

13. $\int \sin x\, dx = -\cos x$

14. $\int \cos x\, dx = \sin x$

19. $\int \tan x\, dx = \ln|\sec x|$

20. $\int \cot x\, dx = \ln|\sin x|$

21. $\int \sec x\, dx = \ln|\sec x + \tan x|$

22. $\int \csc x\, dx = \ln|\csc x - \cot x|$

Vector products

Let $\mathbf{i}, \mathbf{j}, \mathbf{k}$ be unit vectors in the x, y, z directions. Then

$$\mathbf{i}\cdot\mathbf{i} = \mathbf{j}\cdot\mathbf{j} = \mathbf{k}\cdot\mathbf{k} = 1, \qquad \mathbf{i}\cdot\mathbf{j} = \mathbf{j}\cdot\mathbf{k} = \mathbf{k}\cdot\mathbf{i} = 0,$$

$$\mathbf{i}\times\mathbf{i} = \mathbf{j}\times\mathbf{j} = \mathbf{k}\times\mathbf{k} = 0,$$

$$\mathbf{i}\times\mathbf{j} = \mathbf{k}, \qquad \mathbf{j}\times\mathbf{k} = \mathbf{i}, \qquad \mathbf{k}\times\mathbf{i} = \mathbf{j}.$$

Any vector $\mathbf{a}$ with components a_x, a_y, a_z along the x, y, z axes can be written

$$\mathbf{a} = a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k}.$$

Let $\mathbf{a}, \mathbf{b}, \mathbf{c}$ be arbitrary vectors with magnitudes a, b, c. Then

$$\mathbf{a}\times(\mathbf{b}+\mathbf{c}) = \mathbf{a}\times\mathbf{b} + \mathbf{a}\times\mathbf{c}$$

$$(s\mathbf{a})\times\mathbf{b} = \mathbf{a}\times(s\mathbf{b}) = s(\mathbf{a}\times\mathbf{b}) \qquad (s \text{ a scalar}).$$

Let θ be the smaller of the two angles between $\mathbf{a}$ and $\mathbf{b}$. Then

$$\mathbf{a}\cdot\mathbf{b} = \mathbf{b}\cdot\mathbf{a} = a_xb_x + a_yb_y + a_zb_z = ab\cos\theta$$

$$\mathbf{a}\times\mathbf{b} = -\mathbf{b}\times\mathbf{a} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} = (a_yb_z - b_ya_z)\mathbf{i} + (a_zb_x - b_za_x)\mathbf{j} + (a_xb_y - b_xa_y)\mathbf{k}$$

$$|\mathbf{a}\times\mathbf{b}| = ab\sin\theta$$

$$\mathbf{a}\cdot(\mathbf{b}\times\mathbf{c}) = \mathbf{b}\cdot(\mathbf{c}\times\mathbf{a}) = \mathbf{c}\cdot(\mathbf{a}\times\mathbf{b})$$

$$\mathbf{a}\times(\mathbf{b}\times\mathbf{c}) = (\mathbf{a}\cdot\mathbf{c})\mathbf{b} - (\mathbf{a}\cdot\mathbf{b})\mathbf{c}$$

Values of Trigonometric Functions

APPENDIX J

TRIGONOMETRIC FUNCTIONS

Radians	Degrees	Sines	Cosines	Tangents	Cotangents		
.0000	0	.0000	1.0000	.0000	∞	90	1.5708
.0175	1	.0175	.9998	.0175	57.29	89	1.5533
.0349	2	.0349	.9994	.0349	28.64	88	1.5359
.0524	3	.0523	.9986	.0524	19.08	87	1.5184
.0698	4	.0698	.9976	.0699	14.30	86	1.5010
.0873	5	.0872	.9962	.0875	11.430	85	1.4835
.1047	6	.1045	.9945	.1051	9.514	84	1.4661
.1222	7	.1219	.9925	.1228	8.144	83	1.4486
.1396	8	.1392	.9903	.1405	7.115	82	1.4312
.1571	9	.1564	.9877	.1584	6.314	81	1.4137
.1745	10	.1736	.9848	.1763	5.671	80	1.3963
.1920	11	.1908	.9816	.1944	5.145	79	1.3788
.2094	12	.2079	.9781	.2126	4.705	78	1.3614
.2269	13	.2250	.9744	.2309	4.332	77	1.3439
.2443	14	.2419	.9703	.2493	4.011	76	1.3265
.2618	15	.2588	.9659	.2679	3.732	75	1.3090
.2793	16	.2756	.9613	.2867	3.487	74	1.2915
.2967	17	.2924	.9563	.3057	3.271	73	1.2741
.3142	18	.3090	.9511	.3249	3.078	72	1.2566
.3316	19	.3256	.9455	.3443	2.904	71	1.2392
		Cosines	Sines	Cotangents	Tangents	Degrees	Radians

TRIGONOMETRIC FUNCTIONS (*Continued*)

Radians	Degrees	Sines	Cosines	Tangents	Cotangents		
.3491	20	.3420	.9397	.3640	2.748	70	1.2217
.3665	21	.3584	.9336	.3839	2.605	69	1.2043
.3840	22	.3746	.9272	.4040	2.475	68	1.1868
.4014	23	.3907	.9205	.4245	2.356	67	1.1694
.4189	24	.4067	.9135	.4452	2.246	66	1.1519
.4363	25	.4226	.9063	.4663	2.144	65	1.1345
.4538	26	.4384	.8988	.4877	2.050	64	1.1170
.4712	27	.4540	.8910	.5095	1.963	63	1.0996
.4887	28	.4695	.8829	.5317	1.881	62	1.0821
.5061	29	.4848	.8746	.5543	1.804	61	1.0647
.5236	30	.5000	.8660	.5774	1.732	60	1.0472
.5411	31	.5150	.8572	.6009	1.664	59	1.0297
.5585	32	.5299	.8480	.6249	1.600	58	1.0123
.5760	33	.5446	.8387	.6494	1.540	57	0.9948
.5934	34	.5592	.8290	.6745	1.483	56	0.9774
.6109	35	.5736	.8192	.7002	1.428	55	0.9599
.6283	36	.5878	.8090	.7265	1.376	54	0.9425
.6458	37	.6018	.7986	.7536	1.327	53	0.9250
.6632	38	.6157	.7880	.7813	1.280	52	0.9076
.6807	39	.6293	.7771	.8098	1.235	51	0.8901
.6981	40	.6428	.7660	.8391	1.192	50	0.8727
.7156	41	.6561	.7547	.8693	1.150	49	0.8552
.7330	42	.6691	.7431	.9004	1.111	48	0.8378
.7505	43	.6820	.7314	.9325	1.072	47	0.8203
.7679	44	.6947	.7193	.9657	1.036	46	0.8029
.7854	45	.7071	.7071	1.0000	1.000	45	0.7854
		Cosines	Sines	Cotangents	Tangents	Degrees	Radians

Nobel Prize Winners in Physics[a]

APPENDIX K

1901	Wilhelm Konrad Röntgen	1845–1923	German	Discovery of X-rays.
1902	Hendrik Antoon Lorentz	1853–1928	Dutch	Influence of magnetism on the phenomena of atomic radiation.
	Pieter Zeeman	1865–1943	Dutch	
1903	Henri Becquerel	1852–1908	French	Discovery of natural radioactivity and of the radioactive elements radium and polonium.
	Pierre Curie	1850–1906	French	
	Marie Curie	1867–1934	French	
1904	Baron Rayleigh	1842–1919	English	Discovery of argon.
1905	Philipp Lenard	1862–1947	German	Research in cathode rays.
1906	Sir Joseph John Thomson	1856–1940	English	Conduction of electricity through gases.
1907	Albert A. Michelson	1852–1931	U. S.	Invention of interferometer and spectroscopic and metrological investigations.
1908	Gabriel Lippmann	1845–1921	French	Photographic reproduction of colors.
1909	Guglielmo Marconi	1874–1937	Italian	Development of wireless telegraphy.
	Karl Ferdinand Braun	1850–1918	German	
1910	Johannes Diderik van der Waals	1837–1923	Dutch	Equations of state of gases and fluids.
1911	Wilhelm Wien	1864–1928	German	Laws of heat radiation.
1912	Nils Gustaf Dalen	1869–1937	Swedish	Automatic coastal lighting.
1913	Heike Kamerlingh-Onnes	1853–1926	Dutch	Properties of matter at low temperatures; production of liquid helium.
1914	Max von Laue	1879–1960	German	Diffraction of X-rays in crystals.
1915	Sir William Henry Bragg	1862–1942	English	Study of crystal structure by means of X-rays.
	Sir William Lawrence Bragg	1890–	English—his son	
1916	(No award)			
1917	Charles Glover Barkla	1877–1944	English	Discovery of the characteristic X-rays of elements.
1918	Max Planck	1858–1947	German	Discovery of the elemental quantum.
1919	Johannes Stark	1874–1957	German	Discovery of the Doppler effect in canal rays and the splitting of spectral lines in the electric field.

1920	Charles Edouard Guillaume	1861–1938	Swiss	Discovery of the anomalies of nickel-steel alloys.
1921	Albert Einstein	1879–1955	German	Discovery of the law of the photo-electric effect.
1922	Niels Bohr	1885–1963	Danish	Study of structure and radiations of atoms.
1923	Robert Andrews Millikan	1868–1953	U. S.	Work on elementary electric charge and the photoelectric effect.
1924	Manne Siegbahn	1886–	Swedish	Discoveries in the area of X-ray spectra.
1925	James Franck	1882–1964	German	Laws governing collision between electron and atom.
	Gustav Hertz	1887	German	
1926	Jean Perrin	1870–1942	French	Discovery of the equilibrium of sedimentation.
1927	Arthur H. Compton	1892–1962	U. S.	Discovery of the scattering of X-rays by charged particles
	Charles T. R. Wilson	1869–1959	English	Invention of the cloud chamber, a device to make visible the paths of charged particles.
1928	Sir Owen Williams Richardson	1879–1959	English	Discovery of the law known by his name (the dependency of the emission of electrons on temperature).
1929	Louis-Victor de Broglie	1892–	French	Wave nature of electrons.
1930	Sir Chandrasekhara Raman	1888–	Indian	Work on the scattering of light and discovery of the effect known by his name.
1931	(No award)			
1932	Werner Heisenberg	1901–	German	Creation of quantum mechanics.
1933	Paul Adrien Maurice Dirac	1902–	English	Discovery of new fertile forms of the atomic theory.
	Erwin Schrödinger	1887–1961	Austrian	
1934	(No award)			
1935	James Chadwick	1891–	English	Discovery of the neutron.
1936	Victor Hess	1883–1964	Austrian	Discovery of cosmic radiation.
	Carl David Anderson	1905–	U. S.	Discovery of the positron.
1937	Clinton Joseph Davisson	1881–1958	U. S.	Discovery of diffraction of electrons by crystals.
	George P. Thomson	1892–	English	
1938	Enrico Fermi	1901–1954	Italian	Artificial radioactive elements from neutron irradiation.
1939	E. O. Lawrence	1901–1958	U. S.	Invention of the cyclotron.
1940–1942	(No awards)			
1943	Otto Stern	1888	U. S.[a]	Work with molecular beams and magnetic moment of proton.
1944	Isidor Isaac Rabi	1898–	U. S.	Nuclear magnetic resonance.
1945	Wolfgang Pauli	1900–1958	Austrian	Discovery of quantum exclusion principle.
1946	Percy Williams Bridgman	1882–1961	U. S.	High-pressure physics.
1947	Sir Edward Appleton	1892–	English	Upper atmosphere physics and discovery of Appleton layer.
1948	Patrick Maynard Stuart Blackett	1897–	English	Discoveries in cosmic radiation and nuclear physics.
1949	Hideki Yukawa	1907–	Japanese	Prediction of existence of meson.
1950	Cecil Frank Powell	1903–	English	Photographic method of studying nuclear processes; discoveries about mesons.
1951	Sir John Douglas Cockcroft	1897–	English	Transmutation of atomic nuclei by artificially accelerated atomic particles.
	Ernest Thomas Sinton Walton	1903–	Irish	
1952	Felix Bloch	1905–	U. S.	Measure of magnetic fields in atomic nuclei.
	Edward Mills Purcell	1912–	U. S.	
1953	Frits Zernike	1888–	Dutch	Invention of phase contrast microscopy.
1954	Max Born	1882–	English[b]	Work in quantum mechanics and statistical interpretation of wave function.

	Walther Bothe	1891–1957	German	Analysis of cosmic radiation using the coincidence method.
1955	Willis E. Lamb, Jr.	1913	U. S.	Fine structure of hydrogen.
	Polykarp Kusch	1911–	U. S.	Magnetic moment of electron.
1956	John Bardeen	1908–	U. S.	Invention and development of transistor.
	Walter H. Brattain	1902–	U. S.	
	William B. Shockley	1910–	U. S.[c]	
1957	Chen Ning Yang	1922–	Chinese[d]	Non-conservation of parity and work in elementary particle theory.
	Tsung Dao Lee	1926–	Chinese[d]	
1958	Pavel A. Čerenkov	1904–	Russian	Discovery and interpretation of Čerenkov effect of radiation by fast charged particles in matter.
	Ilya M. Frank	1908–	Russian	
	Igor Y. Tamm	1895–	Russian	
1959	Owen Chamberlain	1920–	U. S.	Discovery of the antiproton.
	Emilio Gino Segré	1905–	U. S.[e]	
1960	Donald A. Glaser	1926–	U. S.	Invention of bubble chamber.
1961	Robert L. Hofstadter	1915–	U. S.	Electromagnetic structure of nucleons from high-energy electron scattering.
	Rudolf L. Mössbauer	1929	German	Discovery of recoilless resonance absorption of gamma rays in nuclei.
1962	Lev D. Landau	1908–	Russian	Theory of condensed matter; phenomena of superfluidity and superconductivity.
1963	Eugene B. Wigner	1902–	U. S.[f]	Contributions to theoretical atomic and nuclear physics.
	Maria Goeppert-Mayer	1906–	U. S.[g]	Shell model theory and magic numbers for the atomic nucleus.
	J. H. D. Jensen	1907–	German	
1964	C. H. Townes	1915–	U. S.	Invention of the maser and theory of coherent atomic radiation.
	Nikolai Basov	1922–	Russian	
	Aleksandr Prokhorov	1916–	Russian	
1965	Richard Feynman	1918	U. S.	Development of quantum electrodynamics
	Julian Schwinger	1918	U. S.	
	Shin-Ichiro Tomonaga	1906	Japanese	

[a] See *Nobel: The Man and His Prizes*, by Schück et al., Elsevier, N. Y.

[b] Born in Germany; naturalized British citizen.

[c] Born in England; naturalized U. S. citizen.

[d] Both have permanent U. S. resident status.

[e] Born in Italy; naturalized U. S. citizen.

[f] Born in Hungary; naturalized U. S. citizen.

[g] Born in Germany; naturalized U. S. citizen.

The Gaussian System of Units

APPENDIX L

Much of the literature of physics is written, and continues to be written, in the Gaussian system of units. In electromagnetism many equations have slightly different forms depending on whether it is intended, as in this book, that mks variables be used or that Gaussian variables be used. Equations in this book can be cast in Gaussian form by replacing the symbols listed below under "rationalized mks" by those listed under "Gaussian." For example, Eq. 37–26,

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$$

becomes

$$\frac{\mathbf{B}}{c} = \left(\frac{4\pi}{c^2}\right)\left(\frac{c}{4\pi}\mathbf{H} + c\mathbf{M}\right)$$

or

$$\mathbf{B} = \mathbf{H} + 4\pi\mathbf{M}$$

in Gaussian form. Symbols used in this book that are not listed below remain unchanged. The quantity c is the speed of light.

Quantity	Rationalized mks	Gaussian
Permittivity constant	ϵ_0	$1/4\pi$
Permeability constant	μ_0	$4\pi/c^2$
Electric displacement	$\mathbf{D}$	$\mathbf{D}/4\pi$
Magnetic induction	$\mathbf{B}$	$\mathbf{B}/c$
Magnetic flux	Φ_B	Φ_B/c
Magnetic field strength	$\mathbf{H}$	$c\mathbf{H}/4\pi$
Magnetization	$\mathbf{M}$	$c\mathbf{M}$
Magnetic dipole moment	$\boldsymbol{\mu}$	$c\boldsymbol{\mu}$

In addition to casting the equations in the proper form it is of course necessary to use a consistent set of units in those equations. Below we list some equivalent quantities in mks and Gaussian units. This table can be used to transform units from one system to the other.

Quantity	Symbol	Mks system	Gaussian system
Length	l	1 meter	10^2 cm
Mass	m	1 kg	10^3 gm
Time	t	1 sec	1 sec
Force	**F**	1 newton	10^5 dynes
Work or Energy	W, E	1 joule	10^7 ergs
Power	P	1 watt	10^7 ergs/sec
Charge	q	1 coulomb	3×10^9 statcoul
Current	i	1 ampere	3×10^9 statamp
Electric field strength	**E**	1 volt/meter	$\frac{1}{3} \times 10^{-4}$ statvolt/cm
Electric potential	V	1 volt	$\frac{1}{300}$ statvolt
Electric polarization	**P**	1 coul/meter^2	3×10^5 statcoul/cm^2
Electric displacement	**D**	1 coul/meter^2	$12\pi \times 10^5$ statvolt/cm
Resistance	R	1 ohm	$\frac{1}{9} \times 10^{-11}$ sec cm^{-1}
Capacitance	C	1 farad	9×10^{11} cm
Magnetic flux	Φ_B	1 weber	10^8 maxwells
Magnetic induction	**B**	1 tesla $\equiv$ 1 weber/meter^2	10^4 gauss
Magnetic field strength	**H**	1 amp-turn/meter	$4\pi \times 10^{-3}$ oersted
Magnetization	**M**	1 weber/meter^2	$1/4\pi \times 10^4$ gauss
Inductance	I	1 henry	$\frac{1}{9} \times 10^{-11}$

All factors of 3 in the above table, apart from exponents, should be replaced by (2.997925 ± 0.000003) for accurate work; this arises from the numerical value of the speed of light. For example the mks unit of capacitance (= 1 farad) is actually 8.98758×10^{11} cm rather than 9 ($= 3^2$) $\times 10^{11}$ cm as listed above. This example also shows that not only units but also the dimensions of physical quantities may differ between the two systems. In the mks system (see Appendix F) the dimensions of capacitance are $M^{-1}L^{-2}T^2Q^2$; in the Gaussian system they are simply L, the Gaussian standard unit of capacitance being 1 cm.

The student should consult *Classical Electromagnetism*, p. 611, by J. D. Jackson (John Wiley and Sons, 1962) for a fuller treatment of units and dimensions.

Answers to Odd-Numbered Problems

Chapter 26

1. 0.12 amp.
3. $\pm 2.4 \times 10^{-8}$ coul.
5. 6.0×10^{-8} coul.
7. (a) $Q = -2\sqrt{2}q$,
   (b) no.
9. (a) 5.7×10^{13} coul,
   (b) no,
   (c) 660 tons.
11. 3.8×10^{-5} coul, 1.2×10^{-5} coul.
13. (b) Along the body diagonal.
15. (a) 6.3×10^{11},
    (b) 7.3×10^{-18}.
17. (a) 510 nt,
    (b) 7.7×10^{28} meters/sec^2.

Chapter 27

5. 5.6×10^{-11} coul.
9. (a) The larger charge produces a field of 13×10^4 nt/coul at the site of the small[e]
   the smaller charge produces a field of 5.3×10^4 nt/coul at the site of the larger.
   (b) 1.1×10^{-2} nt, repulsive.
11. E lies in the median plane and points radially away from the charge axis.
13. 1.0×10^5 nt/coul, pointing up.
17. $E = q/8\pi\epsilon_0 a^2$, pointing along the axis of symmetry and away from the hemisphe[re]
21. (a) $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{qx}{(a^2 + x^2)^{3/2}}$,
    (b) $E = \dfrac{1}{2\pi^2\epsilon_0}\dfrac{(q_1 - q_2)a}{(a^2 + x^2)^{3/2}}$.
25. (a) 1.5×10^3 nt/coul,
    (b) 2.4×10^{-16} nt (up),
    (c) 1.6×10^{-26} nt,
    (d) 1.5×10^{10}.
27. (a) 7.1 cm,
    (b) 2.9×10^{-8} sec,
    (c) 11%.
29. $\dfrac{dE}{dz} = -\dfrac{8q}{\pi\epsilon_0 l^3}$, where l is the distance between the charges; yes.
31. 1.64×10^{-19} coul.

Chapter 28

1. $\pi R^2 E$ (an expected result).
3. $EA \cos \theta$.
7. (a) 4.0×10^6 nt/coul,
   (b) $E = 0$.
9. (a) $E = \sigma/\epsilon_0$, to the left,
   (b) $E = 0$,
   (c) $E = \sigma/\epsilon_0$, to the right.
11. 4.9×10^{-10} coul.
13. 0.44 mm.
19. (a) $E = \dfrac{q}{2\pi\epsilon_0 lr}$ (radially inward), where l is the length of the cylinders,
    (b) $-q$ on inner surface and $-q$ on outer surface,
    (c) $E = \dfrac{q}{2\pi\epsilon_0 lr}$ (radially outward).
21. 2.5×10^{-9} coul/meter^2.
23. 1.9×10^2 nt,
    2.9×10^{28} meters/sec^2.
25. (a) 1.1 nt-meters^2/coul,
    (b) 9.3×10^{-12} coul.

Chapter 29

1. 0.89 mm.
3. 900 volts.
5. (a) Between the charges a distance of 25 cm from $+q$ and outside the charges a distance of 50 cm from $+q$.
   (b) Outside the charges a distance of 140 cm from $+q$.
7. $V_A - V_B = \dfrac{q}{2\pi\epsilon_0} \dfrac{d}{a(a+d)}$.
9. 1.9×10^{-29} coul meter; text value (0.61×10^{-29} coul meter) is lower and correct; the assumptions made in this problem are oversimplified.
11. 99 tons.
13. -6.4×10^{-7} joule.
15. (a) -0.12 volt,
    (b) 1.8×10^{-8} nt/coul, radially inward.
17. 2900 volts.
21. No.
23. (a) -180 volts,
    (b) $+2900$ volts and -9000 volts.
27. $-0.21q^2/\epsilon_0 a$.
29. (a) 1.1×10^{17} volts/meter,
    (b) 4.6×10^{21} volts/meter, assuming a nuclear radius of 5×10^{-15} meter.
31. (a) 2.6×10^5 volts,
    (b) $\dfrac{\sqrt{5}}{3} c = 0.745\ c$.
33. 9.0 kw.
35. (a) 3.2×10^{-13} joule,
    (b) 1.6×10^{-13} joule,
    (c) proton.

Chapter 30

1. (a) $q_2 = q_8 = 4.8 \times 10^{-4}$ coul,
       $V_2 = 240$ volts,
       $V_8 = 60$ volts;
   (b) $q_2 = 2.0 \times 10^{-4}$ coul,
       $q_8 = 7.7 \times 10^{-4}$ coul,
       $V_2 = V_8 = 96$ volts;
   (c) $q_2 = q_8 =$ zero,
       $V_2 = V_8 =$ zero.
3. 43 $\mu\mu$f.
11. 3.2 μf.
13. 4 μf.
15. 7.3 μf.
21. Mica.
23. Assuming $\kappa = 5.4$:
    (a) 10^4 volts/meter,
    (b) $+5.0 \times 10^{-9}$ coul, on the positive plate,

(c) -4.1×10^{-9} coul, next to the positive plate.

25. 0.63 meter^2.

27. 0.11 joule/meter^3.

31. (a) 1.3×10^{-7} joule,
(b) no.

33. 7.0×10^{-6} coul.

35. 7.0¢.

37. (a) $q_1 = q_2 = 3.3 \times 10^{-4}$ coul,
$q_3 = 4.0 \times 10^{-4}$ coul;
(b) $V_1 = 33$ volts,
$V_2 = 67$ volts,
$V_3 = 100$ volts;
(c) $U_1 = 5.4 \times 10^{-3}$ joule,
$U_2 = 10.9 \times 10^{-3}$ joule,
$U_3 = 2.0 \times 10^{-2}$ joule.

Chapter 31

1. (a) 1200 coul,
(b) 7.5×10^{21} electrons.

3. (a) 2.4, iron being larger;
(b) no.

5. 6.7×10^{-6} coul/meter^2.

7. 54 ohms.

9. (a) 2.2×10^{-7} ohm,
(b) nickel ($\rho = 6.8 \times 10^{-8}$ ohm-meter).

11. (a) 260°C,
(b) yes.

13. 0.39% (ρ),
0.0017% (l),
0.0034% (A).

17. 11 ohms.

19. (a) 4.9×10^6 amp/meter^2,
(b) 8.4×10^{-2} volt/meter,
(c) 26 volts,
(d) 640 watts.

21. 620 watts.

23. (a) 8.7%,
(b) smaller.

Chapter 32

1. 1.1×10^4 joules.

3. -0.62%.

7. (a) 990 ohms,
(b) 9.9×10^{-4} watt.

9. $V_d - V_c = 1.3$ volt.

11. (a) 120 ohms,
(b) $i_1 = 0.051$ amp,
$i_2 = i_3 = 0.019$ amp,
$i_4 = 0.013$ amp.

13. (a) $R = \frac{1}{2}r$,
(b) $E^2/2r$.

17. 38 ohms.

19. (a) 10 ohms,
(b) 14 ohms,
(c) 10 ohms.

21. series: $i = \dfrac{2}{R + 2r}$.
parallel: $i = \dfrac{2}{2R + r}$.

(a) Put R_1 roughly in the middle of its range; adjust current roughly with R_2; make fine adjustment with R_1.
(b) Relatively large percentage changes in R_1 cause only small percentage changes in the resistance of the parallel combination, thus permitting fine adjustment. The ratio is 1:21.

27. 2.7%.

29. 4.6 time constants.

33. (a) 9.6×10^{-7}
(b) 1.1×10^{-6} watt,
(c) 2.7×10^{-6} watt,
(d) 3.8×10^{-6} watt.

Chapter 33

1. (a) East,
   (b) 6.3×10^{14} meters/sec^2,
   (c) 3.0 mm.
3. 7.5 nt, perpendicular to the wire and to **B**.
5. See Appendix.
7. 3.8 coul.
9. 520 gauss, normal to plane of tracks.
11. 4.3×10^{-3} nt-meter. The torque vector is parallel to the long side of the coil and points down.
15. (a) 1.4×10^{-4} meter/sec,
   (b) 4.5×10^{-23} nt (down),
   (c) 2.8×10^{-4} volt/meter (down),
   (d) 5.7×10^{-6} volt (top +, bottom −),
   (e) same as (b).
17. (a) $K_p = K_d = \frac{1}{2}K_\alpha$,
   (b) $R_d = 14$ cm.
   (c) $R_\alpha = 14$ cm.
19. (a) 2.6×10^7 meters/sec,
   (b) 1.1×10^{-7} sec,
   (c) 14 Mev,
   (d) 7.0×10^6 volts.
23. 1.6×10^{-8} weber/meter^2, horizontal and at right angles to the equator.
25. $T = 3.6 \times 10^{-10}$ sec,
   $p = 0.17$ mm,
   $r = 1.5$ mm.
27. 2.11×10^{-25} kg or 127 proton masses.
29. (a) Increase,
   (b) decrease.
31. (a) 8.5 Mev,
   (b) 0.80 weber/meter^2,
   (c) 34 Mev,
   (d) 24 mc/sec
   (e) 34 Mev, 1.6 webers/meter^2, 34 Mev, 12 mc/sec.
33. 1.4.
35. 3800 meters/sec.

Chapter 34

1. 7.9×10^{-3} weber/meter^2.
3. (a) 3.2×10^{-16} nt, parallel to current;
   (b) 3.2×10^{-16} nt, radially outward if **v** is parallel to the current;
   (c) zero.
7. 1.0×10^{-6} weber/meter.
9. **B** = 0 along a line parallel to the wire and 4.0 mm from it. If the current is horizontal and points toward the observer and the external field points horizontally from left to right, the line is directly above the wire.
11. 8.0×10^{-5} weber/meter^2, up.
13. 3.2×10^{-3} nt, toward the long wire.
23. (a) 1.0×10^{-3} weber/meter^2, out of figure;
   (b) 8.0×10^{-4} weber/meter^2, out of figure.
27. (a) 9.4×10^{-5} weber/meter^2,
   (b) 1.5×10^{-6} nt-meter.

Chapter 35

1. 2.0×10^{-2} coul.
3. Zero.
9. $V_m = \pi^2 BR^2 f$,
   $i_m = \pi^2 BR^2 f/R_M$
11. 3.0×10^{-4} volt.
13. (a) 3.1×10^{-2} webers/sec,
   (b) left to right.
17. (a) 4.4×10^7 meters/sec^2, to the right;
   (b) zero;
   (c) 4.4×10^7 meters/sec^2, to the left.

Chapter 36

1. Let the current charge at 10 amp/sec.
7. 1.0×10^{-7} weber.
9. 12 sec.
13. 27 amp/sec.
15. (*a*) 10 amp,
(*b*) 100 joules.
17. 0.63 joule/meter^3.
21. (*a*) 2.5×10^{-6} joule/meter,
(*b*) 14×10^{-6} joule/meter,
(*c*) 0.8×10^{-6} joule/meter.
23. 1.5×10^8 volt/meter.

Chapter 37

1. (*a*) 5.0×10^7 amp,
(*b*) yes,
(*c*) no.
3. (*a*) 1.4×10^{11} volts/meter,
(*b*) 2.8×10^{-3} weber/meter^2.
5. (*a*) 7.6 amp meter^2,
(*b*) 11 nt-meter.
9. 7.5×10^{-6} weber/meter^2.
11. (*a*) 1.8 webers/meter^2,
(*b*) 6.5×10^{-23} joule.

Chapter 38

1. 600, 710, 1100, and 1300 cycles/sec.
13. (*a*) 35 cycles/sec.
(*b*) 38 or 33 cycles/sec.
15. $\omega = \sqrt{\dfrac{1}{L_1C_1}} = \sqrt{\dfrac{1}{L_2C_2}}$.
19. $i_d = \epsilon_0\pi r^2 \dfrac{dE}{dt} \qquad (r \lessgtr R),$

$i_d = \epsilon_0\pi R^2 \dfrac{dE}{dt} \qquad (r \gtrless R).$
21. (*a*) 1.4×10^{14} volts/meter-sec,
(*b*) 9.9×10^{-6} weber/meter^2.

Chapter 39

3. 4.9 cm, 5.2×10^8 meters/sec
(= 1.7 c).
9. 18 cm, 12 cm.
13. (*a*) a^2EB/μ_0
for faces parallel to *xy*-plane, zero for others;
(*b*) zero.
15. 1000 volts/meter,
3.4×10^{-6} weber/meter^2.

Chapter 40

1. (*a*) 5100 A and 6100 A,
(*b*) 5.5×10^{14} cycles/sec and 1.8×10^{-15} sec.
3. $F_{rad} = 6.0 \times 10^8$ nt,
$F_{gr} = 3.6 \times 10^{22}$ nt.
7. 1.3×10^{-7} nt/meter^2.
11. 0.13.
13. (*b*) 7.3 (cycles/sec)/(miles/hour).
15. 3.8×10^{-2} A.
17. Yellow-orange.

Chapter 41

3. 2.05×10^8 meters/sec.
5. 1.56.
15. (*b*) 0.17.
19. Cover the center of each face with a circle of radius 0.33 cm. The fraction covered is 0.35.

Chapter 42

1. (*a*) 7,
(*b*) 5,
(*c*) 2.
3. 40 cm.

6. Alternate vertical columns:
   (a) +, +40, −20, +2, no, yes;
   (c) concave, +40, +60, −2, yes, no;
   (e) convex, −20, +20, +0.5, no, yes;
   (g) −20, −, −, +5, +0.80, no, yes.

7. Object at center of curvature.

9. 4.24 cm.

10. Alternate vertical columns:
   (a) −18, no;
   (c) +71, yes;
   (e) +30, no;
   (g) −26, no.

11. Alternate vertical columns:
   (a) +, X, X, +20, X, −1, yes, no;
   (c) converging, +, X, X, −10, X, no, yes;
   (e) converging, +30, −15, +1.5, no, yes;
   (g) diverging, −120, −9.2, +0.92, no, yes;
   (i) converging, +3.3, X, X, +5, X, −, no.

17. 4.5 cm, 9.0 cm.

19. Assuming the light is incident from the left, a distance of $-\dfrac{r(n-2)}{2(n-1)^2}$ to the right of the right edge of the sphere.

21. (a) R' is negative and R'' is positive,
   (b) $i = \dfrac{-2r}{n+1}$,
   (c) virtual and erect.

23. (a) Coincides in location with original object and is enlarged 5.0 times,
   (c) virtual and inverted.

Chapter 43

1. Slit separation must be 0.034 mm.
3. 0.15°.
5. 6.6×10^{-8} mm.
7. 3.0 mm.
9. $I = \dfrac{I_m}{9}\left[1 + 8\cos^2\left(\dfrac{\pi d \sin\theta}{\lambda}\right)\right]$.
11. $y = 17.4 \sin(\omega t + 13.3°)$.
13. 80 million.
15. 1.21.
17. 4800 A (blue).
19. 6700 A.
23. 5880 A.
25. 6057.8021 A.

Chapter 44

1. 0.17 mm.
3. (a) $\lambda_a = 2\lambda_b$,
   (b) coincidences occur when $m_b = 2m_a$.
5. 79.7°.
7. (a) 52.9°,
   (b) 10.2°,
   (c) 5.1°.
9. 9100 meters.
11. (a) 0.16 sec of arc,
   (b) 7.4×10^7 km,
   (c) 2.2×10^{-4} mm.
15. 3.
17. (a) Must have $d = 4a$,
   (b) Every fourth fringe is missing.

Chapter 45

1. Three complete orders.
5. The intensity would be concentrated near the twentieth order for blue and the eleventh order for red. The orders would overlap to such an extent as to appear almost white.

7. All wavelengths shorter than 6300 A.

9. 0°, ±10°, ±21°, ±32°, ±45°, and ±62°.

11. 5200 A to 6200 A.

17. (a) 0.0032°/A, 0.0077°/A, 0.024°/A;
(b) 40,000, 80,000, 120,000.

19. 3600 lines.

21. (a) 4.6×10^{-2} A.
(b) No. The resolution could normally be improved by going to a higher order diffraction, but in this case $m = 3$ is the highest order that can exist (assuming that the light falls on the grating at right angles).

23. (a) 6×10^4 A,
(b) 1.5×10^4 A,
(c) 0, 1, 2, 3, 5, 6, 7, 9. The tenth order is at $\theta = 90°$.

25. 33°, 20°, 5.2° (all clockwise); 14° (counterclockwise).

27. Yes, $n = 3$ for $\lambda = 1.29$ A, $n = 4$ for $\lambda = 0.97$ A.

Chapter 46

1. (a) ±55°,
(b) ±35°.

3. Assuming that a right-handed coordinate system is used,
(a) circular, counterclockwise as seen facing the source;
(b) elliptical, counterclockwise as seen facing the source, major axis of ellipse along $y = x$;
(c) plane, along $y = -x$.

5. 55°30′ to 55°46′.

11. 2.7×10^{-14} kg-meter²/sec², 2.1 hr.

Chapter 47

1. 4.8 A.

3. 6.2×10^{23} photons/sec.

7. 5.9×10^{-6} ev.

9. (a) 2.0 ev,
(b) zero,
(c) 2.0 volts,
(d) 3000 A.

11. 100 years.

17. (a) 1,
(b) 5.3×10^{-11} meter,
(c) 1.1×10^{-34} joule-sec,
(d) 2.0×10^{-24} kg-meter/sec,
(e) 4.1×10^{15} radians/sec,
(f) 2.2×10^{6} meters/sec,
(g) 8.2×10^{-8} nt,
(h) 9.0×10^{22} meters/sec²
(i) +13.6 ev,
(j) −27.2 ev,
(k) −13.6 ev.

19. +0.21 ev.

21. 2.6 ev.

25. +54 ev, assuming the electron to be in its ground state initially.

27. (a) 2.6×10^{-13} meter,
(b) 2800 ev,
(c) 4.4 A.

Chapter 48

1. (*a*) 1.7×10^{-35} meter.
3. (*a*) 3.3×10^{-24} kg-meter/sec, for each;
   (*b*) 38 ev for the electron and 6200 ev for the photon.
5. (*a*) Higher orders cannot exist for this accelerating potential and for these planes.
   (*b*) 59°; the crystal must be rotated with respect to the incident beam to satisfy Bragg's law for this new wavelength.
7. 1.5 A.
9. (*a*) 0.20,
   (*b*) 0.40,
   (*c*) 0.33,
   (*d*) 0.33.
11. 0.32.
15. 6.6×10^{-23} kg-meter/sec.

Answers to Odd-Numbered Supplementary Problems

Chapter 26

1. $-\frac{4}{9}q$, located $\frac{l}{3}$ from $+q$.

3. $\pm 1.0 \times 10^{-6}$ coul, $\mp 3.0 \times 10^{-6}$ coul.
5. 1.61×10^{-9} meter.

Chapter 27

1. $2\pi \sqrt{\dfrac{l}{g - \dfrac{q}{m}E}}$, $2\pi \sqrt{\dfrac{l}{g + \dfrac{q}{m}E}}$.

3. $\dfrac{Q}{\pi^2 \epsilon_0 R^2}$, vertically downward.

5. $2\pi \sqrt{\dfrac{pE}{I}}$.

Chapter 28

1. $+3.54 \times 10^{-6}$ coul.
3. 1.98×10^{7} meters/sec.

5. $A = \dfrac{Q}{2\pi a^2}$.

Chapter 29

1. 1.2×10^{-8} coul/meter^2.

3. (*a*) 1.0×10^{-8} coul from small to large sphere;
   (*b*) small sphere: 2×10^{-8} coul, 3000 volts,
   large sphere: 4×10^{-8} coul, 3000 volts.

9. $W = +\dfrac{Q}{8\pi\epsilon_0}\left[\dfrac{1}{r_1} - \dfrac{1}{r_2}\right]$.

11. (*a*) $\dfrac{qQ}{4\pi\epsilon_0 K}$.
    (*b*) $\sqrt{\dfrac{K}{m}}$.

13. (*a*) $\dfrac{\lambda}{4\pi\epsilon_0} \ln\left(\dfrac{y + L}{y}\right)$.
    (*b*) $\dfrac{-\lambda}{4\pi\epsilon_0} \dfrac{L}{y(y + L)}$.
    (*c*) Zero.

Chapter 30

5. $q_1 = \dfrac{C_1C_2 + C_1C_3}{C_1C_2 + C_1C_3 + C_2C_3} C_1V_0$,
   $q_2 = q_3 = \dfrac{C_1C_2}{C_1C_2 + C_1C_3 + C_2C_3} C_1V_0$.

7. (a) $10\epsilon_0$ farad,
   (b) $13.6\epsilon_0$ farad,
   (c) $1200\epsilon_0$ coul, $1200\epsilon_0$ coul,
   (d) 10^4 volts/meter,
   (e) 2.1×10^3 volts/meter,
   (f) 88 volts,
   (g) $19 \times 10^3\epsilon_0$ joules.

Chapter 31

1. (a) 2.3×10^{12},
   (b) 5.0×10^3,
   (c) 10^7 volts.
5. (a) $\rho_A = .10$ ohm-meter, $\rho_B = .05$ ohm-meter,
   (b) $E_A = 1.0$ volt/meter, $E_B = .50$ volts/meter,
   (c) $j_A = j_B = 10$ amp/meter^2,
   (d) $V_A = 40$ volts, $V_B = 20$ volts.
7. $T = 130°$ C.

Chapter 32

1. $R = r_1 - r_2$.
3. (a) r,
   (b) R.
5. (a) $\frac{7}{12}R$,
   (b) $\frac{3}{4}R$,
   (c) $\frac{5}{8}R$.
7. (a) 85.0 ohm,
   (b) 85.0 ohm.
9. (a) 1.0×10^{-3} coul.,
   (b) 1.0×10^{-3} amp.,
   (c) $V_C = V_R = 1000e^{-t}$ volts,
   (d) e^{-2t} watt.

Chapter 33

1. 1 is positively charged, 2 is neutral, and 3 is negatively charged.
3. 2.7×10^{-4} weber/meter^2.
5. (a) 542 ohms, series,
   (b) 2.52 ohms, parallel.
7. (a) 2.8 Mc/sec,
   (b) 0.34 meter.

Chapter 34

1. $-10\mu_0 i_0$.
3. $\frac{3\sqrt{2}\,\mu_0 i^2}{4\pi a}$, toward center of square.
5. zero.
7. $\frac{\mu_0 i}{4}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$, into page.
9. (a) $\frac{\mu_0 i}{2R}\left(1 + \frac{1}{\pi}\right)$, out of page.
   (b) $\frac{\mu_0 i}{2\pi R}\sqrt{1 + \pi^2}$, out of page at an angle of 18° with page.

Chapter 35

3. (a) $\frac{\mu_0 i \pi r^2 R^2}{2x^3}$,
   (b) $\frac{3\mu_0 \pi i r^2 v}{2R^2 N^4}$.
   (c) In the same sense as the current in the larger loop.
5. (a) $q = \frac{-1}{R}\left[\Phi_B(t_2) - \Phi_B(t_1)\right]$,
   (b) No. B field could still have changed between t_1 and t_2 inducing currents.

Chapter 36

3. (a) $i_1 = 3.3$ amp, $i_2 = 3.3$ amp;
   (b) $i_1 = 4.5$ amp, $i_2 = 2.7$ amp;
   (c) $i_1 = 0$, $i_2 = 1.8$ amp;
   (d) $i_1 = 0$, $i_2 = 0$.
5. (a) meter, (b) weber, (c) watt, (d) coulomb, (e) ohm.

Chapter 37

1. $\frac{q\omega r^2}{2}$, in direction of ω.
3. (a) $(N \pm 1)\frac{eB}{m}$,
   (b) 744×10^{10} rad/sec; 759×10^{10} rad/sec.
5. 29 amp.

Chapter 38

1. Let T_1 be the period of inductor and 900 μf capacitor and T_2 the period of inductor and 100 μf capacitor. Then: (a) close S_2, wait $T_1/4$; (b) quickly close S_1 then open S_2; (c) wait $T_2/4$ and then open S_1.

Chapter 39

1. (a) $\frac{2\pi\epsilon_0}{\ln(b/a)}$
   (b) $\frac{\mu_0 \ln(b/a)}{2\pi}$
5. (a) 6.3×10^{-2} volt/meter,
   (b) 2.1×10^{-10} weber/meter^2,
   (c) 1.3×10^4 watts.

7. (a) $B = \mu_0 \sigma R \omega$.
   (b) $E = \frac{1}{2}\mu_0 \sigma R^2 \alpha$.
   (c) $S = \frac{\mu_0}{2} \sigma^2 R^3 \omega \alpha$.
   (d) They are both $\mu_0 \pi \sigma^2 R^4 l \omega \alpha$.

Chapter 40

1. (a) 1.0×10^8 cycles/sec,
   (b) 1.0×10^{-6} weber/meter^2,
   (c) 2.1 meter^{-1}, 6.3×10^8 rad/sec,
   (d) 120 watts/meter^2,
   (e) 4.0×10^{-7} A nt, 4.0×10^{-7} nt/meter^2.
3. (b) About 6×10^{-7} meter (comparable with the wavelength of light).
   (c) No.

Chapter 41

1. 1.95×10^8 meters/sec.
3. 180 cm.
5. (a) $\sqrt{1 + \sin^2 \theta_1}$
   (b) $\sqrt{2}$

Chapter 42

1. 6.
5. (b) No.
   (c) Rays pass undeviated through system.

Chapter 43

1. .072 mm.
3. 8 microns.
7. 8400 A.
9. 1.89 microns.

Chapter 44

1. (a) The droplets act as diffracting obstacles producing the observed ring.
   (b) .20 mm.
3. 71 ft.

Chapter 45

3. (a) 5860 A.
   (b) Since the fourth maximum is missing, the slit width must lie between 1.00 and 1.69 microns.
5. (a) One line to each side of the central maximum.
   (b) 1.44×10^{-4} rad.
   (c) $\Delta\theta = \frac{1}{R}$

Chapter 46

1. 67% polarized, 33% unpolarized.
3. Side A has the Polaroid, and the Polaroid axis must be at 45° to the principal axes of the quarter-wave plate.

Index

SELECTED NUMERICAL CONSTANTS

$\pi = 3.14$ $\quad$ $\pi^2 = 9.87$ $\quad$ $e = 2.72$ $\quad$ $e^{-1} = 1/e = 0.368$

$\ln 2 = 0.693$ $\quad$ $\log e = 0.434$ $\quad$ $\sqrt{2} = 1.41$ $\quad$ $\sqrt{3} = 1.73$

$\sin 30° = \cos 60° = \frac{1}{2} = 0.500$

$\cos 30° = \sin 60° = \sqrt{3}/2 = 0.866$

$\tan 30° = \cot 60° = \sqrt{3}/3 = 0.577$

$\tan 60° = \cot 30° = \sqrt{3} = 1.732$

$\sin 45° = \cos 45° = \sqrt{2}/2 = 0.707$

$\tan 45° = \cot 45° = 1.00$

SELECTED CONVERSION FACTORS

(See Appendix H for a more complete list)

$180° = \pi$ rad

1 radian = 57.3° = 0.159 rev

1 slug = 32.2 lb (mass) = 14.6 kg

1 kilogram = 2.21 lb (mass)

1 pound (mass) = 0.454 kg

1 atomic mass unit = 1.66×10^{-27} kg

1 meter = 39.4 in. = 3.28 ft; 1 inch = 2.54 cm

1 mile = 5280 ft = 1.61 km

1 angstrom unit = 10^{-10} meter = 0.1 mμ

1 millimicron = 10^{-9} meter

1 liter = 61.0 in.^{3}

1 ft^3 = 28.3 li

1 day = 86,400 sec

1 year = 3.16×10^7 sec = 365 days

1 mile/hr = 1.47 ft/sec = 0.447 meter/sec

1 pound = 4.45 nt; 1 newton = 0.225 lb

1 atmosphere = 29.9 in.-Hg = 76.0 cm-Hg = 1.01×10^5 nt/meter^2

1 Btu = 778 ft-lb = 252 cal = 1060 joules

1 calorie = 4.19 joules; 1 joule = 0.239 cal = 2.78×10^{-7} kw-hr

1 electron volt = 1.60×10^{-19} joule

1 horsepower = 550 ft-lb/sec = 746 watts

1 weber/meter^2 = 1 tesla = 10^4 gauss

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