APPENDICES

APPENDIX A 1

THE GREEK ALPHABET

Alpha	Α	α	Iota	Ι	ι	Rho	Ρ	ρ
Beta	Β	β	Kappa	Κ	κ	Sigma	Σ	σ
Gamma	Γ	γ	Lambda	Λ	λ	Tau	Τ	τ
Delta	Δ	δ	Mu	Μ	μ	Upsilon	Υ	υ
Epsilon	Ε	ε	Nu	Ν	ν	Phi	Φ	ϕ, φ
Zeta	Ζ	ς	Xi	Ξ	ξ	Chi	Χ	χ
Eta	Η	η	Omicron	Ο	ο	Psi	Ψ	ψ
Theta	Θ	θ	Pi	Π	π	Omega	Ω	ω

APPENDIX A 2

COMMON SI PREFIXES AND SYMBOLS FOR MULTIPLES AND SUB-MULTIPLES

Multiple			Sub-Multiple		
Factor	**Prefix**	**Symbol**	**Factor**	**Prefix**	**symbol**
10^{18}	Exa	E	10^{-18}	atto	a
10^{15}	Peta	P	10^{-15}	femto	f
10^{12}	Tera	T	10^{-12}	pico	p
10^{9}	Giga	G	10^{-9}	nano	n
10^{6}	Mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-3}	milli	m
10^{2}	Hecto	h	10^{-2}	centi	c
10^{1}	Deca	da	10^{-1}	deci	d

APPENDIX A 3
SOME IMPORTANT CONSTANTS

Name	Symbol	Value
Speed of light in vacuum	c	2.9979×10^{8} m s^{-1}
Charge of electron	e	1.602×10^{-19} C
Gravitational constant	G	6.673×10^{-11} N m^{2} kg^{-2}
Planck constant	h	6.626×10^{-34} J s
Boltzmann constant	k	1.381×10^{-23} J K^{-1}
Avogadro number	N_A	6.022×10^{23} mol^{-1}
Universal gas constant	R	8.314 J mol^{-1}K^{-1}
Mass of electron	m_e	9.110×10^{-31} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Mass of proton	m_p	1.673×10^{-27} kg
Electron-charge to mass ratio	e/m_e	1.759×10^{11} C/kg
Faraday constant	F	9.648×10^{4} C/mol
Rydberg constant	R	1.097×10^{7} m^{-1}
Bohr radius	a_0	5.292×10^{-11} m
Stefan-Boltzmann constant	σ	5.670×10^{-8} W m^{-2} K^{-4}
Wien's Constant	b	2.898×10^{-3} m K
Permittivity of free space	ε_0 $1/4\pi\varepsilon_0$	8.854×10^{-12} C^{2} N^{-1}m^{-2} 8.987×10^{9} N m^{2} C^{-2}
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T m A^{-1} $\cong 1.257 \times 10^{-6}$ Wb A^{-1} m^{-1}

Other useful constants

Name	Symbol	Value
Mechanical equivalent of heat	J	4.186 J cal^{-1}
Standard atmospheric pressure	1 atm	1.013×10^{5}Pa
Absolute zero	0 K	−273.15 °C
Electron volt	1 eV	1.602×10^{-19}J
Unified Atomic mass unit	1 u	1.661×10^{-27} kg
Electron rest energy	mc^2	0.511 MeV
Energy equivalent of 1 u	1 uc^2	931.5 MeV
Volume of ideal gas(0 °C and 1atm)	V	22.4 L mol^{-1}
Acceleration due to gravity (sea level, at equator)	g	9.78049 m s^{-2}

APPENDIX A 4
CONVERSION FACTORS

Conversion factors are written as equations for simplicity.

Length

1 km = 0.6215 mi

1mi = 1.609 km

1m = 1.0936 yd = 3.281 ft = 39.37 in

1 in = 2.54 cm

1 ft = 12 in = 30.48 cm

1 yd = 3ft = 91.44 cm

1 lightyear = 1 ly = 9.461×10^{15}m

1 Å= 0.1nm

Area

1 $m^2 = 10^4$ cm^2

1km^2 = 0.3861 mi^2 = 247.1 acres

1 in^2= 6.4516 cm^2

1ft^2= $9.29 \times 10^{-2} m^2$

1 m^2= 10.76 ft^2

1 acre = 43,560 ft^2

1 mi^2= 460 acres = 2.590 km^2

Volume

1m^3= $10^6 cm^3$

1 L = 1000 cm^3 = 10^{-3} m^3

1 gal = 3.786 L

1 gal = 4 qt = 8 pt = 128 oz = 231 in^3

1 in^3 = 16.39 cm^3

1ft^3 = 1728 in^3 = 28.32 L = 2.832×10^4 cm^3

Speed

1 km h^{-1} = 0.2778 m s^{-1} = 0.6215 mi h^{-1}

1mi h^{-1} = 0.4470 m s^{-1} = 1.609 km h^{-1}

1mi h^{-1} = 1.467 ft s^{-1}

Magnetic Field

1 G = 10^{-4} T

1 T = 1 Wb m^{-2} = 10^4 G

Angle and Angular Speed

π rad = 180°

1 rad = 57.30°

1° = 1.745×10^{-2} rad

1 rev min^{-1} = 0.1047 rad s^{-1}

1 rad s^{-1} = 9.549 rev min^{-1}

Mass

1 kg = 1000 g

1 tonne = 1000 kg = 1 Mg

1 u = 1.6606×10^{-27} kg

1 kg = 6.022×10^{26} u

1 slug = 14.59 kg

1 kg = 6.852×10^{-2} slug

1 u = 931.50 MeV/c^2

Density

1 g cm^{-3} = 1000 kg m^{-3} = 1 kg L^{-1}

Force

1 N = 0.2248 lbf = 10^5 dyn

1 lbf = 4.4482 N

1 kgf = 2.2046 lbf

Time

1 h = 60 min = 3.6 ks

1 d = 24 h = 1440 min = 86.4 ks

1y = 365.24 d = 31.56 Ms

Pressure

1 Pa = 1 N m^{-2}

1 bar = 100 kPa

1 atm = 101.325 kPa = 1.01325 bar

1atm = 14.7 lbf/in^2 = 760 mm Hg

= 29.9 in Hg = 33.8 ft H_2O

1 lbf in^{-2} = 6.895 kPa

1 torr = 1mm Hg = 133.32 Pa

Energy

1 kW h = 3.6 MJ

1 cal = 4.186 J

1ft lbf = 1.356 J = 1.286 × 10^{-3} Btu

1 L atm = 101.325 J

1 L atm = 24.217 cal

1 Btu = 778 ft lb = 252 cal = 1054.35 J

1 eV = 1.602 × 10^{-19}J

1 u c^2 = 931.50 MeV

1 erg = 10^{-7}J

Power

1 horsepower (hp) = 550 ft lbf/s

= 745.7 W

1 Btu min^{-1} = 17.58 W

1 W = 1.341 × 10^{-3} hp

= 0.7376 ft lbf/s

Thermal Conductivity

1 W m^{-1} K^{-1} = 6.938 Btu in/hft^2 °F

1 Btu in/hft^2 °F = 0.1441 W/m K

APPENDIX A 5
MATHEMATICAL FORMULAE

Geometry

Circle of radius r: circumference = $2\pi r$;
area = πr^2

Sphere of radius r: area = $4\pi r^2$;

volume = $\frac{4}{3}\pi r^3$

Right circular cylinder of radius r and height h: area = $2\pi\ r^2 + 2\pi\ r\ h$;

volume = $\pi r^2 h$;

Triangle of base a and altitude h.

area = $\frac{1}{2}\ a\,h$

Quadratic Formula

If $ax^2 + bx + c = 0$,

then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Trigonometric Functions of Angle θ

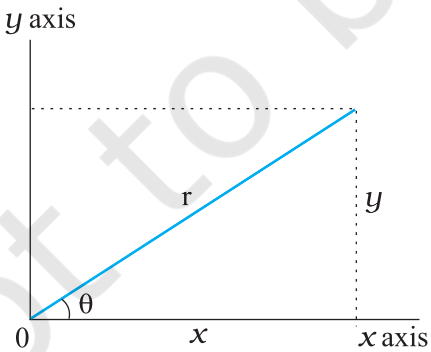


Fig. A 5.1

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

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

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

Pythagorean Theorem

In this right triangle, $a^2 + b^2 = c^2$

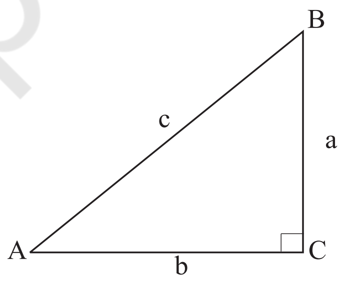


Fig. A 5.2

Triangles

Angles are A, B, C

Opposite sides are a, b, c

Angles $A + B + C = 180^0$

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

$c^2 = a^2 + b^2 - 2ab\ \cos C$

Exterior angle $D = A + C$

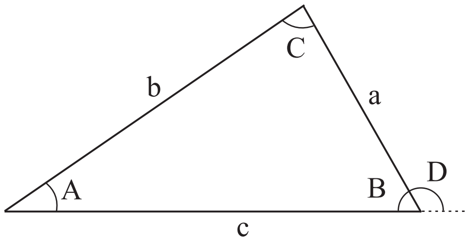


Fig. A 5.3

Mathematical Signs and Symbols

= equals
≅ equals approximately
~ is the order of magnitude of
≠ is not equal to
≡ is identical to, is defined as
> is greater than (>> is much greater than)
< is less than (<< is much less than)
≥ is greater than or equal to (or, is no less than)
≤ is less than or equal to (or, is no more than)
± plus or minus
∝ is proportional to
∑ the sum of
$\overline{x}$ or $<x>$ or x_{av} the average value of x

Trigonometric Identities

$\sin(90^0 - \theta) = \cos\theta$

$\cos(90^0 - \theta) = \sin\theta$

$\sin\theta/\cos\theta = \tan\theta$

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

$\sec^2\theta - \tan^2\theta = 1$

$\csc^2\theta - \cot^2\theta = 1$

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

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

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

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

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

$$\sin\alpha \pm \sin\beta = 2\sin\frac{1}{2}(\alpha \pm \beta)\cos\frac{1}{2}(\alpha\, m\, \beta)$$

$\cos\alpha + \cos\beta$

$$= 2\cos\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha \quad \beta)$$

$\cos\alpha - \cos\beta$

$$= -2\sin\frac{1}{2}(\alpha+\beta)\sin\frac{1}{2}(\alpha \quad \beta)$$

Binomial Theorem

$$(1-x)^n = 1 - \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + ...(x^2 < 1)$$

$$(1-x)^{-n} = 1\, m\, \frac{nx}{1!} + \frac{n(n+1)x^2}{2!} + ...(x^2 < 1)$$

Exponential Expansion

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + ...$$

Logarithmic Expansion

$$\ln(1+x) = x - \frac{1}{2}x^2 + \frac{1}{3}x^3 - ..... \quad (|x| < 1)$$

Trigonometric Expansion
(θ in radians)

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - .....$$

$$\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - .....$$

$$\tan\theta = \theta + \frac{\theta^3}{3} + \frac{2\theta^5}{15} - .....$$

Products of Vectors

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

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

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

Any vector **a** with components a_x, a_y, and a_z along the x,y, and z axes can be written,

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

Let **a**, **b** and **c** be arbitary vectors with magnitudes a, b and c. Then

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

$$(s\mathbf{a}) \times \mathbf{b} = \mathbf{a} \times (s\mathbf{b}) = s(\mathbf{a} \times \mathbf{b}) \quad \text{(s is a scalar)}$$

Let θ be the smaller of the two angles between **a** and **b**. Then

$$\mathbf{a} \cdot \mathbf{b} = \mathbf{b} \cdot \mathbf{a} = a_x b_x + a_y b_y + a_z b_z = ab\cos\theta$$

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

$$\mathbf{a} \times \mathbf{b} = -\,\mathbf{b} \times \mathbf{a} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$= (a_y b_z - b_y a_z)\,\hat{\mathbf{i}} + (a_z b_x - b_z a_x)\,\hat{\mathbf{j}} + (a_x b_y - b_x a_y)\,\hat{\mathbf{k}}$$

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

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

APPENDIX A 6
SI DERIVED UNITS

A 6.1 Some SI Derived Units expressed in SI Base Units

Physical quantity	SI Unit	
	Name	**Symbol**
Area	square metre	m^2
Volume	cubic metre	m^3
Speed, velocity	metre per second	m/s or $m\ s^{-1}$
Angular velocity	radian per second	rad/s or $rad\ s^{-1}$
Acceleration	metre per second square	m/s^2 or $m\ s^{-2}$
Angular acceleration	radian per second square	rad/s^2 or $rad\ s^{-2}$
Wave number	per metre	m^{-1}
Density, mass density	kilogram per cubic metre	kg/m^3 or $kg\ m^{-3}$
Current density	ampere per square metre	A/m^2 or $A\ m^{-2}$
Magnetic field strength, magnetic intensity, magnetic moment density	ampere per metre	A/m or $A\ m^{-1}$
Concentration (of amount of substance)	mole per cubic metre	mol/m^3 or $mol\ m^{-3}$
Specific volume	cubic metre per kilogram	m^3/kg or $m^3\ kg^{-1}$
Luminance, intensity of illumination	candela per square metre	cd/m^2 or $cd\ m^{-2}$
Kinematic viscosity	square metre per second	m^2/s or $m^2\ s^{-1}$
Momentum	kilogram metre per second	$kg\ m\ s^{-1}$
Moment of inertia	kilogram square metre	$kg\ m^2$
Radius of gyration	metre	m
Linear/superficial/volume expansivities	per kelvin	K^{-1}
Flow rate	cubic metre per second	$m^3\ s^{-1}$

A 6.2 SI Derived Units with special names

Physical quantity	SI Unit			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base Units
Frequency	hertz	Hz	-	s^{-1}
Force	newton	N	-	kg m s^{-2} or kg m/s^2
Pressure, stress	pascal	Pa	N/m^2 or N m^{-2}	kg m^{-1} s^{-2} or kg /s^2 m
Energy, work, quantity of heat	joule	J	N m	kg m^2 s^{-2} or kg m^2/s^2
Power, radiant flux	watt	W	J/s or J s^{-1}	kg m^2 s^{-3} or kg m^2/s^3
Quantity of electricity, electric charge	coulomb	C	-	A s
Electric potential, potential difference, electromotive force	volt	V	W/A or W A^{-1}	kg $m^2 s^{-3}$ A^{-1} or kg m^2/s^3 A
Capacitance	farad	F	C/V	A^2 s^4 kg^{-1} m^{-2}
Electric resistance	ohm	Ω	V/A	kg m^2 s^{-3} A^{-2}
Conductance	siemens	S	A/V	m^{-2} kg^{-1} s^3 A^2
Magnetic flux	weber	Wb	V s or J/A	kg m^2 s^{-2} A^{-1}
Magnetic field, magnetic flux density, magnetic induction	tesla	T	Wb/m^2	kg s^{-2} A^{-1}
Inductance	henry	H	Wb/A	kg m^2 s^{-2} A^{-2}
Luminous flux, luminous power	lumen	lm	-	cd /sr
Illuminance	lux	lx	lm/m^2	m^{-2} cd sr^{-1}
Activity (of a radio nuclide/radioactive source)	becquerel	Bq	-	s^{-1}
Absorbed dose, absorbed dose index	gray	Gy	J/kg	m^2/s^2 or m^2 s^{-2}

A 6.3 Some SI Derived Units expressed by means of SI Units with special names

Physical quantity	SI Unit		
	Name	Symbol	Expression in terms of SI base units
Magnetic moment	joule per tesla	J T^{-1}	m^2 A
Dipole moment	coulomb metre	C m	s A m
Dynamic viscosity	poiseiulles or pascal second or newton second per square metre	Pl or Pa s or N s m^{-2}	m^{-1} kg s^{-1}
Torque, couple, moment of force	newton metre	N m	m^2 kg s^{-2}
Surface tension	newton per metre	N/m	kg s^{-2}
Power density, irradiance, heat flux density	watt per square metre	W/m^2	kg s^{-3}

Heat capacity, entropy	joule per kelvin	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
Specific heat capacity, specific entropy	joule per kilogram kelvin	J/kg K	$m^2\ s^{-2}\ K^{-1}$
Specific energy, latent heat	joule per kilogram	J/kg	$m^2\ s^{-2}$
Radiant intensity	watt per steradian	$W\ sr^{-1}$	$kg\ m^2\ s^{-3}\ sr^{-1}$
Thermal conductivity	watt per metre kelvin	$W\ m^{-1}\ K^{-1}$	$m\ kg\ s^{-3}\ K^{-1}$
Energy density	joule per cubic metre	J/m^3	$kg\ m^{-1}\ s^{-2}$
Electric field strength	volt per metre	V/m	$m\ kg\ s^{3}\ A^{-1}$
Electric charge density	coulomb per cubic metre	C/m^3	$m^{-3}\ A\ s$
Electric flux density	coulomb per square metre	C/m^2	$m^{-2}\ A\ s$
Permittivity	farad per metre	F/m	$m^{-3}\ kg^{-1}\ s^4\ A^2$
Permeability	henry per metre	H/m	$m\ kg\ s^{-2}\ A^{-2}$
Molar energy	joule per mole	J/mol	$m^2\ kg\ s^{-2} mol^{-1}$
Angular momentum, Planck's constant	joule second	J s	$kg\ m^2\ s^{-1}$
Molar entropy, molar heat capacity	joule per mole kelvin	J/mol K	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$
Exposure (*x*-rays and *γ*-rays)	coulomb per kilogram	C/kg	$kg^{-1}\ s\ A$
Absorbed dose rate	gray per second	Gy/s	$m^2\ s^{-3}$
Compressibility	per pascal	Pa^{-1}	$m\ kg^{-1}\ s^2$
Elastic moduli	newton per square metre	N/m^2 or $N\ m^{-2}$	$kg\ m^{-1}\ s^{-2}$
Pressure gradient	pascal per metre	Pa/m or $N\ m^{-3}$	$kg\ m^{-2}\ s^{-2}$
Surface potential	joule per kilogram	J/kg or N m/kg	$m^2\ s^{-2}$
Pressure energy	pascal cubic metre	$Pa\ m^3$ or N m	$kg\ m^2\ s^{-2}$
Impulse	newton second	N s	$kg\ m\ s^{-1}$
Angular impulse	newton metre second	N m s	$kg\ m^2\ s^{-1}$
Specific resistance	ohm metre	Ωm	$kg\ m^3\ s^{-3}\ A^{-2}$
Surface energy	joule per square metre	J/m^2 or N/m	$kg\ s^{-2}$

APPENDIX A 7
GENERAL GUIDELINES FOR USING SYMBOLS FOR PHYSICAL QUANTITIES, CHEMICAL ELEMENTS AND NUCLIDES

- Symbols for physical quantities are normally single letters and printed in italic (or sloping) type. However, in case of the two letter symbols, appearing as a factor in a product, some spacing is necessary to separate this symbol from other symbols.
- Abbreviations, i.e., shortened forms of names or expressions, such as p.e. for potential energy, are not used in physical equations. These abbreviations in the text are written in ordinary normal/roman (upright) type.
- Vectors are printed in bold and normal/roman (upright) type. However, in class room situations, vectors may be indicated by an arrow on the top of the symbol.
- Multiplication or product of two physical quantities is written with some spacing between them. Division of one physical quantity by another may be indicated with a horizontal bar or with

solidus, a slash or a short oblique stroke mark (/) or by writing it as a product of the numerator and the inverse first power of the denominator, using brackets at appropriate places to clearly distinguish between the numerator and the denominator.

- Symbols for chemical elements are written in normal/roman (upright) type. The symbol is not followed by a full stop.
  For example, Ca, C, H, He, U, etc.
- The attached numerals specifying a nuclide are placed as a left subscript (atomic number) and superscript (mass number).
  For example, a U-235 nuclide is expressed as ${}^{235}_{92}U$ (with 235 expressing the mass number and 92 as the atomic number of uranium with chemical symbol U).
- The right superscript position is used, if required, for indicating a state of ionisation (in case of ions).
  For example, Ca^{2+}, PO_4^{3-}

APPENDIX A 8
GENERAL GUIDELINES FOR USING SYMBOLS FOR SI UNITS, SOME OTHER UNITS, AND SI PREFIXES

- Symbols for units of physical quantities are printed/written in Normal/Roman (upright) type.
- Standard and recommended symbols for units are written in lower case roman (upright) type, starting with small letters. The shorter designations for units such as kg, m, s, cd, etc., are symbols and not the abbreviations. The unit names are never capitalised. However, the unit symbols are capitalised only if the symbol for a unit is derived from a proper name of scientist, beginning with a capital, normal/roman letter.
  For example, m for the unit 'metre', d for the unit 'day', atm for the unit 'atmospheric pressure', Hz for the unit 'hertz', Wb for the unit 'weber', J for the unit 'joule', A for the unit 'ampere', V for the unit 'volt', etc. The single exception is L, which is the symbol for the unit 'litre'. This exception is made to avoid confusion of the lower case letter l with the Arabic numeral l.
- Symbols for units do not contain any final full stop at the end of recommended letter and remain unaltered in the plural, using only singular form of the unit.
  For example, for a length of 25 centimetres the unit symbol is written as 25 cm and not 25 cms or 25 cm. or 25 cms., etc.
- Use of solidus (/) is recommended only for indicating a division of one letter unit symbol by another unit symbol. Not more than one solidus is used.
  For example :
  m/s^2 or $m\ s^{-2}$ (with a spacing between m and s^{-2}) but not m/s/s;
  1 Pl =1 N s m^{-2} = 1 N s/m^2 = 1 kg/s m=1 kg m^{-1} s^{-1}, but not 1 kg/m/s;
  J/K mol or J K^{-1} mol^{-1}, but not J/K/mol; etc.
- Prefix symbols are printed in normal/roman (upright) type without spacing between the prefix symbol and the unit symbol. Thus certain approved prefixes written very close to the unit symbol are used to indicate decimal fractions or multiples of a SI unit, when it is inconveniently small or large.
  For example :

megawatt (1MW = 10^6 W);	nanosecond (1 ns = 10^{-9} s);
centimetre (1 cm = 10^{-2} m);	picofarad (1 pF = 10^{-12} F);.
kilometre (1 km = 10^3 m);	microsecond (1µs = 10^{-6} s);
millivolt (1 mV= 10^{-3} V);	gigahertz (1GHz = 10^9 Hz);

kilowatt-hour (1 kW h = 10^3 W h = 3.6 MJ = 3.6×10^6 J);
microampere (1μ A = 10^{-6} A); micron (1μm = 10^{-6} m);
angstrom (1 Å=0.1 nm = 10^{-10} m); etc.

The unit 'micron' which equals 10^{-6} m, i.e. a micrometre, is simply the name given to convenient sub-multiple of the metre. In the same spirit, the unit 'fermi', equal to a femtometre or 10^{-15} m has been used as the convenient length unit in nuclear studies. Similarly, the unit 'barn', equal to 10^{-28} m^2, is a convenient measure of cross-sectional areas in sub-atomic particle collisions. However, the unit 'micron' is preferred over the unit 'micrometre' to avoid confusion of the 'micrometre' with the length measuring instrument called 'micrometer'. These newly formed multiples or sub-multiples (cm, km, μm, μs, ns) of SI units, metre and second, constitute a new composite inseparable symbol for units.

- When a prefix is placed before the symbol of a unit, the combination of prefix and symbol is considered as a new symbol, for the unit, which can be raised to a positive or negative power without using brackets. These can be combined with other unit symbols to form compound unit. Rules for binding-in indices are not those of ordinary algebra.
  For example :
  cm^3 means always $(cm)^3 = (0.01\ m)^3 = (10^{-2}\ m)^3 = 10^{-6}\ m^3$, but never 0.01 m^3 or 10^{-2} m^3 or 1cm^3 (prefix c with a spacing with m^3 is meaningless as prefix c is to be attached to a unit symbol and it has no physical significance or independent existence without attachment with a unit symbol).
  Similarly, mA^2 means always $(mA)^2 = (0.001A)^2 = (10^{-3}\ A)^2 = 10^{-6}\ A^2$, but never 0.001 A^2 or 10^{-3} A^2 or m A^2;
  1 $cm^{-1} = (10^{-2}m)^{-1} = 10^2\ m^{-1}$, but not 1c m^{-1} or 10^{-2} m^{-1};
  1μs^{-1} means always $(10^{-6}s)^{-1} = 10^6\ s^{-1}$, but not 1×10^{-6} s^{-1};
  1 km^2 means always $(km)^2 = (10^3\ m)^2 = 10^6\ m^2$, but not 10^3 m^2;
  1mm^2 means always $(mm)^2 = (10^{-3}\ m)^2 = 10^{-6}\ m^2$, but not 10^{-3} m^2.
- A prefix is never used alone. It is always attached to a unit symbol and written or fixed before (pre-fix) the unit symbol.
  For example :
  $10^3/m^3$ means $1000/m^3$ or 1000 m^{-3}, but not k/m^3 or k m^{-3}.
  $10^6/m^3$ means 10,00,000/m^3 or 10,00,000 m^{-3}, but not M/m^3 or M m^{-3}
- Prefix symbol is written very close to the unit symbol without spacing between them, while unit symbols are written separately with spacing when units are multiplied together.
  For example :
  m s^{-1} (symbols m and s^{-1}, in lower case, small letter m and s, are separate and independent unit symbols for metre and second respectively, with spacing between them) means 'metre per second', but not 'milli per second'.
  Similarly, ms^{-1} [symbol m and s are written very close to each other, with prefix symbol m (for prefix milli) and unit symbol s, in lower case, small letter (for unit 'second') without any spacing between them and making ms as a new composite unit] means 'per millisecond', but never 'metre per second'.
  mS^{-1}[symbol m and S are written very close to each other, with prefix symbol m (for prefix milli) and unit symbol S, in capital roman letter S (for unit 'siemens') without any spacing between them, and making mS as a new composite unit] means 'per millisiemens', but never 'per millisecond'.
  C m [symbol C and m are written separately, representing unit symbols C (for unit 'coulomb') and m (for unit 'metre'), with spacing between them] means 'coulomb metre', but never 'centimetre', etc.
- The use of double prefixes is avoided when single prefixes are available.
  For example :

10^{-9} m = 1nm (nanometre), but not 1mμm (millimicrometre),
10^{-6} m= 1μm (micron), but not 1mmm(millimillimetre),
10^{-12} F= 1 pF (picofarad), but not 1μμF (micromicrofarad),
10^{9} W=1 GW (giga watt), but not 1 kMW (kilomegawatt), etc.

- The use of a combination of unit and the symbols for units is avoided when the physical quantity is expressed by combining two or more units.
  For example :
  joule per mole kelvin is written as J/mol K or J mol^{-1} K^{-1}, but not joule/mole K or J/ mol kelvin or J/mole K, etc.
  joule per tesla is written as J/T or J T^{-1}, but not joule /T or J per tesla or J/tesla, etc.
  newton metre second is written as N m s, but not Newton m second or N m second or N metre s or newton metre s, etc.
  joule per kilogram kelvin is written as J/kg K or J kg^{-1} K^{-1}, but not J/kilog K or joule/kg K or J/ kg kelvin or J/kilogram K, etc.
- To simplify calculations, the prefix symbol is attached to the unit symbol in the numerator and not to the denominator.
  For example :
  10^6 N/m^2 is written more conveniently as MN/m^2, in preference to N/mm^2.
  A preference has been expressed for multiples or sub-multiples involving the factor 1000, $10^{\pm 3n}$ where n is the integer.
- Proper care is needed when same symbols are used for physical quantities and units of physical quantities.
  For example :
  The physical quantity weight (W) expressed as a product of mass (m) and acceleration due to gravity (g) may be written in terms of symbols W, m and g printed in italic (or sloping) type as $W = m\ g$, preferably with a spacing between m and g. It should not be confused with the unit symbols for the units watt (W), metre (m) and gram (g). However, in the equation $W = m\ g$, the symbol W expresses the weight with a unit symbol J, m as the mass with a unit symbol kg and g as the acceleration due to gravity with a unit symbol m/s^2. Similarly, in equation $F = m\ a$, the symbol F expresses the force with a unit symbol N, m as the mass with a unit symbol kg, and a as the acceleration with a unit symbol m/s^2. These symbols for physical quantities should not be confused with the unit symbols for the units 'farad' (F), 'metre'(m) and 'are' (a).
  Proper distinction must be made while using the symbols h (prefix hecto, and unit hour), c (prefix centi, and unit carat), d (prefix deci and unit day), T (prefix tera, and unit tesla), a (prefix atto, and unit are), da (prefix deca, and unit deciare), etc.
- SI base unit 'kilogram' for mass is formed by attaching SI prefix (a multiple equal to 10^3) 'kilo' to a cgs (centimetre, gram, second) unit 'gram' and this may seem to result in an anomaly. Thus, while a thousandth part of unit of length (metre) is called a millimetre (mm), a thousandth part of the unit of mass (kg) is not called a millikilogram, but just a gram. This appears to give the impression that the unit of mass is a gram (g) which is not true. Such a situation has arisen because we are unable to replace the name 'kilogram' by any other suitable unit. Therefore, as an exception, name of the multiples and sub-multiples of the unit of mass are formed by attaching prefixes to the word 'gram' and not to the word 'kilogram'.
  For example :
  10^3 kg =1 megagram (1Mg), but not 1 kilo kilogram (1 kkg);
  10^{-6} kg = 1 milligram (1 mg), but not 1 microkilogram (1μkg);
  10^{-3} kg = 1 gram (1g), but not 1 millikilogram (1 mkg), etc.

It may be emphasised again that you should use the internationally approved and recommended symbols only. Continual practice of following general rules and guidelines in unit symbol writing would make you learn mastering the correct use of SI units, prefixes and related symbols for physical quantities in a proper perspective.

APPENDIX A 9
DIMENSIONAL FORMULAE OF PHYSICAL QUANTITIES

S.No	Physical quantity	Relationship with other physical quantities	Dimensions	Dimensional formula
1.	Area	Length × breadth	$[L^2]$	$[M^0 L^2 T^0]$
2.	Volume	Length × breadth × height	$[L^3]$	$[M^0 L^3 T^0]$
3.	Mass density	Mass/volume	$[M]/[L^3]$ or $[M L^{-3}]$	$[M L^{-3} T^0]$
4.	Frequency	1/time period	$1/[T]$	$[M^0 L^0 T^{-1}]$
5.	Velocity, speed	Displacement/time	$[L]/[T]$	$[M^0 L T^{-1}]$
6.	Acceleration	Velocity /time	$[LT^{-1}]/[T]$	$[M^0 L T^{-2}]$
7.	Force	Mass × acceleration	$[M][LT^{-2}]$	$[M LT^{-2}]$
8.	Impulse	Force × time	$[M LT^{-2}][T]$	$[M LT^{-1}]$
9.	Work, Energy	Force × distance	$[MLT^{-2}] [L]$	$[M L^2 T^{-2}]$
10.	Power	Work/time	$[ML^2 T^{-2}]/ [T]$	$[M L^2 T^{-3}]$
11.	Momentum	Mass × velocity	$[M] [LT^{-1}]$	$[M LT^{-1}]$
12.	Pressure, stress	Force/area	$[M LT^{-2}]/[L^2]$	$[ML^{-1}T^{-2}]$
13.	Strain	$\frac{\text{Change in dimension}}{\text{Oringinal dimension}}$	$[L] / [L]$ or $[L^3] / [L^3]$	$[M^0 L^0 T^0]$
14.	Modulus of elasticity	Stress/strain	$\frac{[M L^{-1} T^{-2}]}{[M^0 L^0 T^0]}$	$[M L^{-1} T^{-2}]$
15	Surface tension	Force/length	$[MLT^{-2}]/[L]$	$[ML^0 T^{-2}]$
16.	Surface energy	Energy/area	$[ML^2 T^{-2}]/[L^2]$	$[ML^0 T^{-2}]$
17.	Velocity gradient	Velocity/distance	$[LT^{-1}]/[L]$	$[M^0 L^0 T^{-1}]$
18.	Pressure gradient	Pressure/distance	$[ML^{-1} T^{-2}]/[L]$	$[ML^{-2} T^{-2}]$
19.	Pressure energy	Pressure × volume	$[ML^{-1} T^{-2}] [L^3]$	$[ML^2 T^{-2}]$
20.	Coefficient of viscosity	Force/area × velocity gradient	$\frac{[MLT^{-2}]}{[L^2][LT^{-1} / L]}$	$[ML^{-1} T^{-1}]$
21.	Angle, Angular displacement	Arc/radius	$[L]/[L]$	$[M^0 L^0 T^0]$
22.	Trigonometric ratio (sinθ, cosθ, tanθ, etc.)	Length/length	$[L]/[L]$	$[M^0 L^0 T^0]$
23.	Angular velocity	Angle/time	$[L^0]/[T]$	$[M^0 L^0 T^{-1}]$

24.	Angular acceleration	Angular velocity/time	$[T^{-1}]/[T]$	$[M^0L^0T^{-2}]$
25.	Radius of gyration	Distance	$[L]$	$[M^0LT^0]$
26.	Moment of inertia	Mass × (radius of gyration)^2	$[M]\ [L^2]$	$[ML^2\ T^0]$
27.	Angular momentum	Moment of inertia × angular velocity	$[ML^2]\ [T^{-1}]$	$[ML^2\ T^{-1}]$
28.	Moment of force, moment of couple	Force x distance	$[MLT^{-2}]\ [L]$	$[ML^2\ T^{-2}]$
29.	Torque	Angular momentum/time, Or Force × distance	$[ML^2\ T^{-1}]\ /\ [T]$ or $[MLT^{-2}]\ [L]$	$[ML^2\ T^{-2}]$
30.	Angular frequency	2π × Frequency	$[T^{-1}]$	$[M^0L^0T^{-1}]$
31.	Wavelength	Distance	$[L]$	$[M^0LT^0]$
32.	Hubble constant	Recession speed/distance	$[LT^{-1}]/[L]$	$[M^0L^0T^{-1}]$
33.	Intensity of wave	(Energy/time)/area	$[ML^2\ T^{-2}/T]/[L^2]$	$[ML^0T^{-3}]$
34.	Radiation pressure	$\frac{\text{Intensity of wave}}{\text{Speed of light}}$	$[MT^{-3}]/[LT^{-1}]$	$[ML^{-1}\ T^{-2}]$
35.	Energy density	Energy/volume	$[ML^2T^{-2}]/\ [L^3]$	$[ML^{-1}\ T^{-2}]$
36.	Critical velocity	$\frac{\text{Reynold's number} \times \text{coefficient of viscocity}}{\text{Mass density} \times \text{radius}}$	$\frac{[M^0L^0T^0][ML^{-1}T^{-1}]}{[ML^{-3}][L]}$	$[M^0LT^{-1}]$
37.	Escape velocity	(2 × acceleration due to gravity × earth's radius)$^{1/2}$	$[LT^{-2}]^{1/2}$ x $[L]^{1/2}$	$[M^0LT^{-1}]$
38.	Heat energy, internal energy	Work (= Force × distance)	$[MLT^{-2}]\ [L]$	$[ML^2\ T^{-2}]$
39.	Kinetic energy	(1/2) mass × (velocity)^2	$[M]\ [LT^{-1}]^2$	$[ML^2T^{-2}]$
40	Potential energy	Mass × acceleration due to gravity × height	$[M]\ [LT^{-2}]\ [L]$	$[ML^2\ T^{-2}]$
41.	Rotational kinetic energy	½ × moment of inertia × (angular velocity)^2	$[M^0L^0T^0]\ [ML^2]$x$[T^{-1}]^2$	$[M\ L^2\ T^{-2}]$
42.	Efficiency	$\frac{\text{Output work or energy}}{\text{Input work or energy}}$	$\frac{[ML^2T^{-2}]}{[ML^2T^{-2}]}$	$[M^0L^0T^0]$
43.	Angular impulse	Torque × time	$[ML^2\ T^{-2}]\ [T]$	$[M\ L^2\ T^{-1}]$
44.	Gravitational constant	$\frac{\text{Force} \times (\text{distance})^2}{\text{mass} \times \text{mass}}$	$\frac{[MLT^{-2}][L^2]}{[M]\ [M]}$	$[M^{-1}L^3T^{-2}]$
45.	Planck constant	Energy/frequency	$[ML^2\ T^{-2}]\ /[T^{-1}]$	$[ML^2T^{-1}]$

46.	Heat capacity, entropy	Heat energy / temperature	$[ML^2 T^{-2}]/[K]$	$[ML^2T^{-2}K^{-1}]$
47.	Specific heat capacity	$\frac{\text{Heat Energy}}{\text{Mass} \times \text{temperature}}$	$[ML^2 T^{-2}]/[M]\,[K]$	$[M^0L^2 T^{-2} K^{-1}]$
48.	Latent heat	Heat energy/mass	$[ML^2 T^{-2}]/[M]$	$[M^0L^2 T^{-2}]$
49.	Thermal expansion coefficient or Thermal expansivity	$\frac{\text{Change in dimension}}{\text{Original dimension} \times \text{temperature}}$	$[L]/[L][K]$	$[M^0L^0K^{-1}]$
50.	Thermal conductivity	$\frac{\text{Heat energy} \times \text{thickness}}{\text{Area} \times \text{temperature} \times \text{time}}$	$\frac{[ML^2T^{-2}][L]}{[L^2]\,[K]\,[T]}$	$[MLT^{-3} K^{-1}]$
51.	Bulk modulus or $(\text{compressibility})^{-1}$	$\frac{\text{Volume} \times (\text{change in pressure})}{(\text{change in volume})}$	$\frac{[L^3][ML^{-1}T^{-2}]}{[L^3]}$	$[ML^{-1} T^{-2}]$
52.	Centripetal acceleration	$(\text{Velocity})^2/\text{radius}$	$[LT^{-1}]^2/[L]$	$[M^0 LT^{-2}]$
53.	Stefan constant	$\frac{(\text{Energy}/\text{area} \times \text{time})}{(\text{Temperature})^4}$	$\frac{[ML^2 T^{-2}]}{[L^2]\,[T]\,[K]^4}$	$[ML^0 T^{-3}K^{-4}]$
54.	Wien constant	Wavelength × temperature	$[L]\,[K]$	$[M^0 LT^0K]$
55.	Boltzmann constant	Energy/temperature	$[ML^2 T^{-2}]/[K]$	$[ML^2 T^{-2} K^{-1}]$
56.	Universal gas constant	$\frac{\text{Pressure} \times \text{volume}}{\text{mole} \times \text{temperature}}$	$\frac{[ML^{-1} T^{-2}][L^3]}{[mol]\,[K]}$	$[ML^2 T^{-2} K^{-1} mol^{-1}]$
57.	Charge	Current × time	$[A]\,[T]$	$[M^0 L^0TA]$
58.	Current density	Current /area	$[A]/[L^2]$	$[M^0L^{-2} T^0A]$
59.	Voltage, electric potential, electromotive force	Work/charge	$[ML^2T^{-2}]/[AT]$	$[ML^2 T^{-3} A^{-1}]$
60.	Resistance	$\frac{\text{Potential difference}}{\text{Current}}$	$\frac{[ML^2 T^{-3} A^{-1}]}{[A]}$	$[ML^2 T^{-3} A^{-2}]$
61.	Capacitance	Charge/potential difference	$\frac{[AT]}{[ML^2 T^{-3} A^{-1}]}$	$[M^{-1}L^{-2} T^4 A^2]$
62.	Electrical resistivity or $(\text{electrical conductivity})^{-1}$	$\frac{\text{Resistance} \times \text{area}}{\text{length}}$	$[ML^2 T^{-3} A^{-2}]\,[L^2]/[L]$	$[ML^3 T^{-3} A^{-2}]$
63.	Electric field	Electrical force/charge	$[MLT^{-2}]/[AT]$	$[MLT^{-3} A^{-1}]$
64.	Electric flux	Electric field × area	$[MLT^{-3}A^{-1}][L^2]$	$[ML^3 T^{-3} A^{-1}]$

65.	Electric dipole moment	Torque/electric field	$\frac{[ML^2\ T^{-2}]}{[MLT^{-3}\ A^{-1}]}$	$[M^0\ LTA]$
66.	Electric field strength or electric intensity	$\frac{\text{Potential difference}}{\text{distance}}$	$\frac{[ML^2\ T^{-3}\ A^{-1}]}{[L]}$	$[MLT^{-3}\ A^{-1}]$
67.	Magnetic field, magnetic flux density, magnetic induction	$\frac{\text{Force}}{\text{Current} \times \text{length}}$	$[MLT^{-2}]/[A]\ [L]$	$[ML^0\ T^{-2}\ A^{-1}]$
68.	Magnetic flux	Magnetic field × area	$[MT^{-2}\ A^{-1}]\ [L^2]$	$[ML^2\ T^{-2}\ A^{-1}]$
69.	Inductance	$\frac{\text{Magnetic flux}}{\text{Current}}$	$\frac{[ML^2\ T^{-2}\ A^{-1}]}{[A]}$	$[ML^2\ T^{-2}\ A^{-2}]$
70.	Magnetic dipole moment	Torque/magnetic field or current × area	$[ML^2\ T^{-2}]\ /\ [MT^{-2}\ \ A^{-1}]$ or $[A]\ [L^2]$	$[M^0L^2T^0A]$
71.	Magnetic field strength, magnetic intensity or magnetic moment density	$\frac{\text{Magnetic moment}}{\text{Volume}}$	$\frac{[L^2A]}{[L^3]}$	$[M^0L^{-1}T^0A]$
72	Permittivity constant (of free space)	$\frac{\text{Charge} \times \text{charge}}{4\pi \times \text{electric force} \times (\text{distance})^2}$	$\frac{[AT][AT]}{[MLT^{-2}][L]^2}$	$[M^{-1}L^{-3}T^4\ A^2]$
73.	Permeability constant (of free space)	$\frac{2\pi \times \text{force} \times \text{distance}}{\text{current} \times \text{current} \times \text{length}}$	$\frac{[M^0\ L^0\ T^0][MLT^{-2}][L]}{[A][A][L]}$	$[MLT^{-2}\ A^{-2}]$
74.	Refractive index	$\frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$	$[LT^{-1}]/LT^{-1}]$	$[M^0L^0T^0]$
75.	Faraday constant	Avogadro constant × elementary charge	$[AT]/[mol]$	$[M^0L^0TA\ mol^{-1}]$
76.	Wave number	2π/wavelength	$[M^0L^0T^0]\ /\ [L]$	$[M^0L^{-1}\ T^0]$
77.	Radiant flux, Radiant power	Energy emitted/time	$[ML^2T^{-2}]/[T]$	$[ML^2T^{-3}]$
78.	Luminosity of radiant flux or radiant intensity	$\frac{\text{Radiant power or radiant flus of source}}{\text{Solid angle}}$	$[ML^2T^{-3}]\ /\ \ [M^0L^0T^0]$	$[ML^2\ T^{-3}]$
79.	Luminous power or luminous flux of source	$\frac{\text{Luminous energy emitted}}{\text{time}}$	$[ML^2\ T^{-2}]/[T]$	$[ML^2\ T^{-3}]$

80.	Luminous intensity or illuminating power of source	$\frac{\text{Luminous flux}}{\text{Soild angle}}$	$\frac{[ML^2T^{-3}]}{[M^0L^0T^0]}$	$[ML^2T^{-3}]$
81.	Intensity of illumination or luminance	$\frac{\text{Luminous intensity}}{(\text{distance})^2}$	$[ML^2T^{-3}]/[L^2]$	$[ML^0T^{-3}]$
82.	Relative luminosity	$\frac{\text{Luminous flux of a source of given wavelength}}{\text{luminous flux of peak sensitivity wavelength (555 nm) source of same power}}$	$\frac{[ML^2T^{-1}]}{[ML^2T^{-3}]}$	$[M^0L^0T^0]$
83.	Luminous efficiency	$\frac{\text{Total luminous flux}}{\text{Total radiant flux}}$	$[ML^2T^{-3}]/[ML^2T^{-3}]$	$[M^0L^0T^0]$
84.	Illuminance or illumination	$\frac{\text{Luminous flux incident}}{\text{area}}$	$[ML^2T^{-3}]/[L^2]$	$[ML^0T^{-3}]$
85.	Mass defect	(sum of masses of nucleons)-(mass of the nucleus)	$[M]$	$[ML^0T^0]$
86.	Binding energy of nucleus	Mass defect × (speed of light in vacuum)^2	$[M][LT^{-1}]^2$	$[ML^2T^{-2}]$
87.	Decay constant	0.693/half life	$[T^{-1}]$	$[M^0L^0T^{-1}]$
88.	Resonant frequency	$(\text{Inductance} \times \text{capacitance})^{-\frac{1}{2}}$	$[ML^2T^{-2}A^{-2}]^{-\frac{1}{2}}$ x $[M^{-1}L^{-2}T^4A^2]^{-\frac{1}{2}}$	$[M^0L^0A^0T^{-1}]$
89.	Quality factor or Q-factor of coil	$\frac{\text{Resonant frequency} \times \text{inductance}}{\text{Resistance}}$	$\frac{[T^{-1}][ML^2T^{-2}A^{-2}]}{[ML^2T^{-3}A^{-2}]}$	$[M^0L^0T^0]$
90.	Power of lens	$(\text{Focal length})^{-1}$	$[L^{-1}]$	$[M^0L^{-1}T^0]$
91.	Magnification	$\frac{\text{Image distance}}{\text{Object distance}}$	$[L]/[L]$	$[M^0L^0T^0]$
92.	Fluid flow rate	$\frac{(\pi/8)(\text{pressure})\times(\text{radius})^4}{(\text{viscosity coefficient})\times(\text{length})}$	$\frac{[ML^{-1}T^{-2}][L^4]}{[ML^{-1}T^{-1}][L]}$	$[M^0L^3T^{-1}]$
93	Capacitive reactance	(Angular frequency × capacitance)$^{-1}$	$[T^{-1}]^{-1}[M^{-1}L^{-2}T^4A^2]^{-1}$	$[ML^2T^{-3}A^{-2}]$
94.	Inductive reactance	(Angular frequency × inductance)	$[T^{-1}][ML^2T^{-2}A^{-2}]$	$[ML^2T^{-3}A^{-2}]$

ANSWERS

Chapter 2

2.1 (a) 10^{-6} ; (b) 1.5×10^{4} ; (c) 5 ; (d) 11.3, 1.13×10^{4}.

2.2 (a) 10^{7} ; (b) 10^{-16} ; (c) 3.9×10^{4} ; (d) 6.67×10^{-8}.

2.5 500

2.6 (c)

2.7 0.035 mm

2.9 94.1

2.10 (a) 1 ; (b) 3 ; (c) 4 ; (d) 4 ; (e) 4 ; (f) 4.

2.11 8.72 m^2; 0.0855 m^3

2.12 (a) 2.3 kg ; (b) 0.02 g

2.13 13%; 3.8

2.14 (b) and (c) are wrong on dimensional grounds. Hint: The argument of a trigonometric function must always be dimensionless.

2.15 The correct formula is $m = m_0 (1 - v^2/c^2)^{-1/2}$

2.16 $\cong 3 \times 10^{-7}$ m^3

2.17 $\cong$ 10^4; intermolecular separation in a gas is much larger than the size of a molecule.

2.18 Near objects make greater angle than distant (far off) objects at the eye of the observer. When you are moving, the angular change is less for distant objects than nearer objects. So, these distant objects seem to move along with you, but the nearer objects in opposite direction.

2.19 $\cong 3 \times 10^{16}$ m; as a unit of length 1 parsec is defined to be equal to 3.084×10^{16} m.

2.20 1.32 parsec; 2.64″ (second of arc)

2.23 1.4×10^3 kg m^{-3}; the mass density of the Sun is in the range of densities of liquids / solids and *not* gases. This high density arises due to inward gravitational attraction on outer layers due to inner layers of the Sun.

2.24 1.429×10^5 km

2.25 Hint: tan θ must be dimensionless. The correct formula is tan $\theta = v/v'$ where v' is the speed of rainfall.

2.26 Accuracy of 1 part in 10^{11} to 10^{12}

2.27 $\cong 0.7 \times 10^3$ kg m^{-3}. In the solid phase atoms are tightly packed, so the atomic mass density is close to the mass density of the solid.

2.28 $\cong 0.3 \times 10^{18}$ kg m^{-3} – Nuclear density is typically 10^{15} times atomic density of matter.

2.29 3.84×10^8 m

2.30 55.8 km

2.31 2.8×10^{22} km

2.32 3,581 km

2.33 Hint: the quantity $e^4 / (16\,\pi^2 \epsilon_0^2 m_p\, m_e^2\, c^3\, G)$ has the dimension of time.

Chapter 3

3.1 (a), (b)

3.2 (a) A....B, (b) A....B, (c) B....A, (d) Same, (e) B....A....once.

3.4 37 s

3.5 1000 km/h

3.6 3.06 m s^{-2}; 11.4 s

3.7 1250 m (Hint: view the motion of B relative to A)

3.8 1 m s^{-2} (Hint: view the motion of B and C relative to A)

3.9 T = 9 min, speed = 40 km/h. Hint: $v\,T / (v - 20) = 18$; $v\,T / (v + 20) = 6$

3.10 (a) Vertically downwards; (b) zero velocity, acceleration of 9.8 m s^{-2} downwards; (c) $x > 0$ (upward and downward motion); $v < 0$ (upward), $v > 0$ (downward), $a > 0$ throughout; (d) 44.1 m, 6 s.

3.11 (a) True;, (b) False; (c) True (if the particle rebounds instantly with the same speed, it implies infinite acceleration which is unphysical); (d) False (true only when the chosen positive direction is along the direction of motion)

3.14 (a) 5 km h^{-1}, 5 km h^{-1}; (b) 0, 6 km h^{-1}; (c) $\frac{15}{8}$ km h^{-1}, $\frac{45}{8}$ km h^{-1}

3.15 Because, for an arbitrarily small interval of time, the magnitude of displacement is equal to the length of the path.

3.16 All the four graphs are impossible. (a) a particle cannot have two different positions at the same time; (b) a particle cannot have velocity in opposite directions at the same time; (c) speed is always non-negative; (d) total path length of a particle can never decrease with time. (Note, the arrows on the graphs are meaningless).

3.17 No, wrong. x-t plot does not show the trajectory of a particle. Context: A body is dropped from a tower ($x = 0$) at $t = 0$.

3.18 105 m s^{-1}

3.19 (a) A ball at rest on a smooth floor is kicked, it rebounds from a wall with reduced speed and moves to the opposite wall which stops it; (b) A ball thrown up with some initial velocity rebounding from the floor with reduced speed after each hit; (c) A uniformly moving cricket ball turned back by hitting it with a bat for a very short time-interval.

3.20 $x < 0$, $v < 0$, $a > 0$; $x > 0$, $v > 0$, $a < 0$; $x < 0$, $v > 0$, $a > 0$.

3.21 Greatest in 3, least in 2; $v > 0$ in 1 and 2, $v < 0$ in 3.

3.22 Acceleration magnitude greatest in 2; speed greatest in 3; $v > 0$ in 1, 2 and 3; $a > 0$ in 1 and 3, $a < 0$ in 2; $a = 0$ at A, B, C, D.

3.23 A straight line inclined with the time-axis for uniformly accelerated motion; parallel to the time- axis for uniform motion.

3.24 10 s, 10 s

3.25 (a) 13 km h^{-1} ; (b) 5 km h^{-1}; (c) 20 s in either direction, viewed by any one of the parents, the speed of the child is 9 km h^{-1} in either direction; answer to (c) is unaltered.

3.26 $x_2 - x_1 = 15\ t$ (linear part); $x_2 - x_1 = 200 + 30\ t - 5\ t^2$ (curved part).

3.27 (a) 60 m, 6 m s^{-1} ; (b) 36 m, 9 m s^{-1}

3.28 (c), (d), (f)

Chapter 4

4.1 Volume, mass, speed, density, number of moles, angular frequency are scalars; the rest are vectors.

4.2 Work, current

4.3 Impulse

4.4 Only (c) and (d) are permissible

4.5 (a) T, (b) F, (c) F, (d) T, (e) T

4.6 Hint: The sum (difference) of any two sides of a triangle is never less (greater) than the third side. Equality holds for collinear vectors.

4.7 All statements except (a) are correct

4.8 400 m for each; B

4.9 (a) O; (b) O; (c) 21.4 km h^{-1}

4.10 Displacement of magnitude 1 km and direction 60° with the initial direction; total path length = 1.5 km (third turn); null displacement vector; path length = 3 km (sixth turn); 866 m, 30°, 4 km (eighth turn)

4.11 (a) 49.3 km h^{-1} ; (b) 21.4 km h^{-1}. No, the average speed equals average velocity magnitude only for a straight path.

4.12 About 18° with the vertical, towards the south.

4.13 15 min, 750 m

4.14 East (approximately)

4.15 150.5 m

4.16 50 m

4.17 9.9 m s^{-2}, along the radius at every point towards the centre.

4.18 6.4 g

4.19 (a) False (true only for uniform circular motion)

(b) True, (c) True.

4.20 (a) $\mathbf{v}(t) = (3.0\,\hat{\mathbf{i}} - 4.0t\,\hat{\mathbf{j}})\;\; \hat{\mathbf{a}}(t) = -4.0\,\hat{\mathbf{j}}$

(b) 8.54 m s^{-1}, 70° with *x*-axis.

4.21 (a) 2 s, 24 m, 21.26 m s^{-1}

4.22 $\sqrt{2}$, 45° with the *x*-axis; $\sqrt{2}$, – 45° with the *x* - axis, $\left(5/\sqrt{2},\ -1/\sqrt{2}\right)$.

4.23 (b) and (e)

4.24 Only (e) is true

4.25 182 m s^{-1}

4.27 No. Rotations in *general* cannot be associated with vectors

4.28 A vector can be associated with a plane area

4.29 No

4.30 At an angle of $\sin^{-1}(1/3) = 19.5°$ with the vertical; 16 km.

4.31 0.86 m s^{-2}, 54.5° with the direction of velocity

Chapter 5

5.1 (a) to (d) No net force according to the First Law
(e) No force, since it is far away from all material agencies producing electromagnetic and gravitational forces.

5.2 The only force in each case is the force of gravity, (neglecting effects of air) equal to 0.5 N vertically downward. The answers do not change, even if the motion of the pebble is not along the vertical. The pebble is not at rest at the highest point. It has a constant horizontal component of velocity throughout its motion.

5.3 (a) 1 N vertically downwards (b) same as in (a)
(c) same as in (a); force at an instant depends on the situation at that instant, not on history.
(d) 0.1 N in the direction of motion of the train.

5.4 (i) T

5.5 $a = -2.5$ m s^{-2}. Using $v = u + at$, $0 = 15 - 2.5\,t$ i.e., $t = 6.0$ s

5.6 $a = 1.5/25 = 0.06$ m s^{-2}

$F = 3 \times 0.06 = 0.18$ N in the direction of motion.

5.7 Resultant force = 10 N at an angle of $\tan^{-1}(3/4) = 37°$ with the direction of 8 N force.
Acceleration = 2 m s^{-2} in the direction of the resultant force.

5.8 $a = -2.5$ m s^{-2}, Retarding force = 465 × 2.5 = 1.2 × 10^3 N

5.9 $F - 20{,}000 \times 10 = 20000 \times 5.0$, i.e., $F = 3.0 \times 10^5$ N

5.10 $a = -20$ m s^{-2} $0 \le t \le 30$ s

$t = -5$ s : $x = u\,t = -\,10 \times 5 = -50$ m

$t = 25$ s : $x = u\,t + (½)\ a\,t^2 = (10 \times 25 - 10 \times 625)$m $= -\,6$ km

$t = 100$ s : First consider motion up to 30 s

$x_1 = 10 \times 30 - 10 \times 900 = -\,8700$ m

At $t = 30$ s, $v = 10 - 20 \times 30 = -590$ m s^{-1}

For motion from 30 s to 100 s : $x_2 = -\,590 \times 70 = -\,41300$ m

$x = x_1 + x_2 = -\,50$ km

5.11 (a) Velocity of car (at $t = 10$ s) $= 0 + 2 \times 10 = 20$ m s^{-1}

By the First Law, the horizontal component of velocity is 20 m s^{-1} throughout.
Vertical component of velocity (at $t = 11$s) $= 0 + 10 \times 1 = 10$ m s^{-1}

Velocity of stone (at $t = 11$s) $= \sqrt{20^2 + 10^2} = \sqrt{500} = 22.4$ m s^{-1} at an angle of $\tan^{-1}$ (½) with the horizontal.

(b) 10 m s^{-2} vertically downwards.

5.12 (a) At the extreme position, the speed of the bob is zero. If the string is cut, it will fall vertically downwards.

(b) At the mean position, the bob has a horizontal velocity. If the string is cut, it will fall along a parabolic path.

5.13 The reading on the scale is a measure of the force on the floor by the man. By the Third Law, this is equal and opposite to the normal force N on the man by the floor.

(a) $N = 70 \times 10 = 700$ N ; Reading is 70 kg
(b) $70 \times 10 - N = 70 \times 5$; Reading is 35 kg
(c) $N - 70 \times 10 = 70 \times 5$; Reading is 105 kg
(d) $70 \times 10 - N = 70 \times 10$; Reading would be zero; the scale would read zero.

5.14 (a) In all the three intervals, acceleration and, therefore, force are zero.
(b) 3 kg m s^{-1} at $t = 0$; (c) -3 kg m s^{-1} at $t = 4$ s.

5.15 If the 20 kg mass is pulled,

$600 - T = 20\,a$, $T = 10\,a$

$a = 20$ m s^{-2}, $T = 200$ N

If the 10 kg mass is pulled, a = 20 m s^{-2}, $T = 400$ N

5.16 $T - 8 \times 10 = 8\,a, 12 \times 10 - T = 12a$
i.e. $a = 2$ m s^{-2}, $T = 96$ N

5.17 By momentum conservation principle, total final momentum is zero. Two momentum vectors cannot sum to a null momentum unless they are equal and opposite.

5.18 Impulse on each ball = $0.05 \times 12 = 0.6$ kg m s^{-1} in magnitude. The two impulses are opposite in direction.

5.19 Use momentum conservation : $100\ v = 0.02 \times 80$
$v = 0.016$ m s^{-1} = 1.6 cm s^{-1}

5.20 Impulse is directed along the bisector of the initial and final directions. Its magnitude is $0.15 \times 2 \times 15 \times \cos 22.5° = 4.2$ kg m s^{-1}

5.21 $$v = 2\pi \times 1.5 \times \frac{40}{60} = 2\pi \,\text{m s}^{-1}$$

$$T = \frac{mv^2}{R} = \frac{0.25 \times 4\pi^2}{1.5} = 6.6\,\text{N}$$

$$200 = \frac{mv_{max}^2}{R}, \text{ which gives } v_{max} = 35 \text{ m s}^{-1}$$

5.22 Alternative (b) is correct, according to the First Law

5.23 (a) The horse-cart system has no external force in empty space. The mutual forces between the horse and the cart cancel (Third Law). On the ground, the contact force between the system and the ground (friction) causes their motion from rest.

(b) Due to inertia of the body not directly in contact with the seat.

(c) A lawn mower is pulled or pushed by applying force at an angle. When you push, the normal force (N) must be more than its weight, for equilibrium in the vertical direction. This results in greater friction f ($f \propto N$) and, therefore, a greater applied force to move. Just the opposite happens while pulling.

(d) To reduce the rate of change of momentum and hence to reduce the force necessary to stop the ball.

5.24 A body with a constant speed of 1 cm s^{-1} receives impulse of magnitude 0.04 kg × 0.02 m s^{-1} = 8×10^{-4} kg m s^{-1} after every 2 s from the walls at $x = 0$ and $x = 2$ cm.

5.25 Net force = 65 kg × 1 m s^{-2} = 65 N

$a_{max} = \mu_s g = 2 \text{ m s}^{-2}$

5.26 Alternative (a) is correct. Note $mg + T_2 = m\boldsymbol{v}_2^2/\text{R}$; $T_1 - mg = m\boldsymbol{v}_1^2/\text{R}$

The moral is : do not confuse the actual material forces on a body (tension, gravitational force, etc) with the effects they produce : centripetal acceleration $\boldsymbol{v}_2^2/\text{R}$ or $\boldsymbol{v}_1^2/\text{R}$ in this example.

5.27 (a) 'Free body' : crew and passengers

Force on the system by the floor = F upwards; weight of system = mg downwards;

$\therefore F - mg = ma$

$F - 300 \times 10 = 300 \times 15$

$F = 7.5 \times 10^3$ N upward

By the Third Law, force on the floor by the crew and passengers = 7.5×10^3 N downwards.

(b) 'Free body' : helicopter plus the crew and passengers

Force by air on the system = R upwards; weight of system = mg downwards

$\therefore R - mg = ma$

$R - 1300 \times 10 = 1300 \times 15$

$R = 3.25 \times 10^4$ N upwards

By the Third Law, force (action) on the air by the helicopter = 3.25×10^4 N downwards.

(c) 3.25×10^4 N upwards

5.28 Mass of water hitting the wall per second

$= 10^3 \text{ kg m}^{-3} \times 10^{-2} \text{ m}^2 \times 15 \text{ m s}^{-1} = 150 \text{ kg s}^{-1}$

Force by the wall = momentum loss of water per second = 150 kg s^{-1} × 15 m s^{-1} = 2.25 × 10^3 N

5.29 (a) 3 $m\,g$ (down) (b) 3 $m\,g$ (down) (c) 4 $m\,g$ (up)

5.30 If N is the normal force on the wings,

$$N\cos\theta = mg, \qquad N\sin\theta = \frac{mv^2}{R}$$

which give $R = \dfrac{v^2}{g \tan\theta} = \dfrac{200\times200}{10\times\tan15°} = 15\text{km}$

5.31 The centripetal force is provided by the lateral thrust by the rail on the flanges of the wheels. By the Third Law, the train exerts an equal and opposite thrust on the rail causing its wear and tear.

Angle of banking = $\tan^{-1}\left(\dfrac{v^2}{R\,g}\right) = \tan^{-1}\left(\dfrac{15\times15}{30\times10}\right) \simeq 37°$

5.32 Consider the forces on the man in equilibrium : his weight, force due to the rope and normal force due to the floor.

(a) 750 N (b) 250 N; mode (b) should be adopted.

5.33 (a) $T - 400 = 240$, $T = 640$ N

(b) $400 - T = 160$, $T = 240$ N

(c) $T = 400$ N

(d) $T = 0$

The rope will break in case (a).

5.34 We assume perfect contact between bodies A and B and the rigid partition. In that case, the self-adjusting normal force on B by the partition (reaction) equals 200 N. There is no impending motion and no friction. The action-reaction forces between A and B are also 200 N. When the partition is removed, kinetic friction comes into play.

Acceleration of A + B = [200 – (150 × 0.15)] / 15 =11.8 m s^{-2}

Friction on A = 0.15 × 50 = 7.5 N

200 – 7.5 – F_{AB} = 5 × 11.8

F_{AB} = 1.3 × 10^2 N; opposite to motion .

F_{BA} = 1.3 × 10^2 N; in the direction of motion.

5.35 (a) Maximum frictional force possible for opposing impending relative motion between the block and the trolley = 150 × 0.18 = 27 N, which is more than the frictional force of 15 × 0.5 = 7.5 N needed to accelerate the box with the trolley. When the trolley moves with uniform velocity, there is no force of friction acting on the block.

(b) For the accelerated (non-inertial) observer, frictional force is opposed by the pseudo-force of the same magnitude, keeping the box at rest relative to the observer. When the trolley moves with uniform velocity there is no pseudo-force for the moving (inertial) observer and no friction.

5.36 Acceleration of the box due to friction = μg = 0.15 × 10 = 1.5 m s^{-2}. But the acceleration of the truck is greater. The acceleration of the box relative to the truck is 0.5 m s^{-2} towards the rear end. The time taken for the box to fall off the truck = $\sqrt{\dfrac{2\times5}{0.5}} = \sqrt{20}$ s .

During this time, the truck covers a distance = ½ × 2 × 20 = 20 m.

5.37 For the coin to revolve with the disc, the force of friction should be enough to provide the necessary centripetal force, i.e $\frac{mv^2}{r} \leq \mu m g$. Now $v = r\omega$, where $\omega = \frac{2\pi}{T}$ is the angular frequency of the disc. For a given μ and ω, the condition is $r \leq \mu g / \omega^2$. The condition is satisfied by the nearer coin (4 cm from the centre).

5.38 At the uppermost point, $N + mg = \frac{mv^2}{R}$, where N is the normal force (downwards) on the motorcyclist by the ceiling of the chamber. The minimum possible speed at the uppermost point corresponds to $N = 0$.

i.e. $v_{\min} = \sqrt{R g} = \sqrt{25 \times 10} = 16 \, \text{m s}^{-1}$

5.39 The horizontal force N by the wall on the man provides the needed centripetal force : $N = m R \omega^2$. The frictional force f (vertically upwards) opposes the weight mg. The man remains stuck to the wall after the floor is removed if $mg = f < \mu N$ i.e. $mg < \mu m R \omega^2$. The minimum angular speed of rotation of the cylinder is $\omega_{min} = \sqrt{g / \mu R} = 5 \, \text{s}^{-1}$

5.40 Consider the free-body diagram of the bead when the radius vector joining the centre of the wire makes an angle θ with the vertical downward direction. We have $mg = N \cos\theta$ and $m R \sin\theta \; \omega^2 = N \sin\theta$. These equations give $\cos\theta = g/R\omega^2$. Since $\cos\theta \leq 1$, the bead remains at its lowermost point for $\omega \leq \sqrt{\frac{g}{R}}$.

For $\omega = \sqrt{\frac{2g}{R}}$, $\cos\theta = \frac{1}{2}$ i.e. $\theta = 60^0$.

Chapter 6

6.1 (a) +ve (b) –ve (c) –ve (d) + ve (e) – ve

6.2 (a) 882 J ; (b) –247 J; (c) 635 J ; (d) 635 J;
Work done by the net force on a body equals change in its kinetic energy.

6.3 (a) $x > a$; 0 (c) $x < a$, $x > b$; $-V_1$
(b) $-\infty < x < \infty$; V_1 (d) $-b/2 < x < -a/2$, $a/2 < x < b/2$; $-V_1$

6.5 (a) rocket; (b) For a conservative force work done over a path is minus of change in potential energy. Over a complete orbit, there is no change in potential energy; (c) K.E. increases, but P.E. decreases, and the sum decreases due to dissipation against friction; (d) in the second case.

6.6 (a) decrease; (b) kinetic energy; (c) external force; (d) total linear momentum, and also total energy (if the system of two bodies is isolated).

6.7 (a) F ; (b) F ; (c) F ; (d) F (true usually but not always, why?)

6.8 (a) No
(b) Yes
(c) Linear momentum is conserved during an inelastic collision, kinetic energy is, of course, not conserved even after the collision is over.
(d) elastic.

6.9 (b) t

6.10 (c) $t^{3/2}$

6.11 12 J

6.12 The electron is faster, $v_e / v_p = 13.5$

6.13 0.082 J in each half ; – 0.163 J

6.14 Yes, momentum of the molecule + wall system is conserved. The wall has a recoil momentum such that the momentum of the wall + momentum of the outgoing molecule equals momentum of the incoming molecule, assuming the wall to be stationary initially. However, the recoil momentum produces negligible velocity because of the large mass of the wall. Since kinetic energy is also conserved, the collision is elastic.

6.15 43.6 kW

6.16 (b)

6.17 It transfers its entire momentum to the ball on the table, and does not rise at all.

6.18 5.3 m s^{-1}

6.19 27 km h^{-1} (no change in speed)

6.20 50 J

6.21 (a) $m = \rho A v t$ (b) $K = \rho A v^3 t/2$ (c) $P = 4.5$ kW

6.22 (a) 49,000 J (b) 6.45 10^{-3} kg

6.23 (a) 200 m^2(b) comparable to the roof of a large house of dimension 14m × 14m.

6.24 21.2 cm, 28.5 J

6.25 No, the stone on the steep plane reaches the bottom earlier; yes, they reach with the same speed v, [since $mgh = (1/2)\, m v^2$]

$v_B = v_C = 14.1 \text{ m s}^{-1}$, $t_B = 2\sqrt{2}$ s , $t_C = 2\sqrt{2}$ s

6.26 0.125

6.27 8.82 J for both cases.

6.28 The child gives an impulse to the trolley at the start and then runs with a constant relative velocity of 4 m s^{-1} with respect to the trolley's new velocity. Apply momentum conservation for an observer outside. 10.36 m s^{-1}, 25.9 m.

6.29 All except (V) are impossible.

Chapter 7

7.1 The geometrical centre of each. No, the CM may lie outside the body, as in case of a ring, a hollow sphere, a hollow cylinder, a hollow cube etc.

7.2 Located on the line joining H and C1 nuclei at a distance of 1.24 Å from the H end.

7.3 The speed of the CM of the (trolley + child) system remains unchanged (equal to v) because no external force acts on the system. The forces involved in running on the trolley are internal to this system.

7.6 $l_z = xp_y - yp_x$, $l_x = yp_z - zp_y$, $l_y = zp_x - xp_z$

7.8 72 cm

7.9 3675 N on each front wheel, 5145 N on each back wheel.

7.10 (a) 7/5 MR^2 (b) 3/2 MR^2

7.11 Sphere

7.12 Kinetic Energy = 3125 J; Angular Momentum = 62.5 J s

7.13 (a) 100 rev/min (use angular momentum conservation).

(b) The new kinetic energy is 2.5 times the initial kinetic energy of rotation. The child uses his internal energy to increase his rotational kinetic energy.

7.14 25 s^{-2}; 10 m s^{-2}

7.15 36 kW

7.16 at R/6 from the center of original disc opposite to the center of cut portion.

7.17 66.0 g

7.18 (a) Yes; (b) Yes, (c) the plane with smaller inclination ($\because a \propto \sin\theta$)

7.19 4J

7.20 6.75×10^{12} rad s^{-1}

7.21 (a) 3.8 m (b) 3.0 s

7.22 Tension = 98 N, N_B = 245 N, N_C = 147 N.

7.23 (a) 59 rev/min, (b) No, the K.E. is increased and it comes from work done by man in the process.

7.24 0.625 rad s^{-1}

7.27 (a) By angular momentum conservation, the common angular speed

$\omega = (I_1\,\omega_1 + I_2\,\omega_2) \;/\; (I_1 + I_2)$

(b) The loss is due to energy dissipation in frictional contact which brings the two discs to a common angular speed ω. However, since frictional torques are internal to the system, angular momentum is unaltered.

7.28 Velocity of A $= \omega_o R$ in the same direction as the arrow; velocity of B $= \omega_o R$ in the opposite direction to the arrow; velocity of C $= \omega_o R/2$ in the same direction as the arrow. The disc will not roll on a frictionless plane.

7.29 (a) Frictional force at B opposes velocity of B. Therefore, frictional force is in the same direction as the arrow. The sense of frictional torque is such as to oppose angular motion. $\boldsymbol{\omega}_o$ and $\boldsymbol{\tau}$ are both normal to the paper, the first into the paper, and the second coming out of the paper.

(b) Frictional force decreases the velocity of the point of contact B. Perfect rolling ensues when this velocity is zero. Once this is so, the force of friction is zero.

7.30 Frictional force causes the CM to accelerate from its initial zero velocity. Frictional torque causes retardation in the initial angular speed ω_o. The equations of motion are : $\mu_k\, m g = m a$ and $\mu_k\, m g R = -I\alpha$, which yield $v = \mu_k\, g\, t$, $\omega = \omega_o - \mu_k\, m g R\, t / I$. Rolling begins when $v = R\,\omega$. For a ring, $I = m R^2$, and rolling begins at $t = \omega_o\, R/2\,\mu_k\, g$. For a disc, $I = ½\, m R^2$ and rolling starts at break line $t = R\,\omega_o/3\,\mu_k\, g$. Thus, the disc begins to roll earlier than the ring, for the same R and ω_o. The actual times can be obtained for R = 10 cm, $\omega_o = 10\,\pi$ rad s^{-1}, $\mu_k = 0.2$

7.31 (a) 16.4 N

(b) Zero

(c) 37° approx.

Chapter 8

8.1 (a) No.

(b) Yes, if the size of the space ship is large enough for him to detect the variation in g.

(c) Tidal effect depends inversely on the cube of the distance unlike force, which depends inversely on the square of the distance.

8.2 (a) decreases; (b) decreases; (c) mass of the body; (d) more.

8.3 Smaller by a factor of 0.63.

8.5 3.54×10^8 years.

8.6 (a) Kinetic energy, (b) less,

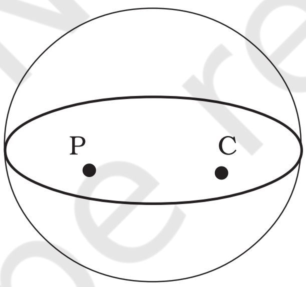
8.7 (a) No, (b) No, (c) No, (d) Yes

[The escape velocity is independent of mass of the body and the direction of projection. It depends upon the gravitational potential at the point from where the body is launched. Since this potential depends (slightly) on the latitude and height of the point, the escape velocity (speed) depends (slightly) on these factors.]

8.8 All quantities vary over an orbit except angular momentum and total energy.

8.9 (b), (c) and (d)

8.10 and **8.11** For these two problems, complete the hemisphere to sphere. At both P, and C, potential is constant and hence intensity = 0. Therefore, for the hemisphere, (c) and (e) are correct.



8.12 2.6×10^8 m

8.13 2.0×10^{30} kg

8.14 1.43×10^{12} m

8.15 28 N

8.16 125 N

8.17 8.0×10^6 m from the earth's centre

8.18 31.7 km/s

8.19 5.9×10^9 J

8.20 2.6×10^6 m/s

8.21 0, 2.7×10^{-8} J/kg; an object placed at the mid point is in an unstable equilibrium

8.22 -9.4×10^6 J/kg

8.23 $GM / R^2 = 2.3 \times 10^{12}$ m s^{-2} , $\omega^2 R = 1.1 \times 10^6$ m s^{-2}; here ω is the angular speed of rotation. Thus in the rotating frame of the star, the inward force is much greater than the outward centrifugal force at its equator. The object will remain stuck (and not fly off due to centrifugal force). Note, if angular speed of rotation increases say by a factor of 2000, the object will fly off.

8.24 3×10^{11} J

8.25 495 km