

# Contents

<b>1 Composition and Resolution of Vectors</b>		<b>5 Newton's Second Law. Gravitation</b>	
1-1	The fundamental indefinables of mechanics . . . . .	1	5-1 Introduction . . . . .
1-2	Standards and units . . . . .	1	5-2 Newton's second law. Mass . . . . .
1-3	Symbols for physical quantities . . . . .	3	5-3 Systems of units . . . . .
1-4	Force . . . . .	4	5-4 Newton's law of universal gravitation . . . . .
1-5	Graphical representation of forces. Vectors . . . . .	4	5-5 Mass and weight . . . . .
1-6	Vector addition. Resultant of a set of forces . . . . .	5	5-6 Applications of Newton's second law . . . . .
1-7	Components of a vector . . . . .	8	
1-8	Resultant by rectangular resolution . . . . .	9	
1-9	Vector difference . . . . .	10	
<b>2 Equilibrium of a Particle</b>		<b>6 Motion in a Plane</b>	
2-1	Introduction . . . . .	13	6-1 Motion in a plane . . . . .
2-2	Equilibrium. Newton's first law . . . . .	13	6-2 Average and instantaneous velocity . . . . .
2-3	Discussion of Newton's first law of motion . . . . .	15	6-3 Average and instantaneous acceleration . . . . .
2-4	Stable, unstable, and neutral equilibrium . . . . .	16	6-4 Components of acceleration . . . . .
2-5	Newton's third law of motion . . . . .	16	6-5 Motion of a projectile . . . . .
2-6	Equilibrium of a particle . . . . .	17	6-6 Circular motion . . . . .
2-7	Friction . . . . .	23	6-7 Centripetal force . . . . .
<b>3 Equilibrium. Moment of a Force</b>		6-8 Motion in a vertical circle . . . . .	
3-1	Moment of a force . . . . .	30	6-9 Motion of a satellite . . . . .
3-2	The second condition of equilibrium . . . . .	31	6-10 Effect of the earth's rotation on $g$ . . . . .
3-3	Resultant of parallel forces . . . . .	33	
3-4	Center of gravity . . . . .	34	
3-5	Couples . . . . .	35	
<b>4 Rectilinear Motion</b>		<b>7 Work and Energy</b>	
4-1	Motion . . . . .	41	7-1 Introduction . . . . .
4-2	Average velocity . . . . .	41	7-2 Work . . . . .
4-3	Instantaneous velocity . . . . .	42	7-3 Kinetic energy . . . . .
4-4	Average and instantaneous acceleration . . . . .	43	7-4 Gravitational potential energy . . . . .
4-5	Rectilinear motion with constant acceleration . . . . .	44	7-5 Elastic potential energy . . . . .
4-6	Velocity and coordinate by integration . . . . .	46	7-6 Conservative and dissipative forces . . . . .
4-7	Freely falling bodies . . . . .	48	7-7 Internal work . . . . .
4-8	Rectilinear motion with variable acceleration . . . . .	50	7-8 Internal potential energy . . . . .
4-9	Velocity components. Relative velocity . . . . .	51	7-9 Power . . . . .
			7-10 Power and velocity . . . . .
			7-11 Mass and energy . . . . .
			<b>8 Impulse and Momentum</b>
			8-1 Impulse and momentum . . . . .
			8-2 Conservation of linear momentum . . . . .
			8-3 Elastic and inelastic collisions . . . . .

8-4	Inelastic collisions . . . . .	119	13-3	Pressure difference across a surface film . . . . .	190
8-5	Elastic collisions . . . . .	120	13-4	Minimal surfaces . . . . .	192
8-6	Recoil . . . . .	121	13-5	Contact angle . . . . .	193
8-7	Principles of rocket propulsion . . . . .	123	13-6	Capillarity . . . . .	195
<b>9 Rotation</b>					
9-1	Introduction . . . . .	128	<b>14 Hydrodynamics and Viscosity</b>		
9-2	Angular velocity . . . . .	128	14-1	Introduction . . . . .	197
9-3	Angular acceleration . . . . .	129	14-2	The equation of continuity . . . . .	198
9-4	Rotation with constant angular acceleration . . . . .	130	14-3	Bernoulli's equation . . . . .	198
9-5	Relation between angular and linear velocity and acceleration . . . . .	130	14-4	Applications of Bernoulli's equation . . . . .	200
9-6	Torque and angular acceleration. Moment of inertia . . . . .	131	14-5	Viscosity . . . . .	204
9-7	Calculation of moments of inertia . . . . .	134	14-6	Poiseuille's law . . . . .	206
9-8	Kinetic energy, work, and power . . . . .	137	14-7	Stokes' law . . . . .	208
9-9	Angular momentum . . . . .	138	14-8	Reynolds number . . . . .	208
9-10	Rotation about a moving axis. The top and the gyroscope . . . . .	141	<b>15 Temperature-Expansion</b>		
<b>10 Elasticity</b>					
10-1	Stress . . . . .	151	15-1	Concept of temperature . . . . .	213
10-2	Strain . . . . .	153	15-2	Thermometers . . . . .	215
10-3	Elasticity and plasticity . . . . .	154	15-3	The establishment of a temperature scale . . . . .	217
10-4	Elastic modulus . . . . .	155	15-4	The Celsius, Rankine, and Fahrenheit scales . . . . .	219
10-5	The force constant . . . . .	157	15-5	Expansion of solids and liquids . . . . .	220
<b>11 Harmonic Motion</b>					
11-1	Introduction . . . . .	160	15-6	Thermal stresses . . . . .	222
11-2	Elastic restoring forces . . . . .	160	<b>16 Heat and Heat Measurements</b>		
11-3	Definitions . . . . .	160	16-1	Heat transfer . . . . .	225
11-4	Equations of simple harmonic motion . . . . .	161	16-2	Quantity of heat . . . . .	225
11-5	Motion of a body suspended from a coil spring . . . . .	166	16-3	Heat capacity . . . . .	228
11-6	The simple pendulum . . . . .	167	16-4	The measurement of heat capacity . . . . .	228
11-7	Lissajous figures . . . . .	168	16-5	Experimental values of heat capacities . . . . .	230
11-8	Angular harmonic motion . . . . .	170	16-6	Change of phase . . . . .	231
11-9	The physical pendulum . . . . .	170	<b>17 Transfer of Heat</b>		
11-10	Center of oscillation . . . . .	171	17-1	Conduction . . . . .	237
<b>12 Hydrostatics</b>					
12-1	Introduction . . . . .	176	17-2	Radial heat flow in a sphere or cylinder . . . . .	239
12-2	Pressure in a fluid . . . . .	176	17-3	Convection . . . . .	239
12-3	The hydrostatic paradox . . . . .	178	17-4	Radiation . . . . .	241
12-4	Pressure gauges . . . . .	178	17-5	Stefan's law . . . . .	242
12-5	Vacuum pumps . . . . .	179	17-6	The ideal radiator . . . . .	243
12-6	Archimedes' principle . . . . .	181	<b>18 Thermal Properties of Matter</b>		
12-7	Forces against a dam . . . . .	183	18-1	Equations of state . . . . .	246
<b>13 Surface Tension</b>					
13-1	Surface tension . . . . .	188	18-2	The ideal gas . . . . .	246
13-2	Surface tension and surface energy . . . . .	190	18-3	$pVT$ -surface for an ideal gas . . . . .	249
			18-4	$pVT$ -surface for a real substance . . . . .	249
			18-5	Critical point and triple point . . . . .	252
			18-6	Effect of dissolved substances on freezing and boiling points . . . . .	256
			18-7	Humidity . . . . .	256
			18-8	The Wilson cloud chamber and the bubble chamber . . . . .	257

<b>19 The Laws of Thermodynamics</b>			
19-1 Work in thermodynamics . . . . .	261	22-6 Interference of longitudinal waves . . . . .	313
19-2 Work in changing the volume . . . . .	261	22-7 Stationary longitudinal waves . . . . .	314
19-3 Heat depends on the path . . . . .	262	22-8 Vibrations of organ pipes . . . . .	315
19-4 The first law of thermodynamics . . . . .	263	22-9 Vibrations of rods and plates . . . . .	316
19-5 Adiabatic process . . . . .	264	<b>23 Acoustical Phenomena</b>	
19-6 Isochoric process . . . . .	264	23-1 Pressure variations in a sound wave . . . . .	319
19-7 Isothermal process . . . . .	265	23-2 Intensity . . . . .	319
19-8 Isobaric process . . . . .	265	23-3 Intensity level and loudness . . . . .	320
19-9 Throttling process . . . . .	265	23-4 Quality and pitch . . . . .	321
19-10 Differential form of the first law . . . . .	266	23-5 Spherical waves . . . . .	322
19-11 Internal energy of a gas . . . . .	266	23-6 Radiation from a piston. Diffraction . . . . .	323
19-12 Heat capacities of an ideal gas . . . . .	267	23-7 Radiating efficiency of a sound source . . . . .	325
19-13 Adiabatic process of an ideal gas . . . . .	269	23-8 Beats . . . . .	326
19-14 The conversion of heat into work . . . . .	270	23-9 The Doppler effect . . . . .	327
19-15 The gasoline engine . . . . .	272	<b>24 Coulomb's Law</b>	
19-16 The Diesel engine . . . . .	273	24-1 Electric charges . . . . .	331
19-17 The steam engine . . . . .	273	24-2 Atomic structure . . . . .	332
19-18 The second law of thermodynamics . . . . .	274	24-3 The leaf electroscope and the electrometer . . . . .	333
19-19 The refrigerator . . . . .	275	24-4 Conductors and insulators . . . . .	334
19-20 The Carnot cycle . . . . .	276	24-5 Charging by induction . . . . .	334
19-21 The Kelvin temperature scale . . . . .	277	24-6 Coulomb's law . . . . .	336
19-22 Absolute zero . . . . .	278	<b>25 The Electric Field. Gauss's Law</b>	
19-23 Entropy . . . . .	278	25-1 The electric field . . . . .	339
<b>20 Molecular Properties of Matter</b>		25-2 Calculation of electric intensity . . . . .	341
20-1 Molecular theory of matter . . . . .	284	25-3 Lines of force . . . . .	345
20-2 Avogadro's number . . . . .	286	25-4 Gauss's law . . . . .	346
20-3 Equation of state of an ideal gas . . . . .	287	25-5 Applications of Gauss's law . . . . .	349
20-4 Molar heat capacity of a gas . . . . .	290	<b>26 Potential</b>	
20-5 Experimental measurement of molecular speeds . . . . .	291	26-1 Line integral of electric intensity . . . . .	358
20-6 Crystals . . . . .	292	26-2 Electrical potential energy . . . . .	359
20-7 Heat capacity of a crystal . . . . .	294	26-3 Potential . . . . .	360
<b>21 Traveling Waves</b>		26-4 Calculation of potential differences . . . . .	360
21-1 Introduction . . . . .	297	26-5 Potential in terms of charge distribution . . . . .	363
21-2 Mathematical representation of a traveling wave . . . . .	298	26-6 Potential gradient . . . . .	364
21-3 Calculation of the speed of a transverse pulse . . . . .	300	26-7 The Millikan oil drop experiment . . . . .	365
21-4 Calculation of the speed of a longitudinal pulse . . . . .	302	26-8 The electron volt. Relativistic variation of mass with velocity . . . . .	367
21-5 Adiabatic character of a longitudinal wave . . . . .	302	26-9 The cathode-ray oscilloscope . . . . .	368
21-6 Waves in a canal . . . . .	304	26-10 Sharing of charge by conductors . . . . .	370
<b>22 Vibrating Bodies</b>		26-11 The Van de Graaff generator . . . . .	371
22-1 Boundary conditions for a string . . . . .	308	<b>27 Capacitance. Properties of Dielectrics</b>	
22-2 Stationary waves in a string . . . . .	310	27-1 Capacitors . . . . .	375
22-3 Vibration of a string fixed at both ends . . . . .	311	27-2 The parallel-plate capacitor . . . . .	375
22-4 Demonstration of the harmonic series in a vibrating string . . . . .	312	27-3 Capacitors in series and parallel . . . . .	376
22-5 Resonance . . . . .	313	27-4 Energy of a charged capacitor . . . . .	378
		27-5 Effect of a dielectric . . . . .	379

27-6	Molecular theory of induced charges on a dielectric . . . . .	380		
27-7	Polarization and displacement . . . . .	382		
27-8	Susceptibility, dielectric coefficient, and permittivity . . . . .	383		
<b>28 Current, Resistance, and Electromotive Force</b>				
28-1	Current . . . . .	388		
28-2	Resistivity . . . . .	390		
28-3	Theory of metallic conduction . . . . .	391		
28-4	Resistance . . . . .	392		
28-5	Electromotive force . . . . .	393		
28-6	Current voltage diagrams . . . . .	399		
28-7	Work and power in electrical circuits . . . . .	400		
28-8	Thermoelectricity . . . . .	403		
28-9	Applications of the fundamental thermocouple equation . . . . .	404		
28-10	The electric field of the earth . . . . .	406		
<b>29 Direct-Current Circuits and Instruments</b>				
29-1	Resistors in series and in parallel . . . . .	410		
29-2	Kirchhoff's rules . . . . .	412		
29-3	Ammeters and voltmeters . . . . .	413		
29-4	The Wheatstone bridge . . . . .	415		
29-5	The ohmmeter . . . . .	416		
29-6	The potentiometer . . . . .	416		
29-7	The <i>R-C</i> series circuit . . . . .	417		
29-8	Displacement current . . . . .	419		
<b>30 The Magnetic Field</b>				
30-1	Magnetism . . . . .	425		
30-2	The magnetic field induction . . . . .	426		
30-3	Lines of induction. Magnetic flux . . . . .	427		
30-4	Orbits of charged particles in magnetic fields . . . . .	428		
30-5	Thomson's measurement of <i>e/m</i> . . . . .	430		
30-6	Positive rays . . . . .	431		
30-7	Isotopes . . . . .	433		
30-8	Mass spectroscopy . . . . .	434		
30-9	Atomic weights. The atomic mass unit . . . . .	435		
30-10	The cyclotron . . . . .	435		
<b>31 Magnetic Forces on Current-Carrying Conductors</b>				
31-1	Force on a current-carrying conductor . . . . .	439		
31-2	The Hall effect . . . . .	439		
31-3	Force and torque on a complete circuit. Magnetic moment . . . . .	440		
31-4	The spinning electron . . . . .	442		
31-5	The galvanometer . . . . .	443		
31-6	The pivoted-coil galvanometer . . . . .	444		
31-7	The ballistic galvanometer . . . . .	444		
31-8	The direct-current motor . . . . .	445		
31-9	The electromagnetic pump . . . . .	445		
<b>32 Magnetic Field of a Current</b>				
32-1	Magnetic field of a moving point charge . . . . .	449		
32-2	Magnetic field of a current element. The Biot law . . . . .	450		
32-3	Magnetic field of a long straight conductor . . . . .	451		
32-4	Force between parallel conductors. The ampere and the coulomb . . . . .	452		
32-5	Magnetic field of a circular turn . . . . .	453		
32-6	Ampère's law . . . . .	455		
32-7	Applications of Ampère's law . . . . .	456		
32-8	Magnetic fields and displacement currents . . . . .	458		
<b>33 Induced Electromotive Force</b>				
33-1	Motional electromotive force . . . . .	463		
33-2	The search coil . . . . .	466		
33-3	Galvanometer damping . . . . .	467		
33-4	Induced electric fields . . . . .	468		
33-5	Lenz's law . . . . .	471		
33-6	The betatron . . . . .	471		
33-7	Eddy currents . . . . .	473		
33-8	Mutual inductance . . . . .	474		
33-9	Self-inductance . . . . .	475		
33-10	Energy associated with an inductor . . . . .	476		
33-11	The <i>R-L</i> circuit . . . . .	477		
33-12	The <i>L-C</i> circuit . . . . .	478		
33-13	The <i>R-L-C</i> circuit . . . . .	479		
<b>34 Magnetic Properties of Matter</b>				
34-1	Equivalent surface currents . . . . .	486		
34-2	Molecular theory of dia- and paramagnetism . . . . .	487		
34-3	Magnetization and magnetic intensity . . . . .	488		
34-4	Magnetic susceptibility, permeability, and magnetic coefficient . . . . .	489		
34-5	Ferromagnetism . . . . .	490		
34-6	Magnetization of iron. Magnetic domains . . . . .	492		
34-7	Hysteresis . . . . .	493		
34-8	Magnetic poles . . . . .	495		
34-9	Demagnetizing fields . . . . .	497		
34-10	The magnetic field of the earth . . . . .	498		
34-11	The magnetic circuit . . . . .	499		
<b>35 Alternating Currents</b>				
35-1	Introduction . . . . .	503		
35-2	Circuits containing resistance, inductance, or capacitance . . . . .	503		
35-3	The <i>R-L-C</i> series circuit . . . . .	506		
35-4	Average and root-mean-square values. AC instruments . . . . .	508		
35-5	Power in AC circuits . . . . .	510		
35-6	Series resonance . . . . .	511		
35-7	Circuits in parallel . . . . .	513		
35-8	The transformer . . . . .	513		

<b>36 Electromagnetic Waves</b>			
36-1 Introduction . . . . .	518	40-10 The magnifier . . . . .	583
36-2 Speed of an electromagnetic wave . . . . .	518	40-11 The camera . . . . .	584
36-3 The Poynting vector . . . . .	521	40-12 The projection lantern . . . . .	585
36-4 Electromagnetic waves in matter . . . . .	522	40-13 The microscope . . . . .	586
36-5 Traveling waves on a transmission line . . . . .	523	40-14 The telescope . . . . .	587
36-6 Stationary waves . . . . .	524		
36-7 Radiation of electromagnetic waves from an antenna . . . . .	526	<b>41 Interference and Diffraction</b>	
36-8 Electromagnetic waves in free space . . . . .	527	41-1 Principles of interference. Mutually coherent sources . . . . .	592
36-9 Maxwell's equations . . . . .	529	41-2 Young's double slit and Pohl's mica sheet . . . . .	594
		41-3 Intensity distribution in interference fringes . . . . .	598
<b>37 The Nature and Propagation of Light</b>		41-4 Phase change in reflection. Lloyd's mirror . . . . .	599
37-1 The nature of light . . . . .	533	41-5 Interference in thin films. Newton's rings . . . . .	600
37-2 Sources of light . . . . .	534	41-6 Thin coatings on glass . . . . .	602
37-3 Waves, wavefronts, and rays . . . . .	536	41-7 Energy conservation in interference . . . . .	603
37-4 The speed of light . . . . .	538	41-8 The Michelson interferometer . . . . .	604
37-5 The laws of reflection and refraction . . . . .	539	41-9 The Michelson-Morley experiment . . . . .	606
37-6 Index of refraction . . . . .	541	41-10 Fresnel diffraction . . . . .	608
		41-11 Fraunhofer diffraction by a single slit . . . . .	611
<b>38 Reflection and Refraction at Plane Surfaces</b>		41-12 The plane diffraction grating . . . . .	614
38-1 Huygens' principle . . . . .	544	41-13 Diffraction of x-rays by a crystal . . . . .	616
38-2 Derivation of the law of reflection from Huygens' principle . . . . .	545	41-14 The resolving power of optical instruments . . . . .	617
38-3 Derivation of Snell's law from Huygens' principle . . . . .	546		
38-4 Total internal reflection . . . . .	548	<b>42 Polarization</b>	
38-5 Refraction by a prism . . . . .	549	42-1 Polarization . . . . .	622
38-6 Dispersion . . . . .	550	42-2 Polarization by reflection . . . . .	623
38-7 The rainbow . . . . .	551	42-3 Double refraction . . . . .	624
		42-4 Polarization by double refraction . . . . .	626
<b>39 Images Formed by a Single Reflection or Refraction</b>		42-5 Percentage polarization. Malus' law . . . . .	627
39-1 Introduction . . . . .	555	42-6 The scattering of light . . . . .	629
39-2 Reflection at a plane mirror . . . . .	555	42-7 Circular and elliptic polarization . . . . .	630
39-3 Reflection at a spherical mirror . . . . .	558	42-8 Production of colors by polarized light . . . . .	631
39-4 Focal point and focal length . . . . .	562	42-9 Optical stress analysis . . . . .	632
39-5 Graphical methods . . . . .	563	42-10 Study of crystals by convergent polarized light . . . . .	632
39-6 Refraction at a plane surface . . . . .	564	42-11 Optical activity . . . . .	634
39-7 Refraction at a spherical surface . . . . .	566		
39-8 Summary . . . . .	568	<b>43 Atoms, Electrons, and Photons</b>	
		43-1 Conduction in gases . . . . .	636
<b>40 Lenses and Optical Instruments</b>		42-2 Thermionic emission . . . . .	637
40-1 Images as objects . . . . .	572	43-3 The triode . . . . .	638
40-2 The thin lens . . . . .	573	43-4 The photoelectric effect . . . . .	639
40-3 Diverging lenses . . . . .	576	43-5 Line spectra . . . . .	641
40-4 Graphical methods . . . . .	577	43-6 The Bohr atom . . . . .	642
40-5 Images as objects for lenses . . . . .	578	43-7 Deuterium . . . . .	645
40-6 The newtonian form of the lens equation . . . . .	578	43-8 Wave mechanics . . . . .	646
40-7 Thick lenses . . . . .	580	43-9 The electron microscope . . . . .	647
40-8 Lens aberrations . . . . .	581	43-10 Absorption spectra . . . . .	648
40-9 The eye . . . . .	581	43-11 The laser . . . . .	650
		43-12 Band spectra . . . . .	651
		43-13 The x-ray tube . . . . .	652
		43-14 X-ray spectra . . . . .	653

<b>44 Radioactivity and Nuclear Physics</b>	
44-1 Natural radioactivity . . . . .	657
44-2 Alpha particles . . . . .	658
44-3 Rutherford's scattering experiment . . . . .	659
44-4 Beta particles . . . . .	660
44-5 Gamma rays . . . . .	661
44-6 Radioactive transformations . . . . .	661
44-7 Artificial nuclear disintegration . . . . .	664
44-8 Cosmic rays. The positron . . . . .	665
44-9 Neutrons and mesons . . . . .	666
44-10 Nuclear stability . . . . .	667
44-11 Nuclear fission . . . . .	668
44-12 Thermonuclear reactions . . . . .	670
<b>Answers to Odd-Numbered Problems</b>	<b>A-1</b>
<b>Natural trigonometric functions</b>	<b>T-1</b>
<b>Common logarithms</b>	<b>T-2</b>
<b>Periodic table of the elements</b>	<b>T-3</b>
<b>Fundamental constants</b>	<b>T-4</b>
<b>Conversion factors</b>	<b>T-5</b>
<b>Index</b>	<b>Index-1</b>