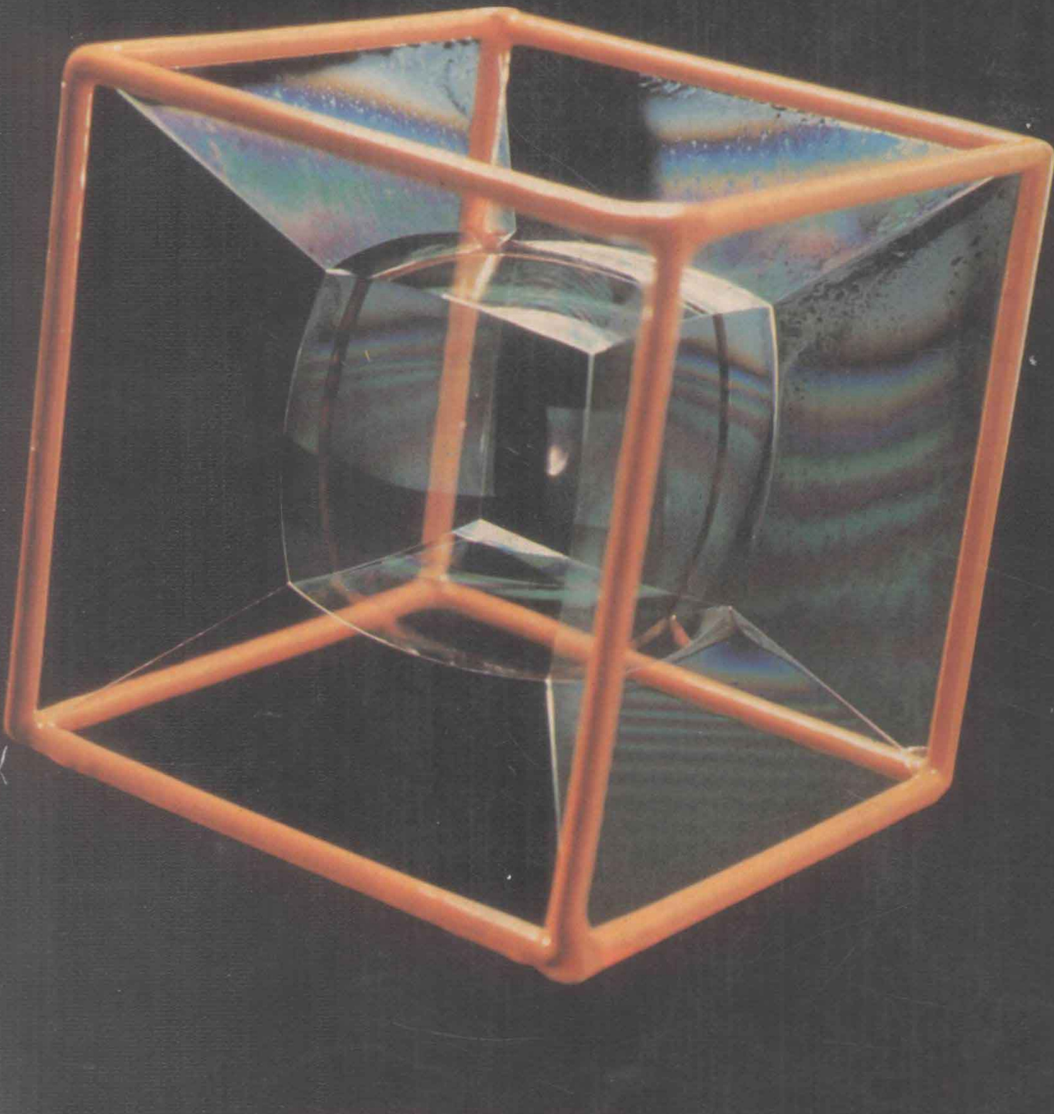
NELKON & PARKER

Advanced Level Physics



Fifth Edition

Advanced Level Physics

Fifth edition

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Books by M. Nelkon

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ADVANCED LEVEL PRACTICAL PHYSICS (*with J. Ogborn*)
SCHOLARSHIP PHYSICS
OPTICS, WAVES, SOUND
MECHANICS AND PROPERTIES OF MATTER
PRINCIPLES OF ATOMIC PHYSICS AND ELECTRONICS
REVISION NOTES IN PHYSICS
Book I. Mechanics, Electricity, Atomic Physics
Book II. Optics, Waves, Sound, Heat, Properties of Matter
GRADED EXERCISES AND WORKED EXAMPLES IN PHYSICS
(with Multiple Choice Questions)
NEW TEST PAPERS IN PHYSICS
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ELECTRICAL PRINCIPLES (*with H. I. Humphreys*)
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SOLUTIONS TO ADVANCED LEVEL PHYSICS QUESTIONS
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PRINCIPLES OF PHYSICS
EXERCISES IN ORDINARY LEVEL PHYSICS
C.S.E. PHYSICS

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ELECTRICITY

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HEAT

Books by P. Parker

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HEAT

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ELECTRONICS

Cover Photographs
(Front) A 'cubic' soap bubble trapped in a wire cube. (*Courtesy of Dr. C. Isenberg, Physics Laboratory, University of Kent*)
(Back) Two photographs of a decorated plate, one taken by reflected light at room temperature (left), the other by its own emitted light when incandescent at about 1100 K (right). (*Courtesy of the Worcester Royal Porcelain Company Limited and Tom Biro, FRSA, FSIAD*)

Preface to Fifth Edition

In this edition the text has been revised and updated to take account of the Advanced level syllabuses of the major Examining Boards, such as the London Advanced level syllabus and that of the Joint Matriculation Board. To assist the student more worked examples in all branches of physics have been added in illustration of the subject matter and more straightforward questions on basic principles have been added to many exercises. The examination questions in exercises have also been updated and graded and two new multiple-choice papers are provided.

Some of the more important text changes are briefly as follows:

(1) In *Mechanics*, the conservation of linear momentum has been given further prominence, the main dynamics sections are now followed by exercises, the rotational dynamics text has been revised, and statics and fluids are reduced in content but there are more exercises on Bernoulli's principle.

The *Properties and Matter* sections have been revised and reordered.

(2) In *Heat*, the section on real gases has been merged with that on vapours and some older matter deleted.

(3) *Geometrical Optics* has been reduced in content in accordance with syllabuses and the telescope section has been rewritten.

(4) *Waves and Optics* has been extended, with additions in the air wedge and diffraction grating topics and an account of the Michelson interferometer.

(5) *Electricity and Atomic Physics.* The sections on electric circuits, magnetic fields and force on conductor, electromagnetic induction, photoelectricity and parts of nuclear energy have been rewritten, and magnetic materials reduced in content.

I am very grateful to the following for their considerable assistance with preparation of the new edition: J. H. Avery, formerly Stockport Grammar School; M. V. Detheridge, William Ellis School, London; S. S. Alexander, formerly Woodhouse School and The Mount School for Girls, Mill Hill, London; and Dr. M. Crimes, Woodhouse School, London.

I am also considerably indebted to the following for their generous assistance with the Fourth Edition on which the new edition is based: Mrs. J. Pope, formerly Middlesex Polytechnic; C. F. Tolman, Whitgift School, Croydon; D. Deutsch, formerly Clare College, Cambridge; P. Betts, The Crossley and Porter School, Halifax; R. D. Harris, Ardingly College, Sussex; R. Croft, The City University; N. Phillips, Loughborough University; and Dr. L. S. Julien, University of Surrey. I am also indebted to Richard Gale and Trevor Hook of the publishers for their unfailing courtesy and expert advice.

Note to 1983 and 1984 Reprints

Further text has been added on the resolving power of a diffraction grating, on the transistor switch with a sine wave input and use as an amplifier, on the motion of a rider round a curve and on the helical path of electrons. I acknowledge with thanks permission by The Associated Examining Board to reproduce questions (AEB) in past Advanced level examinations, and notice of amendments by M. P. Preston, Lewes, and R. D. Harris, Ardingly College.

Preface to Fourth Edition

In this edition we have taken account of the revised syllabuses of the Examining Boards, including the new London Advanced level syllabus. Briefly, the main changes in the text are as follows:

Mechanics and Properties of Matter
(i) Gravitation now includes an account of the potential and kinetic energy of satellites. (ii) In molecular theory, the variation of potential energy with molecular separation has been amplified, and properties of solids deduced. (iii) An account of the various types of bonds, mainly in solids, has been added. (iv) A discussion of dislocation and slip has been included in elasticity.

Heat
(i) The first law of thermodynamics in the form of $\Delta Q = \Delta U + p.\Delta V$ has been applied to ideal gases. (ii) In the kinetic theory of gases, there is now an account of the maxwellian distribution of molecular speeds, mean free path, and viscosity and thermal conductivity. (iii) Electrical methods have been given prominence in specific heat capacity and specific latent heat, and a mechanical method added for specific heat capacity. (iv) In radiation, the non-equilibrium case has been considered. (v) The triple point and its determination have been discussed in thermometry. (vi) In accordance with the new syllabuses, the section on the thermal expansion of solids and liquids has been revised.

Geometrical Optics
There is now a more concise account of mirrors, a more direct treatment of lenses, and early consideration of refractor and reflector telescopes. Except for basic definitions, photometry has been omitted.

Waves
This section has been expanded in accordance with the new syllabuses. It contains a general treatment of (i) mechanical and electromagnetic waves; (ii) progressive and stationary waves; (iii) reflection, refraction, interference, diffraction and polarization of waves. Sound waves, and the measurement of their velocity in air, have been fully discussed.

Wave Optics
(i) A qualitative account of the effect of lenses and mirrors on waves has been given. (ii) There are now separate chapters on interference, diffraction and polarization. The principles of holography and of the radio-telescope resolving power have been added, and the section on polarization has been expanded.

Sound
This section has been revised and now includes the case of the reflector in the Doppler effect and a brief account of high-fidelity reproduction.

Electricity
The electrostatics text now contains applications of the electrometer and d.c. amplifier, and the charge and discharge of a capacitor through a resistor. In current electricity: (i) a comparison of ohmic and non-ohmic conductors has been given; (ii) the classical electron theory has been extended; (iii) a fuller account of the e.m.f. of a thermocouple by the potentiometer, and of the absolute

method of measuring resistance, have been added; (iv) the chapters on electrolysis and magnetic materials have been revised.

Atomic Physics

(i) The chapter on Electrons includes the cathode ray oscilloscope, and the triode valve is only utilised as an introduction to the field effect transistor. (ii) Junction diodes and Transistors now discusses rectifiers, amplifiers, oscillators, switches, logic gates, the multivibrator and the field effect transistor. (iii) In the section on Energy Levels, there is an account of spontaneous and stimulated emission and its application to the laster. (iv) The chapter on Radioactivity and the Nucleus contains a discussion of absorption by metals, more details of the Rutherford scattering law and the nuclear reactor, and an account of the neutron–proton ratio aspect of unstable nuclei.

Preface to First Edition

This text-book is designed for Advanced level students of Physics, and covers Mechanics and Properties of Matter, Heat, Optics, and Sound. Electricity and Atomic Physics to that standard. It is based on the experience gained over many years of teaching and lecturing to a wide variety of students in schools and polytechnics.

In the treatment, an Ordinary level knowledge of the subject is assumed. We have aimed at presenting the physical aspect of topics as much as possible, and then at providing the mathematical arguments and formulae necessary for a thorough understanding. Historical details have also been given to provide a balanced perspective of the subject. As a help to the student, numerous worked examples from past examination papers have been included in the text.

It is possible here to mention only a few points borne in mind by the authors. In Mechanics and Properties of Matter, the theory of dimensions has been utilized where the mathematics is difficult, as in the subject of viscosity, and the 'excess pressure' formula has been extensively used in the treatment of surface tension. In Heat, the kinetic theory of gases has been fully discussed, and the experiments of Joule and Andrews have been presented in detail. The constant value of $n \sin i$ has been emphasised in refraction at plane surfaces in Optics, there is a full treatment of optical treatment of optical instruments, and accounts of interference, diffraction and polarization. In Sound, the physical principles of stationary waves, and their application to pipes and strings, have been given prominence. Finally, in Electricity the electron and ion have been used extensively to produce explanations of phenomena in electrostatics, electromagnetism, electrolysis and atomic physics; the concept of e.m.f. has been linked at the outset with energy; and there are accounts of measurements and instruments.

Publisher's Note

Since the first publication of *Advanced Level Physics*, the revisions for reprints and new editions have been undertaken by Mr. Nelkon owing to the death of Mr. Parker.

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London University School Examinations (*L.*)
Oxford and Cambridge Schools Examination Board (*O. & C.*)
Joint Matriculation Board (*N.*)
Cambridge Local Examinations Syndicate (*C.*)
Oxford Delegacy of Local Examinations (*O.*)

I am indebted to the following for kindly supplying photographs and permission to reprint them:

The late Lord Blackett and the Science Museum, Fig. 41.19; Head of Physics Department, The City University, London, Figs. 23.13, 24.2, 25.5; Dr. B. H. Crawford, National Physical Laboratory, Fig. 21.20; R. Croft, The City University, Figs, 23.6, 27.4, 24.17; Hilger and Watts Limited, Figs. 23.10, 23.14, 24.9, 24.12; National Chemical Laboratory, Fig. 40.22(i); N. Phillips, Loughborough University, Fig. 24.20; late Sir G. P. Thomson and the Science Museum, Fig. 40.22(ii); late Sir J. J. Thomson, Fig. 41.25; United Kingdom Atomic Energy Authority, Figs. 28.10, 41.30; The Worcester Royal Porcelain Company Limited and Tom Biro, Fig. 13.25 and back cover.

Contents

Part One

Mechanics and Properties of Matter

1 Dynamics

Motion in a Straight Line. Velocity

If a car travels in a constant direction and covers a distance s in a time t, then its *mean* or *average velocity* in that direction is defined as s/t. It therefore follows that

$$\textit{distance } s = \textit{average velocity} \times t.$$

The term 'displacement' is given to the distance moved in a constant direction, for example, from L to C in Fig. 1.1 (i). Velocity may therefore be defined as the *rate of change of displacement.*

Velocity can be expressed in *metre per second* (m s^{-1}) or in *kilometre per hour* (km h^{-1}). By calculation, 36 km h^{-1} = 10 m s^{-1}.

If an object moving in a straight line travels equal distances in equal times, no matter how small these distances may be, the object is said to be moving with *uniform* velocity. The velocity of a falling stone increases continuously, and so is a *non-uniform* velocity.

If, at any point of a journey, Δs is the small change in displacement in a small time Δt, the velocity v is given by $v = \Delta s/\Delta t$. In the limit, using calculus notation,

$$v = \frac{ds}{dt}.$$

We call ds/dt the *instantaneous velocity* at the time or place concerned. The term 'mean velocity' refers to finite times and finite distances.

Vectors and Scalars

Displacement and *velocity* are examples of a class of quantities called *vectors* which have both magnitude and direction. They may therefore be represented to scale by a line drawn in a particular direction. For example, Cambridge is 80 km from London in a direction 20° E. of N. We can therefore represent the displacement between the cities in magnitude and direction by a straight line LC 4 cm long 20° E. of N., where 1 cm represents 20 km, Fig. 1.1. (i). Similarly, we can represent the velocity u of a ball initially thrown at an angle of 30° to the horizontal by a straight line OD drawn to scale in the direction of the velocity u, the arrow on the line showing the direction, Fig. 1.1. (ii).

Unlike vectors, *scalars* are quantities which have magnitude but no direction. A car moving along a winding road or a circular track at 80 km h^{-1} is said to have a *speed* of 80 km h^{-1}. 'Speed' is a quantity which has no direction

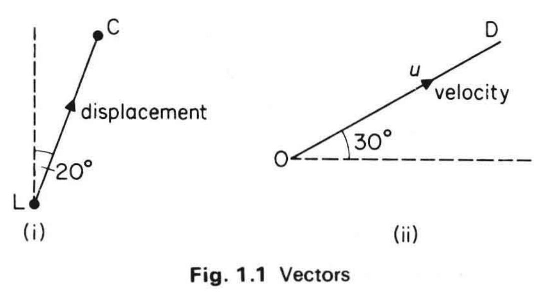

Fig. 1.1 Vectors

but only magnitude, like 'mass' or 'density' or 'temperature'. These quantities are examples of scalars.

The distinction between speed and velocity can be made clear by reference to a car moving round a circular track at say 80 km h^{-1}, Fig. 1.2. At every point on the track the *speed* is the same—it is 80 km h^{-1}. At every point, however, the *velocity* is different. At A, B or C, for example, the velocity is in the direction of the corresponding tangent AP, BQ or CR. So even though they have the same magnitude, the three velocities are all different because they point in different directions.

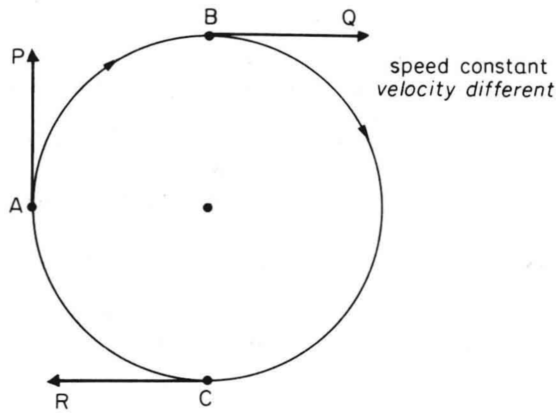

Fig. 1.2 Velocity and speed

Distance-Time Graphs

When the distance, s of a car moving in a constant direction from some fixed point is plotted against the time t, a *distance-time* (s-t) *graph* of the motion is obtained. The velocity of the car at any instant is given by the change in distance per second at that instant. At E in Fig. 1.3, for example, if the change in distance s is Δs and this change is made in a time Δt,

$$\text{velocity at E} = \frac{\Delta s}{\Delta t}.$$

In the limit, then, when Δt approaches zero, the velocity at E becomes equal to the *gradient of the tangent to the curve* at E. Using calculus notation, $\Delta s/\Delta t$

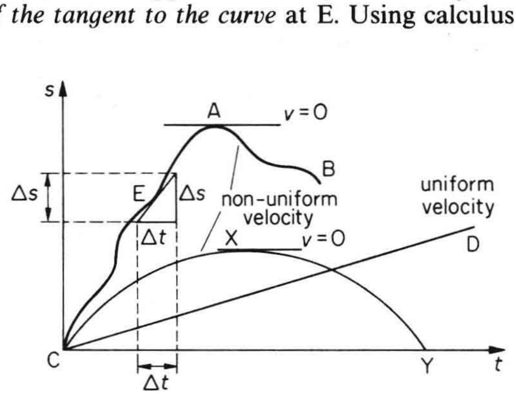

Fig. 1.3 Distance (s)–time (t) graphs (constant direction)

then becomes equal to ds/dt (p. 3). So the gradient of the tangent at E is the instantaneous velocity at E.

If the distance-time graph is a straight line CD, the gradient is constant at all points; it therefore follows that the car is moving with a *uniform* velocity, Fig. 1.3. If the distance-time graph is a curve CAB, the gradient varies at different points. The car then moves with non-uniform velocity. At the instant corresponding to A the velocity is zero, since the gradient at A of the curve CAB is zero.

When a ball is thrown upwards, the graph of the height s reached at any instant t is represented by the parabolic curve CXY in Fig. 1.3. The gradient at X is zero, illustrating that the velocity of the ball at its maximum height is zero.

Velocity-Time Graphs. Acceleration

When the velocity of a moving train is plotted against the time, a 'velocity-time (v-t) graph' is obtained. Useful information can be deduced from this graph, as we shall see shortly. If the velocity is uniform, the velocity-time graph is a straight line parallel to the time-axis, as shown by line (1) in Fig. 1.4. If the train increases in velocity steadily from rest, the velocity-time graph is a straight line, line (2), inclined to the time-axis. If the velocity change is not steady, the velocity-time graph is curved. In Fig. 1.4, for example, the velocity-time graph OAB represents the velocity of a train starting from rest which reaches a maximum velocity at A, and then comes to rest at the time corresponding to B.

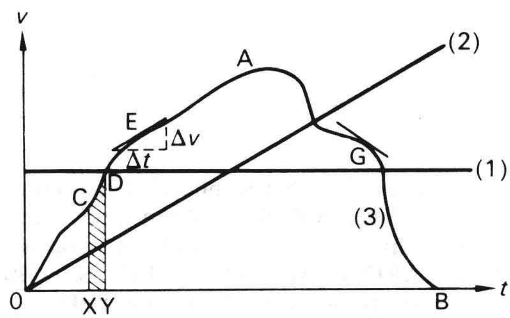

Fig. 1.4 Velocity (v)–time (t) curves

Acceleration is the 'rate of change of velocity', that is, the change of velocity per second. We can see that *the acceleration of the train at any instant is given by the gradient to the velocity-time graph* at that instant, as at E. At the peak point A of the curve OAB the gradient is zero, that is, the acceleration is then zero. At any point, such as G, between A, B the gradient to the curve is negative because the graph slopes downwards. Here the train has a *deceleration* or decrease in velocity with time. Like velocity, acceleration is a vector.

The gradient to the curve at any point such as E is given by:

$$\frac{\text{velocity change}}{\text{time}} = \frac{\Delta v}{\Delta t}$$

where Δv represents a small change in v in a small time Δt. In the limit, the ratio $\Delta v/\Delta t$ becomes dv/dt, using calculus notation.