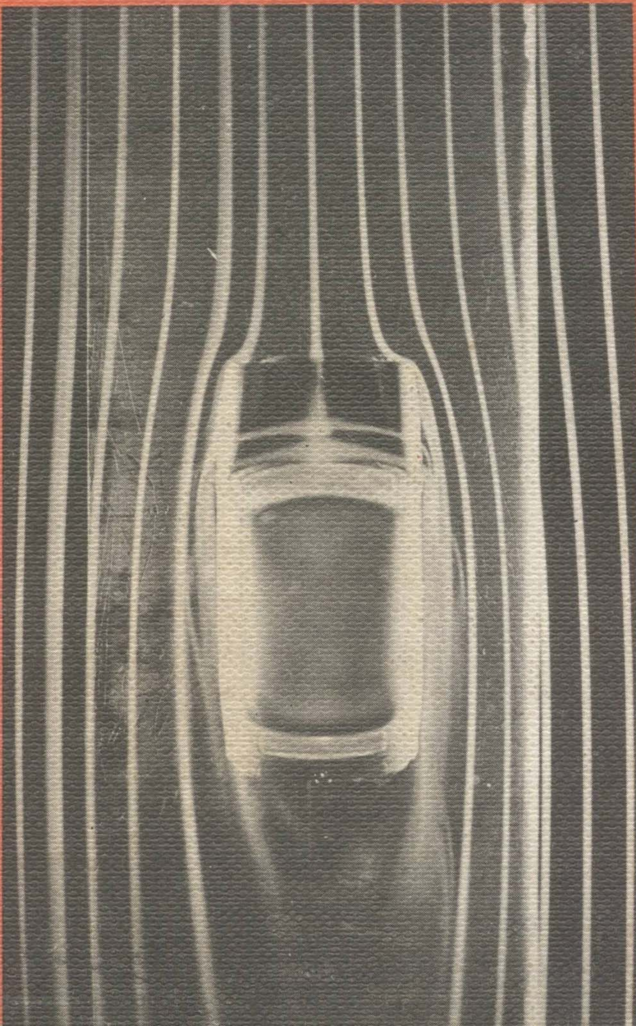
TEACHER'S BOOK

Inquiring into Physics

Book 1

Mechanics and Properties of Matter



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INQUIRING INTO PHYSICS

Study Questions for a Physics Course

BOOK I

Mechanics and Properties of Matter

TEACHER'S BOOK WITH ANSWERS

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This book would never have been written but for the stimulus of a Schoolteacher Fellowship at the University of Surrey, and the opportunities it afforded for discussion and reference.

It is not possible to mention all the sources from which I have gleaned ideas for this book. Many of them are listed in the *References*. One source deserves special mention: Eric Rogers' monumental book *Physics for the Inquiring Mind*. My ideas about physics teaching have been particularly influenced by this work, and those who know it will recognise many reflections of it in these pages.

I am aware that not all my questions are original; some are old friends in a new disguise. To the originators of these, whoever they may be, I can only express my gratitude.

I am greatly indebted to a former colleague, Mr. A. McB. Collieu, for his support and helpful comments arising out of classroom experience with the questions.

All the answers have been checked, but if some errors remain, I would be glad to be told of these.

Tonbridge School, Kent A. W. WILSON

Preface

The questions are of many types but they have one feature in common: their aim is not to test the pupil but to help him learn and understand. Some of them will help him consolidate a newly-introduced definition or relation by means of a quick numerical example (for instance questions **5.1** and **9.16**). Some ask him to apply basic knowledge to real and relevant situations (**7.12, 9.20**) and introduce engineering applications (**13.4, 14.20**). Many questions, by their data and by their answers, will help to give pupils a feel for the magnitude of the physical quantities they deal with (**6.3, 10.2**) and for the relative importance of different effects (**6.27, 13.18**). Still others look at experimental methods (**2.4, 4.11**) and give practice in interpreting graphs (**4.2, 11.11**) and experimental data (**3.2, 12.9**). Several questions are introductory ones (**9.1, 14.16**) in which pupils work step by step through a calculation that they will meet later, using symbols rather than numbers, in the derivation of an important formula. Finally there are the discussion questions (**6.17, 14.15**), which encourage pupils to think generally and imaginatively about a topic, and perhaps to prepare some ideas to talk about in class.

If after working through some of these questions a person not only knows some physics, but is also beginning to think like a physicist, the book will have achieved its aim. Syllabus-pressure can be so high that pupils must simply ingest the subject as a structure of rules and facts, apparently unaware that it has any relevance beyond the classroom walls. For example, plenty of schoolboys when asked to calculate the radius of a piece of wire will happily write down their answer as, say, *75 centimetres*, unconcerned that there may be something wrong with it. They have not learned to think in terms of real situations.

Question **4.5** illustrates this point. Pupils are asked to find the stopping distance of a car with a given maximum deceleration. If this is less than 170 metres a crash will be avoided. The pupil who has been reared on old exam questions, which must for convenience have a single unambiguous answer, will perform the calculation and give his result: 160 metres, no crash. But someone who is thinking about a real situation will realize, particularly if he has already done question **3.6**, that the driver's reaction time is a crucial factor here. At first pupils may regard this as an unfair type of catch question, but experience shows that they soon acquire the new attitude and come to prefer it.

Many situations are of course too complex for rigorous analysis at an elementary level, so care has been taken to indicate when factors such as friction and viscosity can safely be neglected. In general, situations have been chosen in which these approximations lead to no serious error, but occasionally, to make a good question, it has been necessary to turn a blind eye on a factor which may be of importance. Where this is done the question draws attention to the simplification.

With so many different types of question it has not proved possible to classify them in any other way than under general subject headings. There are however more questions in each section than any one pupil would be expected to attempt, so a teacher can select those which, in type, content and standard, most nearly meet his needs. A few questions are mathematically or conceptually more complicated than the rest. These are marked with an asterisk in the *Notes and*

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Answers section; they might be reserved, for example, for a third year sixth form.

The questions cover all the major topics commonly included in the *Mechanics* and *Properties of Matter* sections of an intermediate physics course. A few topics, principally *interatomic force* and the *properties of materials* are gone into a little more deeply than the rest. This is because they are believed to be of greater importance than their treatment by some textbook authors implies.

Very rarely does a question in any section expect knowledge of a topic that would not normally be met until a later section of the book had been covered. Where this does happen, the *Notes and Answers* section draws attention to it.

Care has been taken to adopt a consistent policy about significant figures. All data in a particular question is given to the same number of significant figures, usually two or three (except where it would mean writing, say, 20 as $2{\cdot}0\ 10^{1}$ to distinguish it from $2\ 10^{1}$), and the answers are generally given to the same number of figures. Sometimes the calculation involves the small difference between two larger quantities and in this case the answer is less precise than the data. In some questions, where the data or the nature of its treatment warrant it, only one-figure or order-of-magnitude calculation is expected. In a few questions pupils must make their own estimate of the magnitude of some of the quantities.

The *Notes and Answers* section, in addition to giving answers to all the numerical questions, warns of hidden difficulties in a few of them and gives background information which may help to meet some of the points that will arise in discussion. For those who wish to dig deeper a number of references are given; all are to books or journals suitable for a school or college library. The *Pupils' Book* contains no answers; it is left to the teacher to give out answers if he wishes. With structured questions, in which a calculation is dissected and taken in simple steps, it is sometimes difficult to reveal the answers without giving some clues to the method, and exposing pupils to the temptations of number-juggling to try and come up with the expected result. Also it would be wrong to create the impression that getting the right answer is the principal aim of a question; often the method and discussion are equally important.

To reduce the amount of arithmetic required, the data for the questions is usually provided in the most convenient form for use, that is in SI units or their recognized multiples and submultiples. The option of writing unit symbols with a solidus (m/s, kg/m^{3}) rather than with negative indices (m s^{-1}, kg m^{-3}) has been adopted since this is felt to be easier to write, print and talk about, and also to convey more meaning, at least in simple situations. One rule must be obeyed: only to use one solidus in any combination of units. Example are m/s^{2} for acceleration and J/kg K for specific heat. It is important that the SI units should be more than mere names. Pupils must develop a feel for the magnitudes they represent. This will grow slowly as the metric system comes into everyday use; in the meantime conversion factors can be found in the HMSO publication *Changing to the Metric System*, and the following approximate equivalents may be some help:

30 mile/h $\approx$ 14 m/s
$c = 3.0\ 10^{8}$ m/s
$g = 9.8$ m/s^{2}

The wavelength of visible light ≈ 600 nm
The mass of a 12 stone man ≈ 75 kg
The density of water = 1000 kg/m^3
The density of room air ≈ 1 kg/m^3
It takes 220 gallons to fill 1 m^3
The weight of an apple ≈ 1 N
Atmospheric pressure ≈ $1\ 10^5\ N/m^2$
To lift $\frac{3}{4}$ lb through 1 ft takes about 1 J of energy
A driven golf ball has about 20 J of kinetic energy
1 hp ≈ $\frac{3}{4}$ kW

Notes and Answers

The names in italics are those of the authors of references listed on pages 46 and 47.

The questions marked with an asterisk are rather harder than the rest.

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Contents

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Contents

The Questions

1

Units and Dimensions

The first four questions introduce the SI units. They stress that, although the multiples and submultiples such as kilometre and millisecond are convenient in describing quantities, calculations should be carried out in terms of the un-prefixed primary units.

1.1 (a) m^3
(b) m/s^2
(c) m^3/s for volume rate of flow, kg/s for mass rate of flow, or possibly m/s for speed of flow.
(d) m^2/s
(e) /s.

1.2 (a) $9\ 10^{15}$ m
(b) $5\ 10^9$
(c) 1 s
(d) $7\ 10^{-19}$ s.

1.3 (a) mm
(b) nm. 1 nm = 10 Å.
(c) Mm would be convenient, the diameters being in the 5 Mm to 100 Mm range, but this unit is not in common use.
(d) mg
(e) μs
(f) Two names that have been put forward are 'baram' and 'quilo'.

1.4 (a) $1\ 10^2\ m^3$
(b) $1\ 10^{-2}$ m, 1 cm
(c) $5\ 10^{-7}\ m^3$, $0{\cdot}5\ cm^3$
(d) $1\ 10^{-3}$ kg, 1 g.

1.5 to 1.7 are miscellaneous questions on *units*.

1.5 A microcentury is longer, 52 minutes. A kilosecond is 17 minutes.

1.6 (a) 3 c = 1·8 m (5 ft 11 in.)
(b) 80 c/f = 24 m/s (54 mile/h)
(c) 10^9 c/f exactly
(d) A simple method would be to tell the Xian what volume, in c^3, of a common material identifiable by its chemical behaviour, would have a mass of one kilogramme. To tell the Xian the meaning of the words 'left' and 'right' would be much more difficult; see *Feynman*, Chap. 4.

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1.7 (a) 6 p.m.; 8 a.m.
(b) 0·917 o'clock
(c) 0·125 days; 3 hours
(d) One disadvantage is that the day, defined as the earth's rotation period, is not of constant length; see question 3.7.

The remaining questions are concerned with *dimensions.* 1.9 to 1.11 require knowledge of the dimensions of force.

1.8 (c) The first one, $T = 2\pi\sqrt{\frac{l}{g}}$

1.9 Each term has dimensions $[M]\,[L]\,[T]^{-2}$.

1.10 $[M]\,[L]^5\,[T]^{-2}$; $[L]^3$; $[M]\,[L]^2\,[T]^{-2}$.

1.11 $[M] = [F]\,[L]^{-1}\,[T]^2$.

2

Size and Distance

Questions 2.1 to 2.4 are concerned with the measurement of length and distance.

2.3 (a) 0·5%
(b) 2·0 ± 0·2 cm
(c) 10%.

2.4 This illustrates the distinction between sensitivity and accuracy. The mekometer was developed at the National Physical Laboratory in London, and is considerably more complex than the question indicates. It uses a modulated light beam and compares the modulation phase of the returning light with that of the outgoing beam. Compensation for atmospheric refraction is automatic. The device is portable and operates at ranges up to 3 km, so is particularly useful for surveyors and engineers.
(b) 3·00000 ± 0·00001 km, an uncertainty of 1 cm at this range.
(c) The difference is 0·3 mm, and therefore real.

Questions 2.5 and 2.6 are simple examples introducing *radians*, which will be used in the remainder of the section. Tables are required.

2.5 (a) 29°
(b) 0·080 rev
(c) 0·50 rad

2.6 (a) 0·5%
(b) 1%
(c) 45°

2.7 (a) $1{\cdot}0'' = 4{\cdot}9\ 10^{-6}$ rad
(b) $3{\cdot}1\ 10^{16}$ m
(c) 1·0 parsec = 3·3 light-years

2.8 (c) $3\ 10^{18}$ m, about 100 parsecs or 300 light-years. The distances of several thousand stars have been found by this method.
(d) The coin, 2·4 cm in diameter, would have to be 240 km away.

2.9 Tycho found that, after allowing for the comet's own slight motion, there was no detectable parallax between the two observations. He could therefore deduce that the comet was at least six times further away than the moon.

The last three questions ask pupils to repeat some Greek measurements, of the size of the earth, the size of the moon, and the distance of the sun.

2.10 (b) about 0·13 rad
(c) 4·0 10^4 stades
(d) The Greek value, 6300 km, is remarkably close to the modern one, but there is doubt about the modern equivalent of a stade, so the agreement may be fortuitous.
(e) The Greeks knew that the sun's distance is large compared with the size of the earth; see question 2.12.

2.11 The method involves simple comparison of the moon's diameter with that of the earth, but is made more complicated by the fact that the sun, though effectively at infinity, is of finite size and so gives rise to tapering shadows.
(c) $D - d$
(d) about 2·5. The photograph shows the eclipse of January 29th 1953.
(e) about 3·5
(f) about $32D$
(g) about 4·0 10^5 km. The modern value is 3·8 10^5 km.

2.12 (b) 19
(c) The true value of angle *SEM* is 89·8°. Accurate determination of the sun's distance is difficult. Good values have recently been obtained indirectly by radar measurement of planetary distances and by analysis of spacecraft trajectories.

3

Time

3.2 and 3.3 describe electronic methods of measuring short time intervals. The instruments involved are briefly described, but pupils will probably want further details.

3.2 (a) 0·400 m/s

(b) The time interval would be about 8 ms, with an uncertainty of 0·5 ms, or 6%. Advanced counter-timers are now available with a 100 MHz oscillator and eight-figure digital read-out, suitable for time measurement to 0·1 μs.

3.3 The ripple frequency is 100 Hz. The fluorescent lamp took 120 ms to ignite; old lamps take longer than this. No conclusion can be drawn about the relative intensity of the two sources because different geometrical arrangements were used. General-purpose oscilloscopes are now available with timebase ranges from 5 s/cm to 0·02 μs/cm.

3.5 For pictures of a balloon bursting see *P.S.S.C.*, Chap. 2. Special cameras have been developed to operate at one million frames per second.

3.6 Reaction time; a short experiment is involved. The only apparatus required is a metre rule.

3.7 (a) 22 h

(b) 400 d. There is evidence that this result is correct. Certain present-day corals are found to add about 360 tiny ridges to their skeletons each year, suggesting that one ridge is added every day. Fossilized corals from the Middle Devonian period are found to have 400 daily rings in each annual growth ring. See the article by *Runcorn*.

(c) $1\cdot5\ 10^{-7}$ s; 0·003 s; 50 min. Summation of an arithmetic progression is necessary. The slowing of the earth's rotation explains discrepancies, first noted by Halley, between ancient records of eclipses and 'predictions' obtained by calculating back from present-day observations of the sun and moon.

The section ends with three questions describing special methods for estimating two very long times, the age of the Earth and the age of the universe, and one very short one, the lifetime of a sub-atomic particle.

3.8 (a) $2\ 10^{8}$ years. Modern estimates, using radioactive dating methods, give much higher values, about $4\cdot5\ 10^{9}$ years. The salt method estimates the age of the oceans. It assumes the rivers have always added salt at the same rate as they do at present. This is not so; in earlier epochs the earth was less mountainous than it is now, and the rivers were less active. See the book by *Hurley*.

3.9 A skirmish with cosmology, likely to raise many questions. For further information see, for example, *Bondi* (1).

(a) 900 km/s
(b) 1 10^9 l-y
(c) 1 10^{10} l-y, but Hubble's relation probably does not hold at this range.
(d) 1 10^{10} years. This assumes that the speed of the galaxies has remained constant. Other models make different assumptions, but still give values $\sim 10^{10}$ years for the age of the universe. There is also some doubt about the correct value of Hubble's constant.

3.10 $3{\cdot}5 \pm 1{\cdot}0\ 10^{-16}$ s. At this high speed time goes by more slowly for pions than it does for us, a relativistic effect. The mean life of a stationary pion would be about 2 10^{-16} s. The tracks were observed in photographic emulsion, and the uncertainty arises because the distance moved by the pion is comparable with the grain size of the special film employed. The pion's speed is known from the energetics of the reaction in which it is formed. For a discussion of new fundamental particles see the article by *Richardson*.

4

Motion

The first eleven questions are concerned with the kinematics of one dimensional motion. Graphical methods are introduced first, 4.1 to 4.3.

4.1 (a) 6·7 m/s
(b) 17 m/s
(d) 0.

4.2 (a) 28 m/s.
(b) 1·0 m/s^2
(c) 8·2 km.

4.4 to 4.8 involve *uniform acceleration*, and are suitable for solution by applying the kinematic equations.

4.4 (b) 25 m.

4.5 The car can stop in 160 m, so he will only miss the tree if his reaction time is less than 0·4 s. 25 m/s is nearly 60 mi/h.

4.6 (a) $\sim 10^5$ years
(b) 3·1 10^7 s, just less than a year. Most pupils are aware that no object can reach the speed of light. As seen from the earth the rocket's acceleration would diminish towards zero as the speed of light was approached, even though the thrust of its motor remained unaltered. In practice the rocket, as seen from earth, would have reached $1/\sqrt{2}$ of the speed of light after 3·1 10^7 s, and its mass would then have increased to a factor of $\sqrt{2}$. None of these changes would be apparent to someone inside the spacecraft. See *Bondi* (2) for further details.
(c) 4·6 10^{15} m, 0·11 of the distance.
(d) The astronauts would not be able to distinguish the effect of the acceleration during the flight from the effect of the earth's gravitational field before they set off. This is an example of Einstein's principle of equivalence.

4.7 (a) 18 m/s
(b) 10·5 min
(c) 8·4 km
(d) 13 m/s.

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