Physics Problems for Aspiring Physical Scientists and Engineers
With Hints and Full Solutions

An essential part of studying to become a physical scientist or engineer is learning how to solve problems. This book contains over 200 appropriate physics problems with hints and *full* solutions. The author demonstrates how to break down a problem into its essential components, and how to chart a course through them to a solution. With problem-solving skills being essential for any physical scientist or engineer, this book will be invaluable to potential and current undergraduates seeking a career in these fields.

The book is divided into three parts: questions, hints, and solutions. The first part is subdivided into fifteen chapters, each centred on a different area of physics, from elementary particles, through classical physics, to cosmology. The second part provides brief hints, whilst the third sets out a full and explicit solution to each problem. Most begin with thoughts students might have after reading a problem, allowing the reader to understand which questions they should be asking themselves when faced with unfamiliar situations.

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Preface

The principal aim of this book of physics problems is to allow those advanced school students who seek a future in one of the physical sciences or engineering to develop the skill of being able to 'chart their own course' through a problem or investigation.

For reasons which I well understand, advanced level examination questions are nowadays broken up into many parts, each with its own (small) mark. This has to be done because, with many examiners for any one examination paper, the need for uniformity of marking, guided by a mark scheme, and the necessity of being able to provide an open and justifiable paper trail when appeals are made, make it almost inevitable.

However, the result of such a procedure is effectively to lead every student by the hand, including both those who, on their own, would not know what to do next, and those with a clear understanding of the science involved, who could find their way to the solution without any guidance whatsoever. This set of physics problems is for the latter group – and for those who have the ability and aspiration to join them; they are the scientific innovators and developers of the future.

The physics material covered by the problems is that usually taught in advanced school courses; in the United Kingdom, and in countries where overseas UK examinations are sat, the topics covered are typically those included in an A-level syllabus. In the United States the relevant level is probably that of SAT examinations, whilst in Europe higher level physics in the International or French Baccalaureate would cover the necessary ground. In countries which adopt a less specialized school curriculum than that found in the UK, the relevant level may be that of junior college or the early years of university.

Whatever their school physics course, this book should provide valuable training for those making the transition to university-level study, as the principal aim of the problems is to foster an ability to think things through for oneself, as opposed to being guided through each step. For this reason, the book should also be of value to students already in their first year at university.

Most of the material covered is what is known as 'classical physics', although some 'modern' topics, such as quarks, ultrasound scanning, and the development of the Universe, are included. Several classical physics topics, among them polarized light, inductance, heat conduction, longitudinal waves and adiabatic changes, no longer appear in many school syllabuses, but I have included problems in some of these areas and provided the additional information needed to tackle them; being able to take in and use previously unknown information is a skill all would-be scientists should acquire.

The book is divided into three parts, the questions, the hints, and the full model solutions; this division will help a student to avoid 'accidentally' noticing a hint when reading the question, or the solution when seeking help from the hints! The Questions part of the book is divided into fifteen chapters, each centred on some particular area of physics, though, as always, physics is not compartmentalized, and the same ideas and principles can appear in many different places. The problems within any one chapter are not in any particular order of difficulty, though those marked with an ∗ will probably be found to be the more challenging. Problems marked with a † require some mathematics that is not normally an integral part of school physics, but is likely to have been studied by any student who is also taking mathematics at an equivalent level.

The large majority of the problems posed call for quantitative answers, either as a formula or a numerical value. Seeking quantitative solutions makes it possible to provide intermediate answers and guidance in a reasonably compact form. When doing this, in the second part of the book, a sometimes difficult balance has had to be struck between being so helpful that there is nothing left to the problem, and being so oblique that the hint is merely one more baffling aspect; I hope that in the large majority of cases such a balance has been found. The Hints section, which is not divided into chapters, is comparatively short, and for the very best students will, hopefully, be little used.

Much the largest part of the book is the Solutions section, which aims to set out in explicit detail full solutions to every question. They are presented as one continuous set, since the solution numbering (in bold) provides at least as good a guide to the appropriate page as any division into chapters. As explained in the 'How to use this book' section, many of the model solutions start by setting out the sort of thoughts a student may, and should, have on reading the question.

Some of the problems are quite short, but where they are, they usually require some particular insight. The longer questions tend to be relatively straightforward but require a number of steps, and call for a clear plan and accurate use of the data given. The ability to decide, with little external guidance, what needs to be done, and in what order, is a major learning objective of all of the problems. Some could be solved more efficiently or elegantly by employing university-level methods, but I have tried wherever possible to use only approaches available after following a school-level course.

The symbols used for physical quantities are, in the vast majority of cases, those in standard use by all UK examination boards and by nearly all physics textbooks written in English. Where they are not, I have defined them within the individual problems. In order to make the book self-contained for its own purposes, a table of values for the standard constants is included on the very last page. I have not included a selection of formulae and relationships, partly because there is overlap, but no unanimity, amongst the major examination boards, but mainly because I feel that the practising scientist should, at least in the long run, have them as part of his or her vocabulary. If need be, the data sheet provided for their own course can be consulted.

Naturally, I take responsibility for all errors and ambiguities the questions, solutions and hints may contain, and would be most grateful to have them brought to my attention. Finally, I wish to place on record my appreciation of the help received from Simon Capelin and Esther Migueliz Obanos at CUP, and, although they may not expect it, from Helmut Kopka and Patrick W. Daly whose *A Guide to* LaTeX I have consulted often over the last twenty years.

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Frontmatter
More Information

How To Use This Book

The principle aim of this book is to allow those advanced school students who seek a future in one of the physical sciences or engineering to develop the skill of being able to 'chart their own course' through a problem or investigation. And it is assumed that you are just such a person.

There is no particular aim to cover every part of some or all physics syllabuses, but rather to provide scenarios that offer the chance of logical self-organized thought, without the need for skills or knowledge outside of what you have already studied or is provided in the question. You may have to look up a few topics outside your own course, but they will be no more advanced than those you have already studied, and such research is, in itself, worthwhile training. Equally, you may need to look elsewhere for the values of some physical quantities. A table of standard physical constants is provided at the very end of the Solutions section; some others which will clearly be needed are stated in the question; but some appear only in the corresponding solution, as to include them in the question would provide too much of a clue as to the correct solution method.

As explained in the Preface, this book is divided into three parts, the questions, the hints, and the full model solutions. The Questions part of the book is divided into fifteen chapters, each centred on some particular area of physics, though, as always, physics is not compartmentalized, and the same ideas and principles can appear in many different places.

The large majority of the problems posed call for quantitative answers, either as a formula or a numerical value. That is not to imply that qualitative discussions of physical problems are not important; in some cases they are the only discussions that are possible. However, calling for a quantitative answer will usually ensure that the physics principles involved have been, not only understood, but correctly applied. Further, seeking quantitative solutions makes it possible to provide intermediate answers and guidance in a reasonably compact form. This is done in the second part of the book. There, each of the more than two hundred and twenty questions is provided with a hint, perhaps as a suggestion about an aspect of the problem that should be considered, perhaps as a signpost that should be passed on the way to a successful solution.

Much the largest part of the book is the Solutions section, which aims to provide in explicit detail full solutions to every question. Many of the solutions start by setting out the sort of thoughts a student may, and perhaps should, have on reading the question (but would not normally write down). They may include:

- What kind of processes are involved in this problem?
- Is the explicit data provided sufficient to yield the answer?
- If not, is there additional information implicit in the way the question has been posed?
- Or does everyday knowledge provide useful help, e.g. the length of a day gives the Earth's angular rotation speed.
- Do I need to introduce additional variables that are not mentioned in the question?
- Is there a self-consistency criterion to be satisfied?
- In what order should the various aspects of the problem be tackled?

Planning how issues such as these should be tackled is usually the key to a successful outcome. Some readers may find it helpful to begin each solution with a 'doodle' showing how they are going to approach the problem; a series of words or symbols joined by arrows, sometimes in the form of a closed loop, would suffice – many great inventions and ideas have started out that way!

The problems within any one chapter are not in any particular order of difficulty, though those marked with an $*$ will probably be found to be the more challenging. Problems marked with a † require some mathematics that is not normally an integral part of school physics, but is likely to have been studied by any student who is also taking mathematics at an equivalent level. In some of the questions either too much or too little information appears to have been provided; try not to be distracted by red herrings, but do cast your net widely when thinking how any missing piece of the jigsaw might be provided.