200 More Puzzling Physics Problems
With Hints and Solutions

Like its predecessor, *200 Puzzling Physics Problems*, this book is aimed at strengthening students' grasp of the laws of physics by applying them to situations that are practical and to problems that yield more easily to intuitive insight than to brute-force methods and complex mathematics. The problems are chosen almost exclusively from classical (i.e. non-quantum) physics, but are no easier for that. They are intriguingly posed in accessible non-technical language, and require readers to select an appropriate analysis framework and decide which branches of physics are involved. The general level of sophistication needed is that of the exceptional school student, the good undergraduate or the competent graduate student. Some physics professors may find some of the more difficult questions challenging. By contrast, the mathematical demands are relatively minimal, and seldom go beyond elementary calculus. This further book of physics problems should prove not only instructive and challenging, but also enjoyable.

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Dedicated to

Frederick Károlyházy

from whom we have learned so much

Contents

Preface

As was said in the preface to the predecessor of this book (*200 Puzzling Physics Problems*, Cambridge University Press, 2001), an understanding of the laws of physics is best acquired by applying them to practical problems. Many of the corresponding solutions, however, require routine, but perhaps long and boring, calculations, which tend to deter even the most curiosity-driven students of the subject. This book, like its antecedent, aims to show that not all physics problems are like that, and that a bit of careful thought, a little ingenuity and a flash of insight can go a long way.

Although we have aimed to place as many problems as possible in settings that will be familiar to, and easily understood by, most people (not just physics students and their professors), some have had to be somewhat artificially constructed in order to bring the physics involved to the fore. However, that said, many of these contrived situations can be set up in a laboratory, and theory can be tested against experiment. Even so, some 'test areas', especially those in outer space, and some apparatus, in particular a copious supply of infinitely long rods, were beyond the resources available to us!

Nevertheless, we hope that you will be intrigued by questions such as:

- How do you maximise the gravitational effect of a lump of plasticine?
- How does a spoked wheel appear in a photo-finish picture?
- What happens when a suspended Slinky is suddenly released?
- How can your square-on reflection in a plane mirror show your closed eye, but not your open one?
- How long is it before Santa Claus is discharged?
- Does an electromagnetic field carry angular momentum?
- What is the path of a ball rolled onto a rotating turntable?
- How much charge flows when a magnet is dropped through a metal loop?
- Where should you park your car to avoid a frosted windscreen?

- How large is the force between end-to-end solenoids?
- How do you bring about 'the parting of the waters' in a Florence flask?
- When does an Euler strut go phut?
- What is the pressure produced by a neutron in a box?
- How long is an 'infinite electronic chain'? Does it matter?
- How much harder is it to steer a car with flat tyres?
- What is the maximum speed with which a comet could hit the Earth?
- How do you get into shape for a 'free-wheel bike race'?
- Why do icebergs floating in the open ocean last so long?

These, those on the book cover and some 170 others are problems that can be solved elegantly by an appropriate choice of variables or coordinates, an unusual way of thinking, or some cunning idea or analogy. Of course, when such a eureka moment arrives, and the solution is then found with a minimum of effort, the reader will, quite justifiably, have every reason to be pleased with him- or herself.

However, it needs to be said that inspiration of the kind needed to produce such insights is most unlikely to come to anybody who does not have a sound knowledge and understanding of the basic laws of physics. The vast majority of the problems are based on classical physics, of the kind taught in sixth forms and the early years of university. And even the 'modern' physics questions demand little beyond elementary relativity – there is not a single quantum mechanical wavefunction in sight! This is readily understandable, as real intuition in the field of quantum physics – which often comes in the form of counter-intuition – usually merits a Nobel prize.

Although essentially correct solutions to the problems are clearly the principal goal, we should add that success is not measured by this alone. Whatever help you, the reader, may seek, and whatever stage you may reach in the solution to a problem, we hope that it will bring you both enlightenment and satisfaction, as well as increase your capacity to think in novel ways.

The 200, hopefully interesting, problems contained in this book have been collected by the authors over the course of many years. Some were invented by us, and the rest are, for the most part, taken from the Hungarian *Mathematical and Physical Journal for Secondary Schools*, covering a span of more than 100 years, or from other Hungarian physics contests. We have selected a few very challenging questions from the Boston Area Undergraduate Physics Competition (BAUPC). We have also been guided by the suggestions and remarks of our colleagues. It is impossible to determine the original authors of most of the physics problems appearing in the international 'ideas market'. Nevertheless, some of the inventors of the most puzzling problems deserve our special thanks. They include Zsolt Bihary, András Bodor, László Holics, Jaan Kalda, Frederick Károlyházy[†], Gyula

Radnai, Géza Tichy, István Varga† and Károly Vladár. We thank them and the other people, known and unknown, who have authored, elaborated and improved upon 'puzzling' physics problems.

Péter Gnädig, Gyula Honyek, Máté Vigh

How to use this book

This book has a two-fold objective: to teach and train students, and to intrigue and entertain everybody who likes physics and puzzles. The first chapter contains the 200 problems. If the reader's main objective is to use the book as a basis for studying physics, we recommend that the problems are tackled in the order they appear, though this does not necessarily represent their order of difficulty. Of course, if the reader is using the book for fun or as a challenge, he or she can freely 'cherry-pick' the questions.

It is an essential part of a physicist's skill to be able to recognise the type of problem in front of them, and to identify which areas of science and mathematics will need to be called upon. Almost needless to say, some of the problems could not be unambiguously assigned to, say, mechanics or gravitation or electromagnetism. Nature's secrets are not revealed according to the chapter titles of a textbook, but rather draw on ideas from various areas, and usually in a complex manner. However, after the present section, *for information*, we have included a list of topics, and the numbers of the problems that more or less belong to those topics. Some problems are listed under more than one heading. A list of symbols and numerical values for the principal physical constants, as well as several tables of material and astronomical data, not all of which will be needed, are provided in the Appendix at the end of the book. The Appendix also contains many standard mathematical results, drawn from the areas of vector algebra, conic sections, trigonometry, calculus and solid geometry.

The majority of the problems are not easy; some of them are definitely difficult. You, the reader, are naturally encouraged to try to solve them on your own and, obviously, if you do you will get the greatest satisfaction. If you are unable to achieve this, you should not give up, but turn to the relevant page of the *hints* in the short second chapter. In most cases this will help, though it will not give the complete solution, and the details will still have to be worked out. Once you have done this and want to check your result (or if you have given up and just want to see the *solution*) the final chapter should be consulted.

If a particular problem relates to another one elsewhere in this book, you will find a page reference (rather than a problem number reference) in the relevant hint or solution. Sometimes this may only be a few pages away, but on other occasions it is far removed. In a few places, reference is made to this book's predecessor (*200 Puzzling Physics Problems*, Cambridge University Press, 2001), but the hint or solution can be followed without *having* to consult this external source. Problems whose solutions require especially difficult reasoning or more demanding mathematical calculations are marked by one or two *asterisks* – and one problem has earned itself a *three-star* rating!

There are some problems whose solutions raise questions that are beyond the scope of this book. Points or issues worth further consideration, as well as outlines of possible alternative solution methods, are indicated in *Notes* at the end of the relevant main solution, but answers are not usually given.

Thematic order of problems

* Asterisks indicate problems that require more difficult reasoning or somewhat more advanced mathematics. Many problems warrant two asterisks and one warrants three.