A GUIDE TO PHYSICS PROBLEMS

part 1

Mechanics, Relativity, and Electrodynamics

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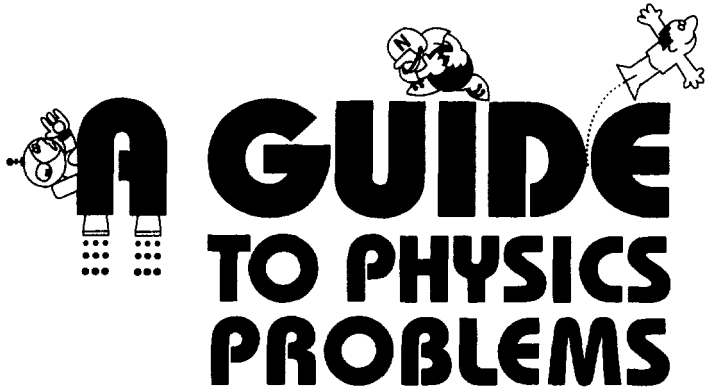

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Mechanics, Relativity, and Electrodynamics

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Foreword

For many graduate students of physics the written qualifying examination is the last and one of the most important of the hundreds of grueling examinations that they have had to take in their career. I remember vividly my own experience in 1947 at the University of Chicago. After the qualifying examination, I knew I was finally free from all future examinations, and that generated a wonderful feeling of liberation and relief.

Be that as it may, the written qualifying examination does serve a useful purpose, both for the faculty and for the students themselves. That is why so many universities give these exams year after year in all parts of the world.

Sidney Cahn and Boris Nadgorny have energetically collected and presented solutions to about 140 problems from the exams at many universities in the United States and one university in Russia, the Moscow Institute of Physics and Technology. Some of the problems are quite easy, others quite tough; some are routine, others ingenious. Sampling them I am reminded of the *tripos* questions of Cambridge University that I had spent so many hours on when I was an undergraduate student in China during the years 1938–1942, studying such books as Whittaker's *Analytical Dynamics,* Whittaker and Watson's *Modern Analysis,* Hardy's *Pure Mathematics,* and Jeans' *Electricity and Magnetism.*

It is perhaps interesting to the readers of this volume to note that the famous Stokes' theorem, so important to modern differential geometry and to physics, first appeared in public as problem No. 8 of the Smith Prize Examination of 1854. Stokes was the examiner and Maxwell was one of the takers of the examination. That Maxwell was impressed with this theorem, and made extensive use of it in 1856 in the first of his epoch-making series

of papers that led to Maxwell's equations, is obvious from his papers and from his *A Treatise on Electricity and Magnetism* (1873). Maybe a hundred years from now somebody will remember one of the problems of the present collection?

C.N. Yang

Stony Brook

Preface

The written qualifying examination, a little publicized requirement of graduate physics programs in most universities, brings some excitement to the generally dull life of the graduate student. While undergoing this ordeal ourselves, we were reminded of the initiation ceremonies into certain strict monastic orders, designed to cause the novices enough pain to make them consider their vocation seriously. However, as the memory of the ghastly experience grows dim, our attitudes are gradually changing, and we now may agree that these exams help assure a minimal level of general physics knowledge necessary for performing successful research. Still, the affair is rather stressful, sometimes more a test of character than of knowledge (see Figure P.1). Perhaps it is the veteran's memory of this searing, yet formative experience that preserves the Institution of the Qualifying Exam.

Some schools do not have written exams, for instance: *Brown, Cal-Tech, Cornell, Harvard, UT Austin, Univ. of Toronto, Yale.* However, the majority do administer them and do so in a more or less standard form, though, the level of difficulty of the problems, their style, etc., may differ substantially from school to school. Our main purpose in publishing this book — apart from the obvious one to become rich and famous — is to assemble, as far as possible, a universal set of problems that the graduate student should be able to solve in order to feel comfortable and confident at the exam. Some books containing exam problems from particular universities (*Chicago, Berkeley, Princeton*) have been published; however, this is the first book to contain problems from different American schools, and for comparison, problems from *Moscow Phys-Tech,* one of the leading Russian universities.

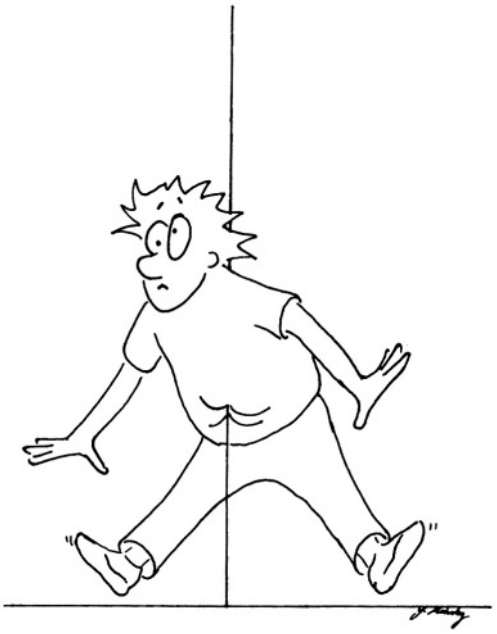

Figure P.1

Hapless Physicist Impaled on his own Delta Function
(Demonstrating the Perils of Insufficient Theoretical Rigor)

The other goal of the book is much more complicated and only partly realized: to allow comparison of problems from different schools in terms of breadth of material, style, difficulty, etc. This would have required analysis of a greater number of problems than we were able to include, and the use of approximately the same number of problems from each department (we had only a few problems from some universities and hundreds from others). We were much more concerned to present problems that would cover as much material as possible. We should note in this regard that the exams with the most difficult problems to solve are not necessarily the most difficult to pass — that depends on the number of problems that have to be solved, the amount of time given for each problem, and the way in which the problems are graded. We have not attempted to present such information, but we wish to point out that it is an important consideration in the selection of a graduate school and well worth investigating.

Quite often the written exam consists of two parts: the first part, covering "fundamental" physics, usually includes classical mechanics, electrodynamics, quantum mechanics, statistical physics and thermodynamics, and

sometimes special relativity and optics; the second part, containing "modern" physics, includes nuclear, atomic, elementary particle, and solid state physics, and sometimes general relativity and astrophysics. The scope and difficulty of the second part vary too much from school to school to allow generalization, and we will only deal with the first part. The problems will appear in two volumes: Part 1 — Mechanics, Relativity, and Electrodynamics, and Part 2 — Quantum Mechanics and Statistical Physics.

While reviewing the material submitted to us, we were not surprised to find that often the same problems, maybe in slightly different formulations, were part of the exams at several schools. For these problems, we have noted the name of the school whose particular version we solved next to the name we assigned to the problem, followed by the name or names of schools whose exams contained variants of the problem. If only part of the problem was used at a different school, we have indicated which one. We have also tried to establish a balance between standard problems that are popular with many physics departments and more original problems, some of which we believe have never been published. Many of the standard problems used in the exams have been published previously. In most cases, though, it is difficult to determine when the problem was first presented; almost as difficult as it is to track down the origin of a fairy tale. However, when we could refer to a standard textbook where the problem may be found, we have done so. Although it may be boring to solve a lot of the standard problems, it is worthwhile – usually they comprise more than half of all the problems given in the exams. We have to acknowledge grudgingly that all errors in the formulation of the problems and solutions are the sole responsibility of the authors. We have tried to provide solutions that are as detailed as possible and not skip calculations even if they are not difficult. We cannot claim that we have the best possible solutions and inevitably there must be some errors, so we would welcome any comments or alternative solutions from the reader.

We were encouraged by the response from most of the schools that we approached, which furnished us with problems for inclusion in this book. We would like to take this opportunity to thank the Physics Departments at Boston University (*Boston*), University of Colorado at Boulder (*Colorado*), Columbia University [Applied Physics] (*Columbia*), University of Maryland (*Maryland*), Massachusetts Institute of Technology (*MIT*), University of Michigan (*Michigan*), Michigan State University (*Michigan State*), Michigan Technological University (*Michigan Tech*), Princeton University (*Princeton*), Rutgers University (*Rutgers*), Stanford University (*Stanford*), State University of New York at Stony Brook (*Stony Brook*), University of Wisconsin (*Wisconsin-Madison*). The problems from Moscow Institute of Physics and Technology (*Moscow Phys-Tech*) came from different sources

— none from graduate qualifying exams, rather from undergraduate exams, oral exams, and magazines (Kvant). A few were published before, in a book containing a lot of interesting problems from Moscow Phys-Tech, but most were compiled by the authors. We wish to thank Emmanuel I. Rashba, one of the authors of that book, for his advice. We realize that there are many schools which are not represented here, and we welcome any submissions for Part 2 of this project.

It is our pleasure to thank many members of the Department of Physics at Stony Brook for their encouragement during the writing of this book, especially Andrew Jackson, Peter Kahn and Gene Sprouse, as well as Kirk McDonald of Princeton. We are indebted to Chen Ning Yang, who agreed to write the foreword for this book. We are grateful to: Dmitrii Averin, Fabian Essler, Gerald Gwinner, Sergey Panitkin, Babak Razzaghe-Ashrafi, Sergey Shokhor and Henry Silsbee for numerous discussions of problems and many useful suggestions, and especially to Bas Peeters, who read most of the manuscript; and to Michael Bershadsky, Claudio Corianò, and Sergey Tolpygo for contributing some of the problems. One of the authors (B.N.) wishes to thank the students at Oxford University and Oxford's Student Union for their invaluable help without which this book might not have been written. Finally, we would like to thank Vladimir Gitt and Yair Minsky for drawing the humorous pictures, and Susan Knapp for typing part of the manuscript.

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Note: CGS units are uniformly used in Chapter 3 for the purpose of consistency, even if the original problem was given in other units.

PART I: PROBLEMS

PART II: SOLUTIONS