Preface

Special Relativity arises from the need for a textbook at intermediate level, especially in North-American universities. There are nowadays several technological applications of Special Relativity in everyday life, including the GPS system, PET scanners, and other medical instruments. There are plenty of college-level, deliberately watered-down introductions to Special Relativity. These introductions typically serve a Modern Physics course and devote two chapters to the subject. Such short introductions are inadequate for physicists or scientists requiring a modern university course. What is worse, and few teachers will deny that, fundamental aspects of Special Relativity are usually not understood by the students and often not presented by the teachers. The four-dimensional world view is usually introduced only in a very colloquial way while the mathematical formalism of four-vectors and four-tensors, which is necessary to understand and formalize the idea of spacetime, is ignored. Yet, the latter is not so complicated and is accessible to students who have taken a linear algebra course provided that room is made in the relativity course for it. For most students the Modern Physics course is the only introduction to Special Relativity that they receive in their entire curriculum and, as a result, physics and mathematics students (the very ones who *must* know it) miss this fundamental subject. This knowledge gap is very serious since Special Relativity is, without doubt, one of the great intellectual achievements of mankind, exactly the kind of stuff that a student gets into physics for. From a teacher's logistical point of view, it is also relatively simple in comparison with, e.g., General Relativity or particle physics. Yet, too often the science student is robbed of this part of his or her education by systems too bent on entertainment and student counts. An essential part of the physics curriculum is sacrificed for fear of mathematics.

For students carrying on to a course on General Relativity, perhaps in graduate studies, this problem quickly becomes irrelevant but such students are a minority and physics departments in many small universities do not offer a General Relativity course or offer it infrequently. This situation is too common and it is true that the mathematical background of second- or third-year undergraduates is limited and that the formalism of tensors necessary for the study of Special Relativity needs to be taught in the course. One problem of this rationalization of the curriculum is the lack of a proper textbook on Special Relativity at a level higher than college physics or current Modern Physics courses, yet accessible to undergraduates who are not prepared to tackle General Relativity textbooks or Special Relativity classics such as Wolfgang Rindler's *Introduction to Special Relativity*.

Another complication is that, in an elementary course in Special Relativity, typical undergraduates have not yet taken a serious course in electromagnetism and do not yet master the Maxwell equations. Therefore, the usual textbook approach using Maxwell's theory as a trampoline for Special Relativity ends up being ineffective for students at this level. In retrospect, although the historical line of thought and the traditional pedagogical approach was electromagnetism first and then Special Relativity, and it is true that Maxwell's theory receives its most elegant and revealing formulation in Special Relativity, the latter is not just electromagnetism pushed to the extreme (this point was stressed early on by Pauli). Although electromagnetism was a useful trampoline to discover relativity, Einstein's 1905 theory is about the unveiling of the four-dimensional nature of the world, spacetime and its Lorentzian geometry, the equivalence of mass and energy, the modified mechanics, and the fundamental symmetries of this theory. The Maxwell field is only one of the possible forms of mass-energy that can live in Minkowski spacetime. This point of view is obvious after one takes a course in General Relativity or particle physics, but it is at odds with the discover-Special-Relativity-through-electromagnetism approach of many textbooks. An axiomatic approach to Special Relativity based on the Principle of Relativity and the constancy of the speed of light seems the best option here—the key physical concepts of the theory (relativity of simultaneity, time dilation, and length contraction) can be derived easily from these two postulates, and this is the path originally followed by Einstein. A constructive approach would need to be based on electromagnetism and the average undergraduate at this point still views the Maxwell equations as rather abstract or has not seen them at all. It is possible, however, to introduce the Lorentz transformation as the transformation relating inertial frames which leaves electromagnetism invariant without considering explicitly the Maxwell equations. An example showing a simple electromagnetic phenomenon will do, and this is the avenue taken in this book. The Lorentz invariance of the full Maxwell equations can be checked later when the student is familiar with them.

The book begins at an elementary level exposing and discussing in Chap. 1 and Chap. 2 all the basic concepts normally contained in college-level expositions, including the Lorentz transformation. Then, in Chap. 3, it introduces the student to the four-dimensional world view, making clear that this is implied by the Lorentz transformations mixing time and space coordinates. This is as far as the best Modern Physics textbooks seem to get. In addition, we make use of spacetime diagrams already in this part of the book (as well as, of course, in the following parts) to visualize the relevant discussion. Following this introduction, in Chap. 4, is the part that is avoided in lower-level courses; the formalism of tensors. It is my experience, gained by teaching Special Relativity courses in Canada, that once the student is persuaded that space and time do mix and is motivated by the need to understand the four-dimensional world, and once time is made during the course to explain this part, this chapter goes surprisingly easily and the fear of tensors proves unfounded. Chapter 5 then introduces the essential concept of causality missed in the Modern Physics courses and details the application of the general formalism of tensors to Minkowski space. The following Chap. 6 discusses the relativistic mechanics of point particles, four-momentum and four-force, the equivalence between mass and energy, and some applications. Chapter 7 describes relativistic optics and, whenever possible, uses the similarities between the motion of massless and massive particles to facilitate understanding and memorization. An optional short Chap. 8 follows, in which measurements in Minkowski spacetime are discussed to dispel the widespread impression that physical observables are coordinate components of four-vectors or four-tensors (and therefore, that all measurements are based on coordinate-dependent components).

Matter in Minkowski spacetime is discussed in Chap. 9. Here the energy-momentum tensor of a continuous distribution of mass-energy and its covariant conservation are introduced, and various (optional) energy conditions are presented. Angular momentum is discussed briefly. This part is followed by a discussion of the scalar field (presented first, as this is the simplest field in theoretical physics), of perfect fluids, and of the Maxwell field (which is now presented as one of the possible energy distributions in Minkowski space, although as an important one describing one of only four fundamental interactions).

For pedagogical reasons, it is easier to work in Cartesian coordinates and all the material introduced thus far (with the exception of the tensor formalism of Chap. 4, which is quite general) is restricted to these coordinates. This restriction facilitates the introduction of the ideas and concepts of Special Relativity, but is too restrictive. At this point, Chap. 10 introduces general coordinates, covariant differentiation, and geodesics (the emphasis is on computational skills rather than rigour or proof) and reformulates the previous material in arbitrary coordinate systems using covariant formulas. This chapter could be skipped if short of time during a course.

The mathematics essential to study Special Relativity is relatively simple: some calculus and linear algebra. The real difficulties are conceptual, not mathematical. The beginning student is fighting his or her own physical sense derived by everyday low-speed intuition, which conflicts with the results of Special Relativity. Mathematics is a tool which facilitates understanding and, by banning it from the course, current low-level oversimplified courses preclude the understanding of the basic concepts of the theory. It is much better to allow room for it in the course, although stripping it down to the essential, and then use it rather than paraphrasing it with obscure and wordy discussions which invariably fail to convey the essence of relativity.

Every chapter is supplemented by a section containing practice problems. These exercises constitute an essential part of the textbook and the student is urged to try them. The solution to selected exercises, as well as the numerical answers to others, appears at the end of the book.

For pedagogical purposes, in this book we retain explicitly the speed of light c in the formulas, i.e., we do not set c to unity except in spacetime diagrams and we include several steps in the calculations to facilitate comprehension by the beginner. We avoid the obsolete notions of rest mass and dynamical mass, transversal and longitudinal mass which were popular in old textbooks. Sections marked with an asterisk are optional and can be omitted without jeopardizing the understanding of the material which follows. Exercises referring to optional sections are also marked with an asterisk.

I hope that this book will help many students enjoy the beauty, elegance, and power of Einstein's theory. Have fun!

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