ABHAY ASHTEKAR, JÜRGEN RENN, ABNER SHIMONY

INTRODUCTION

This Festschrift is dedicated to John Stachel in honor of his seventieth birthday. The broad range of authors and themes represented in this volume testify to John Stachel's own wide intellectual horizons as well as to the large area covered by the intellectual circle around him. The contributions assembled here represent a gift not only to an eminent scholar but also to a warm and inspiring human being. Written by prominent authors in physics as well as in the history and philosophy of physics, these contributions may also constitute a useful compendium for any reader interested in the present discussion about the foundations of relativistic physics. They demonstrate that this discussion can only be fully appreciated if normally disparate strands are brought together and, in particular, if historians of science are willing to learn from active scientists, if philosophers of science are prepared to learn from historians not only about case studies but also about contexts, and if physicists are patient enough to listen to both historians and philosophers. The outstanding scholarly achievements of the physicist, philosopher, and historian John Stachel amply document the benefits that can be drawn from such lessons. He has not only succeeded in crossing disciplinary boundaries in his own work but, perhaps even more importantly, has created a interdisciplinary intellectual community, stimulated by his work and example. The contributions to this volume represent a small selection of the production of this community which has found, for many years now, their *Zentralorgan* in the *Einstein Studies*, co-edited by John Stachel. Many of the volumes that have appeared in this series of books are based on conferences on the history and philosophy of general relativity, another initiative of Stachel.

In accordance with the main themes relevant to Stachel's own oeuvre, the present volume has been divided into four parts, dealing with the "Historical and Philosophical Roots of Relativity," "Foundational Issues in Relativity and their Advancement," "Foundational Issues in Quantum Physics and their Advancement," and with "Science, History, and the Challenges of Progress," respectively. The volume opens with an autobiographical essay by John Stachel, written on the occasion of a workshop held in his honor in 1998 at the Max Planck Institute for the History of Science in Berlin. As one of this institute's first visiting scholars, he has in fact contributed much to shaping its scholarly profile from the very beginning. The volume closes with an appendix displaying the impressive list of Stachel's publications.

The first part is dedicated to the historical roots of the special and general theories of relativity, as well as the philosophical implications of relativity theory. Each con-

A. Ashtekar et al. (eds.). Revisiting the Foundations of Relativistic Physics, xv-xxii.

tribution to this part is in one way or another related to John Stachel's own seminal work in the history of relativity which has profoundly shaped the entire field. As a matter of fact, it is hardly conceivable that *any* scholarly contribution to the understanding of Einstein's work today would not be indebted to *The Collected Papers of Albert Einstein* and thus to their founding editor John Stachel. With his editorial team he not only gathered, identified, and analyzed primary sources, publishing them together with enlightening annotations and masterful surveys that have since been reprinted and translated into numerous languages, he also used the institution of the Collected Papers in an exemplary way making Einstein materials openly available and thus actively shaping the intellectual community surrounding the project. He has, in particular, stimulated many colleagues, and in particular younger scholars, to take up specific themes or materials coming up in the editorial process, thus promoting their careers in a decisive way.

Some of Stachel's key insights into the emergence of special and general relativity figure prominently in the background of the studies presented here. According to him, the tendency to oversimplify special relativity resulted from Einstein's embracing first the relativity principle and then the principle of the constancy of the speed of light, each of them understood as embodying the essence of the classical knowledge to be preserved in the new theory, mechanics and electrodynamics respectively. General relativity, on the other hand, is described by Stachel as the result of a drama in three acts, the first of which is represented by the conception of the Equivalence Principle in 1907, the second by Einstein's recognition of the non-Euclidean nature of the metric in 1912, and the third by the formulation of the field equations of gravitation in 1915. Among his many contributions to the analysis of this drama, three stand out as having attracted special attention not only from historians but also from physicists and philosophers of science. The first was his identification of the rigidly rotating disk as the "missing link" in the history of relativity, which was crucial to the second act of the drama—the identification of the metric tensor as the representation of the gravitational potential. Secondly, Stachel influentially interpreted Einstein's hole argument, originally formulated in 1913, as not only providing a stumbling block on the road to general relativity but as also representing the corner stone for a deep conceptual insight into the nature of spacetime. Thirdly, in a paper co-authored by Stachel, the myth of the anticipation of the discovery of the gravitational field equations by Hilbert was unraveled. This achievement was accomplished, as were several of his other influential contributions to the history of relativity, in the context of a major research project on the genesis of general relativity pursued at the Max Planck Institute for the History of Science.

Some of these issues are taken up by the contributors to the first part of this volume. A beautiful illustration of a conceptual analysis of the problem of rotation in relativity is provided by Malament's contribution, which deals with a definition of relative orbital rotation and its consequences. The contribution of Saunders focuses on Stachel's interpretation of the hole argument, using it to make the case for a non-reductive relationalism in an argument that reaches from Leibniz to Stachel. Stachel has in fact given what most relativists regard as the clearest expositions of Einstein's hole argument. His writings on this subject continue to have a major impact, especially on younger researchers. More generally, he has been a forceful spokesman for the deep lessons Einstein taught us. In numerous conferences and workshops bringing gravity theorists and particle physicists together, he has argued passionately for the theme "gravity is geometry," offering sharp and well-thought-out criticisms of the tendency to treat gravity just as another force in Minkowskian physics. Although largely unrecorded, these are also very significant contributions to the physics community, deeply appreciated by many.

The contributions in the first part of the volume offer a fair impression of some of the main aspects of the present discussion about the history and philosophy of relativity. This discussion is, in fact, characterized, on the one hand, by an ingenious use of the full technical apparatus of mathematical relativity for addressing philosophical questions about space and time, as exemplified by the papers by Malament and Saunders. On the other hand, it also brings out the long-range character of historical developments and of the role ordinary practice plays in the progress of science, beyond the supposedly isolated contributions of a few great discoverers. The importance of long-range developments is particularly evident in Eisenstaedt's paper on the effect of gravity on light in the framework of Newtonian theory. It is also evident in Norton's pursuit of counterfactual history of relativity as pioneered by John Stachel. Actually, Norton's paper illustrates both the continuity of problems between classical and relativistic gravitation theory and the possibility to use methods of counterfactual history in order to address philosophical issues such as the relation between the extension of the relativity of motion to acceleration and the representation of gravitational free fall by a curved affine structure. The collective practice of science is at the focus of Goldstein's and Ritter's analysis of the contributions to unified field theories between 1920 and 1930. The role of the ordinary practice of science—in the sense of practice by ordinary people—for the progress of science may also be illustrated by Einstein's interaction with an amateur scientist and the curious role this interaction played in the early history of gravitational lensing as described in the contribution by Renn and Sauer. Two further contributions to the first part deal with experiments relevant to the history of special relativity, the essay by Melcher on the Michelson experiment and the study by Janssen on the Trouton experiment of 1901. Janssen's painstaking analysis not only resurrects an ingenious but almost forgotten experiment to the glory it warrants. It also illustrates the extent to which even the establishment of special relativity was not a sudden breakthrough but a laborious process. In fact, a full explanation of the negative result of the experiment involved several fundamental conceptual insights of relativity theory introduced only in the decade following the experiment.

The second part, dedicated to "Foundational Issues in Relativity and their Advancement," circles around John Stachel's contributions to relativistic physics but also takes up stimuli produced by his historical work as is illustrated by Vishveshwara's paper on the rigidly rotating disk. Stachel's physics contributions are in fact primarily in the realm of general relativity and related areas. As historians and philosophers would expect of John Stachel, they carry his hallmark of conceptual depth. He has thus significantly contributed to preserving the style so characteristic of Einstein's own achievements, combining technical work with a conceptual analysis informed by philosophical and historical awareness. In the present volume, this style is particularly evident in the contributions by Ellis on the unique nature of cosmology, by Smolin on time, structure, and evolution in cosmology, and in the contribution by Anderson on timekeeping in an expanding universe.

Stachel's contributions to relativistic physics also testify to his remarkable mathematical abilities. In many cases, it is striking to see how far ahead of his time he was—for example in his very first work, his Master's thesis, which dealt with cylindrical gravitational waves. In it, Stachel investigated the global properties of these waves using the then newly discovered framework of null infinity and showed that, contrary to what one might have expected from the presence of the symmetry, these space-times are in fact asymptotically flat except along a single generator of null infinity. Although the mathematical ideas underlying this global analysis were very recent, his work was remarkably complete. Indeed, it could be further developed only in the early nineties. Stachel made another early contribution to the theory of gravitational radiation in exact general relativity by generalizing the Bondi-Sachs framework to include pure radiation matter fields. A second interesting set of contributions is in the area of the Cauchy problem and the issue of identifying the "true degrees of freedom" of the non-linear gravitational field. In particular, he laid the foundations of what is now known as a 2+2 formulation in which space-time is split by a family of two 2-dimensional surfaces, rather than the more familiar 3+1 decomposition in terms of a family of space-like 3-surfaces.

Accordingly, the second part includes a number of technical papers related to Stachel's interest in the foundations and further development of general relativity. Some of them challenge standard convictions or discuss exotic gravity models, in the spirit of both Einstein's and Stachel's unconventionalism, such as the paper by Wesley and Wheeler, proposing the vision of an action-at-a-distance concept of spacetime or the paper by Deser on "dimensionally challenged gravities." Some touch issues dear to Stachel's heart as they are, in one way or another, related to his own work, for example the 2 + 2 formalism exposed by d'Inverno or the masterful exposition of gravitational lensing from a spacetime perspective by Ehlers, Fritelli, and Newman. The subjects of other papers in this part may be more indirectly related to Stachel's own work, such as the issue of new variables approaches to the canonical formalism for general relativity discussed in Robinson's contribution. The canonical formalism is also used in the contribution by Goldberg suggesting an expression for a quasi-local energy in general relativity.

A further area of Stachel's research in relativistic physics concerns the equations of motion and conservation laws for particles with speeds small compared to the speed of light. The thrust of the early work in the subject was on deriving the conservation laws directly from equations of motion. This procedure can turn out to be cumbersome and is often conceptually obscure. In collaboration with Peter Havas, Stachel traced the origin of these conservation laws to symmetries of the appropriately defined Lagrangians and Hamiltonians, thereby providing a deeper understanding of the known laws and obtaining their generalizations to new situations. In his research he was also concerned with strings. In the early eighties, Stachel developed an elegant geometric description of time-like and null strings in general curved space-times. He then considered dust and fluids of strings (rather than point particles) and studied their equations of motion and conservation laws. It is remarkable that this mathematical and technically subtle work was completed during the time he was working on *The Collected Papers of Albert Einstein* in Princeton.

Stachel has enriched the research on relativistic physics with several other insightful papers. For example, he realized that the difference between exact and closed forms can be exploited to construct space-times which are locally static but globally only stationary and these lead to a gravitational analog of the Aharanov-Bohm effect. In another paper, he carried out a careful analysis of the structure of the Curzon space-time and discovered a number of interesting global properties. Yet another paper, devoted to geometry and carried out with Hubert Goenner, provides an elegant treatment of 3-dimensional isometry groups with 2-dimensional orbits in space-time. Further contributions to the second part represent an indirect reflection of this versatility of themes and methods of his physical research, in particular the paper by Plebanski and Przanowski on Cartan's structure equations for the vacuum twisting type-N and the proposal of a new description of autonomous mechanical systems by Tulczyjew.

The third part of this volume is dedicated to "Foundational Issues in Quantum Physics and their Advancement." Again, the contributions reflect themes central to Stachel's own work. Some general remarks on the character and achievements of this work may therefore not be out of place. In view of Stachel's integrity and harmoniousness of character, it is not surprising to find a continuity between features of his worldview and his ruminations on quantum mechanics. His Marxism is manifest in a pervasively critical attitude, a constant awareness of the reality of the material world and the constraints that it imposes on human activities, and an equal awareness of the reality of the social world, with its constraints on language, judgments, and ideals. His lifelong study of Einstein has implanted—or strengthened his native inclination towards—deep curiosity, independence of judgment, search for deep principles, exploratory attitude, love for mathematical beauty, and sense of wonder towards nature (which is almost a religious element in a non-religious temperament).

Though perhaps less known than his contributions to the history of relativity, Stachel has also significantly widened our views on the history of the quantum, focussing on Einstein's adumbrations, contributions, critical evaluations, and philosophical assessments of quantum mechanics. There are some novel discoveries and psycho-historical conjectures in Stachel's history, and new light is thrown even upon the well-known episodes. Stachel marshals evidence, for instance, to support the astonishing thesis that in 1904-5 Einstein had ideas about using the quantum of action to explain the structure of the atom and the emission spectrum.

In 1925 Einstein applied Bose's idea of the statistics of a gas of photons to a gas of identical atoms (later recognized to be of integral spin and named "bosons"). Stachel notes that in the studies of black-body radiation statistics and the statistics of massive bosons Einstein had intimations of the idea of entanglement before Schrödinger exhibited this feature in 1926 in many-particle wave functions. Another surprise revealed by Stachel's compiling of evidence is that Einstein anticipated Born's statistical interpretation of the wave function. He has also pointed out that, in spite of Einstein's life-long attachment to the concept of field, Einstein also explored