Alamos, firmly opposed it. With the revelation in late 1949 of Klaus Fuchs's espionage, President Harry S Truman gave the go-ahead in January 1950.

Looking back 50 years later, it seems to me that neither side had a strong argument. The policy of both the Soviets and the US was not to fight a nuclear war but to deter one; hundreds, and later thousands, of atomic bombs would have been sufficient; it seems to me that the H-bomb was unnecessary. The strength of the bombs was not critical.

Indeed, deterrence was successful; the existence of the two arsenals prevented the escalation of the cold war into a large-scale hot war. Truman had no choice in the political atmosphere of the time. Had Russia developed the H-bomb and the US not, he and the scientific community that opposed it would have been considered traitors.

In 1954, the Atomic Energy Commission cancelled Oppenheimer's security clearance. A hearing was held in April–May. At that hearing, many scientists testified in favor of restoring clearance. Teller and a few other scientists testified against it. When the decision came down against Oppenheimer, not a surprise in the McCarthy era, the majority of the scientific community blamed the witnesses they knew best, particularly Edward Teller.

Teller felt exiled for the third time: He had been forced to leave Hungary, then Germany; now a large portion of the scientific community ostracized him. In addition, he soon lost three of his close scientific friends: Fermi died in 1954, John von Neumann, a fellow Hungarian, died in 1957, and Ernest Lawrence, his patron at Berkeley, died in 1958.

The second half of Teller's life story is equally interesting. He became even more involved in atomic energy and weapons research. He became increasingly part of the political scene, an adviser to Republican politicians—particularly Nelson Rockefeller and Ronald Reagan. He pioneered and championed science education at all levels of schooling. His life and mine continued to intersect, although mostly in conflict on "scientific politics"—such issues as the development of an antimissile system, for example.

Edward Teller is a complex man who has been at the center of weapon development and of the influence of science on politics for much of the 20th century. His memoirs reflect this. I strongly recommend the book.

The Historical Development of Quantum Theory. Volume 6: The Completion of Quantum Mechanics, 1926–1941

Jagdish Mehra
and Helmut Rechenberg

Part 1: The Probability Interpretation and the Statistical Transformation Theory, the Physical Interpretation, and the Empirical and Mathematical Foundations of Quantum Mechanics 1926–1932.

Springer-Verlag, New York. 2000. $129.00, $69.95 paper (670 pp.). ISBN 0-387-98971-4, ISBN 0-387-95181-4 paper

Part 2: The Conceptual Completion and the Extensions of Quantum Mechanics 1932–1941. Epilogue: Aspects of the Further Development of Quantum Theory 1942–1999.

Springer-Verlag, New York. 2001. $149.00, $69.95 paper (941 pp.). ISBN 0-387-95086-9, ISBN 0-387-95182-2 paper

With the publication in two parts of volume 6 of *The Historical Development of Quantum Theory*, Jagdish Mehra and Helmut Rechenberg have completed their ambitious project. These six volumes represent an extraordinary amount of painstaking scholarship: In volume 6 alone are 1265 footnotes containing detailed information on persons in the text. The references to the 1252 pages of text of the two parts require 182 pages, and the author index runs to 27 two-column pages. A similar amount of scholarly apparatus is appended to each of the previously published volumes. The subject index to the six volumes, in part two of volume 6, takes 143 two-column pages! And this is not to mention the many interviews the authors conducted; the hunting down of unarchived correspondences; the background research on such subjects as the history of group theory, the history of probability, the history of causality, the political, economic, social, cultural, and intellectual histories of the countries involved, to name a few; plus the time and effort to master the technical matters they write about.

In volume 6, Mehra and Rechenberg concern themselves principally with the "completion" of quantum mechanics between 1926 and 1941. Part 1 deals with the establishment of the probability interpretation of quantum mechanics and its subsequent extensions. Chapter II treats in rich detail Max Born's scattering theory, the formulation of transformation theory by Pascual Jordan and Paul Dirac, Werner Heisenberg's coming to his uncertainty principle, Niels Bohr's criticism of it, and Bohr's groping toward a clear formulation of the notion of complementarity. Also in chapter II are the Einstein–Bohr debates at the 1927 and 1930 Solvay Congresses, a detailed exposition of the origins of quantum field theory (the quantization of the electromagnetic field by Dirac, and of matter waves by Jordan and Oskar Klein and by Jordan and Eugene Wigner), and the formulation of relativistic quantum mechanics (Dirac equation, Charles Galton Darwin's solution of the hydrogen atom, . . .).

Although much of the material here is known through the work of scholars like Mara Beller, David Cassidy, Olivier Darrigol, John Hendry, and Helge Kragh, it is good to have Mehra and Rechenberg's account; many novel features come through from their detailed chronological exposition. They have done justice to, among others, Jordan's enormous contributions to both the formulation and interpretation of nonrelativistic quantum mechanics, and subsequently to the development of quantum field theory. Jordan has tended to be neglected because of his involvement with National Socialism. Similarly, Heisenberg's struggles are beautifully rendered. Rechenberg's mastery of Heisenberg's scientific papers and of his correspondence with Wolfgang Pauli, Bohr, Albert Einstein, Hendrik Kramers, Paul Ehrenfest, Klein, and the countless others contained in Heisenberg's *Nachlass*, has been translated into a convincing and moving description of Heisenberg putting his stamp on the formalism and interpretation of quantum mechanics. Mehra and Rechenberg's account likewise puts into relief Pauli's staggering contributions to the technical developments (Pauli exclusion principle, solution of the hydrogen atom in matrix mechanics, spin, paramagnetism, quantum electrodynamics, . . .) and to the resolution of the philosophical problems engendered by the new mechanics of the micro domain. Pauli was the critic par excellence who was at the center of the vast network of correspondents and became the ultimate arbiter of the *Kopen-*

hagener Geist der Quantentheorie.

Chapter III of volume 6 contains a section on the empirical foundations of quantum mechanics, with brief, interesting accounts of the Raman effect, electron diffraction, the Ramsauer effect, and the role these experiments played in convincing the community of the validity of quantum mechanics. Mehra and Rechenberg's history of the mathematical foundations of quantum mechanics is detailed and contains a valuable exposition of the contributions of David Hilbert and his assistants Lothar Nordheim and John von Neumann, and those of Aurel Winter, and of Born and Norbert Weiner. The authors also present a fairly thorough history of the initial applications of group theory to quantum mechanics, that is, the work of Hermann Weyl, Wigner, and von Neumann in laying the mathematical foundations and that of Heisenberg, Hans Bethe, and others in applying these methods. Following that history, they present, in rapid fire, the formulation of the quantum mechanical explanation of molecular structure (Born–Oppenheimer approximation, the Heitler–London theory of the covalent bond, the contributions of Friedrich Hund, John Slater, Linus Pauling, Robert Mulliken, . . .) and discuss the evolution of the discipline of quantum chemistry. The free electron theory of metals (the applications of Fermi–Dirac statistics by Pauli and by Arnold Sommerfeld), the researches of Heisenberg on magnetism, and the work of Felix Bloch and Leon Brillouin and others on the band structure of electrons in crystalline solids, are the subjects of the penultimate section of chapter III. Chapter III concludes with a compact exposition of aspects of nuclear and cosmic-ray phenomena (George Gamow's theory of alpha decay, difficulties of the models with electrons in nuclei, scattering of protons off nuclei, . . .).

Chapter IV and an epilogue make up Part 2. Chapter IV presents the conceptual "completion" of the extensions of quantum mechanics during the 1930s. By the conceptual completion, they mean meeting the challenges posed in 1931 by Lev Landau and Rudolf Peierls to the interpretation of uncertainty relations in the relativistic domain and in 1935 by the Einstein, Boris Podolsky and Nathan Rosen (EPR) paper. Those challenges led to the famously obscure and difficult 1933 Bohr–Rosenfeld paper and to the refutation by Bohr, Heisenberg, and others of the claims of the EPR paper that the quantum mechanical description of physical reality is not complete. Chapter IV also includes a brief overview of solid-state and low-temperature physics during the thirties, and a concise account of the application of quantum mechanics and nuclear physics to the problems of stellar structure and evolution. Chapter IV also details the solution of the problem of energy production in stars by Bethe in 1938. As in many other places, Mehra and Rechenberg's thorough acquaintance with the German context provides important details not previously reported in the story of the solution of the stellar energy problem, (for example, the researches of Hund), and they contribute additional insights into Carl von Weizsäcker's researches in this area. The section on nuclear and high-energy physics during the thirties stands out. It is partly based on Laurie Brown and Rechenberg's book, *The Origin of the Concept of Nuclear Forces* (IOP, 1996) and gives a beautiful historical overview of the developments, difficulties, and challenges in these fields.

The epilogue, which concludes Mehra and Rechenberg's historical survey, attempts to cover in 230 pages "aspects of the further development of quantum theory" from 1942 to 1999—clearly an impossible task. The effort is further marred by the authors' devoting almost 100 pages to developments in quantum electrodynamics (QED) in the immediate post-war period (Sin-Itiro Tomonaga, Julian Schwinger, Richard Feynman, Freeman Dyson, . . .), materials taken (almost without change) from Mehra's *The Beat of a Different Drum: The Life and Science of Richard Feynman* (Oxford U. Press, 1994) and Kimball Milton and Mehra's biography of Schwinger, *Climbing the Mountain: The Scientific Biography of Julian Schwinger* (Oxford U. Press, 2000). By comparison only a single paragraph is devoted to spontaneous symmetry breaking (Jeffrey Goldstone, Yichiro Nambu, Peter Higgs, Philip Anderson, . . .), only 13 pages to the "Standard Model and Beyond," 7 to the solution of the problem of superconductivity, and 3 to "Critical Phenomena and the Renormalization Group"! No mention is made of Dyson and Andrew Lenard's and Elliot Lieb's foundational work on the stability of matter, proving that NZ electrons (obeying Fermi–Dirac statistics) interacting through Coulomb forces with N nuclei of charge Z, have a binding energy and occupy a volume proportional to N. Nor is there any mention of the important work of Michael Fisher, Leo Kadanoff, Steven Weinberg, and many others that elucidates why particular representations—Navier–Stokes equations, nonrelativistic Schrödinger equations, QED, and so forth—work so well in their domain of applicability, and what their relationships are to more "fundamental" theories. Expanded treatment of these subjects would have been more in keeping with the spirit of their book. Mehra and Rechenberg do manage to be more thorough when they present the new aspects of the interpretation of quantum mechanics and examine the work of David Bohm, the Aharanov–Bohm effect, and Hugh Everett's formulation of the many-world interpretation; when they point to the important analyses of Andrew Gleason and of Joseph Jauch of the mathematical representations of quantum mechanics; and when they emphasize the critical importance of the researches of John Bell and of his inequalities and analyze the experiments of Alain Aspect, Serge Haroche, and others clarifying facets of the emergence of decoherence in quantum mechanical measurements.

I must confess, with regret, that I find the entire six-volume work only the sum of its parts. To a large extent, Mehra and Rechenberg have written their history of the development of quantum mechanics in the shadow of Leopold von Ranke. The establishment of the facts of the past has been their main effort, and the importance and unique value of archival research in this connection is in evidence throughout all 6 volumes. For them, as for Ranke, "Strict description of the fact . . . is without doubt the supreme law" and they would like their account "to state what actually happened." But clearly this is an illusionary if not futile attempt. Quantum mechanics is so great an "intellectual revolution" that no account of its development can be complete. Mehra and Rechenberg have lavished upon us such rich details, have attempted to make their exposition so complete, that at times we see only the trees and not the forest.

Volume 6 shares a fault that I have found with the earlier volumes. Mehra and Rechenberg tend to ignore the work of other historians of science, or not to refer to them. Beller, Catherine Chevalley, Darrigol, Kragh, John Heilbron, and others have contributed importantly to the history of quantum mechanics, but there is but scant reference to their work. Darrigol has written many papers on the history of quantum field theory, and in particular on the genesis of the Bohr–Rosenfeld paper. But only two of his papers are quoted, and his book, *From c-Numbers to q-Numbers* (U. of California Press, 1992) is not referred to. Chevalley, who has written extensively and insightfully on the philosophical traditions that contributed to Bohr's and Heisenberg's interpretation of quantum mechanics, receives similar treatment. Tian Yu Cao published an important book, *The Conceptual Developments of 20th Century Field Theories* (Cambridge U. Press, 1997), which was extensively and very favorably reviewed by leading physicists, historians, and philosophers. There is no reference to it in Volume 6.

My criticisms notwithstanding, Mehra and Rechenberg's *The Historical Development of Quantum Theory* is indeed a most impressive accomplishment. The volumes will undoubtedly become the point of departure of all future investigations into the history of quantum mechanics.

SILVAN S. SCHWEBER
Brandeis University
Waltham, Massachusetts

Exploring Black Holes: Introduction to General Relativity

Edwin F. Taylor
and John Archibald Wheeler
Addison Wesley Longman,
New York, 2000. $37.33 (286 pp.).
ISBN 0-201-38423-X

It has been 85 years since Einstein's formulation of general relativity. In that time, the theory has been extensively tested in its weak-field limit in the Solar System. The prediction of gravitational waves has also been dramatically confirmed by the orbital decay of the binary pulsar 1913+16. General relativity is crucial to understanding the astrophysics of black holes, neutron stars, gravitational lenses, and the expansion of the universe. It has even found practical applications: The global positioning system would fail very quickly if it did not take into account general relativistic corrections.

General relativity also occupies a central place in modern physics. It is our best theory of the gravitational interaction, and provides a radical new view of what it means to be in an inertial frame of reference in the presence of gravity, which couples to all matter and energy. General relativity is also central to the effort to unify all the fundamental interactions of physics within a consistent and experimentally testable quantum theory of gravity. Finally, classical general relativity is on the brink of an experimental revolution, with the expected detection of gravitational waves by new generations of such ground-based observatories as LIGO (Laser Interferometer Gravitational Wave Observatory).

Nonetheless, there is no sign of general relativity in the core undergraduate physics curricula of most colleges and universities, apart from the trivial (and highly misleading) derivation of the Schwarzschild radius from Newtonian escape velocity arguments. What a shame, especially when students are generally filled with a tremendous desire to learn about such exotic objects as black holes! The likely reason for this gap in the curriculum is that the mathematics is considered to be too daunting. However, books are coming on the market, that succeed in explaining relativistic gravity correctly and with a minimum of math.

Exploring Black Holes, by Taylor and Wheeler, is a superb example. No tensors or differential forms here; not even any calculus of variations to derive geodesics! Instead, the book uses very basic differential and integral calculus to get at all the essential physics of black holes. Every physicist should be exposed to the ideas presented here at some time in his or her career.

As would be expected from these authors, the book is extremely well written, and the presentation is physical and intuitive. Common student questions and misconceptions are anticipated and addressed head-on in a series of dialogue formats sprinkled throughout the text. Technical jargon is almost entirely avoided. The importance of different classes of observers is emphasized, as are the ideas of extremal aging for geodesic motion and the fact that energy is a unified whole in general relativity. Taylor and Wheeler masterfully explain exactly what those coordinates in the metrics mean and how they are related to measurements by local observers.

This book should be accessible to physics majors in their sophomore year or later; by then they should have had some exposure to basic Newtonian mechanics and special relativity. Its organization provides considerable flexibility, making it suitable for use in courses of many kinds. The central material is presented in just five short chapters entitled "Speeding," "Curving," "Plunging," "Orbiting," and "Seeing." Interspersed among these chapters are seven "Project" chapters, which lead the student through various interesting applications, including gravitational lensing, rotating black holes, and an introduction to cosmological spacetimes.

This book is not intended to be a broad overview of general relativity. The Einstein equations are not presented or explained, nor is there any discussion of gravitational waves. The cosmology project chapter just scratches the surface of that important field. Such limited treatment is perhaps just as well, given the authors' stated philosophical objections to the recent observational evidence of accelerating expansion. To their credit, however, this is treated fairly in the text. The book also concentrates on the physics of black holes, not their astrophysics, so readers should not expect to find much on accretion disks, iron K-alpha lines, jets, or black hole mass/stellar velocity dispersion correlations.

As a textbook that really teaches the basic physics of black holes and focuses on that physics rather than on difficult mathematics, this book is right on the mark. I can only hope that *Exploring Black Holes* and similar books will equip us to modernize undergraduate physics curricula to include a discussion of general relativity, one of the truly revolutionary advances in 20th-century physics, an advance that is central to modern fundamental physics.

OMER BLAES
University of California, Santa Barbara

Nearest Star: The Surprising Science of Our Sun

Leon Golub and Jay M. Pasachoff
Harvard U. Press, Cambridge,
Mass., 2001. $29.95 (304 pp.).
ISBN 0-674-00467-1

Nearest Star: The Surprising Science Of Our Sun tells the story of our most important star, the Sun, and its relationship to our most important planet, Earth. It is a story with many facets, and multiple links to fundamental physics that might surprise as well as engage the reader. The book is beautifully written and conveys the love that the authors have for the subject.

One of its authors, Leon Golub, is a solar astronomer and one of the leaders of the Transition Region and Coronal Explorer (TRACE) team. The other, Jay Pasachoff, is a noted astronomer who has seen more total eclipses than perhaps any other person. Pasachoff has written several astronomy textbooks, including, one of the best middle-school science