MAKING 20TH CENTURY SCIENCE

How Theories Became Knowledge

STEPHEN G. BRUSH

Making 20th Century Science

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Stephen G. Brush with Ariel Segal

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To my granddaughter

Rebecca Nicole Roberts

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PREFACE

Historians have chronicled the observations, experiments, and theories of scientists from antiquity to the present. This book could not have been written without surveying their publications. But only a few historians have presented evidence to answer the question: why were these theories accepted, at least for a while, as valid knowledge? Was it because the theories successfully *explained* the observations and experiments, or because they successfully *predicted* the results of observations and experiments not yet done?

This question seems to have been left for philosophers to answer. Yet it calls for historical research plus, in some cases, interviews with scientists. Philosophers sometimes seem more interested in discussing whether scientists *should* accept theories because of predictions or explanations, rather than what they actually *do*. So I have to persuade philosophers to consider historical evidence, and to convince historians that they should answer—in their reception studies—questions of interest to philosophers.

Of course the first thing I needed for my project was access to a good library. I was able to use the Library of Congress and the Princeton University libraries for short periods of time. The Niels Bohr Library at the American Institute of Physics in College Park, Maryland has a unique collection of textbooks, which happens to be just what I needed to study the reception of physics theories in the early twentieth century; the University of Maryland library, also in College Park, owns Max Born's personal library. The University of Pennsylvania Library and the Chemical Heritage Foundation, both in Philadelphia, have excellent collections of older chemistry books.

If you already know what book you need to look at, because someone else has cited it, you may have to rely on interlibrary loan. I have to thank the librarians at three institutions for efficiently obtaining books from other libraries for me: McKeldin Library at the University of Maryland, the Institute for Advanced Study at Princeton, and the Brandywine Hundred Library in Wilmington, Delaware.

What about archives of unpublished letters and manuscripts? In general I have not used these sources, for two reasons: First, to search the archives of the hundreds or thousands of scientists who *might* have recorded their opinions of one of the theories included in my project would be impractical. Therefore I have included only a few such documents, mainly those of Einstein and his correspondents that have been published in the *Collected Papers of Albert Einstein*. Second, published comments on a theory are likely to have more influence on the scientific community and (through textbooks) on the next generation.

During the three decades I have worked on this project, I have enjoyed valuable assistance from many historians, philosophers, and scientists: Peter Achinstein (Chapter 3), Stephen Adler (Chapter 9), Gar Allen (Chapters 1, 13, 14), Ralph Alpher (Chapter 12), Gustav Arrhenius (Chapter 1), Francisco Ayala (Chapter 14), John Beatty (Chapter 14), Richard Bellon (Chapter 2), Vincent Brannigan (Chapter 1), Dieter Brill (Chapter 11), L. M. Brown (Chapters 3 and 9), Louis Brown (Chapter 8), David Cassidy (Chapter 3), Matt Chew (Chapter 14), John Connerney (Chapter 1), David L. Cooper (Chapter 10), David P. Craig (Chapter 10), James Crow (Chapter 14), Lindley Darden (Chapters 3, 13, and 14), Bibhas De (Chapter 1), Alex Dessler (Chapter 1), Igor Dmitriev (Chapter 5), Tim Eastman (Chapter 1), C.W.F. Everitt (Chapter 11), John Gaffey (Chapters 1 and 15), Joseph Garratt (Chapter 10), George Garratty (Chapter 14), Owen Gingerich (Chapter 12), Thomas Gold (Chapter 12), George Gorin (Chapter 5), O. Wally Greenberg (Chapter 9), Ivan Gutman (Chapter 10), J. L. Heilbron (Chapter 7), Sandra Herbert (Chapter 14), Robert Herman (Chapter 12), Robert B. Hermann (Chapter 10), Norris Hetherington (Chapter 12), Richard Highton (Chapter 14), Roald Hoffman (Chapter 10), Gerald Holton (Chapter 11), Ruth Kastner (Chapter 13), Margaret Kivelson (Chapter 1), Alexei Kozhevnikov (Chapter 7), Helge Kragh (Chapters 2 and 3), Larry Laudan (Chapters 1, 2, and 3), Aleksey Levin (Chapters 9 and12), Richard Lewontin (Chapter 14), Jane Maienschein (Chapter 13), David Matthews (Chapter 1), Deborah Mayo (Chapter 3), Robert McColley (Chapter 1), Edward McKinnon (Chapter 3), Arthur I. Miller (Chapters 3 and 11), Peter Morris (Chapter 10), Gonzalo Munevar (Chapters 3 and 7), Ludmilla Nekoval-Chikhaovi (Chapter 5), Norman F. Ness (Chapter 1), Sally Newcomb (Chapters 2, 5, and 12), Mary Jo Nye (Chapter 5), David O'Brochta (Chapter 14), Denis Papadopoulos (Chapter 1), D. J. Pasto (Chapter 10), Lewis Pyenson (Chapter 11), Anya Plutynski (Chapter 14), Duncan Porter (Chapter 2), Helmut Rechenberg (Chapter 3), Alan Rocke (Chapter 5, 6, and 10), William K. Rose (Chapter 12), Theodore Rosenberg (Chapter 1), David Rudge (Chapter 14), Christopher T. Russell (Chapter 1), Halley Sanchez (Chapter 11), Mendel Sachs (Chapter 11), Carl Sagan (Chapter 1), Eric Scerri (Chapters 3 and 5), Wilfried Schroeder (Chapter 1), S. S. Schweber (Chapter 9), Ezra Shahn (Chapter 14), Sason Shaik (Chapter 10), Dudley Shapere (Chapter 9), Stanley Shawhan (Chapter 1), V. Betty Smocovitis (Chapter 14), George A. Snow (Chapter 9), Michael Sokal (Chapters 1, 5, and 11), Carol Sokolski (Chapter 14), Katherine Sopka (Chapter 3), David Stern (Chapter 1), Roger Stuewer (Chapter 7), Frank Sulloway (Chapter 11), Frederik Suppe (Chapter 3), Roger Thomas (Chapter 14), Virginia Trimble (Chapters 1 and 12), Ron Westrum (Chapter 1), Polly Winsor (Chapter 14), John Worrall (Chapter 3), and Nick Zimmerman (Chapter 14).

In a class by himself is my excellent assistant Ariel Segal, who tracked down many missing facts and references essential to this book.

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For permission to reprint substantial portions of articles previously published in journals and books, I thank the American Association for the Advancement of Science, publisher of *Science* (Chapter 11); the American Philosophical Society, publisher of *Choosing Selection* in its *Transactions* (Chapter 14); Elsevier Science Ltd.,

publisher of *Studies in History and Philosophy of Science* (Chapters 6 and 10); the Geological Society (London), publisher of *The Age of the Earth from 4004 BC to AD 2002* (Chapter 12); Kluwer Academic Publishers, publisher of *Journal of the History of Biology* (Chapter 13); the University of Chicago Press, publisher of *Isis* (Chapter 5); the Philosophy of Science Association (Chapter 3); the MIT Press, publisher of *Perspectives on Science* (Chapter 12); the Regents of the University of California (Chapter 7); and Springer Science and Business Media, publisher of *Physics in Perspective* (Chapter 11).

Part One discusses general issues such as the role of prediction and explanation in science, the concept of "reception" as used by historians of science, and the debate about whether science is "socially constructed." Part Two applies these concepts in the history of atomic and molecular chemistry and physics, especially the role of quantum mechanics. Part Three covers relativity theory and cosmology. Part Four discusses a selected sequence of theories in biology including chromosome theories of heredity and the revival of Darwin's theory of evolution by natural selection. Part Five summarizes the results and compares the success of prediction and explanation. Notes for the chapters are followed by a selected bibliography and an index.

Making 20th Century Science

PART ONE

The Reception and Evaluation of Theories in the Sciences

1

Who Needs the Scientific Method?

> Most Americans have never met a scientist, and despite having been 'taught science' at school, most have no real idea of how a scientific consensus is reached. . . . Every adult should have a base of scientific understanding about how the world works. But understanding the process through which scientific knowledge develops is equally critical.
>
> —Bruce Alberts, *former president of the U. S. National Academy of Sciences (2010)*

> Among the work to be done is to achieve some understanding of what is actually involved in rational acceptance and proof in science, of what, in Boyle's words, deserves 'a wise man's acquiescence.' . . . This job involves exploring the diverse range of contexts, historical and contemporary, in which inquiry is carried out.
>
> —Arthur Fine, *professor of philosophy of science at Northwestern University and later the University of Washington (1996)*

How do theories become scientific knowledge? I try here to answer that question by using several examples from the history of modern science. I have selected examples from chemistry, physics, astronomy, and biology. All of them are well known and most have been studied carefully by historians, so we know something about how the theories were developed and tested. The one thing often missing is the final stage of the process: the adoption of the idea by the relevant scientific community. We know that it *was* accepted, but often we don't know much about *why* it was accepted.

The process of acceptance (or rejection) of new theories—their reception, as historians call it—has been widely discussed but not well understood. Most reception studies focus on one of a few famous cases—the theories of Darwin, Freud, and Einstein—and tell us more about the response of the public or by the scientific community as a whole than about the *reasons* why *experts* accepted those theories. When authors do suggest reasons they often just give their own opinions, rather than citing publications or letters that would provide reliable evidence for the views of experts at the time the new theory was published.