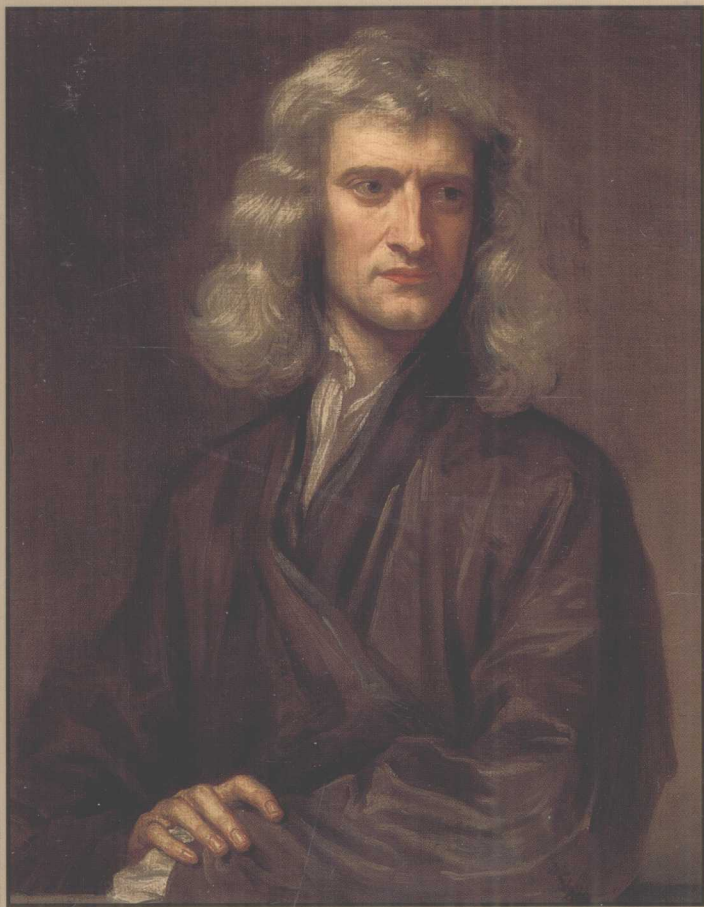


NEWTON



SELECTED AND EDITED BY
I. BERNARD COHEN AND
RICHARD S. WESTFALL

A NORTON CRITICAL EDITION

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NEWTON

TEXTS
BACKGROUNDS
COMMENTARIES

Selected and Edited by

I. BERNARD COHEN RICHARD S. WESTFALL
HARVARD UNIVERSITY and INDIANA UNIVERSITY

W • W • NORTON & COMPANY • *New York • London*

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D. T. Whiteside, "Newton the Mathematician," Zev Bechler, ed. *Contemporary Newtonian Research* (Dordrecht: Reidel, 1982), pp. 110–16. Copyright © D. T. Whiteside. Reprinted by permission of D. T. Whiteside.

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Printed in the United States of America

First Edition

The text of this book is composed in Electra
with the display set in Bernhard Modern.

Composition by Binghamton Valley.

Manufacturing by the Maple-Vail Book Manufacturing Group.

Book design by Antonina Krass

Library of Congress Cataloging-in-Publication Data

Newton, Isaac, Sir, 1642–1727.

Newton : texts, backgrounds, commentaries / selected and edited by

1. Bernard Cohen and Richard S. Westfall.

p. cm.—(A Norton critical edition.)

1. Newton, Isaac, Sir, 1642–1727. 2. Science. I. Cohen,

I. Bernard, 1914– . II. Westfall, Richard S. III. Title.

QC16.N7N475 1995

500—dc20

92-21165

ISBN 0-393-95902-3

W. W. Norton & Company, Inc., 500 Fifth Avenue, New York, N.Y. 10110

W. W. Norton & Company Ltd., Castle House, 75/76 Wells Street,
London W1T 3QT

Preface

The purpose of this volume is to give the reader a collection of the writings of Isaac Newton, together with commentaries that extend over four centuries and display the continuing importance of his thought. In conformity with the goals of the series, this edition attempts to show why Newton has been almost universally hailed as one of the greatest scientists who ever lived, while at the same time illustrating why his achievements came to symbolize the rationality of the Enlightenment at its highest form, justifying the subsidiary title of the *Age of Reason*.

No attempt has been made here to include selections that would illustrate every aspect of Newton's life and career. For example, we have not included documents that relate to his activities as member of Parliament for Cambridge University, nor any documents relating to his activities as Warden and Master of the Mint, nor of his presidency of the Royal Society. Because the aim has been to make available the main lines of his thought, we have also omitted Newton's presentations of the scientific instruments he invented, notably, the reflecting telescope and the reflecting octant for use of navigators at sea. For some specialized subjects, especially those that we have not presented, a Selected Bibliography has been appended. Although many of the major Newton scholars are represented here, no attempt has been made to include writings from each and every contributor to the Newtonian corpus of scholarship—an almost impossible task considering the enormous magnitude of today's "Newton industry."

The seventeenth- and eighteenth-century texts presented here are given in what has been sometimes described as a "modern" but definitely not "modernized" form, that is, we have in no case altered the word order, sentence structure, or spelling of Newton's original documents, nor those of any contemporaries. We have, however, sometimes altered the punctuation for ease of readership, and we have generally spelled out the abbreviations, as eighteenth-century printers did: Where Newton would write a *thorn* (looking like a capital Y), we have replaced this with *th*, and we have similarly dropped all superscript letters. Thus, readers need not be puzzled by trying to interpret abbreviations with the superscript letters, nor need they be puzzled by such expressions (as are found in scholarly transcriptions of Newtonian documents) as *yt* ("that"), *yn* ("than" or "then"), or such almost unintelligible monstrosi-

ties as *matys* (“majesty’s”). We have also spelled out the ampersand. The purpose of our edition is to make texts available and readable, not to pose puzzles for the reader.

The editors hope that this collection will prove of interest to scholars and students alike, as well as general readers interested in the history of thought, science and its history, philosophy, intellectual history, theology, and other disciplines.

I. Bernard Cohen
Richard S. Westfall

General Introduction

Scientists, philosophers, and historians agree that Newton's scientific achievements represent the peak of the Scientific Revolution that began in the late sixteenth century, the series of rapid changes in the knowledge of nature and the mode of studying natural phenomena that produced our modern science. Often, Newton's collective achievements are known as the Newtonian Revolution.

We get some measure of Isaac Newton's greatness when we learn that he was the author of not just one, but several revolutions. One was in mathematics, the others in the physical sciences. In fact, Newton made so many different kinds of fundamental contributions to science that even if we were to ignore most of them, we would still have to rank him as one of the ten or twelve most important scientists who ever lived.

In mathematics, Newton (along with Gottfried Wilhelm Leibniz) invented the calculus—the differential as well as the integral calculus—the language of the exact sciences and now increasingly of the social sciences. He pioneered the use of infinite series, and he introduced methods of calculation and approximation still in use today. This was his first revolution.

In optics, Newton established the heterogeneity of sunlight and reformulated understanding of the nature of color. His work revealed why the sky seems blue, and it led to a mathematical exposition of the formation of rainbows. His analysis of light and color has formed the basis of our continuing understanding of color vision.

One by-product of Newton's discoveries concerning light and color was his design of a new kind of telescope, a reflector, that eliminated chromatic aberration by forming the image by way of a mirror rather than an objective lens, a technique used in almost all large telescopes today. Newton's *Opticks*, first published in 1704, concluded with a general research program in experimental physical science that formed an agenda for research in the eighteenth century. The work in optics constitutes a second Newtonian Revolution.

A third revolution was Newton's codification of the science of mechanics, a subject that he dignified with the name *rational mechanics*. Anyone who has studied physics knows Newton's three laws of motion, which remain fundamental to that subject. It was Newton who defined the modern concept of mass, essential for the development of

the study of matter. He recognized that there are two different measures of mass—one of which today we call gravitational and the other inertial. He appreciated that in classical mechanics only an experiment can prove their equivalence, and he designed and carried out such an experiment. This equivalence is a basic feature of Einsteinian relativity theory, but the recognition of the problem and of the need for a proof must rank as one of Newton's primary discoveries. The establishment of the science of rational mechanics on mathematical principles forms the core of Newton's third and possibly greatest revolution.

In Newton's day, however, and for at least a century or more afterward, when reference was made to the Newtonian Revolution, people had in mind a fourth revolution, symbolized by Newton's discovery of the principle of universal gravitation. Newton not only discovered the principle, but he also found the quantitative law of gravity. He used the law to elaborate the Newtonian "system of the world," to explain the phenomena of heaven and earth in a single mathematical system. He thus fulfilled the dream of Galileo Galilei, Johannes Kepler, and René Descartes.

Newton's gravitational cosmology accounted for the motions of planets, satellites, and comets—the constituent bodies of the universe in which we live—and also the motion of bodies on earth. He was able to explain such puzzling phenomena as Galileo's discovery that freely falling bodies on earth, whatever their weight, have the same acceleration or motion of fall. Newton's cosmology implied that comets are a kind of planet and that therefore most of them will move in elliptical orbits, returning to our part of the solar system from distant space at regular intervals. Newton also was able to explain how the phenomena of tides in the ocean are caused by the gravitational attraction of bodies of water by the sun and moon. Generally speaking, by the phrase "Newtonian Revolution," historians mean the codification and elaboration of rational mechanics and the development of the system of the world based on gravitational celestial mechanics.

Today's reader might find this partial catalogue to be impressive because of the differences among Newton's several areas of activity—pure mathematics, practical computation, experimental physics, optics, rational mechanics, astronomy. The student of Newton's life, however, might be even more impressed by the fact that all of this achievement in science and mathematics was the fruit of only a part of his creative activity. By profession he was a university teacher; later he served as a member of Parliament. During his mature years he was a public servant, directing the Mint during the recoinage in England in the last years of the seventeenth century and during the opening decades of the eighteenth.

Even during Newton's early creative years in science, while he was a university professor, his main concerns were not exclusively science as

we would understand that term today, that is, physics or astronomy or mathematics. Rather, his intellectual activities embraced the interpretation of Scripture, biblical chronology, theology and prophecy, and alchemy. We stand in awe before his mighty scientific achievement, but all the more so when we recognize that it was the product of only a part of his creative energy. Even a modest portion of these achievements would have sufficed to earn him a place among the scientific immortals.

Isaac Newton was born on Christmas Day, 1642, in Woolsthorpe, England, the posthumous child of a father nearly three months dead. Descended from a family of yeomen, Newton seems to have been the first person in the line who could write his own name. His mother remarried when he was three, leaving him to be reared by his aged maternal grandparents. Thus deprived of any contact with his father and of a mother's loving care, Newton grew up an introvert. He never married and had few intimate friends. Suspicious of others, he was reluctant to give forth his discoveries. It has been said that every discovery of Newton had two aspects: Newton had to make the discovery and then others had to find out that he had done so. His life was punctuated by violent intellectual quarrels—with Robert Hooke, with John Flamsteed, and above all with Leibniz.

During most of his creative life, Newton was Lucasian Professor of Mathematics at Cambridge University, where he was a Fellow of Trinity College, which he had attended as an undergraduate. During these intense years, he produced the calculus and his other innovations in mathematics. These were also the years in which he developed his analysis of light and color and invented the reflecting telescope. It was the telescope that first brought him to the attention of the Royal Society, which promptly elected him a Fellow.

The crowning achievement of the years of Newton's professorship was his codification of the principles of rational mechanics and their elaboration in his classic *Mathematical Principles of Natural Philosophy* (*Philosophiae Naturalis Principia Mathematica*; often referred to as the *Principia*), first published in Latin in 1687 and reissued in revised editions in 1713 and 1726. It was in the third "book" of this treatise that Newton set forth the principle and law of universal gravitation and elaborated his "system of the world."

In 1696, just nine years after publishing his *Principia*, Newton left university cloisters to become Warden and later Master of the Mint in London. He spent his remaining years supervising the coinage of English money and (curious to contemplate) the capture, interrogation, and prosecution of counterfeiters. During these years, as president of the Royal Society, he ruled British science with an iron hand. He died on March 20, 1727, at the age of 84 and was buried in Westminster Abbey.

In the eighteenth century and ever afterward, Newton has been esteemed not only for his technical achievements, but also as a formula-

tor of the proper method of scientific investigation. Newton himself assumed this role by devoting the final “queries” of the *Opticks* to questions of methodology, the way to make experiments and to interpret experimental evidence, and by formulating a series of *regulae* (“rules”) for proceeding in *natural philosophy*, or physical science. Furthermore, his own achievements in science stood as proofs of the validity of his method and rapidly became the paradigm of scientific investigation. Newton’s great reputation—among scientists, philosophers, economists, political theorists, social thinkers, and even poets—derived from his *Opticks*, written in a simple and effective English style and dealing with a subject that captures the imagination. His *Principia*, on the other hand, was a difficult book, even for those initiated in the methods of mathematics. This book required of the reader a skill in such topics as conic sections and other technical aspects of mathematics and demanded an understanding of Newton’s own new method of limits and the principles of *fluxions* (the name he gave to the calculus), with the result that the readership was necessarily small. Even the most accessible part of the *Principia*, the elaboration of the “system of the world,” was purposely written by Newton in a difficult manner to prevent all but the hardest readers from going through it.

In spite of the general inaccessibility of the *Principia*, Newtonian natural philosophy gained widespread currency because of the efforts of a dedicated group of interpreters who wrote about Newton’s achievement in terms that the average well-educated person could understand. This group included Henry Pemberton, a medical doctor skilled in mathematics who had edited the third edition of the *Principia* under the author’s direction, Colin Maclaurin, a mathematician whose fame today rests largely on the infinite series that bears his name, and Voltaire, who learned his Newtonian physics from the Marquise du Chastellet, the translator of the *Principia* into French, the best vernacular version of Newton’s masterpiece for two centuries. The significance of Newton’s achievement thus became generally recognized, even among people for whom the densely packed mathematical pages of the *Principia* remained forever a closed book.

In introducing Newton’s *Opticks* in a modern reprint, Albert Einstein wrote of “fortunate Newton,” living in the “happy childhood of science!” Einstein declared that to Newton, “nature . . . was an open book, whose letters he could read without effort.” Above all, he saw Newton as “strong, certain, and alone,” a scientist whose “joy in creation” and “minute precision” are evident in every word and in every figure. The confluence of Newton’s creative genius and a state of science where, as Newton himself wrote, “great oceans of truth” lay undiscovered before him has been the envy of many of Newton’s scientific successors. In different versions, both Joseph-Louis Lagrange and Pierre-Simon, Marquis de Laplace regretted that there was only one fundamental law

of the universe, the law of universal gravitation, and that Newton had lived before them, foreclosing them from the glory of its discovery. Newton's position as the primary discoverer, the scientist who brought to a climax the researches initiated by his illustrious predecessors (scientists such as Nicolaus Copernicus, Galileo, Kepler, Descartes, Hooke, and Christiaan Huygens) became a common theme during the Enlightenment in the eighteenth century, when Newton was enthroned as the primary architect of the Age of Reason. Surely no one has ever captured this image of Newton better than the poet Alexander Pope, with his famous couplet:

Nature and Nature's Laws lay hid in Night:
God said, *Let Newton be!* and All was Light.

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Part 1

NATURAL PHILOSOPHY



Introduction

Newton's introduction to natural philosophy was the Aristotelianism that continued to dominate the curriculum of European universities when he arrived at Cambridge in 1661. This philosophy, which had formed the core of higher education from the time the universities were created, remained the focus of the program that Newton's tutor set for him. Roughly halfway through his undergraduate years, however, apparently sometime during 1664, about the same time when he came upon mathematics, he discovered a new course of reading for himself, the writings of the men who were in the process of creating a new science of nature that was already displacing Aristotelian natural philosophy and would completely supplant it before the seventeenth century was over—the books of René Descartes, Pierre Gassendi, Robert Boyle, and others. The new course of reading determined the direction of Newton's life from that time, and his further advances down the paths the authors had pioneered determined his place in history.

Newton devoured the works he had discovered and effectively enlisted himself in the ranks of their authors. As the word *scientist* did not exist in the seventeenth century, Newton, if asked to define his new vocation, would probably have called himself a natural philosopher, one attempting to understand the nature of the world in which we live. A series of speculations on the nature of things extended from his student notebook, in which he recorded the fruits of his new reading, through the whole of his life, culminating in the final set of *Queries* that he added to his *Opticks* in 1717, his last important composition. These speculations formed the foundation of Newton's scientific achievements.

The initial set of speculations were the “*Quaestiones quaedam philosophicae*” (“Certain Philosophical Questions”), as he entitled the set of notes he began sometime during 1664. Above the title he entered the slogan “*Amicus Plato amicus Aristoteles magis amica veritas*,” which can be translated freely as “Plato is my friend; Aristotle is my friend; but my best friend is truth.” In the pages that followed, Plato and Aristotle did not appear again; Newton's best friend was the new natural philosophy, which Robert Boyle had recently dubbed the *mechanical philosophy*.

Newton set down forty-five headings under which to organize the material gained from his new reading. Under some headings, he never

In order not to encumber the reader with footnotes we have composed a Biographical Register, in which all the people mentioned in the text are identified, and a Glossary, in which technical terms are briefly explicated and such things as organizations, places, publications, and manuscript collections are identified. There is also a Glossary of Chemical Terms that will be useful for this part. The Biographical Register, Glossary, and Glossary of Chemical Terms are located near the end of the volume.