REVOLUTION IN SCIENCE

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Preface

Revolution in Science is a historical and analytic study of a concept through the course of four centuries. Such a complex topic, covering a broad range of events, individuals, and ideas, has seemed to require a number of approaches from different angles. The first of these is an analysis of the stages by which revolutions in science progress from the inception of a revolutionary idea to the acceptance and use of a new science by a sizable number of scientists. Whether a particular set of events in science does or does not constitute a revolution is necessarily a personal judgment, but I have developed a set of criteria — based on historical evidence — for the occurrence of a scientific revolution. These stages and criteria (outlined in chapters 2 and 3) constitute the analytic framework of the book.

I have used this framework to examine critically some of the major revolutions in science which have occurred during the four centuries modern science has existed. For each of those centuries, an introductory section on the political or social revolutions of that age and the images of revolution then current is presented, because I have found

that occurrences of the word 'revolution' in the context of science have always reflected current theories concerning political and social revolution, as well as the awareness of actual revolutions that have taken place. Thus, the thinking about each revolution in science that I discuss is set against the background of social and political revolution.

A distinction must be made between the historical perception of revolution and the historian's perception. The former comprises the judgments made at the time of the revolution and during succeeding ages and are the objective facts or data of history; but the latter are present-day subjective judgments. Of course, in the case of each revolution discussed in this book, I have made a subjective historian's judgment. Yet in every example, I have stressed the historical evidence. In almost every case there is a confluence of the two; those revolutions that pass the test of historical evidence tend to be those that in the judgment of today's historians (and scientists) are also revolutions. But the comparison of historical evidence and the judgment of historians has also disclosed some fascinating anomalies.

In particular, the study of historical evidence shows that the concept of revolution in science, like the concept of revolution itself, is not and has not been static. For example, this book documents the changing views of scientists and historians on whether the progress of science is primarily gradual and incremental or is the result of a succession of revolutions. In addition to alterations in the general viewpoint toward revolutions in science, there have also been shifts of judgment concerning the revolutionary character of particular events. A case in point is the Copernican revolution. The notion that a revolution in astronomy attended the publication of Copernicus's *De Revolutionibus* in 1543 was a fanci ul invention of eighteenth-century historians of astronomy; it was popu arized to such an extent that the Copernican revolution became the paradigmatic revolution in science. But critical examination of the evidence by historians has shown that the revolution was not at all Copernican, but was at best Galilean and Keplerian.

The changing perspective of time has also produced radical alterations of the sense and significance of even great political revolutions. In *The Rights of Man* (1791), Thomas Paine explained how the American and French revolutions had introduced a new kind of revolutionary thinking into political science. Known primarily for his pamphleteering during the American Revolution—*Common Sense* and *The Crisis* are his most notable productions—Paine wrote *The Rights of Man* in reply to Edmund Burke's *Reflection on the Revolution in France* (1790). Paine's

exposition of the new view of revolution resulting from the events in America and in France is a classic example of the way in which political concepts arise in relation to events and not mere theory:

> What we formerly called Revolutions were little more than a change of persons, or an alteration of the local circumstances. They rose and fell like things of course, and had nothing in their existence or their fate that could influence beyond the spot that produced them. But what we now see in the world, from the Revolutions of America and France, are a renovation of the natural order of things, a system of principles as universal as truth and the existence of man, and combining moral with political happiness and national prosperity.

Less than a half-century later, however, in 1835, Giuseppe Mazzini no longer considered the French Revolution to be a sound model for progressive political action. "The progress of France," he wrote (1907, 251) "depends upon its power to emancipate itself from the eighteenth century and the old Revolution." He argued that the French Revolution should be "considered, not as a programme, but as a summary: not as the initiative of a new age, but as the last formula of an expiring age." In the nineteenth century, and even in the twentieth, revolutionaries aimed to achieve what the French Revolution had failed to do, as may be seen clearly in the writings of Marx and Engels and many twentieth-century theorists of revolution.

English political history provides two clear-cut examples of the way in which the passage of time changes the way events may be perceived as revolutions. In other words, revolutions in science are not the only revolutions that undergo successive changes in their image as revolutions. The Glorious Revolution of 1688 was the paradigmatic political revolution for eighteenth-century historians and political theorists, but today it does not appear to have been very revolutionary. And the same is true for the American Revolution, often now called the Revolutionary War or the War of Independence. Contrariwise, the English Revolution of the mid-seventeenth century was not generally conceived to have been a revolution at all until some two hundred years later. This English Revolution was, according to some nineteenth- and twentieth-century commentators, an abortive social revolution rather than a political revolution like the Glorious Revolution. The concept of what constitutes a revolution also differs greatly from one age to the next, as

may be seen by reading the literature of revolution from the late seventeenth and eighteenth centuries, from the half-century or so between the French Revolution and Marx, from Marx's era to Lenin's, from the decades following the Russian Revolution of 1917, and from the 1950s, 60s, 70s, and 80s. Not surprisingly, discussions of revolution in science reflect these changes.

A historical discussion of the origins and successive meanings of the term 'revolution' (whether scientific or political) may seem abstract and innocent of partisanship, but a single example will show that this is not necessarily the case. In his essay "Islamic Concepts of Revolution," Bernard Lewis (1972, 37–38) discussed the occurrence in classical Arabic of "a number of words to denote rebellion or insurrection," among them the word 'thawra'. "The root *th-w-r* in classical Arabic," he wrote, "meant to rise up (e.g., of a camel), to be stirred or excited, and hence . . . to rebel." Lewis then explained that the word "is often used in the context of establishing a petty, independent sovereignty" and that the noun form "at first means excitement, as in the phrase . . . wait till this excitement dies down"—which Lewis said was "a very apt recommendation." Edward Said replied to Lewis (1978, 315) by asking why "introduce the idea of a camel rising in an etymological root for modern Arab revolution except as a clever way of discrediting the modern?" Said alleged that "Lewis's reasoning" had the obvious aim of "bringing down revolution from its contemporary valuation to nothing more noble (or beautiful) than a camel about to raise itself from the ground." We may see the force of Said's critique by imagining a reverse situation, in which an oriental scholar might disparagingly criticize the Western European or American concept of revolution because the term itself had developed from a cyclical idea of return or ebb and flow. Said actually interpreted Lewis's version of etymology to be tinged with a style of thought he has named "Orientalism," a "Western style for dominating, restructuring, and having authority over the Orient." Said considered Lewis's etymological discussion to be an expression of his political and social position, leading him to associate "*thawra* with a camel rising and generally with excitement" rather than "with a struggle on behalf of values." This was also notably the case for the editor's introduction to the volume in which Lewis's essay appears. For here it is said that "struggles for independence and radical movements in the Middle East, *coups d'état,* insurrections and rebellions" are not proper revolutions, as this term is understood in the West (Valikiotis 1972, 11). The alleged reason is that "Western notions of the right to resist bad government are alien to Islamic thought."

I began my book originally as an inquiry into the origins and successive uses of two concepts: the Scientific Revolution (of the sixteenth and seventeenth centuries) and revolution in science as a mode of scientific progress. I found that many historians, and even historians of science, believed that both of these concepts arose in our own days and that historians of science who used them were anachronistically attempting to force events of the past into a twentieth-century mold. The reader may well imagine my astonishment as my research began to produce examples of discussions of revolution in science from each of the past four centuries, and of references to the Scientific Revolutio at least as long ago as the early nineteenth century. Because this material is not at all familiar to historians—and to scientists, philosopher , and sociologists—a large part of the book serves as a chronological record of these usages.

My first findings were presented in an article in the *Journal of the History of Ideas* (1976, 37: 257–288), which I had intended to expand into a small monograph. But as Thomas Mann (in the preface to his Joseph series) and many authors have said, "Fata sua habent libelli" ("Books have their own fate"). The overwhelming accumulation of evidence has led to this more ambitious book. Even it by no means exhausts my findings; I could easily have written a volume three or four times as large. References to revolution in science since World War I and the Russian Revolution could, alone, have been the subject of a monograph. Of necessity, I have given only some carefully selected samples that seem to me either to be typical of current expressions of opinion or to have special interest.

This work is part of a broad research program with a double aim. In part I am concerned with exploring and elucidating the creative process by which a practitioner in one discipline uses the ideas (concepts, methods, theories, tools) of another discipline. I gave an earnest of this investigation in my book *The Newtonian Revolution* (1980). There I stressed the doctrine of 'transformation of ideas' as a key ingredient in the revolutionary process. Here, however, I have restrained my use of this concept of transformation, so as not to put off readers primarily interested in the broad historical chronicle and the analysis of revolutions in science. I reserve for later study the further analysis of conceptual transformations in revolutions in science. The second goal of my research is to define and analyze the interactions between the natural and exact sciences and the social and behavioral sciences. This work combines historical and analytical studies. Its purpose is not only to identify and study in particular cases the general process of transforma-

tion that occurs whenever an idea from one discipline is used in another; additionally, I am concerned with analyzing the 'scientific' basis of the social sciences and examining how they have used the sciences to validate applications of their findings in matters of public policy. Although it is generally believed that ideas tend to flow from the natural and exact sciences to the social and behavioral sciences, there are many significant cases in which the influence has been in the other direction. The present book on revolutions is related to this theme because the concept and name 'revolution' arose in the sciences (astronomy and geometry) and then entered the discourse of political and social change, undergoing a significant initial transformation. As the book documents, this changing concept of revolution was then transferred back from the social sciences and the literature of political theory and action to discussions of scientific change. Thus the book explores an area of the relations between these two worlds of discourse.

The interactions between the concepts of political or social revolution and revolution in science are mentioned throughout this book, but I am fully aware that this topic merits a much more complete exploration. As early as the seventeenth century, even before the modern noncyclical concept of revolution had become universal, various authors sought to explain scientific advance by political analogies. There is also a countertheme, which I have mentioned but not explored, of the possible influence of science and of scientific revolutions on political revolutions. It is well known that Marx and more particularly Engels saw their revolutionary movement as 'scientific'. The terms 'scientific socialism' and 'scientific communism' occur frequently in the Marxian (especially the Soviet) literature, but I know of no critical assessment of th degree to which this use of 'scientific' depends on the use of science as commonly understood in national scientific communities.

Although the theme of change in the concept of scientific revolution is woven throughout this book and is indeed its major thread, many readers will find the case histories of particular revolutions to be of greatest interest. These case histories, which make up a large part of the book, describe some of the great revolutions that mark the development of modern science, and display in specific examples the stages of revolution which I have developed and the evidence for considering a particular series of events to be a revolution in science. These case histories also indicate how the recognition of revolution in the sciences has been (and is) conditioned by the image of political revolutions and by current revolutionary theory. A striking example occurs in relation

to ideas of revolutions in the earth before and after the French Revolution. Another is the effect of T. S. Kuhn's writings on scientists who have identified and chronicled a revolution in the earth sciences growing out of new ideas of plate tectonics and continental drift.

In most of the case histories I have tended to quote expressions of revolution by creating or participating scientists, or even by nonparticipating observers, without in each instance attempting to define precisely what that person may have had in mind. But I have usually given the context or the current state of ideas concerning revolution in general. The problem here is twofold. First of all, we do not know exactly what a particular scientist may have had in mind; second, many scientists (a number of examples appear throughout the book) make very explicit statements about a particular revolution in science or about revolutions in science in general, but without having necessarily developed a carefully worked-out theory of revolutions or even of the modes of scientific change at large. It is tempting, for example, to link Albert Einstein's 1905 and 1906 remarks about revolution in a scientific context to the events of 1905, notably the failed Russian revolution and the idealistic hopes for a radical reform of Russian society; similarly, his statements against revolution in the context of relativity theory could be interpreted as a reaction against the excesses of the 1917 Russian revolution and the immediately post–World War II abortive revolutions in Germany, including the fighting in the streets of Berlin. But Einstein's reaction against the newspapers' extravagant attribution to him of a revolution must also be factored in; it certainly helped incline him to a view that his work had been evolutionary rather than revolutionary. In assessing Einstein's views on revolution in science, one must bear in mind that all of Einstein's statements about revolution and evolution occur in single isolated sentences or phrases, very often responses to a statement by somebody else; I do not know of a single instance of a complete essay or letter or even a completely developed full paragraph on the processes by which science advances, much less on revolutions in science. And the case is much the same for other scientists of the past three centuries who have expressed themselves on particular revolutions in science or even on revolutions in science in general. Hence I have in each case given the reader the actual expressions used in relation to revolution. But the reader will easily be aware that there is no warrant for assuming that the implications of the word 'revolution' are necessarily identical in every statement about revolution by a single person or by different persons in relation to a particular scientific theory.

Finally, I have often referred to my findings in what may be too positive a manner. I am aware that in many cases the phrases 'so far as I know' or 'so far as my research has shown' should have been inserted. Are there earlier examples than I have found? I would be the last person to assume that my research has been exhaustive, a conclusion precluded by the nature of the topic. And so I hope that readers who have access to further information will inform me so that I can make corrections in any later editions.

Readers will naturally wish to know how this book is related to T. S. Kuhn's *Structure of Scientific Revolutions* and other writings. As many readers will be aware, Kuhn's work has been of fundamental importance in reorienting the thinking of scientists and historians of science, converting them to (or making them mindful of) the notion that revolutions are a regular feature of scientific change. Hence, Kuhn's writings constitute a major event in my history of the concept of revolutions in science. A major theme in Kuhn's analysis is that scientific changes of all kinds, including revolutions, are not the result of a contest of ideas, as Ernst Mach and others have supposed, but rather of scientists who accept or believe in ideas. I address this theme by analyzing four stages of development which I find to be characteristic of all revolutions in science. Finally, I accept Kuhn's general notion of revolutions as a shift in a set of scientific beliefs—in 'paradigms', to use that original term introduced in this context by Kuhn but later (unfortunately, in my opinion) abandoned by him when it was shown that he had used this term ambiguously and even in a number of quite different senses.

In my book I do not, however, discuss some particular features that Kuhn has assigned to the "structure of scientific revolutions." For example, I do not explore the theme (which I find to have too many exceptions to be useful) that revolutions in science are necessarily precipitated by crises. And it is the same for other details of his schema. Nor do I go into the question of Kuhn's changing distinctions among 'paradigm', 'exemplar', and 'disciplinary matrix'. It is an interesting fact of record that whereas Kuhn's schema has been subject to considerable discussion, criticism, and approval by historians of science; the latter (including Kuhn himself) have tended not to make use of a Kuhnian framework in their actual writings. Hence Kuhn's influence appears to be stronger among philosophers and sociologists of science (and scholars in wholly different areas such as political theory) than among scientists and practicing historians of science. An exception, however,

must be made for historians of the recent revolution in the earth sciences. (For a first-rate — and good-naturedly irreverent — analytical presentation of Kuhn's system and the history of its reception by the community of historians of science, see Reingold 1980.)

Kuhn refers again and again to smaller revolutions and great revolutions. The latter are those generally accepted as revolutions in scientific discourse — those associated with Copernicus, Newton, Lavoisier, Darwin, and Einstein. But Kuhn's smaller revolutions may involve no more than a couple of dozen scientists replacing an accepted exemplar by a new one. In public discussions and writings Kuhn stresses the ubiquitous nature of these smaller revolutions. In my book, however, I have tended to concentrate on the larger or more visible revolutions. One of the reasons is that my formulation of an objective means of determining when a revolution occurs applies directly to revolutions in science which are more analogous with political revolutions.

Readers will discern, furthermore, that I am neither philosopher nor sociologist of science. As a historian, I have aimed more to produce a critical and analytical historical study than to debate the merits of Kuhn's system or the systems of other philosophers or sociologists of science. In short, my purpose and Kuhn's are not parallel but necessarily intersect. This book is not another discussion of Kuhn's "structure"; it is instead an attempt to examine the subject of revolution in science from a new and strictly historical viewpoint.

I have earlier quoted a Latin phrase used by Thomas Mann and others to indicate the well-known phenomenon that books tend to have a life of their own, that they develop by an internal logic of research and writing. Just as this book was going to press, however, I encountered the complete quotation of which this is an extract. Composed by Terentianus Maurus *(De litteris syllabis et metris Horatii,* line 1286), it reads in full: "Pro captu lectoris habent sua fata libelli." Who could possibly disagree that the fortunes of books depend on their reception by the reader? I hope that this book will find both critical and sympathetic readers, so that it may stimulate further research and thought. If this fascinating subject of revolutions can attract the attention of scholars, it will achieve the potential it so richly deserves.

I. Bernard Cohen

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Science and Revolution

I

1

Introduction

Today we are apt to take it for granted that science and its associated technology progress through a series of revolutionary leaps—giant steps forward that give us an altogether new perspective on the natural world. But has revolution always been so familiar and acceptable a way to describe the advance of science? Could such innovative scientific thinkers as Kepler, Galileo, and Harvey conceive of their own work as being revolutionary in the sense that we use the word today? Did the contemporaries of Darwin, Freud, and Einstein see the theories of these scientists as creating a revolution, or did they prefer to view scientific progress in a less dramatic light? What effect have such social and political upheavals as the French Revolution and the rise of Marxism had on the way scientists, philosophers, and historians think about revolutions in science? For all of their emphasis on the great scientific revolutions of the past, surprisingly few scholars have addressed these sorts of questions—questions having to do with the historical development of the idea of revolution as a feature of scientific change. It was my own curiosity about these problems that led to the writing of this book.

The main body of the presentation deals with the chronological history and successive transformations of the concept of revolution in science in the seventeenth, eighteenth, nineteenth, and twentieth centuries—with illustrations taken from some major revolutions in each of these periods. These revolutions have been chosen either because of their intrinsic historical importance (as in the case of the Copernican, Newtonian, Darwinian, and Einsteinian revolutions) or because of their relevance in clarifying or exemplifying what I see as the central characteristics of all revolutions in science.

In declaring that certain historical episodes constitute revolutions in science, I have not relied solely on my own personal evaluations, or even on the consensus of qualified historians, but rather on historical evidence, both the judgments of contemporaneous observers and participants and the continuing tradition. For example, it is a historical fact that in the early 1700s Fontenelle said *expressis verbis* that the invention of the calculus was a revolution in mathematics, that in 1773 Lavoisier declared that his research program would lead to a revolution, that in 1859 Charles Darwin hailed Lyell's revolution in geology and predicted that the acceptance of his own ideas would produce a "considerable revolution in natural history." Contemporaneous documents show that the radical innovations of Lavoisier and Darwin and both relativity and quantum theory were very quickly acknowledged to be revolutions. Furthermore, almost all scientists and historians of science today agree with the opinion of the past that certain momentous restructurings of scientific thought were revolutions. Such a consensus, of course, does not make these events revolutions; we shall see in chapter 3 that additional tests can be applied to help us decide what is and what is not to be considered a revolution in science, and (in chapter 2) that distinct stages in the development of a revolutionary idea can indicate whether or not a true scientific revolution has occurred. These questions aside, there can be no debate concerning the overall historical record: it shows that for some three hundred years, ever since the first coming-of-age of modern science, great events in the development of science have been seen as revolutions in thought and practice. The main burden of this book is to delineate and to analyze those events and the interpretation of them as revolutions.

Defining 'Revolution in Science'

The problem of defining 'revolution', which plagues almost every discussion of political and social revolutions, has penetrated the literature