CONTENTS

INTRODUCTION

Natural Philosophy and the Sciences

Science as a Product of History

A central means of understanding a human enterprise is to grasp it historically: How did it get this way? Modern science owes its principal intellectual and social traditions to cultural practices developed during the past three or four centuries in European or "Western" contexts. Global expansion, emulation, and modification, occurring especially in the twentieth century, subsequently yielded the worldwide technical endeavors familiar to us in the present. Many ingredients in the development of modern science have come from non-European sources, of course; much of the enterprise itself, however, has owed its dynamic to European projects, especially those of capitalist and imperial expansion. Not all large historical movements creating the present are purely benign, including those producing so celebrated an enterprise as science. Understanding comes from recognizing that the history of science is not about awarding accolades and prizes, but about self-awareness. For many years now there has been a good deal of discussion among historians on the question of why science became established as an ongoing enterprise in early modern Europe (or "the West") while similar practices in other cultural regions of the world did not become established and institutionalized in the same way.[1] But the question seems much less pressing as soon as one ceases to assume that there is a natural kind called "science" that floats free of its historical specificities. Perhaps it is no more than a word people use that contingently links together a variety of activities and knowledge claims under a common designation. Perhaps science is not a "thing" waiting to be discovered by many distinct societies.

This book is about why present-day chemists trace their enterprise back to Lavoisier; why physicists trace theirs, via Einstein and Maxwell, to Newton; why biologists trace theirs to Darwin; and why all of them work in institutional settings that resemble ones that appeared originally in nineteenth-century Germany. These historical connections help us understand the character of what scientists do. But we should not be misled by these connections: we cannot assume that everyone linked in these ways has always been engaged in the same project. Science itself has changed and been reconfigured over the centuries in ways that have been enormously consequential. Before the nineteenth century, one might even argue that our kind of science, often called Western, did not exist.[2]

Science today bears strong marks of its roots in the nineteenth century. Many—perhaps most—of the characteristic features of science as a cultural institution had appeared by 1900. Much has happened since then, of course, but the enterprise of science and the role of the scientist in 1900 remain fully recognizable today. This striking continuity appears most clearly in the terminology we use: we speak of *science* and *scientists* unproblematically; everyone thinks they know what those words mean without ever having to think much about them. Above all, science is and was a *profession* associated with university training, degrees, and self-regulating professional societies. The historical continuity of such markers over the last century or two is striking. But the nineteenth-century creation of science relates also to its intellectual content: scientists promulgate knowledge claims about the world for which their institutional credibility serves to secure assent from the rest of us. And we often describe those scientific knowledge claims as "discoveries," unless we (whether rival scientists or interested nonscientists) wish to deny or contradict them. But the authority of science usually makes serious opposition to claimed discoveries very difficult to maintain.[3]

Science and Natural Philosophy

The modern sense of the word *science* in English, as well as the English word *scientist*, only came into general use in the second half of the nineteenth century; the word *scientist* itself was first coined in the 1830s.[4] Before that time, so-called men of science (to use a common nineteenth-century term) were often described as pursuing "natural philosophy."[5] There are still chairs of natural philosophy at the Universities of Edinburgh and Glasgow (among others) in Scotland, at the University of Cambridge in England, and elsewhere, often founded in the eighteenth century and with their subject areas corresponding nowadays to physics. The term *science* then typically referred to a specific formal discipline (often mathematical in structure), and never to a universalizing science covering all subjects, as now.[6] "The science of . . ." was the typical form of expression for the word; one might refer collectively to "the sciences."

Natural philosophy had a long pedigree.[7] The term in Latin, still the dominant European language of learning at the start of the eighteenth century, was usually *philosophia naturalis*, or its almost-synonym *physica*. Natural philosophy, with its home in the universities, had been particularly associated since the Middle Ages with the texts of the ancient Greek philosopher Aristotle; its name served to distinguish it from moral philosophy, or ethics. By the eighteenth century, this academic, Aristotelian picture had been modified and challenged in many ways, but the central conception of natural philosophy remained: it was an intellectual discipline that sought to understand and explain the world and its behaviors rather than to employ those behaviors for practical ends. But operational dimensions were also present and often celebrated as part of natural philosophy's virtues. Most notably, the projects and ideas of the great English statesman of the early seventeenth century, Francis Bacon, attempted to reform natural philosophy from its foundations by using operational efficacy as a criterion of truthfulness, not merely a possible advantageous spin-off. Bacon's stance was subsequently adopted by the Royal Society of London and by natural philosophers (especially those independent of universities) throughout Europe, and it represented a considerable shift in enterprises dedicated to knowledge of nature. Natural philosophy remained as a way of understanding the world, but it was increasingly coupled to instrumental uses as, so to speak, the other side of the coin. The characteristic shape of something we recognize as modern science dates from this period, the seventeenth and eighteenth centuries, while never abandoning the intellectual goals of natural philosophy as part of its essential character. Henceforward, a mutually justifying hybrid of natural philosophy and instrumental technique (the latter often borrowed from the classical mathematical disciplines) moved to the fore in European knowledge practices and began to be called *Science*.[8]

The Scientific Revolution

In 1700, at the start of the period discussed in this book, Europe had just undergone what is sometimes known as the Scientific Revolution, a label applied to aspects of the intellectual and cultural changes of the sixteenth and seventeenth centuries relating to knowledge of nature. Conventionally, the Scientific Revolution is taken to run from Copernicus's ideas about the motion of the earth around the sun through to Isaac Newton's work on universal gravitation, but its importance amounts to more than just changes in accepted views about the structure of the universe.[9]

Those changes had, to be sure, resulted in many novelties: an indefinitely large universe with the stars as other suns, novel mechanical concepts that included inertia and the inverse square law of gravitation, and many others. But underlying these conceptual innovations were even more basic changes in attitudes that made the new world picture acceptable. By the late seventeenth century, two of the most basic changes in outlook concerned the questions of what counted as a proper explanation of a natural phenomenon and what counted as the proper way to investigate phenomena.

By 1700, proper explanations were taken by many (though not all) prominent natural philosophers—such as Isaac Newton, Robert Boyle, and G. W. Leibniz—to be *mechanical*. But disagreement remained about what that word really meant.[10] The universe was seen as some kind of gigantic machine, and that image determined how it would be understood. If the universe were a mechanical device, different kinds of explanations of phenomena might be given than if it were seen as a living thing, some kind of organic being. Mechanical explanations relied on seeing the world as made up of dead, inert matter that followed determinate mathematical laws. Newton's theory of universal gravitation was criticized by natural philosophers in France and elsewhere on the grounds that Newton's theory failed to explain gravitational attraction in terms of matter pushing on matter (the acme of mechanical force transmission); in a larger sense it, too, was seen by its adherents as mechanical. A Newtonian action-at-a-distance view of gravity simply noted an empirical regularity without committing to some particular means through which the regularity was performed. But in combination with Newton's laws of motion and collision, the account given in Newton's great Latin treatise of 1687, the *Principia* (in English, *The Mathematical Principles of Natural Philosophy*), remained "mechanical" for many insofar as it provided a determinate, predictive set of mathematical rules that supposedly described the motion of all bodies in the universe and the forces that produced that motion. From this perspective, *mechanical* meant an explanation in terms of forces and resultant motions, regardless of the source of the forces. Either way, philosophers routinely expressed their mechanical perspective through a metaphor of the world as a clock and God as the clockmaker.[11]

The clockwork metaphor effectively determined what counted as an adequate explanation. But natural philosophers needed to persuade each other that their particular explanation of some phenomenon was not simply possible because it was consistent with mechanistic principles; they also wanted to show that their explanations were *true*. By 1700, a special form of observation had become a technique of choice among natural philosophers: experimentation.[12] A well-designed experiment created a situation that would result in a different behavior depending on the underlying mechanism that produced it. Given prior assumptions about the universe being a mechanical system, it was reckoned that experiments could narrow down the possibilities so as to approach the truth about a phenomenon even if there was no guarantee that all possible alternative explanations had been taken into account.[13]

Natural philosophy in 1700, then, saw nature as a kind of machine, made up of particles of dead matter interacting with one other. The basic procedure for learning about how that machine worked was by inference from observation and especially experiment. More broadly, natural philosophy concerned itself with understanding the world, and the world was God's creation. Indeed, it has been plausibly argued that this divine component serves to define natural philosophy as a field, distinguishing it from other enterprises like "science."[14] While something of an exaggeration, this view warns against regarding natural philosophy as simply an obsolete terminological alternative to "science."

This book traces natural philosophy as it mutated into science in its recognizable modern form in the nineteenth century. But that mutation occurred only because of the natural philosophers whose work drove it. Who were they? What sorts of communities did they form? And what approaches to knowledge did these communities promote? There is much left out of the following account, and many historians would no doubt claim, with justice, that vitally important matters are ignored or given short shrift (I am particularly conscious of my frequent resort to Western European scientific work). But selection must be made; I have chosen topics, people, and settings that seem to me to represent a coherent and meaningful development of a worldview that frames our present sense of what we think we believe about our home, and that represent the most active scientific communities of their time. The goal is not to ascribe credit to particular figures but to discuss some of the most consequential ideas and approaches found in the natural philosophy of modern science. A variety of similar stories could equally well be told—in particular, the intersecting history of medicine, which might easily generate a parallel and distinct narrative of similar scope—but I am fond of this one.[15]

Natural Philosophers

Natural philosophers in the eighteenth century were not usually university professors; the practice of natural philosophy did not typically take place in universities. Research was not a recognized part of a university's function, and if occasionally someone who was a university teacher took an interest in the pursuit of natural philosophy, it was generally a purely private interest.[16] Research of any kind did not become an integral part of a university's function until the nineteenth century.

Rather, the social focus for the sciences in 1700 was the scientific society, whether a private voluntary affair or an academy under state patronage. Such groups had started to appear in the seventeenth century, with the principal examples, which served as models for others, being the Royal Society of London and the Royal Academy of Sciences in Paris, both founded in the 1660s. Their names reveal a kind of official status deriving from royal patronage. Nonetheless, the Royal Society received no financial benefit from the Crown, and was in effect a self-governing gentleman's club. The Paris Academy, on the other hand, included salaried positions and other material benefits (such as an astronomical observatory) paid for by the state. A similar kind of academy was started in Berlin by the Prussian monarchy in 1700, and Tsar Peter the Great founded his own academy of sciences in St. Petersburg in 1724.[17]

Such societies (and there were many) were the foci of natural philosophical activity outside the pedagogically oriented universities and colleges. Publications by natural philosophers would typically appear in a journal like the *Philosophical Transactions of the Royal Society* or in the *Memoirs* of the Royal Academy of Sciences in Paris, or as books bearing the approval of those groups. Scientific life in large part centered on these regional societies. It should not be thought, though, that they reflected new social arrangements suited to some novel and forward-looking enterprise. These societies or academies tended to be modeled on preexisting social institutions, such as law courts, universities, parliaments, or societies of accredited medical practitioners.

Society members were typically from reasonably well-to-do backgrounds—not usually from the nobility, nor from the working class (besides the occasional instrument maker). They were educated people, perhaps with independent incomes; in England, very often people who might be called members of the gentry, often including clergymen. So the societies comprised "gentlemen." Indeed, very few women were allowed to play this philosophical game, just as there were no female lawyers or members of parliament. When some women engaged in natural philosophy in the seventeenth and eighteenth centuries, they were kept on the sidelines of the organized activity of the scientific academies.[18]

At the beginning of the eighteenth century, then, the new natural philosophy was accorded a status that made it a public enterprise along the same lines as law or medicine or established religion. And the biggest name associated with it soon came to be that of the president of the Royal Society of London, Sir Isaac Newton. After a period of debate and contestation, Newton's picture of the universe, its content and structure, and its relationship to God the Creator, became the primary reference for natural philosophers throughout Europe. It might seem obvious to us now that Newton's world picture should have acquired such dominance—after all, we might say, he more or less got it right, in a way that gave rise to enormously successful research trajectories leading to the physical sciences of the present. And we would not be altogether wrong to do so. But what we must try to achieve, if we are to take historical knowledge seriously, is to see those trajectories as the products of decisions and judgments made by particular kinds of people in specific circumstances, and to understand their scientific enterprises as attempts to answer questions about the world that are not always the same as ours. The natural world that people in the past conjured up was created from the cultural materials available to them; it was not something they simply found and reported. The world as we know it was made by people in history, and we have inherited it from them to make our future.

INDEX

Page numbers in *italics* refer to images