1

Introduction

1.1 Setting Out

This book is a survey of roughly one hundred years of argument about the nature of science. We'll look at a hundred years of argument about what science is, how it works, and what makes science different from other ways of investigating the world. Most of the ideas we will examine fall into the field called "philosophy of science," but we will also spend a good deal of time looking at ideas developed by historians, sociologists, psychologists, and others.

The book mostly has the form of a "grand tour" through the decades; ideas will be discussed in roughly the order in which they appeared. Note the word "roughly" in the previous sentence; there are exceptions to the historical structuring of the book, and I will point out some of them as they arise.

Why is it best to start with older ideas and work through to the present? One reason is that the historical development of general ideas about science is itself an interesting topic. Another reason is that the philosophy of science has been in a state of fermentation and uncertainty in recent years. A good way to understand the maze of options and opinions in the field at the moment is to trace the path that brought us to the state we're in now. But this book does not only aim to introduce the options. I will often take sides as we go along, trying to indicate which developments were probably wrong turns or red herrings. Other ideas will be singled out as being on the right track. Then toward the end of the book, I will start trying to put the pieces together into a picture of how science works.

Philosophy is an attempt to ask and answer some very basic questions about the universe and our place within it. These questions can sometimes seem far removed from practical concerns. But the debates covered in this book are not of that kind. Though these debates are connected to the most abstract questions about thought, knowledge, language, and reality, they have also turned out to have an importance that extends well outside of philosophy. They have made a difference to developments in many other academic fields, and some of the debates have reverberated much further, affecting discussions of education, medicine, and the proper place of science in society.

In fact, throughout the latter part of the twentieth century, all the fields concerned with the nature of science went on something of a roller-coaster ride. Some people thought that work in the history, philosophy, and sociology of science had shown that science does not deserve the dominating role it has acquired in Western cultures. They thought that a set of myths about the trustworthiness and superiority of mainstream science had been thoroughly undermined. Others disagreed, of course, and the resulting debates swirled across the intellectual scene, frequently entering political discussion as well. From time to time, scientific work itself was affected, especially in the social sciences. These debates came to be known as the "Science Wars," a phrase that conveys a sense of how heated things became.

The Science Wars eventually cooled down, but now, as I write these words, it is fair to say that there is still a great deal of disagreement about even the most basic questions concerning the nature and status of scientific knowledge. These disagreements usually do not have much influence on the day-to-day practice of science, but sometimes they do. And they have huge importance for general discussions of human knowledge, cultural change, and our overall place in the universe. This book aims to introduce you to this remarkable series of debates, and to give you an understanding of the present situation.

1.2 The Scope of the Theory

If we want to understand how science works, it seems that the first thing we need to do is work out what exactly we are trying to explain. Where does science begin and end? Which kinds of activity count as "science"?

Unfortunately this is not something we can settle in advance. There is a lot of disagreement about what counts as science, and these disagreements are connected to all the other issues discussed in this book.

There is consensus about some central cases. People often think of physics as the purest example of science. Certainly physics has had a heroic history and a central role in the development of modern science. Molecular biology, however, is probably the science that has developed most rapidly and impressively over the past fifty years or so.

These seem to be central examples of science, though even here we encounter hints of controversy. A few have suggested that theoretical physics is becoming less "scientific" than it used to be, as it is evolving into an esoteric, mathematical model-building exercise that has little contact with the real world (Horgan 1996). And molecular biology has recently been acquiring connections with business and industry that make it, in the eyes of some, a less exemplary science than it once was. Still, examples like these give us a natural starting point. The work done by physicists and molecular biologists when they test hypotheses is science. And playing a game of basketball, no matter how well one plays, is not doing science. But in the area between these clear cases, disagreement reigns.

At one time the classification of economics and psychology as sciences was controversial. Those fields have now settled into a scientific status, at least within the United States and similar countries. (Economics retains an amusing qualifier; it is often called "the dismal science," a phrase due to Thomas Carlyle.) There is still a much-debated border region, however, and at the moment this includes areas like anthropology and archaeology. At Stanford University, where I teach, this kind of debate was one element of a process in which the Department of Anthropology split into two separate departments. Is anthropology, the general study of humankind, a fully scientific discipline that should be closely linked to biology, or is it a more "interpretive" discipline that should be more closely connected to the humanities?

The existence of this gray area should not be surprising, because in contemporary society the word "science" is a loaded and rhetorically powerful one. People will often find it a useful tactic to describe work in a borderline area as "scientific" or as "unscientific." Some will call a field scientific to suggest that it uses rigorous methods and hence delivers results we should trust. Less commonly, but occasionally, a person might call an investigation scientific in order to say something negative about it—to suggest that it is dehumanizing, perhaps. (The term "scientistic" is more often used when a negative impression is to be conveyed.) Because the words "science" and "scientific" have these rhetorical uses, we should not be surprised that people constantly argue back and forth about which kinds of intellectual work count as science.

The history of the term "science" is also relevant here. The current uses of the words "science" and "scientist" developed quite recently. The word "science" is derived from the Latin word "scientia." In the ancient, medieval, and early modern world, "scientia" referred to the results of logical demonstrations that revealed general and necessary truths. Scientia could be gained in various fields, but the kind of proof involved was what we would now mostly associate with mathematics and geometry. Around the seventeenth century, when modern science began its rise, the fields that we would now call science were more usually called "natural philosophy" (physics, astronomy, and other inquiries into the causes of things) or "natural history" (botany, zoology, and other descriptions of the contents of the world). Over time, the term "science" came to be used for work with closer links to observation and experiment, and the association between science and an ideal of conclusive proof receded. The current senses of the term "science" and the associated word "scientist" are products of the nineteenth century.

Given the rhetorical load carried by the word "science," we should not expect to be able to lay down, here in chapter 1, an agreed-on list of what is included in science and what is not. For now we will have to let the gray area remain gray.

A further complication comes from the fact that philosophical (and other) theories differ a lot in how broadly they conceive of science. Some writers use terms like "science" or "scientific" for any work that assesses ideas and solves problems in a way guided by observational evidence. Science is seen as something found in all human cultures, even though the word is a Western invention. But there are also views that construe "science" more narrowly, seeing it as a cultural phenomenon that is localized in space and time. For views of this kind, it was only the Scientific Revolution of the sixteenth and seventeenth centuries in Europe that gave us science in the full sense. Before that, we find the initial "roots" or precursors of science in ancient Greece, some contributions from the Arab world and from the Scholastic tradition in the late Middle Ages, but not much else. So this is a view in which science is treated as a special social institution with a definite history. Science is something that descends from specific people and places, and especially from a key collection of Europeans, including Copernicus, Kepler, Galileo, Descartes, Boyle, and Newton, who all lived in the sixteenth and seventeenth centuries.

To set things up this way is to see science as *unlike* the kinds of investigation and knowledge that routinely go along with farming, architecture, and other kinds of technology. So a view like this need *not* claim that people in nonscientific cultures must be ignorant or stupid; the idea is that in order to understand *science,* we need to distinguish it from other kinds of investigation of the world. And we need to work out how one approach to knowledge developed by a small group of Europeans turned out to have such spectacular consequences for humanity.

As we move from theory to theory in this book, we will find some people construing science broadly, others narrowly, and others in a way that lies in between. But this does not stop us from outlining, in advance, what kind

of understanding we would eventually like to have. However we choose to use the word "science," in the end we should try to develop *both*

1. a general understanding of how humans gain knowledge of the world around them *and*
2. an understanding of what makes the work descended from the Scientific Revolution *different* from other kinds of investigation of the world.

We will move back and forth between these two kinds of questions throughout the book.

Before leaving this topic, there is one other possibility that should be mentioned. How confident should we be that all the work we call "science," even in the narrower sense described above, has that much in common? One of the hazards of philosophy is the temptation to come up with theories that are too broad and sweeping. "Theories of science" need to be scrutinized with this problem in mind.

1.3 What Kind of Theory?

This book is an introduction to the philosophy of science. But most of the book focuses on one set of issues in that field. Within the philosophy of science, we can distinguish between *epistemological* issues and *metaphysical* issues (as well as issues that fall into neither category). Epistemology is the side of philosophy that is concerned with questions about knowledge, evidence, and rationality. Metaphysics, a more controversial part of philosophy, deals with general questions about the nature of reality. Philosophy of science overlaps with both of these.

Most of the issues discussed in this book are, broadly speaking, epistemological issues. For example, we will be concerned with questions about how observational evidence can justify a scientific theory. We will also ask whether we have reason to hope that science can succeed in describing the world "as it really is." But we will occasionally encounter metaphysical issues, and issues in the philosophy of language. The discussion will intersect with work in the history of science and other fields as well.

All of philosophy is plagued with discussion and anxiety about how philosophical work should be done and what a philosophical theory should try to do. So we will have to deal with disagreement about the right *form* for a philosophical theory of science, and disagreement about which questions philosophers should be asking. One obvious possibility is that we might try for an understanding of scientific *thinking.* In the twentieth century, many philosophers rejected this idea, insisting that we should seek a *logical* theory of science. That is, we should try to understand the abstract structure of scientific theories and the relationships between theories and evidence. A third option is that we should try to come up with a *methodology,* a set of rules or procedures that scientists do or should follow. In more recent years, philosophers influenced by historical work have wanted to give a general theory of scientific *change.*

A distinction that is very important here is the distinction between *descriptive* and *normative* theories. A descriptive theory is an attempt to describe what actually goes on, or what something is like, without making value judgments. A normative theory does make value judgments; it talks about what should go on, or what things should be like. Some theories about science are supposed to be descriptive only. But most of the views we will look at do have a normative element, either officially or unofficially. When assessing general claims about science, it is a good principle to constantly ask: "Is this claim intended to be descriptive or normative, or both?"

For some people, the crucial question we need to answer about science is whether or not it is "objective." But this term has become an extremely slippery one, used to mean a number of very different things. Sometimes objectivity is taken to mean the absence of bias; objectivity is impartiality or fairness. But the term "objective" is also often used to express claims about whether the *existence* of something is independent of our minds. A person might wonder whether there really is an "objective reality," that is to say, a reality that exists regardless of how people conceptualize or describe it. We might ask whether scientific theories can ever describe a reality that exists in this sense. Questions like that go far beyond any issue about the absence of bias and take us into deep philosophical waters.

Because of these ambiguities, I will often avoid the terms "objective" and "objectivity." But the questions that tend to be asked using those terms will be addressed, using different language, throughout the book. And I will return to "objectivity" in the final chapter.

Another famous phrase is "scientific method." Perhaps this is what most people have in mind when they imagine giving a general theory of science. The idea of describing a special method that scientists do or should follow is old. In the seventeenth century, Francis Bacon and René Descartes, among others, tried to give detailed specifications of how scientists should proceed. Although describing a special scientific method looks like a natural thing to try to do, during the twentieth century many philosophers and others became skeptical about the idea of giving anything like a recipe for science. Science, it was argued, is too creative and unpredictable a process for there to be a recipe that describes it—this is especially true in the case of great scientists like Newton, Darwin, and Einstein. For a long time it was common for

science textbooks to have an early section describing "the scientific method," but recently textbooks seem to have become more cautious about this.

I said that much twentieth-century philosophy of science aimed at describing the *logical* structure of science. What does this mean? The idea is that the philosopher should think of a scientific theory as an abstract structure, something like a set of interrelated sentences. The philosopher aims to give a description of the logical relations between the sentences in the theory and the relations between the theory and observational evidence. Philosophy can also try to describe the logical relations between different scientific theories in related fields.

Philosophers taking this approach tend to be enthusiastic about the tools of mathematical logic. They prize the rigor of their work. This kind of philosophy has often prompted frustration in people working on the actual history and social structure of science. The crusty old philosophers seemed to be deliberately removing their work from any contact with science as it is actually conducted, perhaps in order to hang onto a set of myths about the perfect rationality of the scientific enterprise, or in order to have nothing interfere with the endless games that can be played with imaginary theories expressed in artificial languages. This kind of logic-based philosophy of science will be discussed in the early chapters of this book. I will argue that the logical investigations were often very interesting, but ultimately my sympathy lies with those who insist that philosophy of science should have more contact with actual scientific work.

If looking for a recipe is too simplistic, and looking for a logical theory is too abstract, what might we look for instead? Here is an answer that will be gradually developed as the book goes on: we can try to describe the scientific *strategy* for investigating the world. And we can then hope to describe what sort of *connection* to the world we are likely to achieve by following that strategy. Initially, this may sound vague or impossible, or both. But by the end of the book I hope to show that it makes good sense.

Several times now I have mentioned fields that "neighbor" on philosophy of science—history of science, sociology of science, and parts of psychology, for example. What is the relation between philosophical theories of science and ideas in these neighboring fields? This question was part of the twentieth-century roller-coaster ride that I referred to earlier. Some people in these neighboring fields thought they had reason to believe that the whole idea of a philosophical theory of science is misguided. They expected that philosophy of science would be replaced by fields like sociology. This replacement never occurred. What did happen was that people in these neighboring fields constantly found themselves doing philosophy themselves, whether they realized it or not. They kept running into questions about truth, about justification, and about the connections between theories and reality. The philosophical problems refused to go away.

Philosophers themselves differ a great deal about what kind of input from these neighboring fields is relevant to philosophy. This book is written from a viewpoint that holds that philosophy of science benefits from lots of input from other fields. But the argument that philosophy of science needs that kind of input will not be given until chapter 10.

1.4 Three Answers, or Pieces of an Answer

In this section I will introduce three different answers to our general questions about how science works. In different ways, these three ideas will be recurring themes throughout the book.

The three ideas can be seen as rivals; they can be seen as alternative starting points, or paths into the problem. But they might instead be considered as pieces of a single, more complicated answer. The problem then becomes how to fit them together.

The first of the three ideas is *empiricism*. Empiricism encompasses a diverse family of philosophical views, and debates within the empiricist camp can be intense. But empiricism is often summarized using something like the following slogan:

Empiricism: The only source of real knowledge about the world is experience.

Empiricism, in this sense, is a view about where *all* knowledge comes from, not just scientific knowledge. So how does this help us with the philosophy of science? In general, the empiricist tradition has tended to see the differences between science and everyday thinking as differences of *detail and degree.* The empiricist tradition has generally, though not always, tended to construe science in a broad way, and it has tended to approach questions in the philosophy of science from the standpoint of a general theory of thought and knowledge. The empiricist tradition in philosophy has also been largely *pro*-science; science is seen as the best manifestation of our capacity to investigate and know the world.

So here is a way to use the empiricist principle above to say something about science:

Empiricism and Science: Scientific thinking and investigation have the same basic pattern as everyday thinking and investigation. In each case, the only source of real knowledge about the world is experience. But science is especially successful because it is organized, systematic, and especially responsive to experience.

So "the scientific method," insofar as there is such a thing, will be routinely found in everyday contexts as well. There was no fundamentally *new* approach to investigation discovered during the Scientific Revolution, according to this view. Instead, Europe was freed from darkness and dogmatism by a few brave and brilliant souls who enabled intellectual culture to "come to its senses."

Some readers are probably thinking that these empiricist principles are empty platitudes. *Of course* experience is the source of knowledge about the world—what *else* could be?

For those who suspect that basic empiricist principles are completely trivial, an interesting place to look is the history of medicine. The history of medicine has many examples of episodes where *huge* breakthroughs were made by people willing to make very basic empirical tests—in the face of much skepticism, condescension, and opposition from people who "knew better." Empiricist philosophers have long used these anecdotes to fire up their readers. Carl Hempel, one of the most important empiricist philosophers of the twentieth century, liked to use the sad example of Ignaz Semmelweiss (see Hempel 1966). Semmelweiss worked in a hospital in Vienna in the mid-nineteenth century; he was able to show by simple empirical tests that if doctors washed their hands before delivering babies, the risk of infection in the mothers was hugely reduced. For this radical claim he was opposed and eventually driven out of the hospital.

An even simpler example, which I will describe in some detail to provide a change from the usual case of Semmelweiss, has to do with the discovery of the role of drinking water in the transmission of cholera.

Cholera was a huge problem in cities in the eighteenth and nineteenth centuries, producing death from terrible diarrhea. Cholera is still a problem whenever there are poor people crowded together without good sanitation, as it is transmitted from the diarrhea through drinking water. In the eighteenth and nineteenth centuries, there were various theories of how cholera was caused—this was before the discovery of the role of bacteria and other microorganisms in infectious disease. Some thought the disease was caused by foul gases, called *miasmas,* exuded from the ground and swamps. In London, John Snow hypothesized that cholera was spread by drinking water. He mapped the outbreak of one epidemic in London in 1854 and found that it seemed to be centered on a particular public water pump in Broad Street. With great difficulty he persuaded the local authorities to remove the pump's handle. The outbreak immediately went away.

This was a very important event in the history of medicine. It was central to the rise of the modern emphasis on clean drinking water and sanitation, a movement that has had an immense effect on human health and well-being. This is also the kind of case that shows the attractiveness of even very simple empiricist views.

You might be thinking that we can just end the book here. Empiricism wins; looking to experience is a sure-fire guarantee of getting things right. Those who are tempted to think that no problems remain might consider a cautionary tale that follows up the Snow story. This is the tale of brave Doctor Pettenkofer.

Some decades after Snow, the theory that diseases like cholera are caused by microorganisms—the "germ theory of disease"—was developed in detail by Robert Koch and Louis Pasteur. Koch isolated the bacteria responsible for cholera quite early on. Pettenkofer, however, was unconvinced. To prove Koch wrong, he *drank* a glass of water mixed with the alleged cholera germs. Pettenkofer suffered no ill effects, and he wrote to Koch saying he had disproved Koch's theory.

It is thought that Pettenkofer might have had high stomach acid, which can protect people against cholera infection. Or perhaps the cholera germs had died in that sample. Clearly Pettenkofer was lucky; Koch was right about what causes cholera. But the case reminds us that direct empirical tests are no *guarantee* of success.

Some readers, I said, might be thinking that empiricism is true but too obvious to be interesting. Another line of criticism holds that empiricism is false, because it is committed to an absurdly simple picture of thought, belief, and justification. The empiricist slogan I gave earlier suggests that experiences pour into the mind and somehow turn into knowledge. It turns out to be very difficult to refine basic empiricist ideas in a way that makes them more psychologically realistic. Empiricists do not deny that reasoning, including very elaborate reasoning, is needed to make sense of what we observe. Still, they insist that the role of experience is somehow fundamental in understanding how we learn about the world. Many critics of empiricism hold that this is a mistake; they see it as a hangover from a simplistic and outdated picture of how belief and reasoning work. That debate will be a recurring theme in this book.

I now turn to the second of the three families of views about how science works. This view can be introduced with a quote from Galileo, one of the superheroes of the Scientific Revolution:

> Philosophy is written in this grand book the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and to read the alphabet in which it is composed. *It is written in the language of mathematics,* and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth. (Galileo [1623] 1990, 237–38, emphasis added)

Putting the point in plainer language, here is the second of the three ideas.

> *Mathematics and Science:* What makes science different from other kinds of investigation, and especially successful, is its attempt to understand the natural world using mathematical tools.

Is this idea an alternative to the empiricist approach, or something that can be combined with it? Perhaps surprisingly, an emphasis on mathematical methods has often been used to argue against empiricism. Sometimes this has been because people have thought that mathematics shows us that there must be another route to knowledge beside experience; experience is *a* source of knowledge, but not the *only* important source. Alternatively, we might claim that empiricism is trivial: of course knowledge is based on experience, but that tells us nothing about what differentiates science from other human thought. What makes science special is its attempt to quantify phenomena and detect mathematical patterns in the flow of events.

Nonetheless, it is surely sensible to see an emphasis on mathematics as something that can be combined with empiricist ideas. It might seem that Galileo would disagree; Galileo not only exalted mathematics but praised his predecessor Copernicus for making "reason conquer sense [experience]" in his belief that the earth goes around the sun. But this is a false opposition. In suggesting that the earth goes round the sun, Copernicus was not ignoring experience but dealing with apparent conflicts between different aspects of experience, in the light of his background beliefs. And there is no question that Galileo was a very empirically minded person; an emphasis on observations made using the telescope was central to his work, for example. So avoiding the false oppositions, we might argue that mathematics used *as a tool within an empiricist outlook* is what makes science special.

In this book the role of mathematics will be a significant theme but not a central one. This is partly because of the history of the debates surveyed in the book, and partly because mathematical tools are not quite as essential to science as Galileo thought. Although mathematics is clearly of huge importance in the development of physics, one of the greatest achievements in all of science—Darwin's achievement in *On the Origin of Species* ([1859] 1964)—makes no real use of mathematics. Darwin was not confined to the "dark labyrinth" that Galileo predicted as the fate of nonmathematical investigators. In fact, most (though not all) of the huge leaps in biology that occurred in the nineteenth century occurred without much of a role for mathematics. Biology *now* contains many mathematical parts, including modern formulations of Darwin's theory of evolution, but this is a more recent development.

So not all of science—and not all of the greatest science—makes much use of mathematics to understand the world.

The third of the three families of ideas is newer. Maybe the unique features of science are only visible when we look at scientific *communities*.

Social Structure and Science: What makes science different from other kinds of investigation, and especially successful, is its unique social structure.

Some of the most important recent work in philosophy of science has had to do with exploring this idea, but it took the input of historians and sociologists of science to bring philosophical attention to bear on it.

In the hands of historians and sociologists, an emphasis on social structure has often been developed in a way that is strongly critical of the empiricist tradition. Steven Shapin argues that mainstream empiricism often operates within the fantasy that each individual can observationally test hypotheses for himself (Shapin 1994). Empiricism is supposed to urge that people be distrustful of authority and go out to look directly at the world. But of course this is a fantasy. It is a fantasy in the case of everyday knowledge, and it is an even greater fantasy in the case of science. Almost every move that a scientist makes depends on elaborate networks of cooperation and trust. If each individual insisted on testing everything himself, science would never advance beyond the most rudimentary ideas. Cooperation and lineages of transmitted results are essential to science. The case of John Snow and cholera, discussed earlier in this section, is very unusual. Snow looks like a "lone ranger" striding up to the Broad Street water pump (with crowds of empiricists cheering in the background). And even Snow must have been dependent on the testimony of others in his assessment of the state of the cholera epidemic before and after his intervention at the pump.

So trust and cooperation are essential to science. But who can be trusted? Who is a reliable source of data? Shapin argues that when we look closely, a great deal of what went on in the Scientific Revolution had to do with working out new ways of policing, controlling, and coordinating the actions of groups of people in the activity of research. Experience is everywhere. The hard thing is working out which *kinds* of experience are relevant to the testing of hypotheses, and working out who can be trusted as a source of reliable and relevant reports.

So Shapin argues that a good theory of the social organization of science will be a better *theory of science* than empiricist fantasies. But philosophers

have begun to develop theories of how science works that emphasize social organization but are also intended to fit in with a form of empiricism (Hull 1988; Kitcher 1993). These accounts of science stress the special balance of cooperation and competition found in scientific communities. People sometimes imagine that seeking individual credit and competition for status and recognition are recent developments in science. But these issues have been important since the time of the Scientific Revolution. The great scientific societies, like the Royal Society of London, came into being quite early—1660 in the case of the Royal Society. A key part of their role was to handle the allocation of credit in an efficient way—making sure the right people were rewarded, without hindering the free spread of ideas. These societies also functioned to create a community of people who could trust each other as reliable co-workers and sources of data. The empiricist can argue that this social organization made scientific *communities* uniquely responsive to experience.

In this section I have sketched three families of ideas about how science works and what makes it distinctive. Each idea has sometimes been seen as *the* starting point for an understanding of science, exclusive of the other two. But it is more likely that they should be seen as pieces of a more complete answer. The first and third ideas—empiricism and social structure—are especially important. These we will return to over and over again. Part of the challenge for philosophy of science in the years to come lies in integrating the insights of the empiricist tradition with the role for social organization in understanding science. That does require significant changes to traditional empiricist ideas.

1.5 Historical Interlude: A Sketch of the Scientific Revolution

Before diving into the philosophical theories, we will take a brief break. Several times already I have mentioned the Scientific Revolution. People, events, and theories from this period carry special weight in discussions of the nature of science. So in this section I will give a historical sketch of the main landmarks, many of which will appear from time to time in later chapters. Before setting out, I should note that there is a good deal of controversy about how to understand this period of history; for example, some historians think that the whole idea of christening this period "The Scientific Revolution" is a mistake, as this phrase makes it sound like there are sharp boundaries between one totally unique period and the rest of history (Shapin 1996). But I will use the phrase in the traditional way.

The Scientific Revolution occurred roughly between 1550 and 1700. These events are positioned at the end of a series of dramatic changes in

Europe, and the Scientific Revolution itself fed into further processes of change. In religion, the Catholic Church had been challenged by Protestantism. The Renaissance of the fifteenth and sixteenth centuries had included a partial opening of intellectual culture. Populations were growing (recovering from the Black Death), and there was increased activity in commerce and trade. Traditional hierarchies, including intellectual hierarchies, were beginning to show strain. As recent writers have stressed, this was a time in which many new, unorthodox ideas were floating around.

The worldview that had been inherited from the Middle Ages was a combination of Christianity with the ideas of the ancient Greek philosopher Aristotle. The combination is often called the Scholastic worldview, after the universities or "Schools" that developed and defended it. The earth was seen as a sphere positioned at the center of the universe, with the moon, sun, planets, and stars revolving around it. A detailed model of the motions of these celestial bodies had been developed by Ptolemy around 150 A.D. (the sun was placed between Venus and Mars).

Aristotle's physical theory distinguished "natural" from "violent" or unnatural motion. The theory of natural motions was part of a more general theory of change in which biological development (from acorn to oak, for example) was a central guiding case, and many events were explained using the idea of *purpose*.

Everything on earth was considered to be made up of mixtures of four basic elements (earth, air, fire, and water), each of which had natural tendencies. Objects containing a lot of earth, for example, naturally fall toward the center of the universe, while fire makes things rise. Unnatural motions, such as the motions of projectiles, have an entirely different kind of explanation. Objects in the heavens are made of a fifth element, which is "incorruptible," or unchanging. The natural motion for objects made of this fifth element is circular.

Some versions of this picture included a mechanism (using the term loosely) for the motions of sun, planets, and stars. For example, each body orbiting the earth might be positioned on a crystalline sphere that revolved around the earth. Ptolemy's own model was harder to interpret in these terms; Ptolemy is sometimes thought to be most interested in giving a tool for astronomical prediction (though interpreters differ on this).

In 1543 the Polish astronomer Nicolaus Copernicus (1473–1543) published a work outlining an alternative picture of the universe. Others had speculated in ancient times that the earth might move around the sun instead of vice versa, but Copernicus was the first to give a detailed theory of this kind. In his theory the earth has two motions, revolving on its axis once a day and orbiting the sun once a year. Copernicus's theory had the same basic placement of the sun, moon, earth, and the known planets that modern astronomy has. But the theory was made more complicated by his insistence, following Aristotle and Ptolemy, that heavenly motions must be circular. Both the Ptolemaic system and Copernicus's system saw most orbits as complex compounds of circles, not single circles. Ptolemy's and Copernicus's systems were about equally complicated, in fact. Writers seem to differ on whether Copernicus's theory was much more accurate as a predictive tool. But there were some famous phenomena that Copernicus's theory explained far better than Ptolemy's. One was the "retrograde motion" of the planets, an apparently erratic motion in which planets seem to stop and backtrack in their motions through the stars.

Copernicus's work aroused interest, but there seemed to be compelling arguments against taking it to be a literally true description of the universe. Some problems were astronomical, and others had to do with obvious facts about motion. Why does an object dropped from a tower fall at the foot of the tower, if the earth has moved a considerable distance while the object is in flight? Copernicus's 1543 book had an extra preface written by a clergyman, Andreas Osiander, who had been entrusted with the publication, urging that the theory be treated just as a calculating tool. This became a historically important statement of a view about the role of scientific theories known as *instrumentalism*, which holds that we should think of theories only as predictive tools rather than as attempts to describe the hidden structure of nature.

The situation was changed dramatically by Galileo Galilei (1564–1642), working in Italy in the early years of the seventeenth century. Galileo vigorously made the case for the literal truth of the Copernican system, as opposed to its mere usefulness. Galileo used telescopes (which he did not invent but did improve) to look at the heavens, and he found a multitude of phenomena that contradicted Aristotle and the Scholastic view of the world. He also used a combination of mathematics and experiment to begin the formulation of a new science of motion that would make sense of the idea of a moving earth and explain familiar facts about dropped and thrown objects. Galileo's work eventually aroused the ire of the pope; he was forced to recant his Copernican beliefs by the Inquisition and spent his last years under house arrest. (Galileo was treated lightly in comparison with Giordano Bruno, whose refusal to disown his unorthodox speculations about the place of the earth in the universe led to his being burned at the stake in Rome, for heresy, in 1600.)

Galileo remained wedded to circular motion as astronomically fundamental. The move away from circular motion was taken by Johannes Kepler (1571–1630), a mystical thinker who combined Copernicanism with an obsession with finding mathematical harmony (including musical tunes) in the structure of the heavens. Kepler's model of the universe, also developed around the start of the seventeenth century, had the earth and other planets moving in *ellipses,* rather than circles, around the sun. This led to massive simplification and better predictive accuracy.

So far I have mentioned only changes in astronomy and related areas of physics, and I have taken the discussion only to the early part of the seventeenth century. Part of what makes this initial period so dramatic is the removal of the earth from the center of the universe, an event laden with symbolism. Another field that changed in the same period is anatomy. In Padua, Andreas Vesalius (publishing, like Copernicus, in 1543) began to free anatomy from dependence on ancient authority (especially Galen's conclusions) and set it on a more empirical path. Influenced by Vesalius's school, William Harvey achieved the most famous breakthrough in this period, establishing in 1628 the circulation of blood and the role of the heart as a pump.

The mid-seventeenth century saw the rise of a general and ambitious new theory about matter: *mechanism.* The mechanical view of the world combined ideas about the composition of things with ideas about causation and explanation. According to mechanism, the world is made up of tiny "corpuscles" of matter, which interact only by local physical contact. Ultimately, good explanations of physical phenomena should only be given in terms of mechanical interactions. The universe was to be understood as operating like a mechanical clock.

Some, like René Descartes (1596–1650), thought that an immaterial soul and a traditional God must be posited as well as physical corpuscles. Though many figures in the Scientific Revolution held religious views that were at least somewhat unorthodox, most were definitely not looking for a showdown with mainstream religion. Most of the "mechanical philosophers" retained a role for a Christian God in their overall pictures of the world. (If the world is a clock, who set it in motion, for example?) However, the idea of dropping souls, God, or both from the picture was sometimes considered.

In England, Robert Boyle (1627–91) and others embedded a version of mechanism into an organized and well-publicized program of research that urged systematic experiment and the avoidance of unempirical speculation. In the mid-seventeenth century we also see the rise of scientific societies in London, Paris, and Florence. These societies were intended to organize the new research and break the institutional monopoly of the (often conservative) universities.

The period ends with the work of Isaac Newton (1642–1727). In 1687 Newton published his *Principia,* which gave a unified mathematical treatment of motion both on earth and in the heavens. Newton showed why Kepler's elliptical orbits were the inevitable outcome of the force of gravity operating between heavenly bodies, and he vastly improved the ideas about motion on earth that Galileo (and others) had pioneered. So impressive was this work that for hundreds of years Newton was seen as having essentially completed those parts of physics. Newton also did immensely influential work in mathematics and optics, and he suggested the way to move forward in fields like chemistry. In some ways Newton's physics was the culmination of the mechanical worldview, but in some ways it was "post-mechanical," since it posited some forces (gravity, most importantly) that were hard to interpret in mechanical terms.

So by the end of the seventeenth century, the Scholastic worldview had been replaced by a combination of Copernicanism and a form of mechanism. As far as method is concerned, a combination of experiment and mathematical analysis had triumphed (though people disagreed about the nature of the triumphant combination). This ends the period usually referred to as the Scientific Revolution. But the changes described above fed into further changes, both intellectual and political. Chemistry began a period of rapid development in the middle to late eighteenth century, a period sometimes called the Chemical Revolution. The work of Lavoisier, especially his description of oxygen and its role in combustion, is often taken to initiate this "revolution," though it was in the nineteenth century, with the work of Dalton, Mendeleyev, and others, that the basic features of modern chemistry, like the periodic table of elements, were established.

Linnaeus had systematized biological classification in the eighteenth century, but it was the nineteenth century that saw dramatic developments in biology. These developments include the theory that organisms are comprised of cells, Darwin's theory of evolution, the germ theory of disease, and the work by Mendel on inheritance that laid the foundation for genetics.

The Scientific Revolution also fed into more general cultural and political changes. In the eighteenth century the philosophers of the French Enlightenment hoped to use science and reason to sweep away ignorance and superstition, along with oppressive religious and political institutions. The intellectual movements leading to the American and French Revolutions in the late eighteenth century were much influenced by currents of thought in science and philosophy. These included empiricism, mechanism, the inspiration of Newton, and a general desire to understand mankind and society in a way modeled on the understanding of the physical world achieved during the Scientific Revolution.

Further Reading

The topics in this chapter will be discussed in detail later, and references will be given then. Two other introductory books are worth mentioning, though. Hempel's *Philosophy of Natural Science* (1966) was for many years the standard introductory textbook in this area. It opens with the story of Semmelweiss and is a clear and reasonable statement of mainstream twentieth-century empiricism. Alan Chalmers's *What Is This Thing Called Science?* (1999) is also very clear; it presents a different view from Hempel's and the one defended here.

For all the topics in this book, there are also reference works that readers may find helpful. Simon Blackburn's *Oxford Dictionary of Philosophy* is a remarkably useful book and is fun to browse through. The *Routledge Encyclopedia of Philosophy* is also of high quality. *The Blackwell Companion to the Philosophy of Science* has many short papers on key topics (though many of these papers are quite advanced). The *Stanford Online Encyclopedia of Philosophy* is still in progress but will be a very useful (and free) resource.

There are many good books on the Scientific Revolution, each with a different emphasis. Cohen, *The Birth of a New Physics* (1985), is a classic and very good on the physics. Henry, *The Scientific Revolution and the Origins of Modern Science* (1997), is both concise and thorough. It has an excellent chapter on mechanism and contains a large annotated bibliography. Schuster 1990 is also a useful quick summary, and Dear's *Revolutionizing the Sciences* (2001) is a concise and up-to-date book with a good reputation. But Toulmin and Goodfield's *Fabric of the Heavens* (1962), an old book recently reprinted, is my favorite. It focuses on the conceptual foundations underlying the development of scientific ideas. (It is the first of three books by Toulmin and Goodfield on the history of science; the second, *The Architecture of Matter* is also relevant here.)

Kuhn's *Copernican Revolution* (1957), is another classic, focused on the early stages, as the title suggests. Shapin's *Scientific Revolution* (1996), is not a good introduction to the Scientific Revolution but is a very interesting book anyway. There are several good books that focus on particular personalities. Koestler, *The Sleepwalkers* (1968), is fascinating on Kepler, and Sobel, *Galileo's Daughter* (1999), is also good on Galileo (and his daughter, a nun leading a tough life). The standard biography of the amazingly strange Isaac Newton, by Robert Westfall, comes in both long (1980) and short (1993) versions.

For a history of medicine, covering the whole world, see Porter, *The Greatest Benefit to Mankind* (1998).

2

Logic Plus Empiricism

2.1 The Empiricist Tradition

The first approach to science that we will examine is a revolutionary form of empiricism that appeared in the early part of the twentieth century, flourished for a time, was transformed and moderated under the pressure of objections, and then slowly became extinct. The earlier version of the view is called "logical positivism," and the later, moderate form is more usually called "logical empiricism." There is variation in terminology here; "logical empiricism" is sometimes used for the whole movement, early and late. Although we will be looking at fossils in this chapter, these remnants of the past are of great importance in understanding where we are now.

Before discussing logical positivism, it will be helpful to go even further back and say something about the empiricist tradition in general. In the first chapter I said that empiricism is often summarized with the claim that the only source of knowledge is experience. This idea goes back a long way, but the most famous stage of empiricist thought was in the seventeenth and eighteenth centuries, with the work of John Locke, George Berkeley, and David Hume. These "classical" forms of empiricism were based upon theories about the mind and how it works. Their view of the mind is often called "sensationalist." Sensations, like patches of color and sounds, appear in the mind and are all the mind has access to. The role of thought is to track and respond to patterns in these sensations. This view of the mind is not implied by the more basic empiricist idea that experience is the source of knowledge, but for many years such a view was common within empiricism.

Both during these classical discussions and more recently, a problem for empiricism has been a tendency to lapse into *skepticism,* the idea that we cannot know anything about the world. This problem has two aspects. One aspect we can call *external world skepticism:* how can we ever know anything about the real world that lies behind the flow of sensations? The