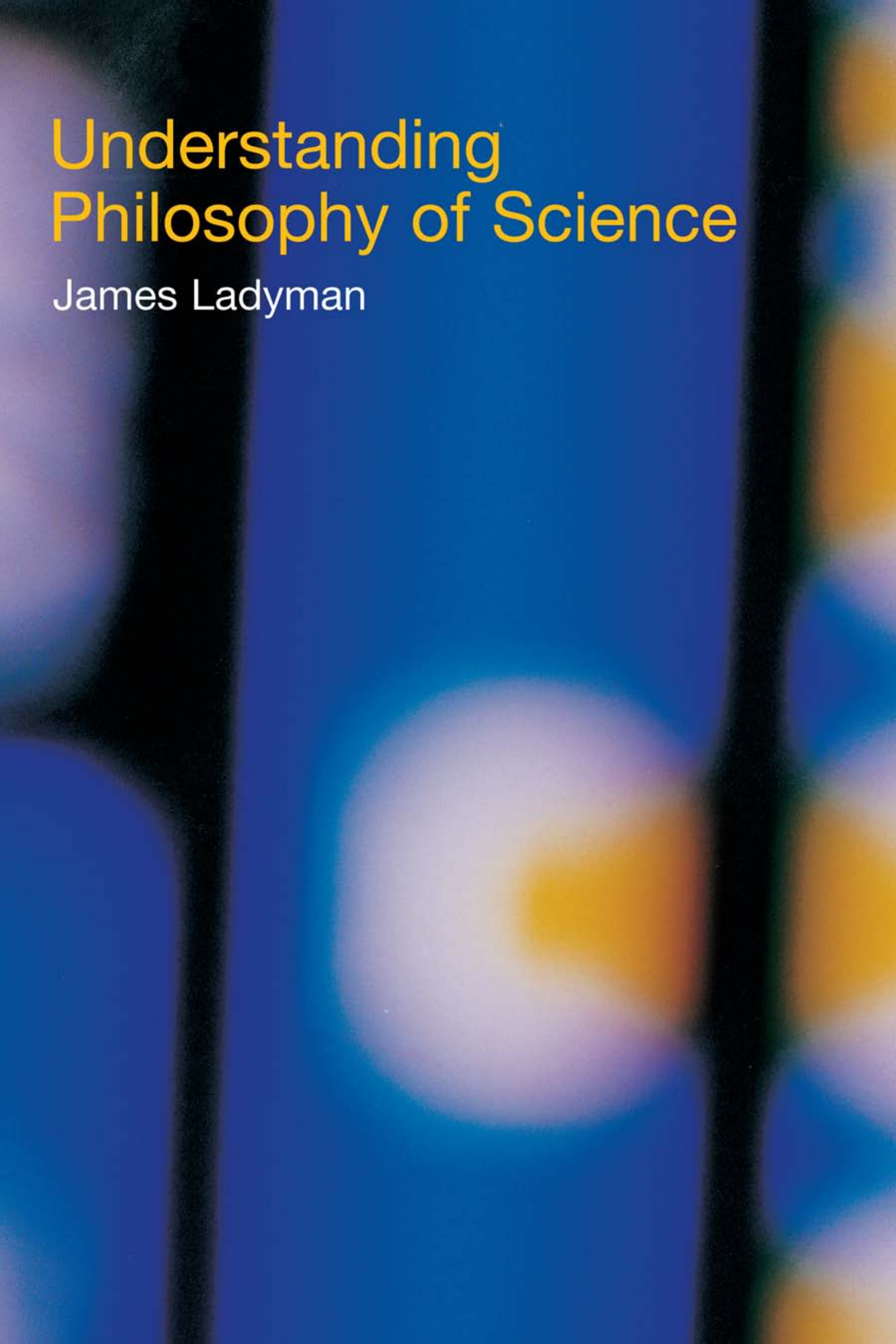
Understanding Philosophy of Science

James Ladyman



UNDERSTANDING PHILOSOPHY OF SCIENCE

> ‘This is the best introduction to philosophy of science I have read. I will certainly use it. The writing is wonderfully clear without being simplistic. It is not at all too difficult for second and third year students. Many of my philosophy of science students have no background in philosophy, and I’m sure they will find the book accessible, informative, and a pleasure to read. I read this manuscript with my students in mind. This is the book we’ve been looking for.’
>
> Peter Kosso, *Northern Arizona University*

Few can imagine a world without telephones or televisions; many depend on computers and the Internet as part of daily life. Without scientific theory, these developments would not have been possible.

In this exceptionally clear and engaging introduction to the philosophy of science, James Ladyman explores the philosophical questions that arise when we reflect on the nature of the scientific method and the knowledge it produces. He discusses whether fundamental philosophical questions about knowledge and reality might be answered by science, and considers in detail the debate between realists and antirealists about the extent of scientific knowledge. Along the way, central topics in the philosophy of science, such as the demarcation of science from non-science, induction, confirmation and falsification, the relationship between theory and observation, and relativism, are all addressed. Important and complex current debates over underdetermination, inference to the best explanation and the implications of radical theory change are clarified and clearly explained for those new to the subject.

The style is refreshing and unassuming, bringing to life the essential questions in the philosophy of science. Ideal for any student of philosophy or science, this book requires no previous knowledge of either discipline. It contains the following textbook features:

- suggestions for further reading
- cross-referencing with an extensive bibliography.

James Ladyman is Lecturer in Philosophy at the University of Bristol, UK.

UNDERSTANDING PHILOSOPHY OF SCIENCE

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For Audrey Ladyman

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Preface

This book is intended to provide an introduction to the philosophy of science. In particular, it is aimed at science students taking a philosophy of science course but no other philosophy classes, as well as at those students who are studying philosophy of science as part of a philosophy degree. Hence, I have assumed no prior knowledge of philosophy, and I have not relied upon detailed knowledge of science either. I have also avoided using any mathematics. This means that some issues are not discussed despite their interest. For example, the implications of quantum mechanics for philosophy of science, and the mathematical theory of probability and its use in modelling scientific reasoning are not dealt with here. Nonetheless, an introductory text need not be superficial and I have tried to offer an analysis of various issues, such as induction, underdetermination and scientific realism from which even graduate students and professional philosophers may benefit. My aim throughout has been to make the reader aware of questions about which they may never have thought, and then to lead them through a philosophical investigation of them in order that they appreciate the strength of arguments on all sides, rather than to offer my own views. Hence, there are few answers to be found in what follows and if my readers are left puzzled where previously they were comfortable then I will be satisfied.

I hope this book will also interest scientists and general readers who are curious about the philosophy of science. I have tried to keep the exposition clear and accessible throughout, and also to illustrate important lines of argument with everyday and scientific examples. However, the reader will find that the discussion in Chapter 5 is largely about the historical and philosophical background to the contemporary debate about scientific realism. Those who do not see its relevance immediately are urged to persevere, since the issues discussed are of fundamental importance. Finally, I must confess in advance to historians that I have subordinated historiography to my pedagogical aims by sometimes presenting a narrative that only just begins to address the complexities and ambiguities of the historical development of philosophy and science.

For the benefit of the reader, the first instances of each term expanded in the Glossary are set in bold.

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I am very grateful to all those who have taught me about philosophy of science, but special thanks are due to Richard Francks, Steven French, David Papineau, Anthony Sudbery and Bas van Fraassen. Thanks to all my students, especially Carlton Gibson and Nick Talbot who gave me feedback on portions of this book at early stages. Katherine Hawley kindly allowed me to see her lecture notes on Kuhn, which were very helpful. Dawn Collins, Andrew Pyle, Paul Tappenden and an anonymous referee read the whole manuscript and gave me extensive comments for which I am extremely grateful. Thanks also to Leah Henderson who gave me useful advice on the later chapters, and Jimmy Doyle who eventually managed to read the preface and the acknowledgements. I would like to thank all my colleagues in the Department of Philosophy at the University of Bristol for affording me study leave with which to write this book, and also the *Arts and Humanities Research Board* for a research leave grant. I am very grateful to Tony Bruce, philosophy editor at Routledge, who encouraged me to undertake this project, and to Siobhan Pattinson who guided it through the publication process. Finally, thanks to Audrey and Angela Ladyman for their love and support.

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James Ladyman

Introduction

In many ways, our age is no different from any other: most people work hard merely to survive, while a few live in the lap of luxury; many perish in wars and conflicts, the causes of which they have no control over; the cycle of birth, reproduction and death is fundamentally the same for us as it was for our distant ancestors. Yet certain features of the contemporary world are quite new: for example, I can pick up the phone and speak to a relative on the other side of the globe, and I can see that it is indeed a globe that I inhabit by looking at a photograph taken from space; many people's everyday lives are enhanced by, and unimaginable without, computers, televisions and music systems; medicine can treat forms of illness and injury that would have brought certain death for earlier generations. On the downside, but equally unprecedented, the nuclear weapons that many countries now have are sufficient in number to wipe out almost all life on the planet, and our skies and oceans are polluted by substances that only exist because we make them in chemical factories.

Whether good or bad in their effects, none of these technologies would exist without science. It is possible to develop ploughs, wheels, bandages and knives without much in the way of theory, but without the scientific theories and methods developed mainly in the last few hundred years there would be no electronic devices, spacecraft, micro-surgery or weapons of mass destruction. The products of science and technology have a huge effect on the way we live our lives and how we shape our environment; if you are in any doubt about this try and imagine going through an average day without using anything powered by electricity or containing plastic.

The importance of science does not only derive from its use in technology. Science enjoys unparalleled prestige in society compared with other institutions, and everyone is likely to agree about the need to fund and understand modern science while many may deride modern art or literature. Furthermore, most people are likely to trust the word of a scientist much more than they do that of a journalist, lawyer or politician (although that may not be saying much). Rightly or wrongly, science is often thought to be the ultimate form of objective and rational inquiry, and scientists are widely regarded as being able to gather and interpret evidence and use it to arrive at conclusions that are 'scientifically proven' and so not just the product of ideology or prejudice. Courts do not convict or acquit someone of a crime on the say-so of a priest or a novelist, but they do routinely rely to large extent on the evidence of an expert witness who is a scientist of some sort; if a ballistics expert says that a bullet came from a certain direction, or a pathologist says that a person had a certain drug in their system when they died, their testimony will usually be taken as establishing the facts of the case. Most of us consult a doctor when we have something wrong with us and if the doctor prescribes some drug or other therapy we take it assuming that it will help with our symptoms and not itself cause us harm. Often, modern medicine is explicitly claimed to be 'evidence-based' and hence scientific. Similarly, if the scientists appointed by the government say that a particular food or chemical is unsafe, its use and sale will be banned.

The examples above concerning justice, health and safety could readily be expanded to cover activities from engineering and construction to fishing and farming. Hence, in almost all areas of modern life, people are likely to seek or rely indirectly upon the scientific evidence and the opinions of scientists before making important decisions. Whether or not we as individuals share this faith in science and scientists, our lives are enormously affected by it, and this is one reason why understanding and thinking about science is important. Of course, most of us know very little science, and the degree of specialisation within particular sciences is now so great that no individual could possibly know all there is to know about any one scientific field let alone all about science in its entirety. For this reason, we have no choice but to rely upon co-operation and co-ordination between many individuals in order to develop further and apply scientific thought. However, there are some features of science that are more or less universal and which we can investigate philosophically without needing to know much about the cutting edge of scientific research.

Before thinking about what philosophy of science is about, it will be helpful to say what it is not about. Obviously, there are important ethical questions raised by scientific research, such as whether it is morally acceptable to conduct experiments on animals that cause them suffering, or to give psychiatric patients treatments when they may be incapable of giving their informed consent. Similarly, there are important social, political and economic questions about what research to fund and what not and, for example, whether or not to build nuclear power stations, and whether the genetic engineering of plants and animals is ethical or practically advisable. Although science policy and the ethics of scientific research ought to be informed by the philosophy of science, and indeed are part of the philosophy of science broadly conceived, they are not addressed here. Furthermore, as philosophers, we are not primarily concerned to make progress in any of the particular sciences (although philosophical thinking has often affected how work in the particular sciences is carried out and philosophical inquiry sometimes overlaps with theoretical science).

While there are other disciplines that study the sciences, the types of questions they address and their means of trying to answer them are different from those in the philosophy of science. Questions about, for example, the development of particular scientific disciplines and theories need to be addressed by historians of science, not philosophers. On the other hand, questions like, ‘what sort of personality makes for a good scientist?’ or ‘what role do journals play in the communication and assessment of theories in physics?’ are matters for the psychology or sociology of science, respectively. Philosophical questions about science, like philosophical questions in general, cannot be answered by going out in the world and gathering information, and finding out what happened, or how a particular scientific community is, as a matter of fact, organised; rather, philosophical inquiry proceeds by analysis, argument and debate.

This characterisation of history, sociology and psychology as empirically based and distinct in both subject matter and method from philosophy is itself philosophically controversial. Many philosophers think that the traditional conception of philosophy as a subject based on armchair reflection is untenable and that philosophy is really continuous with empirical inquiry and science itself (this view is known as *naturalism*). On this view, questions about scientific methodology and knowledge in philosophy of science are really continuous with questions in cognitive science about how human beings reason and form beliefs. However, one need not imagine an absolute distinction between philosophy and empirical forms of inquiry to appreciate the broad differences between the latter and the study of philosophical questions that arise when we reflect on science.

Of course, this characterisation is of little use unless we know what science is, so perhaps the most fundamental task for the philosophy of science is to answer the question, 'what is science?'. Given the status of science, this question is of great importance and many philosophers have sought to provide an answer so that it can be used to assess whether beliefs that are claimed to be scientific really are. The problem of saying what is scientific and what is not is called the **demarcation problem**. Some people have claimed scientific status for beliefs and practices, such as those of astrology, creationism (the doctrine that God created the Earth a few thousand years ago as stated in the Bible), Marxism and psychoanalysis, and some philosophers have wanted to be able to show that they are not scientific, that they are in fact merely pseudo-scientific. It is usually thought that if there is anything of which science consists it is a method or set of methods, so the study of scientific method (known as **methodology** of science) is at the centre of the philosophy of science.

We may not yet know how to define science or how to tell whether certain contentious activities or beliefs count as scientific or not, but we certainly have lots of examples of sciences. It is usual to divide the sciences into two types, namely the natural sciences and the social sciences. The former have as their object of study the natural world and include physics, chemistry, astronomy, geology and biology; the latter study the specifically human or social world and include psychology, sociology, anthropology and economics. Because the social sciences study the behaviour and institutions of human beings, they must deal with meanings, intentional actions and our apparent free will; hence, the philosophical questions they raise are often quite different from those raised by the natural sciences. Furthermore, it is an important issue in the philosophy of the social sciences whether or not a subject such as sociology is, can, or should be, scientific. Such questions do not arise for the natural sciences – if anything is a science then physics certainly is. For the purposes of this book (and here I follow standard practice) the philosophy of science is the philosophy of natural science, although many of the topics to be discussed are of concern in the philosophy of social science as well.

Philosophy of science as epistemology and metaphysics

Apart from any philosophical interest that we may have in science because of its status and influence on our lives, science is important to philosophy because it seems to offer answers to fundamental philosophical questions. One such question is 'how can we have knowledge as opposed to mere belief or opinion?', and one very general answer to it is 'follow the scientific method'. So, for example, whatever any of us may believe, rightly or wrongly, about whether smoking causes cancer or traffic fumes cause asthma, a government will not act unless there is scientific evidence supporting such beliefs (of course, they may still not act even when there is evidence). Similarly, in all the examples mentioned above, respect is accorded to the views of scientists because their conclusions are supposed to have been reached on the basis of proper methods of gathering and assessing evidence, and hence are supposed to be justified.

The branch of philosophy that inquires into knowledge and justification is called **epistemology**. The central questions of epistemology include: what is knowledge as opposed to mere belief?; can we be sure that we have any knowledge?; what things do we in fact know?. The first of these is perhaps the most fundamental epistemological question. Each of us has many beliefs, some true and some false. If I believe something that is, as a matter of fact, false (suppose, for example, that I believe that the capital city of Australia is Sydney) then I cannot be said to know it. In logical terminology we say a **necessary condition**, that is a condition that must be satisfied, for somebody knowing some **proposition** is that the proposition is true. In other words, if somebody knows some proposition then that proposition is true. (The converse obviously does not hold; there are lots of propositions that are true but which nobody knows, for example, there is a true proposition about how many leaves there are on the tree outside my window, but I presume nobody has bothered to find out what it is.) Where someone believes something that turns out to be false (no matter how plausible it seemed) then we would say that they thought they knew it but that in fact they did not.

Suppose too that another necessary condition for somebody knowing some proposition is that he or she believes that proposition. We now have two necessary conditions for knowledge; knowledge is at least true belief, but is that enough? Consider the following example: suppose that I am very prone to wishful thinking and every week I believe that my numbers will come up on the lottery, and suppose that one particular week my numbers do in fact come up; then I had a belief, that my numbers would come up, and it was a true belief, but it was not knowledge because I had no adequate reason to believe that my numbers would come up on that particular week rather than on all the other weeks when I believed they would come up, but when they did not. Hence, it may be the case that I believe something, and that it is true, but that I do not know it.

So it seems that for something someone believes to count as knowledge, as well as that belief being true, something else is required. My belief about the lottery in the example above did not count as knowledge because I lacked an adequate reason to believe that I would win that week; we would say that my belief was not justified. The traditional view in epistemology has been that knowledge can only be claimed when we have an adequate justification for our beliefs, in other words, knowledge is *justified* true belief. Although recently this 'tripartite' definition of knowledge has been the subject of much criticism and debate, justification is still often regarded as necessary for knowledge. This brings us to the issue of what justification amounts to and, as suggested above, justification is often thought to be provided by following scientific methods for testing or arriving at our beliefs (the word science comes from the Latin word *scientia*, which means knowledge).

So one area of philosophy that overlaps considerably with philosophy of science is epistemology. The epistemological questions that are addressed in later chapters (along with some of the competing answers to them) include the following. What is the scientific method? How does evidence support a theory? Is theory change in science a rational process? Can we really be said to know that scientific theories are true?

If we accept the idea that science really does give us some sort of knowledge then we must examine what scientific theories tell us about how the world is, and decide what is the scope of scientific knowledge. The modern scientific picture of the world seems to tell us a great deal, not just about how things are now, but how they were millions and even billions of years ago. Astrophysics tells us about the formation of the Earth, the solar system and even the universe, geophysics tells us about the development of mountains, continents and oceans, and biochemistry and evolutionary biology tell us about the development of life itself. Such scientific theories tell us more about familiar things, so, for example, we may learn where a particular river used to flow or how bees pollinate flowers. However, scientific theories, especially those in physics and chemistry, also describe entities that are not part of our everyday experience, such as molecules, atoms, electromagnetic waves, black holes, and so on. Such theories raise particular problems and questions in the philosophy of science; for example, should we believe in the existence of such esoteric and unobservable entities, and if so, what is to count as evidence for their existence and how do we manage to refer to them?

Of course, science does not just describe the world; it also gives us explanations of how and why things are as they are. Often this involves describing unobservable causes of things we observe. Hence, Newton is not famous for discovering that unsupported objects fall to the Earth, he is famous for explaining why they do so (the gravitational force is what causes apples to fall out of trees), and for giving us a law that allows us to calculate the rate at which they do so. Newton's mechanics, like many scientific theories, is formulated in terms of a few fundamental principles or laws. Central to our understanding of science is this idea of *laws of nature*; for example, it is supposed to be a law of nature that all metals expand when heated. So science seems to tell us about the ultimate nature of things, what the world is made of and how it works. It has even been thought that science has replaced **metaphysics** not just by telling us about what exists, and explaining what happens in terms of laws of nature and causation, but also by answering other fundamental philosophical questions about, say, the nature of space and time. But what exactly is a law of nature, and what does it mean to say that something has caused something else? What is it to explain something?

Many philosophers and scientists take it for granted that the aim of science is not merely to describe what we see, but also to arrive at the truth about the unobservable entities, laws and causes that lie behind the phenomena we observe. On the other hand, there is also a long tradition of disregarding questions about the real nature of things, the laws of nature and so on, and emphasising instead the search for theories that accurately predict what can be observed, without worrying about whether they are true or false beyond that. The question on which this book will focus is, 'ought we to believe in the unobservable entities postulated by our best scientific theories?', or more crudely, 'do electrons really exist?'. You might think this question makes little sense because electrons are, in fact, observable. After all, don't television sets work by firing electrons at a phosphorus screen, and so don't we, indirectly at least, observe electrons all the time? Exactly what is meant by observability will be discussed in the latter part of Chapter 6; however, it ought to be clear that electrons, atoms and the like are not observable in the same way that tables and trees are. Scientific realism is the view that we should believe in the likes of electrons, whereas scientific antirealism is the view that we should stop short of believing in the truth of scientific theories and content ourselves with believing what they say about what we can observe. In trying to decide the issue of scientific realism we will have to address all the epistemological and metaphysical questions mentioned above along the way.

Part I

The scientific method

1

Induction and inductivism

1.1 The sceptic's challenge

Our starting point is the desire to arbitrate the following dispute that arises when Alice, who has been reading *A Brief History of Time* by Stephen Hawking, is trying to explain the exciting things she has learned about the Big Bang and the history of the universe to her friend Thomas.

Alice: . . . and so one second after the Big Bang the temperature of the universe was about ten thousand million degrees, which is about the same as the temperature in the middle of the explosion of a nuclear bomb.

Thomas: Do you really buy all that stuff? Don't you think it's a bit far-fetched?

Alice: Of course I believe it, and I don't think it is any more far-fetched than the fact that this table we are sitting at is almost all empty space and that it is made of atoms so tiny that millions of them could fit on the end of a pin.

Thomas: Exactly, it is just as far-fetched and you are just gullible for believing it.

Alice: But that is what science tells us.

Thomas: 'Science' doesn't tell us anything; scientists, people like you or me, tell us things and like all people they tell us what is in their interest to tell us.

Alice: What do you mean?

Thomas: Isn't it obvious? A used-car dealer will tell you that a car is a lovely little runner with one previous owner because they want you to buy the car, priests tell you that you must come to church so you can go to heaven, because otherwise they would be out of a job, and scientists tell us all that nonsense so we will be amazed at how clever they are and keep spending taxpayers' money on their research grants.

Alice: Now you are just being cynical; not everyone is out for themselves you know.

Thomas: And you are just being naïve; anyway, even supposing that scientists really believe their theories, can't you see that science is just the modern religion?

Alice: What do you mean?

Thomas: Well, if you were living five hundred years ago you would believe in angels and saints and the Garden of Eden; science has just replaced religion as the dominant belief system of the West. If you were living in a tribe in the jungle somewhere you would believe in whatever creation myths the elders of the tribe passed down to you, but you happen to be living here and now, so you believe what the experts in our tribe, who happen to be the scientists, tell us.

Alice: You can't compare religious dogma and myth with science.

Thomas: Why not?

Alice: Because scientists develop and test their beliefs according to proper methods rather than just accepting what they are told.

Thomas: Well you are right that they *claim* to have a method that ensures their theories are accurate but I don't believe it myself, otherwise they would all come to the same conclusions and we know that scientists are always arguing with each other, like about whether salt or sugar is really bad for you.

Alice: Well it takes time for theories to be proven but they will find out eventually.

Thomas: Your faith is astounding – and you claim that science and religion are totally different. The scientific method is a myth put about by scientists who want us to believe their claims. Look at all the drugs that have been tested by scientific methods and pronounced safe only to be withdrawn a few years later when people find out how dangerous they are.

Alice: Yes but what about all the successful drugs and the other amazing things science has done.

Thomas: Trial and error, that's the only scientific method there is, it's as simple as that. The rest is just propaganda.

Alice: I can't believe that; scientific theories, like the Big Bang theory, are proved by experiments and observations, that is why we ought to believe them and that is what makes them different from creation myths and religious beliefs.

Thomas: So you say but how can experiments and observations prove a theory to be true?

Alice: I suppose I don't really know.

Thomas: Well let me know when you've found out.

In this dialogue, one of the characters challenges the other to explain why her beliefs, which are based on what she has been told by scientists, are any better supported than belief in angels and devils or the spirits and witchcraft of animistic religions. Of course, there are lots of things that each of us believe that we cannot justify directly ourselves; for example, I believe that large doses of arsenic are toxic to humans, but I have never even seen any arsenic as far as I am aware, and I have certainly never tested its effects. We all believe all kinds of things to be the case because we rely upon what others tell us directly or indirectly; whether or not we are justified depends upon whether or not they are justified. Most readers of this book probably believe that the Earth revolves around the Sun, that we as human beings evolved from animals that were more like apes, that water is made of twice as much hydrogen as oxygen, that diseases are often caused by viruses and other tiny organisms, and so on. If we believe these things it is because the experts in our tribe (the scientists) tell us them; in that way, the causes of our beliefs are of much the same kind as those of someone who believes what the local witch-doctor tells them about, say, the cause of disease being the witchcraft of another person. We like to think that there is a difference between our beliefs and belief in witchcraft nonetheless; if there isn't then why do we spend so much money on modern drugs and treatments when a few sacrifices or spells would do just as well?

Our believer (Alice) thinks that the scientific method is what makes the difference, in that our beliefs are ultimately produced and proven by it, and that it has something to do with experiments and observation. In this chapter we will investigate the nature of the scientific method, if indeed there is one, beginning with the origins of modern science in the search for a new method of inquiry to replace reliance on the authority of the Church and the pronouncements of the ancients. Our goal will be to determine whether Alice, who believes in what science tells her, is entitled to her faith or whether the attitude of the sceptic, Thomas, is in fact the more reasonable one.

1.2 The scientific revolution

The crucial developments in the emergence of modern science in the western world took place during the late sixteenth and the seventeenth centuries. Within a relatively short space of time, not only was much of what had previously been taken for granted discredited and abandoned, but also a host of new theoretical developments in astronomy, physics, physiology and other sciences were established. The study of the motion of matter in collisions and under the influence of gravity (which is known as mechanics) was completely revolutionised and, beginning with the work of Galileo Galilei (1564–1642) in the early sixteen hundreds and culminating in the publication of Isaac Newton's (1642–1727) mathematical physics in 1687, this part of physics became a shining example of scientific achievement because of its spectacular success in making accurate and precise predictions of the behaviour of physical systems. There were equally great advances in other areas and powerful new technologies, such as the telescope and microscope, were developed.

This period in intellectual history is often called *the Scientific revolution* and embraces *the Copernican revolution*, which is the name given to the period during which the theory of the solar system and the wider cosmos, which had the Earth at the centre of everything (geocentrism), was replaced by the theory that the Earth revolved around the Sun (heliocentrism). From the philosophical point of view the most important development during the scientific revolution was the increasingly widespread break with the theories of Aristotle (384–322 BC). As new ideas were proposed, some thinkers began to search for a new method that could be guaranteed to bring knowledge. In the Introduction we found that for a belief to count as knowledge it must be justified, so if we want to have knowledge we might aim to follow a procedure when forming our beliefs that simultaneously provides us with a justification for them; the debate about what such a procedure might consist of, which happened during the scientific revolution, was the beginning of the modern debate about scientific method.

In medieval times, Aristotle's philosophy had been combined with the doctrines of Christianity to form a cosmology and philosophy of nature (often called *scholasticism*) that described everything from the motions of the planets to the behaviour of falling bodies on the Earth, the essentials of which were largely unquestioned by most western intellectuals. According to the Aristotelian view, the Earth and the heavens were completely different in their nature. The Earth and all things on and above it, up as far as the Moon, were held to be subject to change and decay and were imperfect; everything here was composed of a combination of the elements of earth, air, fire and water, and all natural motion on the Earth was fundamentally in a straight line, either straight up for fire and air, or straight down for water and earth. The heavens, on the other hand, were thought to be perfect and changeless; all the objects that filled them were supposed to be made up of a quite different substance, the fifth essence (or quintessence), and all motion was circular and continued forever.

Although not everyone in Europe prior to the scientific revolution was an Aristotelian, this was the dominant philosophical outlook, especially because of its incorporation within official Catholic doctrine. The break with Aristotelian philosophy began slowly and with great controversy, but by the end of the seventeenth century the radically non-Aristotelian theories of Galileo, Newton and others were widely accepted. Perhaps the most significant event in this process was the publication in 1543 of a theory of the motions of the planets by the astronomer Nicolaus Copernicus (1473–1543). In the Aristotelian picture, the Earth was at the centre of the universe and all the heavenly bodies, the Moon, the planets, the Sun and the stars revolved around the Earth following circular orbits. An astronomer and mathematician called Ptolemy of Alexandria (circa AD 150) systematically described these orbits mathematically. However, the planets' motions in the sky are difficult to reproduce in this way because sometimes they appear to go backwards for a while (this is called retrograde motion). Ptolemy found that to get the theory to agree at all well with observations, the motions of the planets had to be along circles that themselves revolved around the Earth, and this made the theory very complex and difficult to use (see Figure 1).

Copernicus retained the circular motions but placed the Sun rather than the Earth at the centre of the system, and then had the Earth rotating both about its own axis and around the Sun, and this considerably simplified matters mathematically. Subsequently, Copernicus' theory was improved by the work of Johannes Kepler (1571–1630), who treated the planets as having not circular but elliptical orbits, and it was the latter's theory of the motions of the planets that Newton elaborated with his gravitational force and which is still used today for most practical purposes.

One thing to note about the Copernican system is that it may seem to be counter to our experience in the sense that we do not feel the

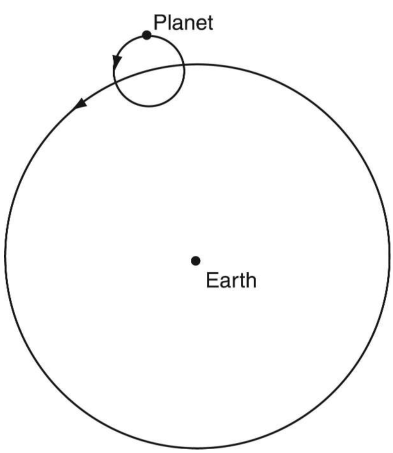

Figure 1

Earth to be moving when we stand still upon it, and moreover we observe the Sun to move over our heads during the day. This is an important example of how scientific theories seem to describe a *reality* distinct from the *appearance* of things. This distinction between appearance and reality is central to metaphysics because the latter seeks to describe things 'as they really are' rather than how they merely appear to be. When Copernicus' book was published, after his death, it included a preface by Andreas Osiander (1498–1552) (a friend of Copernicus who had helped prepare the book for publication) which declared that the motion of the Earth was a convenient assumption made by Copernicus but which need only be regarded as a mathematical fiction, rather than being taken literally as asserting that the Earth really was in orbit around the Sun. This is an early example of the philosophical thesis of **instrumentalism**, according to which scientific theories need not be believed to be true, but rather should be thought of as useful or convenient fictions. On the other hand, to be a realist about Copernicus' theory is to think that it should be taken literally and to believe that the Earth really does orbit the Sun. Realists, unlike instrumentalists, think that scientific theories can answer metaphysical questions. (We shall return to the **realism** versus instrumentalism debate later.)

The doctrine that the Earth is not at the centre of the universe and that it is, in fact, in motion around the Sun was in direct contradiction with Catholic doctrine and Osiander's preface did not prevent a controversy arising about Copernicus' theory. This controversy became quite fierce by the early years of the seventeenth century and, in 1616, Copernicus' book and all others that adopted the heliocentric hypothesis were placed on a list of books that Catholics were banned from teaching or even reading. It may be hard to appreciate why the Church was so worried about a theory in astronomy, but heliocentrism not only conflicted with the Aristotelian picture of the universe and rendered its explanations of motion inapplicable, it also conflicted with the traditional understanding of the Book of Genesis and the Fall of Adam and Eve, the relationship between the Earth and the Devil on the one hand and the Heavens and God on the other, and so on. The consequence of this was that if one were to adopt the Copernican theory, a great deal of what one took for granted was thrown into doubt – hence the need for a way of replacing the Aristotelian picture of the world with a set of beliefs that were equally comprehensive, but more up to date.

1.3 The 'new tool' of induction

The emergence of modern science required not just the contribution of those like Copernicus and Galileo who proposed new theories, but also the contribution of people who could describe and then advocate and propagate the new ways of thinking. In modern parlance, science needed to be marketed and sold to intellectuals who would otherwise have accepted the established Aristotelian thinking. Greatest among the propagandists of the emerging sciences was Francis Bacon (1561–1626), who explicitly proposed a method for the sciences to replace that of Aristotle. In his book *Novum Organum* of 1620 he set out this method in great detail and it still forms the core of what many people take the scientific method to be. Many of Bacon's contemporaries thought that the ancients had understood all there was to be known and that it was just a matter of recovering what had been lost. By contrast, Bacon was profoundly ambitious about what new things could be known and how such knowledge could be employed practically (he is often credited with originating the phrase 'knowledge is power').

Bacon's method is thoroughly egalitarian and collectivist in spirit: he believed that if it was followed by many ordinary people working together, rather than a few great minds, then as a social process it would lead to the production of useful and sure beliefs about the functioning of nature. When one bears in mind that nowadays a single paper in physics is routinely co-authored by tens of people, it is apparent that Bacon was prophetic, both in his vision of science as a systematic and collaborative effort involving the co-ordinated labour of many individuals to produce knowledge, and in his belief that the practical applications of science would enable people to control and manipulate natural phenomena to great effect. (On the other hand, one consequence of the growth of scientific knowledge has been that a great deal of training is now necessary before someone can become a researcher in, say, microbiology or theoretical physics.)

The translation of *Novum Organum* is New Tool, and Bacon proposed his method as a replacement for the *Organum* of Aristotle, this being the contemporary name for the textbook that contained Aristotelian logic. Logic is the study of reasoning abstracted from what that reasoning is about. Hence, in logic the following two arguments are treated as if they were the same because their form or structure are equivalent despite the difference in their content:

(1) All human beings are mortal (PREMISE)
Socrates is a human being (PREMISE)
Therefore Socrates is mortal (CONCLUSION)

(2) All guard dogs are good philosophers
Fido is a guard dog
Therefore Fido is a good philosopher

The premises of the first argument are true and so is the conclusion, while the first premise of the second argument is probably false and so is the conclusion. What they have in common is that they exemplify the following structure:

All Xs are Y
A is X
Therefore A is Y

Such an argument is *valid*, which is to say if the premises are true then so must be the conclusion; in other words, if an argument is valid then it is *impossible* for the premises all to be true and the conclusion false.

An *invalid* argument is one in which the premises may all be true and the conclusion false, so for example, consider:

All Xs are Ys
A is Y
Therefore A is X

This argument is invalid as we can see if we have the following premises and conclusion:

All guard dogs are good philosophers
James is a good philosopher
Therefore James is a guard dog

Even if we suppose the first and second premises to be true, implausible as they may seem, it does not follow that James is a guard dog. (To reason in accordance with an invalid form of argument is to fall prey to a *logical fallacy*.) That this argument form is invalid is obvious when we consider the following argument that has the same structure but true premises and a false conclusion:

All human beings are animals
Bess is an animal
Therefore Bess is a human being

Here we have an instance of the same form of argument where it is obviously possible for the premises to be true and the conclusion false (actually Bess is a dog) and hence it must be invalid. (Make sure you understand why this argument has the same form as the one immediately preceding it, and why both are invalid. It is important that validity has nothing to do with whether the premises or conclusion are actually true or false; it is a matter of how the premises and conclusion are related in form or structure. If a valid argument happens to have true premises it is said to be *sound*.)

Deductive logic is the study of valid arguments and Aristotelian logic is a type of deductive logic. The paradigm of deductive reasoning in science is Euclidean geometry. From a small number of premises (called axioms) it is possible to deduce an enormous number of conclusions (called theorems) about the properties of geometric figures. The good thing about deductive logic is that it is truth-preserving, which is to say that if you have a valid argument with true premises (such as argument (1)), then the conclusion will be true as well. The problem with deductive logic is that the conclusion of a deductively valid argument cannot say more than is implicit in the premises. In a sense, such arguments do not expand our knowledge because their conclusions merely reveal what their premises already state, although where the argument is complex we may find the conclusion surprising just because we hadn't noticed that it was already implicit in the premises, as with Pythagoras' theorem for example. Where the argument is simple, the fact that the conclusion says nothing new is obvious: if I already know that all humans are mortal, and that I am a human, I don't really learn anything from the conclusion that I am mortal, although I may find it strikes me with more force when it is made explicit.