UNDERSTANDING PHILOSOPHY OF SCIENCE

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For Audrey Ladyman

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

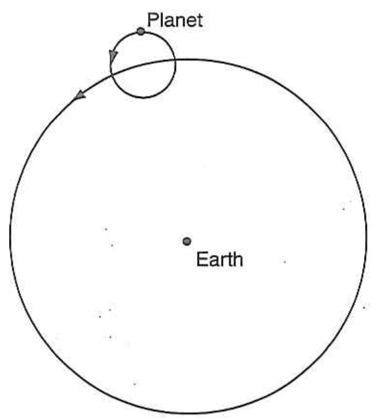

Figure 1

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.

The Aristotelian conception of knowledge (or scientia) restricts the domain of what is knowable to what is necessary and cannot be otherwise. Knowledge of some fact about the natural world, for example that flames go upwards but not downwards, consists of having a deductive argument that demonstrates the causal necessity of that fact from first principles; in this case, all things seek their natural place, the natural place of the element of fire is at the top of the terrestrial sphere, therefore flames near the surface of the Earth rise. In this view, geometry (in particular) and mathematics (in general) provide a model for knowledge of the natural world. Hence, the premises that one proceeds with have to concern the essence of the relevant entities. This knowledge of the essence of things, say that the natural place of fire is at the top of the terrestrial sphere, is presupposed by a demonstration, so the natural question is where does this knowledge of essences come from? The Aristotelian answer to this appeals to a kind of faculty of intellectual intuition that allows someone to perceive the causes of things directly, and among the causes that Aristotelian scientific inquiry aims to determine are the final causes of things, which is to say the ends towards which they are moving. Hence, Aristotelian science is concerned with **teleology**, which is the study of purposive behaviour.

The obvious objection to all this from the modern point of view is that there is little about the role of actual sensory experience in the acquisition of knowledge of how things work. If we want to know whether metals expand when heated we expect to go out and look at how metal actually behaves in various circumstances, rather than to try and deduce a conclusion from first principles. To the modern mind, science is immediately associated with experiments and the gathering of data about what actually happens in various circumstances and hence with a school of thought in epistemology called **empiricism**. Empiricists believe that knowledge can only be obtained through the use of the senses to find out about the world and not by the use of pure thought or reason; in other words, the way to arrive at justified beliefs about the world is to obtain evidence by making observations or gathering data. Aristotle's logic was deductive and, although he took great interest in empirical data and his knowledge of natural phenomena, especially zoology and botany, was vast, apparently he never carried out any experiments. Bacon proposed his 'inductive logic' to replace Aristotelian methods and gave a much more central role to experience and experiments.

Remember, as we saw in the discussion of Fido the guard dog, not all valid arguments are good ones. Another example of a valid but bad argument is the following:

The Bible says that God exists
The Bible is the word of God and therefore true
Therefore God exists

This argument is deductively valid because it is not possible for the premises both to be true and the conclusion false, and indeed it may even have true premises, but it is not a good argument because it is circular; we only have a reason to believe that the second premise is true if the conclusion is true, and so a non-believer is unlikely to be persuaded by it. Similarly, perhaps not all invalid arguments are intuitively bad arguments. For example:

Jimmy claims to be a philosopher
I have no reason to believe he is lying
Therefore Jimmy is a philosopher

This argument is invalid because it is possible for both premises to be true, but for the conclusion to be false, but it is nonetheless persuasive in ordinary circumstances. Validity is a formal property of arguments. Inductive reasoning, or **induction**, is the name given to various kinds of deductively invalid but allegedly good arguments. What distinguishes bad invalid arguments from good ones, if indeed there are any of the latter? Bacon claims to have an answer to this question that vastly improves on Aristotle's answer. A large part of what Bacon advocates is negative in the sense that it amounts to a way of avoiding falling into error when making judgements rather than offering a way of gaining new judgements. This negative side to the scientific method is recognisable in science today when people insist that to be a scientist one must be sceptical and prepared to break with received wisdom, and also not leap to conclusions early in the process of investigation of some phenomenon. Bacon called the things that could get in the way of right inductive reasoning the *Idols of the Mind* (which are analogous to fallacies of reasoning in deductive logic).

The first of these are the *Idols of the Tribe*, which refers to the

tendency of all human beings to perceive more order and regularity in nature than there is in reality, for example, the long-standing view mentioned above that all heavenly bodies move in perfect circles, and to see things in terms of our preconceptions and ignore what doesn't fit in with them. The *Idols of the Cave* are individual weaknesses in reasoning due to particular personalities and likes and dislikes; someone may, for example, be either conservative or radical in temperament and this may prejudice them in their view of some subject matter. The *Idols of the Marketplace* are the confusions engendered by our received language and terminology, which may be inappropriate yet which condition our thinking; so, for example, we may be led into error by our using the same word for the metal lead and for that part of a pencil that makes a mark on paper. Finally, the *Idols of the Theatre* are the philosophical systems that incorporate mistaken methods, such as Aristotle's, for acquiring knowledge.

So much for the negative aspects of Bacon's philosophy, but what of the positive proposals for how to acquire knowledge of the workings of the natural world? His method begins with the making of observations that are free from the malign influence of the first three Idols. The idea is to reach the truth by gathering a mass of information about particular states of affairs and building from them step by step to reach a general conclusion. This process is what Bacon called the composition of a Natural and Experimental History. Experiments are important because if we simply observe what happens around us we are limited in the data we can gather; when we perform an experiment we control the conditions of observation as far as is possible and manipulate the conditions of the experiment to see what happens in circumstances that may never happen otherwise. Experiments allow us to ask 'what would happen if . . .?'. Bacon says that by carrying out experiments we are able to 'torture nature for her secrets'. (Some feminist philosophers have emphasised that the conception of science as the masculine torture of feminine nature was very common in the scientific revolution and have argued that the science that we have today has inherited this gender bias.)

Experiments are supposed to be repeatable if at all possible, so that others can check the results obtained if they wish. Similarly, scientists prefer the results of experiments to be recorded by instruments that measure quantities according to standard definitions and scales so that the perception of the individual performing the experiment does not affect the way the outcome is reported to others. Bacon stressed the role of instruments to eliminate, as far as possible, the unreliable senses from scientific data gathering. In this way the scientific method of gathering data that will count as evidence for or against some view or other is supposed to ensure objectivity or impartiality. It seems obvious to the modern mind that science is all to do with experiments, but prior to the scientific revolution experiments were mainly associated with the practices of alchemists, and experiments played almost no role in Aristotle's methods.

Having gathered data from naturally occurring examples of the phenomenon we are interested in, as well as those produced by the ingenious manipulation of experimental design, we must then put the data in tables of various kinds. This process is best illustrated with Bacon's own example of the investigation of the phenomenon of heat. The first table to be drawn up is that of Essence and Presence, which consists of a list of all the things of which heat is a feature, for example, the Sun at noon, lava, fire, boiling liquid, things that have been vigorously rubbed and so on. The next table is that of Deviation and Absence by Proximity, which includes things that are as close to the above phenomena as possible but which differ by not involving heat; so, for example, the full Moon, rock, air, water that is cold, and so on. One big problem with the little that Aristotle did say about induction, as far as Bacon was concerned, was that it seemed to sanction the inference from particular instances straight to a generalisation without the mediation of so-called middle axioms. For Bacon the advantage of his inductive method was that it would avoid this problem by searching for negative instances and not just positive ones. There follows a table of Degrees or Comparisons in which the phenomena in which heat features are quantified and ranked according to the amount of heat they involve.

Having drawn up all these tables, the final stage of Bacon's method is the Induction itself. This involves studying all the information displayed in the tables and finding something that is present in all instances of the phenomenon in question, and absent when the phenomenon is absent, and furthermore, which increases and decreases in amount in proportion with the increases and decrease of the phenomenon. The thing that satisfies these conditions is to be found by

elimination and not by merely guessing. Something like the method of elimination is used by people all the time, for example, when trying to find the source of a fault with an electrical appliance such as a hi-fi system. First, one might try another appliance in the same socket; if it works then the socket is not to blame so one might next change the fuse, if the system still does not work the fuse is not to blame so one might check the connections in the plug, then one might test the amplifier, and so on. In the case of heat Bacon decides that heat is a special case of motion, in particular the 'expansive motion of parts' of a thing. This accords remarkably well with the modern understanding of heat (which was not developed until the mid-nineteenth century), known as the kinetic theory of heat according to which heat consists of molecular motion, and the faster the average velocity of the molecules in some substance then the hotter it will be.

According to Bacon, the form of expansive motion of parts is what underlies the phenomenon of heat as it is observed. Bacon thought that, following his method, one could discover the forms, which, although not directly observable, produce the phenomena that we can perceive with the senses. Once knowledge of the true forms of things was obtained then nature could be manipulated and controlled for the benefit of people. Bacon suggested that the kind of power over nature that was claimed by magicians in the Renaissance could be achieved through scientific methods. If we consider the development of science and technology since Bacon's time it certainly seems that technology has accomplished feats that surpass the wildest boasts of magicians: who would have believed a magus who claimed to be able to travel to the Moon or to the depths of the oceans; who would have imagined synthesising the materials out of which computers are made, or the transmission of images by photograph, film and television?

When Bacon says that science ought to discover the forms of things, he means, as in the case of heat, the concrete and immediate physical causes of them, and not the final causes that Aristotelians aimed to find by direct intuition, such as the cause of the motion of a dropped stone towards the Earth being the fact that the 'natural place' of the element of which the stone is composed is at the centre of the Earth. Such explanations seemed vacuous to Bacon, as with the notorious claim that opium sends people to sleep because it possesses a dormative virtue. The abandonment of the search for final causes was one of the main consequences of the scientific revolution. By the eighteenth century, the French writer Voltaire (1694–1778) in his play *Candide* was ridiculing the Aristotelian model of explanation; the character Doctor Pangloss explains the shape of the nose of human beings in terms of its function in holding a pair of glasses on the face. Bacon explicitly urged that teleological reasoning be confined to the explanation of human affairs where it is legitimate since people are agents who act so as to bring about their goals. One characteristic of natural science since Bacon is that explanations are required to refer only to the immediate physical causes of things and the laws of nature that govern them. (Whether or not this requirement is satisfied is a controversial issue, especially because evolutionary biology has reintroduced talk of functions and design into science. However, it is often claimed that such talk is only legitimate because it is, in principle, eliminable or reducible to a series of proper causal explanations. We shall return to this issue in Chapter 7.)

So the 'forms' of Bacon are the immediate causes or the general principles or laws that govern phenomena in the material world. However, Bacon's account of scientific theorising leaves us with a problem to which we shall return throughout this book, namely how exactly do we come to conceive of the forms of things given that they are not observable? In the case of heat we may be relatively happy with Bacon's induction, but motion is a feature of the observable world too and not confined to the hidden forms of things. When it comes to something like radioactivity, which has no observable counterpart, how could we ever induce its presence from tables like Bacon's? Baconian induction is meant to be a purely mechanical procedure but there will be many cases where no single account of the form of some phenomenon presents itself and where different scientists suggest different forms for the same phenomenon; an example is the debate about the nature of light which concerned two theories, a wave theory and a particle theory.

Bacon does offer us something else that may help with this problem, which is his notion of a 'pejorative instance' (although this is the subject of great controversy, as we shall see). He argues that when we have two rival theories that offer different accounts of the form of

something then we should try and design an experiment that could result in two different outcomes where one is predicted by one theory and the other by the other theory so that, if we perform the experiment and observe the actual outcome, we can choose between them. (The great seventeenth century scientist Robert Hooke (1635–1703) called such experiments 'crucial experiments'.) An example Bacon suggests is an experiment to see if gravity is really caused by the force of attraction produced by large bodies like the planets and the Sun; if this is really so then a clock that works by the gravitational motion of a pendulum ought to behave differently if it were placed up a church tower, or down a mine (further from, or closer to, the centre of the Earth respectively), hence, performing this experiment ought to allow us to tell whether the attractive hypothesis is correct. (In fact, the gravitational attraction of the Earth is stronger down a mine-shaft than up a tower, but the difference is very small and hence very hard to detect.)

This is an important idea because it implies that experiments in science will not be a simple matter of going out and gathering data but rather will involve the designing of experiments with the testing of different theories already in mind. This may seem to undermine Bacon's claim that we should record our natural and experimental history of the phenomenon we are studying without being influenced by our preconceptions (and so avoid the Idols of the Theatre), however, Bacon would argue that the need for pejorative instances will only arise once we have carried out our initial investigations and ended up with more than one candidate for the form of the phenomenon.

1.4 (Naïve) inductivism

We can abstract Bacon's method and arrive at a simple account of the scientific method. The method of Bacon rested on two pillars, *observation* and *induction*. Observation is supposed to be undertaken without prejudice or preconception, and we are to record the results of the data of sensory experience, what we can see, hear, and smell, whether of the world as we find it, or of the special circumstances of our experiments. The results of observation are expressed in what are called *observation statements*. Once we have made a whole host of observations these are to be used as the basis for scientific laws and theories. Many scientific laws are of the form of what are called *universal generalisations*; these are statements that generalise about the properties of all things of a certain kind. So, for example, 'all metals conduct electricity' is a universal generalisation about metals, 'all birds lay eggs' is a universal generalisation about birds, and so on. These are simple examples but, of course, scientific theories are often much more complicated and the generalisations and laws often take the form of mathematical equations relating different quantities. Some well known examples include:

- *Boyle's law*, which states that for a fixed mass of a gas at constant temperature, the product of pressure and volume is constant.
- Newton's *law of universal gravitation*, which states that the gravitational force, F, between two bodies with masses m_1, m_2, and separated by distance r, is given by: $F = m_1 m_2 G/r^2$ (where G is the gravitational constant).
- The *law of reflection*, which states that the angle at which a beam of light strikes a mirror is equal to the angle at which it is reflected.

Induction in the broadest sense is just any form of reasoning that is not deductive, but in the narrower sense that Bacon uses it, it is the form of reasoning where we generalise from a whole collection of particular instances to a general conclusion. The simplest form of induction is *enumerative induction*, which is where we simply observe that some large number of instances of some phenomenon has some characteristic (say some salt being put in a pot of water dissolves), and then infer that the phenomenon always has that property (whenever salt is put in a pot of water it will dissolve). Sometimes scientific reasoning is like this, for example, many of the drug and other medical treatments that are used today are based on trial and error. Aspirin was used to relieve headaches a long time before there were any detailed explanations available of how it worked, simply because it had been observed on many occasions that headaches ceased following the taking of the drug.

The question that we must now ask is: 'when is it legitimate to infer a universal generalisation from a collection of observation statements?', for example, when can we infer that 'all animals with hearts

have livers' on the basis of the observation of many instances of animals having hearts having livers as well. The answer according to naïve **inductivism** is *when a large number of observations of Xs under a wide variety of conditions have been made, and when all Xs have been found to possess property Y, and when no instance has been found to contradict the universal generalisation 'all Xs possess property Y'*. So, for example, we need to observe many kinds of animals in all parts of the Earth, and we need to look out for any instance that contradicts our generalisation. If we carry out a lot of observations and all support the law while none refute it, then we are entitled to infer the generalisation.

This accords with our common sense; someone who concluded that all philosophers are neurotic, having observed only a handful of philosophers in Bristol to be neurotic, would be considered quite unreasonable. Similarly, someone who drew such an inference having observed one perfectly stable and balanced philosopher would be considered unreasonable no matter how many other philosophers they had observed showing signs of neurosis. However, if someone claimed to believe that all philosophers are neurotic and when questioned it turned out they had observed philosophers both young and old, of both sexes and in various parts of the world over many years and they had all been neurotic to varying degrees and not one had no trace of neurosis, we would think their conclusion quite reasonable in the circumstances.

What we have just been discussing is known as a *Principle of Induction*; it is a principle of reasoning that sanctions inference from the observation of particular instances to a generalisation that embraces them all and more. We must take care to observe the world carefully and without preconception, and to satisfy the conditions expressed in the principle, but if we do this then, according to the naïve inductivist, we are following the scientific method and our resulting beliefs will be justified. Once we have inductively inferred our generalisation in accordance with the scientific method, then it assumes the status of a law or theory and we can use deduction to deduce consequences of the law that will be predictions or explanations.

It's time we caught up with the discussion with which this chapter began:

Alice: ... and so the scientific method consists in the unbiased accumulation of observations and inductive inference from them to generalisations about phenomena.

Thomas: But even if I buy that for claims about metals conducting electricity and the like, which I don't, I still don't see how induction explains how we know about atoms and all that stuff you were going on about before.

Alice: I guess it's to do with Bacon's idea about crucial experiments; someone says that there are atoms and someone else works out how to do an experiment that ought to go one way if there are atoms and another way if there are not.

Thomas: Well anyway, let's forget about atoms for now and just concentrate on your principle of induction and Bacon's idea about observation without prejudice or preconception. I can already think of problems with both of these; for one thing, how do you know that your principle of induction is true, and for another, how would you know what to start observing unless you already had the idea of metals and electricity? Observation without any bias whatsoever is impossible, and you haven't explained to me why I should believe in induction. I still reckon that science is just witchcraft in a white coat.

Further reading

For an excellent account of the scientific revolution see Steven Shapin *The Scientific Revolution* (Chicago University Press, 1996). Another introductory book is I. Bernard Cohen, *The Birth of a New Physics* (Pelican, 1987). On Francis Bacon see Chapter 3 of Barry Gower, *Scientific Method: An Historical and Philosophical Introduction* (Routledge, 1997), Chapter 2 of Roger Woolhouse, *The Empiricists* (Oxford University Press, 1988), Peter Urbach, *Francis Bacon's Philosophy of Science: An Account and a Reappraisal* (Open Court, 1987), and also the references to Bacon's works in the bibliography.

2

The problem of induction and other problems with inductivism

According to the account of scientific method that was introduced in the previous chapter (naïve inductivism), scientific knowledge derives its justification by being based on generalisation from experience. Observations made in a variety of circumstances are to be recorded impartially and then induction is used to arrive at a general law. This is an attractive view, not least because it agrees with what many scientists have claimed about their own practice. It also explains the alleged objectivity of scientific knowledge by reference to the open-mindedness of scientists when they make observations, and it keeps scientific knowledge firmly rooted in experience. I hope it is a reasonably familiar conception of how science works and how scientific knowledge acquires its justification.

We need to distinguish two questions in order to evaluate inductivism as a theory of scientific methodology:

(1) Does inductivism seem to be the method that has actually been followed by particular individuals in the history of science?
(2) Would the inductive method produce knowledge if we did use it?

The first question obviously calls for some empirical inquiry; to answer it we need to gather information from artefacts, journals, letters, testimony and so on. The second question is characteristically philosophical and concerns not our actual beliefs but whether the inductive method will confer justification on beliefs that are produced using it. We will return to question (1) later, while in the next section we will consider whether or not induction is justified.

2.1 The problem of induction

The classic discussion of the problem of induction is in *An Enquiry Concerning Human Understanding* by David Hume (1711–1776). Hume relates induction to the nature of causation and the laws of nature, and his influence on the development of western philosophy in general, and philosophy of science in particular, has been profound. To understand Hume's arguments about scientific knowledge it will be helpful to have a basic grasp of his general epistemology and theory of 'ideas'.

Hume makes a distinction between two types of proposition, namely those that concern *relations of ideas* and those that concern *matters of fact*. The former are propositions whose content is confined to our concepts or ideas, such as a horse is an animal, bachelors are unmarried, and checkmate is the end of a game of chess. (Hume also included mathematics in this category, so triangles have angles totalling 180° is another example.) Propositions concerning matters of fact are those that go beyond the nature of our concepts and tell us something informative about how the actual world is. So, for example, snow is white, Paris is the capital of France, all metals expand when heated, and the battle of Hastings was in 1066 are all propositions that concern matters of fact. Of course, these propositions are all true (as far as I know), but the distinction between relations of ideas and matters of fact applies equally to propositions that are false, so for example, a whale is a fish is a false proposition concerning relations among our ideas, and Plato died in 399 BC is a false proposition concerning a matter of fact.

According to Hume, any true proposition about the relations among our ideas is provable by deduction, because its **negation** will imply a contradiction. Those who have studied mathematics or logic will be familiar with the method of *reductio ad absurdum*. Essentially, the idea is that some proposition, say that there are an infinite number of prime numbers, can be proved if you can show that the negation of it is inconsistent with other things you already know. Such a proof would begin with the assumption that there is a biggest prime number. This is then used in conjunction with other assumed facts about numbers (in particular, about the existence of prime factors) to derive a contradiction. (Not all proofs have this form on the

surface but the definition of a logically necessary truth is that its negation is a contradiction.) In everyday life, something similar to this method is also sometimes employed when people try to show that an absurd or known to be false consequence follows from some proposition under discussion.

On the other hand, Hume argued that knowledge of matters of fact could only be derived from the senses because the ideas involved are logically unrelated and hence the propositions are not deductively provable. Take the proposition that Everest is the tallest mountain on Earth. The concepts involved – mountain, tallest, Earth, and that of some specific mountain in the Himalayas – have no logical relation to each other that determines the truth of the proposition, and there is no contradiction in supposing that some other mountain is the tallest. Hence, it is not possible to find out if the proposition is true merely by reasoning; only by using the senses can the status of such propositions be investigated. (Hume, who was Scottish, is a central figure in the philosophical tradition known as British empiricism, which also includes the English John Locke (1632–1704) and the Irish George Berkeley (1685–1753).) All these thinkers shared the belief that there are no innate concepts and that all our knowledge of the world is derived from, and justified by, our sensory perceptions, hence they all deny that any ***a priori*** knowledge of matters of fact is possible.

Hume was also very sceptical about metaphysical or theological speculation. Now, many people, including some philosophers, think that philosophy is often concerned with concepts so abstract and distanced from everyday life that they have no bearing on anything one could measure or experience, and that because of this they are more or less meaningless. Some people would also argue that thinking in this manner is a waste of time. Hume agreed and suggested that if one takes some book, or other text, and it contains neither 'abstract reasoning concerning quantity or number', nor 'experimental reasoning concerning matter of fact and existence', then it should be burned since it is merely 'sophistry and illusion'. This dichotomy is known as *Hume's fork*. (I leave it as an exercise for the reader to decide what ought to be done with the present volume.)

Hume's distinction between matters of fact and relations of ideas roughly corresponds to Immanuel Kant's (1724–1804) distinction between synthetic and **analytic** truths. Kant was inspired by Hume and made the latter distinction a central part of his (critical) philosophy. In the hands of a group of philosophers of science, called the *logical positivists*, in the early twentieth century, it became a way of distinguishing form from content in formal mathematical and logical languages that were used to represent scientific theories. They thought that they could separate the empirical content of theories, the synthetic part, from the theoretical and analytic part. The positivists argued that a factual statement was not meaningful if it said nothing about any past, present or future observations, in other words if it has no empirical content. This gives us a way of deciding whether someone is talking nonsense or not; we check to see if what he or she is saying has any implications for what we can observe. Positivism, which will often come up again (see especially 5.3), was very influential among philosophers and scientists for a while, and still has adherents. Many people sympathise with the idea that scientific and philosophical theories should have a definite connection to what can somehow be observed, and perhaps also measured, recorded and ultimately given a theoretical description in terms of laws and causes.

Now, it is plausible to argue that some of our knowledge of matters of fact is directly based on experience. That it is windy, cloudy and cold outside, that the light is on and the tea luke-warm, all this I seem to know by my present sensory experience. Another class of the things I know are those that I learned by the same means in the past; such knowledge is based on my memory of my perceptions. What of my beliefs about things I have not myself observed? I certainly have many such beliefs, for example, I believe that the Sun will rise tomorrow, that Everest is the tallest mountain, that my friend is currently in Scotland, and so on. These are all matters of fact because, in each case, the negation of the proposition is not a contradiction and so we cannot deductively prove them to be true. How can we *know* such things, if indeed we can?

Hume claimed that all reasoning that goes beyond past and present experiences is based on cause and effect. Suppose that you play pool a lot; it doesn't take long to notice that if you hit the white ball off centre it will impart a particular kind of spin to the next ball it hits. This is a useful generalisation about the behaviour of pool balls. You infer that hitting the ball off centre *causes* it to spin and that you can reliably predict the behaviour of the balls in future on this basis,

provided of course you can hit them right. Similarly, we observe that when the Sun is out, the Earth and the objects on its surface become warmer and we infer that this pattern of behaviour will continue in the future and that the Sun causes the objects to heat up. Hume pointed out that there is nothing logically inconsistent in a pool ball suddenly spinning the opposite way or not at all, nor is there any contradiction in supposing that the Sun might cool down the Earth. The only way we connect these ideas is by supposing that there is some causal connection between them.

Of course, many of our beliefs depend upon the testimony of others, whether in the form of spoken accounts, books, newspapers, or whatever. In such cases we believe in a causal relation between what has happened or is the case, and what the person experiences and then communicates. Once again it is a causal relation that connects ideas that have no logical relation. This is the basis of induction according to Hume, and so if we want to understand our knowledge of matters of fact we need to consider our knowledge of the relation of cause and effect. Hume argues that we can only obtain our knowledge of cause and effect by experience because there is no contradiction in supposing that some particular causal relation does not hold, and so this knowledge is of a matter of fact that could be otherwise. We cannot tell that fire will burn us or that gunpowder will explode without trying it out because there is no contradiction in supposing that, for example, the next fire we test will not burn but freeze a hand placed in it. (Of course we may be told about causal relations, but then the source of our information is ultimately still someone's experience.)

What more can we say about this relation of cause and effect? Hume argues that, just as it is only by experience that we can find out about particular causal relations, and hence make inductive inferences about the future behaviour of things in the world, so it is only by examining our experience of the relation of cause and effect that we can understand its nature, and hence see whether it is fit to offer a justification for our inductive practices. When we examine our experience of causal relations, Hume argues that it is apparent that our knowledge of cause and effect is the result of extrapolating from past experience of how the world has behaved to how it will behave in future. For example, because the experience of eating bread has always been followed in the past by the experience of feeling nourished, I suppose that bread nourishes in general and hence that the next piece of bread I eat will be nourishing. Fundamentally then, for Hume, causation is a matter of what is known as *constant conjunction*; A causes B means A is constantly conjoined in our experience with B: 'I have found that such an object has always been attended with such an effect, and I foresee, that other objects, which are, in appearance similar, will be attended with similar effects' (Hume 1963: 34–35). But of course we have not yet experienced the future behaviour of the objects in question and so belief in a particular relation of cause and effect relies upon the belief that the future will resemble the past. (This is a crucial point to which we shall return below.)

Hume further examines the concept of causality and finds that an important feature of it is that of *contiguity*, which is the relation of being connected in space and time. Often, when a causal connection is postulated between events, the events are either close in space and time or connected by a chain of causes and effects, each member of which is close in space and time to the next. So, for example, there is a causal relation between someone typing words into a computer and someone else reading words on a page, because there is an intermediate chain of contiguous causes and effects, however long and complicated. However, Hume does not say that this is always the case where there is a postulated causal connection.

Another characteristic of causal relations is that causes usually precede effects in time. Whether this is always so is not immediately obvious, because sometimes it seems that causes and effects can be simultaneous, as when we say that the heavy oak beam is the cause of the roof staying up. Furthermore, some philosophers hold that 'backwards causation' where a cause brings about an effect in the past is possible. In any case, Hume has identified the following features that usually pertain to the relation A causes B:

(1) Events of type A precede events of type B in time.
(2) Events of type A are constantly conjoined in our experience with events of type B.
(3) Events of type A are spatio-temporally contiguous with events of type B.

(4) Events of type A lead to the *expectation* that events of type B will follow.

This is called the Humean analysis of causation, but is that all there is to causal relations? Consider the following example; a pool ball X strikes another Y, and Y moves off at speed. We say that X causes Y to move, but what does this mean? We are inclined to say things like the following; X made Y move, X produced the movement in Y, Y had to move because X hit it, and so on. Hume is well aware that many philosophers have held the view that X causes Y means that there is some sort of *necessary connection* between X happening and Y happening, but he argues that this notion is not one that we really understand. His empiricism led him to argue that since we have no experience of a necessary connection over and above our experience of constant conjunction, we have no reason to believe that there is anything corresponding to the concept of a necessary connection in nature. All we ever see are events conjoined; we never see the alleged connection between them, but over time we see the same kinds of events followed by similar effects and so we get into the habit of expecting this to continue in future.

In a form of argument we will return to later he argues as follows. Consider two theories about causation: according to the first, a causal relation consists of nothing more than the Humean analysis above reveals; according to the second there is all that but also some kind of necessary connection (call this the *necessitarian* view). Hume points out that there is nothing that can be found in our experience that will tell in favour of either one of these hypotheses over the other. These are two different hypotheses that agree about everything we can observe; yet one of them posits the existence of something that the other does not. Hence, Hume argues, we should adopt the Humean analysis because it does without metaphysical complications. Implicit in this argument is an appeal to the principle called 'Occam's razor' according to which, whenever we have two competing hypotheses, then if all other considerations are equal, the simpler of the two is to be preferred. Hume's empiricism means that he thinks that, because the two hypotheses entail exactly the same thing with respect to what we are able to observe, then all other considerations that are worth worrying about are indeed equal.

So, although our inductive reasoning is founded on reasoning about cause and effect, this is no foundation at all since it is always possible that a causal relation will be different in the future. Hume argues that the only justification we have for such beliefs as that the Sun will rise tomorrow, or that pool balls will continue to behave as they do, is that they have always been true up to now, and this isn't really any justification at all. Of course, we may appeal to the conservation of momentum and the laws of mechanics to explain why X caused Y to move. Similarly, we can now appeal to proofs of the stability of the solar system and predictions of the lifetime of the Sun to justify our belief that the Sun will rise tomorrow. However, Hume would say that the causal links and laws we are appealing to are just more correlations and regularities.

Fundamentally, Hume's problem with induction is that the conclusion of an inductive argument could always be false no matter how many observations we have made. Indeed, there are notable cases where huge numbers of observations have been taken to support a particular generalisation and it has subsequently been found to be wrong, as in the famous case of the generalisation *all swans are white* which was believed by Europeans on the basis of many observations until they visited Australia and found black swans. As Bertrand Russell (1872–1970) famously argued in the *Problems of Philosophy*, sometimes inductive reasoning may be no more sophisticated than that of a turkey who believes that it will be fed every day because it has been fed every day of its life so far, until one day it is not fed but eaten. The worrying thought is that our belief that the Sun will rise tomorrow may be of this nature.

Of course, we are capable of being more discriminating. Many of our beliefs seem to be based on something like the principle of induction that we discussed at the end of the previous chapter, which allows the inference from particular observations to a generalisation when there are many observations made under a wide variety of circumstances, none of which contradict the generalisation but all of which are instances of it. Yet, such a principle also expresses a tacit commitment to the uniformity of natural phenomena in space and time. But why should the future resemble the past or the laws of nature be the same in different places? Hume points out that the proposition that the future will not be like the past is not contradictory.

Of course, in the past we have observed patterns and believed that they will continue to hold in the future and we have been right. But for Hume this is just to restate the problem, for the fact that in the past the future has been like the past doesn't mean that, in the future, the future will be like the past. In other words, our past experience can only justify our beliefs about the future if we have independent grounds for believing that the future will be like the past, and we do not have such grounds.

Similarly, we might try and defend induction with an inductive argument along the lines of the following; induction has worked on a large number of occasions under a variety of conditions, therefore induction works in general. But Hume argues that this is viciously circular: it is inductive arguments whose justification is in doubt, therefore it is illegitimate to use an inductive argument to support induction, to do so would be like trying to persuade someone that what you have just said is true by informing them that you always tell the truth; if they already doubt what you have said then they already doubt that you always tell the truth and simply asserting that you do will not move them. By definition, in inductive arguments, it is possible the premises may all be true and the conclusion nonetheless false. So any defence of induction must either appeal to a principle of induction or presuppose the justification of inductive inference. Hence, Hume thought all justifications of induction are circular.

Note that, although we have taken inductive reasoning to be that which proceeds from past experience to some generalisation about the future behaviour of things, it is really the extrapolation from the observed to the unobserved that is at issue. Hume thinks that the same problem arises even if we infer not a generalisation but just some particular prediction, like that the Sun will rise tomorrow or that the next piece of bread I eat will be nourishing.

Of course, in order to survive we have to act in various ways and so we have no choice but to assume that the next piece of fresh bread we eat will be nourishing, that the Sun will rise tomorrow, and that in numerous other ways the future will be like the past. Hume does not think his scepticism seriously threatens what we actually believe and how we will behave. However, he also thinks that we will continue to make inductive inferences because of our psychological disposition to do so, rather than because they are rational or justified. It is our passions, our desires, and our animal drives that compel us to go beyond what reason sanctions and believe in the uniformity of nature and the relation of cause and effect.

To summarise, Hume observes that our inductive practices are founded on the relation of cause and effect, but when he analyses this relation he finds that all that it is, from an empiricist point of view, is the constant conjunction of events, in other words, the objective content of a posited causal relation is always merely that some regularity or pattern in the behaviour of things holds. Since the original problem is that of justifying the extrapolation from some past regularity to the future behaviour of things appealing to the relation of cause and effect is to no avail. Since it is logically possible that any regularity will fail to hold in the future, the only basis we have for inductive inference is the belief that the future will resemble the past. But that the future will resemble the past is something that is only justified by past experience, which is to say, by induction, and the justification of induction is precisely what is in question. Hence, we have no justification for our inductive practices and they are the product of animal instinct and habit rather than reason. If Hume is right, then it seems all our supposed scientific knowledge is entirely without a rational foundation.

2.2 Solutions and dissolutions of the problem of induction

Hume accepts that scepticism cannot be defeated but also that we have to get on with our lives. However, he argues that what is sometimes today called inductive reasoning, inductive inference or ampliative inference, is not really reasoning at all, but rather merely a habit or a psychological tendency to form beliefs about what has not yet been observed on the basis of what has already been observed. He is quite sure that, despite learning of the problem of induction, people will continue to employ induction in science and everyday life, indeed he thinks that we cannot help but do so in order to be able to live our lives, but he does not think this behaviour can be justified on rational grounds. Because of the way he tries to resolve philosophical problems by appealing to natural facts about human beings and their physiological and psychological make-up, Hume is an important

figure in a philosophical tradition, called naturalism, that is particularly prominent in contemporary philosophy, although nowadays naturalists are not usually sceptics like Hume (recall from the Introduction that naturalists think that philosophy is continuous with empirical inquiry in science).

Most philosophers have not been satisfied with his sceptical naturalism and various strategies have been adopted to solve or dissolve the problem of induction. Note that some philosophers have employed more than one of the following.

(1) *Induction is rational by definition*

This response comes in crude and sophisticated versions; the crude version is as follows: in everyday life – in other words outside of academic philosophy – people do not use the term 'rational' to apply only to deductively valid inferences, indeed they often describe inductive inferences as rational. For example, consider three ways of making inferences about the fortunes of a football team based on past experience: if we are following the first method we predict the results of the next match by reading tea leaves; if we are following the second method we look at how the team did in their last few matches and then infer that they will do well next time if they did badly last time and vice versa; if we are following the third method we will again look at how the team did in their last few matches but then infer that they will do well next time if they did well last time and vice versa. Obviously the latter method is the one that everyone would say was the rational method, but this method is just the one that assumes that the future will be like that past and that nature is uniform. Indeed, most people would say that, in general, it is rational to base beliefs about the future on knowledge about the past. Hence, it is part of what everyone means by 'rational' that induction is rational.

This mode of philosophical argument was once very fashionable, but it is not sufficient to dispel philosophical worries about induction because when we ordinarily use a term like rational we are taking it to have some *normative* (or *prescriptive*) as well as descriptive content. In other words, we suppose that reasoning is rational because it conforms to some sort of standard and that it is the sort of