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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

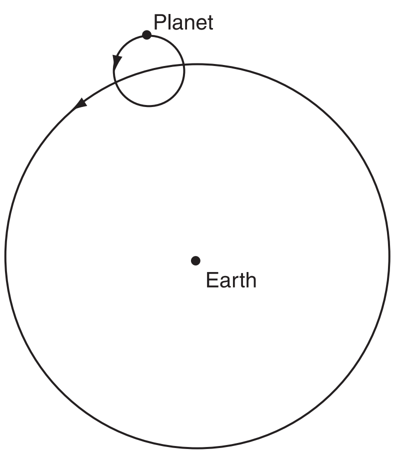

Figure 1

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.

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.

UNDERSTANDING PHILOSOPHY OF SCIENCE

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London and New York

First published 2002
by Routledge
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Routledge
29 West 35th Street, New York, NY 10001

Routledge is an imprint of the Taylor & Francis Group

This edition published in the Taylor & Francis e-Library, 2002.

British Library Cataloguing in Publication Data
A catalogue record for this book is available
from the British Library

Library of Congress Cataloging in Publication Data
Ladyman, James, 1969– .
Understanding philosophy of science/James Ladyman.
p. cm.
Includes bibliographical references and index.
1. Science – Philosophy. I. Title.
Q175.L174 2001
501 – dc21 2001048105

ISBN 0–415–22156–0 (hbk)
ISBN 0–415–22157–9 (pbk)
ISBN 0-203-46368-4 Master e-book ISBN
ISBN 0-203-77192-3 (Glassbook Format)