WHAT IS THIS THING CALLED SCIENCE?

An assessment of the nature and status of science and its methods

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Inductivism: Science as Knowledge Derived from the Facts of Experience

1. A widely held common-sense view of science

Scientific knowledge is proven knowledge. Scientific theories are derived in some rigorous way from the facts of experience acquired by observation and experiment. Science is based on what we can see and hear and touch, etc. Personal opinion or preferences and speculative imaginings have no place in science. Science is objective. Scientific knowledge is reliable knowledge because it is objectively proven knowledge.

I suggest that statements of the foregoing kind sum up what in modern times is a popular view of the kind of thing that scientific knowledge is. This view first became popular during and as a consequence of the Scientific Revolution that took place mainly during the seventeenth century and that was brought about by such great pioneering scientists as Galileo and Newton. The philosopher Francis Bacon and many of his contemporaries summed up the scientific attitude of the times when they insisted that if we want to understand nature we must consult nature and not the writings of Aristotle. The progressive forces of the seventeenth century came to see as mistaken the preoccupation of mediaeval natural philosophers with the works of the ancients, especially Aristotle, and also with the Bible, as the sources of scientific knowledge. Spurred on by the successes of "great experimenters" like Galileo, they came more and more to regard experience as the source of knowledge. This assessment has only been enhanced since then by the spectacular achievements of experimental science. "Science is a structure built upon facts", writes J.J. Davies in his book *On The Scientific Method.*[1] And here is a modern assessment of Galileo's achievement, due to H.D. Anthony:

> It was not so much the observations and experiments which Galileo made that caused the break with tradition as his *attitude* to them. For him, the facts based on them were treated as facts, and not related to some preconceived idea. . . . The facts of observation might, or might not, fit into an acknowledged scheme of the universe, but the important thing, in Galileo's opinion, was to accept the facts and build the theory to fit them.[2]

The *naive inductivist* account of science, which I will outline in the following sections, can be looked on as an attempt to formalize this popular picture of science. I have called it *inductivist* because it is based on inductive reasoning, as will be explained shortly. In later chapters, I will argue that this view of science, together with the popular account that it resembles, is quite mistaken and even dangerously misleading. I hope that by then it will be apparent why the adjective "naive" is appropriate for the description of many inductivists.

2. Naive inductivism

According to the naive inductivist, science starts with observation. The scientific observer should have normal, unimpaired sense organs and should faithfully record what he can see, hear, etc. to be the case with respect to the situation he is observing, and he should do this with an unprejudiced mind. Statements about the state of the world, or some part of it, can be justified or established as true in a direct way by an unprejudiced observer's use of his senses. The statements so arrived at (I will call them observation statements) then form the basis from which the laws and theories that make up scientific knowledge are to be derived. Here are some examples of some not very exciting observation statements.

> At twelve midnight on 1 January 1975, Mars appeared at such and such a position in the sky.
>
> That stick, partially immersed in water, appears bent.
>
> Mr Smith struck his wife.
>
> The litmus paper turned red when immersed in the liquid.

The truth of such statements is to be established by careful observation. Any observer can establish or check their truth by direct use of his or her senses. Observers can see for themselves.

Statements of the kind cited above fall in the class of so-called

singular statements. Singular statements, unlike a second class of statements that we will meet shortly, refer to a particular occurrence or state of affairs at a particular place at a particular time. The first statement refers to a particular appearance of Mars at a particular place in the sky at a specified time, the second to a particular observation of a particular stick, and so on. It is clear that all observation statements will be singular statements. They result from an observer's use of his or her senses at a particular place and time.

Next, we look at some simple examples that might form part of scientific knowledge.

From astronomy:	Planets move in ellipses around their sun.
From physics:	When a ray of light passes from one medium to another, it changes direction in such a way that the sine of the angle of incidence divided by the sine of the angle of refraction is a constant characteristic of the pair of media.
From psycholoIgy:	Animals in general have an inherent need for some kind of aggressive outlet.
From chemistry:	Acids turn litmus red.

These are general statements that make claims about the properties or behaviour of some aspect of the universe. Unlike singular statements, they refer to *all* events of a particular kind at all places and at all times. All planets, wherever they are situated, always move in ellipses around their sun. Whenever refraction takes place it always takes place according to the law of refraction stated above. The laws and theories that make up scientific knowledge all make general assertions of that kind, and such statements are called *universal statements.*

The following question can now be posed. If science is based on experience, then by what means is it possible to get from the singular statements that result from observation to the universal statements that make up scientific knowledge? How can the very general, unrestricted claims that constitute our theories be justified on the basis of limited evidence comprised of a limited number of observation statements?

The inductivist answer is that, provided certain conditions are satisfied, it is legitimate to *generalize* from a finite list of singular observation statements to a universal law. For instance, it may be legitimate to generalize from a finite list of observation statements referring to litmus paper turning red on being immersed in acid to the universal law, "Acids turn litmus red", or to generalize from a list of observations referring to heated metals to the law, "Metals expand when heated". The conditions that must be satisfied for such generalizations to be considered legitimate by the inductivist can be listed thus:

1. The number of observation statements forming the basis of a generalization must be large.
2. The observations must be repeated under a wide variety of conditions.
3. No accepted observation statement should conflict with the derived universal law.

Condition (1) is regarded as necessary because it is clearly not legitimate to conclude that all metals expand when heated on the basis of just one observation of a metal bar's expansion, say, any more than it is legitimate to conclude that all Australians are drunkards on the basis of one observation of an intoxicated Australian. A large number of independent observations will be necessary before either generalization can be justified. The inductivist insists that we should not jump to conclusions.

One way of increasing the number of observations in the examples mentioned would be to repeatedly heat a single bar of metal, or to continually observe a particular Australian getting drunk night after night, and perhaps morning after morning. Clearly, a list of observation statements acquired in such a way would form a very unsatisfactory basis for the respective generalizations. That is why condition (2) is necessary. "All metals expand when heated" will only be a legitimate generalization if the observations of expansion on which it is based range over a wide variety of conditions. Various kinds of metals should be heated, long iron bars, short iron bars, silver bars, copper bars, etc. should be heated at high pressure and low pressure, high temperatures and low temperatures, and so on. If, on all such occasions, the heated samples of metal all expand, then and only then is it legitimate to generalize from the resulting list of observation statements to the general law. Further, it is evident that if a particular sample of metal is observed not to expand when heated, then the universal generalization will not be justified. Condition (3) is essential.

The kind of reasoning that we have discussed, which takes us from a finite list of singular statements to the justification of a

universal statement, which takes us from some to all, is called *inductive* reasoning and the process is called induction. We might sum up the naive inductivist position by saying that, according to it, science is based on the *principle of induction*, which we can write:

> If a large number of As have been observed under a wide variety of conditions, and if all those observed As without exception possessed the property B, then all As have the property B.

According to the naive inductivist, then, the body of scientific knowledge is built by induction from the secure basis provided by observation. As the number of facts established by observation and experiment grows, and as the facts become more refined and esoteric due to improvements in our observational and experimental skills, so more and more laws and theories of ever more generality and scope are constructed by careful inductive reasoning. The growth of science is continuous, ever onward and upward, as the fund of observational data is increased.

The analysis so far constitutes only a partial account of science. For surely a major feature of science is its ability to *explain* and *predict*. It is scientific knowledge that enables an astronomer to predict when the next eclipse of the sun will occur or a physicist to explain why the boiling-point of water is lower than normal at high altitudes. Figure 1 depicts, in schematic form, a summary of the complete inductivist story of science. The left-handed side of the figure refers to the derivation of scientific laws and theories from observation that we have already discussed. It remains to discuss the right-hand side. Before doing so, a little will be said of the character of logic and deductive reasoning.

3. Logic and deductive reasoning

Once a scientist has universal laws and theories at his disposal, it is possible for him to derive from them various consequences that serve as explanations and predictions. For instance, given the fact that metals expand when heated, it is possible to derive the fact that continuous railway tracks not interrupted by small gaps will become distorted in the hot sun. The kind of reasoning involved in derivations of this kind is called *deductive* reasoning. Deduction is distinct from the induction discussed in the previous section.

A study of deductive reasoning constitutes the discipline of

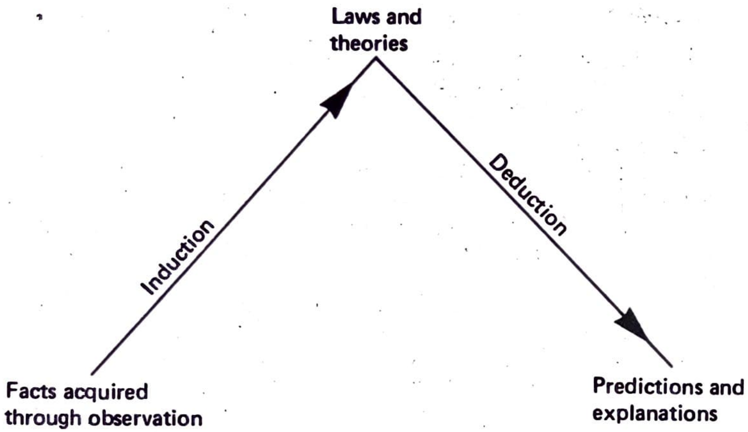

Figure 1

logic.[3] No attempt will be made to give a detailed account and appraisal of logic here. Rather, some of its important features relevant to our analysis of science will be illustrated by means of trivial examples.

Here is an example of a logical deduction.

Example 1:

1. All books on philosophy are boring.
2. This book is a book on philosophy.
3. This book is boring.

In this argument, (1) and (2) are the premises and (3) is the conclusion. It is self-evident, I take it, that if (1) and (2) are true, then (3) is bound to be true. It is not possible for (3) to be false once it is given that (1) and (2) are true. For (1) and (2) to be true and (3) to be false would involve a contradiction. This is the key feature of a *logically valid* deduction. If the premises of a logically valid deduction are true, then the conclusion must be true.

A slight modification of the above example will give us an instance of a deduction that is not valid.

Example 2:

1. Many books on philosophy are boring.
2. This book is a book on philosophy.
3. This book is boring.

In this example, (3) does not follow of necessity from (1) and (2). It is possible for (1) and (2) to be true and yet for (3) to be false. Even if (1) and (2) are true, then this book may yet turn out to be one of the minority of books on philosophy that is not boring. Asserting (1) and (2) as true and (3) as false does not involve a contradiction. The argument is invalid.

The reader may by now be feeling bored. Experiences of that kind certainly have a bearing on the truth of statements (1) and (3), in examples (1) and (2). But a point that needs to be stressed here is that logic and deduction alone cannot establish the truth of factual statements of the kind figuring in our examples. All that logic can offer in this connection is that *if* the premises are true *then* the conclusion must be true. But whether the premises are true or not is not a question that can be settled by an appeal to logic. An argument can be a perfectly logical deduction even if it involves a premise that is in fact false. Here is an example.

Example 3:

1. All cats have five legs.
2. Bugs Pussy is my cat.
3. Bugs Pussy has five legs.

This is a perfectly valid deduction. It is the case that if (1) and (2) are true, then (3) must be true. It so happens that in this example, (1) and (3) are false. But this does not affect the status of the argument as a valid deduction. Deductive logic alone, then, does not act as a source of true statements about the world. Deduction is concerned with the derivation of statements from other given statements.

4. Prediction and explanation in the inductivist account

We are now in a position to understand in a simple way the functioning of laws and theories as predictive and explanatory devices in science. Once again, I will start with a trivial example to illustrate the point. Consider the following argument:

1. Fairly pure water freezes at about 0°C (if given sufficient time).
2. My car radiator contains fairly pure water.
3. If the temperature falls below 0°C, the water in my car radiator will freeze (if given sufficient time).

Here we have an example of a valid logical argument to deduce the prediction (3) from the scientific knowledge contained in premise (1). If (1) and (2) are true, (3) must be true. However, the truth of (1), (2) or (3) is not established by this or any other deduction. For an inductivist, the source of truth is not logic but experience. On that view, (1) will be ascertained by direct observation of freezing water. Once (1) and (2) have been established by observation and induction then the prediction (3) can be *deduced* from them.

Less trivial examples will be more complicated, but the roles played by observation, induction and deduction remain essentially the same. As a final example, I will consider the inductivist account of how physical science is able to explain the rainbow.

The simple premise (1) of the previous example is here replaced by a number of laws governing the behaviour of light, namely the laws of reflection and refraction of light and assertions about the dependence of the degree of refraction on colour. These general principles are derived from experience by induction. A large number of laboratory experiments are performed, reflecting rays of light from mirrors and water surfaces, measuring angles of incidence and refraction for rays of light passing from air to water, water to air, etc., under a wide variety of conditions, repeating the experiments with light of various colours, and so on, until the conditions that need to be met to legitimate the inductive generalization to the laws of optics are satisfied.

Premise (2) of the previous example will also be replaced by a more complex array of statements. These will include assertions to the effect that the sun is situated at some specified position in the sky with respect to an observer on earth, and that raindrops are falling from a cloud situated in some specified region relative to the observer. Sets of statements like these, which describe the details of the set-up under investigation, will be referred to as *initial conditions*. Descriptions of experimental set-ups will be typical examples of initial conditions.

Given the laws of optics and the initial conditions, it is now possible to perform deductions yielding an explanation of the formation of a rainbow visible to the observer. These deductions will no longer be as self-evident as in our previous examples and will involve mathematical as well as verbal arguments. The argument

will run roughly as follows. If we assume a raindrop to be roughly spherical, then the path of a ray of light through a raindrop will be roughly as depicted in Figure 2. If a ray of white light is incident on a raindrop at *a*, then, if the law of refraction is true, the red ray will travel along *ab*, and the blue ray will travel along *ab'*. Again, if the laws governing reflection are true, then *ab*, must be reflected along *bc*, and *ab'* along *b'c'*. Refraction at *c* and *c'* will again be determined by the law of refraction, so that an observer viewing the raindrop will see the red and blue components of the white light separated (and also all the other colours of the spectrum). The same separation of colours will also be made visible to our observer for any raindrop that is situated in a region of the sky such that the line joining the raindrop to the sun makes an angle *D* with the line joining the raindrop to the observer. Geometrical considerations then yield the conclusion that a coloured arc will be visible to the observer provided the rain cloud is sufficiently extended.

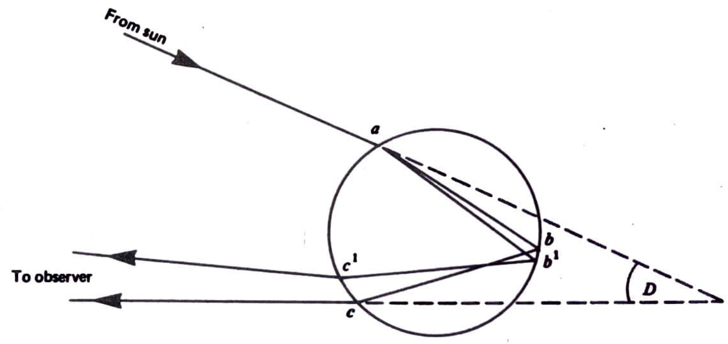

Figure 2

I have only sketched the explanation of the rainbow here, but what is offered should suffice to illustrate the general form of the reasoning involving. Given that the laws of optics are true (and for the naive inductivist, this can be established from observation by induction), and given that the initial conditions are accurately described, then the explanation of the rainbow necessarily follows. The general form of all scientific explanations and predictions can be summarized thus:

1. Laws and theories
2. Initial conditions
3. Predictions and explanations

This is the step depicted on the right-hand side of Figure 1.

The following description of the scientific method by a twentieth-century economist conforms closely to the naive inductivist account of science as I have described it, and indicates that it is not a position that I have invented solely for the purpose of criticizing it.

> If we try to imagine how a mind of superhuman power and reach, but normal so far as the logical processes of its thought are concerned, . . . would use the scientific method, the process would be as follows: First, all facts would be observed and recorded, *without selection* or *a priori* guess as to their relative importance. Secondly, the observed and recorded facts would be analysed, compared, and classified, without *hypothesis or postulates*, other than those necessarily involved in the logic of thought. Third, from this analysis of the facts, generalizations would be inductively drawn as to the relations, classificatory or casual, between them. Fourth, further research would be deductive as well as inductive, employing inferences from previously established generalizations.[4]

5. The appeal of naive inductivism

The naive inductivist account of science does have some apparent merits. Its attraction would seem to lie in the fact that it gives a formalized account of some of the popularly held impressions concerning the character of science, its explanatory and predictive power, its objectivity and its superior reliability compared with other forms of knowledge.

We have already seen how the naive inductivist accounts for the explanatory and predictive power of science.

The objectivity of inductivist science derives from the fact that both observation and inductive reasoning are themselves objective. Observation statements can be ascertained by any observer by normal use of the senses. No personal, subjective elements should be permitted to intrude. The validity of the observation statements when correctly acquired will not depend on the taste, opinion, hopes or expectations of the observer. The same goes for the inductive reasoning by means of which scientific knowledge is derived from the observation statements. Either the inductions satisfy the

prescribed conditions or they do not. It is not a subjective matter of opinion.

The reliability of science follows from the inductivist's claims about observation and induction. The observation statements that form the basis of science are secure and reliable because their truth can be ascertained by direct use of the senses. Further, the reliability of observation statements will be transmitted to the laws and theories derived from them, provided the conditions for legitimate inductions are satisfied. This is guaranteed by the principle of induction that forms the basis of science according to the naive inductivist.

I have already mentioned that I regard the naive inductivist account of science to be very wrong and dangerously misleading. In the next two chapters, I will begin to say why. However, I should perhaps make it clear that the position I have outlined is a very extreme form of inductivism. Many more sophisticated inductivists would not wish to be associated with some of the characteristics of my naive inductivism. Nevertheless, all inductivists would claim that in so far as scientific theories can be justified, they are justified by supporting them inductively on the basis of some more-or-less secure basis provided by experience. Subsequent chapters of this book will provide us with plenty of reasons for doubting that claim.

FURTHER READING

The naive inductivism that I have described is too naive to be sympathetically dealt with by philosophers. One of the classic, more sophisticated attempts to systematize inductive reasoning is John Stuart Mill's *A System of Logic* (London: Longman, 1961). An excellent, simple summary of more modern views is Wesley C. Salmon, *The Foundations of Scientific Inference* (Pittsburgh: Pittsburgh University Press, 1975). The extent to which inductivist philosophers are concerned with the empirical basis of knowledge and its origin in sense perception is very evident in A.J. Ayer, *The Foundations of Empirical Knowledge* (London: Macmillan, 1955). A good simple description and discussion of the traditional positions on sense perception is C.W.K. Mundle, *Perception: Facts and Theories* (Oxford: Oxford University Press, 1971). For a taste of that particular brand of inductivism referred to as logical positivism, I suggest two collections, A.J. Ayer, ed., *Logical Positivism* (Glencoe: Free Press, 1959) and P.A. Schilpp, ed., *The*

Philosophy of Rudolf Carnap (La Salle, Illinois: Open Court, 1963). The extent to which the inductivist programme became a highly technical one is evident in R. Carnap, *Logical Foundations of Probability* (Chicago: University of Chicago Press, 1962).

1. J.J. Davies, *On the Scientific Method* (London: Longman, 1968), p.8.
2. H.D. Anthony, *Science and Its Background* (London: Macmillan, 1948), p.145.
3. Logic is sometimes taken to include the study of inductive reasoning, so that there is an inductive logic as well as a deductive logic. In this book, logic is understood to be the study of deductive reasoning only.
4. This quotation, due to A.B. Wolfe, is as cited by Carl G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs, N.J.: Prentice-Hall, 1966), p.11. The italics are in the original quotation.

2

The Problem of Induction

1. Can the principle of induction be justified?

According to the naive inductivist, science starts with observation, observation supplies a secure basis upon which scientific knowledge can be built, and scientific knowledge is derived from observation statements by induction. In this chapter, the inductivist account of science will be criticized by casting doubt on the third of these assumptions. Doubt will be cast on the validity and justifiability of the principle of induction. Afterwards, in Chapter 3, the first two assumptions will be challenged and refuted.

My rendering of the principle of induction reads: "If a large number of *A*s have been observed under a wide variety of conditions, and if all those observed *A*s without exception have possessed the property *B*, then all *A*s possess the property *B*". This principle, or something very much like it, is the basic principle on which science is founded, if the naive inductivist position is accepted. In the light of this, an obvious question with which to confront the inductivist is, "How can the principle of induction be justified?" That is, if observation provides us with a secure set of observation statements as our starting-point (an assumption that we have granted for the sake of the argument of this chapter), why is it that *inductive* reasoning leads to reliable and perhaps even true scientific knowledge? There are two lines of approach open to the inductivist in attempting to answer this question. He might try to justify the principle by appealing to logic, a recourse that we freely grant him, or he might attempt to justify the principle by appealing to experience, a recourse that lies at the basis of his whole approach to science. Let us examine these two lines of approach in turn.

Valid logical arguments are characterized by the fact that, if the premise of the argument is true, then the conclusion must be true. Deductive arguments possess that character. The principle of induction would certainly be justified if inductive arguments also possessed it. But they do not. Inductive arguments are not logically valid arguments. It is not the case that, if the premises of an inductive inference are true, then the conclusion must be true. It is possible for the conclusion of an inductive argument to be false and for the premises to be true and yet for no contradiction to be involved. Suppose, for example, that up until today I have observed a large number of ravens under a wide variety of circumstances and have observed all of them to have been black and that, on that basis, I conclude, "All ravens are black". This is a perfectly legitimate inductive inference. The premises of the inference are a large number of statements of the kind, "Raven x was observed to be black at time t", and all these we take to be true. But there is no logical guarantee that the next raven I observe will not be pink. If this proved to be the case, then "All ravens are black" would be false. That is, the initial inductive inference, which was legitimate insofar as it satisfied the criteria specified by the principle of induction, would have led to a false conclusion, in spite of the fact that all premises of the inference were true. No logical contradiction is involved in claiming that all observed ravens have proved to be black and also that not all ravens are black. Induction cannot be justified purely on logical grounds.

A more interesting if rather gruesome example of the point is an elaboration of Bertrand Russell's story of the inductivist turkey. This turkey found that, on his first morning at the turkey farm, he was fed at 9 a.m. However, being a good inductivist, he did not jump to conclusions. He waited until he had collected a large number of observations of the fact that he was fed at 9 a.m., and he made these observations under a wide variety of circumstances, on Wednesdays and Thursdays, on warm days and cold days, on rainy days and dry days. Each day, he added another observation statement to his list. Finally, his inductivist conscience was satisfied and he carried out an inductive inference to conclude, "I am always fed at 9 a.m.". Alas, this conclusion was shown to be false in no uncertain manner when, on Christmas eve, instead of being fed, he had his throat cut. An inductive inference with true premises has led to a false conclusion.

The principle of induction cannot be justified merely by an appeal to logic. Given this result, it would seem that the inductivist, according to his own standpoint, is now obliged to indicate how the

principle of induction can be derived from experience. What would such a derivation be like? Presumably, it would go something like this. Induction has been observed to work on a large number of occasions. For example, the laws of optics, derived by induction from the results of laboratory experiments, have been used on numerous occasions in the design of optical instruments and these instruments have functioned satisfactorily. Again, the laws of planetary motion, derived from observations of planetary positions etc., have been successfully employed to predict the occurrence of eclipses. This list could be greatly extended with accounts of successful predictions and explanations made possible by inductively derived scientific laws and theories. In this way, the principle of induction is justified.

The foregoing justification of induction is quite unacceptable, as David Hume conclusively demonstrated as long ago as the mid-eighteenth century. The argument purporting to justify induction is circular because it employs the very kind of inductive argument the validity of which is supposed to be in need of justification. The form of the justificatory argument is as follows:

The principle of induction worked successfully on occasion x_1.
The principle of induction worked successfully on occasion x_2 etc.
___
The principle of induction always works.

A universal statement asserting the validity of the principle of induction is here inferred from a number of singular statements recording past successful applications of the principle. The argument is therefore an inductive one and so cannot be used to justify the principle of induction. We cannot use induction to justify induction. This difficulty associated with the justification of induction has traditionally been called "the problem of induction".

It would seem, then, that the unrepentant naive inductivist is in trouble. The extreme demand that all knowledge should be derived from experience by induction rules out the principle of induction basic to the inductivist position.

In adition to the circularity involved in attempts to justify the principle of induction, the principle as I have stated it suffers from other shortcomings. These shortcomings stem from the vagueness and dubiousness of the demand that a "large number" of observations be made under a "wide variety" of circumstances.

How many observations make up a large number? Should a metal bar be heated ten times, a hundred times, or how many times before we can conclude that it always expands when heated?

Whatever the answer to such a question, examples can be produced that cast doubt on the invariable necessity for a large number of observations. To illustrate this, I refer to the strong public reaction against nuclear warfare that followed the dropping of the first atomic bomb on Hiroshima towards the end of the second world war. This reaction was based on the understanding that atomic bombs cause widespread death and destruction and extreme human suffering. And yet this generally held belief was based on just one dramatic observation. Again, it would take a very stubborn inductivist to put his hand in a fire many times before concluding that fire burns. In circumstances like these, the demand for a large number of observations seem inappropriate. In other situations, the demand seems more plausible. For instance, we would be justifiably reluctant to ascribe supernatural powers to a fortune-teller on the basis of just one correct prediction. Nor would it be justifiable to conclude some causal connection between smoking and lung cancer on the evidence of just one heavy smoker contracting the disease. It is clear, I think, from these examples that if the principle of induction is to be a guide to what counts as a legitimate scientific inference, then the "large number" clause will need to be qualified in some detail.

The naive inductivist position is further threatened when the demand that observations be made under a wide variety of circumstances is scrutinized. What is to count as a significant variation in the circumstances? When investigating the boiling-point of water, for instance, is it necessary to vary the pressure, the purity of the water, the method of heating and the time of day? The answer to the first two suggestions is "Yes" and to the second two it is "No". But what are the grounds for these answers? This question is important because the list of variations can be extended indefinitely by adding a variety of further variations such as the colour of the container, the identity of the experimenter, the geographical location, and so on. Unless such "superfluous" variations can be eliminated, the number of observations necessary to render an inductive inference legitimate will be infinitely large. What, then, are the grounds on which a large number of variations are deemed superfluous? I suggest the answer is clear enough. The variations that are significant are distinguished from those that are superfluous by appealing to our *theoretical knowledge of the situation* and of the kinds of physical mechanisms operative. But, to admit this is to admit that theory plays a vital role *prior to* observation. The naive inductivist cannot afford to make such an admission. However, to pursue this would lead on to criticisms of inductivism that I have reserved for the next chapter. Here I merely note that the "wide variety of circumstances" clause in the principle of induction poses serious problems for the inductivist.

2. The retreat to probability

There is a fairly obvious way in which the extreme naive inductivist position criticized in the previous section can be weakened in an attempt to counter some of the criticism. An argument in defence of a weaker position might run somewhat as follows.

We cannot be one hundred per cent sure that, just because we have observed the sun to set each day on many occasions, the sun will set every day. (Indeed, in the Arctic and Antarctic, there are days when the sun does not set.) We cannot be one hundred per cent sure that the next dropped stone will not "fall" upwards. Nevertheless, although generalizations arrived at by legitimate inductions cannot be guaranteed to be perfectly true, they are *probably* true. In the light of the evidence, it is very probable that the sun will always set in Sydney, and that stones will fall downwards when they are dropped. Scientific knowledge is not proven knowledge, but it does represent knowledge that is probably true. The greater the number of observations forming the basis of an induction and the greater variety of conditions under which these observations are made, the greater the probability that the resulting generalizations are true.

If this modified version of induction is adopted, then the principle of induction will be replaced by a probabilistic version that will read something like, "If a large number of *A*s have been observed under a wide variety of conditions, and if all these observed *A*s without exception have possessed the property *B*, then all *A*s probably possess the property *B*". This reformulation does not overcome the problem of induction. The reformulated principle is still a universal statement. It implies, on the basis of a finite number of successes, that all applications of the principle will lead to general conclusions that are probably true. Attempts to justify the probabilistic version of the principle of induction by appeal to experience must suffer from the same deficiency as attempts to justify the principle in its original form. The justification will employ an argument of the very kind that is seen as in need of justification.

Even if the principle of induction in its probabilistic version could be justified, there are further problems facing our more cautious inductivist. The further problems are associated with difficulties that are encountered when trying to be precise about just how probable a law or theory is in the light of specified evidence. It may seem intuitively plausible that as the observational support that a universal law receives increases, the probability that it is true also increases. But this intuition does not stand up to inspection. Given standard probability theory, it is very difficult to construct an account of induction that avoids the consequence that the probability of any universal statement making claims about the world is zero, whatever the observational evidence. To make the point in a non-technical way, any observational evidence will consist of a finite number of observation statements, whereas a universal statement makes claims about an infinite number of possible situations. The probability of the universal generalization being true is thus a finite number divided by an infinite number, which remains zero however much the finite number of observation statements constituting the evidence is increased.

This problem, associated with attempts to ascribe probabilities to scientific laws and theories in the light of given evidence, has given rise to a detailed technical research programme that has been tenacioulsy pursued and developed by inductivists over the last few decades. Artificial languages have been constructed for which it is possible to ascribe unique, non-zero probabilities to generalizations, but the languages are so restricted that they contain no universal generalizations. They are far removed from the language of science.

Another attempt to save the inductivist programme involves giving up the idea of ascribing probabilities to scientific laws and theories. Instead, attention is directed towards the probability of individual predictions being correct. According to this approach, the object of science is, for instance, to gauge the probability of the sun rising tomorrow rather than the probability that it will always rise. Science is expected to be able to provide a guarantee that a bridge of some design will withstand various stresses and not collapse, but not that all bridges of that design will be satisfactory. Some systems have been developed along such lines that enable non-zero probabilities to be ascribed to individual predictions. Two criticisms of them will be mentioned here. Firstly, the notion that science is concerned with the production of a set of individual predictions rather than with the production of *knowledge* in the form of a complex of general statements is, to say the least, counter-intuitive. Secondly, even when attention is restricted to individual predictions, it can be argued that scientific theories, and hence universal statements, are inevitably involved in the estimation of the likelihood of a prediction being successful. For instance, in some intuitive, non-technical sense of "probable", we may be prepared to assert that it is to some degree probable that a very heavy smoker will die of lung cancer. The evidence supporting the assertion would presumably be the available statistical data. But this intuitive probability will be significantly increased if there is a plausible and well-supported theory available that entails some causal connection between smoking and lung cancer. Similarly, estimates of the probability that the sun will rise tomorrow will be increased once the knowledge of the laws governing the behaviour of the solar system are taken into account. But this dependence of the probability of the correctness of predictions on universal laws and theories undermines the attempt of the inductivists to ascribe non-zero probabilities to individual predictions. Once universal statements are involved in a significant way, the probabilities of the correctness of individual predictions again threaten to be zero.

3. Possible responses to the problem of induction

Faced with the problem of induction and related problems, inductivists have run into one difficulty after another in their attempts to construe science as a set of statements that can be established as true or probably true in the light of given evidence. Each manoeuvre in their rearguard action has taken them further away from intuitive notions about that exciting enterprise referred to as science. Their technical programme has led to interesting advances within probability theory, but it has not yielded new insights into the nature of science. Their programme has degenerated.

There are a number of possible responses to the problem of induction. One of them is a sceptical one. We can accept that science is based on induction and Hume's demonstration that induction cannot be justified by appeal to logic or experience, and conclude that science cannot be rationally justified. Hume himself adopted a position of that kind. He held that beliefs in laws and theories are nothing more than psychological habits that we acquire as a result of repetitions of the relevant observations.

A second response is to weaken the inductivist demand that all non-logical knowledge must be derived from experience and to argue for the reasonableness of the principle of induction on some other grounds. However, to regard the principle of induction, or something like it as "obvious" is not acceptable. What we regard as obvious is much too dependent on and relative to our education, our prejudices and our culture to be a reliable guide to what is reasonable. To many cultures, at various stages in history, it was obvious that the earth was flat. Before the scientific revolution of Galileo and Newton, it was obvious that if an object was to move, then it required a force or cause of some kind to make it move. This may be obvious to some readers of this book lacking a physics education, and yet it is false. If the principle of induction is to be defended as reasonable, then some more sophisticated argument than an appeal to its obviousness must be offered.

A third response to the problem of induction involves the denial that science is based on induction. The problem of induction will be avoided if it can be established that science does not involve induction. The falsificationists, most notably Karl Popper, attempt to do this. We will discuss those attempts in some detail in Chapters 4, 5 and 6.

In this chapter, I have sounded much too much like a philosopher. In the next chapter, I move on to a more interesting, more telling and more fruitful critique of inductivism.

FURTHER READING

The historical source of Hume's problem of induction is Part 3 of D. Hume, *Treatise on Human Nature* (London: Dent, 1939). Another classic discussion of the problem is Chapter 6 of B. Russell, *Problems of Philosophy* (Oxford: Oxford University Press, 1912). A very thorough and technical investigation and discussion of the consequences of Hume's argument by an inductivist sympathizer is D.C. Stove, *Probability and Hume's Inductive Scepticism* (Oxford: Oxford University Press, 1973). Popper's claim to have solved the problem of induction is summarized In K.R. Popper, "Conjectural Knowledge: My Solution to the Problem of Induction", in his *Objective Knowledge* (Oxford: Oxford University Press, 1972), Ch. 1. A criticism of Popper's position from the point of view of a falsificationist sympathizer is I. Lakatos, "Popper on Demarcation and Induction", in *The Philosophy of Karl R. Popper*, ed. P.A. Schlipp (La Salle, Illinois: Open Court, 1974), pp. 241-73. Lakatos has written a provocative history of developments in the inductivist programme in his "Changes in the Problem of Inductive Logic", in *The Problem of Inductive

Logic*, ed. I. Lakatos (Amsterdam: North Holland Publ. Co., 1968), pp. 315-417. Criticisms of inductivism from a point of view somewhat different from the one adopted in this book are in the classic P. Duhem, *The Aim and Structure of Physical Theory* (New York: Atheneum, 1962).