A.F. Chalmers:
"What is this thing called Science?"
2. ed.
Open University Press 1982

1

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

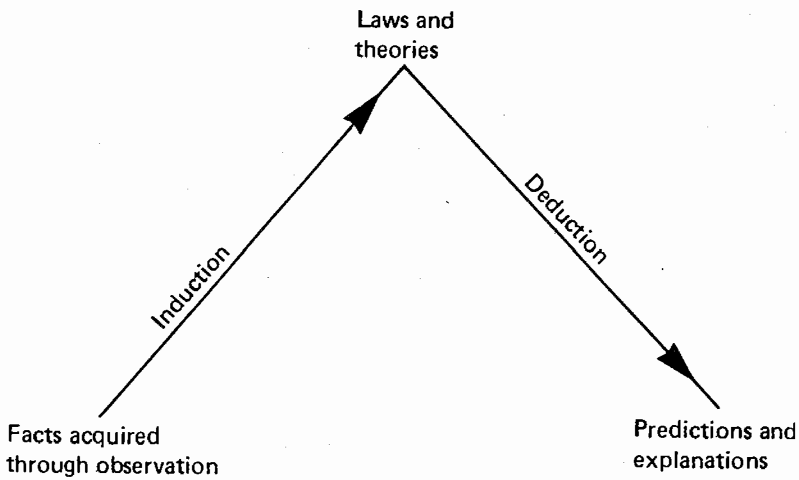

Figure 1

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.

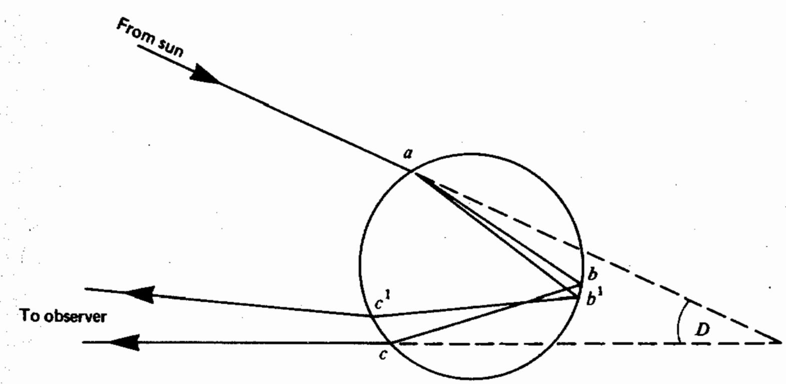

Figure 2

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