This is guaranteed by the principle of induction which is presumed to form the basis of science.

Attractive as it may have appeared, we have seen that the inductivist position is, at best, in need of severe qualification and, at worst, thoroughly inadequate. We have seen that facts adequate for science are by no means straightforwardly given but have to be practically constructed, are in some important senses dependent on the knowledge that they presuppose, a complication overlooked in the schematisation in figure 2, and are subject to improvement and replacement. More seriously, we have been unable to give a precise specification of induction in a way that will help distinguish a justifiable generalisation from the facts from a hasty or rash one, a formidable task given nature's capacity to surprise, epitomised in the discovery that supercooled liquids can flow uphill.

In chapter 12 we will discuss some recent attempts to rescue the inductivist account of science from its difficulties. Meanwhile, we will turn in the next two chapters to a philosopher who attempts to sidestep problems with induction by putting forward a view of science that does not involve induction.

Further reading

The historical source of Hume's problem of induction is Hume's *Treatise on Human Nature* (1939, Part 3). Another classic discussion of the problem is Russell (1912, chapter 6). A thorough, technical investigation of the consequences of Hume's argument is Stove (1973). Karl Popper's claim to have solved the problem of induction is in Popper (1979, chapter 1). Reasonably accessible accounts of inductive reasoning can be found in Hempel (1966) and Salmon (1966), and a more detailed treatment is found in Glymour (1980). See also Lakatos (1968) for a collection of essays, including a provocative survey by Lakatos himself, of attempts to construct an inductive logic.

CHAPTER 5

Introducing falsificationism

Introduction

Karl Popper was the most forceful advocate of an alternative to inductivism which I will refer to as "falsificationism". Popper was educated in Vienna in the 1920s, at a time when logical positivism was being articulated by a group of philosophers who became known as the Vienna Circle. One of the most famous of these was Rudolph Carnap, and the clash and debate between his supporters and those of Popper was to be a feature of philosophy of science up until the 1960s. Popper himself tells the story of how he became disenchanted with the idea that science is special because it can be derived from the facts, the more facts the better. He became suspicious of the way in which he saw Freudians and Marxists supporting their theories by interpreting a wide range of instances, of human behaviour or historical change respectively, in terms of their theory and claiming them to be supported on this account. It seemed to Popper that these theories could never go wrong because they were sufficiently flexible to accommodate any instances of human behaviour or historical change as compatible with their theory. Consequently, although giving the appearance of being powerful theories confirmed by a wide range of facts, they could in fact explain nothing because they could rule out nothing. Popper compared this with a famous test of Einstein's theory of general relativity carried out by Eddington in 1919. Einstein's theory had the implication that rays of light should bend as they pass close to massive objects such as the sun. As a consequence, a star situated beyond the sun should appear displaced from the direction in which it would be observed in the absence of this bending. Eddington sought for this displacement by sighting the star at a time when the light from the sun was blocked out by an eclipse. It transpired that the displacement was observed and Einstein's theory was borne out. But Popper makes the point that it might not have been. By making a specific, testable prediction the general theory of relativity was at risk. It ruled out observations that clashed with that prediction. Popper drew the moral that genuine scientific theories, by making definite predictions, rule out a range of observable states of affairs in a way that he considered Freudian and Marxist theory failed to do. He arrived at his key idea that scientific theories are *falsifiable*.

Falsificationists freely admit that observation is guided by and presupposes theory. They are also happy to abandon any claim implying that theories can be established as true or probably true in the light of observational evidence. Theories are construed as speculative and tentative conjectures or guesses freely created by the human intellect in an attempt to overcome problems encountered by previous theories to give an adequate account of some aspects of the world or universe. Once proposed, speculative theories are to be rigorously and ruthlessly tested by observation and experiment. Theories that fail to stand up to observational and experimental tests must be eliminated and replaced by further speculative conjectures. Science progresses by trial and error, by conjectures and refutations. Only the fittest theories survive. Although it can never be legitimately said of a theory that it is true, it can hopefully be said that it is the best available; that it is better than anything that has come before. No problems about the characterisation and justification of induction arise for the falsificationists because, according to them, science does not involve induction.

The content of this condensed summary of falsificationism will be filled out in the next two chapters.

A logical point in favour of falsificationism

According to falsificationism, some theories can be shown to be false by an appeal to the results of observation and

experiment. There is a simple, logical point that seems to support the falsificationist here. I have already indicated in chapter 4 that, even if we assume that true observational statements are available to us in some way, it is never possible to arrive at universal laws and theories by logical deductions on that basis alone. However, it is possible to perform logical deductions starting from singular observation statements as premises, to arrive at the falsity of universal laws and theories by logical deduction. For example, if we are given the statement, "A raven which was not black was observed at place x at time t", then it logically follows from this that "All ravens are black" is false. That is, the argument:

Premise	A raven, which was not black, was at place x at time t.
Conclusion	Not all ravens are black.

is a logically valid deduction. If the premise is asserted and the conclusion denied, a contradiction is involved. One or two more examples will help illustrate this fairly trivial logical point. If it can be established by observation in some test experiment that a ten-kilogram weight and a one-kilogram weight in free fall move downwards at roughly the same speed, then it can be concluded that the claim that bodies fall at speeds proportional to their weight is false. If it can be demonstrated beyond doubt that a ray of light passing close to the sun is deflected in a curved path, then it is not the case that light necessarily travels in straight lines.

The falsity of universal statements can be deduced from suitable singular statements. The falsificationist exploits this logical point to the full.

Falsifiability as a criterion for theories

The falsificationist sees science as a set of hypotheses that are tentatively proposed with the aim of accurately describing or accounting for the behaviour of some aspect of the world or universe. However, not any hypothesis will do. There is one fundamental condition that any hypothesis or system of hypotheses must satisfy if it is to be granted the status of a scientific law or theory. If it is to form part of science, an hypothesis must be *falsifiable.* Before proceeding any further, it is important to be clear about the falsificationist's usage of the term "falsifiable".

Here are some examples of some simple assertions that are falsifiable in the sense intended.

1. It never rains on Wednesdays.
2. All substances expand when heated.
3. Heavy objects such as a brick when released near the surface of the earth fall straight downwards if not impeded.
4. When a ray of light is reflected from a plane mirror, the angle of incidence is equal to the angle of reflection.

Assertion 1 is falsifiable because it can be falsified by observing rain to fall on a Wednesday. Assertion 2 is falsifiable. It can be falsified by an observation statement to the effect that some substance, x, did not expand when heated at time t. Water near its freezing point would serve to falsify 2. Both 1 and 2 are falsifiable and false. Assertions 3 and 4 may be true, for all I know. Nevertheless, they are falsifiable in the sense intended. It is logically possible that the next brick to be relased will "fall" upwards. No logical contradiction is involved in the assertion, "The brick fell upwards when released", although it may be that no such statement is ever supported by observation. Assertion 4 is falsifiable because a ray of light incident on a mirror at some oblique angle could conceivably be reflected in a direction perpendicular to the mirror. This will never happen if the law of reflection happens to be true, but no logical contradiction would be involved if it did. Both 3 and 4 are falsifiable, even though they may be true.

An hypothesis is falsifiable if there exists a logically possible observation statement or set of observation statements that are inconsistent with it, that is, which, if established as true, would falsify the hypothesis.

Here are some examples of statements that do not satisfy this requirement and that are consequently not falsifiable.

5. Either it is raining or it is not raining.
6. All points on a Euclidean circle are equidistant from the centre.
7. Luck is possible in sporting speculation.

No logically possible observation statement could refute 5. It is true whatever the weather is like. Assertion 6 is necessarily true because of the definition of a Euclidean circle. If points on a circle were not equidistant from some fixed point, then that figure would just not be a Euclidean circle. "All bachelors are unmarried" is unfalsifiable for a similar reason. Assertion 7 is quoted from a horoscope in a newspaper. It typifies the fortune-teller's devious strategy. The assertion is unfalsifiable. It amounts to telling the reader that if he has a bet today he might win, which remains true whether he bets or not, and if he does, whether he wins or not.

Falsificationists demand that scientific hypotheses be falsifiable, in the sense discussed. They insist on this because it is only by ruling out a set of logically possible observation statements that a law or theory is informative. If a statement is unfalsifiable, then the world can have any properties whatsoever, and can behave in any way whatsoever, without conflicting with the statement. Statements 5, 6 and 7, unlike statements 1, 2, 3 and 4, tell us nothing about the world. A scientific law or theory should ideally give us some information about how the world does in fact behave, thereby ruling out ways in which it could (logically) possibly behave but in fact does not. The law "All planets move in ellipses around the sun" is scientific because it claims that planets in fact move in ellipses and rules out orbits that are square or oval. Just because the law makes definite claims about planetary orbits, it has informative content and is falsifiable.

A cursory glance at some laws that might be regarded as typical components of scientific theories indicates that they satisfy the falsifiability criterion. "Unlike magnetic poles attract each other", "An acid added to a base yields a salt plus water" and similar laws can easily be construed as falsifiable. However, the falsificationist maintains that some theories, while they may superficially appear to have the characteristics of good scientific theories, are in fact only posing as scientific theories because they are not falsifiable and should be rejected. Popper has claimed that some versions at least of Marx's theory of history, Freudian psychoanalysis and Adlerian psychology suffer from this fault. The point can be illustrated by the following caricature of Adlerian psychology.

A fundamental tenet of Adler's theory is that human actions are motivated by feelings of inferiority of some kind. In our caricature, this is supported by the following incident. A man is standing on the bank of a treacherous river at the instant a child falls into the river nearby. The man will either leap into the river in an attempt to save the child or he will not. If he does leap in, the Adlerian responds by indicating how this supports his theory. The man obviously needed to overcome his feeling of inferiority by demonstrating that he was brave enough to leap into the river, in spite of the danger. If the man does not leap in, the Adlerian can again claim support for his theory. The man was overcoming his feelings of inferiority by demonstrating that he had the strength of will to remain on the bank, unperturbed, while the child drowned.

If this caricature is typical of the way in which Adlerian theory operates, then the theory is not falsifiable. It is consistent with any kind of human behaviour, and just because of that, it tells us nothing about human behaviour. Of course, before Adler's theory can be rejected on these grounds, it would be necessary to investigate the details of the theory rather than a caricature. But there are plenty of social, psychological and religious theories that give rise to the suspicion that in their concern to explain everything they explain nothing. The existence of a loving God and the occurrence of some disaster can be made compatible by interpreting the disaster as being sent to try us or to punish us, whichever seems most suited to the situation. Many examples of animal behaviour can be seen as evidence supporting the assertion, "Animals are designed so as best to fulfil the function for which they were intended". Theorists operating in this way are guilty of the fortune-teller's evasion and are subject to the falsificationist's criticism. If a theory is to have informative content, it must run the risk of being falsified.

Degree of falsifiability, clarity and precision

A good scientific law or theory is falsifiable just because it makes definite claims about the world. For the falsificationist, it follows fairly readily from this that the more falsifiable a theory is the better, in some loose sense of more. The more a theory claims, the more potential opportunities there will be for showing that the world does not in fact behave in the way laid down by the theory. A very good theory will be one that makes very wide-ranging claims about the world, and which is consequently highly falsifiable, and is one that resists falsification whenever it is put to the test.

The point can be illustrated by means of a trivial example. Consider these laws:

(a) Mars moves in an ellipse around the sun.
(b) All planets move in ellipses around their sun.

I take it that it is clear that (b) has a higher status than (a) as a piece of scientific knowledge. Law (b) tells us all that (a) tells us and more besides. Law (b), the preferable law, is more falsifiable than (a). If observations of Mars should turn out to falsify (a), then they would falsify (b) also. Any falsification of (a) will be a falsification of (b), but the reverse is not the case. Observation statements referring to the orbits of Venus, Jupiter, etc. that might conceivably falsify (b) are irrelevant to (a). If we follow Popper and refer to those sets of observation statements that would serve to falsify a law or theory as *potential falsifiers* of that law or theory, then we can say that the potential falsifiers of (a) form a class that is a subclass of the potential falsifiers of (b). Law (b) is more falsifiable than law (a), which is tantamount to saying that it claims more, that it is the better law.

A less-contrived example involves the relation between Kepler's theory of the solar system and Newton's. Kepler's theory I take to be his three laws of planetary motion. Potential falsifiers of that theory consist of sets of statements referring to planetary positions relative to the sun at specified times. Newton's theory, a better theory that superseded Kepler's, is more comprehensive. It consists of Newton's laws of motion plus his law of gravitation, the latter asserting that all pairs of bodies in the universe attract each other with a force that varies inversely as the square of their separation. Some of the potential falsifiers of Newton's theory are sets of statements of planetary positions at specified times. But there are many others, including those referring to the behaviour of falling bodies and pendulums, the correlation between the tides and the locations of the sun and moon, and so on. There are many more opportunities for falsifying Newton's theory than for falsifying Kepler's theory. And yet, so the falsificationist story goes, Newton's theory was able to resist attempted falsifications, thereby establishing its superiority over Kepler's.

Highly falsifiable theories should be preferred to less falsifiable ones, then, provided they have not in fact been falsified. The qualification is important for the falsificationist. Theories that have been falsified must be ruthlessly rejected. The enterprise of science involves the proposal of highly falsifiable hypotheses, followed by deliberate and tenacious attempts to falsify them. To quote Popper (1969, p. 231, italics in original):

> I can therefore gladly admit that falsificationists like myself much prefer an attempt to solve an interesting problem by a bold conjecture, *even (and especially) if it soon turns out to be false*, to any recital of a sequence of irrelevant truisms. We prefer this because we believe that this is the way in which we can learn from our mistakes; and that in finding that our conjecture was false we shall have learnt much about the truth, and shall have got nearer to the truth.

We learn from our *mistakes*. Science progresses by trial and *error*. Because of the logical situation that renders the derivation of universal laws and theories from observation statements impossible, but the deduction of their falsity possible, *falsifications* become the important landmarks, the striking achievements, the major growing-points in science. This somewhat counter-intuitive emphasis of the more extreme falsificationists on the significance of falsifications will be criticised in later chapters.

Because science aims at theories with a large informative content, the falsificationist welcomes the proposal of bold speculative conjectures. Rash speculations are to be encouraged, provided they are falsifiable and provided they are rejected when falsified. This do-or-die attitude clashes with the caution advocated by the extreme inductivist. According to the latter, only those theories that can be shown to be true or probably true are to be admitted into science. We should proceed beyond the immediate results of experience only so far as legitimate inductions will take us. The falsificationist, by contrast, recognises the limitation of induction and the subservience of observation to theory. Nature's secrets can only be revealed with the aid of ingenious and penetrating theories. The greater the number of conjectured theories that are confronted by the realities of the world, and the more speculative those conjectures are, the greater will be the chances of major advances in science. There is no danger in the proliferation of speculative theories because any that are inadequate as descriptions of the world can be ruthlessly eliminated as the result of observational or other tests.

The demand that theories should be highly falsifiable has the attractive consequence that theories should be clearly stated and precise. If a theory is so vaguely stated that it is not clear exactly what it is claiming, then when tested by observation or experiment it can always be interpreted so as to be consistent with the results of those tests. In this way, it can be defended against falsifications. For example, Goethe (1970, p. 295) wrote of electricity that:

> it is a nothing, a zero, a mere point, which, however, dwells in all apparent existences, and at the same time is the point of origin whence, on the slightest stimulus, a double appearance presents itself, an appearence which only manifests itself to vanish. The conditions under which this manifestation is excited are infinitely varied, according to the nature of particular bodies.

If we take this quotation at face value, it is very difficult to see what possible set of physical circumstances could serve to falsify it. Just because it is so vague and indefinite (at least when taken out of context), it is unfalsifiable. Politicians and fortune-tellers can avoid being accused of making mistakes by making their assertions so vague that they can always be construed as compatible with whatever may eventuate. The demand for a high degree of falsifiability rules out such manoeuvres. The falsificationist demands that theories be stated with sufficient clarity to run the risk of falsification.

A similar situation exists with respect to precision. The more precisely a theory is formulated the more falsifiable it becomes. If we accept that the more falsifiable a theory is the better (provided it has not been falsified), then we must also accept that the more precise the claims of a theory are the better. "Planets move in ellipses around the sun" is more precise than "Planets move in closed loops around the sun", and is consequently more falsifiable. An oval orbit would falsify the first but not the second, whereas any orbit that falsifies the second will also falsify the first. The falsificationist is committed to preferring the first. Similarly, the falsificationist must prefer the claim that the velocity of light in a vacuum is 299.8 x 10^6 metres per second to the less-precise claim that it is about 300 x 10^6 metres per second, just because the first is more falsifiable than the second.

The closely associated demands for precision and clarity of expression both follow naturally from the falsificationist's account of science.

Falsificationism and progress

The progress of science as the falsificationist sees it might be summed up as follows. Science starts with problems, problems associated with the explanation of the behaviour of some aspects of the world or universe. Falsifiable hypotheses are proposed by scientists as solutions to a problem. The conjectured hypotheses are then criticised and tested. Some will be quickly eliminated. Others might prove more successful. These must be subject to even more stringent criticism and testing. When an hypothesis that has successfully withstood a wide range of rigorous tests is eventually falsified, a new problem, hopefully far removed from the original solved problem, has emerged. This new problem calls for the invention of new hypotheses, followed by renewed criticism and testing. And so the process continues indefinitely. It can never be said of a theory that it is true, however well it has withstood rigorous tests, but it can hopefully be said that a current theory is superior to its predecessors in the sense that it is able to withstand tests that falsified those predecessors.

Before we look at some examples to illustrate this falsificationist conception of the progress of science, a word should be said about the claim that "Science starts with problems". Here are some problems that have confronted scientists in the past. How are bats able to fly so dexterously at night, when in fact they have very small, weak eyes? Why is the height of a simple barometer lower at high altitudes than at low altitudes? Why were the photographic plates in Roentgen's laboratory continually becoming blackened? Why does the perihelion of the planet Mercury advance? These problems arise from more or less straightforward *observations.* In insisting on the fact that science starts with problems, then, is it not the case that, for the falsificationist just as for the naive inductivist, science starts from observation? The answer to this question is a firm "No". The observations cited above as constituting problems are only problematic *in the light of some theory.* The first is problematic in the light of the theory that living organisms "see" with their eyes; the second was problematic for the supporters of Galileo's theories because it clashed with the "force of a vacuum" theory accepted by them as an explanation of why the mercury does not fall from a barometer tube; the third was problematic for Roentgen because it was tacitly assumed at the time that no radiation or emanation of any kind existed that could penetrate the container of the photographic plates and darken them; the fourth was problematic because it was incompatible with Newton's theory. The claim that science starts with problems is perfectly compatible with the priority of theories over observation and observation statements. Science does not start with stark observation.

After this digression, we return to the falsificationist conception of the progress of science as the progression from problems to speculative hypotheses, to their criticism and eventual falsification and thence to new problems. Two examples will be offered, the first a simple one concerning the flight of bats, the second a more ambitious one concerning the progress of physics.

We start with a problem. Bats are able to fly with ease and at speed, avoiding the branches of trees, telegraph wires, other bats, etc., and can catch insects. And yet bats have weak eyes, and in any case do most of their flying at night. This poses a problem because it apparently falsifies the plausible theory that animals, like humans, see with their eyes. A falsificationist will attempt to solve the problem by making a conjecture or hypothesis. Perhaps he suggests that, although bats' eyes are apparently weak, nevertheless in some way that is not understood they are able to see efficiently at night by use of their eyes. This hypothesis can be tested. A sample of bats is released into a darkened room containing obstacles and their ability to avoid the obstacles measured in some way. The same bats are now blindfolded and again released into the room. Prior to the experiment, the experimenter can make the following deduction. One premise of the deduction is his hypothesis, which made quite explicit reads, "Bats are able to fly avoiding obstacles by using their eyes, and cannot do so without the use of their eyes". The second premise is a description of the experimental set-up, including the statement, "This sample of bats is blindfolded so that they do not have the use of their eyes". From these two premises, the experimenter can derive, deductively, that the sample of bats will not be able to avoid the obstacles in the test laboratory efficiently. The experiment is now performed and it is found that the bats avoid collisions just as efficiently as before. The hypothesis has been falsified. There is now a need for a fresh use of the imagination, a new conjecture or hypothesis or guess. Perhaps a scientist suggests that in some way the bat's ears are involved in its ability to avoid obstacles. The hypothesis can be tested, in an attempt to falsify it, by plugging the ears of bats before releasing them into the test laboratory. This time it is found that the ability of the bats to avoid obstacles is considerably impaired. The hypothesis has been supported. The falsificationist must now try to make the hypothesis more precise so that it becomes more readily falsifiable. It is suggested that the bat hears echoes of its own squeaks rebounding from solid objects. This is tested by gagging the bats before releasing them. Again the bats collide with obstacles and again the hypothesis is supported. The falsificationist now appears to be reaching a tentative solution to the problem, although it has not been *proved* by experiment how bats avoid collisions while flying. Any number of factors may turn up that show the hypothesis to have been wrong. Perhaps the bat detects echoes not with its ears but with sensitive regions close to the ears, the functioning of which was impaired when the bat's ears were plugged. Or perhaps different kinds of bats detect obstacles in very different ways, so the bats used in the experiment were not truly representative.

The progress of physics from Aristotle through Newton to Einstein provides an example on a larger scale. The falsificationist account of that progression goes something like this. Aristotelian physics was to some extent quite successful. It could explain a wide range of phenomena. It could explain why heavy objects fall to the ground (seeking their natural place at the centre of the universe), it could explain the action of siphons and liftpumps (the explanation being based on the impossibility of a vacuum), and so on. But eventually Aristotelian physics was falsified in a number of ways. Stones dropped from the top of the mast of a uniformly moving ship fell to the deck at the foot of the mast and not some distance from the mast, as Aristotle's theory predicted. The moons of Jupiter can be seen to orbit Jupiter and not the earth. A host of other falsifications were accumulated during the seventeenth century. Newton's physics, however, once it had been created and developed by way of the conjectures of the likes of Galileo and Newton, was a superior theory that superseded Aristotle's. Newton's theory could account for falling objects, the operation of siphons and liftpumps and anything else that Aristotle's theory could explain, and could also account for the phenomena that were problematic for the Aristotelians. In addition, Newton's theory could explain phenomena not touched on by Aristotle's theory, such as correlations between the tides and the location of the moon, and the variation in the force of gravity with height above sea level. For two centuries Newton's theory was successful. That is, attempts to falsify it by reference to the new phenomena predicted with its help were unsuccessful. The theory even led to the discovery of a new planet, Neptune. But in spite of its success, sustained attempts to falsify it eventually proved successful. Newton's theory was falsified in a number of ways. It was unable to account for the details of the orbit of the planet Mercury and was unable to account for the variable mass of fast-moving electrons in discharge tubes. Challenging problems faced physicists, then, as the nineteenth century gave way to the twentieth, problems calling for new speculative hypotheses designed to overcome these problems in a progressive way. Einstein was able to meet this challenge. His relativity theory was able to account for the phenomena that falsified Newton's theory, while at the same time being able to match Newton's theory in those areas where the latter had

proved successful. In addition, Einstein's theory yielded the prediction of spectacular new phenomena. His special theory of relativity predicted that mass should be a function of velocity and that mass and energy could be transformed into one another, and his general theory predicted that light rays should be bent by strong gravitational fields. Attempts to refute Einstein's theory by reference to the new phenomena failed. The falsification of Einstein's theory remains a challenge for modern physicists. Their success, if it should eventuate, would mark a new step forward in the progress of physics.

So runs a typical falsification account of the progress of physics. Later we shall have cause to doubt its accuracy and validity.

From the foregoing, it is clear that the concept of progress, of the growth of science, is a conception that is a central one in the falsificationist account of science. This issue is pursued in more detail in the next chapter.

Further reading

The classic falsificationist text is Popper in *The Logic of Scientific Discovery* (1972), first published in German in 1934 and translated into English in 1959. More recent collections of his writings are Popper (1969) and Popper (1979). Popper's own story about how he came to his basic idea through comparing Freud, Adler and Marx with Einstein is in chapter 1 of his 1969 text. More sources related to falsificationism will be given at the end of the next chapter.