Theory of Science: A Short Introduction

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fore we investigate the matter, whether the quantum event has occurred or not. But if so, reasons Schrödinger, then the cat, before we open the box and look, is also in a superposition: neither dead nor alive, but somehow both at the same time (or perhaps neither).

Further interpretations of quantum mechanics in addition to Bohr's and the instrumentalism sketched above have been offered over the years, and philosophical debate as to which is correct (if any) continue to this day (one of these sees all the different possible states of a photon as actually obtaining in different *possible worlds* or universes – the so-called *many worlds* interpretation of quantum mechanics). But even the brief survey offered here shows how quantum mechanics, perhaps to an even greater extent than the theory of relativity, involves a radical break with traditional scientific precepts and basic common sense assumptions concerning, not just the nature of reality, but about the relationship between mind and reality, and perhaps even logic. It also serves to underline the fundamentally empirical nature of modern science, which is concerned to develop, first and foremost, just ever more adequate mathematical models for the prediction of empirical phenomena.

3. Logical positivism

The movement known as logical positivism is associated primarily with a group of German-speaking Jewish scientists, mathematicians and philosophers who met regularly in Vienna in the period of fragile peace between the two great wars of the twentieth century. With names such as Moritz Schlick, Otto Neurath, Hans Reichenbach, Carl Hempel and Rudolf Carnap (perhaps the most influential), the group came to be known as the 'Vienna Circle', though they also held several meetings and conferences in other European cities, such as Berlin, Paris and Prague. The name of the movement builds on the observation-based view of science of the nineteenth century (the term 'positivism' was coined by French sociologist Auguste Comte), but it was especially influenced by the developments in the natural sciences we have just charted, including those in logic that allowed for a greater formalisation of mathematics (hence the label *logical* positivism). It was also their aim to combat spurious ideology, notably the kind of race ideology promulgated by Hitler and the Nazis. When the persecution of Jews intensified, most of its members sought refugee status in the West, primarily USA; the movement diversified, but the broad orientation persisted under the heading of *logical empiricism*. In the English-speaking world, this approach still indelibly influences many areas of philosophical enquiry. One of the ablest spokesmen for logical positivism was the Oxford philosopher Freddy Ayer, who wrote a book called *Language, Truth and Logic* (first published in 1936) which laid out and defended the movement's basic precepts.

According to logical positivism, science and rational belief are coextensive: what is not rational is not science, and – much more controversially – what is not science is not rational. This gives expression to a doctrine that has come to be known as the *unity of science*: science, that is, all rational beliefs, can be incorporated into one overarching system. Typically, physics and chemistry are seen as providing the basis of this system with other, special sciences, such as biology, psychology and economics as somehow building on these. The whole edifice is viewed as a logically articulated language whose sentences are given meaning and rationale by being brought into connection with observable reality. One of the trademarks of logical positivism is the rejection of what its proponents called 'metaphysics', which for them was a catch-all phrase for any theory that cannot be grounded in experience.

At the heart of logical positivism is a fundamental precept known as *the principle of verification*. This says that all meaningful claims – all claims that genuinely say something we can evaluate as true or false – must be such that we can specify the steps for determining their truth or falsity, i.e. be *verifiable*. This signals an important shift in thinking about science that can be related to the rise of relativity theory and quantum mechanics. In charting the inadequacies of Newtonian and classical physics, scientists were led to place greater emphasis on the mathematical and empirical nature of scientific method. The important question in distinguishing between a scientific claim and a non-scientific one becomes, not *Is the claim true?*, but *Can you decide whether the claim is true or not (and how)?* To be a meaningful, scientific claim one must be able to specify for that claim how one would decide or determine its truth – specify exactly what one's claim commits one to in concrete empirical and/or mathematical terms. It is not difficult to find here echoes of Einstein's stress on the measurability of physical magnitudes as the criterion for saying what they in fact are.

The principle of verification induces, in turn, a division of all meaningful claims into two fundamental categories, which the positivists (as we shall henceforth call them) termed the *analytic* and the *synthetic*. These labels are due to Kant, but the positivists were in many ways endorsing Hume's earlier distinction between knowledge concerning matters of fact, and knowledge concerning relations between ideas insofar as they saw all synthetic claims as *a posteriori* (i.e. justified empirically, by reference to sense experience) and all analytic ones as *a priori* (justified independently of sense experience). There is thus no category of the synthetic *a priori*, as for Kant. A synthetic claim is one that can be verified in relation to observation, whilst an analytical one is to be verified through the meanings of the terms and their logical interrelations.

Here are some synthetic ((1)-(4)) and analytic ((5)-(6)) claims (as classified by the positivists):

(1) This tomato is red
(2) There is acid in the test-tube
(3) All ravens are black
(4) $E = mc^2$
(5) All bachelors are unmarried
(6) $2 + 2 = 4$

(1) is meant to be *directly* and *conclusively* verifiable; it is what the positivists called an *observation statement*. You just 'read off' your sensory experience in verifying it. *Theoretical statements* by contrast are *indirectly* and/or *inconclusively* verifiable, by reference to several observation statements. This process often requires *conceptual analysis* to determine the theoretical statement's underlying logical structure. For example, statement (2) might be analysed as (2)':

(2)' If the liquid in the test-tube is poured on litmus paper, it will turn red

Both the component sentences of (2)' are observation statements, hence one can empirically verify (2)'. (3) is meant to be directly verifiable by observations of individual black ravens. However, it seems we could never *conclusively* verify such a universal statement, since that would require observing all ravens that ever have lived or will live. Similar considerations apply to a scientific law such as (4), except that this would be also viewed as indirectly verifiable (since its concepts are non-observational). (Below we shall consider some problems surrounding the ideas of indirect and inconclusive verifiability.)

(5) is analytic because, given the definition of the word bachelor, it just follows, logically, that anyone who is a bachelor is unmarried (to deny it would be implicitly self-contradictory). We thus don't need to verify it empirically, indeed, it would be absurd to do so. (6) is also meant to be analytic, along with the rest of mathematics. (In view of Gödel's proof referred to in section 1, this last commitment turned out to be something of a stumbling block for logical positivism, though we won't pursue this issue here.)

The most direct consequence of this exhaustive division of meaningful sentences into the analytic and synthetic is that anything that is not in the one or the other category is rendered meaningless – in the sense of not saying anything that could be true or false. This view echoes Hume's admonition against rationalistic metaphysics as empty word play; in a more positive vein, it enunciates a philosophical need to see different kinds of discourse as having different kinds of function (an idea that can also be traced to Hume's thinking on ethics and aesthetics). The impossibility of traditional metaphysics was certainly seen as a welcome consequence of the principle of verification, insofar as the positivists were deeply suspicious of purely philosophical speculation – associated with thinkers like Hegel, Schopenhauer and, to an extent, Kant – that had no anchorage in what could be empirically ascertained. As the positivists saw things, such talk was not merely empty, but pernicious. In failing to be factual, it had to appeal tacitly to emotions for support, but it nevertheless posed as factual and hence could be used to back up spurious ideologies. Religious language was likewise fit for the chop, but, understandably, the positivists wanted to take a less dismissive attitude towards ethical statements, such as 'What Hitler did was wrong'. The general form of the positivist solution to this was to regard ethical statements, not as purporting to describe anything (not even inner feelings), but as *giving expression* to feelings, or as implicitly *laying down prescriptions* for or against certain kinds of behaviour (two philosophical theories known respectively as *emotivism* and *prescriptivism*).

With the years, logical positivism evolved along many different routes, through distinct but related programmes of study concerning different aspects of scientific method and the analysis of different kinds of discourse; in the process, the strict tenets of the principle of verification were often substantially modified. To recount in any detail the fate of the movement would be a major work of philosophical histiography, so instead we shall conclude by briefly considering three problems with the core ideas of logical positivism, which will also serve as background to the discussions in the rest of the book.

The first problem concerns the *status* of the principle of verification. According to this, all meaningful statements must be verifiable, either as analytic or synthetic claims. But the question then arises as to the verifiability of the principle itself. It seems clearly not to be an empirical, i.e. synthetic statement; nor would it appear be an analytic one, following from the definitions of the terms involved – at least, the positivists presumably did not intend it have such a trivial status. Thus, by its own standard it would appear meaningless, to make no claim assessable as true or false – but if so, how can we take it seriously? In many ways, this is just an example of a general problem for philosophical theories that claim to do without philosophy (Hume's is another such example), but it is worth mentioning because of logical positivism's staunch rejection of philosophy as a substantive mode of knowledge acquisition (for them the activity of professional philosophers should be restricted to conceptual analysis).

The second problem we shall consider concerns the *interpretation* of the principle of verification. It seems that science abounds with claims, such as universal laws and about unobservable entities (electrons, black holes and so on) that cannot, at least at all obviously, be reduced in their entirety to claims about observable states of affairs. For example, it seems that we could never get conclusive verification for the claim that all ravens are black.

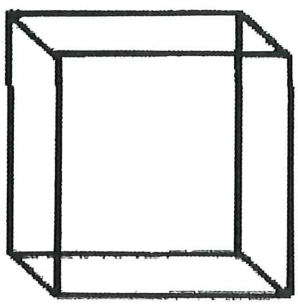
This leads to a dilemma for logical positivism. On the one hand, one could decide to understand verification weakly, demanding only that a statement, to be meaningful, must be such that it can be checked empirically, i.e. that it have one or more consequences for what we can observe (so-called *empirical consequences*). On the other hand, one could understand verification strongly, demanding that all meaningful statements be exhaustively accountable for in observational terms. Consider the first option. It seems clear we can verify, albeit non-conclusively, whether or not all ravens are black by looking at the next black raven. The problem for this is that it seems that many claims the positivists would not want to regard as meaningful or scientific also have such empirical consequences – such as 'God exists'. If God exists, then surely we would expect the natural world to exhibit a large degree of harmony and give a general impression of design – which is also a consequence we can ratify by experience.

To this a positivist might reply that 'God exists' only entails statements about a harmonious world in conjunction with other statements about, say, God's beneficence. But it seems this feature is also shared by typical scientific statements, such as that metals are surrounded by clouds of electrons. This has as an empirical consequence that metals will conduct electricity – but only if one also assumes many other things about the nature of these clouds, about the properties of electrons, and so on.

Let us now consider the possibility that verification be understood in a strong sense, such that all genuine statements must be exhaustively reducible to observation statements. This would certainly seem to rule out religion and metaphysics, but conversely the problem is that it also threatens much of science. To begin with, it seems that universal statements, like (3) and (4) above, in principle cannot be so reduced. Some positivists sought to overcome this problem by regarding such statements, not as assessable as absolutely true or absolutely false, but only as more or less likely in relation to the observational evidence, developing a logic of probability to handle this relation (this is connected to the issue of inductive method in science, which we shall discuss in Chapter 2). A further problem concerns how one should go about reducing statements about unobservables – electrons, say – to those concerning just observational states of affairs. As we have seen, statements abut unobservables tend only to have empirical consequences together with other theoretical statements, which in turn will only entail empirical consequences with other theoretical statements, and so on and so forth. Scientific hypotheses tend to come in bundles that preclude specifying for each exactly what their empirical consequences are. (This point was made famous by the American philosopher W.V.O. Quine.[1] Again, we will discuss it further in Chapter 2.) The only option here, consistent with positivism, would seem to be reject much of what actually passes for science as literally meaningful – as saying things apt for adjudication as true or false. This was a move some positivists were prepared to take, tending towards an instrumentalistic understanding of scientific theories, with the latter being evaluated with respect to criteria such as elegance and simplicity and their ability to make correct predictions, but not their truth content. However intuitively unsatisfactory, instrumentalism is a view that, as we have seen, is not without support from actual developments in physics.

The final problem for positivism we shall consider is the nature of observation itself. It is a legacy of modern empiricist philosophy (from Locke onwards) to see what is given in sense perception as somehow unproblematic from a philosophical point of view. What we can legitimately seek to ground beyond observation is a moot question, but at least we can build on an independent ground of observable states of affairs (given we are in favourable conditions – the light good, our brains uninfluenced by drugs and so on). However, it is now widely accepted that this theory-neutral view of observation is untenable. Observation and observation statements are theory-dependent, or 'theory-laden' as it is often put.

This theory-ladenness takes several different forms. One stems from that fact that what we perceive does not just depend on the physical stimuli that reach our sensory surfaces (e.g. the pattern of light that reaches the retina of the eye; we shall concentrate on visual perception). This is illustrated by so-called ambiguous figures made famous by Gestalt psychologists, such as the following:

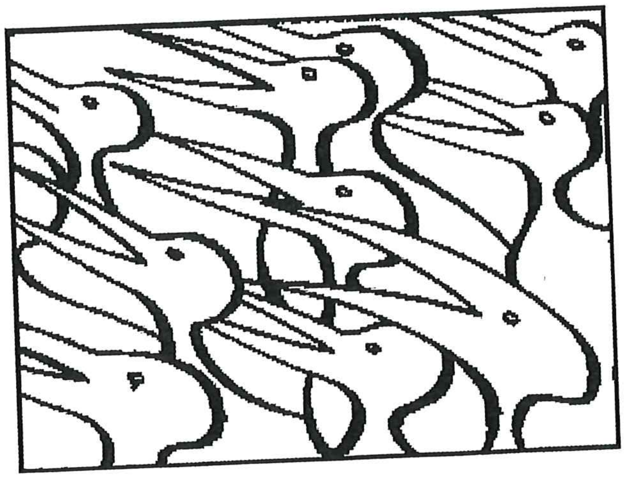


The Necker Cube (facing upwards or downwards?)

1. In his famous article from 1953 'Two dogmas of empiricism'.

Bird or antelope?

The point of such ambiguous figures is not merely that we can see them in two different ways, depending on how we shift our visual attention. For the question of the theory-ladenness of observation, the point is that they suggest that much of what we take ourselves to be given of the world through perception is in fact a *joint* product of what is out there *together* with our prior experiences and expectations. This point was first clearly made by the philosopher Norwood Hanson, from whose work the bird-antelope figure is taken.[2] To make this point, he presents it again in the following two drawings:



2. The book *Patterns of Discovery*, from 1965.

We are strongly inclined to see the figure as an antelope in the first and a bird in the second, whilst in isolation it is ambiguous. If such principles operate in perception generally, then what a scientist sees could be heavily influenced by his background experience and knowledge and/or by what he expects to see.

There is a deal of controversy, both in philosophy and empirical psychology, about the extent to which these kinds of examples really do undermine the objectivity of perception. Most of the examples concern line drawings, not 3-D objects, raising the question of whether perceptual ambiguity is nearly so wide-spread in reality as in the psychologist's laboratory. One thing seems sure, and that is that the world at least provides very strong *constraints* on what we see. You cannot, to put it bluntly, see an antelope as a telephone! Another point of controversy is whether *theoretical beliefs* impact on visual perception, as opposed to *experience*, shaping what we see at an unconscious level. On the other hand, there are real-life examples of both prior experience and theoretical knowledge apparently affecting what is seen. A famous example is due to Michael Polanyi (a doctor and chemist who later in life wrote extensively on the philosophy of science), in which a radiologist asks a student to tell him what an X-ray picture of a pair of lungs tells him about the patient's condition. The poor student sees only random blotches and lines, whilst the radiologist sees – literally, *sees* – clear symptoms of a pathology. Polanyi's ideas have been further developed by Thomas Kuhn in his theory of scientific paradigms, which we shall examine in Chapter 3.

So what we see, it would appear, is not wholly independent of what we have experienced in the past, and perhaps not of our knowledge either. It was however a further aspect of the theory-ladenness of observation that most taxed positivist thinkers directly. This springs from that fact that to have any impact on theoretical statements, observations must themselves be articulated as observational *statements*. I see – have an experience of – a red tomato. But if I am going to draw any conclusions about hypotheses concerning whether all or many tomatoes are red, I need to ascertain *that* there is a red tomato here, *that* this tomato is a red, or some such. The problem about this arises from the fact that in so doing I am using *concepts* – concepts, moreover, which it seems are not wholly derivable from sense experience. To see this, consider a young child eating her dinner one day, and being encouraged to eat a tomato. She says 'This tomato tastes disgusting', something which would presumably count as an observation statement. Later the same day, she is given a red plum, which she enjoys, and pronounces: 'This tomato tastes nice!' Clearly, we could not accept the latter as part of our evidence for anything, even though the child has made no perceptual mistake. What she lacks is full competence with the concept 'tomato'. And what such competence involves is knowledge, not just of what tomatoes look like, but of what kind of thing they are (and that they *are* a kind of thing). Thus, in saying things about one's experiences of tomatoes, one is implicitly bringing to bear conceptual knowledge that is not given in the perception of them, and which may be mistaken. And if this applies in such mundane contexts as talk of fruit and vegetables, it seems it will apply with at least as great a force in scientific ones, from the zoologist investigating fauna to the particle physicist observing interference patterns.

The reaction of many positivists to this point was essentially to concede it, but insist that it was thus necessary to adopt *conventions* for the reporting of observations – simply to *decide* what predicates could be used for describing what is seen, thereby providing a reductive basis for theoretical claims. For example, one could decide to take talk of ordinary middle-sized objects as one's observational language, or perhaps the readings of measuring instruments. This again tends to push positivism towards an instrumentalistic position in which scientific theories are evaluated, not by reference to whether they reflect an external reality, but the extent to which they can be used to frame elegant theories and make correct and interesting predictions.

At the same time, attempts were made to develop a purely observational or 'phenomenalist' language, free from any theoretical assumptions about the world, and which might thus provide an absolute bedrock for scientific theorising. Notably Carnap attempted to specify such a language;[3] ingenious though the attempt was, however, it is widely agreed today to be a failure. Though we do not describe the world's underlying structure in reporting on how it appears to us, it seems we do inevitably bring with us implicit assumptions about this structure that can render what we claim to see false. This has no better illustration than the famous bone of contention from the time of the scientific revolution: *Does the earth move?* For most people then, it was plain to *see* that the answer was no. Nevertheless, when the theories of Galileo and others began to have an impact, people understood that what was meant by 'move' was not so clear as to make an affirmative answer absurd; and today we all take it to be obviously correct.

These examples illustrate yet another aspect of the theory-ladennes of observation, which in the final analysis is perhaps the most fundamental. What we naturally tend to see, even under ideal conditions, is not guaranteed to be a full or correct representation of reality. Hence, which of our observations we can trust and which we should reject becomes a question to which ultimately only science itself can give an answer. This precept is implicit in the practice of modern science, with its widespread use of telescopes, microscopes and diverse kinds of measuring equipment to enhance and, to an extent, correct for our natural propensities. Nor is it something of recent date. When Galileo urged the use of telescopic data, he was doing so because he believed the capacities of the naked eye were inadequate to the task of accurately registering information about heavenly bodies, a belief which he sought to validate experimentally and has since been vindicated. Certainly, the idea was wildly at odds with the prevailing Aristotelian epistemological theory of Galileo's time, according to which human beings are naturally designed simply to 'absorb' the truth of the natural world by opening their eyes and looking attentively around them, but this epistemological theory fell with the teleological metaphysics it presupposed. This is not to say that human observation does not continue to play a central role in modern science, nor that we are not by and large reliable in our perceptual capacities – presumably, at some level, we must be, otherwise our ancestors would never have survived to produce us. The details, however, as to how and to what extent we are reliable are scientific ones. Thus observation and theory go hand in hand; both are necessary in science, but neither can be seen as wholly fundamental with respect to the other.

In conclusion, though logical positivism *per se* is not – at least in part for the reasons we have reviewed – a position many espouse today, it has played a vital role in the subsequent development of philosophy, both in general but especially in relation to the nature of scientific knowledge and rationality. It also continues to exert a strong influence

3. In *Der Logische Aufbau der Welt* from 1928 (English title: *The Logical Structure of the World*.)

on the ways these things are investigated, as witnessed by the continued search for inductive principles of scientific inference, and defences of the objective anchoring of science in observable reality (an idea which survives the above critique of theory-neutral observation). Perhaps its most abiding, but also controversial impact has been the idea of the unity of science that we began with, according to which all rational belief is susceptible to systematization in one overall body of knowledge. We shall investigate this idea explicitly in chapter 5 when considering explanation in human and natural science.

Conclusion

This main aim of this chapter has been to present certain central developments in the natural sciences and in philosophy of science that occurred early in the twentieth century; together with a basic knowledge of earlier thinkers and events, this provides the necessary background for understanding the debates and discussions we shall be presenting in this book. Of central ideas, we should mention again the replacement of Newtonian mechanics and classical physics with the very different ideas contained in the theory of relativity and quantum mechanics, with their greater emphasis on empirical adequacy, something that also can be understood in relation to the formalistic developments in mathematics. These ideas are centrally reflected in the logical positivists' distinction of all meaningful statements into the synthetic and analytic. However, the most plausible form of logical positivism appears to be one that moves in an instrumentalistic direction. It thus remains to see whether we can give an account of science that, consonant with its more recent developments, regards its theories as telling us something about the hidden nature of the universe.

References and Bibliography

On relativity theory and quantum mechanics:

Bullock, A. & Stallybrass, O., eds., *The Fontana Dictionary of Modern Thought*, London: Fontana 1977.

Dammann, E. *Bak tid og rom* [Behind Time and Space], Oslo: Deyer 1987.

Dybvig, D. & Dybvig, M. *Det tenkende menneske* [The Thinking Man], 2nd edition, Trondheim: Tapir 2003: ch. 16.

Russell, B. *The ABC of Relativity*, 3rd edition, New York: Allen & Unwin 1958.

Applet Thumbnails from The Atomic Lab: http://www.colorado.edu/physics/2000/index.pl

Double-slit experiment: http://en.wikipedia.org/wiki/Double-slit_experiment

Young's Double Slit: http://www.ux1.eiu.edu/~cfadd/1160/Ch25WO/Young.html

Special Relativity explained by thought experiments: http://aether.lbl.gov/www/classes/p139/exp/gedanken.html

On logical positivism:

Ayer, A. *Language, Truth and Logic*, 2nd edition, Harmondsworth: Penguin 1975.

Carnap, R. *The Logical Structure of the World and Pseudoproblems in Philosophy*, Illinois: Open Court 2003.

Chalmers, A. *What is this thing called science?* 1st edition, Milton Keynes: Open University Press 1978: ch. 1.

Knowles, J. *Vitenskap, rajonalitet og common sense* [Science, Rationality and Common Sense], Oslo: Cappelen 2000: ch. 4.3.

Quine, W. 'Two dogmas of empiricism' in his *From a Logical Point of View*, Cambridge, Mass.: Harvard University Press 1953.

Hanson, N. *Patterns of Discovery*, Cambridge: Cambridge University Press 1965.

Schlipp, P. ed., *The Philosophy of Rudolf Carnap*. Illinois: Open Court 1963.

Shand, J. *Philosophy and Philosophers: An Introduction to Western Philosophy*, Buckinghamshire: Acumen 2002: ch. 10.