By the same author

Atomic Reactions (1933)
U.S.S.R. Economics (1936)
The Contempt of Freedom (1940)
Full Employment and Free Trade (1945)
Science, Faith and Society (1946)
The Logic of Liberty (1951)

PERSONAL KNOWLEDGE

Towards a Post-Critical Philosophy

by

MICHAEL POLANYI

1958

LONDON
ROUTLEDGE & KEGAN PAUL

—in fact all natural motion as such—must be circular. Rectilinear motion implies change of place, and this can occur only from disorder to order: that is, either in the transition from primeval chaos to the right disposition of the parts of the world, or in violent motion, i.e. in the endeavour of a body artificially moved to return to its 'natural' place. Once world order is established, all bodies are 'naturally' at rest or in circular motion. Galileo's observations of inertial motion along a plane terrestrial surface were interpreted by him as circular motions around the centre of the earth.

Thus the first century after the death of Copernicus was inspired by Pythagorean intimations. Their last great manifestation was perhaps Descartes's universal mathematics: his hope of establishing scientific theories by the apprehension of clear and distinct ideas, which as such were necessarily true.

But a different line of approach was already advancing gradually, stemming from the other line of Greek thought which lacked the mysticism of Pythagoras, and which recorded observations of all kinds of things, however imperfect. This school, derived from the Ionian philosophers, culminated in Democritus, a contemporary of Socrates, who first taught men to think in materialistic terms. He laid down the principle: 'By convention coloured, by convention sweet, by convention bitter; in reality only atoms and the void.' [1] With this Galileo himself agreed; the mechanical properties of things alone were primary (to borrow Locke's terminology), their other properties were derivative, or secondary. Eventually it was to appear that the primary qualities of such a universe could be brought under intellectual control by applying Newtonian mechanics to the motions of matter, while its secondary qualities could be derived from this underlying primary reality. Thus emerged the mechanistic conception of the world which prevailed virtually unchanged till the end of the last century. This too was a theoretical and objective view, in the sense of replacing the evidence of our senses by a formal space-time map that predicted the motions of the material particles which were supposed to underlie all external experience. In this sense the mechanistic world-view was fully objective. Yet there is a definite change from the Pythagorean to the Ionian conception of theoretical knowledge. Numbers and geometrical forms are no longer assumed to be inherent as such in Nature. Theory no longer reveals perfection; it no longer contemplates the harmonies of Creation. In Newtonian mechanics the formulae governing the mechanical substratum of the universe were differential equations, containing no numerical rules and exhibiting no geometrical symmetry. Henceforth 'pure' mathematics, formerly the key to nature's mysteries, became strictly separated from the *application* of mathematics to the formulation of empirical laws. Geometry became the science of empty space; and analysis, affiliated since

[1] H. Diels, *Die Fragmente der Vorsokratiker* (6th edn.), Berlin (1952), **2**, p. 97 (Democritus A 49).

Descartes to geometry, seceded with it into the region beyond experience. Mathematics represented all rational thinking which appeared necessarily true; while reality was summed up in the events of the world which were seen as contingent—that is, merely such as happened to be the case.

The separation of reason and experience was pressed further by the discovery of non-Euclidean geometry. Mathematics was thereafter denied the capacity of stating anything beyond sets of tautologies formulated within a conventional framework of notations. Physical theories were correspondingly also subjected to a further reduction of status. Towards the end of the nineteenth century a new positivist philosophy arose, denying to the scientific theories of physics any claim to inherent rationality, a claim which it condemned as metaphysical and mystical. The earliest, most energetic and influential development of this idea was due to Ernst Mach, who by his book, *Die Mechanik*, published in 1883, founded the Vienna school of positivism. Scientific theory, according to Mach, is merely a convenient summary of experience. Its purpose is to save time and trouble in recording observations. It is the most economical adaptation of thought to facts, and just as external to the facts as a map, a timetable, or a telephone directory; indeed, this conception of scientific theory would include a timetable or a telephone directory among scientific theories.

Accordingly, scientific theory is denied all persuasive power that is intrinsic to itself, as theory. It must not go beyond experience by affirming anything that cannot be tested by experience; and above all, scientists must be prepared immediately to drop a theory the moment an observation turns up which conflicts with it. In so far as a theory cannot be tested by experience—or appears not capable of being so tested—it ought to be revised so that its predictions are restricted to observable magnitudes.

This view, which can be traced back to Locke and Hume, and which in its massive modern absurdity has almost entirely dominated twentieth-century thinking on science, seems to be the inevitable consequence of separating, in principle, mathematical knowledge from empirical knowledge. I shall now proceed to the story of relativity, which is supposed to have brilliantly confirmed this view of science, and shall show why in my opinion it has supplied on the contrary some striking evidence for its refutation.

3. Relativity

The story of relativity is a complicated one, owing to the currency of a number of historical fictions. The chief of these can be found in every textbook of physics. It tells you that relativity was conceived by Einstein in 1905 in order to account for the negative result of the Michelson-Morley experiment, carried out in Cleveland eighteen years earlier, in 1887. Michelson and Morley are alleged to have found that the speed of light measured by a terrestrial observer was the same in whatever direction the signal was sent out. That was surprising, for one would have expected that the observer would catch up to some extent with signals sent out in the direction in which the earth was moving, so that the speed would appear slower in this direction, while the observer would move away from the signal sent out in the opposite direction, so that the speed would then appear faster. The situation is easily understood if we imagine the extreme case that we are moving in the direction of the signal exactly at the speed of light. Light would appear to remain in a fixed position, its speed being zero, while of course at the same time a signal sent out in the opposite direction would move away from us at twice the speed of light.

The experiment is supposed to have shown no trace of such an effect due to terrestrial motion, and so—the textbook story goes on—Einstein undertook to account for this by a new conception of space and time, according to which we could expect invariably to observe the same value for the speed of light, whether we are at rest or in motion. So Newtonian space, which is 'necessarily at rest without reference to any external object', and the corresponding distinction between bodies in absolute motion and bodies at absolute rest, were abandoned and a framework set up in which only the relative motion of bodies could be expressed.

But the historical facts are different. Einstein had speculated already as a schoolboy, at the age of sixteen, on the curious consequences that would occur if an observer pursued and kept pace with a light signal sent out by him. His autobiography reveals that he discovered relativity

> after ten years' reflection . . . from a paradox upon which I had already hit at the age of sixteen: If I pursue a beam of light with the velocity *c* (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations. From the very beginning it appeared to me intuitively clear that, judged from the standpoint of such an observer, everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest.[1]

There is no mention here of the Michelson-Morley experiment. Its findings were, on the basis of pure speculation, rationally intuited by Einstein before he had ever heard about it. To make sure of this, I addressed an enquiry to the late Professor Einstein, who confirmed the fact that 'the Michelson-Morley experiment had a negligible effect on the discovery of relativity'.[2]

[1] *Albert Einstein: Philosopher-Scientist*, Evanston, 1949, p. 53.

[2] This statement was approved for publication by Einstein early in 1954. Dr. N. Balazs, who was working with Einstein in Princeton in Summer 1953, introduced my questions to him and reported his replies. The result of his first interview with Einstein was described by Mr. Balazs in a letter of July 8th, 1953, as follows:

'Today I discussed with Einstein the basic ideas which have led to the foundation of the special theory of relativity.

The result is about the following:

There were basically two problems whose contemplation was of fundamental im-

Actually, Einstein's original paper announcing the Special Theory of Relativity (1905) gave little grounds for the current misconception concerning the origins of his discovery. It opens with a long paragraph referring to the anomalies in the electrodynamics of moving media, mentioning in particular the lack of symmetry in its treatment, on the one hand, of a wire with current flowing through it moving relative to a magnet at rest, and on the other of a magnet moving relative to the same electric current at rest. It then goes on to say that 'similar examples, as well as the unsuccessful attempts to observe the relative motion of the earth in respect to the medium of light lead to the conjecture that, as in mechanics, so also in electrodynamics, absolute rest is not observable. . . .' [1] The usual textbook account of relativity as a theoretical response to the Michelson-Morley experiment is an invention. It is the product of a philosophical prejudice. When Einstein discovered rationality in nature, unaided by any observation that had not been available for at least fifty years before, our positivistic textbooks promptly covered up the scandal by an appropriately embellished account of his discovery.

There is an aspect of this story that is even more curious. For the programme which Einstein carried out was largely prefigured by he very positivist conception of science which his own achievement so flagrantly refuted. It was formulated explicitly by Ernst Mach, who, as we have seen, had first advanced the conception of science as a timetable or telephone directory. He had extensively criticized Newton's definition of space and absolute rest on the grounds that it said nothing that could be tested by experience. He condemned this as dogmatic, since it went beyond experience, and as *meaningless*, since it pointed to nothing that could conceivably be tested by experience.[2] Mach urged that Newtonian dynamics should be reformulated so as to avoid referring to any movement of bodies except as the relative motion of bodies with respect to each other, and Einstein acknowledged the 'profound influence' which Mach's book exercised on him as a boy and subsequently on his discovery of relativity.[3]

portance. (1) The problem he is referring to in his autobiographical sketch about the impressions of an observer moving with the velocity of light and viewing a lightwave; (2) the lack of symmetry of action between phi current elements and phi magnets. (In the pre-relativistic electrodynamics of moving media it made a lot of difference whether you move a wire with a current relative to a magnet, or the magnet relative to the wire.) (1) suggested to him that the velocity of light must play a privileged role; (2) seemed strange since, among other reasons, he felt that the situation is to be determined by the relative velocities which are the same. I hope I do not misrepresent him.

The Michelson-Morley experiment had no role in the foundation of the theory. He got acquainted with it while reading Lorentz's paper about the theory of this experiment (he of course does not remember exactly when, though prior to his papers), but it had no further influence on Einstein's considerations and the theory of relativity was not founded to explain its outcome at all.'

[1] Albert Einstein, 'Zur Elektrodynamik bewegter Körper'; *Annalen der Physik* (4), 17 (1905), p. 891.

[2] E. Mach, *Die Mechanik in ihrer Entwicklung*, 2nd edn., Leipzig (1889), pp. 213–14.

[3] *Albert Einstein: Philosopher-Scientist*, p. 21.

Yet if Mach had been right in saying that Newton's conception of space as absolute rest was meaningless—because it said nothing that could be proven true or false—then Einstein's rejection of Newtonian space could have made no difference to what we hold to be true or false. It could not have led to the discovery of any new facts. Actually, Mach was quite wrong: he forgot about the propagation of light and did not realize that in this connection Newton's conception of space was far from untestable. Einstein, who realized this, showed that the Newtonian conception of space was not *meaningless* but *false*.

Mach's great merit lay in possessing an intimation of a mechanical universe in which Newton's assumption of a single point at absolute rest was eliminated. His was a super-Copernican vision, totally at variance with our habitual experience. For every object we perceive is set off by us instinctively against a background which is taken to be at rest. To set aside this urge of our senses, which Newton had embodied in his axiom of an 'absolute space' said to be 'inscrutable and immovable', was a tremendous step towards a theory grounded in reason and transcending the senses. Its power lay precisely in that appeal to rationality which Mach wished to eliminate from the foundations of science. No wonder therefore that he advanced it on false grounds, attacking Newton for making an empty statement and overlooking the fact that—far from being empty—the statement was false. Thus Mach prefigured the great theoretic vision of Einstein, sensing its inherent rationality, even while trying to exorcise the very capacity of the human mind by which he gained this insight.

But there yet remains an almost ludicrous part of the story to be told. The Michelson-Morley experiment of 1887, which Einstein mentions in support of his theory and which the textbooks have since falsely enshrined as the crucial evidence which compelled him to formulate it, actually did not give the result required by relativity! It admittedly substantiated its authors' claim that the relative motion of the earth and the 'ether' did not exceed a quarter of the earth's orbital velocity. But the actually observed effect was not negligible; or has, at any rate, not been proved negligible up to this day. The presence of a positive effect in the observations of Michelson and Morley was pointed out first by W. M. Hicks in 1902[1] and was later evaluated by D. C. Miller as corresponding to an 'ether-drift' of eight to nine kilometres per second. Moreover, an effect of the same magnitude was reproduced by D. C. Miller and his collaborators in a long series of experiments extending from 1902 to 1926, in which they repeated the Michelson-Morley experiment with new, more accurate apparatus, many thousands of times.

The layman, taught to revere scientists for their absolute respect for the observed facts, and for the judiciously detached and purely provisional manner in which they hold scientific theories (always ready to abandon a theory at the sight of any contradictory evidence), might well have

[1] W. M. Hicks, *Phil. Mag.*, 6th ser., 3 (1902), pp. 9–42.

thought that, at Miller's announcement of this overwhelming evidence of a 'positive effect' in his presidential address to the American Physical Society on December 29th, 1925, his audience would have instantly abandoned the theory of relativity. Or, at the very least, that scientists—wont to look down from the pinnacle of their intellectual humility upon the rest of dogmatic mankind—might suspend judgment in this matter until Miller's results could be accounted for without impairing the theory of relativity. But no: by that time they had so well closed their minds to any suggestion which threatened the new rationality achieved by Einstein's world-picture, that it was almost impossible for them to think again in different terms. Little attention was paid to the experiments, the evidence being set aside in the hope that it would one day turn out to be wrong.[1]

The experience of D. C. Miller demonstrates quite plainly the hollowness of the assertion that science is simply based on experiments which anybody can repeat at will. It shows that any critical verification of a scientific statement requires the same powers for recognizing rationality in nature as does the process of scientific discovery, even though it exercises these at a lower level. When philosophers analyse the verification of scientific laws, they invariably choose as specimens such laws as are not in doubt, and thus inevitably overlook the intervention of these powers. They are describing the practical demonstration of scientific law, and not its critical verification. As a result we are given an account of the scientific method which, having left out the process of discovery on the grounds that

[1] In his Presidential Address to Section A of the British Association, Cambridge, 1938, C. G. Darwin says of D. C. Miller's experiments: 'We cannot see any reason to think that this work would be inferior to Michelson's, as he had at his disposal not only all the experience of Michelson's work, but also the very great technical development of the intervening period, but in fact he failed to verify the exact vanishing of the aether drift. What happened? Nobody doubted relativity. There must therefore be some unknown source of error which had upset Miller's work.'—I can confirm from my own experience that this was the attitude of contemporary physicists all during that period. Only Soviet physicists, who objected to relativity for ideological reasons, felt that Miller's experiments casted a doubt on the theory. I owe this information to Mme. T. Ehrenfest, who was a professor of physics in Soviet Russia at the time.

The true position was explicitly stated by J. L. Synge, *Scientific Proc. Royal Dublin Society*, **26**, N.S. (1952), pp. 45–54. The special theory is accepted on other grounds than the experiments of Michelson and Morley. Among these are the observations by G. Joos, *Ann. d. Physik*, **7** (1930), p. 385; R. J. Kennedy, *Proc. Nat. Acad. Science*, **12** (1926), p. 621; K. K. Illingworth, *Phys. Rev.*, **30** (1927), p. 692; Michelson, Pease and Pearson, *J. Opt. Soc. Amer.*, **18** (1929), 181, which have shown the absence of ether-drift by other methods than the Michelson interferometer. Hence Synge rejects the explanation given by D. C. Miller for his experiments and accepts 'the theorist's description' of the Michelson-Morley experiment which 'is to be found in any book on relativity'.

Synge thinks that Miller's results are to be explained by the fact that the interferometer is not carried in a uniform straight motion, but in a circle, by the rotating earth. More recently, some of Miller's original data sheets have been analysed by R. S. Shankland, S. W. McCuskey, F. C. Leone and G. Kuerti in *Rev. Modern Phys.*, **27** (1955), p. 167, who conclude that the apparent ether drift was simulated by statistical fluctuations and temperature effects.

it follows no definite method,[1] overlooks the process of verification as well, by referring only to examples where no real verification takes place.

At the time that Miller announced his results, relativity had yet made few predictions that could be confirmed by experiment. Its empirical support lay mainly in a number of already known observations. The account which the new theory gave of these known phenomena was considered rational, since it derived them from one single convincingly rational principle. It was the same as when Newton's comprehensive account of Kepler's Three Laws, of the moon's period and of terrestrial gravitation—in terms of a general theory of universal gravitation—was immediately given a position of surpassing authority, even before any predictions had been deduced from it. It was this inherent rational excellence of relativity which moved Max Born, despite the strong empirical emphasis of his accounts of science, to salute as early as 1920 'the grandeur, the boldness, and the directness of the thought' of relativity, which made the world-picture of science 'more beautiful and grander'.[2]

Since then, the passing years have brought wide and precise confirmation of at least one formula of relativity; probably the only formula ever sent sprawling across the cover of *Time* magazine. The reduction of mass (m) by the loss of energy (e) accompanying nuclear transformation has been repeatedly shown to confirm the relation $e = mc^2$, where c is the velocity of light. But such verifications of relativity are but confirmations of the original judgment of Einstein and his followers, who committed themselves to the theory long before these verifications. And they are an even more remarkable justification of the earlier strivings of Ernst Mach for a more rational foundation of mechanics, setting out a programme for relativity at a time when no avenues could yet be seen towards this objective.

The beauty and power inherent in the rationality of contemporary physics is, as I have said, of a novel kind. When classical physics superseded the Pythagorean tradition, mathematical theory was reduced to a mere instrument for computing the mechanical motions which were supposed to underlie all natural phenomena. Geometry also stood outside nature, claiming to offer an *a priori* analysis of Euclidean space, which was regarded as the scene of all natural phenomena but not thought to be involved in them. Relativity, and subsequently quantum mechanics and modern physics generally, have moved back towards a mathematical conception of reality. Essential features of the theory of relativity were anticipated as

[1] Take the following two statements: 'The philosopher of science is not much interested in the thought processes which lead to discovery . . .' (H. Reichenbach in *Einstein: Philosopher-Scientist*, Evanston (1949), p. 289); or 'The gist of the scientific method is . . . verification and proof, not discovery' (H. Mehlberg in *Science and Freedom*, London (1955), p. 127). Actually, philosophers deal extensively with induction as a method of scientific discovery; but when they occasionally realize that this is not how discoveries are made, they dispose of the facts to which their theory fails to apply by relegating them to psychology.

[2] Max Born, *Einstein's Theory of Relativity*, translated by H. L. Brose, London (1924), p. 289.

mathematical problems by Riemann in his development of non-Euclidean geometry; while its further elaboration relied on the powers of the hitherto purely speculative tensor calculus, which by a fortunate accident Einstein got to know from a mathematician in Zürich. Similarly, Max Born happened to find the matrix calculus ready to hand for the development of Heisenberg's quantum mechanics, which could otherwise never have reached concrete conclusions. These examples could be multiplied. By them, modern physics has demonstrated the power of the human mind to discover and exhibit a rationality which governs nature, before ever approaching the field of experience in which previously discovered mathematical harmonies were to be revealed as empirical facts.

Thus relativity has restored, up to a point, the blend of geometry and physics which Pythagorean thought had first naïvely taken for granted. We now realize that Euclidean geometry, which until the advent of general relativity was taken to represent experience correctly, referred only to comparatively superficial aspects of physical reality. It gave an idealization of the metric relations of rigid bodies and elaborated these exhaustively, while ignoring entirely the masses of the bodies and the forces acting on them. The opportunity to expand geometry so as to include the laws of dynamics was offered by its generalization into many-dimensional and non-Euclidean space, and this was accomplished by work in pure mathematics, before any empirical investigation of these results could even be imagined. Minkowski took the first step in 1908 by presenting a geometry which expressed the special theory of relativity, and which included classical dynamics as a limiting case. The laws of physical dynamics now appeared as geometrical theorems of a four-dimensional non-Euclidean space. Subsequent investigation by Einstein led, by a further generalization of this type of geometry, to the general theory of relativity, its postulates being so chosen as to produce invariant expressions with regard to all frames of reference assumed to be physically equivalent. As a result of these postulates, the trajectories of masses follow geodetics, and light is propagated along zero lines. When the laws of physics thus appear as particular instances of geometrical theorems, we may infer that the confidence placed in physical theory owes much to its possessing the same kind of excellence from which pure geometry and pure mathematics in general derive their interest, and for the sake of which they are cultivated.

4. Objectivity and Modern Physics

We cannot truly account for our acceptance of such theories without endorsing our acknowledgement of a beauty that exhilarates and a profundity that entrances us. Yet the prevailing conception of science, based on the disjunction of subjectivity and objectivity, seeks—and must seek at all costs—to eliminate from science such passionate, personal, human appraisals of theories, or at least to minimize their function to that of a