A “free play with concepts”: Philosophy and epistemology in Albert Einstein's scientific thought

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> About ten years ago I spoke with Einstein about the astonishing fact that so many ministers of various denominations are strongly interested in the theory of relativity. Einstein said that according to his estimation there are more clergymen interested in relativity than physicists. A little puzzled I asked him how he would explain this strange fact. He answered, a little smiling, “Because clergymen are interested in the general laws of nature and physicists, very often, are not.
>
> Philipp Frank [Fra]

1 Introduction

Without offence to those scientists for whom philosophy of science is just “a pleasing gloss on the history and discoveries of science” [Wei, p. 167] – the phrase is due to Steven Weinberg, Nobel Prize laureate in Physics in 1979, as well as one of the fathers of the Standard Model of the physics of elementary particles – one of the great assets of Western culture is precisely the interaction between science and philosophy and the meaning of their relations. This was especially true for Einstein, for whom philosophy was a longstanding interest, since the times of the “Akademie Olympia”, the jocular name by which he and his friends Conrad Habicht and Maurice Solovine called their periodic meetings, between 1902 and 1904, devoted to passionate debates about topics in philosophy and science. But this is not just a biographical curiosity. In a more general theoretical point of view, we might represent the relationship between philosophy and epistemology on the one hand, and the whole of Einstein's scientific work on the other as a sort of “three-dimensional” model. In what follows, due to limits of space, we will touch on only a few points of this model:

- along the first axis there are the wide-ranging philosophical implications that Einstein's scientific results raised on notions such as space-time, symmetry, causality, determinism, probability, laws, scientific realism and so on;
- along the second axis we place the influence of philosophy on Einstein himself and some specific turning points of his research activity;
- the third axis includes the speculations developed by Einstein in a specifically philosophical and epistemological direction, which are directly significant for 20th-century philosophy of science.

Even without considering the (fortunate!) sociological circumstance by which the education of a good average scientist in the 19- and early 20-century Austro-German culture included a non-occasional exposure to the classics of philosophy, the importance attributed by Einstein to philosophy is certainly not, in itself, a recent finding, and Einstein himself never kept it secret. In some way his scientific work represents an admirable example of actual integration of science and philosophy, and in some key passages – as we shall see later – he actually seems to develop within his activity as a physicist an application, ahead of his time, of epistemological positions that would be developed explicitly only later. Moreover, 20th-century scientific culture itself had already officially recognised the "dual" soul of the German physicist, devoting to him a work now classical: the celebrated volume eloquently titled *Albert Einstein: Philosopher-Scientist*, published in 1949 and edited by P.A. Schilpp [Sch], which contains the physicist's "Autobiographical Notes" and a collection of essays about different aspects of Einstein's work by philosophers and scientists, with Einstein himself replying to them in the same volume, with results often of enormous interest.

It is in these replies that we find a passage often quoted in discussions about the philosophical repercussions of Einstein's work, one which, with regard to the scientist's attitude towards philosophy, evokes a form of "epistemological opportunism":

> [The scientist] accepts gratefully the epistemological conceptual analysis; but the external conditions, which are set for him by the facts of experience, do not permit him to let himself be too much restricted in the construction of his conceptual world by the adherence to an epistemological system. He therefore must appear to the systematic epistemologist as a type of unscrupulous opportunist [Ein49a, pp. 683–684].

It would be a serious mistake to deduce from statements such as this the notion that Einstein took a somewhat instrumental stand in analysing the philosophical suggestions raised by his work. In a strict analogy with the development of his properly scientific activity, Einstein's philosophical and epistemological framework is also inspired by a strong unity, which manifests in similar forms from his early works, at the beginning of the 20th century, to his attempts to construct unified field theories, which unsuccessfully occupied him in the last part of his career. Thus, in what follows we shall dwell upon some of the main traits that characterised Einstein's philosophical and epistemological thought: Ernst Mach's influence and Einstein's ambivalence towards his theoretical legacy, the philosophical problem of the complex relationship between theory and experience, as well as that peculiar depiction of scientific rationality to which Einstein devoted some of his weightiest, explicitly philosophical essays.[1]

2 Ernst Mach and the sources of Einstein's epistemology

It is well known that one of the key factors in Einstein's scientific and philosophical education was the work of Ernst Mach. In a letter dated 8 April 1952, Einstein wrote Carl Seelig that he had, around 1897, read Mach's *Die Mechanik in ihrer Entwicklung*, following a suggestion by his friend Michele Besso: “The book exerted a deep and persisting impression upon me ..., owing to its physical orientation toward fundamental concepts and fundamental laws” (quoted in [Hol, p. 28]). It was not just a “youthful” tribute: Einstein – who in 1897 was just 18 – paid a deep, public homage to Mach's influence in what is historically the first account of general relativity: the paper “Die Grundlage der allgemeinen Relativitätstheorie”, published in 1916 in the *Annalen der Physik* [Ein16a] a few weeks after Mach's death. Describing the reasons why he intends to apply the principle of relativity to *all* reference frames, and not just inertial ones, Einstein points out Mach as the first to realise that the implicit assumption of classical mechanics about an a priori difference, as for the validity of the principle of relativity, between inertial and non-inertial frames of reference is “an inherent epistemological defect” [Ein16a, p. 148]. Nonetheless, Einstein's assessment of Mach's scientific legacy *as a whole* has always been ambivalent and evenly divided between recognising a deep influence on his own physical work and an equally deep disagreement with the methodology and philosophy of science:

[1] For a broader analysis of the importance of the philosophical point of view in Einstein's scientific work, see [Lau].

understanding the meaning of this ambivalence will allow us to perceive some of the most significant epistemological aspects of Einstein's scientific work. But in exactly what does this ambivalence consist?

As the holder of the first chair in history and theory of inductive sciences at the University of Vienna between 1895 and 1901, Ernst Mach occupied an important position in the European scientific and philosophic milieu at the turn of the 20th century. Even though his complex epistemology, influenced among other things by the suggestions of the then young Darwinian theory, cannot be easily summed up in a few simplistic formulae, it is characterised by a radical empiricism, which is supposed to guide the construction and the evaluation of scientific theories and which, in Mach's thought, is charged with a strong anti-metaphysical thrust. In a 1882 lecture about the "economical nature of physics", for instance, Mach sketched a theory in which the guiding principle of physical knowledge is a structuring as conceptually economical as possible of sensible phenomena: "Physics is experience, arranged in economical order" and its goal is "the *simplest* and *most economical* abstract expression of facts" [Mac, pp. 197 and 207]. These processes of structuring, in turn, are founded on "primitive psychical functions" of the human being, so that the criterion of economy for physical thought would simply be the theoretical counterpart of a *biological* and *physiological* need for adaptation to the natural world: "These primitive psychical functions are rooted in the economy of our organism not less firmly than are motion and digestion. ... Such primitive acts of knowledge constitute to-day the solidest foundation of scientific thought" [Mac, p. 190].[2]

In 1916 Einstein was asked to write an obituary to honour Mach and his work. It is precisely here that Einstein suggests a mental attitude that, in scope, goes far beyond Mach and alludes to what, in later years, was to become a decidedly anti-Machian epistemology:

> Concepts that have proven useful in ordering things can easily attain an authority over us such that we forget their wordly origin and take them as immutably given. They are then rather rubber-stamped as a "sine-qua-non of thinking" and an "a priori given," etc. Such errors make the road of scientific progress often impassable for long times. *Therefore, it is not at all idle play when we are trained to analyze the entrenched concepts, and point out the circumstances that promoted their justification and usefulness and how they evolved from the experience at hand.* This breaks their all too powerful authority. They are removed when they

[2] For a detailed analysis of Mach's theses about the economy of thought, see [Ban].

> cannot properly legitimize themselves; they are corrected when their association with given things was too sloppy; they are replaced by others when a new system can be established that, for various reasons, we prefer [Ein16b, p. 142, our emphasis].

Einstein's discontent towards Mach's epistemology was again expressed in several later occasions. On 6 April 1922 a meeting to debate relativity theory was held at the Société Française de Philosophie, attended by mathematicians, physicists and philosophers of the calibre of Jacques Hadamard, Henri Becquerel, Jean Perrin, Élie Cartan, Henri Bergson and Émile Meyerson, as well as, of course, Einstein himself. In response to a question by Meyerson about his distance from Mach's theses, Einstein answered as follows:

> There does not appear to be a great relation from the logical point of view between the theory of relativity and Mach's theory. For Mach, there are two points to distinguish: on one hand there are the immediate data of experience, things we cannot touch; on the other there are concepts which we can modify. Mach's system studies the existing relations between data of experience; for Mach, science is the totality of these relations. *That point of view is wrong, and, in fact, what Mach has done is to make a catalogue, not a system.* To the extent that Mach was a good mechanician he was a deplorable philosopher. His view of science, that it deals with immediate data, led him to reject the existence of atoms [Ein23, our emphasis].

In some texts dating to the last part of Einstein's life, and in which he took a kind of theoretical stock, this assessment was confirmed. In that *Bildungsroman* provided by his "Autobiographical Notes", Einstein credits Mach for having shaken his dogmatic faith in mechanics as the basis of all physics, but in qualifying Mach's influence he writes significantly:

> I see Mach's greatness in his incorruptible skepticism and independence; *in my younger years*, however, Mach's epistemological position also influenced me very greatly, a position which today appears to me to be essentially untenable. For he did not place in the correct light the essentially constructive and speculative nature of thought and more especially of scientific thought; in consequence of which he condemned theory on precisely those points where its constructive-

> speculative character unconcealably comes to light, as for example in the kinetic atomic theory [Ein49, p. 21, our emphasis].

Science historian I.B. Cohen, remarking on Einstein's last interview, given to Cohen himself in April 1955 and published in *Scientific American* a few months later, wrote that Einstein emphasised that:

> he had always believed that the *invention* of scientific concepts and the building of theories upon them was one of the great creative properties of the human mind. His own view was thus opposed to Mach's, because Mach assumed that the laws of science were only an economical way of describing a large collection of facts [Coh, pp. 72–73, our emphasis].

Summing up, if the emphasis given by Mach to the need of "rooting" the debate about the fundamental concepts of physics in experience exerted a strong influence on young Einstein, Mach's radical phenomenalism and anti-metaphysical extremism appeared to Einstein to be unsuited to describe the *ideal* character of physical research. From Einstein's point of view, the tendency to attribute to some assumptions the nature of incontrovertible facts, rather than hypotheses freely chosen, may represent a serious obstacle to scientific progress, leading one to obscure the "constructive-speculative character" that Einstein refers to in the "Autobiographical Notes". If the freely chosen hypotheses are an essential component in the construction of a scientific theory, it is clear that an entirely Mach-like epistemology would have a hard time accounting for this fact.[3]

3 At the origins of relativity: facts, hypotheses, conventions

Einstein's remarks in Mach's obituary also furnish us with another set of reflections, since it is not difficult to recognise in the passage quoted above a fundamental component of Einstein's

[3] In the opinion of Gereon Wolters, a great expert of Mach's work, the distance between Mach's and Einstein's epistemology was exaggerated by Einstein himself, for whom this would not be the only such theoretical "opportunism" [Wol, pp. 44–45]. I don't believe that the remarks by Wolters, while historically sound, significantly change the problem from a philosophical standpoint.

1905 paper on special relativity.[4] That work starts off precisely from the recognition of the arbitrariness in assuming an absolute time that is common to all inertial observers independent of their state of motion, an arbitrary assumption exactly in the sense of the quotation given, that is, not dictated by empirical facts but implicitly adopted following a long and glorious tradition in the history of physics. But Einstein's 1905 paper is exactly the classical place of operational and para-empiricist interpretations of his epistemology! Let us then try to understand, in simple terms, whence derives the misunderstanding that leads to exaggerate the scope of operationalism of Einsteinian work and to obscure its conventionalism, which is in fact inseparable from the former and already completely consistent with what would be the life-long Einsteinian epistemology.

As is well known, the starting point of the paper lies in the apparent difficulty in reconciling the two main threads in the physics of the time: the laws of mechanics by Galileo and Newton on the one hand – with the requirement of the principle of relativity – and Maxwell-Lorentz laws of electromagnetism on the other hand. Indeed, a necessary consequence of electromagnetic laws is that the speed of light in a vacuum is a universal constant (denoted by c), which does not depend on the state of motion of the source. This implies a violation of the requisite of addition of velocities, a perfectly reasonable requisite in a physical context such as classical mechanics. In this context, indeed, the velocities of two physical systems X and Y as defined in the respective inertial reference frames S_X and S_Y are essentially *relative*: that is, they have to compose (that is, add or subtract) when we want to indicate the velocity of X in the reference frame S_Y or the velocity of Y in the reference frame S_X. In the case of light, instead, if we imagine that a light ray is emitted by a source, the constancy of the value c for the speed of light implies that an observer A within a reference frame at rest with respect with the source (assume, for the sake of simplicity, that A is quite close to the source itself) finds for the speed of light a value *equal* to that found by an observer B who runs at some speed along the ray. Hence the intuition – an apparently reasonable solution in a physical, pre-relativistic context – that c is the speed of light in a *particular* reference frame (denoted by the ancient term "ether") and so that it is in principle possible to verify the motion of Earth with respect to this frame. However, repeated experiments designed to verify this yield no useful result: no terrestrial motion in the ether turns out to be detectable.

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[4] There is of course a huge body of literature about the 1905 work on relativity: a classical text is [Mil], which includes a detailed study of the paper and an analysis of the first reactions.

Rather than looking for a possible explanation within known physics, Einstein considered the inaccessibility of ether as a proof in favour of the idea that a principle of relativity has to hold *for electromagnetic laws too*, and its universal validity makes it a kind of “meta-criterion” to accept any fundamental physical law.[5] Thus, in his work Einstein showed that the “incompatibility” between the theoretical pictures of mechanics and electromagnetism is only apparent: indeed, this incompatibility simply follows from the hypothesis that the principle of relativity has to be, so to speak, “implemented” by Galilean transformations, which imply that the speed of light has different values when measured by two observers in relative motion with respect to each other. But what, exactly, is this “hypothesis”? Is it a logical necessity, an empirical fact, or something else? The assumption of this hypothesis is actually a theoretical *choice*, and as such not susceptible of a *direct* derivation from “facts”. It is thus a choice that, with a decision equally theoretical and on bases that are not strictly empirical, can be modified if the final goal is that of a precise compatibility between mechanics and electromagnetism, a goal inspired by the strong search for unity and a systematic method in the physical investigation that constantly guided Einstein. This particular relationship between theory and experience, which we have seen expressed in Einstein's way of elaborating the “crisis” of physics at the turn of the 20th century, is renewed in the case of the status of the relation of simultaneity between distant events, which is one of the most celebrated consequences of the two postulates introduced by the theory of special relativity, the constancy of the speed of light in a vacuum and the principle of relativity [Ein17].

On a more general plane, the philosophical and gnoseological teaching of Einstein's work offers two fundamental components whose combination determines the original synthesis between the operative (and hence empiricist in a wide sense) aspect and the speculative-theoretical aspect, which is one of the most distinctive characteristics of Einstein's scientific and philosophical thought. On the one hand, Einstein requires that an only apparently obvious notion such as the simultaneity between events be given an operational foundation, and this implies a careful analysis of the *procedures* needed to confer a physical meaning on the claim that two events are “simultaneous”. This point is made explicit in the 1905 paper, as well as in many later texts. In the first pages of the original paper, we read:

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[5] Several scholars have remarked that the actual importance of the results of these experiments for the working out of special relativity has been certainly lesser than the urgency, in Einstein's research, of extending the principle of relativity to the laws of electromagnetism too (see for instance [Sta87a]).

> If we want to describe the *motion* of a material point, we give the values of its coordinates as a function of time. However, we should keep in mind that for such a mathematical description to have physical meaning, we first have to clarify what is to be understood here by "time" [Ein05].

In the popular exposition "Relativity: The Special and General Theory", this point is rephrased as follows:

> We encounter the same difficulty with all physical statements in which the conception "simultaneous" plays a part. The concept does not exist for the physicist until he has the possibility of discovering whether or not it is fulfilled in an actual case [Ein17].

However, the necessity of providing the definition of simultaneity with an operational foundation is just one of the components of Einstein's analysis. The other component, no less fundamental, consists in recognising that the postulate of time as absolute is itself of a speculative nature, in the precise sense of not being *forced by facts*. In other words, this postulate is an assumption that can be removed if its substitution is useful with a view to finding a synthesis between the laws of mechanics and the laws of electromagnetism. Thus, the solution to the problem addressed by Einstein develops through a first moment of critical analysis of the *empirical* groundlessness of the prejudice that hindered the formulation of the new theory. But the critical analysis of the axiom about the absolute nature of time heralds, as we know, the *theoretical* possibility of a unifying reorganisation of the two sets of apparently irreconcilable laws. This possibility is granted precisely by the fact that the absolute nature of time is a freely adopted theoretical hypothesis and, as such, can be removed and substituted by other theoretical hypotheses, just as freely adopted. Thus, the operational moment of Einstein's analysis is not the main goal, but rather a first phase of investigation: it is *oriented* towards a plan of theoretical reorganisation based on different postulates which, just like that of the absoluteness of time, are not in any sense "forced" by facts but find their justification in their capacity to integrate mechanics and electromagnetism in a consistent and unitary picture.

4 Holism and underdetermination

The multitude of philosophical implications that have been associated – rightly or wrongly – to Einstein's relativistic theories is, as we know, enormous. For our purposes, one of the most important aspects involves the phenomenon that 20th-century philosophers of science have defined as "underdetermination", an essential phenomenon for correctly situating the operation-oriented readings proposed by many to interpret a posteriori the foundations of Einstein's theory. Underdetermination occurs when the set of experimental evidence about some class of phenomena is in itself insufficient to decide which among two or more competing theories is the most authoritative candidate to explain those phenomena. In this case, the philosophers of science say that the competing theories are underdetermined *by the facts*, which implies that, in order to decide among the two or more competitors, we have to use other criteria in addition to the comparison with empirical data.

When Einstein proposed his theory in 1905, there was a situation of underdetermination. With respect to the experimental evidence of the time – mostly consisting, as we have recalled, of the repeated but unsuccessful attempts to detect the motion of Earth with respect to the ether – the main theory competing with Einstein's was due to no less than Hendrik Lorentz, the celebrated Dutch physicist whose name is associated to his well-known transformations and who Einstein himself held in great esteem and admiration. Lorentz's theory was a *dynamic* theory, that is, one that tried to explain the effects of time dilation and length contraction by assuming particular interactions between the electrons and the ether. These interactions would have as their effect that of contracting the length of *all* bodies in motion through ether: thus, the very apparatus involved in the experiments to detect the motion through ether would itself undergo the same effects and, as a consequence, this would explain the failure of these experiments.[6] As has been remarked, among others, by the historian of physics John Stachel, the difference between Lorentz's and Einstein's reactions to the failure of the experiments to detect the motion of Earth through ether typifies two equally different epistemological and methodological positions:

> Lorentz's approach to the explanation of failure of attempts to detect motion through the ether, thus, was to show that the basic equations of the electron

[6] The paper in which Lorentz described this theory in detail was [Lor], published in 1904, which Einstein did not know about when he wrote his 1905 paper about relativity.

> theory, in spite of the fact that they single out the ether rest frame, can still be used to explain the failure of all optical and electromagnetic attempts to detect the earth's motion through the ether. Einstein's work was based on a new outlook on the problem. Instead of regarding the failure of electromagnetic and optical experiments to detect the earth's motion through the ether as something to be deduced from the electrodynamical equations, he took this failure as empirical evidence for the validity of the principle of relativity in electrodynamics and optics [Sta87b].

Thus, the dominance of Einstein's theory is not due so much to some hypothetical confirmation by raw facts, as to totally *theoretical* virtues: that is, the ability to harmonise a "hard" physical discovery – the existence of a limit speed in nature that remains unchanged in any reference frame – with an epistemological requisite such as the principle of relativity, about nature and the form of physical laws.[7] As we have mentioned, this capacity to harmonise is, so to speak, a two-dimensional virtue. In the first dimension, it requires that physical notions, in order to acquire a meaning, pass through an operational elucidation while, in the second one, the assumption of an absolute time is removed and substituted by an alternative assumption on the basis of its *conventional* and *not empirically derivable* nature. Recognition of this aspect is precisely the keystone of Einstein's theoretical synthesis, which passes in an essential way through the awareness that there is always a fundamental gap between facts and theory and that a theoretical description makes conceptual choices that cannot be reduced to a simple catalogue of experiences.

The notion of underdetermination, used in practice in the 1905 paper on relativity, was also confirmed from a conceptual standpoint in later years, a circumstance that makes it all the more improbable to consider even only the first part of Einstein's scientific career as influenced by a "Mach-like" conception of physical theories. A fundamental contribution in this direction comes from Einstein's frequent study of the epistemological work by the Frenchman Pierre Duhem (1861-1916). Duhem was a physicist, a philosopher and a historian of science with very wide-ranging interests, whose active contribution to reflections about the foundations of physical theories at the turn of the 20th century was heavily underrated. In particular, his 1906 *La théorie physique: son objet et sa structure* [Duh] received a far less attention than it deserved

[7] For a discussion about the general epistemological relevance of the different views of Lorentz and Einstein on, respectively, the dynamic or kinematic nature of relativistic effects, see [Jan].

from 19th-century epistemology, roused almost only by the logician and philosopher of science Willard V.O. Quine (1908-2000), who in one of the most famous papers in philosophy of science of the whole century, entitled "Two Dogmas of Empiricism" [Qui], goes back to and develops so-called "confirmation holism", actually one of Duhem's fundamental theses.
Einstein came across Duhem's work when in 1909 he obtained his first academic position at the University of Zurich. During that period he spent long hours with his friend Friedrich Adler discussing "questions whose importance is generally not understood by the majority of other physicists" (as Adler wrote to his parents in a letter in October 1909). Adler, not coincidentally, had been the German translator of the book by Duhem just mentioned (which translation was published in Germany in 1908 with a foreword by Mach), as well as the person who most likely first introduced Einstein to Duhem's thought [How, pp. 367-368].
Two main epistemological theses in Duhem's text had the strongest effect on Einstein, and both concerned the complex relationship between theories and experience: the critique of the idea of *experimentum crucis* and the idea mentioned earlier of underdetermination of theory with respect to experience. First, Duhem criticises the idea of an *experimentum crucis*, that is, the idea that it is possible to conceive a single experiment able – in case of a negative result – to refute an entire theory clearly and definitively. Indeed, Duhem claims that an advanced stage of science implies an experimental apparatus that, in addition to being extremely sophisticated from a technological viewpoint, requires heavy doses of theory that are necessary to interpret and evaluate the result obtained by using such apparatus in experiments. In Duhem's opinion, if so much theory is required, the very idea of experimental testing implies "an act of faith in a whole set of theories" and the testing will be based on the comparison between experience on the one side and a block of theories on the other.

> Physics is not a machine which lets itself be taken apart; we cannot try each piece in isolation and, in order to adjust it, wait until its solidity has been carefully checked. Physical science is a system that must be taken as a whole; it is an organism in which one part cannot be made to function except when the parts that are most remote from it are called into play, some more than others, but all to some degree. … In sum, the physicist can never subject an isolated hypothesis to experimental test, but only a whole group of hypotheses [Duh, pp. 55–6].

But the idea that theories must be checked as a whole justifies – and this is the second thesis by Duhem that turns out to be important for Einstein – the notion of underdetermination, according to which existing experience can be compatible with several "blocks" of theories, blocks that turn out to be impossible to reduce to one another but are empirically equivalent, that is, are able to explain the same set of experimental data.

Even though Einstein rarely cited Duhem explicitly, the influence of Duhem's epistemological ideas already appears in the lecture notes for a course on electromagnetism that Einstein taught between 1910 and 1911; these ideas came to be a stable part of Einstein's epistemology [How]. The most important conceptual consequence consists of the thesis that the connection between experience and theory – that is, that which in the end represents the most general task of a scientist – is established through a process that is largely conjectural and provided with an ample margin of speculative freedom, a margin on the other hand not so boundless as to prevent the achievement, in the scientific practice, of a reasonable compromise between theoretical daring and the precise bounds imposed by the experimental and empiric sphere. In the point of view never to be abandoned by Einstein, the best science continuously negotiates between theoretical hypotheses and experimental bottlenecks, aware that experience *suggests* a possible theoretical organisation, but does not *dictate* it. In a celebrated 1918 text dedicated to Max Planck on the occasion of his sixtieth birthday, Einstein wrote:

> The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. *There is no logical path to these laws; only intuition, resting on sympathetic understanding of experience, can reach them.* In this methodological uncertainty, one might suppose that there were any number of possible systems of theoretical physics all equally well justified; and this opinion is no doubt correct, theoretically. But the development of physics has shown that at any given moment, out of all conceivable constructions, a single one has always proved itself decidedly superior to all the rest. Nobody who has really gone deeply into the matter will deny that in practice the world of phenomena uniquely determines the theoretical system, in spite of the fact that there is no logical bridge between phenomena and their theoretical principles; this is what Leibniz described so happily as a "pre-established harmony" [Ein18, p. 31, our emphasis].

Einstein came back on the role that the "underdetermined" character of theoretical investigation is bound to play in a short but effective 1919 article entitled "Induktion und Deduktion in der Physik", written for a German newspaper [Ein19] . In the common-sense image of science, Einstein writes, a scientific theory is born inductively: in this view, a first phase of fact-collecting is followed by the formulation of patterns that seem to "emerge" from those facts, in a process that arrives to the pinpointing of an actual theoretical system of ever-increasing generality. This picture, however, turns out to be fragile from both a historical and a conceptual viewpoint: historically, because the actual development of science did not follow these common-sense prescriptions; conceptually, because building a wide-ranging theory requires several preliminary guidelines without which the investigation cannot go forward:

> Galileo would never have found the law of free-fall without the preconceived opinion that the situations as we find them are complicated by the effects of air resistance, and therefore, that one has to focus on cases where this effect has only negligible influence [Ein19].

In referring to Galileo, Einstein implicitly takes up here Immanuel Kant's vision as expressed in one of the most famous passages of modern philosophy of knowledge, from the preface to the second edition of his *Critique of Pure Reason*. There Kant attributed the credit for consolidating physics as a science precisely to the awareness of the central role of theorisation, writing that without those *preconceived* theoretical hypotheses "accidental observations, made with no previously fixed plan, will never be made to yield a necessary law, which reason, however, seeks and requires" [Kan, p. 16]. In an anticipation of themes central to Karl Popper's epistemology, the consequence drawn by Einstein is trenchant:

> The truly great advances in our understanding of nature originated in a manner *almost diametrically opposed to induction*. The intuitive grasp of the essentials of a large complex of facts leads the scientist to the postulation of a hypothetical basic law, or several such basic laws. ... [W]hile the researcher always starts out from facts, whose mutual connections are his aim, he does not find his system of ideas in a methodical, inductive way; rather, he adapts to the facts by intuitive selection among the conceivable theories that are based upon axioms [Ein19, our emphasis].

We have therefore attempted to show how a trivially positivist and operation-based image even of young Einstein is incompatible with his actual epistemological position, a position aiming at grafting a strong dose of underdeterminationist conventionalism on a background of physical realism. In another page of the "Autobiographical Notes", of great interest for our point of view, Einstein recalled the deep difference in opinions with Mach about the reality of atoms – Mach, as is known, strenuously opposed the kinetic theory of matter – and demonstrated clearly that the difficulty in accepting the kinetic theory for even a person as intellectually brave as Mach lay in the inability to attribute to spontaneously theoretical and hypothetical activity the role to which it is entitled in the scientific edifice:

> The antipathy of these scholars [Ostwald, Mach] towards atomic theory can indubitably be traced back to their positivistic philosophical attitude. This is an interesting example of the fact that even scholars of audacious spirit and fine instinct can be obstructed in the interpretation of facts by philosophical prejudices. The prejudice – which has by no means died out in the meantime – consists in the faith that facts by themselves can and should yield scientific knowledge without free conceptual construction. Such a misconception is possible only because one does not easily become aware of the free choice of such concepts, which, through verification and long usage, appear to be immediately connected with the empirical material [Ein49, p.49].

5 *Envoi*

These pages have attempted to draw a concise profile of Einstein's epistemological reflection, with the goal of putting in the right light some fundamental aspects: the topicality and internal coherence of the scientific image of the world that emerges from it, the organic connection between philosophical analysis and strictly scientific work and – last but not least – the relevance of this analysis also from the standpoint of "professional" philosophy of science. From a more general point of view, Einstein's scientific and philosophical contribution once again provides an opportunity to reassess the dialectics between revolution and continuity in the development of the scientific thought. Indeed, Einstein's scientific work brought about a radical transformation in the structure of fundamental physics; however, this transformation did not happen in a vacuum, but in an environment with a composite scientific culture, made up of urges toward future and from the past that entangle with and complete each other. We must not forget that, while Einstein's theories completely reorganised the picture of the natural world, it is just as true that the representation of theoretical work (both scientific and philosophic) which Einstein defended througout his life had deep elements of continuity with a *classical* ideal of scientific investigation: an ideal in which the scientist is actually in search of the structure and fundamental laws of a world that is given and independent on us and that has not a lot to do with some romantic visions circulated by many old and new popular texts, especially about quantum mechanics.

Translated from the Italian by Daniele A. Gewurz

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