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Experiment and Scientific Method in Ernst Mach

ABSTRACT: The aim of this article is to bring out, both on historical and theoretical plane, the original epistemological contribution of the Moravian physicist and philosopher Ernst Mach (1838–1916). Those phenomenological and experimental characteristics of his methodology are particularly emphasized which culminate in setting up of the so-called thought experiment (*Gedankenexperiment*), outlined in a famous chapter of his philosophical-scientific masterpiece *Erkenntnis und Irrtum* (1905). Despite critical reservations on the part of various reliable scholars (from Meinong to De Sarlo, to cite only two), the "thought experiment" showed itself to be extremely flexible and fruitful, not simply in the field of physics (as one can observe in the theories of Albert Einstein in particular), but also in those of literature, art, religion and politics. From the philosophical point of view, it is well-known that it was made full use of by, for instance, Ludwig Wittgenstein. At its base, in fact, one can detect a specific use of visual intuition, which acts as the hinge of experimental research, alongside the principle of economy. Their synergy stimulates not only the scientifically more sophisticated work but also spontaneous elementary productions.
KEYWORDS: Mach • Cassirer • experimentation • percepts • concepts • symbolic form • Galileo • experiment • discovery • continuity

The modern scientific method, whose initial theorisation and application essentially go back to the revolutionary philosophic and scientific work of Galileo, is traditionally defined as "mathematical-experimental". In reality, however, it is far more complex and elaborate than would appear from this general definition, and this is already clear from a more accurate historical-theoretical examination even of the experimental component alone. A similar examination of the mathematical component would, moreover, involve the highlighting of important aspects at times perhaps neglected or not adequately exploited.

Given that a correct analysis of the scientific method – like any other "object" of inquiry – must eventually lead to an overall synthesis of the various elements disclosed and their reciprocal connections, the fact remains, indeed demands, that from time to time each of these elements be tempo-

Archiwum HF_60 2015 KSIAZKA.indb 157 2015-12-15 11:31:48

rarily placed under specific examination, with the precise aim of reaching a more advanced synthesis.

To a certain degree, then, it is legitimate, or better still necessary, to discuss the importance of experimentation in the scientific methodology that has developed from Galileo onwards. The effective role it has played has perhaps not, in fact, been sufficiently recognised and exploited so far, despite the countless applications and innumerable theorisations which have been made of it.

We shall pause to consider in outline one of these – the Machian theorisation – both because it is without doubt one of the most instructive and innovative, and because it can provide, directly or indirectly, substantial aid in attempts to overcome certain difficulties in which current epistemological thought seems to be stuck.

It is precisely in this light that we would like to emphasize certain moments in the Machian theorisation which seem to be more important in relation to the problems indicated. To this end it may be particularly useful to place this theorisation right from the beginning within certain systems of coordinates, very different one from another, but nonetheless fit to immediately bring out the significant epistemological problem inherent in the Machian perspective.

To begin with we shall refer to the critical stance which is the most authoritative from a specifically philosophical point of view, namely that adopted by Ernst Cassirer, in particular in his work *Zur Einstein'schen Relativitätstheorie*, dating back to 1921[1]. This text, as is well known, provides a powerful contribution to the strategy of neo-Kantianism (pursued in particular by the Marburg School) designed to "save" the criticism from dangers, real or imagined, coming chiefly from the evolution of the physics, mathematics and philosophy of post-Newtonian science (non-Euclidean geometries, crisis of mechanism, theory of relativity, quantum theory, *etc.*). Cassirer's observations must therefore be interpreted in this light.

Towards the end of the cited text he particularly approves of the clear distinction Mach makes between spatial-temporal s e n s a t i o n s on the one hand, and their "metrical" calculations on the other (based on the postulate of isotropy and homogeneity). This distinction is in fact consistent with the Kantian definition of "transcendental subjectivity", meant not as subjectivity of the l i v e d experience, but as the unity of the conditions that make possible the same "objective" e x p e r i m e n t a l knowledge[2].

[1] E. Cassirer, *Zur Einstein'schen Relativitätstheorie*, Verlag Bruno Cassirer, Berlin 1920 (also: Paperback, Hamburg, Felix Meiner 2001).

[2] M. Schlick was instead accused of having created confusion between the two meanings of "subjectivity".

Archiwum HF_60 2015 KSIAZKA.indb 158 2015-12-15 11:31:48

As a result – again Cassirer is quite clear – Machian positivism and critical idealism also find agreement in recognising that the general empirical laws, which by means of mathematical equations govern metrical calculations, constitute "the kernel of physical objectivity". There is, however, a fundamental aspect in which the two points of view (respectively positivist-empirical and idealist-critical) differ drastically: while for the first the measurements refer to sensations, for the second they always pertain to "conceptual symbols" which are no longer even copies of sensations, precisely because they are c o n c e p t s and not p e r c e p t s[3].

It must be emphasised that in these terms the Cassirerian position is as irrefutable as it is discounted, since it is obvious that if science deals with concepts and not percepts, these latter will never be able to be the "object" of scientific investigation. So it is evident that, as Cassirer reasserts, "to arrive at an expression and to a conceptual understanding of the facts of experience", every physical theory must "first of necessity detach itself from the form in which these facts are given initially and immediately to perception"[4]. It is interesting that to this end Cassirer refers to the same thesis formulated by the French epistemologist Pierre Duhem in his important work *Théorie physique*: "Empirical facts taken in their native brutishness could not serve mathematical reasoning; to feed such reasoning, they must be t r a n s f o r m e d a n d p u t i n t o s y m b o l i c f o r m"[5].

It does not seem to us to over-simplify the question but rather to reveal an essential point concerning it by observing that, in contrast to Mach, neither Cassirer nor Duhem has taken into adequate consideration that moment which even they themselves have, however cursorily, pointed to: namely that one must a r r i v e at a conceptual expression of the facts of experience (Cassirer), or that one must t r a n s f o r m the brute empirical facts to be able to put them in symbolic form (Duhem). It seems to us that it is precisely such "transformation" and, that is to say, the cognitive procedures capable of producing it, which Mach has his eye upon, he having identified in them the hinge of the passage from percepts to concepts – and thereby the decisive moment in the passage from prescientific knowledge to scientific. And even if he did not succeed (as might be thought) in clarifying adequately the nature and function of these procedures – what must still be recognised is his very great merit in having come upon the basic role.

[3] E. Cassirer, *Zur Einstein'schen Relativitätstheorie*, *op. cit.*, p. 90.
[4] *Ibidem.*
[5] *Ibidem.*

Archiwum HF_60 2015 KSIAZKA.indb 159 2015-12-15 11:31:48

In actual fact a great part of the philosophy of modern science, in its varied and conflicting presentations, is as it were ossified in the rigid dualism of sensations-concepts, induction-deduction, *a-posteriori–a-priori*, facts-theories, protocol propositions-general propositions, *etc.* The hiatus produced by such unbending oppositions is too broad and deep to be bridged without forcing matters. The only valid solution must therefore consist rather in seeking to "reduce" this fracture, or better, to recognise and expose from the very beginning its essentially fictitious character, a product of intellectualistic forcing, whether it bear an empirical-positivistic stamp or, by contrast, a critical-idealistic.

Extremes often risk ending up by meeting in make-believe. Hence the resort, also in epistemologies nominally more "liberal" (as, for example, the Popperian), to precepts, demarcations, prohibitions of various types and degrees of severity, designed in any case to confine real scientific research within set limits. Determining this common underlying attitude, begetter of one-sided positions and counter-positions and therefore irreparably off-balance and unstable, is always the matrix (or the "myth") of the logos, namely of the prerogative, peculiar to the human mind, of capturing the "real" in its own conceptual nets, be their mesh finely woven or stronger (*a priori* categories) or loosely woven or weaker (*a posteriori* abstractions or associations).

It might seem – and indeed does so to many – that Ernst Mach fully belongs to the second group, that of the advocates of the empirical basis as the bedrock of scientific knowledge. And it is not by chance that the "Vienna Circle" wanted initially to take him on as its tutelary deity. The reasons for such an hypothesis are certainly not to be disclaimed, neither is the not irrelevant presence, in the philosophy of Machian science, of original elements such as to remove it, at least in part, from the claim of empirical-positivistic orthodoxy.

An indication of such potentialities inherent in the Machian approach is, for instance, the subheading of the basic work *Erkenntnis und Irrtum* (*Knowledge and Error*), which reads: "Sketches for a Psychology of Research", and which seems significantly opposed to the title of Popper's main text: *The Logic of Scientific Discovery*[6]. It is certainly not about once more putting forward the classic opposition between psychologisms and logicisms which erupted between 19th and 20th century, and which produced, together with large and illuminating flares, also suffocating clouds of ash. The task that today presents itself is one not so much of opposing as of reorganising

[6] E. Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, Leipzig 1905.

Archiwum HF_60 2015 KSIAZKA.indb 160 2015-12-15 11:31:48

"logos" on the one hand and "psyche" or "mind" on the other, even though not in the sense, of course, of reducing them to an enforced cohabitation, but rather of configuring a new dimension, in which the value of both can be enhanced without abuse of power on either side.

The Machian s k e t c h e s must be seen in this perspective, even though they undoubtedly appear to be more inclined to the empirical-psychologistic pole, but not without substantial ideas capable of rendering it clearer and more productive than its more canonical formulations suggest. It is not possible here adequately to shed light on all, or even just the more important, of these ideas, also because one would need to free them from the conceptual fetters with which Mach himself has sometimes weighed them down, thereby encouraging misunderstandings or critical interpretations like those that emerged, other than in the mentioned adopting of the Cassirerian position, in the bitter controversy with Planck, or in the criticism of Popper. It is precisely from an examination of these interpretations that one can focus more satisfactorily upon the authentic Machian approach and the fruitfulness of some of its components – in particular, the experimental.

The more bitter of the polemical remarks, on the epistemological-scientific side itself, are perhaps those made by Max Planck. We are talking about a frontal attack, carried out against the crucial points of the Machian conception. The most fundamental of them – on which the critics, including Cassirer, Popper, Lenin and others, concentrate – is without doubt Mach's "sensationalism", or rather the thesis – as Planck says – "that no other reality exists apart from our sensations"[7].

Likewise for Cassirer a "positivism" of the Machian stamp bases all knowledge of law, like all knowledge of objects, upon the "simple elements of sensation and can never go beyond their ambit"[8]. And Popper, in turn, stresses how Mach, like Berkeley (considered in some ways his precursor), believes in the "doctrine, today known as phenomenalism, according to which physical objects are bundles, complexes, or constructs of experienced phenomenal qualities, of particular colours, noises, *etc*.., [namely] 'complexes of elements'"[9].

It is interesting that Lenin, in his well-known work *Materialism and Empiriocriticism* of 1909, adopts the same argument as Planck, for whom scientific truth is knowledge of an objective reality, that is to say, of imma-

[7] For the Mach-Planck dispute, as also for the critical observations of Lenin, cf. A. D'Elia, *Ernst Mach*, Firenze 1971, p. 239 ff.

[8] Others have interpreted the Machian "phenomenalism" as closer to "sensationalism" than to empiricism.

[9] See: A. D'Elia, *Ernst Mach*, *op. cit.*, p. 298.

Archiwum HF_60 2015 KSIAZKA.indb 161 2015-12-15 11:31:49

nent connections with the real, of intrinsic legality with nature. From that follows the similar criticism of "subjectivism" levelled against the Machian approach. Anyway, in Lenin this "subjectivism" bears a Kantian imprint, since it is brought back to knowledge intended as an "organising structure of experience", so that it turns out that "the laws do not belong entirely to the sphere of experience. They are not given from experience but are sought for by thought as a means to organize experience, to coordinate it harmoniously in a symmetrical unity". In short, one arrives thus at the conclusion that "man gives laws to nature and not nature to man".

Except that such a conclusion is at odds – and this is extremely revealing – with what Cassirer arrives at. For him, with regard to the laws "the strict positivism" Mach-style

> has only one answer: all knowledge of laws like all knowledge of objects in itself is founded on the simple elements of sensation and can never go beyond their ambit. As a result, knowing the laws has, after all, the same purely passive character that attends our knowing individual perceptible qualities. The laws are considered like things, whose properties can be grasped with immediate perception[10].

The clear conflict between these two interpretations is an indication of the fact that neither of the two hits the mark – and also, no doubt, that the mark shifts. In effect it does not seem that Mach's position is identifiable *sic et simpliciter* with a "strict positivism", on the one hand, or with a critical philosophy whether it be simply empirical, or empiriocriticism, on the other. Perhaps it is a rather unstable position which involves pronounced oscillations from one pole to the other, yet not because it is not very solid but because it is driven by an internal spring which is based, so to speak, on a kind of third pole, albeit not a very steady one. To seek to shed light on this further component of the Machian perspective, more than on the explicit philosophemes that act as its support, it is worth pausing on the contents of the historical-critical analyses from which that perspective extracts its most sophisticated lymph.

What seems particularly important, among the many examples that could be adduced, is the one concerning the Galilean formulation of the law of inertia and of what governs falling bodies. This concerns laws, as is well-known, which are at the root of dynamics and therefore, together with those of statics, at the root also of mechanics. Their discovery and formulation therefore required, on the part of Galileo (and of the other pioneers of

[10] E. Cassirer, *Zur Einstein'schen Relativitätstheorie, op. cit.*, p. 89.

Archiwum HF_60 2015 KSIAZKA.indb 162 2015-12-15 11:31:49

modern physics) a thorough and creative work of conceptual formulation which constitutes the real matrix of that "revolution" which, even before being scientific, was intellectual and therefore also philosophical (since it was philosophy that really concerned itself with "concepts", and science with "objects" or "phenomena" described in the light of those concepts).

So it is no coincidence that Mach, who like few others is a genuine scientist-philosopher, identified with particular lucidity the nucleus of the modern "scientific revolution" in this conceptual formulation, devoting himself with great acuteness and interpretative brilliance, and no less historical preparation, to what we could call the "splitting of the nucleus" (the nucleus, to be exact, of the conceptual revolution). However, it seems to us that from this splitting Mach did not succeed in obtaining that synthesis which constitutes the real nucleus – the nucleus of the nucleus, so to speak – of the scientific procedure; nevertheless he must be given the credit for having gone further in the right direction than had the majority of the philosophers of science before and after him.

One could verify this by going over the numerous historical-critical analyses – especially in the *Mechanik*) but also in other texts of Mach's[11] – dedicated to the main stages in the evolution of modern physics. In particular his criticism of the basic concepts on which Newtonian mechanics are based (especially those "absolutes" of space, time and motion) remain very instructive – above all as regards their repercussions on the problems of physics in Mach's time, in particular the relativistic.

It is nonetheless advisable to pause first on certain aspects of the Galilean approach, considered by Mach as decisive factors in the success of the modern scientific method by virtue of their heuristic capacity and efficacy. It is exactly this aspect – namely the moment of "discovery" – that constituted the decisive spring for the progressive increase in scientific knowledge, and its almost violent impact on the scene of human knowledge, despite all the attempts – more or less justified and successful – to downsize its "validity".

Indeed, Mach clearly underlines how the valuable work of preparation carried out by the predecessors of Galileo (such as Leonardo, Benedetti, *etc.*) consisted more in calling into question the Aristotelian doctrines than in proposing new theories capable of substituting them. This seems to us a very important point to which, perhaps, more attention should be paid than hitherto. One can advance the hypothesis, namely that the more one succeeds in clarifying the effective procedures and implications that enable thought not

[11] See in particular E. Mach, *Die Mechanik in ihrer Entwicklung historisch-kritisch dargestellt*, Leipzig 1883.

Archiwum HF_60 2015 KSIAZKA.indb 163 2015-12-15 11:31:49

only to invent new theories but also, and especially, to discover new aspects of natural reality, the problem of the validity of the knowledge so obtained – which has obsessed a great part of the philosophy of modern science, starting from Hume and Kant – could become considerably lessened.

So let us consider briefly the most important moments in the Galilean approach and contribution to the question of falling bodies and the principle of inertia, on the basis of the analysis carried out by Mach (for whom it constitutes the best evidence given by Galileo of his creative intelligence as a researcher). It must first of all be stressed that the first attempt at solution presented by Galileo was very soon revealed to be wrong by Galileo himself, who then did not fail to record it openly in a passage from the Third Day of the *Discorsi e dimostrazioni matematiche* of 1638, admitting that he had thought "uniformly accelerated motion to be that in which the speed increases in proportion to the increase in space through which it passes"[12]. In other words, Galileo reckons at first that uniformly accelerated motion is that in which the speed grows in arithmetical proportion to the space travelled.

It must be noted that the mistake is in itself instructive, inasmuch as it serves to clarify the real terms of the problem – which obviously constitutes the indispensable premise to finding the right solution to the problem itself. So – as the Galilean example seems to show – the unsuccessful identification of the r e a l t e r m s of the problem depends, at bottom, on the unsuccessful identification of a r e a l p r o b l e m, or better, on the more or less conscious idea that the problem and its related solution are graspable in perceptual experience just as it appears to immediate observation or, in a certain way, superficial. In this case, the solution first set out by Galileo seems simply to trace the perceptual data; that is to say, the fact that we observe the body increase its speed, in the course of its fall, in the same proportion with which it departs from the starting point of the same fall. Galileo in fact formulates his own theory as follows:

> if a heavy body falls from A along the line $ABCD$, I regard the degree of velocity which it has at C to be related to the degree of velocity it has at B as the distance CA is related to the distance BA. Thus, in consequence, at D it has a degree of velocity greater than at C in just the same measure that the distance DA is greater than the distance CA[13].

[12] G. Galilei, *Opere*, ed. naz., vol. VIII, p. 203: "moto uniformemente accelerato essere quello, nel quale la velocità andasse crescendo secondo che cresce lo spazio che va passando".

[13] *Ibidem*, vol. X, p.115: "cadendo il grave dal termine *a* per la linea *abcd*, suppongo che il grado di velocità che ha in *c* al grado di velocità che hebbe in *b* esser come la distanza *ca* alla distanza *ba*, et così conseguentemente in *d* haver grado di velocità maggiore che in *c* secondo che la distanza *da* è maggiore della *ca*".

Archiwum HF_60 2015 KSIAZKA.indb 164 2015-12-15 11:31:49

Here we clearly discern how the source of the error is too superficial an observation of the phenomenon.

To get past this stage, it is necessary to subject the observed datum to the scrutiny of a deliberation which, far from imposing its own "logic", knows how to grasp, so to speak, its inner logic. If one proceeds in this way, one soon realises that it is not possible to overlook, as did Galileo, the time factor, since this too increases and so the relation between temporal and spatial increase must be assessed. The first is less immediately perceptible than the second, but not so as to render it imperceptible.

At this point the problem then takes another turn, assumes a different shape: it becomes, that is to say, the problem of rendering observable, or rather measurable, what immediately or on the surface is not there. Well then, what renders observation more effective and at the same time more targeted is experiment: not meant, however, as proving or disproving a theory, but rather as determining precisely, on the plane of observation, the physical factors "recognisable" as essential in describing or interpreting phenomena.

This is about two very different meanings and conceptions of "experiment", and it is this difference that provides the key to understanding a component, as decisive as it is generally underrated, of the modern scientific method, as well as of Machian epistemological thought. Albeit without yet having defined this basic question clearly and thoroughly, Mach nevertheless shows that he is immediately aware of its crucial relevance. In fact he stresses that the exact solution to the problem of falling bodies – namely that the velocity increases in proportion to the time – was obtained by Galileo's verifying experimentally (or better, shall we say, by rendering it observationally evident) that "space increases in proportion to time". The first relation, in itself not directly observable, becomes so indirectly through the second relation. This means that, if the latter is exactly measurable, the former is verified, in the sense that it is rendered observable in its turn and therefore, as they say, "experimentally verified".

Mach realises, even if still a bit obscurely, that the meaning of this phrase is equivalent to that of the phrase "observationally highlighted". He in fact underlines how Galileo, to obtain this verification or evidence, had to slow down the motion of falling bodies by using spheres that rolled in grooves scooped out along inclined planes; to measure, then, the smallest intervals of time he used a vase into which water dripped, flowing into another receptacle placed on a scales. With such devices he succeeded in observing that, while the spaces covered grew like their respective squares, the times increased like the series of whole numbers, and he could therefore translate these observations into the final familiar formula, derived from another to

Archiwum HF_60 2015 KSIAZKA.indb 165 2015-12-15 11:31:49

which he had arrived through a similar "experimental verification" obtained through a purely mental schematization (a kind of anticipation of what will be called "thought experiment"). It seems clear, then, that "experimental verification", in the sense of validation (or invalidation) of the hypothesis or theory of starting-out, is already largely "anticipated" by conceptual/observational verification, and that the moment of discovery entails that of validation.

Thus it must be recognised that to Mach – and it is well to reassert it – belongs the great merit of having contributed in remarkable measure to establishing the value of this original nucleus of modern scientific methodology. At the same time, however, it must be acknowledged that he did not succeed in giving an epistemological justification of it, capable of protecting him from being greatly misunderstood – as much on his part as on the part of other scientists and philosophers of science.

The precariousness of the position reached is both the effect and origin of those ambivalences which then his critics played on, among whom were those we mentioned before. We will now seek to untie this somewhat intricate knot, also because it can be very informative as to the conditioning exercised by philosophic "ideology" even on a highly critical and independent mind such as Mach's.

Thus to conclude the analysis described above of the Galilean theory of falling bodies, Mach observes that fundamental mechanical concepts are formed after examining particular cases of mechanical processes. Therefore Galileo would not have intended to formulate a "theory" of falling bodies, but simply to establish the fact of the falling and give it a precise definition. One sees, from this consideration of his, how Mach very well understands the fact that theories do not overlap and are imposed externally on phenomena, but does not equally well understand that they are not thereby reducible to mere statements of fact or accurate definitions of the phenomena themselves.

In reality, so that they can be accurate and explanatory the descriptions of phenomena must in some measure be theoretical, "idealizations" or "ideal experiments". This is the basic Machian ambivalence, the origin of all the others, which renders his thought at once so stimulating and so ambiguous.

One can see it, for that matter, in another highly illuminating analysis of Mach's in connection with the Galilean formulation of the law of inertia, which states, as is well-known, that a body in movement upon which no force is acting preserves its speed and direction indefinitely. Mach works out this law in particular from two famous passages in the third day of the *Discorsi e dimostrazioni matematiche*, where the experiment of the inclined planes is

Archiwum HF_60 2015 KSIAZKA.indb 166 2015-12-15 11:31:49

described and illustrated. The interpretation Mach gives of it seems clearly influenced by a sensationalist-positivist orientation which seems in this case once more to abuse its power by reorganising the more authentic original. Mach wants, in fact, to maintain that the law of inertia expresses nothing if not the extreme case of a series of observed cases; and that the relevant demonstration is obtained, from Galileo, on the basis of a procedural principle which can be defined as "continuity". This consists in passing from a series of similar cases (like the series of progressively lesser-inclined planes) to an "extreme case", apparently unlike the others if isolated from them, but which the "passage to the limit" (that is, to no inclination at all) classifies as the last case of a series conceived of as infinite. Thus it would occur in Galileo's reasoning, who would consider the indefinite uniform motion on the horizontal plane to be like the extreme case of the falling motion on vertical planes. Except that in Galileo's reasoning this motion is well defined by its velocity, and is so precisely for the fact that in it no recourse is had to the "passage to the limit" hypothesised by Mach.

The said "passage", as it is formulated in the Machian interpretation, is effectively a "logical" procedure, but imposed from having reduced the empirical basis to a mere series of observed or observable cases. The passage in question, then, is to be formulated rather as a kind of "somersault" from the empirical to the meta-empirical – somersault, since in reality there cannot be a "passage", not even to the limit, between two levels of reality totally different from each other. It is significant that a similar incongruity will be reproduced in the area of "logical neo-positivism" which, as the very name indicates, will itself undertake to establish the passage from the purely logical level of theoretical propositions to the purely empirical level of "official" propositions – getting entangled in insuperable difficulties, then rigorously denounced by Popper's falsification theory.

Such an imbalance between empirical moment and logical moment reverberates and reflects significantly also on the Machian conception of law. After having identified the presumed heuristic principle which would be put into action by Galileo, Mach in fact moves on to indicate what, on the basis of such a principle, should be the consequent nature of the law by whose virtue it was discovered. He points out that if we specify in a single view the relations between the times, the velocities acquired and the spaces travelled, we are in a position to take in at a single glance the law. Now, there is no doubt that the law, in its mathematical formulation, can act, and in fact does act, as a rule of derivation in the manner illustrated by Mach. As he points out, the faculties of comprehension and memory of each one of us being limited, it is necessary to impose order on phenomena so as to render them acces-

Archiwum HF_60 2015 KSIAZKA.indb 167 2015-12-15 11:31:49

sible to the said faculties. In the case in question, we cannot memorise all the times of the falling body and their corresponding spaces. Thanks to the mathematical formula, however, we have at our disposal a "rule of derivation" which enables us, knowing a time, to find the corresponding space, thereby replacing the exhausting work of memory with an instrument as easy as it is trustworthy.

Naturally there is nothing to object to a similar use of the formulas in which the laws are expressed; or at least there is nothing to object to as far as the practical use of the laws themselves is concerned, regarding which criteria such as reliability, simplicity, ease, speed *etc.* are clearly essential. On the other hand there would be something to object to already on the didactic plane, since use of the automatic or mechanical type not only does not require comprehension and memory – on the contrary, it dulls and blunts them. But still more serious objections are to be raised on the epistemological plane – objections, though, suggested by the very evidence related to the procedures of scientific discovery highlighted by Mach himself. He, in fact, draws from the above-mentioned considerations the disconcerting conclusion that the rule of derivation, or rather the formula of the "law", has no objective value at all superior to that of individual facts taken together. For its value – he states as resolutely as unambiguously – consists solely in its ease of use, and is therefore purely economic.

It is statements like these, evidently, that have led interpreters and critics to classify Mach *sic et simpliciter* among the instrumentalists, conventionalists, sensationalists, positivists, *etc.*; and above all – as Benedetto Croce in particular has maintained – among those who adapt scientific knowledge completely to their own practical uses, depriving it of all objective and theoretical value. But such statements should not make us forget (as Albert Einstein, for instance, did not forget) that Mach himself, by contrast, has at least glimpsed the profound cognitive matrix, begetter of that theoretical knowledge that seemed to him removed from science.

This is the already noted Machian ambivalence, which sets in when the subject becomes the passage, in scientific work, from the phase of research and discovery to that of using the knowledge acquired through their translation into formulas perfectly fit for similar use. In reality, then, we are dealing with an ambivalence which is actually present in scientific activity – but in the sense of the twofold significance, double value, theoretical and practical, characteristic of scientific knowledge: in which, therefore, there is no relation of exclusion but rather of mutual involvement between theory and practice.

This twofold significance, however, effectively risks becoming, in the Machian perspective, ambivalence, ambiguity, for the fact that what often

Archiwum HF_60 2015 KSIAZKA.indb 168 2015-12-15 11:31:49

transpires is the tendency to "reduce" the theoretical matrix, although thus originally identified at the cognitive level, to its presumed practical-empirical base postulated on the philosophical-metaphysical plane. But striving in fact in every way to eliminate from science all concepts "metaphysical" in origin (that is those that are connoted as "absolutes", of the type, for example, of the Newtonian "absolutes" of motion, space, time – upon which modern mechanism hinges), Mach in turn ends up by founding his epistemology on a philosophy that presents characteristics that are still "metaphysical", even though he has naturally always vigorously rejected such a charge. The majority of interpreters have identified in the doctrine of the "elements" the Machian metaphysics (of a subjectivist type). In fact the combinations of the elements constitute our entire world. If, however, only consciousness can establish relations, objects become constructions of the mind.

According to this critical interpretation, therefore, the Machian philosophical theory of the elements would be reduced, as we have said, to a kind of spurious Kantianism or empiriocriticism, based on *a posteriori* instead of *a priori*; or of an empiricism à la Berkeley, but unlike him deprived of the support of a spiritual substance.

Nevertheless, as Mach shows, in particular in *The Analysis of Sensations* and then in *Knowledge and Error*, for him the "elements" are in reality the result of a complete breaking up of the totality or whole given in immediate sensation: they are therefore the final constituent parts of the whole. The breaking up happens on the basis of inter-subjective criteria such as form, and therefore it re-enters the scientific method that has classification and measurement as its aim. It is applied as much to the external world as to the internal, psychic or mental.

Also those that study the human psyche find themselves confronting, not an ego substantial and indivisible, but rather a "Whole-ego not yet analysed", and so can do nothing other than a n a l y s e i t. In fact the method of introspection, of inner perception, of intentionality, of apperception – considered by many the only suitable way to understand genuine inner reality – is not a scientific method; „characteristic of science is analysis" – so the Austrian thinker firmly asserts.

With this statement he places himself in the front line of the considerable body of supporters of the analytic method, so numerous in epistemology and in contemporary philosophy (in particular of a scientific-logical-linguistic orientation). But he also places himself on "metaphysical" terrain – exactly at the moment in which he thinks he is completing the decisive move to abandon it. As always, once more there re-emerges, in fact, the Machian ambivalence. That science is also analysis there is no doubt; but that it

Archiwum HF_60 2015 KSIAZKA.indb 169 2015-12-15 11:31:49

is *only* analysis – this is an arbitrary postulate and therefore "metaphysical" in the deprecatory sense of the term.

A postulate, however, whose inconsistency Mach himself helped to clarify by exploiting, in the way he tried to illustrate first, the heuristic moment of discovery within the scientific method. Upon this moment certainly follows that of placement, arrangement, putting in symbolic form – in a word, analysis. But the first moment, although it too can or ought to take advantage of some analytical help, hinges on a synthetic-intuitive capacity which with one bound gets past the linear concatenation of analysis. Synthesis and analysis are both necessary, and are always present at the same time, in a balanced and appropriate application of the scientific method. Only, their roles are and must be very distinct so as to render them as productive as possible in the construction of the complex edifice of scientific knowledge.

In point of fact Mach applied this idea, but did not recognise it in principle. In the effort to undermine the metaphysics of the "absolute" he ended up by putting in its place a sort of metaphysics of the "relative", even though based on a physical principle, that of the "universal reciprocal dependence of nature's phenomena", which expresses in its turn t h e r e s u l t o f e x p e r i e n c e . The sensible elements in the world – he points out – present themselves as dependent upon one another; and e x p e r i e n c e t e a c h e s that they are subject to variations, as well as that some of them are connected to others, so that they present themselves and disappear together, which is why the presenting of the elements of one type is linked to the disappearance of the elements of another.

In this conception the component "metaphysics" surfaces in the crucial role assigned to experience on the basis of a clear assumption of a sensationalist or empirical nature. In the more sophisticated historical-critical analyses carried out by Mach – and of which we sought to give some meaningful example – there emerges, instead, a position far more adroit and innovative: on the basis of which it is not the "experience" that "teaches" but rather the "experiment", and more precisely the "thought experiment". Thus the conception is not "relativistic" *per se*, to be subject to a "metaphysical" mortgage but rather an axiom that it is the mere "result" of experience. Certainly, the effect of the Darwinian Theory, explicitly recognised by Mach, is not alien to a similar presupposition: in this theory knowledge is in fact conceived as the instrument fit to find in the living environment the means to satisfy the needs of the organism.

This must be the reason why, according to Mach,

Archiwum HF_60 2015 KSIAZKA.indb 170 2015-12-15 11:31:49

> we never in thought reproduce facts in their completeness, but only in those aspects that are important to us, in view of an aim born directly or indirectly from a practical need. Our reproductions of reality are always abstractions[14].

It is clear that environmental conditioning, the need to adapt, natural selection, all go to produce that "cognitive selection" which in turn begets our abstract reproductions of reality; but it is equally clear that this production does no more than pass on, thereby enabling their fulfilment, the demands coming from the natural world, from sensible experience.

As Mach stresses more than once, the hub of the entire process turns out to be the already discussed breaking up of a certain sensory whole into elements, as a function of the fulfilment of vital needs. And so it is reconfirmed that, from this "ideologically" conditioned visual angle, Machian thought depends actually on sensationalist "metaphysics" of a precise Darwinian orientation.

But it must also be added, on the other hand, that Mach's epistemological sensibility makes him feel the limits of such a *Weltanschauung*, urging him in some way to go beyond them. In fact he realises that the "cognitive selection" of the important elements of a sensory whole leaves out other elements that may be no less important from another point of view; and that therefore it must be integrated or substituted by other abstractions. But it is clear that these different points of view go beyond the limits of the basic point of view, which is that of evolutionary adaptation to the environment. Only when other needs – cultural and scientific – make themselves felt do new points of view arise, and therefore new "cognitive selections" aimed at satisfying "interests" rather than real vital "needs". At this point we enter a different "world" ("world three", Popper would say), the world of culture and science.

But in this "new" world do "new" cognitive means become necessary, or not? Even in the reply to this question the oscillations so typical of the Machian philosophy of science come back to breed. They are always due to the twofold need to maintain, even in the upper reaches of knowledge, a relationship of continuity with the sensory base, and to preserve at the same time, however, such reaches from too direct an influence from that same base. The conflictual face-off of similar instances is shown in a more drastic manner in particularly critical cases, as that of Mach's well-known distancing of himself from modern atomic theory. To begin with, he charges

[14] A. D'Elia, *Ernst Mach*, *op. cit.*, p. 98.

Archiwum HF_60 2015 KSIAZKA.indb 171 2015-12-15 11:31:49

it with "applying representations of matter that were formed in a lower stage of culture to phenomena accessible in a higher stage"[15].

Such a theory, that is to say, performs undue extrapolations from the macroscopic to the microscopic, attributing properties that may appear only to immediate perception to bodies that are not available to perception. In this case, therefore, the fundamental "principle of continuity" cannot be applied, since it becomes a mongrel mental procedure, by which some facts genuinely observed are arbitrarily integrated with others that are not observed, with the aim of rendering the microscopic body, the atom, intuitable, and thus knowable in a manner similar to the visible macroscopic bodies. Despite this Mach acknowledges, however, "the heuristic and didactic value of atomism, which resides precisely in its intuitablity, and which sets in motion the more habitual, positive, elemental and instinctive functions of imagination and intellect"[16].

Nevertheless these functions must in the end be substituted by the more abstract ones of conceptualisation, of measurement and formulation mathematically expressed, alone capable of transforming the body-thing into mathematically definable relations, so satisfying the new needs, which are the needs of science:

> Science d e m a n d s that mental reproductions of sensible experiences have an abstract form. Only thus, in reality, can they be u s e d to find, by way of an abstract calculus, from a property classified by abstract measurement other properties dependent on it, to complete the property given only in part[17].

Thus it is confirmed that Mach only glimpsed the decisive heuristic role of the intuitive representation in science, as the errors in interpreting the Galilean experiment of the sloping planes already made clear. The "thought experiment" is the exact bench test for Machian epistemology, the reactant which reveals its internal continuity and secret fractures.

In the chapter dedicated to "thought l experiment" in his work *Knowledge and Error*, Mach identifies his first typical characteristic in the v a r i a t i o n m e t h o d, which already manifests itself in the behaviour of the infant, or also to a lesser extent in that of the animals, when they freely change certain circumstances while keeping others constant, thereby satisfying certain needs. So this is already a form of experiment, of instinctive

[15] *Ibidem*, p. 202.
[16] *Ibidem*, p. 204.
[17] *Ibidem*, p. 170.

Archiwum HF_60 2015 KSIAZKA.indb 172 2015-12-15 11:31:49

character. At the more advanced stages of cultural evolution "experiment guided by thought – Mach states –- founds science, broadens experience with awareness and intention"[18]. Nevertheless – he still underlines – the function of instinct and habit remains important, since it helps to deal with complex situations.

At a higher intellectual level is placed a type of more sophisticated experiment, which is in fact the "thought experiment". This is made use of in the most varied fields, from the artistic to the literary, from the religious and political to the scientific. In each one of these fields it consists in representing certain circumstances and the hopes and expectations that can be linked to them. Only in certain cases, however, among which that of science, one worries whether the representations reflect reality. Why make thought experiments? In the first place for their convenience, since we have our representations more easily to hand than the physical facts, therefore each experimenter must have in mind an ordered disposition before translating it into action.

Secondly, the thought experiments enable one to mentally alter the facts in such a way as to adapt, always for the better, concepts to physical experience, which is always richer than ideas taken in isolation. The outcome of a thought experiment can be (and often is) uncertain, and therefore requires the integration and corroboration of the "physical experiment".

Thirdly, the thought experiments, with skilful manipulation of the method of continuous variation, enable one to discover unsuspected connections, which would not be deducible from a purely logical point of view. As we saw before, the master in this type of very fruitful exploitation of the thought experiment, also from the didactic point of view, was Galileo – but also, to a greater or lesser degree, all the more creative scientists.

Mach, in conclusion, attributes cognitive and didactic weight to thought experiments, and hence it is perhaps the epistemologist that has developed more acutely and explicitly the experimental component in science, claiming its heuristic potentialities beside those of control. Unfortunately later epistemological thought has neglected this innovative import of Machian thought more than it has appreciated its more traditional aspects, like the analytic and the sensational. Mach himself, of course, as we have had the opportunity to see, had not grasped in full the range of this, his new way of criticising science, remaining trapped in the conditioning of powerful philosophical "ideologies".

[18] E. Mach, *Erkenntnis und Irrtum*, *op. cit.*, p. 183.

Archiwum HF_60 2015 KSIAZKA.indb 173 2015-12-15 11:31:49

And perhaps he did not even grasp the exceptional significance of the testimony rendered him by Albert Einstein in an impassioned and appreciative letter of 1913, in which the great scientist decidedly takes his side in the controversy with Planck which we mentioned earlier. In telling him of the delivery of his work on general relativity, Einstein emphasizes that, in case of experimental confirmation,

> your [Mach's] brilliant researches into the foundations of mechanics – despite the unjustified criticism of Planck! – will find splendid confirmation. Actually it is necessary that inertia originated in a type of interaction of bodies exactly in the manner of the observations that Ella expressed on the Newtonian experiment with the bucket [...]. It is with great joy – Einstein concludes – that I communicate this to you, given that I have always considered Planck's criticism unjustified[19].

And yet, despite such an enthusiastic and authoritative recognition, Mach seems never to have openly shown equal enthusiasm for Einstein's theory (indeed, as Popper remembers, he remained firmly against the theory of special relativity). This is indubitably unusual since, as Einstein rightly believed, the principal supporter of the relativist approach, at the epistemological level, was Mach himself, who precisely for this was exposed to the harsh criticism of prestigious scientists such as Max Planck. But a similar attitude, apparently incomprehensible, is perhaps explicable with the outlined philosophical-ideological conditioning that finished by diminishing, perhaps also in the eyes of Mach himself, the revolutionary scope of the critical revision he entered upon. This work of revision remained interrupted in the long period of epistemological reflection dominated by logical-analytical problems, but today, maybe, the right conditions are returning for a fruitful renewal of the more original and innovative ideas scattered throughout the works of Mach. ~

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[19] See A. D'Elia, *Ernst Mach*, *op. cit.*, p. 243.

Archiwum HF_60 2015 KSIAZKA.indb 174 2015-12-15 11:31:49