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## Ernst Mach and the Theory of Relativity\*

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The first published work of Ernst Mach's to deal explicitly with the theory of relativity ('Relativitätslehre') appeared five years after his death. In his "Prinzipien der physikalischen Optik" (Mach 1921) Mach writes succinctly:

'I gather from the publications which have reached me, and especially from my correspondence, that I am gradually becoming regarded as the forerunner of relativity. Today I am now able to picture approximately what interpretations and misinterpretations many of the ideas expressed in my book on Mechanics will receive in the future from the point of view of relativity.

It was to be expected that philosophers and physicists should carry on a crusade against me, for, as I have repeatedly observed, I was merely an unprejudiced Rambler, endowed with original ideas, in varied fields of knowledge. I must, however, as assuredly disclaim to be a forerunner of the relativists as I withhold from the atomistic belief of the present day.

The reason why, and the extent to which, I discredit the present-day relativity theory, which I find to be growing more and more dogmatical, together with the particular reasons which have led me to such a view – the considerations based on the physiology of the senses, the epistemological reservations, and above all the insights resulting from my experiments – must remain to be treated in the sequel.

The ever-increasing amount of thought devoted to the study of relativity will not, indeed, be lost; it has already been both fruitful and of permanent value to mathematics. Will it, however, be able to maintain its position in the physical conception of the universe of some future period as a theory which has to find a place in a universe enlarged by a multitude of new ideas? Will it prove to be more than a transitory inspiration in the history of this science?

München-Vaterstetten, July, 1913

Ernst Mach.'

As far as I can see, the *authenticity* of this text has never been doubted up to now in the secondary literature on Mach. This is also true of the corresponding, shorter quotes attributed to Ernst Mach which are located in the preface to the ninth edition of Mach's "Mechanik" (Mach 1933). The preface to this edition is signed by Ludwig Mach, Ernst Mach's

\* The lecture format has been retained. A book is <sup>finished\*</sup> ~~in preparation~~ containing an extensive documentation of what in this limited space can only be maintained as well as a good deal more. The remarks on Einstein's undated letter were taken from the abstract.

\* Mach I, Mach II, Einstein und die Relativitätstheorie.  
Eine Fälschung und ihre Folgen (to be published 1967).  
(de Gruyter, Berlin / New York)

eldest son. It was also Ludwig Mach who had brought Ernst Mach's "Optik" to press.

A series of documents, which I have uncovered, as well as a partial re-interpretation of those previously known, have led me to the conclusion that both of the texts attributed to Ernst Mach which reject the theory of relativity are *not authentic*. According to my hypothesis they were written by *Ludwig Mach*. Furthermore, my suspicion is that Ludwig Mach felt himself justified in doing so, possibly because of a misinterpretation of his father's statements, which was influenced by his own miserable personal circumstances.

How correct my view is depends on several necessary conditions being fulfilled. 1. There should be no statements in existence in addition to the ones mentioned which can be proved to have been from Ernst Mach and which reject the theory of relativity or are decidedly opposed to it. 2. There should be no manuscript or typescript of the "Optik" preface or of the shorter remarks in the "Mechanik" in existence which were demonstrably written or approved by Mach. *Both* conditions have been fulfilled: (ad 1) There exist three very short, but pertinent footnotes published by Mach. In these footnotes Mach refers to the theory of relativity without mentioning it explicitly. The thematic context always remains the problem of space and time. The connection with the theory of relativity is made by mentioning proper names: Lorentz, Einstein, Minkowski. A more precise analysis of the passages reveals that they should be understood as attempts on the part of Mach to establish a continuity between his ideas about space and time and the newer conceptions, at least as far as a critique and clarification of these concepts are concerned. Mach is reclaiming provisionally his place in the history of science. We have used 'provisionally' here because Mach believed like most of his contemporaries that the last word had not been spoken on the subject of relativity. If the whole matter should turn out well, then Mach was intent upon having his name put down as an important milestone in the development of the theory of relativity. Unlike the cautiously positive published statements to the theory of relativity we know of at least one *emphatically positive* remark in the *correspondance* written in 1914. This is in a letter addressed to Joseph Petzoldt. (ad 2) The second necessary condition has also been met: the manuscript of the "Optik" is in possession of the Ernst Mach Institut in Freiburg (Germany). Both the introduction and the actual text are either written in Ernst Mach's own handwriting or carry clear signs of his editing. The typescript of the preface to the "Optik", however, was clearly written *after* Ernst Mach's death, presumably in the spring of 1921.

An additional though less important condition has also been fulfilled in addition to both of these 'technical' conditions. The older relativity

theorists, particularly Einstein himself, had grounds for the conviction that the general theory of relativity (and in a sense also the special one) owed much to Mach's thought. It was correspondingly an enormous and unpleasant surprise when Mach's "Optik" appeared with the quoted passages in 1921. As expected, they attributed this strange phenomenon to *external* factors. Mach's age and illness, as well as Hugo Dingler's negative influence were the most important. (Dingler was an unpaid university lecturer (although 'professor') and only allowed to lecture at the university of München on 'The Methods, Teaching and History of the Mathematical Sciences', a subject for which no regular teaching positions were available. The faculty had not agreed to his habilitation in 'Mathematics'.) The first of these two arguments (age and illness) is plausible in principle. In Mach's case, however, there are significant factors opposing this explanation, which rob this otherwise sensible argument of all plausibility. It is clearly false to assume that Dingler influenced Mach. Recent historians of science such as Blackmore (1972) and Holton (1973) have felt themselves obliged to add *internal* explanatory factors to these external ones. These have without exception little support in Mach's writings and are either incorrect or highly implausible. A single exception can be cited. Paul Feyerabend (1984) demonstrates that there might be reasons why one should assume that Mach's accusation of dogmatism against the theory of relativity must be traced to its reception through Planck. Feyerabend's assumption contradicts neither Mach's texts nor the fundamentals of his thought and thus has a certain plausibility. External factors place the internal consistency of Feyerabend's observations in question and make them in turn implausible as historical fact.

The sole evidence for the authenticity of the "Optik" preface is simply that it was printed posthumously with Ernst Mach's signature. And this is certainly not very much. The documents I have uncovered, however, reveal something entirely different: Mach's son Ludwig (referred to in the following as 'Ludwig') developed a hostile attitude to the theory of relativity only in 1919. Like his father, he was still clearly in agreement with it by the middle of 1914. This is revealed in Mach's letter to Joseph Petzoldt from April 27th, 1914. Less than a year *after* he was supposed to have rejected the theory of relativity, Ernst Mach wrote the following: 'I have meanwhile received the copy of the positivist journal containing your article on relativity which pleased me not only because you fully recognized the merits of my modest contribution (bescheidenen Verdienste) to this topic but in other ways as well (sondern auch sonst).' In my opinion we can make the following observations on the basis of this passage: 1. Towards the end of April 1914 Mach is pleased that his role as forerunner of the theory of relativity has been clearly emphasized. This,

however, is precisely what the preface to the "Optik" written supposedly a year before, decisively rejects. 2. Mach was also pleased 'in other ways' with Petzoldt's article. This is particularly important. Petzoldt's article is titled "The Theory of Relativity in Physics" (Die Relativitätstheorie in der Physik), but this is actually misleading. The title should have been worded in something like the following way: "The Theory of Physical Relativity as Continuation and Logical Extension of Mach's Theory of Knowledge". The whole article is full of emphatic references to Mach and takes a *very* positive stand on Einstein's theory despite admittedly marginal criticisms. Mach can only have meant this positive attitude when he mentioned in his letter that Petzoldt's work pleased him 'in other ways as well'. What I would like to stress here is that Mach had a positive attitude toward the theory of relativity at the end of April, 1914. (Petzoldt's critique of the theory of relativity refers in particular to the assumption of a constant velocity of light, which is part of the basis of the special theory. This criticism, however, is admittedly only marginal for Petzoldt and did not affect what he considered to be the fully correct direction, in which the theory was pointing.) Another letter Mach wrote to Petzoldt a few days later on May 1st, 1914 reveals how positive Mach's opinion was of the theory of relativity: 'The enclosed letter from Einstein is proof of the fact that positivist philosophy has invaded physics. You should be pleased. A year ago philosophy was still a mere blunder (eine bloße Dummheit). — The details confirm this'. I think it is impossible to interpret this letter in any other way than the following: *In May, 1914* Mach measured the value of philosophy according to the extent to which it was able to invade physics and particularly the theory of relativity. And he considered philosophy 'a mere blunder' before it succeeded in gaining entry. It should be clear that up to 1914 Mach certainly did not have a negative attitude toward the theory of relativity, provided that the statements just quoted are not considered completely hypocritical. I can hardly imagine how it should be possible to furnish proof of this. Additional evidence for Mach's positive attitude toward the theory of relativity *after* July, 1913 (the supposed date of the "Optik" preface) can be gathered from a letter Einstein wrote to Mach. This letter has given historians of science a lot of headaches. Mach and Einstein corresponded with each other. The letters Mach wrote to Einstein are lost (probably for ever). Einstein wrote Mach at least four times. Three of these letters are dated, *one* is not. Those dated are: 1. a letter dated August 9th, 1909. 2. A postcard dated August 17th, 1909, in which Einstein expresses his pleasure that Mach was 'pleased with the theory of relativity'. 3. A letter from June 25, 1913. An unusual balancing act has occurred concerning the dating of the fourth letter. At the very beginning

Einstein expresses pleasure 'at the friendly interest that you [Mach] show in the new theory'. In order to assist the reader in understanding this issue, I have quoted those portions of the letter relevant for dating it:

'I am very pleased at the friendly interest you show in the new theory. The mathematical difficulties one encounters when following this reasoning are unfortunately also very great of me. I am extraordinarily pleased that the depth and importance of your investigations into the foundations of classical mechanics have been revealed with the development of the theory. Today I still cannot grasp how Planck whom I have otherwise learned to value more than practically anyone else, could bring so little understanding to bear on your efforts. He has moreover also taken a negative attitude toward my new theory. [...] For me it is absurd to ascribe physical characteristics to "space". The totality of mass generates a  $G_{\mu\nu}$ -field (gravitational field) which in turn controls the course of all processes, including the dispersion of light rays and the behaviour of measuring rods and clocks. I will send you shortly some publications on this subject in which formal aspects are reduced and the content (das Sachliche) emphasized as much as possible. But I haven't really succeeded with these abstract things in separating the content from the form.

With best wishes for the new year,

yours sincerely,

A. Einstein.' (Herneck, 1966a)

The above mentioned balancing act in the secondary literature with respect to the date of the letter is a result of the following: Whoever assumes that Mach bluntly rejected the theory of relativity 'in July, 1913' will have to connect the following facts with this date: 1. Mach had taken a 'friendly', i.e. most likely a positive interest in Einstein's 'new theory'; 2. This 'new theory' deals with  $G_{\mu\nu}$ -fields (gravitational fields); 3. Mach expressed himself on this subject around one of the New Years prior to 1913 as well as 4. the previously quoted letter that Mach wrote to Petzoldt on May 1st, 1914.

An additional factor pertinent to dating the letter is Einstein's assumption in the letter from June 25, 1913 that Mach had received his [Einstein's] 'new work on relativity and gravitation'. The eclipse of the sun in the following year (1914) should bring the empirical proof of the bending of light rays in the gravitational field of the sun which Einstein's theory required. 'If yes', Einstein continues, 'then your ingenious investigations into the foundations of mechanics would receive a brilliant confirmation. It would then necessarily follow that *inertia* originates in a sort of *interaction* between bodies, quite in line with your thoughts on Newton's bucket experiment. You will find a first result (eine erste Konsequenz) in this sense on page 6 of my paper.' (Herneck, 1966a)

Now I will turn to the question of the proper date. 1. F. Herneck

(1963, 242) writes: 'Two dates can be considered for the letter which was composed at some point between the postcard from 8/17/1909 and the letter from 6/25/1913. Since the subject was the 'new theory', the so-called 'Prague theory', Einstein wrote the letter – judging from the concluding remark – at the earliest in Prague around the turn of the year 1911/12 and at the latest in Zürich around the turn of the following year.' The latter date, because of the 'mathematical problems' mentioned by Einstein, which he solved only with the help of Marcel Grossmann 'during his second professorship at Zürich (1912/13)'. – Herneck (1966a, 8) considers this date (1912/13) 'more probable' than 1911/12, while Herneck (1966b, 51) favors 'around 1912' without further comment. 2. G. Holton (1973, 228), in favor of 'around New Year's 1911–12', adds the explanatory (?) comment: 'perhaps just before or after Einstein's sole (and, according to Philipp Frank's account in *Einstein: His Life and Times*, not very successful) visit to Mach, and after the first progress toward the general relativity theory.' 3. A. Pais (1982, 282) is in favor of 'around January 1913'. But he gives no support for this contention which is probably only motivated, as in the case of Herneck and Holton, by the compelling *terminus ante quem* 'July, 1913'. This is all the more surprising as Pais supplies sufficient grounds for assuming that the dating is incorrect in his book, which is hard to surpass in knowledgeableness, good judgement and excellent presentation. – Correct is, however, *that Einstein wrote the letter around New Year's 1913/14*. The 'new theory' Einstein mentions in both letters is not the 'Prague theory'. This can be seen 1. by simply comparing what was discussed in the Prague papers with what Einstein wrote Mach about his 'new theory'. 2. Neither Mach, whose mathematical abilities were often underrated because of a misinterpretation of his own occasional remarks about these abilities nor Einstein could have had trouble with the mathematics in the Prague papers. 3. Einstein was not so satisfied with his work in Prague, as one can gather from Pais (1982, 192 ff.), that he could have presented it proudly as his 'new theory'. Whoever is not convinced by all of this should try to find a reference to Mach on page 6 of one of the Prague papers. – There is *none*. All of the points mentioned here that do not apply to the 'Prague theory' do in fact apply to Einstein/Grossmann (1913), including the remark 'page 6', which refers to the pagination in the *special impression*. And it was this impression that Mach received from the publisher. In this special impression 'page 6' Einstein honors Mach's 'bold thought, that inertia originates in a sort of interaction between the observed mass point with all other (masses)'. 4. Furthermore, the metric tensor  $G_{\mu\nu}$  appears for the first time in the above mentioned work from 1913. Einstein was able to use the mathematical tool of tensor analysis only after his friend Gross-

mann had introduced him to it upon his return to Zürich from Prague. This introduction took place, as Pais (1982, 213) has convincingly shown, in the week prior to August 16th, 1912.

What can we infer from all of this? – I would say something quite simple. Einstein instructed his publisher to send Mach a special impression of Einstein/Grossmann (1913). This work probably appeared in June, 1913 and on June 25th, 1913 Einstein wrote a letter to Mach commenting the work. Mach indicated, what Einstein understood as ‘friendly interest’, but also difficulty in understanding the mathematical apparatus which had not been available to Einstein either until shortly before. I assume that this took place towards the end of 1913 because Einstein’s answer seems to have been a direct response to Mach’s letter. Einstein wrote accordingly his undated letter to Mach around New Year’s 1913/14. – At this point I can only recommend reading the two letters from Einstein dealt with here in the chronological order I have suggested. One may perhaps wonder at ever having read them in a different order.

Between May, 1914 (letter to Petzoldt) and Mach’s death (February, 1916) I am aware of no further statements by Mach concerning the theory of relativity. Even if such statements should be found in previously unknown documents, this would not change the fact that the preface to the “Optik” published under his name was *not* written by him. For Mach cannot have written the preface at the time of its supposed composition, if we attribute to him a halfway consistent behavior. Which we must do on the basis of all that we know. ‘Cannot’ also means that Mach was incapable of writing the preface if we consider what actually happened in the years prior to the publication of the “Optik”. ‘Cannot’ means furthermore that there are no convincing arguments that make Mach’s rejection of the theory of relativity plausible. The latter is of course no stringent proof, since such arguments could still be made. As yet I have seen no sign of them anywhere. – In this paper I would just like to touch briefly on the *historical* ‘cannot’.

As can be seen from a footnote to the preface, the publication of the “Optik” began in the Summer of 1916 and lasted until 1921. Ludwig Mach attended to the printing. Mach spent the last three years of his life at Ludwig’s house in München-Vaterstetten. Ludwig had already dedicated his own life more or less to his father for some time. In these last years he became his father’s physician, nurse, private secretary, and experimental assistant. When Mach finally died in 1916 at the age of 78, the 48 year old physician, Ludwig, who had moreover only practiced for a short time, was without a job. The unlucky Ludwig had invested most of what he had earned from optical patents, in war bonds. He might have already foreseen at that time that he would have to write off this investment. The future



looked dim. Induction into military service was impending and occurred soon thereafter. Ludwig spent the rest of the war with an air force unit in Berlin.

While in Berlin in May, 1917 he received mail from Hugo Dingler, the philosopher and historian of science (but *not* physicist) from Munich. Dingler had visited Mach three times between June, 1913 and the outbreak of the war and met Ludwig at least once on these occasions. In the letter from May, 1917 we have just mentioned, Dingler inquired about the "Optik" and remarked: 'He [Mach] certainly did not allow his classical way of viewing the secular guidelines of the development to be very much modified by modern endeavors whose duration is in no way predictable.' Ludwig answered by return mail on May 8th. 'You are quite right, he spoke sometimes with a touch of irony (leise ironisierend) about the theory of electrons, the relativity as if he wanted to dampen the great enthusiasm a little.' — This seems to me to be an important statement of Mach's *actual* attitude toward the theory of relativity. In fact there had already been a certain ruckus about relativity in 1914. This came about as a result of the attempt to measure the bending of light in the gravitational field of the sun during the eclipse in Russia in August 1914. I consider it very plausible that Mach cautioned restraint 'with a touch of irony' on this point or with respect to similar things as well. For one of the principles, which he may have drawn from his historical analyses, might have been that theories normally need a long time until they have attained an acceptable standard. 'Just a while' may have been the motto, but along with a *fundamentally positive attitude* to the theory of relativity as a further step away from a 'mechanistic view of nature' to the view of nature in the future, which in Mach's eyes essentially carries characteristics of the theory of electromagnetism. For Mach the direction is the right one, only that exaggerated and hasty enthusiasm should be dampened 'a little'.

Towards the end of 1919 Dingler and Ludwig became increasingly close. At the end of the year Dingler's "Grundlagen der Physik" appeared. Dingler attacked the theory of relativity for the first time in this publication, though not quite as sharply as was later the case. At this point in time Ludwig had not divulged his secret to Dingler. Dingler still believed early in 1920 that he had fallen into disfavor with Ludwig Mach because he has spoken out so vehemently *against* the theory of relativity. All the same, the documents in my possession reveal that Ludwig made the attempt at precisely this time to replace his father with Dingler as intellectual mentor. Ludwig's plan was that *together* they should take over the legacy and develop especially the 'experimental insights' directed against the theory of relativity which the preface to the "Optik" had promised.

Quite a grotesque project with the blind (philosopher and (unsuccessful) mathematician, Dingler) leading the blind (physician and inventor, Ludwig).

At just about the same time the project for a new edition of Mach's "Mechanik" got underway. In his testament Mach had empowered Petzoldt with the publication of the new editions of the "Mechanik" and had given him the right to touch on newer developments in the appendices. This meant in view of the state of affairs — let me draw attention to Petzoldt's above mentioned article from 1914 — that Petzoldt would honor the merits of Mach's contributions to the theory of relativity. At first Ludwig also had no objection to this project. Petzoldt wanted to write an appendix on Mach's epistemology with special reference to the theory of relativity and directed an inquiry at Ludwig, who understood this as if he, Ludwig, as physicist, which he was not in any formal sense, should write something on the theory of relativity from the point of view of physics. Realistically, Ludwig had to reject this offer, which he did in the following way: 'What should I write as a 'physicist' [quotes by Ludwig Mach]', the 51 year old Ludwig responded. 'If the war had not come, I had done something on relativity and had something to say *in the spirit* [im Sinne von, my italics] of E. Mach, but that must take place sometime later, if at all.' — This statement from December 26th, 1919 is especially interesting. It implies (1) that Ludwig at that time, i.e. the end of 1919, knew of *nothing* he could pass on which *Mach himself* had said on the theory of relativity and (2) that at the very most he could say something *in the spirit* of the deceased. According to customary usage of 'to do something in the spirit of a person x' and with respect to what I have to say under point (3) that means: applying x's intentions to a concrete case. (3) Ludwig admits to knowing his father's intentions *and* that realizing them could not be accomplished without further difficulty, i.e. that realizing them would presuppose work on *Ludwig's* part. I shall touch on that point again in connection with Ludwig's experiments towards the end of this paper. — In any event, it should be clear that any reservations on Mach's part concerning the theory of relativity must have been *hypothetical*. Reservations of the following sort: 'If one *could* demonstrate this or that experimentally, then a serious argument against the theory of relativity *would* develop out of this'.

By the middle of February, 1920 Ludwig had recognized that at least part of his own future lay in the experimental realization of his father's intentions (which I suspect were misunderstood by him) as well as in the further management and exploitation of his legacy. But Joseph Petzoldt as Mach's executor in matters concerning the "Mechanik" stood in his way. The disagreement between Ludwig and Petzoldt over the

“Mechanik”, which I can document, shows how step for step an anti-relativism develops in Ludwig under Dingler’s influence, an anti-relativism which he then ascribed to his father.

The passage just quoted from the letter to Petzoldt dated December 26, 1919 shows that Ludwig is still not in a position to realize his father’s intentions as he understood them. On February 14th, 1920 he is one step further. He writes to Petzoldt: ‘Prior to the publication of part II of the “Optik” I *can* [italics L.M.] take no stand on relativity in his [i.e. Mach’s] sense. But Dingler will make you reconsider.’ Here as well as there can be found no realization of his father’s presumed intentions. He does, however, begin to see more clearly that he will realize them *negatively*. This is due to Hugo Dingler, whose almost messianic anti-relativistic sense of mission Ludwig can in no way withstand. Furthermore, Ludwig is determined to realize his father’s supposed intentions in a second volume of the “Optik”, with Dingler as his intellectual mentor. The third step is finally reached with the preface to the “Optik”. But at this final stage one is still looking in vain for realization of Mach’s supposed intentions. The preface only offers a *program*: arguments, based on the physiology of the senses, epistemological and ‘above all’ experimental arguments are supposed to be presented. But it never went that far. And Dingler still complained bitterly after Ludwig’s death in 1951 that Ludwig had ‘led him around by the nose’ for thirty years.

Two years after the “Optik”-preface Ludwig was still plagued by a bad conscience. When in January 1923 he still wanted to explain to Petzoldt that Mach was against the theory of relativity, he did it in the following way (and please pay close attention to the personal pronouns): ‘In *our* experiments *I* for *my* part not only rejected but also attempted to uncover what was absurd or nonsensical, and so on this purely physical basis there arose [with whom?] a new attitude [with whom?] in the relevant questions’ (emphasis and additions are G.W.). What is especially interesting in an additional way about this letter is the fact that the *first draft* referred to ‘the rejection’ instead of ‘new attitude’. In view of the “Optik”-preface ‘rejection’ is certainly the appropriate expression, however its relation to the facts is questionable to say the least. The right feeling for this may have moved Ludwig to speak nebulously of a ‘new attitude’. In this quote, and others could be added, Ludwig Mach reveals a certain reluctance to openly tell an untruth. He clearly suggests this misrepresentation and in fact he must do so because in the preface to the “Optik” he presents his father’s supposed intention as already having been realized. In an enormous amount of material one looks in vain for a clear sentence such as the following: ‘Ernst Mach rejected the theory of relativity for such and such reasons.’

Nonetheless I believe that Ludwig *acted in good faith to a certain extent*, because he believed he knew his father's intentions. He never possessed the means to realize them, however, although he does not only suggest this in the "Optik"-preface. My reasons for assuming this are first of all related to his (i.e. Ludwig's) own personal situation. Ludwig was completely isolated at the time he wrote the preface. He had lost almost all of his savings. He had no profession at the age of 52 and was addicted to drugs (cocain). It seems as if Ludwig had misinterpreted his father's statements in this situation. This misinterpretation was most likely based on remarks of his father concerning possible experiments on the general theory of relativity done with the help of the interferometer. Ludwig was an expert in the field of interferometry and had designed a new type of interferometer, probably together with Mach. His plan was to measure interferometrically the bending of light rays by *small* masses. He mentions trees, balls etc. as acceptable objects for experimentation. But I can hardly imagine how this experimental set-up could possibly have been devised by Mach. I would tend to assume a misinterpretation on Ludwig's part of casual statements made by Mach on the theory of relativity in the same vein as the above mentioned quote from the 1917 letter.

However that may be. – I hope that what little I have told you here about my research on Ernst Mach's relationship to the theory of relativity will help to clarify the widely accepted view of Mach in the philosophy and history of science. I would especially like to correct the view of those who consider him a dullwitted sensualist who was not even in a position to recognize the progress of physics in his time.

For this reason I dedicate my paper to the memory of Ernst Mach and the 100 anniversary of the publication of the "Mechanik" (1883–1983).

(Translated by Steven Gillies)

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