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History and Root of the Principle of the Conservation of Energy

The Austrian scientist Ernst Mach (1838–1916) carried out work of importance in several fields of enquiry, including physics, physiology and psychology. In this short work, first published in German in 1872 and translated here into English in 1911 by Philip E.B. Jourdain (1879–1919) from the 1909 second edition, Mach discusses the formulation of one of science's most fundamental theories. He provides his interpretation of the principle of the conservation of energy, claiming its foundations are not in mechanical physics. Mach's 1868 work on the definition of mass – one of his most significant contributions to mechanics – has been incorporated here. His perspective on the topic as a whole remains relevant to those interested in the history of science and the theory of knowledge. Also reissued in this series in English translation are Mach's *The Science of Mechanics* (1893) and *Popular Scientific Lectures* (1895).

History and Root of the Principle of the Conservation of Energy

Ernst Mach
Translated by
Philip E.B. Jourdain

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HISTORY AND ROOT

OF THE PRINCIPLE OF THE

CONSERVATION OF ENERGY

BY

ERNST MACH

TRANSLATED FROM THE GERMAN AND ANNOTATED BY

PHILIP E. B. JOURDAIN, M.A. (Cantab.)

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CONTENTS

TRANSLATOR'S PREFACE

The pamphlet of fifty-eight pages entitled *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit.*[1] *Vortrag gehalten in der k. böhm. Gesellschaft der Wissenschaften am 15. Nov. 1871 von E. Mach, Professor der Physik an der Universität Prag* was published at Prague in 1872, and a second—unaltered—edition at Leipzig (Barth) in 1909. To this second edition (pp. iv, 60) were added a short preface and a few notes by Mach himself. This preface is translated below.

Quite apart from the interest which must attach to the first sketch of a way of regarding science which has become of such great importance to students both of science and of the theory of knowledge, this pamphlet is quite essential to the thorough understanding of Mach's work. In the first place, it contains a reprint of Mach's article (1868) on the definition of mass, which is, perhaps, his most important contribution to mechanics; and, in the second place, the discussion of the logical root of the principle of the conservation of energy is fuller than that in any of his later publications.[2]

[1] In the title of this translation, *Arbeit* is translated by *Energy*, as this word conveys a better idea, at the present time, than the older and more literal equivalent of *Work*. In the text, on the other hand, the word *Work* will always be used, as it corresponds more closely to the terminology of science at the time of the first publication of this essay.

[2] Thus, the questions connected with the uniqueness of determination of events are discussed and illustrated very fully in this essay,

It is proper here to give some references to discussions of Mach's point of view in science.

A fairly good general account of Mach's various works was given in Harald Höffding's lectures on modern philosophers held at the University of Copenhagen in 1902;[3] and another account, with a hostile criticism, was given by T. Case in his article "Metaphysics" in the new volumes which make up the tenth edition of the *Encyclopaedia Britannica*.[4] Often valuable criticisms of Mach's position are to be found in the reviews of the first and second editions of the *Analyse der Empfindungen* written by C. Stumpf,[5] Elsas,[6] Lucien Arréat,[7] and W. R. Boyce Gibson.[8]

The last-named writer speaks[9] of the "generous

and it was this essay that formed the starting-point of Petzoldt's development of the view involved.

The essay "On the Principle of the Conservation of Energy" in Mach's *Popular Scientific Lectures* (3d ed., Open Court Publishing Co., 1898, pp. 137–185), though in many respects like the pamphlet of 1872, is not nearly so complete as it is—a remark made by Hans Kleinpeter (*Die Erkenntnistheorie der Naturforschung der Gegenwart*, Leipzig, 1905, p. 150), who therefore pointed out the need for a reprint of this rare pamphlet.

3 In the German translation, by F. Bendixen, of these lectures under the title: *Moderne Philosophen* (Leipzig, 1905), the part relating to Mach is on pp. 104–110. The section devoted to Maxwell, Mach, Hertz, Ostwald, and Avenarius is on pp. 97–127.

4 Vol. XXX, pp. 665–667. Cf. also the references to Mach's work in Ludwig Boltzmann's article "Models" (*ibid.*, pp. 788–790.)

5 *Deutsche Litteraturzeitung*, Nr. 27, 3. Juli, 1886.

6 *Philosophische Monatshefte*, Vol. XXIII, p. 207.

7 *Revue Philosophique*, 1887, p. 80.

8 *Mind*, N.S., Vol. X, pp. 246–264 (No. 38, April, 1901).

9 *Ibid.*, p. 253.

recognition he [Mach] is always ready to give to anyone who succeeds in improving upon his own attempts," and "his still more eager readiness to put fact before theory. With this eagerness to find out the truth is associated a corresponding ardour in developing and applying it when found."

But philosophers seem hardly to have done justice to Mach's work. Mach himself, indeed, has repeatedly disclaimed for himself the name of philosopher; yet, in a sense, any man who forms a general position from which to regard, say, science, is a philosopher.[10] It must be acknowledged that the least satisfactory parts of Mach's writings are those in which he discusses mathematical conceptions, such as numbers and the continuum; and in which he implies that logic is to be founded on a psychological basis; but such things are unconnected with the greater part of his valuable work.

There are three sets of notes to this translation. The first set, referred to by numerals in the body of the text, consists of the notes added by the author to the

[10] Through a reference in the *Jahrbuch über die Fortschritte der Mathematik* for 1904 (Bd. XXXV, p. 78) I learn that D. Wiktorov has published, in Russian, an exposition of Mach's philosophical views, in the periodical whose name, translated, is *Questions of Philosophy and Psychology*, No. 73 (1904, No. 3), pp. 228–313.

J. Baumann (*Archiv für systematische Philos.*, IV, 1897–1898, Heft 1, October, 1897) gave an account of "Mach's philosophy." Cf. also Hönigswald, *Zur Kritik der Mach'schen Philosophie*, Berlin, 1903; and Mach, *Erkenntnis und Irrtum*, 1906, pp. vii–ix. Adolfo Levi ("Il fenomenismo empiristico," *Riv. di Fil.*, T. I., 1909) analyzed the theories of knowledge of Mill, Avenarius, Mach, and Ostwald.

original edition; the second set consists of those added by the author to the reprint of 1909;[11] and the third set, which contains some account of later work by the author and others on subjects connected with the history and root of the principle of the conservation of work, has been added by the translator. Any other notes by the translator, added for the purpose of giving fuller references, are enclosed in square brackets.

Professor Mach has been most kind in carefully reading my manuscript; and so I trust that not all of the freshness, the force of conviction, and the humour of the original are lost in the present translation.[12]

PHILIP E. B. JOURDAIN

THE MANOR HOUSE
BROADWINDSOR
BEAMINSTER, DORSET
November, 1909

[11] These notes are translated, with the exception of one correcting a misprint in the original edition.

AUTHOR'S PREFACE TO THE SECOND EDITION

In this pamphlet, which appeared in 1872, I made the first attempt to give an adequate exposition of my epistemological standpoint—which is based on a study of the physiology of the senses—with respect to science as a whole, and to express it more clearly in so far as it concerns physics. In it both every *metaphysical* and every one-sided *mechanical* view of physics were kept away, and an arrangement, according to the principle of economy of thought, of facts—of what is ascertained by the senses—was recommended. The investigation of the dependence of phenomena on one another was pointed out as the aim of natural science. The digressions, connected with this, on causality, space, and time, may then have appeared far from the point and hasty; but they were developed in my later writings, and do not, perhaps, lie so far from the science of to-day. Here, too, are to be found the fundamental ideas of the *Mechanik* of 1883,[12] of the *Analyse der Empfindungen* of 1886,[13] which was addressed prin-

[12] [*Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt*, Leipzig, five editions from 1883 to 1904; English translation by T. J. McCormack under the title *The Science of Mechanics*, Open Court Publishing Co., Chicago, three editions from 1893 to 1907 (the third edition of this is quoted hereafter as *Mechanics*).]

[13] [*Beiträge zur Analyse der Empfindungen*, Jena, 1886; Eng. trans. by C. M. Williams under the title *Contributions to the Analysis of the Sensations*, Open Court Publishing Co., Chicago, 1897. A

cipally to biologists, in the *Wärmelehre* of 1896,[14] and in the *Erkenntnis und Irrtum*—a book which treats at length questions of the epistemology of physics—of 1905.[15]

Certainly it is right that, in response to repeated demands, this work, which was out of print twelve years ago, should appear in an *unaltered* form. I could not have entertained sanguine expectations as to the immediate result of my little work; indeed, many years before, Poggendorff had refused for his *Annalen* my short essay on the definition of mass, which definition is now generally accepted. When Max Planck wrote, fifteen years after I did, on the conservation of energy,[16] he had a remark directed against one of my developments, without which remark one would have supposed that he had not seen my pamphlet at all. But it was a ray of hope for me when Kirchhoff[17] pronounced, in 1874, the problem of mechanics to be the complete and simplest description of motions, and this nearly corre-

second, much enlarged, German edition was published at Jena in 1900 under the title: *Die Analyse der Empfindungen und das Verhältnis des Physischen zum Psychischen;* and a fifth edition appeared in 1906.]

[14] [*Die Principien der Wärmelehre historisch-kritisch entwickelt*, Leipzig, 1896; 2d ed., 1900. The 2d edition is hereafter referred to as *Wärmelehre*.]

[15] [*Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, Leipzig, 1905; 2d ed., 1906.]

[16] [*Das Prinzip der Erhaltung der Energie*, Leipzig, 1887; 2d ed., 1909. The reference to Mach's work of 1872 is on p. 156 of the second edition.]

[17] [*Vorlesungen über mathematische Physik, Bd. I, Mechanik*, Leipzig, 1874; 4th ed., 1897.]

sponded to the economical representation of facts. Helm esteemed the principle of the economy of thought and the tendency of my little treatise towards a general science of energetics. And, finally, though H. Hertz did not give an open expression of his sympathy, yet the utterances in his *Mechanik* of 1894[18] coincide as exactly as is possible with my own,[19] considering that Hertz was a supporter of the mechanical and atomic physics and a follower of Kant. So those whose positions are near to mine are not the worst of men. But since, even at the present time, when I have almost reached the limit of human age, I can count on my fingers those whose standpoint is more or less near to my own—men like Stallo,[20] W. K. Clifford, J Popper, W. Ostwald, K. Pearson,[21] F. Wald, and P. Duhem, not to speak of the younger generation—it is evident that in this connexion we have to do with a very small minority. I cannot, then, share the apprehension that appears to lie behind utterances like that of M. Planck,[22] that

[18] [*Die Prinzipe der Mechanik*, Vol. III of Hertz's *Ges. Werke*, Leipzig, 1894; Eng. trans. by D. E. Jones and J. T. Walley, under the title *The Principles of Mechanics*, London, 1899.]

[19] [On Hertz's mechanics, see Mach, *Mechanics*, pp. 548–555.]

[20] [*The Concepts and Theories of Modern Physics*, 4th ed., London, 1900.]

[21] [*The Grammar of Science*, London, 1892; 2d ed., 1900. The account of the laws of motion in W. K. Clifford's book: *The Common Sense of the Exact Sciences* (London, 1885, 5th ed., 1907), which was completed by Pearson, agrees with Mach's views; but this statement was due, not to Clifford, but to Pearson, whose (see pp viii–ix of the work just mentioned) views were developed independently.]

[22] [*Die Einheit des physicalischen Weltbildes*, Leipzig, 1909, pp. 31–38.]

orthodox physics has need of such a powerful speech in its defence. Rather do I fear that, with or without such speeches, the simple, natural, and indeed inevitable reflections which I have tried to stir up will only come into their rights very late.

"Not every physicist is an epistemologist, and not everyone must or can be one. Special investigation claims a whole man, so also does the theory of knowledge."[23] This must be my answer to the excessively naïve demand of a physicist who was justly celebrated and is now dead, that I should wait with my analysis of the sensations until we knew the paths of the atoms in the brain, from which paths all would easily result. The physicist who thinks under the guidance of a working hypothesis usually corrects his concepts sufficiently by accurate comparison of the theory with observation, and has little occasion to trouble himself with the psychology of knowledge. But whoever wishes to criticize a theory of knowledge or instruct others about it, must know it and have thought it out. I cannot admit that my physicist critics have done this, as I will show without difficulty at the proper place.

E. MACH

VIENNA
May, 1909

[23] *Analyse der Empfindungen*, 5th ed., p. 255.