Maxwell, Boltzmann, and Hertz on Models and Analogies in Physics

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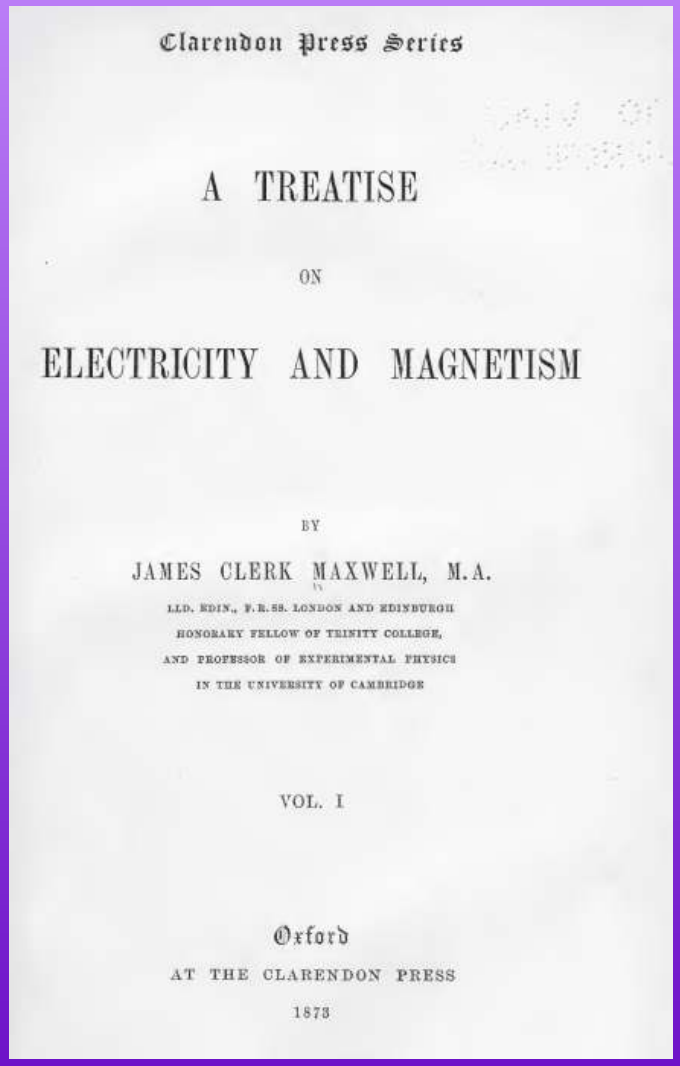

Clarendon Press Series

A TREATISE

ON

ELECTRICITY AND MAGNETISM

BY

JAMES CLERK MAXWELL, M.A.

LLD. EDIN., F.R.SS. LONDON AND EDINBURGH
HONORARY FELLOW OF TRINITY COLLEGE,
AND PROFESSOR OF EXPERIMENTAL PHYSICS
IN THE UNIVERSITY OF CAMBRIDGE

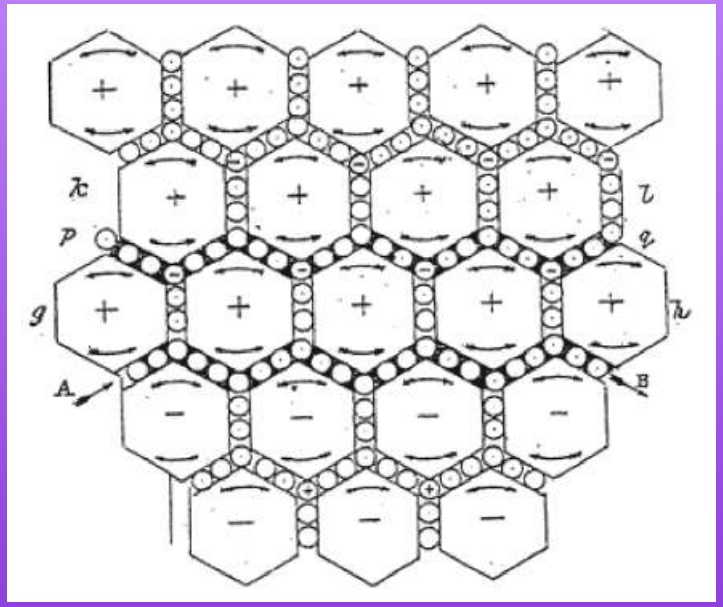
VOL. I

Oxford
AT THE CLARENDON PRESS
1873

Maxwell on Models and Analogies

A mechanical model of the electromagnetic ether.

It appears therefore that, according to our hypothesis, an electric current is represented by the transference of the moveable particles interposed between the neighbouring vortices. We may conceive that these particles are very small compared with the size of a vortex, and that the mass of all the particles together is inappreciable compared with that of the vortices, and that a great many vortices, with their surrounding particles, are contained in a single complete molecule of the medium. The particles must be conceived to roll without sliding between the vortices which they separate, and not to touch each other, so that, as long as they remain within the same complete molecule, there is no loss of energy by resistance. When, however, there is a general transference of particles in one direction, they must pass from one molecule to another, and in doing so, may experience resistance, so as to waste electrical energy and generate heat.



"On Physical Lines of Force." *Philosophical Magazine and Journal of Science*, March 1861.

Two Flawed Historiographies

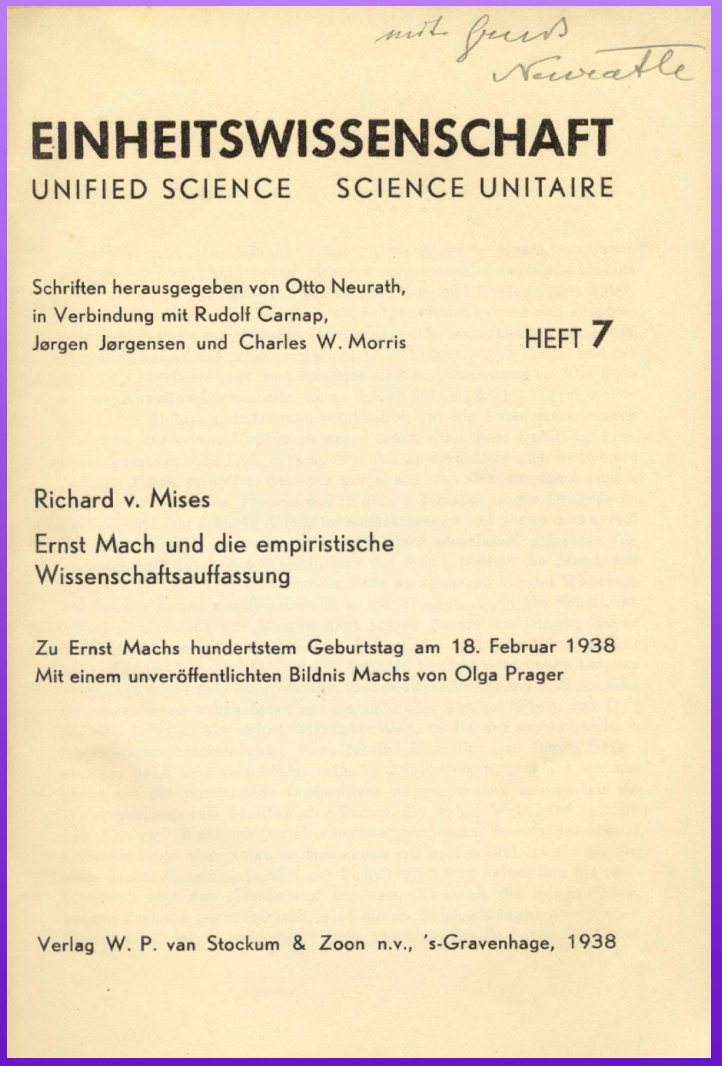
1. The Positivist Historigraphy

Hume => Mill => Mach => Logical Empiricism

Examples

Richard von Mises. *Ernst Mach und die empiristische Wissenschaftsauffassung*. Einheitswissenschaft, vol. 7. Otto Neurath, ed. 's-Gravenhage, 1938.

Viktor Kraft. *Der Wiener Kreis. Der Ursprung des Neopositivismus.* Springer: Vienna, 1950.


mit Gruss
Neurath

EINHEITSWISSENSCHAFT

UNIFIED SCIENCE SCIENCE UNITAIRE

Schriften herausgegeben von Otto Neurath,
in Verbindung mit Rudolf Carnap,
Jørgen Jørgensen und Charles W. Morris

HEFT 7

Richard v. Mises

Ernst Mach und die empiristische
Wissenschaftsauffassung

Zu Ernst Machs hundertstem Geburtstag am 18. Februar 1938
Mit einem unveröffentlichten Bildnis Machs von Olga Prager

Verlag W. P. van Stockum & Zoon n.v., 's-Gravenhage, 1938

Two Flawed Historiographies

2. The Realist Historigraphy

Herschel => Whewell => Peirce => Boltzmann
=> Planck

Example

Ralph M. Blake, Curt J. Ducasse, and Edward H. Madden. *Theories of Scientific Method: The Renaissance through the Nineteenth Century*. Seattle, University of Washington Press, 1960.

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Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models

James Clerk Maxwell, "On Faraday's Lines of Force." *Transactions of the Cambridge Philosophical Society*, 10, Part 1 (1856), 27-83. [Read December 10, 1855 and February 11, 1856.]

The first process therefore in the effectual study of the science, must be one of simplification and reduction of the results of previous investigations to a form in which the mind can grasp them. The results of this simplification may take the form of a purely mathematical formula or of a physical hypothesis. In the first case we entirely lose sight of the phenomena to be explained; and though we may trace out the consequences of given laws, we can never obtain more extended views of the connections of the subject. If, on the other hand, we adopt a physical hypothesis, we see the phenomena only through a medium, and are liable to that blindness and rashness in assumption which a partial explanation encourages. We must therefore discover some method of investigation which allows the mind at every step to lay hold of a clear physical conception, without being committed to any theory founded on the physical science from which that conception is borrowed, so that it is neither drawn aside from the subject in pursuit of analytical subtleties, nor carried beyond the truth by a favourite hypothesis.

In order to obtain physical ideas without adopting a physical theory we must make ourselves familiar with the existence of physical analogies. By a physical analogy I mean that partial similarity between the laws of one science and those of another which makes each of them illustrate the other.

Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models

James Clerk Maxwell, "On Faraday's Lines of Force." *Transactions of the Cambridge Philosophical Society*, 10, Part 1 (1856), 27-83. [Read December 10, 1855 and February 11, 1856.]

[Maxwell gives examples from optics and kinetic theory. About the analogy between light and the vibrations of an elastic medium Maxwell writes:]

The other analogy, between light and the vibrations of an elastic medium, extends much further, but, though its importance and fruitfulness cannot be over-estimated, we must recollect that it is founded only on a resemblance *in form* between the laws of light and those of vibrations. By stripping it of its physical dress and reducing it to a theory of "transverse alternations," we might obtain a system of truth founded strictly on observation, but probably deficient both in the vividness of its conceptions and the fertility of its method.

. . .

It is by the use of analogies of this kind that I have attempted to bring before the mind, in a convenient and manageable form, the mathematical ideas which are necessary to the study of the phenomena of electricity.

Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models

James Clerk Maxwell, “Are There Analogies in Nature?”

Apostle’s Club, February 1856

If all we know is relation, and if all the relations of one pair of things correspond to those of another pair, it will be difficult to distinguish the one thing from the other, although not presenting a single point of resemblance, unless we have some difference of relation to something else, whereby to distinguish them. Such mistakes can hardly occur except in mathematical and physical analogies. . . . Perhaps the “book,” as it has been called, of nature is regularly paged: if so, the introductory parts will explain those that follow, and the methods taught in the first chapters will be taken for granted and used as illustrations in the more advanced parts of the course; but if it is not a “book” at all, but a magazine, nothing is more foolish to suppose than that one part can throw light on another.

James Clerk Maxwell
(1831-1879)

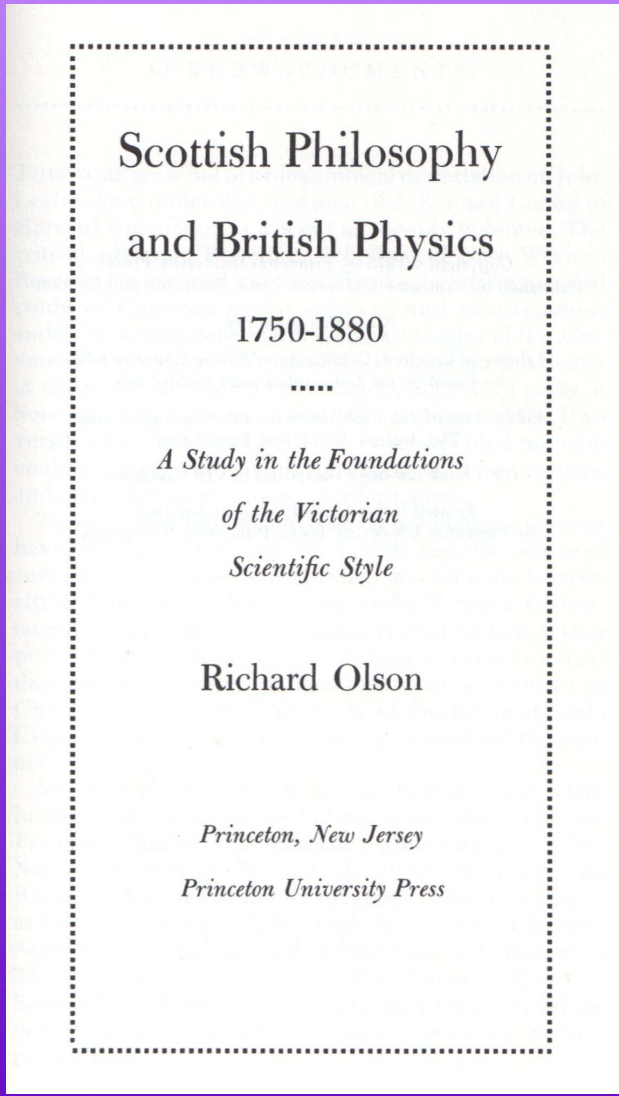
Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models and analogies

One of my favorite books:

Richard Olson. *Scottish Philosophy and British Physics, 1750-1880: A Study in the Foundations of the Victorian Scientific Style*. Princeton, NJ: Princeton University Press, 1975.

Emphasizes the influence on Maxwell of the Scottish Common Sense tradition, especially Thomas Brown, Dugald Stewart, and William Hamilton. Maxwell studied with Hamilton at Edinburgh.



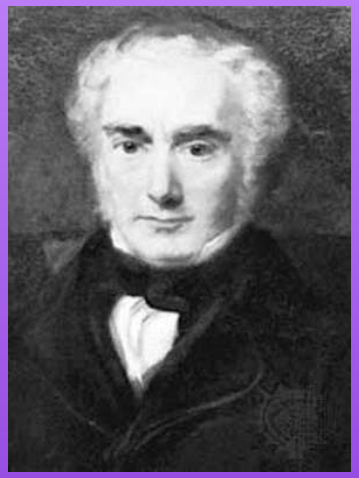
Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models

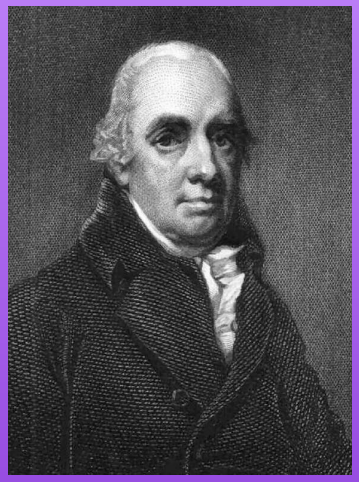
Another favorite:

John Theodore Merz. *A History of European Thought in the Nineteenth Century*, 4 vols. Edinburgh: William Blackwood & Sons, 1903-1912. Vols 1 and 2 reprinted as A *History of European Scientific Thought in the Nineteenth Century*. New York: Dover, 1964.

Also discusses the influence of what he terms the "Scot's School" on physicists like Maxwell, William Thomson, and P. G. Tait.



William Hamilton
(1788-1856)



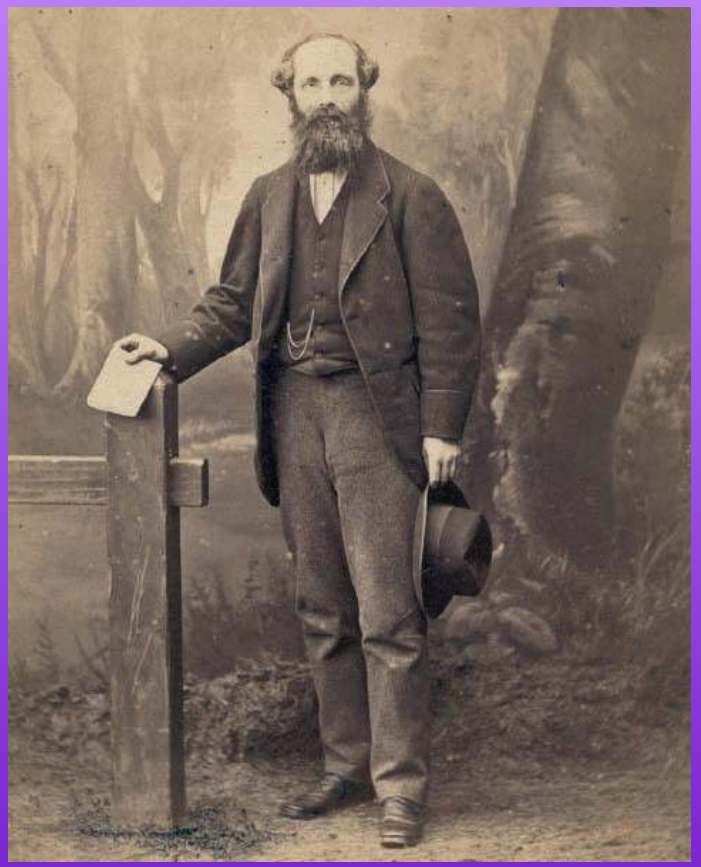
Dugald Stewart
(1753-1828)

Maxwell on Models and Analogies

Maxwell on the heuristic and psychological role of models

The Scottish Common Sense view of models:

1. All knowledge is relational.
2. Analogies and models are among the chief such relational modes of knowing.
3. Analogies and models are necessary for psychological reasons. For most people, understanding requires the use of models for simplifying and organizing knoweldge. One cannot understand an uninterpreted mathematical formalism.
4. Strong psychologistic tendencies in the Scottish Common Sense tradition.
5. The importance of varying analogies.



Boltzmann on Models

The Lübeck Naturforscherversammlung and the Energeticism Debate

Ludwig Boltzmann (1844-1906)

Georg Helm (1851-1923)

Wilhelm Ostwald (1853-1932)

Boltzmann on Models

The 1895 Lübeck Naturforscherversammlung and the Energeticism Debate

Georg Helm. *Die Energetik nach ihrer geschichtlichen Entwickelung*. Leipzig: Veit & Comp, 1898.

But one does not, therefore, need to go as far as Ostwald has done, and simply reject models. . . . Energetics does not at all need to combat models as being *inimical;* for they are, in truth, *subordinate* to it, however independently they may behave. How . . . do we recognize whether a model proves correct? One says, by its agreement with experience, or by the agreement of its logical consequences with experience. But how then? Is not then the model qualitatively different from the fact that it models, how can one compare it or its consequences with the latter? Where is the *tertium comparationis*? Consider an example. One devises a model for describing thermal phenomena, a certain quantity that is not heat is supposed to represent the heat, another the temperature. What does it mean then to test in experience whether the model is usable? All of the traits of the model do not agree with our experiences of heat; otherwise it would not be a model. Which must agree in order to satisfy exact science? *Only energetics* provides the answer to this question. We can treat as heat only a quantity that can be conceived as an energy form, e.g., that submits to the principle of the conservation of energy; as temperature we can recognize only such a quantity as shares with the temperature, e.g., the property of being an intensive magnitude. In short, the traits that the model must reproduce are exactly those necessary for a perfect quantitative description of experience, exactly those portrayed in energetics. Thus, in every sense, energetics stands *over* the mechanical models, she is their judge; only through her critique is it determined whether the model is a correct description of reality, no empty play of the fantasy, but rather poetic truth.

Boltzmann on Models

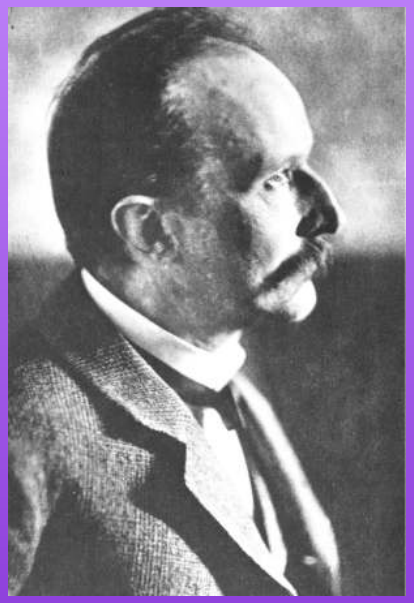
The Planck-Mach Controversy

Max Planck. “Die Einheit des physikalischen Weltbildes.” *Physikalische Zeitschrift* 10 (1909), 62- 75. [The famous “Leiden” lecture.”]

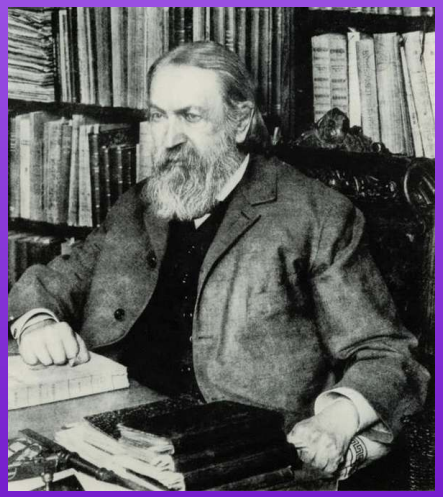
Ernst Mach. “Die Leitgedanken meiner natur-wissenschaftlichen Erkenntnislehre und ihre Aufnahme durch die Zeitgenossen.” *Scientia* 7 (1910), 2ff. Reprinted in *Physikalische Zeitschrift* 11 (1910), 599-606.

Max Planck. “Zur Machschen Theorie der physikalischen Erkenntnis. Eine Erwiderung.” *Physikalische Zeitschrift* 11 (1910), 1186-1190.

Max Planck. *Positivismus und reale Aussenwelt.* Vortrag, gehalten am 12. November 1930 im Harnack-Haus der Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften. Leipzig: Akademische Verlagsanstalt,1931.



Max Planck (1858-1947)



Ernst Mach (1838-1916)

Boltzmann on Models

Some Cautions

1. What looks to modern philosophers' eyes like a philosophical debate, such as the debate over the reality of atoms, might have been more a scientific debate in the eyes of the original participants in the debate. Example: Anomalous specific heats and atomism.

2. Interpreting a formalism by means of a model or arguing that only a model provides understanding does not imply realism about the model.

3. Recall that, even by the mid-1890s, the separation between philosophy and psychology that we now take for granted was not common. Psychologism and, more generally, epistemological naturalism were still common, if not still the norm. Thus –

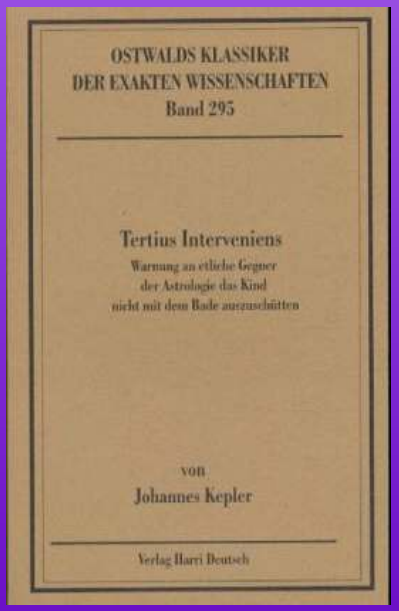
"Let us analyze this further: in accordance with our introductory remarks, we have not proved anything but merely described; nor, in the sequel, shall we be able to prove anything, but merely to develop certain views psychologically."

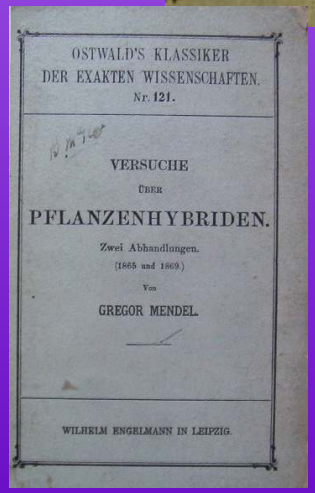
Ludwig Boltzmann. "Über die Frage nach der objektiven Existenz der Vorgänge in der unbelebten Natur." *Akademie der Wissenschaften* (Vienna). *Sitzungsberichte* 106, Part II (January 1897), 83ff.

Boltzmann Edits Maxwell

Ostwalds Klassiker

Scores of classic works, translated and edited with helpful historical and analytic commentaries, often by Ostwald, himself, but in some cases by the very best of Ostwald's scientific contemporaries.

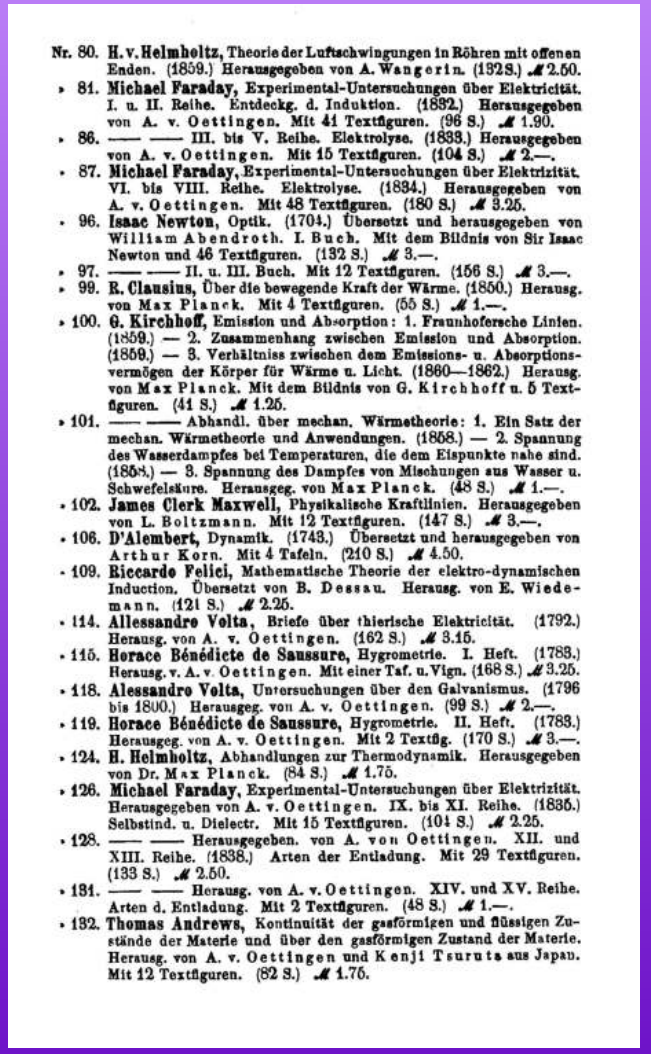




Boltzmann Edits Maxwell

Ostwalds Klassiker

When Boltzmann's edition of Maxwell's "On Physical Lines of Force" was published in 1898, the Klassiker series comprised one hundred and eighty-eight titles.



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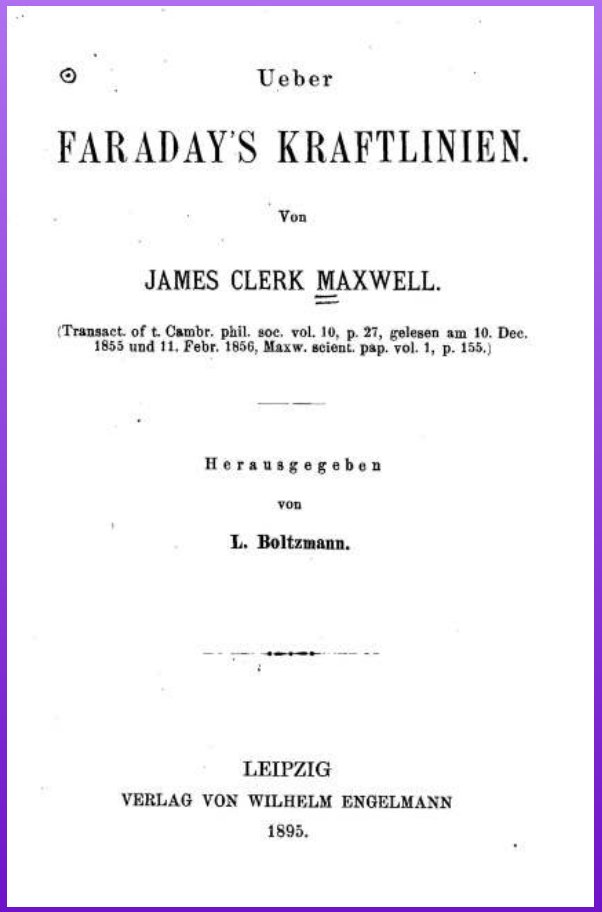
Boltzmann Edits Maxwell

Ostwalds Klassiker

Boltzmann's edition of *Ueber Faradays Kraftlinien* appeared in 1895 as number 69. 96 pages of text and 32 pages of notes by Boltzmann.

His edition of *Ueber physikalische Kraftlinien* appeared in 1898 as number 102. 84 pages of text and 60 pages of notes by Boltzmann.



Ueber

FARADAY'S KRAFTLINIEN.

Von

JAMES CLERK MAXWELL.

(Transact. of t. Cambr. phil. soc. vol. 10, p. 27, gelesen am 10. Dec. 1855 und 11. Febr. 1856, Maxw. scient. pap. vol. 1, p. 155.)

Herausgegeben

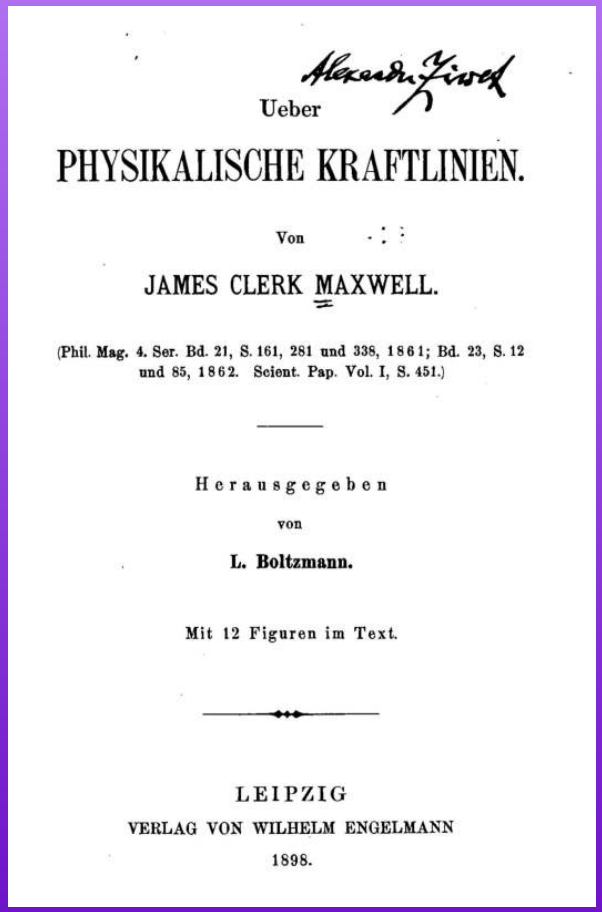
von

L. Boltzmann.

LEIPZIG

VERLAG VON WILHELM ENGELMANN

1895.



Ueber

PHYSIKALISCHE KRAFTLINIEN.

Von

JAMES CLERK MAXWELL.

(Phil. Mag. 4. Ser. Bd. 21, S. 161, 281 und 338, 1861; Bd. 23, S. 12 und 85, 1862. Scient. Pap. Vol. I, S. 451.)

Herausgegeben

von

L. Boltzmann.

Mit 12 Figuren im Text.

LEIPZIG

VERLAG VON WILHELM ENGELMANN

1898.

Boltzmann Edits Maxwell

Boltzmann on Maxwell's "epistemological" introduction.

Maxwell's Introduction demonstrates . . . that he was just as much a pathbreaker in epistemology as in theoretical physics. All of the new paths taken by epistemology in the following 40 years are already clearly presaged in these few pages, indeed, by means of the same analogies. Later epistemologists expressed all of this in greater detail, but also, for the most part, in a more one-sided way.

Boltzmann Edits Maxwell

Boltzmann on Maxwell's "epistemological" introduction.

Maxwell:

"The first process therefore in the effectual study of the science, must be one of simplification and reduction of the results of previous investigations to a form in which the mind can grasp them."

Boltzmann's note:

"An overly weak expression, however, of the principle of economy. (Cf. Mach, *Almanach der Wiener Acad. der Wissensch*. 1882."

Boltzmann Edits Maxwell

Boltzmann on Maxwell's "epistemological" introduction.

Maxwell:

"If, on the other hand, we adopt a physical hypothesis, we see the phenomena only through a medium, and are liable to that blindness and rashness in assumption which a partial explanation encourages."

Boltzmann's note:

"Mach says exactly the same thing 'On the Principle of Comparison in Physics' (*Naturforscher-verhandlungen* 1894, p. 7 of the separatum): 'It (the matter theory of heat) blinded Black's followers.'"

Boltzmann Edits Maxwell

Boltzmann on Maxwell's "epistemological" introduction.

Maxwell:

"In order to obtain physical ideas without adopting a physical theory we must make ourselves familiar with the existence of physical analogies."

Boltzmann's note on the term "analogies":

"This word has since become a motto [Schlagwort]. Cf. Helmholtz, Studien zur Statik monozyklischer Systeme (*Berl. Ber*. März, Dec. 1884), or the just-cited essay of Mach's, also the translator's [Boltzmann's] 'Über die Methoden der theoretischen Physik.' *Catolog der math. Ausstellung zu München* 1892 and 1893."

Boltzmann Edits Maxwell

Boltzmann on Maxwell's "epistemological" introduction.

Maxwell:

"The other analogy, between light and the vibrations of an elastic medium, extends much further, but, though its importance and fruitfulness cannot be over-estimated, we must recollect that it is founded only on a resemblance *in form* between the laws of light and those of vibrations. By stripping it of its physical dress and reducing it to a theory of "transverse alternations," we might obtain a system of truth founded strictly on observation, but probably deficient both in the vividness of its conceptions and the fertility of its method."

Boltzmann's note on the expression "stripping it of its physical dress":

"Hertz says exactly the same (Untersuch. über die Ausbreitung der elek. Kraft p. 31): 'Scientific rigor requires that we distinguish the colorful dress that we throw over the theory from the plain and simple Form of nature itself.' The clarity with which Maxwell had already then distinguished the fact of the periodic alternation in any transversally oriented state and the hypothesis of an oscillating motion is, in general, a proof of his insight in the epistemological domain."

Boltzmann Edits Maxwell

Ludwig Boltzmann. “Über die Frage nach der objektiven Existenz der Vorgänge in der unbelebten Natur.” *Akademie der Wissenschaften* (Vienna). *Sitzungsberichte* 106, Part II (January 1897), 83ff.

We must aim at having ideas that are correct [predictively successful] and economical as well, that is, we are to be able always to reach the correct mode of action with the least expenditure of time and effort. The demand on any theory is that it be correct and economical; for on that very account it will then correspond to the laws of thought. I do not think that this needs to be set up as a special requirement, as Hertz has done. . . .

Processes in inanimate nature are for us mere ideas for representing regularities of certain complexes of phenomena. . . .

Processes in inanimate nature likewise exist for us merely in imagination, that is we mark them by certain thoughts and verbal signs, because this facilitates our construction of a world picture capable of foretelling our future sensations in inanimate nature.

Boltzmann Edits Maxwell

Ludwig Boltzmann. “Model.” *Encyclopaedia Britannica*. 10th ed. (1902),Vol. 30, 788-791.

Models in the mathematical, physical and mechanical sciences are of the greatest importance. Long ago philosophy perceived the essence of our process of thought to lie in the fact that we attach to the various real objects around us particular physical attributes - our concepts - and by means of these try to represent the objects to our minds. Such views were formerly regarded by mathematicians and physicists as nothing more than unfertile speculations, but in more recent times they have been brought by J. C. Maxwell, H. v. Helmholtz, E. Mach, H. Hertz and many others into intimate relation with the whole body of mathematical and physical theory. On this view our thoughts stand to things in the same relation as models to the objects they represent. The essence of the process is the attachment of one concept having a definite content to each thing, but without implying complete similarity between thing and thought; for naturally we can know but little of the resemblance of our thoughts to the things to which we attach them. What resemblance there is lies principally in the nature of the connexion, the correlation being analogous to that which obtains between thought and language, language and writing, the notes on the stave and musical sounds, &c.

Boltzmann Edits Maxwell

Ludwig Boltzmann. “Model.” *Encyclopaedia Britannica*. 10th ed. (1902),Vol. 30, 788-791.

In explaining magnetic and electrical phenomena it inevitably fell into somewhat artificial and improbable hypotheses, and this induced J. Clerk Maxwell, adopting the ideas of Michael Faraday, to propound a theory of electric and magnetic phenomena which was not only new in substance, but also essentially different in form. If the molecules and atoms of the old theory were not to be conceived of as exact mathematical points in the abstract sense, then their true nature and form must be regarded as absolutely unknown, and their groupings and motions, required by theory, looked upon as simply a process having more or less resemblance to the workings of nature, and representing more or less exactly certain aspects incidental to them. With this in mind, Maxwell propounded certain physical theories which were purely mechanical so far as they proceeded from a conception of purely mechanical processes. But he explicitly stated that he did not believe in the existence in nature of mechanical agents so constituted, and that he regarded them merely as means by which phenomena could be reproduced, bearing a certain similarity to those actually existing, and which also served to include larger groups of phenomena in a uniform manner and to determine the relations that held in their case.

Boltzmann Edits Maxwell

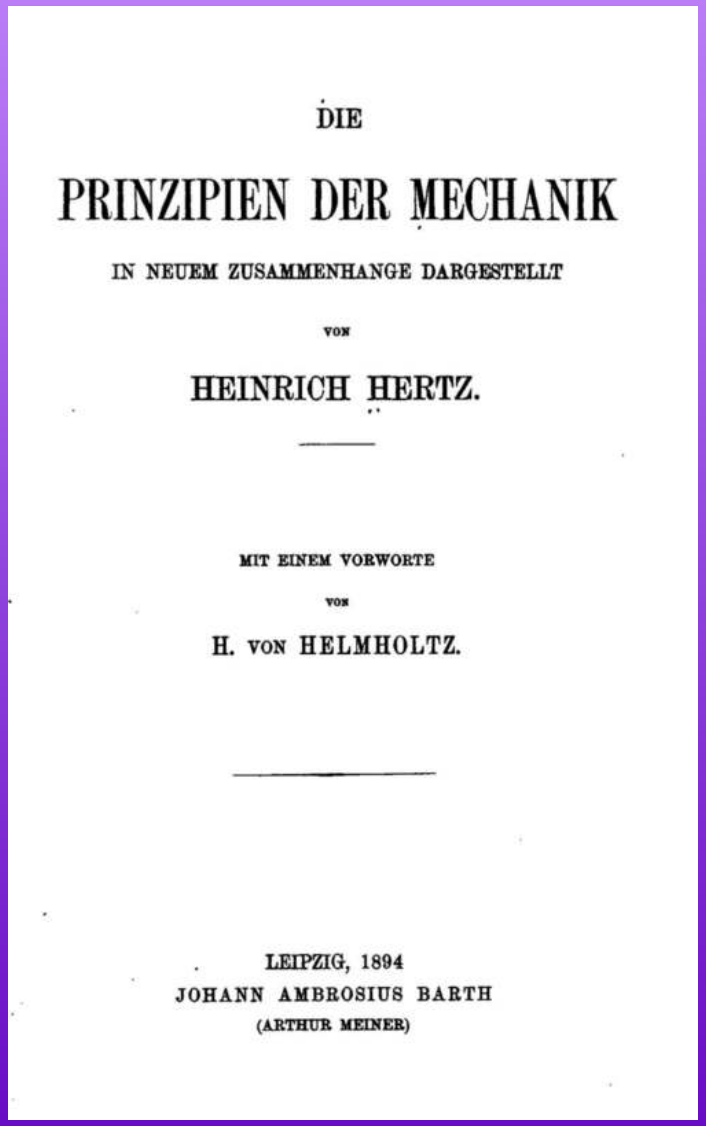
Ludwig Boltzmann. “Model.” *Encyclopaedia Britannica*. 10th ed. (1902),Vol. 30, 788-791.

The question no longer being one of ascertaining the actual internal structure of matter, many mechanical analogies or dynamical illustrations became available, possessing different advantages; and as a matter of fact Maxwell at first employed special and intricate mechanical arrangements, though later these became more general and indefinite. This theory, which is called that of mechanical analogies, leads to the construction of numerous mechanical models. Maxwell himself and his followers devised many kinematic models, designed to afford a representation of the mechanical construction of the ether as a whole as well as of the separate mechanisms at work in it: these resemble the old wave-machines, so far as they represent the movements of a purely hypothetical mechanism. But while it was formerly believed that it was allowable to assume with a great show of probability the actual existence of such mechanisms in nature, yet nowadays philosophers postulate no more than a partial resemblance between the phenomena visible in such mechanisms and those which appear in nature. Here again it is perfectly clear that these models of wood, metal and cardboard are really a continuation. and integration of our process of thought; for, according to the view in question, physical theory is merely a mental construction of mechanical models, the working of which we make plain to ourselves by the analogy of mechanisms we hold in our hands,and which have so much in common with natural phenomena as to help our comprehension of the latter.

Hertz and the Model-theoretic Tradition in Philosophy of Science

Heinrich Hertz. *Die Prinzipien der Mechanik. In neuem Zusammenhange dargestellt*. Philipp Lenard, ed. Leipzig: Johann Ambrosius Barth, 1894.

Heinrich Hertz
(1857-1894)



DIE

PRINZIPIEN DER MECHANIK

IN NEUEM ZUSAMMENHANGE DARGESTELLT

VON

HEINRICH HERTZ.

MIT EINEM VORWORTE

VON

H. VON HELMHOLTZ.

LEIPZIG, 1894
JOHANN AMBROSIUS BARTH
(ARTHUR MEINER)

Hertz and the Model-theoretic Tradition in Philosophy of Science

Heinrich Hertz. *Die Prinzipien der Mechanik. In neuem Zusammenhange dargestellt* . Philipp Lenard, ed. Leipzig: Johann Ambrosius Barth, 1894.

We form for ourselves images or symbols of external objects; and the form which we give to them is such that the necessary consequents* of the images in thought are always the images of the necessary consequents* in nature of the things pictured. In order that this requirement may be satisfied, there must be a certain conformity between nature and thought. Experience teaches us that this requirement can be satisfied and hence that such conformity does exist. . . . The images which we here speak of are our conceptions of things. With the things themselves they are in conformity in *one* important respect, namely, in satisfying the above-mentioned requirement. For our purpose it is not necessary that they should be in conformity with things in any other respect whatever. As a matter of fact, we do not know nor do we have any means of knowing, whether our conceptions of things are in conformity with them in any other than this *one* fundamental respect.

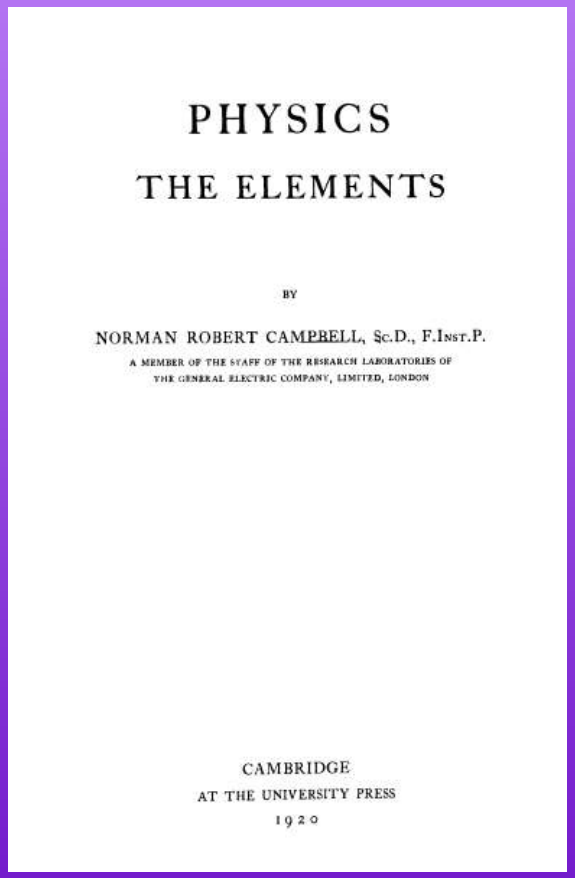
* “consequents” = “Folgen” in German. Does Hertz mean logical consequences or causal consequences?

Hertz and the Model-theoretic Tradition in Philosophy of Science

Heinrich Hertz. *Die Prinzipien der Mechanik. In neuem Zusammenhange dargestellt* . Philipp Lenard, ed. Leipzig: Johann Ambrosius Barth, 1894.

The images which we may form of things are not determined without ambiguity by the requirement that the consequents of the images must be the images of the consequents. Various images of the same objects are possible, and these images may differ in various respects. . . . Of two images of the same object that is the more appropriate which pictures more of the essential relations of the object. . . . We cannot decide without ambiguity whether an image is appropriate or not; as to this differences of opinion may arise. One image may be more suitable for one purporse, another for another.

Later Impact on Philosophy of Science



PHYSICS

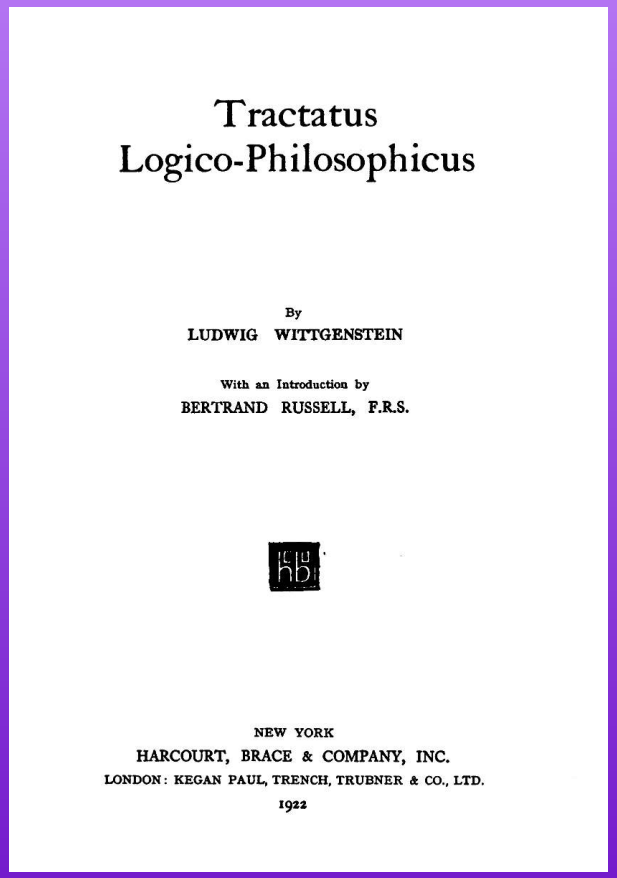
THE ELEMENTS

BY

NORMAN ROBERT CAMPBELL, Sc.D., F.Inst.P.

A MEMBER OF THE STAFF OF THE RESEARCH LABORATORIES OF THE GENERAL ELECTRIC COMPANY, LIMITED, LONDON

CAMBRIDGE
AT THE UNIVERSITY PRESS
1920



Tractatus
Logico-Philosophicus

By
LUDWIG WITTGENSTEIN

With an Introduction by
BERTRAND RUSSELL, F.R.S.

NEW YORK
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LONDON: KEGAN PAUL, TRENCH, TRUBNER & CO., LTD.
1922

Later Impact on Philosophy of Science

Bas vam Fraassen (1941-)

The Scientific Image , 1980

Later Impact on Philosophy of Science

van Fraassen's "Constructive Empiricism"

One of the most influential forms of anti-realism in later-twentieth century philosophy of science

- Theories are sets of models
- A theory is empirically adequate if the observable substructure of at least one of its models is isomorphic with the observable phenomena
- Science aims not at truth but at empirical adequacy
- Postulating empirical adequacy as the aim of science explains scientific practice at least as well as does postulating that science aims at truth