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'TIS THE GIFT TO BE SIMPLE: A RETROSPECTIVE APPRECIATION OF MACH'S THE SCIENCE OF MECHANICS[1]

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Ernst Mach (1838-1916) was one of the most influential figures of the 19th century and led the way for the development of a scientific framework for both physics and psychology in the 20th century (Blackmore, 1972). His experimental contributions ranged from gas dynamics to psychophysics, but his formulation of the nature and goals of the scientific enterprise was to be the most stimulating and controversial of his creations. Mach, as a representative of the positivist movement and as a phenomenalist, gets little attention these days. When his name does appear in the literature concerned with the history and philosophy of science, the criticism he receives is often harsh and is not always enlightened (e.g., Bunge, 1979; d'Abro, 1951; Lindsay & Margenau, 1981; Toraldo di Francia, 1981). There are, however, major exceptions to these trends (Cohen & Seeger, 1970; Laudan, 1981).

Of his very large output of books, relatively few of which are now available in English, *The Science of Mechanics* must rank first in its influence on subsequent developments in physics in particular and the tenor of scientific formulation in general. The issues raised in this book provided both stimulation for further positivistic developments (e.g., logical positivism) and a persisting focus for reactions against such movements. It is perhaps not surprising that a burgeoning science of behavior would feast upon the fruits of positivism to nourish and develop its strength in joining the ranks of the natural sciences.

Skinner, if not the first, was among the first psychologists to use the approach of Mach in formulating a behavioristic experimental analysis. He had been introduced to Mach's *The Science of Mechanics* while a student at Harvard (Skinner, 1979), and it was to shape his thesis, published as "The concept of the reflex in the description of behavior" (Skinner, 1931). Certain of Mach's views may be seen as exerting special influences on Skinner's methods and on the conceptual development of radical behaviorism. In considering Mach's book, I shall point out what I believe these influences are, and shall indicate as well some of Skinner's views that might be regarded as departures from Mach's views.

Why should a book that is ostensibly about classical mechanics exert such a strong influence on scientific philosophy? A hint is found in the complete title: *The Science of Mechanics, A Critical and Historical Account of its Development*. In the preface to the first German edition, Mach states the purpose of his book: "The present volume is not a treatise upon the application of the principles of mechanics. Its aim is to clear up ideas, expose the real significance of the matter, and get rid of metaphysical obscurities" (1960, p. xxii). Mechanics is treated as an exemplar in the development of a science. In other writings, Mach provided similar treatments of optics, thermodynamics, and electricity (these, unfortunately, are not available in English). Thus, mechanics was not considered the fundamental branch of physics to be singled out for such treatment, a

[1]Mach, E. (1960). *The Science of Mechanics: A Critical and Historical Account of its Development* (T. J. McCormack, Trans.; 3rd paperback ed., 1974). LaSalle, IL: Open Court. xxxi + 634 pp., including index. (Original work published 1883.)

Unless otherwise indicated, italicized words in quotations are as they appear in Mach's translated text.

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point to which I wish to return later.

The organization of the book follows in part what has become a common frame in modern physics texts. Chapter 1 treats statics, including the lever, the inclined plane, and the principle of the composition of forces. Chapter 2 deals with dynamics, including the contributions of Galileo and Newton. Chapter 3 takes up the conservation laws, kinetic and potential energy and minimum principles, and gives some attention to hydrodynamics. Chapter 4 provides a more formal (but brief) development of minimum principles (what ordinarily is called the calculus of variations) and of analytical mechanics. Also included is a critical view of the place of mechanics in the science of physics as well as a discussion of the "Economy of Science," a highly significant aspect of Mach's scientific philosophy. The final chapter is a commentary on "Relations of Mechanics to Physics" and "Relations of Mechanics to Physiology."

THE PHILOSOPHICAL-HISTORICAL METHOD

Mach stated in his introduction the rationale behind his method:

> The history of the development of mechanics is quite indispensable to a full comprehension of the science in its present condition. It also affords a simple and instructive example of the processes by which natural science is developed. (p. 1)

Skinner, in his treatment of the reflex, provides a similar rationale:

> Certain historical facts are considered for two reasons: to discover the nature of the observations upon which the concept has been based, and to indicate the source of the incidental interpretations with which we are concerned. (1931, p. 427)

The historical method in the hands of Mach and Skinner is fundamentally an examination of the verbal behavior of the scientist to yield possible controlling relations. For Mach, the very foundations of science emerged as rule-governed behavior from what he called "instinctive, irreflective knowledge" or simply "experience"—terms congruent with Skinner's "contingency-controlled behavior" (Skinner, 1969, 1974). It is a theme that runs throughout the book:

> An *instinctive*, irreflective knowledge of the processes of nature will doubtless always precede the scientific, conscious apprehension, or *investigation*, of phenomena. The former is the outcome of the relation in which the processes of nature stand to the satisfaction of our wants. (p. 1)

> These beginnings [of scientific principles] point unmistakably to their origin in the experiences of the manual arts. To the necessity of putting these experiences into *communicable* form and of disseminating them beyond the confines of class and craft, science owes its origin. (p. 89)

> A rule, reached by the observation of facts, cannot possibly embrace the *entire* fact, in all its infinite wealth, in all its inexhaustible manifoldness; on the contrary, it can furnish only a rough *outline* of the fact, one-sidedly emphasizing the feature that is of importance for the given technical (or scientific) aim in view. *What* aspects of a fact are taken notice of, will consequently depend upon circumstances, or even on the caprice of the observer. (p. 90)

> Science is communicated by instruction, in order that one man may profit by the experience of another and be spared the trouble of accumulating it for himself; and thus, to spare posterity, the experiences of whole generations are stored up in libraries. (p. 577)

The reader of Skinner will recognize the correspondences. For example:

> Contingencies were . . . in effect long before they were formulated. . . . Eventually men learned to behave more effectively under such contingencies by formulating them. (1969, p. 140)

> Scientific laws probably emerged from the lore of craftsmen. (1974, p. 123)

> Rule-governed behavior is in any case

> never exactly like the behavior shaped by contingencies. (1969, p. 150)
>
> The point of science . . . is to analyze the contingencies of reinforcement found in nature and to formulate rules or laws which make it unnecessary to be exposed to them in order to behave appropriately. (1969, p. 166)

In a more formal context, Mach attempted to purify physics by removing metaphysical contaminants. Thus:

> Faithful adherence to the method that led the greatest investigators of nature . . . to their great results, restricts physics to the expression of *actual facts*, and forbids the construction of hypotheses behind the facts, where nothing tangible and verifiable is found. If this is done, only the simple connection of the motions of masses, of changes of temperature, of changes in the values of the potential function, of chemical changes, and so forth is to be ascertained, and nothing is to be imagined along with these elements except the physical attributes or characteristics directly or indirectly given by observation. (p. 597)

One of Mach's goals was to give Newtonian physics a foundation upon which observation and economical descriptions of relationships between observables would support the enterprise. The practices of talking about one's observations and manipulating data by conventional steps are, as Skinner has pointed out (1945), the inherent properties of operationism. For Mach, the operational definition is "the outcome of an endeavor to establish *the interdependence of phenomena* and to remove all metaphysical obscurity, without accomplishing on this account less than other definitions have done" (p. 267). Mach provided operational analyses of Newton's concepts of space, mass, time, and force. For example, Newton defined mass: "The quantity of matter is a measure of the same, arising from its density and bulk conjunctly" (1687/1964, p. 13). As Mach pointed out, this is a pseudo-definition, because density is defined as mass divided by volume. Mach defined mass in terms of interactions between bodies. Thus, "If we take A as our unit, we assign to that body the mass *m* which imparts to A *m* times the acceleration that A in the reaction imparts to it" (p. 266). As he puts it: "We have, in this, simply designated, or *named*, an actual relation of things" (p. 266). Skinner was to follow a similar path in proposing an operational definition of the reflex as an observed relation between stimuli and responses, and in the process substituting statements about behavior for pseudo-definitions and other obscurities inherent in mental description (Skinner, 1979; see also Harzem & Miles, 1978).

Mach's careful reformulations of the concepts of space, mass, time, and force were to profoundly influence the future development of physics. The generation that was to revolutionize 20th century physics—with relativity and quantum mechanics—had learned its physics from Mach. Einstein, who had a very complex relationship with Mach, expressed in his later years a debt to him: "As for the influence of Mach on my own thinking, it has certainly been very great" (letter to Besso, quoted in Speziali, 1979, p. 266). Special relativity is fundamentally a formal expression of operational definitions of length, mass, and time, with the assumption that the velocity of light is independent of the source. So too with general relativity, founded on the principle of equivalence of inertial and gravitational mass. Mach's influence on theorizing in quantum mechanics was more subtle but no less powerful, especially on the early Heisenberg (Bergmann, 1970; Heisenberg, 1971, 1983).

Mach has been criticized for his none-too-careful historical research (e.g., Cohen, 1977; Shapere, 1974). However, as Blüh (1970) has sympathetically emphasized: "He did not write the *Mechanics* to set the history of mechanics right, but to set Newtonian mechanics right; not to discuss Newton's achievement in its historical meaning, but in its scientific meaning" (p. 11).

CAUSALITY AND THE FUNCTIONAL RELATION

Skinner begins Chapter III of *Science and*

Human Behavior: "The terms 'cause' and 'effect' are no longer widely used in science. . . . The old 'cause-and-effect connection' becomes a 'functional relation' " (1953, p. 23). The establishment of a system of functional relations that embodies description, prediction, and control of behavior is an essential pillar of Skinner's system. So it was with Mach. In the "Formal Development" chapter (pp. 516-595), he provides an essentially Humeian analysis of the interpretations of cause and effect, suggesting that "The notion of the *necessity* of the causal connection is probably created by our voluntary movements in the world and by the changes which these indirectly produce" (p. 581). But he asserts: "There is no cause nor effect in nature; nature has but an individual existence; nature simply *is*" (p. 580). Neither are there laws in nature: "In nature, there is no *law* of refraction, only different cases of refraction" (p. 582). Later, he states:

> The business of physical science is the reconstruction of facts in thought, or the abstract quantitative expression of facts. The rules which we form for these reconstructions are the laws of nature. In the conviction that such rules are possible lies the law of causality. The law of causality simply asserts that the phenomena of nature are *dependent* on one another. (p. 604)

ECONOMY OF THOUGHT

Mach viewed scientific activity as an enterprise shaped by the needs and desires of human culture. "All science has its origin in the needs of life" (p. 609). Mach had been very impressed by Darwin's *The Origin of Species*, and saw the development of science as reflecting an evolutionary trend favoring the survival of the species. The "philosophical-historical" method exemplified in *The Science of Mechanics* derived in part from Mach's notions of "transformations of thought": Just as there are gradual transformations of species into new species, "[ideas] fight the battle for existence not otherwise than do the Ichthyosaurus, the Brahman, and the horse" (quoted in Cohen, 1980, p. 284). The Skinnerian will certainly be sympathetic to the view that, like other operants, scientific verbal behavior is controlled by its consequences—in a manner analogous to the shaping of species characteristics through natural selection (Skinner, 1969). This may be extended to encompass the notions of "simplicity," "economy," or "efficiency" in the adaptiveness of a species to its environment. Darwin thus provided some of the inspiration for Mach's notion of economy of thought (Blackmore, 1972). As mentioned earlier, Mach's views on the development of science emphasized the efficiency of rules, instructions, abstractions, etc., over the acquisition of such principles through individual experience.

> We must admit . . . that there is no result of science which in point of principle could not have been arrived at wholly without methods. But, as a matter of fact, within the short span of a human life and with man's limited powers of memory, any stock of knowledge worthy of the name is unattainable except by the *greatest* mental economy. Science itself, therefore, may be regarded as a minimal problem, consisting of the completest possible presentment of facts with the *least possible expenditure of thought*. (p. 586)

Proper scientific practice should not only yield descriptions of phenomena, but the most economical, efficient, and simple descriptions congruent with the facts, yet capable of effective prediction. One is reminded of Skinner's comment about Newton's *Principia*: "[It] was not simple to the man in the street, but in one sense it was simpler than everything which the man in the street had to say about the same subject" (1957, p. 45). A major expression of such economy is what Mach called the "principle of continuity" inspired by Galileo's thought experiments.

> Once we have reached a theory that applies to a particular case, we proceed gradually to modify in thought the conditions of that case, as far as it is at all possible, and endeavor in so doing to adhere throughout as closely as we can to the conception originally reached. There is no method of procedure more surely calculated to lead to that comprehension of all natural phenomena which is the *simplest* and also attainable with

> the least expenditure of mentality and feeling. (p. 168)

This principle is embodied in the methodological exercise known as systematic replication (Sidman, 1960), whereby generalizability of a finding is tested by systematically changing the conditions in a series of experiments.

Skinner's treatment of private events exemplifies a conceptual application of the principle of continuity, in that such events are described or controlled by the same class of variables that describe or control public events.

> We need not suppose that events which take place within an organism's skin have special properties for that reason. A private event may be distinguished by its limited accessibility but not, so far as we know, by any special structure or nature. (1953, p. 257)

His treatment economically finesses the problems inherent in the public-private distinctions of the methodological behaviorist (Skinner, 1969; see also Moore, 1975, 1981). This brings me to consider Mach's phenomenalist position.

SENSATIONS AS PRIMITIVES

Mach asserts his phenomenalist position as follows:

> Nature is composed of sensations as its elements. . . . Sensations are not signs of things; but, on the contrary, a thing is a thought-symbol for a compound sensation of relative fixedness. Properly speaking the world is not composed of "things" as its elements, but of colors, tones, pressures, spaces, times, in short what we ordinarily call individual sensations. (p. 579)

The notion of sensory experiences forming the primary data for scientific practice has persisted up to the present time. Kendler and Spence, writing in 1971, said, "sensory experience of the observing scientist is the basic datum of psychology" (p. 12). This kind of view, as Skinner and others have emphasized, reinforces a public-private dualism, makes science the slave of intersubjectivity, and is inherently solipsistic (Skinner, 1969, 1974).

Despite the surface differences in epistemological perspective between Mach and Skinner, there are intriguing similarities. Both attempt to avoid a mental-physical dualism. For Mach, sense elements are neither mental nor physical, because the descriptions "mental" and "physical" are themselves abstractions of sense elements. In a similar way, Mach escapes solipsism by asserting that "ego" or "self" are themselves constructs of elements, and thus have no privileged status (Turner, 1967). Indeed, Mach's use of the term "element" as a neutral substitute for "sensation" was based on an avoidance of a distinction between independent (i.e., "real") properties of objects and self-centered experience (Cohen, 1970).

Mach's phenomenalist view has been called "neutral monism" and it was subsequently to form an important component of the philosophies of William James and Bertrand Russell, among others (see Rorty, 1979, for a discussion of neutral monism). Mach, however, would be uncomfortable with such philosophical labels, because he attempted to rid his scientific formulation of metaphysical questions—mind versus matter, perception versus reality, idealism versus materialism, etc.

> The basis of all my investigations into the logical foundation of physics as well as into the physiology of perceptions has been one and the same opinion: that all metaphysical propositions must be eliminated, because they are idle and disturbing to the economical design of science. (quoted in Frank, 1970, p. 237)

His advocacy of the "unity of science" was based upon the economic reduction of all scientific practice to statements about perceptions and not on an assumption that *all* that exists in the world are sensations and complexes of sensations. Whether these are all or not is a metaphysical issue. It is not difficult to see the links between this perspective and the logical positivism to come, with its focus on formal operationism, issues of verifiability, and the exclusiveness of the analytic-synthetic dichotomy. However, there is also an important link to Skinner, who views the behavior of scientists as an integral part of behavioral science. The sciences are unified in the sense that common variables may control effective scientific practice regardless of the particular focus of interest (Skinner, 1945, 1957, 1969, 1974). Skinner appears to share Mach's anti-ontological position, as Day (1969) indicates:

> The radical behaviorist is aware that we may attribute thing-ness to events largely because we are accustomed to speak of the world about us as composed of objects which are felt to possess an inherent constancy or stability. He is reluctant to take for granted that all useful knowledge must be conceptualized in terms of verbal patterns of thought derived simply from our experience with material objects. Consequently, he is led to a position which is peculiarly anti-ontological. (p. 319)

Frank (1970) makes an observation about Mach that also seems applicable to Skinner:

> Why is the essence of Mach's doctrine described by different authors in such different ways? The chief reason for these differences is, I think, that philosophers, and sometimes scientists too, endeavor to discuss Mach's doctrine in the language of traditional philosophy. In this language such terms occur as 'idealism', 'spiritualism', 'materialism', 'real objective world', 'subjective opinion of the real world', etc. But the point is that it is impossible to describe Mach's doctrine in this language, impossible to describe it at all in terms of traditional philosophy. (p. 236)

Yet Zuriff (1980) can assert regarding Skinner's ontological views:

> What emerges from this conception is an almost Kantian metaphysics. On the one hand is the world as it is, the noumenal world, on the other hand, human responses to that world. Human knowledge of the world consists of responses to that world, but humans cannot transcend their own behavior to step out of the causal stream. (p. 342)

Skinner has been labeled as a physicalist (Gier, 1981: Malcolm, 1964), and this label appears supported by such statements as "I contend that my toothache is just as *physical* as my typewriter" (Skinner, 1945, p. 294, italics added); or "to agree that what one feels or introspectively observes are conditions of one's own body is a step in the right direction. It is a step toward an analysis both of seeing and of seeing that one sees in *purely physical terms*" (1974, p. 216, italics added). But statements of this kind (and many other examples could be given) are not necessarily metaphysical or ontological arguments. They are, in part, an expression of Machian economics. Thus:

> The theory of knowledge called Physicalism holds that when we introspect or have feelings we are looking at states or activities of our brains. But the major difficulties are practical: we cannot anticipate what a person will do by looking directly at his feelings *or* his nervous system, nor can we change his behavior by changing his mind *or* his brain. But in any case we seem no worse off for ignoring philosophical problems. (Skinner, 1974, p. 11)

But the variables entering into contingencies controlling behavior are "expressed" in physical terms, as is the case in all sciences. Whatever the controlling relations of the term "physical" are, the effect is, as Wittgenstein would say, "to allow us to go on"—that is, to deal in some effective way with the world. To achieve this, Mach talked about "elements"; Skinner talks about "contingencies."

OBSERVABLES AND HYPOTHESES

Mach was a powerful spokesman for a large and distinguished group of physicists in the late 19th century who did not subscribe to atomic theory. Indeed, Mach died in 1916 still believing that atoms were simply "things of thought" (p. 509). (Modern theoretical physics has provided a certain peculiar justification for this view.) Mach's objections to atomic theories were more complex and subtle than those usually presented, as both Hiebert (1970) and Laudan (1981) ably demonstrate. I will not detail his objections here, except to emphasize that Mach did not object in principle to the inclusion of unobservables in a theoretical system. What was important was that such entities be expressed in functional relations. "Center of mass" and "moment of inertia" are not observable, but are useful concepts calculated from observable variables. "Probability of response" and "response strength" play a similar role in the experimental analysis of behavior.

Mach was especially sensitive to the possible heuristic value of unobservable theoretical entities—"provisional helps," he calls them (p. 589). "Theories, however, are like withered leaves, which drop off after having enabled the organism of science to breathe for a time" (quoted in Frank, 1970, p. 220). Thus, they may have a role to play in economy of thought. Skinner, who shares with Mach a pragmatic view of scientific practice, does not disagree fundamentally with the heuristic value of mediating entities, but emphasizes the danger of their becoming reified into essential explanatory features (Skinner, 1964; see also, Morris, Higgins, & Bickel, 1982).

Mach also was sympathetic to hypothesis testing and to the development of deductive, formal systems.

> The deductive development of the science is followed by its *formal* development. Here it is sought to put in a clear compendious form, or *system*, the facts to be reproduced, so that each can be reached and mentally pictured with the *least intellectual effort*. (p. 516)

Skinner has been less than enthusiastic about either hypothesis testing or deductive, formal systems (Skinner, 1950, 1956, 1966). In these respects, the difference in views is best accounted for by the differences between the science of mechanics and the science of behavior.

The development of mechanics was dependent upon formal—that is, mathematical—modes of description. For Mach, mathematical description is another manifestation of economy of thought (pp. 583-586). Mathematics itself is basically empirical in foundation. Its rules are derived from experience; it is not the expression of some Platonic ideal to be *discovered* by doing mathematics.

Behavioral analysis is only gradually becoming formalized in a mathematical sense, although there is an accelerating trend in this direction (Nevin, 1984). But in most fields of interest to a behavior analyst, we are clearly beyond the Baconian, inductive stage described by Skinner in "A Case History in Scientific Method" (1956), as a cursory glance at the *Journal of the Experimental Analysis of Behavior* will reveal.

REDUCTIONISM

The term "reductionism" has a multitude of roles to play in the language game of science (Nagel, 1979a). This is illustrated vividly in Mach's work. He could be labeled a reductionist on at least two counts. First, his doctrine of "elements" is reductive in the sense that such elements comprise fundamental "atoms" of experience—including scientific observation and conceptual practice. Second, his principle of "economy of thought" and the corollary of "continuity" are reductive in the sense of reducing descriptions of nature to the simplest and most effective (i.e., encompassing and predictive) forms—systematic structures of functional relations. Thus Newton was able to encompass the cosmos of Kepler and the kinematics of Galileo (and much else) into three laws of motion. As mentioned earlier, Mach's accomplishment in *The Science of Mechanics* was to put Newton into better order by reducing the vague Newtonian notions of space, time, mass, and force into operational and functional dimensions. This form of reduction is inherent in all scientific behavior, and in formal terms is the outcome of both deductive and inductive logic.

Skinner is likewise a reductionist, in the sense that complex performance can be said to be composed of "units" (see *Verbal Behavior*, 1957, for many examples; see also Zeiler & Harzem, 1979). But more generally, behavior, especially that traditionally described in mentalistic terms (intentions, expectations, etc.) is reduced to the outcomes of present and past contingencies. The experimental *analysis* of behavior and, more recently, the experimental *synthesis* of behavior (Catania, 1983) are descriptive of a field of study embracing a form of reductionism.

The forms of reductionism just described occasion less controversy in science than what Nagel (1979a) calls "inhomogeneous reductionism." This is, in Skinner's words, "any explanation of an observed fact which appeals to events taking place somewhere else, at some other level of observation, described in different terms, and measured, if at all, in different dimensions" (1950, p. 193). Mach's "elements" do not, as one might think, fall into this category: "The world consists of colors, sounds, temperatures, pressures, spaces, times, and so forth, which now we shall not call sensations, nor phenomena, because in either term an arbitrary, one-sided theory is embodied, but simply *elements*" (quoted in Nagel, 1979b, p. 120). Mach's physics was not founded on anything beyond such elements and their complexes. Mach repudiated the kinds of reductive theories Skinner was also to eschew many years later. Within physics, he argued against the prevailing notion that mechanics was the foundation of all physics:

> The view that makes mechanics the basis of the remaining branches of physics, and explains all physical phenomena by mechanical ideas, is in our judgment a prejudice. Knowledge which is historically first, is not necessarily the foundation of all that is subsequently gained. . . . We have no means of knowing, as yet, which of the physical phenomena go *deepest*, whether the mechanical phenomena are perhaps not the most superficial of all, or whether they all do not go *equally deep*. (pp. 596-597)

And in a delightfully modern, almost Wittgensteinian passage, he exposes those who would seek foundations in conceptual (in this case, mechanical) models.

> A person who knew the world only through the theater, if brought behind the scenes and permitted to view the mechanism of the stage's action, might possibly believe that the real world also was in need of a machine-room, and that if this were once thoroughly explored, we should know all. Similarly, we, too, should beware lest the *intellectual* machinery, employed in the representation of the world on *the stage of thought*, be regarded as the basis of the real world. (p. 610)

Just as physics is not reducible to mechanics, other sciences are not seen as reducible to physics. Each is seen as having its own domain, concepts, and methods (Laudan, 1981). What leads us to consider the possibilities of such reduction is the notion that the concepts of physics are somehow more fundamental:

> We find . . . that greater *confidence* is placed in our experiences concerning relations of time and space; that we attribute to them a more objective, a more *real* character than to our experiences of colors, sounds, temperatures, and so forth. Yet, if we investigate the matter accurately, we must surely admit that our sensations of time and space are just as much *sensations* as are our sensations of colors, sounds, and odors, only that in our knowledge of the former we are surer and clearer than in that of the latter. (pp. 610-611)

Each science is seen as exploring *aspects* of the world, with no science (certainly not mechanics) comprising the foundations. Mach was particularly contemptuous of Fechner's attempts to explain mental processes in atomic terms:

> Such an overestimation of physics, in contrast to physiology, such a mistaken conception of the true relations of the two sciences, is displayed in the inquiry whether it is possible to *explain* feelings by the motions of atoms. (p. 610)

Mach's anti-atomic stance was inextricably linked to his anti-reductionism. Had Mach lived to experience the enormous effectiveness of modern atomic theory, perhaps he would have altered his position. Nevertheless, as both Mach and Skinner have stressed, it may be "uneconomical" to attempt reducing one science to another. There is the question of practical control and prediction; the two sciences may complement each other's ignorance; each may proceed more rapidly and effectively by its own methods and conceptions; and advances in the two sciences will, in general, be out of phase (Skinner, 1938, 1974).

As embodied in *The Science of Mechanics*, the philosophical and practical legacy of Ernst Mach for the experimental analysis of behavior is profound, in terms of both those views directly adopted and those rejected. In an attempt to redress some imbalance and to avoid a certain Whiggishness, I have emphasized the positive contributions. This has not been difficult, perhaps because there is a common theme running throughout Mach's work so harmonious with Skinner's "empirical epistemology": that science is not some exalted, incorrigible, Platonic domain of Truth, but a *human* activity after all, controlled by history and circumstances and consequences.

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