This general position is well beyond Roger Joseph Boscovich and Thomas Reid but is not idealistic. It points toward the theory of the conservation of energy, which, however, Herschel did not approve in its 1860 form. He felt that "potential energy" was not a physical reality, but a mere mathematical expression introduced into the theory "*to save the truth of its verbal enunciation.*"

In methodology Herschel was interested in discovery, not in a justification of the process of induction. (Mill's "methods" were derived directly from Herschel's *Discourse.*) Thus one Herschelian method was "at once to form a bold hypothesis," that is, to guess. Herschel emphasized the central importance of rigorous deduction to confirm hypotheses; it is this which makes science not a craft. One should at all costs avoid specialties of investigation (e.g., chemistry vs. physics), for no actual phenomenon is so divided. Herschel thought that contingency is the most obvious aspect of the universe. Science must grapple with the apparently arbitrary complexities of the actual world, such as sunspot changes, the shapes of nebulae, the variations in terrestrial magnetism, trade winds, and so on, and try to reduce them to scientific laws. It should not content itself with simple general laws concerning force and matter considered in abstraction.

Herschel's contemporary influence was perhaps greatest among working scientists. He gave a reasoned basis for the shift from a purely abstract treatment of physical parameters (as in Joseph-Louis Lagrange) to a belief in the actual existence of the entities used in scientific theories (e.g., the fields of force of his friend Michael Faraday and his admirer Maxwell, which were felt to be actually present in space, not merely mathematical symbols). He upheld the importance of the scientist's feeling for the reality of his constructs. Sheltered by his great authority, scientists pursued their intuitional ideas without worrying about attacks from Humean or other philosophers, or from Evangelical preachers. Herschel, for example, authoritatively established the naturalistic origin of species as a proper subject of investigation for Victorian Englishmen. Young scientists of the period, such as Charles Darwin and Thomas Andrews, admired him extravagantly.

See also Boscovich, Roger Joseph; Causation: Philosophy of Science; Darwin, Charles Robert; Epistemology; Epistemology, History of; Faraday, Michael; Jevons, William Stanley; Maxwell, James Clerk; Mill, John Stuart; Reid, Thomas; Whewell, William.

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There are no modern editions of Herschel's works. Recent partial treatments are C. J. Ducasse, "John Herschel's Philosophy of Science," in the American Council of Learned Societies collection, *Studies in the History of Culture* (Menasha, WI, 1942), reprinted in *Theories of Scientific Method,* edited by E. H. Madden (Seattle: University of Washington Press, 1960); W. F. Cannon, "The Impact of Uniformitarianism," *Proceedings of the American Philosophical Society* 105 (1961): 301–314; and W. F. Cannon, "John Herschel and the Idea of Science," *Journal of the History of Ideas* 22 (1961): 215–239, containing an error on "will" that has been corrected in the present entry.

Walter F. Cannon (1967)

HERTZ, HEINRICH RUDOLF

(1857–1894)

The German physicist and philosopher of science Heinrich Rudolf Hertz was born in Hamburg. Early in his student days he showed an interest in engineering but soon took up the study of physics, to which he quickly made important contributions, mainly in the study of magnetism and electricity. He studied in Berlin under Hermann von Helmholtz and Gustav Kirchhoff and inherited their interest in the philosophy of science. In 1883 he began teaching in Kiel, where he worked on James Clerk Maxwell's electromagnetic theory. He became professor of physics at the technological institute at Karlsruhe in 1885, where he produced his most celebrated work on electromagnetic waves. In 1889 he was appointed professor of physics to succeed Clausius at Bonn. He was in failing health, however, and he died five years later.

Hertz's most important book for philosophy is his *Principles of Mechanics,* written during his last illness and published in 1894. This is an attempt to rewrite classical mechanics in such a way as to exhibit its systematic nature, increasing its rigor, reducing its assumptions to a minimum, and keeping it as empirical and nonmetaphysical as possible. His aims were firmly in the spirit of his teachers and of Ernst Mach, who expressed his admiration for Hertz's work. The preface to the *Principles of Mechanics* is a classic in the philosophy of science and deserves to be better known.

Hertz was prepared to admit that various logical categories of statement figure necessarily in the sciences; he even thought, unfashionably, that metaphysical statements could be of considerable value to the scientist. But, he held, it is of the utmost importance for anyone who would understand the methods of the sciences, and for the scientist himself, to distinguish clearly the different categories of statement and not to suppose that, for example, a nonempirical statement is empirical. In his reconstruction of mechanics he wanted especially to ensure, among other things, that such distinctions are made.

Rather in the manner of Immanuel Kant, who greatly influenced the philosopher-scientists of this period, he begins by dividing mechanics into two parts, one depending upon the formal necessities of our thought and the other depending upon our experience. Moreover, as Jules Henri Poincaré was to argue later, certain features of mechanics depend upon our arbitrary choice. The structure of scientific theories in general exhibits these features, and understanding this structure involves disentangling them.

Further, very much in the modern manner, Hertz holds that a scientific theory is a deductive system that, according to whether it is correct or incorrect, corresponds or fails to correspond to the observable world. *The Principles of Mechanics* shows how one such theory can be set out as an axiom system in which we may deduce conclusions that are testable against reports of our observations.

However, Hertz's aim in this was not merely theoretical and academic, for he seems to have thought that the progress of science might be impeded if scientists do not fully and clearly understand the logic of the concepts they use. He holds, and regards it as generally held by scientists, that the laws of mechanics are fundamental in the solution of all problems in physics; yet there are concepts used in mechanics that are by no means clear and upon which physicists do not even agree. The outstanding example of such a concept—and here Hertz agrees with Mach—is "force." In fact, Hertz fiercely criticizes physicists for relying on this concept without having any very clear notion of what it entails.

The way to understand the concept of force is to see how it functions in the theories in which it is used. But when we look at classical mechanics, we find that force is not used in the way physicists think it is; the usual method of expounding mechanics obscures this and, in general, obscures the very nature of the concept of force. The understanding of scientific concepts is inextricably bound up with the understanding of the theories in which they figure.

Hertz's approach to mechanics is largely determined by his views about explanation in general; mechanics explains the motions of bodies by bringing them under laws, but these laws cannot be in terms only of what is directly observable. Hertz seemingly holds that it has been found that this is so, although he also shows signs of thinking that it must be so—that it is a necessity of explanation. At any rate, he points to many of the explanations accepted in the sciences and shows that they rely upon concealed mechanisms or, as he says, "'confederates' concealed beyond observed masses and motions."

REPRESENTATIONS OF MECHANICS

There are two existing interpretations of mechanics that rely upon force and energy, respectively, as the nonempirical concepts to be used in explanation. Here a further presupposition of Hertz's enters: We will understand our explanations best if all the concepts we use are as similar as possible to concepts of what we experience, that is, to empirical concepts. Force and energy are quite unlike anything we experience, so Hertz seeks to replace them, in his rewriting of mechanics, by motion and mass, which are exactly like observed motion and mass except that they are unobserved (concealed). Or, rather, force and energy are given minor and subordinate roles in his mechanics; all the important roles go to mass and motion. This, he believed, fitted in with the physical theorizing of his time. For example, Maxwell gave an account of electromagnetic forces in terms of concealed masses and motions.

Although force and energy are not empirical concepts, space, time, and mass are. Hertz therefore reconstructs mechanics using only space, time, and mass as primitive concepts. This means that they are not defined in any verbal or symbolic way, although we understand them through our experience of observable masses in motion. Force and energy must not figure in mechanics—as they have tended to do—as basic terms, *as if* they were empirical concepts. They may be introduced at some later stage, but only by defining them—ultimately, at least—in terms of the primitives.

Hertz outlines the two existing "representations" or "images" of mechanics, criticizes them, and then develops his own alternative, which forms the bulk of *The Principles of Mechanics.* He puts forward, as tools of criticism for theories or their representations, three conditions that they must fulfill. They must be *logically permissible* (sometimes abbreviated to *permissible*), that is, consistent with the laws of our thought; they must be *correct,* that is, their structure must not conflict with the structure of observable things; they must be *appropriate,* that is, they must be simple in the sense of containing the fewest possible superfluous or empty relations. Appropriateness is merely relative: we should, where there are alternatives, accept the more appropriate rather than the less appropriate. These requirements concern the three features of theories mentioned above—one depending upon the nature of our minds, one depending upon our external experiences, and one depending upon our conventional systems of notation.

The first representation Hertz considers is the one then current in most textbooks, taking space, time, force, and mass as its fundamental concepts. It is, among other things, too much influenced by the historical development of mechanics, the order of which may have little to do with its logical structure. It takes force as an independent concept and regards force as the cause of motion. However, the weakness of this representation is that the idea of force is not clear. This affects both the permissibility and the appropriateness of this version: Because our notion of force is vague, it cannot help us to reason precisely, and because we associate with it certain nonessential anthropomorphic ideas, it imports superfluous elements into mechanics. This latter point also seems, for Hertz, to include the idea that too much which is not directly perceptible is thus brought into mechanics. He looks askance at forces that "cancel out in the calculations" as robbing an explanation of its simplicity, or what Mach calls its economy. Apart from this, the first representation satisfies the condition of correctness; if we are merely considering alternative ways of expressing mechanics, we should indeed expect something to be satisfactory in each. What is satisfactory here is that the structure of this way corresponds to, or at least does not conflict with, the structure of observable phenomena.

The second representation is one that was favored in Hertz's day by the more advanced physicists, including Helmholtz. This representation attempts to sidestep the difficulties involved in the concept of force by taking as fundamental the concepts of space, time, mass, and energy. It is then possible to introduce force by definition and merely as an aid to calculation. The advantage of energy over force, it was claimed, was that energy depends upon direct experience because it depends only upon positions or velocities, both of which are directly experienced. This ensures that the second representation is more appropriate than the first. If we consider only motions that occur in nature, Hertz argues, it lacks nothing in correctness. Its weakness lies in its permissibility, as is seen when we try to define energy, as it is here used, in terms of "simple, direct experiences." A substantial view of energy tended to be associated with this representation, but it is difficult to treat potential energy as a substance, especially when, as is sometimes necessary, we must ascribe negative potential energy to a system or must regard the potential energy of a finite quantity of matter as infinite. This version is superior to the first, but it still contains serious difficulties.

HERTZ'S REPRESENTATION

Since force and energy, respectively, appear to be responsible for the problems arising over these two representations. Hertz attempts to do without them, at least as primitive concepts for his representation. He begins with space, time, and mass. That is, he begins with kinematics, the abstract study of motion, and sets out to derive the whole of mechanics from it without using force and energy except as devices for calculation. Kirchhoff had already asserted that three independent concepts are necessary and sufficient for mechanics.

Time, space, and mass are primitive terms for Hertz's system, but they are not mere abstract counters like the uninterpreted symbols of the logicians. They are understood through experience, and the particular experiences that are to count for the purposes of mechanics can be specified. Moreover, these concepts are, as we also discover in experience, permanently related in various ways. Hertz puts forward a "Fundamental Law" that has similarities to the law of inertia and that summarizes the connection between the three basic concepts taken together: "Every natural motion of an independent material system consists herein, that the system follows with uniform velocity one of its straightest paths." This law, together with the concepts of space, time, and mass and the hypothesis of concealed masses, allows us, by purely deductive reasoning, to derive the whole of mechanics and so to explain mechanical phenomena.

Other concepts, such as force and energy, are introduced into the system later by definition and so are regarded merely as aids to deduction. They are defined ultimately in terms of the primitive concepts.

The Principles of Mechanics is divided into two parts to emphasize the independence of the mathematical form and the physical content of mechanics. The equation "2 horses + 2 horses = 4 horses" has a mathematical form, expressed by "2 + 2 = 4," that is independent of its application to horses. In the same way, mechanics as a whole can be regarded as having these two aspects. Book I of the *Principles* draws out the implications of the fundamental ideas: space, time, and mass. At this stage these concepts are intuitive and independent of experience except insofar as all our intuitions and modes of reasoning depend upon experience. Book II contains the application of these concepts to experience through the Fundamental Law and the derivation of testable assertions about observable phenomena. The apparently equivocal nature of Hertz's basic concepts can best be understood in relation to Kantian philosophy: Our intuitions, peculiarly adapted to fit the general form of what we experience, are analogous to colored spectacles which determine our seeing the world as colored. Nevertheless, the details of our pictures of the world have the nature of hypotheses and are open to empirical testing.

Hertz's account of mechanics is important from the standpoint of the philosophy of science because it represents an early attempt to see a scientific theory as a system and to bring out its logical structure accordingly. It was influential in connection with the conventionalism later championed by Poincaré and attempted to do justice to, on the one hand, the undoubted empirical nature of science and, on the other, the apparent claims of scientific laws to embody natural necessities. Hertz's view that mechanics is the foundation of all physical explanation was the most backward-looking element in his work and was strangely belied by both his scientific work, which was largely influential in breaking down that view, and his work in the philosophy of science, which contained the seeds of a far more flexible view of explanation.

See also Classical Mechanics, Philosophy of; Helmholtz, Hermann Ludwig von; Kant, Immanuel; Mach, Ernst; Maxwell, James Clerk; Philosophy of Science; Poincaré, Jules Henri.

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Peter Alexander (1967)

HERVAEUS NATALIS

(c. 1250–1323)

Hervaeus Natalis, or Harvey Nedellec (c. 1250–1323) was one of the first followers of Thomas Aquinas, but also an original thinker, especially in the areas of intentionality and the mental word. Hervaeus was born in Brittany in the mid-thirteenth century. He entered the Dominicans in 1276 and studied at the University of Paris, where he