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CONCEPTS OF FORCE: A STUDY IN THE FOUNDATIONS OF DYNAMICS. By MAX JAMMER. Cambridge, Harvard University Press, 1957. Pp. 269. $5.50.

Roughly speaking, books on the foundations of physics may be put in one of three classes. One class consists of those which approach the subject historically, another of those which approach it logically and systematically, and a third of those which treat foundations from what is perhaps best called an epistemological standpoint. Jammer's book is an excellent example of the first class, although the last two chapters are perhaps to be placed in one of the other two classifications.

Of the twelve chapters, the second, third, and fourth cover the history of the development of concepts of force from early Greek cosmologists up to but not including the work of Kepler. (I delay consideration of the introductory first chapter on the formation of scientific concepts.) Chapter 2 constitutes a brief survey of prescientific concepts of force in the religious myths and legends of various ancient civilizations. Chapter 3 is devoted to the development of the concept of force in Greek science. The first half of the chapter is a brief but competent survey of the Presocratics, Plato, and Aristotle. Jammer rightly emphasizes the historically important point that for Aristotle external forces are always those of push and pull; a force acting at a distance is conceptually inadmissible. Jammer also observes that Aristotle seriously attempted to work out a quantitative mechanics in the *Physics*, but his failure to indicate how force is to be measured left empirical applications of his mechanics in an indefinite state.

The scholarly elucidation in Chapter 4 of concepts of force in the Middle Ages up to the end of the sixteenth century is a good antidote to those like the reviewer, who out of ignorance tend to think of only a few important figures (Roger Bacon, William of Occam, Bradwardine, Buridan, Copernicus, say). There is one aspect of this ancient and medieval line of development to which I think Jammer does not give sufficient emphasis. That is the extraordinarily deep and technical development of kinematical astronomy. No one can fail

to be impressed by the intellectual acumen of Bradwardine or Buridan, yet from the standpoint of the subsequent history of physics, the systematic work of Ptolemy was probably more important, for the glory of physics does not consist in the statement of generally correct concepts but in the intricate elaboration of theory and relevant fact, of which Book III of Newton's *Principia* is a supreme example. The observational data in Book III and the methods for obtaining it stretch directly back to Ptolemy's *Almagest*. Jammer does not emphasize sufficiently the technical problems of quantitative verification of a new concept of force, and the agonizingly slow realization that it is such verification that is the most important test of a new concept.

Chapters 5 to 9 carry us from Kepler to Kant and Spencer. Chapter 5 on Kepler's concept of force is a useful antidote to the popular tendency to associate Kepler only with his laws and thereby the kinematical development of celestial mechanics. Chapter 6, devoted to the immediate precursors of Newton, is mainly concerned with the ideas of Galileo, Descartes, and Huyghens. Chapter 7 is devoted to Newton's concept of force and is a well-balanced account of the variety of views expressed by Newton over a long lifetime in letters, books, and communications to the Royal Society. Jammer makes an important point in observing that Newton was methodologically much more cautious in asserting what is the true physical nature of forces than he was in making similar declarations about space and time. Without doubt dispute about the physical nature of forces has been more central to the scientific development of physics than has argument about the nature of space or time. Newton was essentially faced with a paradox. The central forces of his highly successful theory of gravitation were most naturally interpreted as forces acting at a distance, but every general methodological principle of physics in the seventeenth century argued against forces acting at a distance. They constituted a flagrant resurrection of the occult qualities of the Scholastics, so recently buried by Descartes. Newton's solution of the paradox was to hedge. He simply admitted that he did not have a complete understanding of the physical situation. In spite of his devastating critique of Descartes' vortex theory, he was not able to escape the general Cartesian framework within which the only genuine mechanical explanations were in terms of contact forces of impact. Much of his genius lay in his ability to penetrate deeply into particular questions without first settling on the one true general scheme of the universe.

Chapter 8 deals with a fascinating topic in the history of thought,

theological interpretations of Newtonian mechanics. Unfortunately there is space for only a brief review of the main figures like Cudworth, More, and Bentley. Chapter 9 examines the dynamism of Leibniz, Boscovich, Kant, and Spencer; and Chapter 10 considers eighteenth- and nineteenth-century mechanistic theories of force, with special reference to gravitation.

Chapter 11 is devoted to modern criticisms of the concept of force, particularly of the concept of force as a cause. It is an excellent survey of the major views from Berkeley to Mach, Kirchhoff, and Hertz. A question of central importance is the claim of Mach and Kirchhoff that force can be *defined* by Newton's second law. Jammer unfortunately follows the vague practices that dominate the literature of physics and the foundations of physics. What I mean by this is that no clear doctrine of the nature of definition is appealed to in the many discussions of possible definitions of force and mass. From a formal standpoint the theory of definition used by physicists and by most philosophers of physics can only be characterized as Pickwickian. Perhaps the best way for sketching a precise characterization of proper definitions is to describe Padoa's principle for proving that a primitive notion of a theory is not definable. The method is a simple and powerful one: One gives two models of the theory in which all the other primitive concepts are precisely the same, but the concept whose indefinability is being proved is different in the two models. With this method in mind let us consider standard definitions of force by use of Newton's second law. Because this law is stated in the form of an equation it is perfectly obvious that the *resultant* force can indeed be defined this way. On the other hand, even the simplest problems of mechanics do not usually begin with the consideration of resultant forces, but rather *component* forces are summed to obtain the resultant force, and it is just as apparent that these component forces cannot be defined by use of Newton's second law. The appeal to Padoa's principle is direct. We consider two models for the theory of mechanics with the same resultant forces, the same masses and paths of motion, but different component forces. The central point is that if the concept of component force is admitted as part of our formal theory of mechanics, any natural axiomatization of the theory will be such as to permit us to show that the concept of force is not definable. The methodological points involved in this analysis are exceedingly simple and straightforward. I am continually surprised by the vagueness and carelessness even of such serious authors as Jammer in discussions of the definability of physical concepts.

Contrary to the functional view advocated by Jammer in his final chapter, it seems to me that there remains a good case for the interpretation of forces as causes. It has been fashionable for a long time to claim that the concept of cause has disappeared from physics. The most superficial reading of a current issue of *Physical Review* should make anyone skeptical. In those formulations of classical or quantum mechanics which do not use the concept of force but rather the notion of potential energy or that of a Hamiltonian function, it is still always intuitively clear what the relation is between these notions and that of force and also what the intuitive analysis is for the causal relations in the system.

I mentioned earlier that I would delay consideration of the first chapter until I had remarked on the historical chapters. This first chapter is a relatively brief one on the formation of scientific concepts. By and large I would take what Jammer has to say as being on the side of the angels. He considers as basic the familiar characterization of a physical theory as a hypothetico-deductive system, together with a set of experimental interpretations or operational definitions for some of the concepts of the theory. He is also properly cautious about the problems of identifying a concept through several centuries of changing physical ideas. Unfortunately, the obeisance to the notion of a hypothetico-deductive system is essentially perfunctory. The consequences of not having a deeper view of deductive systems and their formal structure have been indicated in the discussion of Mach and Kirchhoff. On the other hand, such formal sophistication is not necessary and would almost be out of place for most of the historical periods covered by the book, and these periods occupy the vast majority of the pages. For those in search of a reasonably detailed and objective historical overview of concepts of force I can think of no better book to recommend than Jammer's. The present volume, together with its companion, *Concepts of Space*, by the same author, would make good supplementary reading for any serious course in the history of philosophy.

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