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LOGICAL EXAMINATION OF PHYSICAL THEORY*

Theoretical physics may be treated in the fashion of Cartesians and Atomists. They resolve the bodies perceived by the senses and instruments into immensely numerous and much smaller bodies of which reason alone has knowledge. Observable motions are regarded as the combined effects of the imperceptible motions of these little bodies. These little bodies are assigned shapes which are few in number and well defined. Their motions are given by very simple and entirely general laws. These bodies and these motions are, strictly speaking, the only real bodies and the only real motions. When they have been suitably combined, and recognized as together capable of producing effects equivalent to the phenomena we observe, it is claimed that the explanation of these phenomena has been discovered.

Our own view, Energetics, does not proceed in this manner. The principles it embodies and from which it derives conclusions do not aspire at all to resolve the bodies we perceive or the motions we report into imperceptible bodies or hidden motions. Energetics presents no revelations on the true nature of matter. Energetics claims to explain nothing. Energetics simply gives general rules of which the laws observed by the experimentalist are particular cases.

Alternatively, theoretical physics may be conceived in the [737b] manner of Newtonians. They reject all hypotheses about imperceptible bodies and hidden motions, of which the bodies and motions accessible to the senses and instruments may be composed. The [152] only principles admitted are very general laws known through induction, based on the observation of facts.

Energetics does not follow the method of the Newtonians. Energetics recognizes without doubt an experimental origin to the principles it admits, in the sense that observation has suggested them, and that experiment has many times counselled their modification. But Energetics does not regard these experiments, which explain the possible genesis of the principles that Energetics embodies, as capable of conferring any certainty whatever on these principles. Energetics regards

Synthese **83**: 183–188, 1990.

these principles as pure postulates, or arbitrary decrees of reason. When they produce numerous consequences conforming to experimental laws, Energetics regards them as playing their assigned roles well. Agreement with the teaching of observation is not, therefore, as the Newtonian method would require, the beginning of physical theory; it has its place at the end.

Is Energetics being wise when it refuses equally to follow the method of Cartesians and Atomists, and the method of the Newtonians? Does careful examination of the epistemological methods of physics justify the attitude that Energetics adopts? To this question we have replied: Yes.

We have criticized the method of the Cartesians and Atomists for not being autonomous (Duhem 1892, 1906a). The physicist who wishes to follow it cannot use [738a] exclusively the methods proper to physics, since, behind perceptible bodies and motions which he regards as appearances, he aspires to get hold of other bodies and other appearances, which are the only true ones. Here he enters the domain of cosmology. He no longer has the right to shut his ears to what metaphysics wishes to tell him about the real nature of matter; hence, as a consequence, through dependence on metaphysical cosmology, his physics suffers from all the uncertainties and from all the vicissitudes of that doctrine. Theories constructed by the method of Cartesians and Atomists are also condemned to infinite multiplication and to perpetual reformulation. They do not appear to be in any state to assure consensus and continual progress to science.

We have criticized the Newtonian method for being impractical (Duhem 1894, 1906a).

A science may progress following the Newtonian method [153] while its epistemological methods remain those of common sense (*sens commun*). When science no longer observes facts directly, but substitutes for them measurements, given by instruments, of magnitudes that mathematical theory alone defines, induction can no longer be practiced in the manner that the Newtonian method requires.

> An experiment in physics is not simply the observation of a phenomenon...An experiment in physics is the precise observation of a group of phenomena accompanied by the interpretation of these phenomena. For concrete sense-impressions [*données*] really collected by observation, this interpretation substitutes abstract and symbolic representations, which correspond to them in virtue of physical theories admitted by the observer. (Duhem 1894, 1906a)

From this truism follow numerous consequences strongly opposed to the idea of a science in which each principle may be supplied by induction:

> The physicist can never submit an isolated hypothesis to the control of experiment, but only a whole group of hypotheses. When experiment is in disagreement with his predictions, it teaches him that one at least of the hypotheses that constitute this group is wrong and must be modified. But experiment does not show him the one that must be changed.
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> Here we are a long way from the mechanism of experiment such as people who are strangers to its functioning readily imagine it. One commonly thinks [738b] that each of the hypotheses used by physics may be taken in isolation, submitted to the control of experience, and then, when varied and repeated proofs have established its value, placed into the totality of science, in an almost definitive fashion. In reality, it is not so; physics is not a machine that lets itself be disassembled. We cannot address each piece in isolation, and wait to adjust it until its soundness has been minutely controlled. Physical science is an organism one must take hold of in one piece. It is an organism in which one part cannot be made to function without the parts most distant from it coming into play, some more, some less, all to some degree. If some difficulty, some *malaise* reveals itself in its functioning, the physicist will be obliged to discover the organ that needs to be adjusted or modified without it being possible for him to isolate that organ and [154] to examine it on its own. The clockmaker to whom one gives a clock that does not work takes all the wheels out of it and examines them one by one until he finds the bent or broken one. But the doctor to whom one brings a sick person cannot dissect the patient to establish his diagnosis; he must discover the seat of the illness only through the inspection of effects produced on the whole body. The physicist responsible for repairing a rickety theory resembles the latter, not the former. (Duhem 1894,1906a)

Physical theory is not an explanation of the inorganic world; still less is it an inductive generalization of the teachings of experience. So what is it? (Duhem 1893b,1906a, 1908a, 1908d). Is theory simply, as the Pragmatists would like it, a tool [device] that gives us truths of empirical knowledge in the easiest manner, permits us to make faster and more profitable use of it in our action on the external world, but does not teach us anything about this world that we would not already have been taught by experience alone?

Or, on the contrary, does theory teach us about what is real – something that experience has not taught us and would not be able to teach us, something that would be transcendent to purely empirical knowledge?

If we were to respond affirmatively to this last question, we would be saying that physical theory is true, that it has value as knowledge. If, on the contrary it is the first question that constrains us to say "Yes", we would have to say also that physical theory is not true, but simply

convenient; that it has no value as knowledge, but solely practical value. [739a]

When the physicist, turning his attention to the science he is constructing, submits the procedures that he has used to a rigorous examination, he discovers nothing able to introduce into the edifice the least particle of truth, except experimental observation. Of propositions attempting to state the facts of experience and of these alone we may say: *It is true* or: *It is false*. Of these alone we may assert that they will not permit illogicality, and that of two contradictory propositions one at least must be rejected. As for propositions introduced by theory, they are neither *true* nor *false*. They are simply *convenient* or *inconvenient*. If the physicist finds it convenient to construct two chapters [155] of physics with the aid of hypotheses that contradict each other, he is free to do so. The principle of contradiction is able to judge truth and falsity decisively. It has no ability to decide what is useful and what is not. Therefore, to require physical theory to observe a rigorous logical unity in its development would be to exert an unjust and insupportable tyranny on the intellect of the physicist.

When, after having submitted the science that concerns him to this minute examination, the physicist returns to his own concerns, when he takes notice of the tendencies that direct the steps of his reasoning, he recognizes at the same time that all his most profound and most powerful aspirations are crushed by the heartbreaking conclusions of his analysis. No, he cannot bring himself to see in physical theory only a collection of practical procedures, a bag full of tools. No, he cannot believe that physical theory only catalogs knowledge accumulated through empirical science, without changing the nature of this knowledge in the least, and without imprinting it with a character that experience alone would not be able to engrave at all. If there were no more in physical theory than critical examination had shown him in it, he would stop devoting his time and his efforts to a work of so little importance. *The study of the method of physical science is powerless to show the physicist the reason that leads him to construct physical theory.*

No physicist, however positivistic we imagine him to be, would be able to deny this declaration. But his positivism must be sufficiently rigorous that he would not go beyond this declaration, and say that his efforts towards a physical theory, which is always more unitary and always more general, are reasonable, although critical examination of the method of physical science has not been able to discover a reasonable basis for it. Such a basis, might be [739b] expressed precisely in the following propositions:

Physical theory gives us a type of knowledge of the external world not reducible to purely empirical knowledge. This knowledge comes neither from experience nor from the mathematical procedures the theory employs. Purely logical dissection of the theory would not discover the crack by which this knowledge introduces itself into the edifice of physics, through a route which the physicist can no more deny is real, any more than he can describe its course. This knowledge derives from a truth [156] other than the truths which our instruments are appropriate to grasp. The order into which theory places the results of observation does not find its full and complete justification in its practical or aesthetic aspects. We come to see, on the other hand, that this order is, or tends to become, a *natural classification*. Through an analogy the nature of which escapes the grasp of physics, but the existence of which imposes itself on the mind of the physicist as certain, we come to know that this order corresponds better and better to a certain overarching order.

In a word, the physicist is forced to recognize that *it would be irrational to work towards the progress of physical theory if that theory were not the more and more clear, and more and more precise reflection of a metaphysics. The belief in an order transcending physics is the sole reason for the existence of physical theory.*

The attitude, hostile or favorable by turns, which all physicists take towards this declaration is captured in this saying of Pascal: "Our powerlessness to prove anything is invulnerable to Dogmatism; our idea of truth is invulnerable to Skepticism [*Pyrrhonisme*]." (Duhem 1908a)

Separated from the various schools of Pragmatists on the subject of the value of physical theory, we do not take our stand, in any circumstances, among the number of their followers. The analysis we have given of experiments in physics shows fact to be completely interpenetrated by theoretical interpretation, to the point where it becomes impossible to express fact in isolation from theory, in such experiments. This analysis has found great favor on the side of many Pragmatists. They have applied it to the most diverse fields: to history, to exegesis, to theology. We do not deny that this extension is legitimate to some extent. However different the problems may be, it is always the same human intellect that exerts itself to resolve them. In the same way, there is always something common in the several procedures reason employs. But if it is good to notice the analogies between our diverse scientific methods [740a], it is on condition that we do not forget the differences separating them. And, when we compare the method of physics, so strangely specialized in the application of mathematical theory and by the use of instruments of measurement, to other methods, there are surely more differences to describe than analogies to discover.

[157] We accept that physical theory is able to obtain a certain type of knowledge of the nature of things; but this knowledge, which is purely analogical, appears to us as the terminus of theoretical progress, as the limit which theory endlessly approaches without ever reaching it. On the contrary, the schools of the Cartesians and Atomists place hypothetical knowledge of the nature of things at the origin of physical theory. If, therefore, we separate ourselves from the Pragmatists, it is not to take a place among the Cartesians or the Atomists.

The school of the neo-Atomists, the doctrines of which center on the concept of the electron, have taken up again with superb confidence the method we refuse to follow. This school thinks its hypotheses attain at last the inner structure of matter: that they make us see the elements as if some extraordinary ultra-microscope were to enlarge them until they are made perceptible to us.

We do not share this confidence. We are not able to recognize in these hypotheses a clairvoyant vision of what there is beyond sensible things; we regard them only as models. We have never denied the usefulness of these models, dear to physicists of the English school (Duhem 1893a, 1906a). We believe they lend an indispensable aid to minds more broad than deep, more able to imagine the concrete than to conceive the abstract. But the time will undoubtedly come when, through their increasing complications, these representations or models will cease to be aids for the physicist. He will regard them instead as embarrassments and impediments. Putting aside these hypothetical mechanisms, he will carefully release from them the experimental laws they have helped to discover. Without pretending to explain these laws, he will seek to classify them according to the method we have just analyzed and to understand them within a modified and a broader Energetics.

NOTES

* Part II of Duhem 1917, pp. 151–57, translated by Peter Barker and Roger Ariew; published also by Duhem in Duhem 1913a, pp. 737–40.