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# HOLISM A CENTURY AGO: THE ELABORATION OF DUHEM'S THESIS

ABSTRACT. Duhem first expounds the holistic thesis, according to which an experimental test always involves several hypotheses, in articles dating from the 1890s. Poincaré's analysis of a recent experiment in optics provides the incentive, but Duhem generalizes this analysis and develops a highly original methodological position. He is led to reject inductivism. I will endeavor to show the crucial role history of science comes to play in the development of Duhem's holism.

The claim that our knowledge confronts the tribunal of experience as a whole, which is known as the holistic thesis, has spurred much debate and, in consequence, has received a good deal of attention. Yet it is not at all obvious that the historical origin of this idea has been thoroughly studied. It is generally acknowledged that Pierre Duhem was the first to expound the thesis in 1906 in the first edition of *The Aim and Structure of Physical Theory*. But how he arrived at the idea and why he adopted it are questions which are most often neglected. Tracing the holistic thesis back within Duhem's work, one discovers that it originated in the 1890s, that is, almost a century ago. The initial context shows that the philosophical claim is intimately related to ongoing scientific discussions; it also reveals more clearly Duhem's motives. An analysis of the elaboration of holism and its impact on Duhem's thought yields some noteworthy results. First, a remarkable evolution is brought to light. Duhem came to reject inductivism; this shift occurs after he began to philosophize. Secondly, Duhemian holism does not reduce to a single narrowly interpreted thesis: generalizing the thesis, the French philosopher endeavors to formulate a holistic methodology. Thirdly, new significance is given to some inductivist remarks, which commentators have noted in *The Aim and Structure*: Duhem maintains several ideas developed within his earlier inductivist approach; in this respect, his philosophy is not free from inconsistencies. Finally, a clue is provided for Duhem's conversion to history of science, for the second half of the French physicist's career is devoted almost exclusively to history. External factors and even factors lying within

*Synthese* **83**: 325–335, 1990.

the province of history alone do not explain why, from 1903 on, Duhem undertook to rewrite the history of science, especially the pre-Copernican period, an ambitious program, which culminated in his monumental *Système du Monde*.

1.

Some twelve years before synthesizing in *The Aim and Structure* his reflections on the methodology of physics, Duhem announced in 'Quelques réflexions au sujet de la physique expérimentale' the basic idea of holism: "an experiment in physics can never condemn an isolated hypothesis but only a whole theoretical group" (Duhem 1894a, p. 187).[1] In 1894 this claim was truly novel. Not only was it absent in the earlier articles, but it even appears to conflict with the initial conception set forth there. In his first philosophical article, 'Quelques réflexions au sujet des théories physiques', Duhem recommended an inductive method for selecting hypotheses, and he did not point out the shortcomings of such a method (Duhem 1892, pp. 146f, for example). In support of this contention, let us simply note that in an autobiographical passage of 'Physics of a Believer' Duhem acknowedges such an evolution of thought, which implies the rejection of an earlier inductivism (Duhem 1905, pp. 275–78).

A contemporary experiment in physics provided the incentive for philosophical reflections: Otto Wiener's experiment on the direction of vibration of polarized light, whose results were published in 1890. This experiment created a stir at the time, not because it revealed a yet unknown property of light, but because it seemed to make it possible to decide between two competing theories. For a good number of years physicists had been hesitating between Fresnel's theory and F. E. Neumann's and MacCullagh's theory. The customary interpretation of these theories yielded two diametrically opposed predictions: if light, following the classical view, is taken to be a vibration in an ether medium, according to the first theory, the vibration is normal to the plane of polarization; according to the second theory, the vibration is parallel to the same plane. By verifying the first prediction, Wiener's experiment infirmed Neumann's theory and confirmed Fresnel's theory. Some scientists did not fail to take the experiment as an example of a crucial experiment. Thus, for example, Cornu in his appraisal of the experiment:

> This beautiful experiment deserves to mark the beginning of a new era in the history of optics: *it decisively overthrows* theories which place the vibration in the plane polarization of light, like those of MacCullagh and Neumann; on the other hand, *it confirms in a spectacular manner* the ideas of Fresnel and his pupils . . . . This experiment reveals by a palpable fact the dynamic character of the vibration of light, which had begun to be considered, by some mathematicians, as an abstract conception, a symbolic entity indifferently reducible to many different kinematic equivalents. In the light of this experiment in which the experimentator directs as he wishes the mechanical action of light vibration like sound vibration, one can no longer assert that optical vibration is a mere geometrical abstraction. (Cornu 1891a, p. 187; italics mine)

An exceptional situation warrants a strong conclusion: because two competing theories which lead to contradictory predictions are involved, Wiener's experiment, indeed, enforces the truth, the reality, of the surviving theory. Cornu seizes the opportunity to attack abstract nonrealist conceptions, like those already presented by Poincaré and Duhem in several branches of physics. His interpretation of Wiener's experiment constitutes a challenge for such conceptions.

Duhem rebuts such an interpretation in 'Les théories de l'optique', citing the intricacy of experimenting: "What Mr. O. Wiener's experiment condemns is not the particular hypothesis that the vibration is parallel to the plane of polarization; what it condemns is the group of hypotheses which constitute MacCullagh's and Neumann's theory; his experiment teaches us to abandon some part of it, but it does not tell us what to change; we can for example give up placing the motion of the ether molecule in the plane of polarization of the ray; but we can also let the ether molecule vibrate in the plane of polarization as long as we change some other hypothesis of the theory, for example the hypothesis which explains the mechanical sense ascribed to light intensity" (Duhem 1894b, p.112). One need only adopt another interpretation of one of the fundamental concepts of optics in order to provide an entirely different situation. Nothing prevents such a move, as the concepts involved admit of several interpretations.

Here Duhem is following Poincaré, this being one instance of the latter's influence. The famous mathematician gave an account of Wiener's experiment in 1891 in front of the Paris Academy of Sciences; he held that this experiment in itself is not crucial (Poincaré 1891a).[2] Poincaré took up again this view the following year, in the second volume of his *Théorie mathématique de la lumière*, in a passage which Duhem did not fail to call attention to in his review of the book (Duhem 1893, p. 257). For both authors the philosophical question is in the foreground. Neither Poincaré nor Duhem are interested in rescuing Neumann's theory; in their scientific research, they both favor Fresnel's theory (Poincaré 1891a, p. 325; Duhem 1896).

Where does Duhem's originality lie? Should Poincaré be given the credit for formulating the holistic thesis? If Poincaré may have been the first to advance a critical interpretation of Wiener's experiment, from his analysis he never inferred a general conclusion concerning the nature of experimental testing. It is true that he writes in 1902: "In optics . . . Fresnel believed the vibration to be perpendicular to the plane of polarization; Neumann considered it to be parallel to this plane. An 'experimentum crucis' which would make it possible to decide between these two theories was sought for some time, but it was not possible to find one" (Poincaré 1968, p. 224; this remark appeared in his 1890, vol. 2, p. xiv). But this passage of *La science et l'hypothèse*, is very ambiguous; in fact, Poincaré is reproducing here a text published in 1890, most likely before he learned of Wiener's experiment. Why does Poincaré not recall here his interpretation of Wiener's experiment? He not only passes over this interpretation in silence, but he even continues to speak of decisive experiments as well as crucial experiments (for example, in Poincaré 1968, pp. 158, 165). Poincaré neglects Duhem's early formulation of holism, which had been noticed right away by Milhaud, another member of the loosely structured critique of science movement, which Le Roy characterizes as a "new positivism".

Unlike Poincaré, Duhem generalizes the critical interpretation of Wiener's experiment into a philosophical thesis: "What we have here is not a particularity of the experiment carried out by Mr. O. Wiener but a general characteristic of experimental method; it is never possible to subject an isolated hypothesis to the test of experiment, but only the group of hypotheses" (Duhem 1894, p. 112). Duhem perceives the importance of this result, and he pursues his analysis in his next article, 'Réflexions au sujet de la physique expérimentale', where he chooses a new example to illustrate his claim, Foucault's experiment. This experiment shows that light travels faster in air than in water, thereby infirming a prediction of the corpuscular theory of light, while confirming a prediction of the wave theory. Duhem demonstrates that this experiment in itself is not, any more than Wiener's, a crucial experiment, that is, an experiment that imposes decisively one theory. Now, this experiment was considered as a classic example of crucial experiment.[3] By giving another view of Foucault's experiment, Duhem challenges the methodology of crucial experiment, one of the dogmas of traditional philosophy of science. What was merely a critical interpretation of a recent experiment becomes a full-fledged thesis. This thesis implies an entirely new conception of experimental method.

## 2.

Retrospectively, 'Réflexions au sujet de la physique expérimentale' appears to be a complement to the first article, but this should not conceal the novelty of the text. To subject experimental method to an exacting analysis after Claude Bernard, whose aim was to introduce experimental reasoning in physiology, must have seemed like a superfluous endeavor. The opening remark of the article is not a rhetorical device: "What is an experiment in physics? This question will undoubtedly astonish more than one reader . . . ; is there any need to raise it, and is not the answer self-evident?"[4] It is not the importance of experimental method which Duhem questions, but the soundness of the classical conception. He is conscious of contradicting traditional methodology: "By declaring that the interpretation of facts by means of theories is an integral part of a physical experiment . . . , we will perhaps scandalize more than one mind concerned with scientific rigor; more than one will bring up against us the rules framed hundreds of times by philosophers and observers from Bacon to Claude Bernard."[5] Duhem explicitly challenges Bacon's idea of crucial experiment; he rejects Bernard's account when applied to a highly developed theoretical science like physics. In *The Aim and Structure* he will come to condemn the inductive or Newtonian method.

Up to this point Duhem has shown that, because multiple theoretical choices are involved, there are no experiments which are truly decisive in themselves. But so-called crucial experiments were considered exceptional. Duhem goes a step further and gives us a general analysis of physical experiments; he emphasizes here the importance of theoretical interpretation: "An experiment in physics is the precise observation of phenomena accompanied by an *interpretation* of these phenomena; this interpretation substitutes for the concrete data really gathered by observation abstract and symbolic representations which correspond to them by virtue of the theories admitted by the observer" (Duhem 1894a, p. 182 and again in his 1914, p. 221f; 1954, p. 147; Duhem's italics). Theoretical interpretation separates and distinguishes the practical fact, the brute evidence, and the theoretical fact, the evidence incorporated into the theory. One example Duhem chooses for illustrating these remarks is Regnault's series of experiments on the compressibility of gases, which had become a paragon of experimental research. This is an ordinary experiment in the sense that the experimental procedure is straightforward;[6] Regnault's results are not controversial, that is, within a certain degree of approximation and pending some minor corrections, they are definitive.[7] Let us take the simplest measurement involved, the volume occupied by the gas: "In a sighting device Regnault saw the image of a certain surface of mercury become level with a certain line; is that what he recorded in the report of his experiments? No, he recorded that the gas occupied a volume having such and such a value. . . ." The operation involves concepts of several different areas of physics, namely, general mechanics and celestial mechanics.[8] The volume occupied by a gas is not only an abstract idea but also a theoretical idea. An experiment always involves a theory as a whole and even brings in several different chapters of physics. Duhem's interpretation of experimental method is thus intimately connected with the holistic thesis.

It is not necessary to dwell on this point, which has received much attention. Let us simply register that Duhem's conception of experimental testing is acquired, in the main, as early as 1894. In fact, the article is almost identical with the text found in *The Aim and Structure*, chapters four, five, and six of part two. What is striking, however, is the omission in the article of the two paragraphs concerning Newtonian method. Let us follow up this clue. From his analysis of experiment Duhem draws some conclusions; for example, he rejects a particular method of construction or presentation of a theory, according to which "one would like the professor to arrange all the hypotheses of physics in a certain order, to take the first one, enounce it, expound its experimental verifications, and then when the latter has been recognized as sufficient, declare the hypothesis accepted; he would begin this operation again on the second hypothesis, on the third, and so on until all of physics was constituted . . . . This idea is a false idea" (Duhem 1894a, p. 196). Such a method clearly contradicts the holistic thesis: it is not possible to test an isolated hypothesis. *The Aim and Structure* takes up almost word for word this sentence, inserting a highly revealing clause: "One would like [the professor] to formulate the first hypothesis by *inductive generalization* of a purely experimental law" (Duhem 1914, p. 304; 1954, p. 200; italics mine). What is being referred to is the inductive method, which *The Aim and Structure* condemns unambiguously; "The teaching of physics by the *purely inductive method* such as Newton defined it is a chimera" (Duhem 1914, p. 309; 1954, p. 203; italics mine). What is true of teaching is all the more so of theory construction. Apparently, in 1894 Duhem did not attempt to deduce all the consequences of his analysis of experimental method, since the same analysis will lead him, twelve years later, to declare the inductive method impracticable. It is true that only two years before Duhem recommended this method against the excesses of mechanism.

Duhem's criticism of the inductive method raises a question: how to choose the principles on which to build a theory? In the first article this choice appeared in fact to be determined, guided, in some way, by the inductive method. By what to replace this method? The pedagogical hints given in 'Réflexions au sujet de la physique expérimentale' are obviously an insufficient answer. In *The Aim and Structure* the difficulty is no longer avoided; the author sends the reader on to the following chapter on the selection of hypotheses, where recourse is made to history of science. History of science thus appears in Duhem's methodological treatise; it has its place in the construction as well as in the teaching of physical theories: "The legitimate, sure, and fruitful method of preparing a student to receive a physical hypothesis is the historical method" (Duhem 1914, p. 408f; 1954, p. 268). In 1894 Duhem does not yet perceive the role that history of science should play; this is undoubtedly the deep reason why he hesitated to criticize explicitly the inductive method.

## 3.

How does history of science come to provide a solution? It is by no means accidental that after rejecting the inductivist schema of the transition from Kepler's laws to Newton's principle in part two chapter six of *The Aim and Structure*, Duhem gives a long account of the historical genesis of the principle in the next chapter. This account is clearly intended as an alternative to the inductivist reconstruction. The author places the principle of gravitation in the history of scientific thought. Duhem integrates some material from his erudite *Origines de la statique*, which he is working on simultaneously. Duhem no longer leaves out the Middle Ages; he has an inkling of his famous thesis: many major ideas of modern science have their origin in the thirteenth and fourteenth centuries. Already Duhem criticizes the classic idea of scientific revolution, a drastic and sudden change: "In the course of this long and laborious birth, we can follow the slow and gradual transformations through which the theoretical system evolved; but at no time can we see a sudden and arbitrary creation of new hypotheses" (Duhem 1914, p. 384; 1954, p. 252). The slowness, the gradualness of scientific evolution is a sign of its continuity. Duhem explicitly links continuism with his idea of natural classification: "By virtue of a *continuous tradition*, each theory passes on to the one that follows it a share of the *natural classification* it was able to construct" (Duhem 1914, p. 44; 1954, p. 33; italics mine). History of science then provides the missing link for Duhem's rejection of inductivist methodology.

Let us test this idea by attempting a final comparison between one of the early articles and *The Aim and Structure*. It is not a coincidence if the text in which the holistic thesis first occurs is Duhem's first article pertaining to history of science. 'Les théories de l'optique' offers a rapid overview of optical theories since the seventeenth century. During the second half of the seventeenth century, Huygens formulated a wave theory of light. This theory inspired by Cartesian physics, in turn, was rejected by Newton and his successors in favor of a corpuscular theory based on an attractionist model. Toward the middle of the nineteenth century, in the light of new discoveries, scientists took up again the wave hypothesis. This evolution is quite astonishing: the rehabilitation of a hypothesis which had been rejected and was believed to have been refuted.

Duhem uses the history of optics to illustrate a general thesis concerning the nature of physical theories. Theories are fragile and temporary constructions. Historical distance shows that many of the pretensions of traditional mechanism concerning the value of its hypotheses are unfounded. Duhem foretells the imminent decline of mechanism: "Mechanical hypotheses have disappeared, broken up by experimental contradictions or carried away by the torrent which has, for three centuries, turned over and over metaphysical systems" (Duhem 1894b, p. 124). These critical remarks serve to justify abandoning realistic and mechanistic conceptions. Physical theory is to be conceived as a convenient representation of laws and not an explanation of reality. History serves to justify this view.

Skepticism is not however the final lesson of Duhem's history. Behind the succession of theories and hypotheses, he perceives an evolution, a direction of history. Old theories disappear, while contributing to the evolution of science. First of all, the experimental laws which were discovered with the help of these theories remain. But if theories merely serve to suggest experimental laws, their usefulness would seem slight; one might even propose to do away with them altogether. Yet theories appear to play an essential role. This is how Duhem sees the legacy of hypotheses which have been discarded: "Huygens' hydrodynamic ideas are outmoded; but they have given to mathematical optics the notion of wave surface, the form of this surface for isotropic and uniaxial media. Newton's light particles have disappeared, with their access of easy reflection and easy transmission; but optics has continued to represent light phenomena by means of a magnitude which varies periodically in time and whose period, very short, characterizes color. Young assimilated the ether of the ray of light with a column of vibrating air; this assimilation is no longer accepted, but it led to ascribe a direction to the magnitude represented by light phenomena and to compose these magnitudes with one another like forces or speeds. Fresnel's ether and its motions seem about to disappear; but through them it has become known in optics that the magnitude representing light phenomena is governed by the same equations as the transversal motions of elastic solids" (Duhem 1894b, p. 125). In this series of examples some of the fundamental concepts of modern optics are to be found. The contribution of a theory is, in the final analysis, quite different from what its creator foresaw. The elements of a theory are altered and incorporated in a new context. The scientist is surprised by the strange origin, and the historian by the unexpected evolution. Even when they prove to be false, theories can add something to the language of science. This language is refined and enriched, progressively becoming a more and more efficient instrument.

In *The Aim and Structure* Duhem often calls on the history of optics in order to illustrate his argumentation; he draws heavily on 'Les théories de l'optique'. But the ideas of the article undergo an interesting modification. Duhem relates in the article Arago's experiment so as to explain the acceptance of Fresnel's theory. The same example in *The Aim and Structure* shows that theory can anticipate experiment and serves to introduce the idea of natural classification, which is absent in the article: "[Physical theory] assumes, while being completed, the characteristics of a *natural classification*. The groups it establishes permit hints as to the real affinities of things. This characteristic of *natural* *classification* is marked, above all, by the fruitfulness of the theory which anticipates experimental laws not yet observed, and promotes their discovery" (Duhem 1914, p. 40; 1954, p. 30; italics mine). Duhem thus expands his idea of a progressive development of the languages of science and expounds a continuist philosophy, which has both methodological and historical implications.

An analysis of 'Réflexions au sujet de la physique expérimentale' and 'Les théories de l'optique' shows that the first formulation of the holistic thesis is unaccompanied by an explicit criticism of the inductive method; it also indicates the bearing history of science has on the author's evolution of thought. What I suggest is that methodology and history of science are intimately connected in Duhem's philosophy and that this connection deserves careful attention. Going back a century, returning to the initial context, also helps us to understand better the meaning of holism. Holism is not an abstruse idea framed only by philosophers; it originates in a precise scientific setting and becomes a general philosophical thesis, in an attempt to break with traditional methodology. Holism thus lies at the origin of contemporary philosophy of science.

## NOTES

[1] The same remark is taken up again in his (1914), p. 183, translated by P. Wiener as Duhem (1954), p. 278; I give throughout the pagination of the original with that of the translation. In places I modify the English translation.

[2] A. Cornu replied in his (1891b); Poincaré, nevertheless, maintained his position in his (1891b).

[3] As Duhem says, in his (1894a), "An experiment regarded as one of the most decisive ones in optics", p. 190. This remark is taken up in his (1914), p. 282; (1954), p. 186.

[4] Duhem (1894a), p. 179. The same remark occurs in his (1914), p. 218; (1954), p. 144. Duhem foresees the reader's astonishment again in another passage of his (1914), p. 231; (1954), p. 153.

[5] Duhem (1894a), p. 182. This passage does not occur in *The Aim and Structure*, but Bacon and Bernard are mentioned in Part II, chap. 6, section 1.

[6] Duhem (1894a): "What Regnault did is what every experimental physicist necessarily does", p. 182. "Let us take any experiment whatever for example, Regnault's experiment", p. 185. Only the first passage appears in his (1914), p. 221f; (1954), p. 147.

[7] Duhem (1894a): "In his experiment on the compressibility of gases Regnault let exist a cause of systematic error which he did not perceive and which has since been pointed out: he neglected the action of weight on the gas under pressure", p. 206. Also in his (1914), p. 239; (1954), p. 158.

[8] Duhem (1894a), p. 181. Also in his (1914), p. 220f.; (1954), p. 146. In *The Aim and*

*Structure*, Duhem adds hydrostatics and optics to the list, before concluding: "The knowledge of a good many chapters of physics necessarily precedes the formation of that abstract idea, the volume occupied by a certain gas."

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