A REAPPRAISAL OF DUHEM'S CONCEPTION OF SCIENTIFIC PROGRESS

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"Never was any science invented at any particular time, but from the beginning of the world knowledge has grown slowly and is still not complete at this very age" (Pierre Duhem, *Le système du monde*, volume 3, p. 440).

Introduction

For Pierre Duhem, the history of science consists principally in the gradual development of physical theory towards a true description of relations among natural entities, a process which he portrayed as a "progressive evolution" (Duhem 1914/1962, p. 220). Some branches of the tree of science are severed in consequence of this progressive evolution, but Duhem maintained that this pruning merely dispensed with false explanations and metaphysical suppositions. Though the tree of science is leaner, the result of this progress is that it is better able to give scientists hints about the natural order of things.

What I will suggest in this paper is that, while Duhem's conception of progress is consistent with his restricted view of physical science as essentially the refinement of theory, it clashes with a more robust account of scientific practice which considers the relationship between theory, the experimental practices of scientists, and the range of phenomena that are adapted to particular theories and experimental practices. From the perspective of this less restricted view, it appears as though many once flourishing traditions have achieved a kind of stability which clashes with Duhem's progressivism.

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AN OVERVIEW OF DUHEM'S ACCOUNT OF PHYSICAL THEORY

The aim of *La théorie physique, son objet et sa structure* is to provide "a simple logical analysis of the method by which physical science makes progress" (Duhem 1914/1962, p. 3). Duhem's general strategy is to make good his contention that physical theories are *economizers* of experimental law, as opposed to (metaphysical) explanations, and then to furnish support for his unwavering conviction that "physical theory is not merely an artificial system, suitable today and useless tomorrow, but ... an increasingly natural classification" (Duhem 1914/1962, p. 270) ([1]). Though Duhem sided with many of his contemporaries in regarding theories as economizers of experimental law, scattered provocative remarks about an external reality grounded in *bon sens* testify to his commitment to a fairly robust metaphysical realism that sets his account of physical theory apart from Comte's positivism, Mach's sensationalism, and Poincarés conventionalism.

Duhem's critique of Bacon's appealing notion of an *experimentum crucis* is the centerpiece of his logical analysis of scientific method ([2]). Brenner (1990, pp. 326-27) has alerted scholars to the role Duhem's interpretation of Otto Wiener's experiment of 1890 on the direction of vibration of polarized light played in Duhem's celebrated thesis that it is not possible to subject an individual hypothesis to an experimental test but only a group of hypotheses (cf. Duhem 1914/1962, p. 112). Whenever a cluster of hypotheses clashes with experience, Duhem pointed out that the physicist has no way to identify which member of the cluster of hypotheses is the problematic one (Duhem 1914/1962, p. 187). In an article published in 1894, "Réflixions au sujet de la physique expérimentale", Duhem extracted the critical lesson for philosophers who persist in advocating a straightforward induction between theory and the facts established

(1) Cf. DUHEM 1914/1962, p. 31 : "... the aim of physical theory is to become a natural classification, to establish among diverse experimental laws a logical coordination serving as a sort of image and reflection of the true order according to which the realities escaping us are organized". For a sympathetic discussion of Duhem's notion of a natural classification, see Lugg 1990.

(2) Jaki rightly contends that "the impossibility of experimentum crucis was one of the negative aspects of Duhem's taking rigorously the always partial reliability of the symbolic translation [of experimental data]" (1984, p. 329).

by experiment, namely, that experimental results are always interpenetrated by theoretical interpretation to the point where it is impossible to express facts in isolation from theory :

> 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" (1894, p. 182 ; cited by Brenner 1989, p. 329 ; cf. Duhem 1917).

Since the physicist can fashion any number of symbolic translations of experimental results, no experiments can be decisive in and of themselves. An experiment involves the production of some phenomenon *along with its interpretation* — an interpretation that substitutes abstract, symbolic representations for concrete experimental results and which, moreover, corresponds to these results on account of the theories that the scientist brings to her interpretation (Duhem 1914/1962, p. 182).

Physical theory furnishes a translation for experimental data through its associated mathematical symbolism which is subject to the dictates of mathematical rigor. This approach — which avoids reference to mechanical models — was doubtless attractive to Duhem and many of his contemporaries on account of growing worries about the ability of classical mechanics to respond to newly ascertained phenomena in chemical dynamics and in the physics of heat and gases. The classic illustration of this approach is Duhem's own *Traité d'énergétique* (1911), a work with nary a word about atoms. It is also reflected in Duhem's (1902) insistence that Maxwell's electromagnetic theory was not sufficiently general to explain the existence of permanent magnets.

In view of all the necessary revision involved in revising an entire theoretical system, it seemed inconceivable to Duhem that scientists would abandon entire clusters of fundamental assumptions and create a new physical theory "out of whole cloth" (1914/1962, p. 221). On this basis, he advanced a gradualist account of the historical development of scientific ideas, and in assorted writings attempted to debunk the idea of revolutions in science (3). The process of

(3) See Duhem's 1914/1962, pp. 221-252 for an account of the "metamorphosis" of the doctrine of universal gravitation "in the course of its millenary evolution".

comparing entire systems of representation is a slow, evolutionary movement, guided by *bon sens* and characterized by "the hesitations, the gropings and the gradual progress obtained by a series of partial retouchings ..." (Duhem 1914/1962, p. 253).

Over the long haul, Duhem maintained that the history of physical theory reveals an increasing correspondence between idealized and actual relations among entities ; it becomes more "the reflection of an ontological order" (4). The reason is that

> 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, as in certain ancient games each runner handed on the lighted torch to the courier ahead of him, and this continuous tradition assures a perpetuity of life and progress for science" (Duhem 1914/1962, pp. 32-33).

The natural classifications towards which Duhem regarded physical theory as evolving are not explanations. He regarded physical theories as representations or condensations of laws and phenomena. It is in the representative part of a theory where Duhem located what appears as a natural classification. His reading of Newton's law of gravitation, for instance, is an illustration of Duhem's belief that natural classifications are not explanatory :

> It is not to this explanatory part that theory owes its power and fertility ; far from it. Everything good in the theory, by virtue of which it appears as a natural classification and confers on it the power to anticipate experience, is found in the representative part ; all that was discovered is by the physicist while he forgot about the search for explanation. On the other hand, whatever is false in the theory and contradicted by the facts is found above all in the explanatory part ; the physicist has brought error into it, led by a desire to take hold of realities (1914/1962, pp. 32-33).

Duhem's views express an *ideal* for physical theory — a set of logical postulates for co-ordinating senses experience — one which he believed would assure to physics an uninterrupted progress.

(4) The appendix of the second edition (1914) of *La théorie physique*, titled "Physics of a Believer", suggests an analogy between general thermodynamics and "the profound thoughts which are at the very heart of the Aristotelian cosmology" which is rather startling : "... we recognize in these two doctrines two pictures of the same ontological order, distinct because they are each taken from a different point of view, but in no way discordant" (1914/1962, pp. 308-310).

Duhem's conception of scientific progress

I've already remarked on Duhem's depiction of the history of physical theory as a "progressive evolution". Throughout his writings, the term 'evolution' is employed by Duhem in a non-technical sense as signifying a *directed* change ; the rider that this directed change is "progressive" gives expression to the notion that this change is *desirable* ([5]). The "slow and progressive evolution" detected by Duhem consists in the replacement of classifications that are partly representative and partly explanatory with ones that are more representative and less explanatory. Progress simply means that science is converging on a natural classification :

> When the progress of experimental physics goes counter to a theory and compels it to be modified or transformed, the purely representative part enters nearly whole in the new theory, bringing to it the inheritance of all the valuable possessions of the old theory, whereas the explanatory part falls out in order to give way to another explanation (Duhem 1914/1962, pp. 32).

What the history of science discloses, Duhem submits, is the flourishing of certain traditions, and the demise of other approaches. By examining "the continuous tradition through which the science of each epoch is nourished by the systems of past centuries, through which it is pregnant with the physics of the future", and by "exhuming doctrines once triumphant from the oblivion in which they lie" (Duhem 19914/1962, p. 270), Duhem contends that the physicist will discover rules of thumb about the limits of theory, while vindicating her belief that the entire historical process is one of enlightenment. Historical examination, in other words, engenders

(5) Scholars (e.g., Westman 1990, p. 263) sometimes take Duhem a face value and refer to his account as "evolutionist". Though Duhem freely employs this term, I use the expression "progressivist" to register the fact that, unlike some of his contemporaries, such as Herbert Spencer, Duhem seems to have been unaffected by Darwin's ideas in any substantial way. Jaki, in contrast, credits Duhem with a "fondness for the evolutionary perspective", and then undermines his assertion by conceding that Duhem "emphatically rejected the portrayal of human history as seen through the inexorable struggle of the survival of the fittest which leaves no room for purpose" (1984, p. 376). The implication would seem to be that Jaki is not at all clear as to the difference between evolutionary and progressivist views, and their influence on nineteenth century scholars.

the realist conviction that the trend of ideas points toward a natural classification.

Duhem's brand of progressivism entails *continuity* at the level of theory. This continuity is expressed in two distinct ways :

(1) The first is Duhem's contention that there is no *terminus ad quem* for flourishing traditions (cf. Westman 1990). With reference to his own program of Energetics, he remarks that

> it would be quite presumptuous to imagine that the system for the achievement of which he [the physicist] works will escape the fate common to the systems that have preceded it and will merit lasting longer than them ; but without vain boasting, he has the right to believe that his efforts will not be sterile ; through the centuries the ideas that he has sown and germinated will continue to increase and to bear their fruit" (1980, pp. 188-89).

Even the best scientific theories have the degree of *instability* which is consistent with their explanatory parts being continuously replaced by parts that are more representative. The history of science is an essentially *open-ended process* which may approach a natural classification but only as an ideal. "We do not possess this perfect theory", Duhem declares in the "Physics of a Believer", "and mankind will never possess it ; what we possess and what mankind will always possess is an imperfect and provisional theory which by its innumerable gropings, hesitations, and repentances proceeds slowly toward that ideal form which would be a natural classification" (1914/1962, p. 302). The message of this passage is that physics is essentially incomplete.

(2) The second is Duhem's maxim that for any scientific idea some predecessor is to be found. All scientific ideas, Duhem maintains, have a *terminus a quo*. Thus, in the preface to the first volume of *Origines de la statique* (1905), Duhem states that

> the science of mechanics and physics, of which modern times are so rightfully proud, derives in an uninterrupted sequence of hardly visible improvements from doctrines professed in medieval schools. The pretended intellectual revolutions were all too often but slow and long-prepared evolutions. The so-called renaissances were often but unjust and sterile reactions. Respect for tradition is an essential condition of scientific progress (cited by Jaki 1984, p. 387).

Throughout his writings, Duhem is keen to resist the suggestion that progress is occasioned by sudden and unforeseen discoveries, whether it be Newton's discovery that the same force governs terrestrial and celestial phenomena, or Maxwell's discovery that electricity and magnetism are aspects of a single electromagnetic field. It is a mistake to suppose that scientific hypotheses have no precursors at all. With respect to the tension between tradition and innovation, Duhem stood foursquare with tradition, and dismissed claims about radical new approaches as "the gossip of the moment" (Duhem 1914/1962, p. 304). Continuity — in the sense that every idea has a predecessor — is the principal lesson to be drawn from history : "science, no more than nature, makes no brisk jumps" (cited by Jaki 1984, p. 390).

Duhem's vision of the continuous development of scientific ideas is sustained by the fact that entire systems of scientific belief have become unstable after a time. A striking illustration is the classical theory of the kinematics and the dynamics of solid objects which disappeared in the wake of the transition from classical mechanics to the special theory of relativity. Duhem's progressivism attributes a certain degree of instability to all scientific beliefs, and so it is not surprising that some scientific systems grow so unstable that they are severed from the tree of science ([6]). Moreover, there is a trivial sense in which continuity is just a by-product of science's cumulative nature, and nothing more. Science is getting increasingly difficult to master as it advances into new frontiers. One way of enabling students to make their way to the cutting edge of disciplines where the real action occurs is to forge mathematical descriptions of greater generality. The practical benefits of being able to deduce

(6) By and large, philosophers have fastened onto the notion that an account of scientific progress must presume that our knowledge of nature is unstable. Only if we presume that all scientific statements are capable of revision can we justify the judgement that change is conducive to progress ; i.e., that conceptual change ensures successively superior views of the world (cf. Hacking 1988). In terms of this presumption, there is little to choose between Duhem's thesis that knowledge grows gradually through the successive modification of existing theoretical resources or the notion, which was popularized during the eighteenth century by such scholars as Alexis-Claude Clairaut and d'Alembert, that science grows primarily through revolutionary upheaval. Gradualist and radicalist models presume alike that the *instability* of scientific knowledge is a necessary ingredient in any account of scientific progress.

many laws from a few general principles, and dispensing with complex models that consume time and memory, can be considerable.

Progress through revolution

By and large, friends and foes of Duhem approached Duhem's conception of progress in terms of his contention that all scientific ideas have a *terminus a quo*. A typical example is the well-known challenge laid down by the historian of science, Alexander Koyré (widely known for disputing the importance that Duhem attached to the importance of Domingo de Soto, the Parisian doctors, and Leonardo da Vinci for Galileo's mathematical physics), which contends that "the apparent continuity in the development of medieval and modern physics (a continuity so emphatically stressed by Caverni and Duhem) is an illusion" (1968, pp. 21-22). Under the influence by Husserl (7), Koyré came to believe that the mathematization of nature had made a profound impression on modern philosophy. Koyré contended that physical science was wrested by Galileo from the ancients by *philosophical argument*, and by Newton from Descartes also by philosophical argument. Koyré (1957) characterized this revolution as a transition from the closed domestic world (the cosmos) of the Greeks to the infinite universe of Newtonian physics. What Koyré submitted, then, was that the rise of Newtonian science concerned mathematics itself. The philosophical wrangles that Duhem decried in his "SOZEIN TA PHAINOMENA" (1908) and elsewhere (cf. Duhem 1914/1962, p. 107) were at the hub of the new mathematical physics, according to Koyré, rather than extraneous metaphysical epicycles, which could well have been avoided. The message implicit in Koyré's work, therefore, is that Duhem misrepresented the role and nature of mathematics itself in the effort to interpret seventeenth century science as merely developments in mathematics.

Koyré message to practicing historians of science was that scientific revolution alone could confer meaning on the idea of progress —

(7) Koyré was a student of Edmund Husserl when Husserl was writing his *Crisis of the European Sciences* in 1935, a book which exerted a profound impact on Koyré's view of science.

a message which capitalized on the upheaval in twentieth century physics and which, moreover, was given added impetus as philosophers became bewitched by the incommensurability thesis. Historians of science have responded to this challenge in two ways. One prominent group has made the study of the impact of mathematical thinking on scientists its primary objective (for example, see Cohen 1980). A second group has followed in Duhem's footsteps and attempted to show that the seventeenth century mathematization of nature was in essence an achievement of medieval and renaissance science. A contest waged on this terrain is bound to be inconclusive, however, if only because the comparison of ideas — even mathematical ideas — is at best an inexact judgement which reflects the interests and point of view of the parties at dispute. Indeed, if we restrict our scrutiny to the development of a scientific theory, it is fairly easy to render plausible the contention that a precursor exists for even the most innovative idea ; and conversely, that a commonplace notion has been transformed into something truly revolutionary.

I suggest that we shift our attention to Duhem's contention that no scientific idea has a *terminus ad quem*. His contention that "we do not possess this perfect theory" seems to be reasonable if, by the expression a 'perfect' theory, we take Duhem to mean a theory which yields a reprentation of the true nature of things. However, if we take this expression to mean that all we possess — and all we will ever possess — is an imperfect and provisional theory which is only partially complete, then it is arguable that Duhem was mistaken. In addition to the many living sciences that are constantly being culled by scientists so as to harmonize them with new phenomena, there are some ossified theories that effectively constitute *closed systems of knowledge*. Werner Heisenberg remarked on the existence of ossified scientific theories as follows :

> I believe that Newtonian mechanics cannot be improved at all ; and thereby I mean the following : As far as any phenomenon can be described by the concepts of Newtonian mechanics, namely, position, velocity, acceleration, mass, force, etc., the Newtonian laws are also valid with absolute precision, and this will not change during the next hundred thousand years. More precisely I should perhaps say : With that degree of accuracy with which the phenomena can be described by the Newtonian concepts, the Newtonian laws are also valid" (1969, p. 135 ; cited by Schiebe 1988, p. 252).

On Heisenberg's view, the stability of the system of Newtonian hypotheses reflects a special relationship between Newtonian science and experience ; i.e., in so far as phenomena can be described by the concepts of Newtonian mechanics, its laws will be valid for these phenomena (8). The Newtonian system *cannot be improved by modification of its guiding assumptions*. Of course, startling new proposals, such as de Broglie's thesis that particles may display wave properties, may disclose that new concepts are required to express some novel state of affairs. In this event, there will be some prospect for improvement, but only because *the old concepts are no longer applicable* and not, as Duhem supposed, because the representative part of the old theory has been grafted onto a new theory which is more representative and less explanatory. Any improvement, therefore, will lead to a new system of beliefs produced to explain the novel state of affairs, resulting in a *gap* between the new system and the old one.

Classical mechanics seems perfectly adapted to a world which contains two kinds of things — particles and waves — but its concepts seem ill-suited to the *era quantique* where everything is made of a single kind of entity that combines properties of particle and wave in a peculiar quantum style of its own. Duhem's metaphysical realism seems to be too global to register the fact that, if anything, classical mechanics reflects bits and pieces of the ontological order, but certainly not the whole story. The only way around Heisenberg's contention that physics signifies a perfectly stable relationship between its concepts and a domain of phenomena is to hold that quantum mechanics represents a development of classical mechanics, a claim which may be plausible if we focus exclusively on theory, but seems improbable if we take into account the entire structure of theory, experimental devices, and quantum phenomena. The gap between classical and quantum mechanics that seems fairly innocuous at the level of theory takes on significant

(8) This paper focuses on one element in the stability of a science (namely, the relationship between its laws and the phenomena that they describe), but it does not rule out other considerations. Ian Hacking (1988), for example, suggests that theories and laboratory equipment evolve in such a way that they match each other and are mutually self-vindicating. On Hacking's view, then, experiment and stability are closely related, so much so that laboratory stability is consistent with gaps or disunities between different kinds of sciences (see Baigrie 1989, p. 14, fn. 7).

proportions when we turn to the experimental procedures that are at work in quantum mechanics.

The issue for Duhem's progressivism concerns the existence of ossified bodies of knowledge, such as classical mechanics and geometrical optics, that were once thriving disciplines but which have now been effectively relocated in engineering and applied science departments. Duhem's verdict that science is progressive is a judgement to the effect that it is *moving in a desirable direction*. The critical factor for Duhem is the idea of movement, which is mirrored in the ongoing refinement of theory. Accordingly, Heisenberg's suggestion that a science can signify a completed body of knowledge is an anathema to Duhem's progressivism, i.e., without the continuous refinement of hypotheses, there can be no progress at all.

As against Duhem, we could hold that the historical movement in science involves the closure of bodies of knowledge, and the commencement of new fields of study. Progress, we could hold, is engendered by the production of stable sciences simply because these completed sciences afford us different perspectives from which to study the world and, in turn, a plurality of points of view that collaborate so as to make us better acquainted with the world as a whole. If we resist Duhem's suggestion that physical theory is converging on one unified natural classification, we may be able to discern that there is progress in the completion of discrete branches of science ([9]).

EXPERIMENTAL PRACTICE

In the previous section, I suggested that the ossification of some sciences presents a problem for those who are enamored of continuity in the history of theory. It seems to me that the underlying difficulty is Duhem's presumption that physical science is essentially a body of theory. Indeed, if we examine completed bodies of scientific knowledge, we will find that their stability reflects an *interaction* between theory, phenomena, and experimental devices of various kinds. Examination of a particular apparatus, in concert with certain

(9) A theme of Duhem's work that I do not discuss here in detail is his enthusiasm for the unity of science. For a brief discussion, see Jaki 1984, pp. 298-300.

views about how the apparatus works and other beliefs about that aspect of the world which is under investigation, suggest that it is designed to produce certain kinds of phenomena. The apparatus in this way is vindicated by the phenomena ; and conversely, the production of the phenomena vindicate the employment of the apparatus. The collection of theoretical and material resources thereby stabilize in the sense that their collaboration is required for the production of the fact that is reported by the experimenters.

As historians we can trace the development of theory, but this in turn engenders the mistaken belief that the theory of an earlier era has been thrown in the dustbin. In truth, it still sustains and is sustained by experimental devices and phenomena that are true to these conceptual and material resources. As scientists build new devices that produce new phenomena, the old science is either discarded or relocated in an environment where it can be employed so as to produce stable and reliable results. Duhem has a story to tell us about experiment, of course, but it is not uncharitable to remark that his progressivism is infused by the presumption that physics is primarily a movement towards better theories and not, as an experimentalist like Heinrich Hertz would maintain, a movement towards better kinds of experimental devices.

If we simply attend to the difficulty of framing a comprehensive account of scientific practice, one which sees science both as a body of theory and as a cluster of practices that depend on scientists fiddling with devices of all kinds, it is not clear that we are in a position to render any verdict on scientific change. If we consider the entire range of resources that collaborate in the making of a science — *a material procedure* which includes such activities as setting up an apparatus and attending to its operation, *an instrumental model* which embodies the experimenter's beliefs about how the apparatus works, and *a phenomenal model* which expresses a view about whatever aspect of the phenomenal world is under investigation ([10]), it matters less what history looks like than whether we are able to tell a coherent story which gives each of these resources its due. Perhaps this helps to explain why the literature of a third, empirically-minded group of scholars (sociologists and some phi-

(10) The anatomy of experimentation which I employ is borrowed from Pickering 1989, pp. 276-77.

losophers and historians of science), who have started to look at science as something which depends on the experimental activities of its practitioners, seems insensitive to the traditional concern about science's credentials as a progressive body of belief. In terms of the suggestion that science is in many respects an activity of fiddling with devices which can even occur in the absence of theory ([11]), the grand old fight between radicalists and gradualists is no longer on the agenda.

Conclusion

Duhem may have been right to insist that "all the great innovators have had forerunners". I applaud those scholars (e.g., Menn 1990) who have taken on as their task the exploration of new paths to link medieval with modern physics, despite the fact that for many of these scholars the search for missing links is an end in itself, divorced from any tangible concern for how the historical phenomena appear in the light cast by a different account of scientific practices and institutions. As against Duhem, if we take the "invention" of a science in more practical terms to signify its completion as a body of knowledge, it does not follow that "not a single science was invented at a particular time". Even if the archives yield new 'sources' for early modern science, we will not thereby have furnished support

(11) Derek de Solla Price (1983) has argued that there is a marked difference between the work of experiments which, on Price's view, proceeds largely in the absense of theory, and the inscriptions of scientists that are often composed with an eye to such practical matters as funding. Price points to the early history of radio which, he argues, was "not so much a matter of physics, but the control of experimental techniques like spark gaps and of detectors and of such devices as coherors, surface magnetism, etc. Quite often the detecting devices in particular were known to work, but the reason why was not ascertained till much later. There is simply no way to apply a theory. The crucial point is to acquire and operate with a technique or a new effect, even if one has no idea why it works. That can come later" (Price 1983 ; cf. Buchwald 1991). What Price is suggesting is that experiment is not an extension of theory, as Duhem seems to supose, but largely autonomous from physical theory. What Price predicts is the existence of gaps between theory and experiment and — further to this — that the critical task for scholars is to see how theory and experiment sometimes interact in a way which stabilizes both tradictions. The consequence for Duhem's account of history is that it is not only an *entrepôt* of conceptual traditions but experimental traditions as well.

for Duhem's brand of progressivism. Though science may be an *entrepôt* of intellectual traditions, not all scientific traditions are moving forward. Duhem does predict that some scientific theories (e.g., the phlogiston and the caloric theories) will be discarded as the tree of science is pruned. What he does not predict — indeed, the phenomenon which seems inexplicable in terms of his restricted conception of physical science as an essentially theoretical activity — is that some flourishing traditions will ground to a halt. His view leads us to expect that the dustbin will be the *terminus ad quem* for some theories. With respect to the rest, we are led to expect that they will continuously approach, however slowly, a natural classification.

Duhem was above all else a theoretical physicist. His philosophy of science was not targeted at physics in a comprehensive sense of the term but, more accurately, at a very specific scientific activity conceived in the fashion of Energetics as the formulation of general rules which treat experimental laws as particular cases (see Duhem 1917, Part II). Duhem's narrow focus on a conception of physical theory suitable to his own work in Energetics rendered him insensitive to the burgeoning interest in experiments bearing on the real existence of atoms (see Duhem 1914/1962, p. 304). Indeed, in harsh tones reminiscent of Jean Baptiste Dumas and his bitter antagonist, Marcelin Berthelot, Duhem dismissed the rising interest in the structure of the atom as "a clairvoyant vision of what there is beyond sensible things" (Duhem 1917/1990, p. 188), less than a decade before Jean Baptiste Perrin furnished the first direct evidence for the atomic hypothesis by counting the number of atoms in a drop of water ([12]). Even so, Duhem's deliberations concerning this restriced conception of scientific practice are invaluable because they do afford the historian of science a framework for identifying the presence of tradition in even the most innovative ideas. It is certainly not my intention to deny Duhem's progressivist thesis that the history of science in this respect is an *entrepôt* of intellectual traditions.

(12) Astronomy was the one part of science which Duhem regarded as having achieved the appropriate integration between mathematical theory and experience prior to the seventeenth century, a harmony which was upset when the likes of Kepler and Galileo began to take seriously the notion that celestial bodies have the same natures as sticks and stones.

Duhem's perspective was not that of the laboratory scientist who explores bits and pieces of nature, not merely to know the world, but in order to *manipulate* it, with the aim of manufacturing phenomena that do not occur readily in a pure state of nature (see Hacking 1988). Nor was his perspective that of the engineer or the applied scientist who deals with those ossified theories that were once thriving sciences, such as classical mechanics and geometrical optics, and for whom a science signifies a stable and closed relationship between theory, assorted instruments and devices, and a cluster of phenomena that are true to these conceptual and material resources. The perspective of the engineer, in particular, offers us a different picture of the development of science — a picture of progress, if we are prepared to countenance the suggestion that the addition of a completed body of knowledge signifies progress — but one which is punctuated by grunts and gasps between sciences, as one chapter of the book of physics is closed and another opened. Whether it adds anything to our understanding of science to portray these gaps as "revolutions" is not an item for discussion here. It will be sufficient, I think, if scholars of Duhem come to acknowledge that there are other historical perspectives in terms of which science only makes sense as an activity which progresses through discrete jumps.

These considerations are critical of those scholars who still presume that the history of science is a homogeneous thing ready for subsumption under some general philosophy of physics, i.e., that the history of science is detached from our interests and our particular philosophical point of view. What underwrites this presumption is the realist conviction that there is only one world to be discovered by our best scientific theories, and so only one (rational) history of science for the telling. Presupposing the very metaphysical realism which enjoins Duhem's vision of history as converging on a grand natural classification can hardly be construed as support for Duhem's continuity thesis. As opposed to the idea that history is a single kind of thing which will help us to choose between different conceptions of scientific progress, we might be well advised to investigate the thesis that each of our sciences investigates bits and pieces of nature according to its associated cognitive and material recourses and, accordingly, that there are many histories for the telling. Some of these stories no doubt will reinforce Duhem's convictions. Others may not. Perhaps what an historical *bon sens* tells us is that we need not choose between these stories.

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