

ANDREW LUGG

PIERRE DUHEM'S CONCEPTION OF NATURAL CLASSIFICATION*

ABSTRACT. Duhem's discussion of physical theories as natural classifications is neither antithetical nor incidental to the main thrust of his philosophy of science. Contrary to what is often supposed, Duhem does not argue that theories are better thought of as economically organizing empirical laws than as providing information concerning the nature of the world. What he is primarily concerned with is the character and justification of the scientific method, not the logical status of theoretical entities. The crucial point to notice is that he took the principle of the autonomy of physics to be of paramount importance and he developed the conception of natural classification in opposition to accounts of physical theories that contravened it.

Pierre Duhem's view that physics aims to establish a 'natural classification' of phenomena is generally treated as something of an embarrassment, so much so in fact that it is frequently dismissed as an aberration or passed over in silence. Taking his official view to have been that the sole purpose of theorizing in physics is to facilitate discussion, commentators have tended to think that he must have regarded theories as 'artificial classifications'. Duhem could not, they suppose, reasonably have taken the theoretical physicist's aim to be both one of summarizing empirical laws in a compendious fashion and one of providing insight into the realities behind the appearances. Indeed some commentators have gone so far as to argue that he introduced the idea of natural classification because he could not bring himself to deny what physicists instinctively believe and some have even argued that he meant something quite different by the idea from what he seems to have meant.¹

This line of argument is tempting if only because Duhem devoted considerable effort to arguing that theories should be regarded as economical classifications. However, it also labours under the difficulty that Duhem frequently stresses that physical theories provide information about the nature of the world and it strains the imagination to suppose that he did not appreciate the difference between artificial and natural classification. While Duhem certainly thought that theories summarize empirical laws, this did not prevent him from arguing throughout his career for the view that they are converging on natural

classifications and he seems never to have doubted the consistency of his position.² In fact we would seem far better advised to take Duhem's remarks about physics converging on a natural classification at face value and to attempt to figure out how they can be reconciled with the rest of his philosophy.

Undoubtedly much of what Duhem says in *La Théorie physique* needs careful interpretation, but what he says about natural classification seems clear enough. Consider for instance his view that "physical theory is not merely an artificial system, suitable today and useless tomorrow, but . . . an increasingly more natural classification".³ Better still, consider his explicit contention that "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".⁴ In these and similar remarks Duhem distinguishes natural classifications for artificial ones, rejects the view that physical theorizing is restricted to the logical classification of experimental laws, and suggests that the classifications that physicists provide are becoming increasingly natural.

In fact Duhem's picture of science is the familiar one of a self-contained evolutionary enterprise in which less good theoretical classifications are replaced by better ones. In his view physicists make progress by replacing classifications that are partly 'representative' and partly 'explanatory' with ones that are more 'representative' and less 'explanatory'.⁵ More specifically, he holds that clashes between theory and experiment result in "the purely representational part" of the theory (i.e., the part obtained using the methods of theoretical physics) being taken up "nearly whole" by the new theory and "the explanatory part" (i.e., the part not so obtained) giving way to "another explanation". We are to think of each theory as passing on to its successor "by virtue of a continuous tradition . . . a share of the natural classification that it was able to construct".

True, Duhem takes consistency, unity and agreement with experimental laws to be the only 'logical conditions' on physical theories.⁶ He does not however take these conditions to be the only ones that theories should satisfy, still less regard theories that satisfy them as equally acceptable. In his view 'logically acceptable' theories are all too easy to come by and it is essential that new theories also be transformations of those already in place. To be acceptable a theory must, he

argues, be "the slow and progressive result of an evolution"; it must not be "the sudden product of a creation".⁷ In other words we should prefer theories that naturally extend flourishing traditions to ones involving new concepts all other things being equal. It is only when a tradition falls short on experimental or logical grounds that it is appropriate to contemplate the introduction of new theoretical principles.

Here it is important to keep in mind that Duhem's view of theories as converging on natural classifications is closely allied with his insistence on the autonomy of physics and its historical continuity. Given his conception of physics as an essentially autonomous enterprise, it is entirely unsurprising that he should appeal to the history of physics (rather than something external to it) to supplement the logical constraints on classifications. And given his commitment to the principle of historical continuity, there is nothing particularly remarkable about his rejection of the view that physical theories are artificial classifications in favour of the view that they are becoming increasingly natural. One can well imagine him thinking that physical theories can be reasonably regarded as natural classifications just to the extent that they are obtained by methods that are strictly autonomous and are appropriately continuous with what went before.⁸

It might be thought that such an interpretation runs foul of Duhem's conception of 'explanation' as radically at variance with 'logical classification' of his criticism of arguments to the effect that physical theories 'explain' experimentally established laws. But this is far less clear than it might appear. For what Duhem's attack on explanation is actually directed against is not explanation as such but 'metaphysical explanation'. Even in the first chapter of *La Théorie physique*, which is often taken to clinch the issue, Duhem does not deny that theories tell us something about the world. Here his main point is the negative one that it is neither desirable nor possible to derive physics from metaphysics. In the terminology of a later chapter, the butt of his criticism is the view that physics provides "definitive explanations"; he was not against thinking of physics as directed toward the discovery of "provisional representations".⁹

Far from wishing to show that theories should be thought of as artificial classifications, Duhem was mainly concerned to combat attempts on the part of some of his contemporaries to subordinate physics to metaphysics. What he rejected was not the usual conception of physical theorizing as culminating in 'nonmetaphysical' explanations but

rather the view of it as resting in one way or another on metaphysical assumptions, as subject to *a priori* restrictions. The main point that he wanted to emphasize was that the methods of physics are our sole means of investigating the world, that they are all that we can reasonably rely on, that they alone provide us with 'representations'. It is, he tells us, central to his conception of physical science that it "proceeds by an autonomous method absolutely independent of any metaphysical opinion".¹⁰

Similarly it is a mistake to trace Duhem's hostility to atomism and mechanism to his rejection of the conception of physical theories as explanations. The reason that he regarded Energetism as deserving special consideration was not that it happened to have a particular form but that he was of the opinion that "the means of knowledge available to Physics justifies the course it takes", his view being that physicists were – "the gossip of the moment" notwithstanding – in the process of securing the "complete realization of [the] ideal [of an abstract theory]".¹¹ For him the problem with scientific inquiry based on atomistic and mechanistic assumptions was that it violated the requirements of the autonomy and continuity of physics. He did not think that atomism and mechanism could not possibly be made good, only that they have not been (and that there was a better alternative available).¹²

Undoubtedly part of the explanation of why commentators misunderstand Duhem's position is that they fail to appreciate that he held his primary task to be one of delineating how the scientific method is deployed in practice. It is a mistake to assume – as is usually done – that he aimed to show that the methods of theoretical science are less robust than normally thought or that he believed that progress in physics occurs exclusively at the observational level or that thought of physical truth and theological truth as having to do with different 'ontological orders'. As he himself put it at the beginning of *La Théorie physique* his object was to provide "a simple logical analysis of the method by which physical science makes progress".¹³ The question of the theoretical progress of physics was never an issue for him; even at his most philosophical he remained true to his scientific and historical convictions.

To appreciate Duhem's stance it is helpful to remember that he took the positivism of his day (its important merits notwithstanding) to be no less flawed than the metaphysical approaches against which it was then being pitted. He agreed with Ernst Mach and like-minded thinkers

concerning the autonomy of physics and he took attempts to ground physics in metaphysics (including contemporary neo-scholastic attempts to integrate it into a general theological cosmology) to be subject to positivist criticism. Yet he was also convinced that the positivists were wrong to relegate the aim of physical theorizing to the development of an economical summary or artificial classification of empirical laws. Indeed he can perhaps best be regarded as attempting to appropriate the positivist's criticisms without embracing positivism itself.

Duhem virtually states as much when he observes that "the history of science alone can keep the physicist from the mad ambitions of dogmatism as well as the despair of Pyrrhonian skepticism".¹⁴ A sensitivity to history and the method by which physical science progresses is, he insists, an effective antidote both to dogmatic claims about the subservience of physical theory to metaphysical speculation and to skeptical counterclaims to the effect that such theory tells us nothing whatsoever about the world. In his view a study of the history of physics highlights both the "vicissitudes of cosmological schools" and the inadequacy of picturing "physical theory [as] an artificial system [rather than as] an increasingly clearer reflection of realities". Whenever physicists are "on the point of going to [either] extreme", such a study can, he avers, be relied on to provide the 'appropriate correction'.¹⁵

What is less clear – and with this we come to the nub of the issue – is how Duhem can hold that physical theories gradually approach natural classifications. It would seem that all that he should believe in this regard is that theories are artificial classifications, this being all that is warranted by considerations of logic and history. To Duhem's way of thinking however such a conclusion would be premature. For while he certainly believes that nothing stronger can be justified on the basis of the logical and historical arguments appropriate to physical inquiry, he is also of the view that there are additional nonlogical, nonhistorical arguments that need to be considered. As he states the matter, "no scientific method carries in itself its full and entire justification [and] we should . . . not be astonished that theoretic physics rests on postulates which can be authorized only by reasons foreign to physics".¹⁶

Once again Duhem accepts some of the positivists' principles and rejects others. He agrees with them concerning the character of the methods of physics and the particular theories that can be obtained using these methods. But he disagrees concerning the nature of the theories and what these tell us about the world. In particular he takes

the positivists to err in supposing that scientific justification is the only sort of justification that counts. The fact that physics is an autonomous enterprise in which an attempt is made to devise economical classifications of phenomena is, he insists, no reason to believe that all that a proper application of its methods can yield are economical classifications. As he sees the matter, physics is capable of establishing far more than it itself can establish that it has established.¹⁷

In support of this central point Duhem argues that it is taken for granted – albeit surreptitiously – even by positivists. One cannot, he argues, accept the positivist’s assumption that physical theorizing results in unified classifications without admitting that such theorizing goes well beyond what can be justified in its own terms, hodgepodes of empirical laws being perfectly compatible with pure logic and economy of thought. Indeed Duhem explicitly states that “neither the principle of contradiction nor the law of economy of thought permits us to prove in an irrefutable manner that a physical theory should be logically coordinated”.¹⁸ If one takes physics to be a well-founded enterprise one must, he concludes, admit the existence of another “source [from which] an argument [can be drawn] in support of this opinion”.

To avoid misunderstanding I should stress that I am not arguing that Duhem took the positivists to be right about physics and wrong about what lies beyond it. He did not hold that physicists stray beyond the confines of physics strictly understood when they assert that their theories are becoming increasingly natural, nor did he believe that they are – in their capacity as physicists – obliged to think of their theories as artificial classifications. To the contrary Duhem held that physicists are even in this capacity entirely justified in taking their aim to be the establishment of natural classifications and their theories to be even now natural (at least to a certain extent). In his view what lies beyond physics are only the arguments that warrant physicists believing what they happen to believe.¹⁹

Duhem himself devotes considerable effort to spelling out arguments for these beliefs; he does not simply state that arguments are required. Thus he points out that “it is impossible for us to believe that [the order and organization revealed by our theories] are not the reflected image of a real order and organization” and he argues in some detail that physicists are best thought of as “yielding to an intuition which Pascal would have recognized as one of those reasons of the heart “that reason does not know”.²⁰ In his view we are entirely justified in believ-

ing that theories tell us something about the world since it is entirely natural to do so. We should not be misled by the fact that such belief requires an intuitive judgement involving a 'reason of the heart'; this does not mean that it is unimportant or unreliable.

In addition Duhem would have us believe that physicists are justified in thinking of theories as natural classifications to the extent that they are able to use them to obtain novel predictions. The possibility of obtaining information about new situations would in his view be exceedingly remote were physical theories not at least roughly in accord with how the world actually is. If a "theory [were] a purely artificial system", its confirmation by a "hitherto unknown law" would, he stresses, "be a marvelous feat of chance" and we should be quite unwilling to "bet fearlessly in its favour".²¹ Of course this is not a deductively valid argument, it being impossible to derive a conclusion having to do with the nature of theories (namely that they are natural classifications) from a premise having to do with how theories have actually been used (namely that the best of them successfully anticipate the future). But for Duhem it is none the worse for that; he has no objection to this type of nondeductive ('transcendental') argument.²²

In this connection it is helpful to recall that Duhem takes theoretical physics and "spiritualistic metaphysics" to be both "radically heterogeneous" and "approach[ing] each other in their perfect form".²³ It is, he reminds us, one thing to deny that metaphysical conclusions can be derived solely from physical premises, quite another to hold that they cannot be derived from physical premises in conjunction with other reasonable (nonphysical) assumptions. What Duhem wishes to stress is not that theoretical physics has no bearing on theological cosmology, only that its bearing is never direct. One can, he insists, see that such heterogeneous viewpoints are (or are not) analogous given "reasons foreign to physics"; what is totally divorced from metaphysics is physical theory "in itself and by its essence".²⁴

Thus I would dispute the widely-held view that Duhem contradicted himself when he took general thermodynamics to approximate a natural classification analogous to Aristotelian cosmology. In arguing this way he was not compromising the principle of the autonomy of physics nor was he going back on his views about the separability of physical findings from metaphysics. While general thermodynamics "in itself and by its essence" neither accords nor conflicts with Aristotelian cosmology, we have every reason to hold that the two views are in

substantial agreement given the direction in which physics is tending and certain extrascientific considerations. "Aristotle's cosmology reduced to its essential affirmations" is indeed plausibly taken to be analogous to "the teachings of thermodynamics" and it is not difficult to appreciate Duhem's insistence that this is "all the more striking" for not having been planned in advance.²⁵

Be this as it may, it should be clear that Duhem stands foursquare against instrumentalistic conceptions of physical theories.²⁶ He meant what he said when he spoke of theories as "permit[ing] hints as to the real affinities of things" and stated that natural classification serves as "a sort of image and reflection of the true order according to which the realities escaping us are organized".²⁷ For him it would have been quite implausible to maintain that physical theories tell us nothing except that certain experimental laws are logically coordinated. While physics is (and always will remain) incomplete, we are well within our rights to think of theories associated with traditions tending in definite directions as reliable indicators of the realities behind the appearances.

In particular I should emphasize that it is not only those who regard Duhem's philosophy as instrumentalist through and through who are at fault. If the present interpretation is correct, it is just as wrong to describe his view as 'mitigated' or 'qualified' instrumentalism or to classify it as 'semantic realism' or to think of it as a species of 'common-sense realism'. Duhem was not attempting to straddle the fence, nor did he merely believe that physical theories should be regarded as true or false, nor was he any less committed to the reality of scientific objects than to the reality of everyday ones. Quite the reverse. If anything he espoused a version of what is nowadays called convergent realism. As we have seen he held that physics – left to its own devices – yields information about the nature of the world and that we are entirely justified in believing that its ontological claims are for the most part close to the truth.²⁸

Admittedly it is not difficult to cobble together quotations from Duhem's writing that make him sound as though he was uncompromisingly opposed to realism of any kind.²⁹ It is also true, however, that we omit an important part of his story when we read him this way. His general strategy is to argue first that theories are classifications (as opposed to metaphysical explanations) and then to provide considerations for the view that they are more or less natural (rather than artificial). Far from regarding physics as aiming at logical classification,

he takes this view of the matter to be the unsatisfactory outcome of an overly narrow conception of what physics can achieve. For him "physical theory confers on us a certain knowledge of the external world which is irreducible to merely empirical knowledge" and there is no avoiding the fact that a purely instrumentalistic physics would be of "meager importance".³⁰

NOTES

* I have benefited from discussions with Howard Duncan concerning Duhem's philosophy, and from Roger Ariew's and Michel Stack's criticisms of an earlier version of the paper. Also I would like to thank Ernan McMullin for his comments at the Blacksburg Conference.

¹ Compare L. de Broglie's suggestion that Duhem "mitigate[d] the rigor" of his view because he felt that physical theory must be accorded "a deeper bearing than that of mere methodical classification of facts already known" (1962, p. x) and R. Poirier's claim that "[Duhem's] expression 'natural classification' is roughly equivalent to 'language'" (1967, p. 403).

² Duhem invokes the conception of natural classification not only in *La théorie physique* of 1906 but also in 'L'école anglaise et les théories physiques' of 1893 and in 'Notice sur les titres et travaux scientifiques' of 1913.

³ Duhem (1914/1962), p. 270.

⁴ Duhem (1914/1962), p. 31. Also compare Duhem's view that "we can and we must . . . attempt to make [our] classifications as little artificial and as natural as possible" (1893b/1987, p. 137) and his claim that "physical theory may attain a certain knowledge of the nature of things . . . [as] the goal of [its] progress, the limit it constantly approaches without ever reaching" (1917/1987, p. 338).

⁵ Duhem (1914/1962), p. 32; see also pp. 204–5 and p. 221.

⁶ Duhem (1914/1962), p. 220.

⁷ Duhem (1914/1962), p. 221; see also p. 295. A good example is Duhem's criticism of Maxwell's introduction of the notion of displacement current (see pp. 78–79 and Ariew and Barker 1986, pp. 140–50). Also it should be remembered that Duhem argues that "the physicist does not choose the hypothesis on which he will base a theory" but rather draws on "the thoughts habitual with those among he lives and tendencies impressed on his own mind by his previous studies" (1914/1962, pp. 255–56).

⁸ The importance of the autonomy of physics for Duhem can hardly be overstated, it being one of his "constant" concerns (1914/1962, p. 274). Compare Martin (1976), p. 127, where Duhem is said to have regarded the autonomy of physics as "an essential regulative principle". In emphasizing this point I do not of course mean to belittle the importance of Duhem's critique of the "Newtonian method of induction from observation" (see also Ariew 1984, pp. 319–20).

⁹ Duhem (1914/1962), p. 270; see also Duhem (1893a/1987). In addition note that the title of the first chapter of the *La Théorie physique* is "Physical Theory and Metaphysical Explanation" and that explanation and classification are introduced as the two main answers that "logicians" have given to the question of the aim of physical theory (p. 7). Moreover Duhem is not in the least averse to speaking of other possible aims (see, e.g.,

p. 81). It is, I suggest, wrong to suppose that his discussion rests on a “dogmatic and unsupported presupposition about the nature of explanation” (compare Alexander 1967, p. 423).

¹⁰ Duhem (1914/1962), p. 274. Contrast Karl Popper’s suggestion (1969, p. 104) that Duhem “seems to think that . . . there are essences but they are undiscoverable by human science (although we may, somehow, move towards them)”. As I read Duhem, his view was not that “essences . . . are undiscoverable by human science” but that they are only discoverable this way. Incidentally there are many striking parallels between Popper’s own philosophy and Duhem’s (see e.g., Duhem (1914/1962), pp. 23, 27, 53, 177, and 277).

¹¹ Duhem (1917/1987), p. 334 and Duhem (1914/1962), p. 304.

¹² Significantly Duhem argues that atomism and Cartesianism are plagued by faulty reasoning and at variance with important experimental laws; he does not challenge them on philosophical grounds (compare his (1914/1962), pp. 80–86, 280, and 304). While Duhem agrees with Hertz that “Maxwell’s theory is the system of Maxwell’s equations” (p. 80), he no more takes the theory to be an artificial classification than does Hertz, his main point being that it should not be encumbered with mechanical models. Also compare Duhem’s criticism of the atomist and the Cartesian for placing “hypothetical knowledge of the nature of things at the starting point of physical theory” (1917/1987, p. 338).

¹³ Duhem (1914/1962), p. 3. Also note that Duhem believed that “to give the history of a physical principal is at the same time to make a logical analysis of it” (p. 269).

¹⁴ Duhem (1914/1962), p. 270.

¹⁵ Also compare Duhem’s rejection of the complaint that his view “opens the door to skepticism” and “makes a concession to positivism” (1893a/1987, p. 97). In this paper I do not consider Duhem’s historical work but it is worth noting that here too one of his major themes is that physical theories are neither subordinate to metaphysics nor merely ‘artificial’.

¹⁶ Duhem (1914/1962), p. 293; see also p. 298. In arguing this point I part company with R. N. D. Martin, who holds that Duhem was concerned with the possibility of logically justifying the requirement that physical theories be “logical and coherent” (see his 1987, p. 306). As I read Duhem his point was that certain scientific procedures cannot be established given logic (and history); he did not think of logic (or history) as being in need of justification.

¹⁷ See also Duhem (1893a/1987), p. 99.

¹⁸ Duhem (1914/1962), p. 102; see also pp. 293–4 and 334, and Duhem (1893b/1987), p. 134. The same point can be made about the common positivist demand – defended, e.g., by Mach – that later theories connect up with earlier ones.

¹⁹ If this is right, Duhem did not hold that “the scientist qua scientist must work with theories as if they are only instruments [i.e. mere classifications]” (Joy 1975, p. 197). In the terminology of Bas van Fraassen (see his 1980) Duhem maintained that physicists are justified in believing their theories as well as in accepting them as empirically adequate. As Michael Stack has pointed out to me there is an interesting analogy between physical theories (as I take Duhem to conceive them) and perceptual beliefs in that both provide information the reliability of which can be vouchsafed only by invoking ‘external considerations’.

²⁰ Duhem (1914/1962), pp. 26 and 27. Significantly Duhem also speaks of the physicists’s concern with unity as being “a legitimate one because it results from an innate feeling”

(p. 102). "The aspiration towards a theory whose parts all agree logically with one another is", he insists, "the inseparable companion of [the] aspiration . . . towards a theory which is a natural classification of physical laws" (pp. 103-4).

²¹ Duhem (1914/1962), pp. 28; see also pp. 195 and 297. In the same context Duhem states that "the wonderful order [that] classification . . . brings about in the tremendous arsenal of chemistry already assures us that the classification is not a purely artificial system" (pp. 28-29; see also p. 300).

²² Thus I reject N. Cartwright's contention (1982, p. 112) that Duhem is antipathetic to "theoretical laws because he does not countenance inference to the best explanation". On my reading, Duhem espoused a version of what has come to be called "the miracle argument" and he was opposed neither to theoretical laws nor to inference to the best explanation.

²³ Duhem (1914/1962), pp. 301 and 299.

²⁴ Duhem (1914/1962), p. 285. It is irrelevant that there are normally disanalogies as well as analogies between physics and metaphysics (p. 303). The crucial point is that we can on occasion legitimately step beyond physics and "recognize in [physics and metaphysics] two pictures of the same ontological order, distinct [only] because they are each taken from a different point of view" (p. 310). When Duhem speaks of his view as being positivist in both "its origins" (p. 275) and "its conclusions" (p. 279), what he means is that he developed his ideas without appealing to metaphysics and without having had any specific conclusion in mind.

²⁵ Duhem (1914/1962), pp. 310 and 307. I might note in passing that Duhem's discussion of refutation rests on considerations similar to those just outlined. Duhem's basic idea is that it often makes "good sense" to reject a theory rather than an auxiliary assumption and that while decisions based on good sense cannot be justified scientifically they are nonetheless perfectly reasonable (see p. 217).

²⁶ Compare, e.g., Alexander (1967), p. 425, Popper (1959), p. 78, and van Fraassen (1980), p. 86.

²⁷ Duhem (1914/1962), pp. 30 and 31. It should not be forgotten that Duhem took his preference for Energetism over atomism to have important consequences for our understanding of the nature of the world and that he recognized the existence of "microscopic nuclei" (see p. 221).

²⁸ For the views criticized in this paragraph see Joy (1975), p. 199 and Martin (1987), p. 309, Giedymin (1976), p. 184, and Jaki (1984), p. 320.

²⁹ Compare Duhem (1914/1962), pp. 8, 19, 21, 115, 124, 144, and 180.

³⁰ Duhem (1914/1962), p. 334.

REFERENCES

- Alexander, P.: 1967, 'Pierre Duhem', in P. Edwards (ed.), *Encyclopedia of Philosophy*, Macmillan, New York, Vol. 2, pp. 423-5.
- Ariew, R.: 1984, 'The Duhem Thesis', *British Journal for the Philosophy of Science* 35, 313-25.
- Ariew, R. and P. Barker: 1986, 'Duhem on Maxwell', *PSA 1986*, Philosophy of Science Association, East Lansing, Michigan, pp. 145-56.
- de Broglie, L.: 1962, 'Forward' to P. Duhem 1914/1962, pp. v-xiii.

- Cartwright, N.: 1982, 'When Explanation Leads to Inference', *Philosophical Topics* **13**, 111–22.
- Duhem, P.: 1893a/1987, 'Physique et métaphysique', reprinted in S. L. Jaki (ed.), *Pierre Duhem: prémices philosophiques*, E. J. Brill, Leiden, pp. 84–112.
- Duhem, P.: 1893b/1987, 'L'école anglaise et les théories physiques', reprinted in S. L. Jaki (ed.), *Pierre Duhem: prémices philosophiques*, E. J. Brill, Leiden, pp. 113–46.
- Duhem, P.: 1914/1962, *La théorie physique: son objet, sa structure*, 2nd ed., translated by P. P. Wiener as *The Aim and Structure of Physical Theory*, Atheneum, New York.
- Duhem, P.: 1917/1987, 'Notice sur les titres et travaux scientifiques', translated in part by Y. Murciano and L. Schramm in *Science and Context* **1**, pp. 333–48.
- Giedymin, J.: 1976, 'Instrumentalism and Its Critique: A Reappraisal', in R. S. Cohen et al. (eds.) *Essays in Memory of Imre Lakatos*, Reidel, Dordrecht, pp. 179–207.
- Jaki, S.: 1984, *Uneasy Genius: The Life and Work of Pierre Duhem*, Nijhoff, The Hague, The Netherlands.
- Joy, G.: 1975, 'Instrumentalism: A Duhemian Reply to Popper', *Modern Schoolman* **52**, 194–99.
- Martin, R. N. D.: 1976, 'The Genesis of a Mediaeval Historian', *Annals of Science* **33**, 119–29.
- Martin, R. N. D.: 1987, 'Saving Duhem and Galileo', *History of Science* **25**, 301–19.
- Poirier, R.: 1967, 'L'épistémologie de Pierre Duhem et sa valeur actuelle', *Etudes philosophiques* **22**, 300–419.
- Popper, K. R.: 1959, *Logic of Scientific Discovery*, Hutchinson, London.
- Popper, K. R.: 1969, *Conjectures and Refutations*, 3rd revised edition, Routledge and Kegan Paul, London.
- van Fraassen, B.: 1980, *The Scientific Image*, Oxford University Press, Oxford.

Department of Philosophy
 University of Ottawa
 Ottawa, Ontario, K1N 6N5
 Canada