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DUHEM, THE ARABS, AND THE HISTORY OF COSMOLOGY

ABSTRACT. Duhem has generally been understood to have maintained that the major Greek astronomers were instrumentalists. This view has emerged mainly from a reading of his 1908 publication *To Save the Phenomena*. In it he sharply contrasted a sophisticated Greek interpretation of astronomical models (for Duhem this was that they were mathematical contrivances) with a naive insistence of the Arabs on their concrete reality. But in *Le Système du monde*, which began to appear in 1913, Duhem modified his views on Greek astronomy considerably; his more subtle understanding included the recognition that many Greeks subordinated mathematical astronomy to physical theory. But he could not completely repudiate his earlier views about Greek astronomy in part because his extreme nineteenth century prejudices led him to continue to insist on a clear-cut demarcation between Greek and Arabic astronomy. The inevitable result is a certain unevenness in the *Système* and some glaring inconsistencies.

Given the totality of Duhem's enormous output, one would be hard put to claim that Arabic science played more than a peripheral role in his historical and philosophical writings. And because Duhem, who did not know Arabic, was often grossly mistaken in his views and interpretations of Arabic science, leaving it little more than a grotesque caricature, it is appropriate to ask: why bother? There are several reasons, which may serve both as an introduction and an apologia. It is a far from worthless exercise to try to discover why a great thinker goes so far off the track. It is rather facile to claim that Duhem's views were a result of his anti-Semiticism; but this takes us only so far and fails to put his views into historical perspective. Yes, Duhem was rather extreme in his notions of Arabic science, but I think he only took to a logical conclusion views that were until recently fairly prevalent. And the continuing influence of Duhem's historical works makes an evaluation of his attitude toward Arabic science even more imperative than it would otherwise be. Another reason to look at Duhem's understanding of Arabic astronomy is because of his use of it as a foil to put in bolder relief the genius of Greek science. As we know from recent debates, Duhem left himself open to interpretation in the use of his cherished 'saving the phenomena'. Because in Duhem's view the Arabs could never rise to the Greeks' elevated understanding of astronomical

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theory, a study of what he said about their failure – indeed ignorance – can provide, I believe, some useful insight into what he intended by 'saving the phenomena'. My own contention will be that there was a marked evolution and refinement in his thinking about Greek astronomy between *To Save the Phenomena* (herein abbreviated STP), which appeared in 1908, and the second volume of *Le Système du monde*, which was published in 1914. But there was no similar change in thinking about Arabic astronomy, a situation that led to a major inconsistency in the *Système*; ironically this inconsistency could have been dealt with, though perhaps not completely resolved, if Duhem had been willing to be less hostile toward the Arabs. But he was unable, or perhaps unwilling, to do this.

In order to illustrate my point, I shall be concentrating on the question of Duhem's understanding of the relation of ancient physics to mathematical astronomy. I believe that by examining this issue (rather than, say, the much more intractable question of the reality of astronomical models)[1] one can most clearly understand Duhem's evolution as well as the importance, and limitation, of the criticism of G. E. R. Lloyd (1978), Duhem's most severe critic on this point. Without going into a detailed exposition or analysis of STP, I should like to give a brief overview of some of its main points.[2]

According to Duhem, there were basically two methods for dealing with the celestial realm: the method of the astronomer and the method of the physicist. Plato had set forth the method of the astronomer, namely to save the appearances of the planets using only uniform, circular motions. This was the method of Eudoxus and Callippus, who sought to save the appearances with homocentric spheres. On the other hand, Aristotle, representing the physicists, went beyond the merely mathematical saving of the appearances and sought to impose other restrictions that had to do with the nature of the heavenly bodies. Thus the fictitious models of Eudoxus were turned by Aristotle into combinations of real spheres whose nature it was to move with uniform, circular motion. Because they were real and not simply mathematical, Aristotle needed to add extra counterspheres in order to keep the system of spheres for each planet from interfering with the others.

At this point, Duhem was illustrating the relation of physics to astronomy by using the example of a physicist, in this case Aristotle, attempting to make real the mathematical models of the astronomers. But the relationship became more complicated when the Greek astronomers

found that different hypotheses or models could equally well save the phenomena. This was emphasized by Hipparchus who was struck by the fact that an epicycle on a concentric deferent could be made mathematically equivalent to an eccentric model. The relationship was further complicated by the fact that an astronomy using epicycles and eccentrics was no longer compatible with an Aristotelian physics that demanded that all celestial motion be uniform about the center of the Universe. Among others Adrastus of Aphrodisias and Theon of Smyrna sought to accommodate the new astronomy by proposing a modified Aristotelian physics that exempted celestial motion from being about the center of the world but still held that the orbs, whether eccentric, epicyclic, or concentric, had to be solid bodies.

As we have seen, Duhem claimed that Eudoxus and Callippus had followed the method of the astronomers as laid out by Plato; he also put Hipparchus in this category. But it was with Ptolemy that a new, much more sophisticated understanding of the relation of mathematical astronomy to physics was reached. Since "no craftsman could have constructed a wooden or metal representation of [his hypotheses in the *Syntaxis*] . . . Ptolemy's followers were bound – on pain of abandoning their own doctrines – to liberate astronomical hypotheses from the conditions to which physicists had generally subjected them".[3] Duhem quoted a number of passages to support his position but the most important by far was from the *Almagest*, Bk. 13, Chap. 2,[4] in which Ptolemy, according to Duhem, "means to indicate...that the many motions he compounds in the *Syntaxis* to determine the trajectory of a planet have no physical reality; only the resultant motion is actually produced in the heavens".[5] Duhem related this interpretation of Ptolemy to the earlier doctrine of the Stoic Cleanthes (d.ca. 230 B.C.), who held that the planet was self-propelled and described whatever curves were observed, and to the later view of the neo-Platonist Proclus (d. 485 A.D.), who, in Duhem's reading, took the essence of the heavenly motions to be irregularity. The final freeing of the astronomers from the restrictions of the physicists was complete. And what would be the role of the physicist?

> But only the physicist would be authorized to say whether or not [the mathematical models] conform to reality. Generally speaking, the principles he is able to affirm are too general, too remote from particulars, to empower him to pronounce that kind of judgment.[6]

In other words, the method of the astronomer was eventually victorious in ancient Greece.

Lloyd has severely criticized most of Duhem's contentions in a detailed way. There is no need to rehearse the entire list; it is only important for our purposes to identify three of his main objections. First he makes the case that Duhem has ignored the strong evidence that the astronomers, far from being independent, took their starting-points or principles from the physicists. This, for example, was stated explicitly by Geminus, whom Duhem took as a witness for the opposite point of view.[7]

A second criticism by Lloyd concerns Ptolemy. Whatever one may wish to say about his position in the *Almagest*, there is the matter of the *Planetary Hypotheses* in which there is no doubt that he is taking a realist stance. How else is one to understand the transforming of the circles of the *Almagest* into physical bodies, a metamorphosis effected in Book II of the *Planetary Hypotheses*? And even if one were to excuse Duhem in 1908 for not having gotten hold of L. Nix's German translation from the Arabic of the nonextant Greek text of Book II, a work published in 1907,[8] one could still argue, as does Lloyd, that the physical arguments in Book I of the *Almagest* should have alerted Duhem that Ptolemy was ostensibly basing his mathematical models, indeed subordinating them, to a revised Aristotelian physics.[9]

Lloyd's third criticism has to do with Proclus. Duhem did not hesitate to compare him to the positivists, indeed to John Stuart Mill;[10] but Lloyd systematically shows that whatever Proclus's neo-Platonist position may have been, and if anything it is ambiguous, he was fairly consistent in arguing from realist assumptions whether he was criticizing realist or instrumentalist alternatives.[11]

One cannot but admire the incisive way Lloyd has gone about refuting Duhem's contentions in *To Save the Phenomena*. It is a masterful piece of writing, but it has not gone without criticism. Niall Martin (1987) has criticized Lloyd and others for viewing Duhem too simplistically; Martin claims that Duhem was more than aware that the ancients were not instrumentalists per se but rather tied their instrumentalism, if we can call it that, to cosmological and epistemological stances. Thus Ptolemy's instrumentalism was not to be separated from his stoicism just as Maimonides' should not be understood as separable from his religious beliefs; in both cases their skepticism about the possibility of a complete understanding of celestial phenomena, as distinct from

sublunar phenomena, led them to their quasi-instrumentalism.[12] Now both Lloyd and Martin are basing their positions on STP; from that context alone, Martin may have a point but one must admit that Duhem certainly seems to be attributing instrumentalist views to the Greeks. After all it was Duhem, not Lloyd, who evoked the name of John Stuart Mill in his discussion of Proclus. But to judge Duhem solely with reference to STP, as Lloyd and Martin both do, is to do him a grave disservice. For this was not Duhem's final word; in Volume II of *Le Système du monde* (1914) he took up many of the issues of Greek and Arabic astronomy that he had dealt with before in STP but in a much more careful way. This is Duhem's mature work, and I think it only fair that we take it into account when we discuss his views on Greek astronomy. And on the crucial issue of the relation of physics to astronomy, Duhem has made a number of significant shifts.

While one can hardly say that Duhem has repudiated the thesis of STP, one can say that he has modified it in subtle and at times decisive ways in the *Système*. On the surface Duhem seems to carry the main theme of STP into his later work. For example in the *Système*, he characterized what he calls "this war" as being between "those who want Physics [in the modern sense] to be deducible from a set philosophical system and . . . between those who require nothing more from [physics] than that it agree exactly with experience".[13] But whereas many points made in STP were repeated, sometimes verbatim, in the *Système*, the important relationship between the principles of physics and mathematical models in Greek astronomy was explored with much greater depth and precision, and Duhem reached certain conclusions that undermine, if not contradict, various assertions of STP. For example, in discussing the homocentric spheres of Eudoxus and Callippus in the *Système*, Duhem posed a question never addressed in STP, namely

> If Plato and Aristotle were only interested in obtaining mathematical rules that would permit them to predict with certainty and precision the movements of the stars, why would they impose in advance of these rules the obligation to be constructed in a certain manner? . . . Why would they constrain [astronomy] . . . with circular and uniform movements? Why would they further restrain [astronomy's] ability to choose by obliging it to configure the World with a system of homocentric spheres? Such requirements are enough to give notice that neither Plato nor Aristotle would have consented to reduce the object of astronomy to the [following] single problem: to conceive of geometrical hypotheses that would save the phenomena.[14]

There is more than one thing surprising here. After all Plato in STP

had been assigned the role of initiator of the call to the astronomers 'to save the phenomena'. Duhem had mentioned there that Plato had required that this be done with uniform, circular motions, but the obvious physicalist implications had been ignored. Here, however, we see that he has not only recognized the problem but has also drawn the obvious conclusion about Plato, namely that he was hardly an instrumentalist.[15]

But there is another aspect to the problem that was new in the *Système*. Did an astronomer who accepted uniform, circular motion as a starting point for astronomy accept *ipso facto* the constraints of the physicists? And if so, what did this do to the radical separation between astronomers and physicists in STP? Again the ambiguities and silence of STP gave way to a direct assault on the problem in the *Système*. In discussing Dercyllides, Duhem noted that he was not an innovator when he "affirms the dependence, generally recognized by the philosophers, between astronomy and physics; others...have also detailed the character of this dependence". This is not very different from what one might find in STP. But then he went on to say that "those who compose astronomical treatises, respectful [*respectueux*] observers of these precepts, begin by enunciating the postulates, borrowed from Physics, which must [*devaient*] serve as points of departure for their deductions".[16] We should recall here that one of Lloyd's criticisms was that Duhem ignored the relation of the physical principles to the starting points of the astronomers. But in addressing his future critic, Duhem has made the previously clear-cut notion of 'saving the phenomena' rather ambiguous in the *Système*.

Lest one think that this is somehow unrepresentative, we should examine what Duhem said in the *Système* about Ptolemy, who was after all the Greek astronomer Duhem had claimed in STP most clearly represented the doctrine of 'saving the phenomena'. Far from denying that Ptolemy was constrained by physics, Duhem must admit that "at the beginning of his work, Ptolemy formulates his postulates as if astronomy must be entirely based upon principles of complete certitude, upon incontestable verities from Physics". But Duhem found that "at the end [of the work] . . . instructed by experience, the author does not grant his hypotheses to be anything more than contrivances that are appropriate to save, as simply as possible, the phenomena".[17] Here one would have expected the Duhem of STP to end the matter; Ptolemy

had paid lip service to the physical principles, found them too constraining, and ended by rejecting them. But instead Duhem provided a real surprise. At this point he himself introduced the same weapon that Lloyd and others have used to question the Duhemian interpretation of Ptolemy, namely the *Planetary Hypotheses*. After assuring his readers, no doubt sadly, that the text is authentic, he proceeded to give a fairly detailed summary of the second book in which Ptolemy attempted to physicalize his models from the *Almagest*.[18] Duhem was fully aware of what this meant for his interpretation of Ptolemy. But he tried to salvage what he could:

> Ptolemy had rightly been able to scorn this desire to represent the movements of the celestial and imperishable bodies by means of these rough and changing bodies that make up for us the sublunar world; his criticisms had not won a definitive victory; the error that they were combatting was one of those which, apparently vanquished, overturned one moment, rise up again without ceasing, because they are the necessary consequence of an incorrigible failing of the human spirit. What Dercyllides, Adrastus and Theon had wanted was to embody abstract thoughts in concrete models that the eyes could see, that the hands could touch and move; it was to drive away reason in order to put imagination in its place. Ptolemy, after having defended reason, became, in his turn, a slave of the imagination.[19]

At this point Duhem turned to the neo-Platonists, in particular Proclus. What he found was someone less ambiguous and much more to his liking. But he had to retranslate the relevant passages from the *Hypotyposes* since he realized, long before Lloyd would make the point, that Father Halma's translation that he had depended on in STP was seriously defective. Thus Duhem could no longer have Proclus saying that the "essence of [the celestial] movements...is irregularity".[20] But Duhem still held that Proclus viewed astronomical hypotheses as mere fictions in part because he chose to concentrate on his Platonic world-view, a philosophical stance that led Proclus to be sceptical of all attempts to deal with the celestial appearances as distinct from the real heavens, which to him were, as they had been to the divine Plato, beyond perception. Lloyd, on the other hand, while recognizing this aspect of Proclus's position,[21] could counter Duhem's contentions by pointing to Proclus's realist (or perhaps it would be better to call them physicalist) suppositions under which he operated even when dealing with the appearances.

But again where did this leave Duhem? After losing both Plato

and Ptolemy as pure representatives of the view that the astronomical hypotheses were mere contrivances, he was basically left with Proclus, someone that Lloyd has accurately characterized as "not exactly one of the leading lights in the history of Greek astronomical theory".[22] One would think that Duhem would be forced to back off from some of the more extreme claims of STP. But Duhem did not draw the obvious conclusion from his work, namely that the most important Greek thinkers held a basically realist position and subordinated mathematical astronomy to physics. It was not a pure position, it was not completely clear-cut, but his work could lead to no other conclusion. Though it is too much to expect that Duhem would have completely repudiated the major thesis of STP, it still comes as a shock to find the following passage from STP repeated in the *Système*:

> After some initial hesitation [the Greeks] balked at the idea that the eccentrics and epicycles are bodies, really up there on the vault of the heavens. For the Greeks they were simply geometric fictions requisite to the subjection of celestial phenomena to calculation. If these calculations are in accord with the results of observation, if the hypotheses succeed in saving the phenomena, the astronomer's problem is solved.[23]

Interestingly enough, this passage does not occur in the chapter on the Greeks but rather in the introduction to the one on the 'Semites'. All the ambiguity, the subtlety of the previous chapter on the Greeks is lost; Ptolemy once again becomes someone whose hypotheses are 'calculating devices'.[24] The *Planetary Hypotheses* are conveniently forgotten. Why Duhem chose to start his chapter on the 'Semites' in this way is apparent from the next paragraph:

> The prodigious geometric ingenuity of the Greeks did not form part of the heritage they passed on to the Arabs. Nor did the Arabs have the Greeks' remarkably sure and precise logical sense. They brought only some very minor improvements to the hypotheses whereby the Greek astronomers had managed to resolve the complex course of the planets into simple motions. Moreover, when they did at last come to examine these hypotheses in an attempt to make out their nature, their vision could not match the penetration of a Posidonius, a Ptolemy, a Proclus, or a Simplicius; slaves to their imagination, they tried to see and touch what the Greek thinkers had declared fictive and abstract.[25]

It is this stark contrast between the Greek mind and the Arab mind that Duhem wished to bring out in both STP and the *Système*. The fact that the Greeks were no longer so pure and that Ptolemy himself had been called a slave to the imagination did not prevent Duhem from repeating verbatim in the *Système* what he had written in STP. Duhem's

antipathy toward the Arabs is not in doubt; indeed one can see it as part of the nineteenth century European cultural baggage.[26] But even for the nineteenth century Duhem was extreme. The person closest to his view on Arabic science was Ernest Renan, with whom Duhem shared hardly anything else.[27] Renan had denied both the Arabs and Islam a role in the history of science; nomadic Arabs were incapable of science or philosophy and Islam was too hostile to allow science to flourish. What went under the name Arabic or Islamic science was due to Christians, Jews, Persians, and others, or Muslims who, like Galileo, had heroically freed themselves of their religion.[28] But Duhem went Renan one better; while Renan had not discounted the contributions that went under the name Arabic or Islamic science, Duhem essentially denied that there was anything of importance in Arabic astronomy.[29] When he did find something worthwhile, such as the homocentric system of the Spanish Arab Biṭrūjī (fl. 1200 A.D.), which he claimed helped pave the way for Copernicus by providing an alternative to the Ptolemaic system, he rejected the possibility that any Arab could have been responsible for it.[30] The way he did this is extraordinary; Duhem maintained that the ordering of letters in the diagrams of Biṭrūjī followed the Greek alphabet and hence his system must depend on or be plagiarized from a Greek original.[31] It would be hard to exaggerate the silliness of this argument, and it is incredible to me that someone of Duhem's immense abilities could have fallen for something so ludicrous.[32] Since the Arabic alphanumeric system follows the old Semitic ordering, the one used, for example, by the Phoenicians who bequeathed it to the Greeks, it is no wonder that the Greek and Arabic ordering would be the same. Thus using Duhem's reasoning, one could hardly escape the conclusion that virtually every Arabic scientific text was plagiarized from some Greek original.[33]

We have seen how Duhem's wish to draw a sharp dichotomy between the Greeks and Arabs led him to gloss over what I consider to be some of his most important work in the history of cosmology. What is sad, and indeed unfortunate for the history of science, is that Duhem did not notice, or did not wish to notice, that the ambiguous Greek attitude toward the relation of physics and astronomy that he brought to light in the *Système* was dealt with in interesting ways in Islamic astronomy. If Duhem had simply drawn the obvious conclusion from his own research that the major Greek philosophers and astronomers were committed in varying degrees to the proposition that the principles of

mathematical astronomy must come from both mathematics and physics, he would have been more sensitive to the fact that the Arab thinkers that he studied were not so much naive realists as scientists interested in reconciling the inconsistencies in astronomical theory that they had inherited from the Greeks. Let me try to make this point as clear as possible. In accepting that astronomy was based on both mathematical and physical principles, Arab astronomers reached a rather simple conclusion – the mathematical models had to be consistent with the physical principles. Ptolemy had not been able to accomplish this in the *Almagest*, and indeed in Bk. 13, Chap. 2, he does seem to be taking refuge in some neo-Platonic worldview. But starting with Ibn al-Haytham in the eleventh century, this was seen not so much as a serious position on the relation of physics to mathematics but as simple inconsistency.[34]

Despite the fact that Duhem in the *Système* had understood the difference between metaphysics and physics in the Greek context and in fact had used it to distinguish between the justifications of Aristotle and Plato for uniform, circular motion, I would agree with Martin that Duhem remained committed to the view that "'astronomy' is the ancient correlate of modern physics, and 'physics' the ancient correlate of modern metaphysics".[35] This was what led him, as well as other historians of astronomy such as E. S. Kennedy and Otto Neugebauer, not to take the physical principles of ancient and medieval astronomy as seriously as the physical principles of modern physics. (This is reflected in the terminology regarding these physical principles, which are usually referred to as 'philosophical'.)[36] Thus it is easy to see why for Duhem, such figures as Ptolemy, Proclus, and Maimonides were the heroes of his story because they, as 'neo-Platonists', sharply separated astronomy from some true metaphysical reality. But what this ignores is that the physical principles were not justified solely in a metaphysical way either by the Greeks or Arabs and were regarded as having, for example, empirical justifications. Thus Aristotle, despite having what we would call metaphysical reasons for preferring uniform, circular motion in the heavens, did not shy away from giving 'empirical proofs'.[37] For reasons that we need not go into here, Islamic astronomers and physicists sought at various times to disentangle the physical principles from any metaphysical taint.[38] Uniform, circular motion could therefore be understood as justified physical premises that were established both from observation and from successful usage. In this

regard it is interesting that when a physical premise did not seem to have empirical justification, a position taken by Ṭūsī concerning the Earth's state of rest, the response by his successors was to find an empirical justification, not to insist on some metaphysical principle.[39]

It may be argued that Duhem did not know enough about Arabic science to be able to form a proper judgement. Obviously he did not know of some of the more recent discoveries nor of the relation of Copernicus to Islamic astronomy.[40] He did, however, know of Naṣīr al-Dīn al-Ṭūsī's attempt to reform the Ptolemaic system since this was in a French translation that Duhem cited in the *Système*.[41] Duhem should have realized that Ṭūsī's proposed model that circumvented the equant, a device used by Ptolemy in his planetary theory that led to an irregular motion of the orb, resulted from a desire to deal with logical inconsistency in the Ptolemaic system, not from naive realism. This should have been especially clear to him in view of his understanding of the relation of physics and mathematics that he had come to in the *Système*. And it should have also been clear to him since Ṭūsī, like Duhem himself, took seriously the logical foundations of his discipline. Thus if one begins with certain principles it only seems reasonable to stick with them, something that Ptolemy did not do. Whether Duhem would have seen the Arabic contribution in this light we shall never know. I take this as a tragedy not only for Duhem but for the history of science since he was a man of great insights and intuitions. But blinded by prejudice, he did not care to delve into the problems of those who were 'slaves to the imagination'.

NOTES

[1] As I shall elaborate on below, the issue that became of paramount importance in Islamic astronomy was that of the consistency between the physical and mathematical principles. I would argue that given the admitted mathematical equivalence between various astronomical models that were considered physically acceptable, the question of whether the models represented the 'real world' became rather secondary.

[2] Cf. Duhem (1908), pp. 1–27; translation, 1969, pp. 3–24.

[3] Ibid., p. 17; translation, p. 16.

[4] Heiberg (1903), pp. 532–34; translation, Toomer (1984), pp. 600–601.

[5] Duhem (1908), p. 18; translation, 1969, p. 17.

[6] Ibid., p. 27; translation, p. 25.

[7] Lloyd (1978), pp. 212–14.

[8] Heiberg (1907), pp. 111–45.

[9] Lloyd (1978), pp. 215–17.

[10] Duhem (1908), pp. 23–24; translation, 1969, p. 21. Duhem hedges a bit on the comparison with the positivists by remarking that "the line of demarcation [separating the objects accessible to human knowledge from those that are essentially unknowable to man] is not the same for Proclus as it is for John Stuart Mill".
[11] Lloyd (1978), pp. 204–11.
[12] Martin (1987), pp. 309–12.
[13] Duhem (1914), **2**, 62–63.
[14] Ibid., **2**, 69–70.
[15] The quoted passage is rather less shocking as regards Aristotle since in STP we had already been apprised of his physicalist leanings. But Duhem explored the implications of both Plato's and Aristotle's positions in much greater depth in the *Système*. He concluded that for Plato the insistence on uniform, circular motion was a theological requirement that resulted from an ontological hierarchy in which the true motions, as distinct from the observed ones, were as perfect as possible. For Aristotle this was a physical requirement that resulted from an epistemological hierarchy that made geometrical astronomy subordinate to physics (ibid., **2**, 71). Duhem's entire discussion of the relation of physics and astronomy before Ptolemy (ibid., **2**, 67–83) is extremely valuable. It is now clear to me that had I read the *Système* more carefully earlier, I would have seen that the Islamic discussion of this relation owes more to Greek precedents than I had assumed in Ragep (1982), **1**, 129–89; I was there still, at least partially, under the spell of STP, even while reacting against it, and did not take into account the extent to which Greek astronomy subordinated itself to physics.
[16] Duhem (1913), **1**, 469.
[17] Duhem (1914), **2**, 86.
[18] Ibid., **2**, 86–99.
[19] Ibid., **2**, 99.
[20] Duhem (1908), p. 20; translation, 1969, p. 19. Duhem (1914), **2**, 103 (n. 1) criticized Halma's translation (1820, p. 151) that he had depended on in 1908. In one of the few places he refers to the *Système*, Lloyd (1978), p. 205, n. 20, notes Duhem's correction of Halma.
[21] See Lloyd (1978), esp. pp. 207, 209.
[22] Ibid., p. 211.
[23] Duhem (1908), p. 27 (translation, 1969, p. 25); Duhem (1914), **2**, 117. I have not modified the translation though it does introduce minor changes to Duhem's text.
[24] Duhem (1914), **2**, 118.
[25] Duhem (1908), pp. 27–28 (translation, 1969, pp. 25–26); Duhem (1914), **2**, 117–18.
[26] Recent books that have rather provocatively described this 'baggage' are Said (1978) and Bernal (1987).
[27] Some of the antipathy between Renan's 'scientific' worldview and Duhem's 'religious' one can be gleaned from Jaki (1984), passim.
[28] Renan (1883), esp. pp. 14–19.
[29] "Islamic science is in large part the plundered spoils of *decadent* Greek science" [italics added] (Duhem 1914, **2**, 179).
[30] Ibid., **2**, 156–71.
[31] Ibid., **2**, 156–57.
[32] Duhem stated that he got this argument from Friedrich Hultsch, who claimed that the

ordering of letters in Arabic is a "sure indication by which one may recognize a work of Greek origin that has been translated into Arabic" (ibid., **2**, 157). Hultsch, who is principally remembered today for his editions of Greek mathematical and scientific texts, does not seem to have dealt with Arabic works, at least as far as I have been able to ascertain. If he did study Arabic, one would have to conclude that he did not get as far as the alphabet.

[33] It is perhaps worth noting here in passing that Duhem's position cannot be simply characterized as anti-Semitic; for one of the people he admired and who Duhem felt had something of the Greek spirit of Proclus and Ptolemy was Maimonides. In this assessment Duhem parted company with Renan, who had lumped Maimonides with Averroes; cf. Duhem (1908), pp. 37–40 (translation, 1969, pp. 33–35) and Duhem (1914), **2**, 140–41.

[34] On the question of consistency between physics and astronomy in Islam, see Sabra (1978) and Sabra (1984), pp. 133–34, esp. n. 3; cf. Ragep (1982), **1**, 129–89.

[35] Martin (1987), p. 303. Duhem expresses this explicitly in his introduction to STP (1908), pp. 1–2 (translation, 1969, pp. 3–4).

[36] See, for example, Kennedy (1966), pp. 366–67; Neugebauer (1975), **1**, p. 1; **2**, 572, 942; Hartner (1975), p. 9; and Goldstein (1980), p. 142. For different viewpoints, see Sabra (1984), esp. n. 3, pp. 145–46 and Ragep (1987), pp. 330–31.

[37] See, for example, Aristotle, *On the Heavens*, Bk. I, Chap. 3, 270b5–16 where he says "our theory seems to confirm phenomena and to be confirmed by them"; cf. *Metaphysics*, Bk. XII, Chap 7, 1072a20–23. For an extended discussion of this point, see Ragep (1982), **1**, 149–61.

[38] Ragep (1982), **1**, 166–74.

[39] For an elaboration, and the possible effect of this discussion on Copernicus, see Ragep (forthcoming), commentary to II.1[6].6–14.

[40] For a discussion of this relationship and further references, see Kennedy (1966), Hartner (1975), and Sabra (1984), n. 5, p. 146.

[41] Duhem (1914), **2**, 129. The translation was due to Carra de Vaux (1893), whose pejorative characterization of Ṭūsī's efforts no doubt met with Duhem's approval: "Le chapitre dont nous allons donner la traduction suffira peut-être a faire sentir ce que la science musulmane avait de faiblesse, de mesquinerie, quand elle voulait être originale".

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