Science, Certainty, and Descartes

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It is difficult to determine the place of experience in Descartes' philosophy and science. His *a priori*, rationalist metaphysics would seem, on the face of it, difficult to reconcile with the explicit appeal he makes to sensory evidence in both his scientific practice and methodological remarks. Although earlier descriptions of Descartes as a pure a priorist in natural science (e.g., Koyré 1978, pp. 89-94) have rightly been rejected, it would be a mistake to embrace the other extreme, as does Clarke (1982), with his bold revisionist thesis that Descartes was, in actuality, an empiricist. And yet the possibility of combining the rationalist and empiricist elements in Descartes' thought has also seemed problematic, for it has been assumed that Descartes required that experientially based knowledge meet the standard of absolute certainty set by the the method of doubt in the First Meditation (Garber 1978). This difficulty notwithstanding, any adequate treatment of Descartes' mature philosophy must accommodate both his rationalist metaphysics and his acknowledgment that sense experience plays an essential role in natural philosophy, as the work of scholars such as Buchdahl (1969, chap. 3) and Williams (1978, chap. 9) has shown.

Attempts to develop a satisfactory understanding of the role of experience in Descartes' philosophy have been hindered by two myths. The first of these is the assumption just mentioned: that Descartes applied the standard of hyperbolic doubt from the First Meditation to the sensory evidence used in natural philosophy. Let us call this the myth of absolute sense certainty. It has been pervasive, and has led to a deep misunderstanding of Descartes' conception of the role of experience in the acquisition of knowledge, because it has encouraged the assimilation of Descartes' position to the doctrines of twentieth-century sense-data philosophers (for one of many instances of this tendency, see Rorty 1978, chap. 1, sec. 2). The second myth, which may be called the myth of method, consists in the belief that Descartes subscribed to a single method, announced in the *Discourse on Method* but only fully articulated in the posthumously published *Rules for the Direction of the Mind*, to which he credited his achievements in both metaphysics and natural philosophy (Beck 1952, chap. 16, 18). These two myths reinforce one another. For if it is assumed that Descartes continuously subscribed to a single method, and that this method required that all knowledge meet the standard of hyperbolic certainty, then it will seem that he must have expected absolute certainty from the sensory evidence used to support conclusions in natural science.

Recently, Garber (1987) has rejected the claim that a unified method extends from the *Rules* to the *Meditations*, only to replace it with the claim that a continuous methodologi-

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cal doctrine extends from the *Rules* to the *Discourse* and the scientific practice of the *Optics* and *Meteorology*. He supports his belief that the *Rules* describe the method Descartes used in his scientific program of the 1630s by providing a careful analysis of Descartes' account of the primary and secondary bows of the rainbow. According to this analysis, Descartes could reasonably claim that his explanation of the rainbow constituted a successful application of his method; only later did he realize that in other cases his demand for absolute certainty could not be squared with his appeals to sense experience. This realization caused him, in Part Four of the *Principles of Philosophy*, to admit the failure of his scientific program (Garber 1978).[1]

In the following discussion, I will argue that early in his mature period Descartes recognized the need to accept less than absolute certainty in the investigations of the particular sciences, and that this recognition was a secondary consequence of his discovery, in 1629-30, of general metaphysical foundations for his physics. This discovery led Descartes to develop what was for him a radically new conception of nature and of the sciences that describe it. Before 1629, he spoke of various sciences of nature; his examples came from the traditional Aristotelian "mixed" mathematical sciences, from Archimedian sciences such as fluid statics, and from Gilbert's work on the magnet. After 1629, he thought of physics as a single, general science of nature, which could provide framework principles for particular sciences such as optics and meteorology. At the most general level, his new physics shared some features of the traditional mathematical sciences, in that it posited general laws or rules of action, as expressed in Descartes' laws of motion. But, perhaps to his surprise, the mode of explanation that Descartes now found appropriate to wide ranges of particular phenomena was mechanistic, rather than mathematical—where "mechanistic" indicates explanations framed by analogy with the explanation of machines through the interaction of their parts, rather than explanations cast in the form of derivations from a formal mechanics. Although Descartes at first hoped that his physics would allow the details of such explanations to be deduced *a priori*, he soon came to realize that such a deduction would not be forthcoming. Consequently, his conception of the method appropriate to work in the particular sciences changed. He came to recognize the legitimacy and importance of conjectural hypotheses in particular areas of physics, and to acknowledge that, in deciding among competing hypotheses, absolute certainty could not to be expected.

The interpretation of the development of Descartes' conceptions of science and certainty just sketched cannot be fully supported in the space allotted here. In previous work, I have argued that Descartes recognized that a diminished standard of certainty was appropriate to those portions of his physics which could not be derived *a priori* from his metaphysics (see also Clarke 1982), and that as a consequence he abandoned the traditional conception that scientific knowledge consists in necessary demonstrations (Hatfield 1985). Recently, I have urged that in 1629-30 Descartes radically reconceived the relations among physics, mathematics, and metaphysics (Hatfield forthcoming; see also 1986, pp. 65-69). In the present paper, I hope to establish a connection between the beginning of Descartes' mature project in natural philosophy and his acceptance of a lowered standard of certainty. I will contend that after 1629 Descartes abandoned the idea that a single method was suitable for metaphysics and the whole of physics. His attention to method became divided. In metaphysics, he developed the "method of doubt" with its standard of absolute certainty; in physics, reflection on his actual practice in formulating mechanistic hypotheses resulted in a lowered standard of certainty for such hypotheses.

1. Method in Descartes

As do several of the myths about Descartes, the myth about method has a basis in his own words. Indeed, one might say that Descartes himself initiated the myth, as early or earlier than his debate with Chandoux in 1628 (Descartes 1964-74, hereafter AT, vol. I, p. 213), and that in the anonymous *Discourse on the Method* of 1637 he publicly affirmed the rumor that he possessed a special method. Moreover, it can be granted that the *Rules* provided the basis for Descartes' sketch of his method in Part Two of the *Discourse,* so that the former work (abandoned in 1628) provides an interpretive key for the latter. The story that Descartes once claimed to have discovered a special method, indeed, the secret method of the ancients, is, then, far from a myth. The ascription of a special method to Descartes achieves mythic proportions, however, when it is made the primary basis for understanding the *Meditations* and *Principles* (Beck 1952, 1965; Gueroult 1984-5, chap. 1), and when it is read laterally into the entire *Meteorology* or into Part Six of the *Discourse* itself (Garber 1978). The problem is only compounded when the epistemological project of the *Discourse* and *Meditations* is read back into the *Rules* (Schuster 1980, 1986), thereby creating an illusion of programmatic continuity which implicitly supports the thesis of methodological continuity.[2]

Certain resemblances among the *Rules*, the *Discourse*, the *Meditations* (1641), and the *Principles* (1644) have lent *prima facie* plausibility to the thesis of methodological continuity. In all four works Descartes portrays philosophical knowledge as a deductive system in which all claims to knowledge arise through small, certain steps from self-evident beginnings. Following Schuster (1986, p. 41), we may call this picture the latticework conception of knowledge. Descartes remained faithful to this picture as a demand on first principles. The requirements placed on the principles of philosophy in the preface to the *Principles*, that "they must be so clear and so evident that the human mind cannot doubt their truth when it attentively concentrates on them," and that they be such that "the knowledge of other things must depend on them" (AT IX, 2; translations, here and below, are from Descartes 1984-5), might equally well have come from Rule Four, or from the end of Part Two of the *Discourse*, or from the Dedicatory Letter to the *Meditations*. And the wording of Rule Two, that "we should attend only to those objects of which our minds seem capable of having certain and indubitable cognition," would have fit seamlessly into the later works.

Despite the constancy of Descartes' ideal of philosophical knowledge from the *Rules* through the *Principles*, his conception of the relation between certainty and deductive structure in natural philosophy changed dramatically during the 1630s. The change was not the product of isolated reflections on method per se; as we shall see in sections 2-4, it resulted from a shift in the type of explanation he found himself providing for a variety of natural phenomena. But the change was reflected in Descartes' discussions of method, for it altered the role he assigned to method in descriptions of his philosophical achievements. Whereas in the *Rules* and in Part Two of the *Discourse*, he claimed to have discovered a special method, in Part Six of the *Discourse* (AT VI, 63-64), in the *Meditations*, and in the *Principles* he made a quite different claim. There he boasted of having discovered the true principles of philosophy, principles which extend to everything in the created world. He no longer characterized his achievement as the discovery of a special method that applies to all cognition; rather, he claimed to have achieved fundamental cognitions that apply to all existing things, and thereby to have answered certain substantive questions about the natural world once and for all. Prominent among the principles so established were the equation of matter with extension and the three laws of motion.

From a methodological perspective, the important consequence of this change was its effect on the latticework picture. In the period of the *Rules*, Descartes conceived typical explanations as involving appeal to mathematical laws, or to mathematically-expressed rules of action; optics was the paradigm case (Rule Eight). In explanations involving such rules or laws (e.g., of reflection and refraction), once the law had been determined, its application required simply that empirically determined values of variables (e.g., the angle of incidence) be plugged in. Although in Part Six of the *Discourse* and thereafter, Descartes claimed, in language superficially similar to that used in the *Rules*, to "deduce" his physics from first principles, such deductions no longer resembled a mathematical derivation. Beginning in the early 1630s, the explanations in Descartes' writings on natural philosophy involved the conjectural positing of microstructures; the primary explanatory work was performed not by laws, but by the positing of configural mechanisms, like so many gears in a clock, or like so many valves in a hydraulic machine. While such explanations may presuppose the lawfulness of material interactions, they are not couched in terms of lawful relations. In Descartes' new vision of a unified physics of the entire universe, micro-mechanistic explanations came to the fore. The fundamental metaphysical principle of this new physics was the equation of matter with extension, which, in Descartes' conception, implied the denial of the void, and so the physics of a plenum. This conception led to a picture of the universe as a tissue of fluid vortices irregularly studded with large chunks of congealed matter (planets), on which various hydraulic machines were located, along with various groupings of particles having sufficiently similar microstructures to produce regular effects and thus to be denominated as varieties and subvarieties of elemental kinds. In section 2 we shall see that although Descartes had hoped to be able to "deduce" the details of this physics from general principles in a strictly *a priori* manner, he came to realize that a strict deduction was not possible. Yet he continued to use the term "deduce" for the relation between the first principles of his physics and particular mechanistic explanations, and to do so even in close proximity to the passages acknowledging that a strict deduction was not possible (*Discourse*, Part Six, AT VI, 64-65). In such contexts, his use of the term "deduce" is best understood through the etymological sense of the term: his micro-mechanical explanations were "lead out" from his metaphysical principles, in the sense that those principles provided a description of the fundamental concepts, or the building blocks, out of which an explanation was to be be conjecturally constructed.

The method of the *Rules* did not disappear all at once. As mentioned above, Descartes summarized it in Part Two of the *Discourse*. This summary, however, should not be accepted without question as a description of his actual or preferred method in natural philosophy at the time the *Discourse* was composed. Indeed, there are good grounds for reading the methodological remarks in Part Two as an autobiographical account of Descartes' thinking during the time when the *Rules* were composed. As a characterization of a method associated with practice, the early method describes the achievements of Descartes' early work in mathematics and optics. In particular, his account of reflection and refraction in the rainbow is of interest precisely because it illustrates the earlier method (the work dates from 1629; AT I, 23). By the mid 1630s Descartes had abandoned further mathematical work (AT II, 268), and he had expanded his conception of physics in such a way that the methodological discussions developed in conjunction with his work in optics no longer described his primary methodological problems. It is true that the physics of Descartes' new *World* (written from 1629-1633) was not without mathematically expressed laws, in the form of laws of motion. Further, Descartes contended that the subtle aether of light was fine enough to act unhindered by other matter, and thus to exhibit mathematically precise behavior. But explanation by appeal to precise laws of action had become the exception, not the rule. As Descartes' dismissal of Galileo's law of fall made clear (see Koyré 1978, pp. 92-94), in practice the picture of nature described in *The World* could discourage the search for mathematical laws. Descartes began to realize by the mid 1630s that his earlier methodological conceptions no longer applied to his mechanistic explanations.

Although Descartes' new vision of nature was first expressed in *The World*, before beginning that work he had developed a general metaphysical justification for its fundamental doctrines. The attempt to use metaphysical argumentation to justify substantive claims about nature—an attempt made public in the *Meditations* and the *Principles*—marked a radical departure from the philosophical program of the *Rules*. Let us see how.

2. From Method to Principles

It is interesting to note that although he claimed in the *Rules* that his method would reveal "every truth for the knowledge of which human reason is adequate" (AT X, 395), Descartes did not claim that human reason was adequate for every truth (see AT X, 396). He left open the possibility that nature contains powers or agencies which lie beyond human comprehension. The fact that he should leave open this possibility—a possibility he would later foreclose—may be understood by considering the aim of the *Rules*. That work took as its object of investigation the conditions for application of the "knowing power," rather than the natures of the things to be known. It granted primacy to method over metaphysics. The methodological ambition and metaphysical timidity of the *Rules* are most evident in the analysis of perfect and imperfect problems in Rules Twelve and following. Rule Twelve also explicitly disavows the search for a metaphysical guarantee that the method of the *Rules* will yield insight into the essence of corporeal things.

The distinction between "perfectly understood" problems and those "imperfectly understood" occurs near the end of Rule Twelve. Perfectly understood problems are those for which all of the following are known: (1) the criteria for a solution, (2) the premises (or "data") for a solution, and (3) the means by which it is to be proved that premises and solution "are so mutually dependent that the one cannot alter in any respect without there being a corresponding alteration in the other" (AT X, 429). Imperfect problems are defined by contrast with perfect ones; presumably, they are problems for which one or more of these conditions have not been met. We learn further that perfect problems pertain only to the purest of simple natures, and are found primarily in arithmetic and geometry. Imperfect problems pertain to compound natures; the examples given, including magnetism and acoustics, suggest that such problems arise primarily in natural philosophy or physics (AT X, 431).

Unfortunately, the third part of the *Rules*, which was to have been about imperfect problems, was never written. However, the existing Rules contain indications of what Descartes had intended to argue in the unfinished portion. In Rule Thirteen he purports to show how imperfect problems can be transformed into perfect ones. In particular, he says that the problem of discerning the nature of the magnet can be made perfect by limiting the given elements of the problem to "the experiments which Gilbert claims to have performed, be they true or false" (AT X, 431). In the subsequent Rule, he further observes about this problem that "if the magnet contains some kind of entity the like of which our intellect has never before perceived, it is pointless to hope that we shall ever get to know it simply by reasoning; in order to do that, we should need to be endowed with some new sense, or with a divine mind. But if we perceive very distinctly that combination of familiar entities or natures which produces the same effects which appear in the magnet, then we shall credit ourselves with having achieved whatever it is possible for the human mind to attain in this matter" (AT X, 439). These two comments speak, in reverse order, to the first two conditions on perfect problems. The remark from Rule Fourteen indicates how to proceed if the problem of the magnet is imperfect because sure criteria for a solution are lacking, given that the magnet may contain something unfamiliar to the human mind; by requiring proposed solutions to appeal only to known entities, we can achieve "whatever it is possible for the human mind to attain" by way of knowledge of the magnet. Interestingly, it is not claimed that by restricting solutions to known entities, we can be assured of achieving truth about the magnet (as opposed to truth about the solution to the problem, as restricted). Similarly, the remarks from Rule Thirteen suggest that if the problem is imperfect because we are unsure whether all of the data have been observed, we may restrict the data for the problem to that given in a particular source.

These remarks on the problem of the magnet reveal that Descartes was quite willing to trade scope for power in the *Rules*; he was willing to limit the scope of the knowledge attained, in order to be assured that what he did attain possessed certainty. If we look ahead to the correspondence from 1637 and 1638, and to the end of the *Principles*, it would seem that the "imperfection" of the problem of the magnet should in part be ascribed to the difficulty in inferring a true cause from known effects, especially since Descartes demanded of perfect problems that data and solution be tied as necessary and sufficient conditions. But the *Rules* show no concern with this difficulty; either Descartes believed there was no problem in inferring true causes from effects when he wrote that work, or he was satisfied merely "to save the phenomena." Moreover, the fact that he was willing to turn imperfect problems into perfect ones by limiting investigation to the proffered "data," whether they be true or false, reveals a limitation to the scope of the claim that in following the *Rules*, the human mind will attain a knowledge of everything it can know. For now it can be seen that among the things known will be certain conditional truths, such as: if these are all the relevant data for the magnet, then the nature of magnetism is such and such. Under this condition the problem becomes "perfect," but at the expense of assurance that a solution will yield the truth about the nature of the magnet.

The problem of limited data may seem a merely practical one, to be overcome by making the requisite observations. Whether it is merely practical depends upon what may be expected from sensory observation. The *Rules* do not suggest that sensory data is inherently defective; indeed, some sensory experience is included within the domain of intuitive knowledge (AT X, 383, 423), and so is granted certainty equivalent to that of mathematics. But such certainty pertains only to experiential knowledge of things that are "entirely simple and absolute" (AT X, 394). The "simple and absolute" includes the mathematical dimensions of things (size, shape, number; AT X, 419, 439), where the things having such dimensions are as varied as stars, sounds, weight, and speed (AT X, 378, 447-448). But, in any case, no reason is given for expecting that all natural phenomena will present data sufficiently clear to render perfect the problem of assigning a cause for the phenomena. Where such data is wanting, Descartes' message is clear: the truth about the cause of the phenomena lies beyond the scope of human knowledge.

It may seem, however, that there is no need to despair about either the possibility of knowing what is required for a solution, or the possibility of discovering sufficiently clear data. For it may seem that elsewhere in the *Rules* Descartes has provided reason to hope that there is nothing more to be met with in nature than compounds of common and familiar simple natures; and if it could be known that each observed thing is a compound of perfectly knowable natures, that would provide reason to hope that all phenomena could be rendered clear and intelligible. Such hopes would seem to receive encouragement in Rule Twelve, in which Descartes asserts that the simple natures found in bodies include "size, extension, motion, etc." (AT X, 419). This pronouncement would appear to be the familiar Cartesian doctrine that the essence of matter is extension. On the assumption that it is, the *Rules* make a quite powerful claim; for if it is granted that bodies possess geometrical properties only, it follows that the solutions to all imperfect problems regarding compound bodies can be restricted to such properties. Any given data could be truthfully explained through some combination of perfectly intelligible simple natures.

It is at this point that the metaphysical timidity of the *Rules* comes into play. Nowhere in that work does Descartes claim that the essence of matter is extension. Although he recommends that we treat colors, sounds, etc. as if they could be equated with geometrical figures, and contends that if we do so, we will be able clearly to understand their effects upon the sense organs, he doesn't claim, and so doesn't argue, that the qualities of bodies are actually constituted by purely geometrical properties (AT X, 412-414). Indeed, further on in Rule Twelve he explicitly eschews such ontological conclusions, explaining that he is concerned with things "only as they are perceived by the intellect," and not with "how they exist in reality" (AT X, 418; see also AT X, 399). The "simple natures" discerned in the *Rules* are epistemically simple; there is no guarantee that they correspond to something ontically simple. Indeed, it is not clear that Descartes was committed to the central metaphysical tenets of his mature physics when he wrote the *Rules*. In Rule Fourteen, for instance, he treats weight as something real, that is, as something "having a real basis in bodies" (AT X, 448). Although this description contradicts his later denial that weight is a real property of bodies, it accords with his treatment of weight in a document surviving from the early part of the period during which the *Rules* were composed, the physico-mathematical writings undertaken in connection with Beeckman (AT X, 69-74). Because the denial that weight is a real property of bodies is a paradigmatic instance of Descartes' doctrine that the essence of matter is extension, it would seem that the latter doctrine postdates the *Rules*.

The *Rules* describe the requisites for knowledge, without implying that the world is entirely knowable. Perhaps Descartes believed prior to 1629 that the world contains nothing unknowable, but had no argument for his belief, or none that he was willing to divulge. Or perhaps he had no such belief.

Be that as it may, in the spring of 1630 Descartes announced that he had discovered the foundations of physics during the previous year (AT I, 144). I have contended elsewhere that this discovery included the fundamental arguments of the *Meditations* (Hatfield, forthcoming). I will not rehearse that story here. But it is worth noting that by the early 1630s, Descartes was prepared to state explicitly the doctrine that was missing from the *Rules*—that matter is to be equated with extension. But he would state it only as a hypothesis. Thus, in *The World*, he assigned only the properties of size, shape, and motion to the matter of his new, hypothetical, imaginary world (chap. 6). At the outset of the Fifth Part of the *Discourse* he alluded to this hypothesis, and he presented it again in the First Discourse of the *Meteorology*. As Descartes remarked in *The World*, according to this hypothesis matter contains "nothing that you do not know so perfectly that you could not even pretend to be ignorant of it" (AT XI, 35). In correspondence dating from 1638 (February 22, to Vatier) he claimed he could prove this hypothesis in his metaphysics (AT I, 563), and he attempted to do so in the *Meditations* and *Principles*.

It has been maintained, on reasonable grounds, that the arguments presented in the *Meditations* and redescribed in the *Principles*—both those attempting to prove that the essence of matter is extension, as well as others—are generic instances of the regressive method described in the *Rules* (Beck 1952, chap. 18; 1965, chap. 13). Indeed, Descartes himself characterized the method of the *Meditations* in this manner (though without, of course, explicit reference to the *Rules*; AT VII, 3; compare AT VII, 156 and X, 376). There is, then, some methodological continuity between the later works and the *Rules*. To acknowledge this continuity is not, however, to equate the method of the *Meditations* with that of the earlier period. There are significant differences between the two. The hyperbolic doubt of the *Meditations* was new; it was not explicit in *Discourse*, and it was opposed to the teaching of the *Rules* (according to which the intuitively evident should be accepted straightaway; Rule Three). Correspondingly, the certainty that was methodologically required prior to the *Meditations* was not hyperbolical, but ordinary certainty; it follows that the certainty accorded to sense experience prior to the *Meditations* also was ordinary certainty. And so even though it is true that a descendant of the early method appears in the *Meditations*, and that the *Meditations* provide the foundations for the physics, it should not be assumed that the early method therefore extends to the physics so grounded. In fact, it is in connection with the new physics that the greatest methodological discontinuity occurs.

3. Deductive Structure and *a priori* Physics

In order for the thesis of methodological continuity to be true, it must be the case that Descartes understood the explanations of natural phenomena in his mature physics to be strict deductions from basic principles—deductions that meet the standards of the latticework model in the *Rules*, a model in which each link in a chain of reasoning is connected to the succeeding one as its necessary and sufficient condition. In the present section I shall argue that as Descartes began to construct his *World*, he actually did envision the possibility of a thoroughly *a priori* science, one which would allow a suitably tight *a priori* deduction of the structure of various kinds of earthly body.

Two letters to Mersenne in 1632, which report progress on *The World*, reveal Descartes' vision of a completely *a priori* science. In the first, written in April, Descartes described an addition to his original project:

> In the treatise which I now have in hand, after the general description of the stars, the heavens and the earth, I did not originally intend to give an account of particu-

> lar bodies on the earth but only to treat of their various qualities. In fact, I am now discussing in addition some of their substantial forms, and trying to show the way to discover them all in time by a combination of experiment and reasoning. This is what has occupied me these last days; for I have been making various experiments to discover the essential differences between oils, ardent spirits, common and strong waters, salts etc. (Descartes 1970, p. 22)

In fact, the addition here described has come down to us not as part of *The World*, but as part of the *Meteorology*. In any event, the brief allusion to experiment and reason in this letter is not by itself methodologically distinctive. One month later, however, Descartes wrote that he hoped to discover a means of knowing the forms and essences of earthly bodies in an *a priori* manner:

> For the last two or three months I have been rapt in the heavens. I have discovered their nature and the nature of the stars we see there and many other things which a few years ago I would not even have dared to hope; and have now become so rash as to seek the cause of the position of each fixed star. For although they seem very irregularly distributed in various places in the heavens, I do not doubt that there is a natural order among them which is regular and determinate. The discovery of this order is the key and foundation of the highest and most perfect science of material things which men can ever attain. For if we possessed it we could discover *a priori* all the different forms and essences of terrestrial bodies, whereas without it we have to content ourselves with guessing them *a posteriori* from their effects. (10 May; 1970, pp. 23-24)

In this puzzling passage Descartes held out the hope of an *a priori* physics, one that would enable him to discover even the microstructures of the various types of terrestrial bodies. What could he have had in mind?

Consider the account of the development of the universe given in *The World* and later in the *Principles*; in each work, the world as we see it now arises from a hypothetical beginning in a chaos of matter in motion. A completely *a priori* science, as Descartes envisioned it, would begin with a general description of this chaos and would show how our present world could arise. Without relying on any observations of the present world, this science would succeed in "deducing" the features of that world, including the particular "forms" and "essences" of its minerals. Perhaps the passage just quoted expressed Descartes' belief that an understanding of the principles of star location could provide insight into vortical formation, and that this insight would be sufficient to allow a completely *a priori* deduction of the particular species of matter which, by hypothesis, were churned out by the vortex and which then congealed to form the earth (a deduction of the sort found in a more limited form in the *Principles*).

While such speculations have the makings of an interesting fable, sadly, as Descartes went on to admit in the letter just quoted, there was little hope that the principles of star placement could be discovered. This pessimistic presentiment seems to have been borne out, for in the *Principles* he confided that the vortices exhibit an "inexplicable variety" (1983, Part III, art. 68). In that work he provides what is presumably an *a priori* account of the formation of the matter surrounding the earth; he explains the chief qualities of such matter, which were vortical motion, weight, light, and heat (IV, 15-31). But as the account descends to the explanation of more particular qualities of matter, it becomes less clear whether it should to be construed as *a priori* or *a posteriori*. (See, for example, the account of the formation of air and water; IV, 32-48.) Descartes refers back to the "particular hypotheses" introduced in the First Discourse of the *Meteorology* (to be distinguished from the more general hypothesis of the corpuscular constitution of matter) in order to support his conclusions regarding the microstructures of various minerals, including those structures that explain the difference between water and salt water (IV, 48). In attempting to explain the properties of various minerals and metals, he is forced to appeal to experience (IV, 16), to rely on the hypotheses of the *Meteorology*, or to curtail his presentation for want of experiments (IV, 63). Thus, he fails to advance beyond the position he had envisioned in April, 1632; he can do no better than to guess causes from effects, *a posteriori*. His initial suspicion that it would be necessary to employ the method of hypothesis in describing his new world, a suspicion that arose not long after he turned his attention to the explanation of terrestrial particularities, was proven sound.

4. *A posteriori* Physics, Experience, and Certainty

As numerous commentators have observed (Buchdahl 1969, chap. 3; Clarke 1982; Garber 1978; Laudan 1966), Descartes himself explained that it was the explanatory fertility of his own first principles which drove him to the method of hypothesis. The properties of salts, oils, ardent spirits, common and strong waters, and so forth could be explained in many ways; Descartes' problem was to see which among the potential explanations were true. On occasion, he characterized each of the variety of potential explanations as a "deduction" from his first principles (e.g., AT VI, 65). As already noted, the notion of a deduction expressed in such remarks was not very strict; it was less strict than that found in the *Rules*, and bore little resemblance to formal deduction (see also Buchdahl 1969; Clarke 1982). Descartes' claim to have provided multiple "deductions" of the phenomena from his principles may be read as the claim that starting from size, shape, and motion, together with the laws of motion and the assumption of an initial chaos, a variety of micro-mechanisms, any one of which would be adequate to explain the known phenomena, can reasonably be imagined to arise. Given this imagined variety, the problem becomes that of discovering tests based upon sense experience that could serve to determine which of the micro-mechanisms is actual. Although hypothetical posits tested in this manner might in some cases be established with a high degree of confidence, in the letters of 1637-38 and in the final remarks to the *Principles* Descartes refrained from granting them certainty comparable merely to the mathematical variety—let alone hyperbolic certainty (Hatfield 1985).

My claim that Descartes refused to grant mathematical or metaphysical certainty to the postulation of micro-mechanisms must be distinguished from the claim that he believed all sense-based knowledge of the external world lacks certainty. Contemporary appreciations of the Cartesian spirit notwithstanding, Descartes was willing to grant ordinary certainty—again, as opposed to the hyperbolical variety—to claims about material objects that go beyond the "immediately given" in sensory experience. This willingness is foreshadowed in the First Meditation. Descartes offers an initial sceptical challenge to the senses based on their occasional deceptiveness, only to rebut this challenge by suggesting that under good conditions the senses are perfectly reliable. The dream argument and the hypothesis of an evil deceiver are successively stronger skeptical responses to this rebuttal; it seems fair to assume, therefore, that once these grounds for doubt have been removed, the senses may be treated as reliable sources of knowledge of things which are close at hand, which can be touched as well as seen, etc. And indeed, the senses are vindicated in the Sixth Meditation (AT VII, 80; see Hatfield 1986), in which it is suggested that even factual details about the material world, such as the size of the sun, can be known by means of the senses (in conjunction, of course, with reasoning), as can the properties of objects which are relevant to the preservation of one's bodily well-being (AT VII, 80-1). Further, in Parts One and Four of the *Principles* (I, 69-70; IV, 200), Descartes affirms that size, shape, and motion can be "clearly perceived" in bodies by means of the senses (in conjunction with the understanding).

Descartes was prepared to allow that, when sufficient care is taken, sensory observation can yield certainty. But the possibility of such certainty does little to solve the problem of how to achieve certain knowledge about those micro-mechanisms that must, as remarked in 1632, be "guessed" from their effects, *a posteriori*. The task of attaining certainty about hypothetical posits could be completed only by means of extensive experimentation, if at all; Descartes was aware of the underdetermination of micro-mechanical hypotheses by sensory evidence. Of course, he thought he had a head start toward solving the problem of underdetermination in framing his conjectural hypotheses, for he believed that he had established, once and for all, what the theoretical vocabulary of any physical hypothesis must be: theoretical posits must be couched in the language of size, shape, and motion. But the fact that he claimed to be metaphysically certain that his general approach to physics was correct does not alter the fact that he granted, from near the inception of his fully mechanistic conception of natural phenomena, that he was not entitled to claim such certainty about the particular mechanisms he posited.

The use of mechanistic hypotheses became central to Descartes' natural philosophy in the early thirties. Its absence from the primary examples of method in the *Rules* helps to explain how Descartes could there envision the attainment of certainty with respect to particular problems in physics. Let us put to one side the certainty that arises from the transformation of imperfect problems into perfect ones, for such certainty is purchased at the price of forfeiting knowledge that the solutions of the problems are true. There remain other examples from the *Rules*, or from the period of its composition, which offer the possibility of certainty for natural scientific conclusions that rely on experience. The determination of the anaclastic as envisioned in Rule Eight is a case in point. To it may be added the explanation of the angle at which the rainbow is seen. As Descartes observed in Rule Eight, in the *Optics* (Second Discourse), and in the *Meteorology* (Eighth Discourse), experience must play a role in each case.

Despite this fact, Descartes claimed in such cases to have achieved the sort of "deductive" certainty required by the *Rules*. The notion of "deduction" in these cases is regressive (Buchdahl 1969, chap. 3, sec. 2d; Garber 1987); it requires working back to the explanatory basis from which the given problem can be progressively derived. Descartes could claim that certainty is achievable in the instances cited because the relevant experientially based claims provide evidence not for postulating micro-mechanisms, but for determining a mathematical law governing observable relations among phenomena. And although the law presumably cannot simply be "read off" from experience, experiential elements can and must play an intrinsic role in the process of deduction. Experience can play a role, because Descartes allows that sensory experience can count as an instance of "intuition" if the objects of the experience are pure and simple natures (AT X, 383, 394), as the dimensions of things listed in Rule Fourteen presumably are (AT X, 447-8). The angular relations between the paths of a light ray before and after refraction might also count as an instance of an intuited dimension (within the limits of accurate measurement; see the table of measurements in the Eighth Discourse of the *Meteorology*). In this last example, experience must play a role in both the regressive and progressive phases of the "deduction," for the refractive indices of various media such as water and air can only be determined through experience, as Descartes himself made clear (AT VI, 102, 337). (This point about refractive indices does not contradict Descartes' claim to have derived the sine law of refraction on *a priori* grounds, on which see Smith 1987.)

If it is correct that the *Rules* permit sense certainty only in the case of the sensory intuition of medium-sized objects, it becomes apparent that once Descartes accorded primacy to his vision of a universe of little machines, this route to certainty would become less central to his philosophy of science. Once this change in emphasis had occurred, most cases of reasoning in Cartesian physics ceased to be like the case of determining the position of the rainbow; typical problems no longer involved the use of direct measurement to determine a law or relation. Because the majority of explanations involved an appeal to micro-mechanisms, the mode of inference depended on analogical reasoning from the known to the unknown, from observable mechanisms to posited microstructures (Galison 1984). Admittedly, in his discussion of the position of the rainbow, Descartes did reason from the big to the little, inasmuch as he used glass globes to model raindrops. But in this case, the "analogy" involved merely shrinking the scale of a model which exhibited a "macro" version of the phenomenon in question. By contrast, when inferring hidden mechanisms, one is free to posit any of a great variety of mechanisms as a means of explaining a phenomenon; the methodological constraints enjoyed when investigating the operation of a single mathematical law in larger and smaller spheres are no longer present. The possible posited mechanisms are virtually endless, under the limitation that any mechanism posited be truly mechanical, that is, that such mechanisms be ascribed only the properties of size, shape, and motion (AT I, 420; *Principles* IV, 200, 201). Given these circumstances, even if a particular posited mechanism saves all of the phenomena, one may assert that it is the true mechanism with merely "moral" certainty; that degree of certainty may suffice for the rational fixation of belief, but it falls short of the notorious absolute certainty of Cartesian metaphysics.

5. Science, Hypothesis, and Descartes

Descartes recognized the need to proceed by the method of hypothesis from near the inception of the mechanistic program described in the *World*, the *Meteorology*, and the *Principles*. As Laudan (1966) and Buchdahl (1969) have observed, he adopted a "hypothetical-deductive" mode of supporting his claims about particular mechanisms. The description of Descartes' strategy as "hypothetical-deductive" cannot be left unqualified, for Descartes did not leave the domain of allowable hypotheses unrestricted (see Buchdahl, pp. 144-7); it was restricted by metaphysically determined principles, including the equation of matter with extension, and the laws of motion. Assuming this qualification, it may be recognized as a point in the history of methodology that Descartes explicitly described the limitations on certainty that result from a hypothetical mode of reasoning.

Despite the presence of the method of hypothesis in Descartes' mature science, it would be misleading to portray Cartesian science as directly continuous with post-Newtonian science. Indeed, the method of hypothesis which Descartes applied to mechanisms contrasts both with the method he used in explaining the rainbow's position—and so with the method of the *Rules*—and with the type of scientific explanation inspired by Newton's *Principia* and *Optics*. From a methodological point of view, the central examples of Newtonian explanation, such as the derivation of elliptical orbits from the inverse-square law, seem closer to explanations contained in the *Rules* than to those found in Descartes' mature work.

The difference in spirit between the mature Descartes' primary model of scientific explanation and that of Newton may be brought into relief by briefly considering an aspect of Descartes' mature scientific program that has been cited as a common feature of Cartesian and Newtonian science: the "mathematization" or "geometrization" of nature. In the attempt to understand Descartes' claim that his science was "geometrical" or "mathematical," two interpretations might naturally come to mind. The claim might be taken to refer either to the alleged deductive structure of his science, or to its use of mathematical laws, such as the sine law of refraction or the laws of impact. However, when Descartes wrote in the *Principles* that the "only principles" of his physics are those of "geometry and pure mathematics" (II, 64), he had yet a third point in mind: he was simply expressing the doctrine that the essence of matter is "pure extension." For this doctrine amounts to the view that matter is wholly describable in terms of the geometrical properties of size, shape, position, and motion. Inasmuch as size or volume may be measured, these properties may be described as "quantitative"; but the ascription of such properties to matter does not lead necessarily to a "quantitative" approach to nature of the sort that we are likely to associate with Newton, or with Galileo's discovery of the law of fall. It does not lead inevitably to a notion of nature as governed by quantitative laws, or to the notion that scientific reasoning is principally concerned with mathematical derivation. As we have seen, in Descartes' mature natural philosophy the ultimate emphasis was on mechanisms, not laws; "mathematization" amounted to "mechanization" (see also Hatfield, in press).

Of course, a mechanistic account of nature such as Descartes' is unthinkable unless it is supposed that matter in motion moves with lawful regularity, and Descartes did invoke the required regularity in his three laws of motion and seven rules of impact. These laws *are* cast in quantitative terms—as relations between the fundamental magnitudes, "quantity of matter" and speed. But the possibility of such quantitative laws is not established by the doctrine of extension, even if this doctrine is taken to include the idea that motion is a geometrical (kinematic) property and hence is a "mathematical" property; a kinematic (purely descriptive) treatment of motion does not entail that the patterns of motion in the world are describable by simple laws. As is well known, Descartes went outside the notion of matter as extension and introduced God as a "dynamic" element to fix these laws—the laws are understood as a manifestation of God's immutability, specifically, of his conservation of the same quantity of motion in the material world as at the creation (see Hatfield 1979 for further discussion).

The introduction of universal laws of motion governing the interaction of all particles in the universe was, indeed, a step of some significance in the march of the world spirit toward Newtonian science: it provided a prominent example of the conception of nature as a single, law-governed system, to replace the conception of a universe bifurcated into two regions governed by different principles; methodologically, it encouraged replacement of the conception of physics as a series of particular sciences of nature with the picture of one basic science of physics, possessing various branches. But these valid points of comparison between Descartes' program and the development of post-Newtonian science should not lead us to be misled by other seemingly valid comparisons. In particular, we should not be led to believe that the laws of motion played the same explanatory role in each instance. A mistake on this point would explain why the role of hypothesis in Descartes' mature science was at one time routinely overlooked. To an interpreter imbued with a post-Newtonian conception of science, the character and the extent of the role that Descartes accorded to hypothesis in his physics would seem insignificant in comparison to the things Descartes claimed could be known independently of experience, through metaphysics. In particular, Descartes' claim to know his laws of motion *a priori* would seem of especial importance; for to a reader with post-Newtonian sensibilities, it would seem that once the laws governing motion (including the law of gravitation, which has no counterpart in Cartesian physics) had been established, the explanatory basis of physics was largely complete. For if Newton's laws could be known *a priori*, it would seem of small consequence that, say, the masses of individual bodies could not be. But in Descartes' mechanistic account of natural phenomena, the chief explanatory work is performed by the configuration of the particles in various types of body. There are no cases in which the laws governing motion serve to explain an important class of phenomena, such as the planetary orbits; moreover, given his explanatory ambition, the postulation of micro-mechanisms—which might seem to a Newtonian like so many speculations about "initial conditions," which should be avoided if the conditions cannot be determined through measurement—becomes the central activity of Cartesian science. The postulation of such configurations proceeds by a method of hypothesis, based upon analogy. Hence Descartes' mathematical conception of matter, far from permitting him to adopt a geometrical style of proof in natural philosophy, and far from leading him to retain a mathematical or metaphysical standard of certainty, led him to acknowledge that absolute certainty may be beyond reach throughout much of the science of nature, because that science must proceed conjecturally, by means of hypothesis.

Notes

[1]Garber continues to hold the view that there was a fundamental and persistent tension between Descartes' demand for certainty and his appeal to experience in science, and that the methodological points made at the end of the *Principles* constituted an admission of defeat for his program, as is evident from his "Descartes and Experiment in the *Discourse* and *Essays*," presented at San Jose State University during April, 1988 (p. 10 of the distributed draft).

[2]Schuster (1986) chastises others for seeking to find methodological continuity in Descartes' work; yet he is guilty himself of adopting the position that a single "problem of justification"—the problem of justifying the applicability of mathematics to matter—may be found in both the *Rules* and the *Meditations*, being met in the first by the "optics-psychology-physiology nexus" (1980, pp. 59-73), the failure of which led to the metaphysical arguments of the second (1980, pp. 75-79).

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