Newton, Barrow and the Hypothetical Physics*

by ROBERT KARGON**

The celebrated statement of Sir Isaac Newton to the effect that "Hypotheses non fingo (I do not frame hypotheses)," has been the subject of a great deal of scholarly comment. This interest is well deserved, because the statement is indicative of some of the fundamental changes in 17th century physics which Newton effected. Yet most of this scholarly commentary has, unfortunately, removed Newton's views from their historical context, resulting in an incomplete picture of the situation. It is important, therefore, to return to the context of 17th century physics, and assess Newton's reaction to the prevailing methods and theory in the mid-sixteen hundreds.

The key to the understanding of Newton's refusal to engage in the manufacturing of "hypotheses" lies in the accepted view of natural philosophy. It was this accepted view which Newton was consciously attempting to overthrow. In this paper, I shall try to trace out Newton's concept of mathematical physics, and suggest, furthermore, that he was following a program laid out by his respected teacher at Cambridge, the famous mathematician and theologian, Isaac Barrow. In order to understand this program, one must first examine the so-called "mechanical philosophy" which played so important a role in the Scientific Revolution.

I

The "Scientific Revolution" of the 17th century involved, as part of its efforts, the establishment of the mechanical philosophy, i. e., that view of nature which held that all phenomena can be explained solely

* The research for this paper was done with the guidance of Professor Henry Guerlac of Cornell University.

** The Johns Hopkins University, Baltimore, U.S.A.

Centaurus 1965: vol. 11: no. 1: pp. 46–56

on the basis of matter and its motion. All types of mechanical philosophies, of which there were several, were, therefore, involved with the impact or collision of matter with matter. By the 1660's, the mechanical philosophy largely replaced the moribund Aristotelian world-view as the dominant one in natural philosophy.

Briefly, the natural world-view of the 17th century Aristotelians was as follows. Visible matter, they claimed, is composed of a *materia prima* or unformed material principle of pure potentiality. To this *materia prima* are added certain Substantial Forms which produce, by their presence, all the qualities seen in the world. Specifically, matter actually exists as four elements – air, earth, fire and water – with which are associated four qualities: hotness, coldness, wetness and dryness. Through the combination of prime matter and its associated forms and qualities, natural phenomena, the Aristotelians claimed, can be explained[1].

The system of substantial forms and qualities involved explanations such as the following: the magnet attracts iron because it has within it the "form" of attractiveness. This kind of tautology is the one which Molière satirized in the "Physician in Spite of Himself" when the mock-physician "explained" the fact that opium puts one to sleep by ascribing to it a "dormitive virtue." It is understandable that this mode of elucidation increasingly became foreign to natural philosophers who by 1600 were being trained not nearly so thoroughly in scholastic discourse as in the crafts or mathematics. These men turned away from scholastic classification, and, using the analogies of the world around them, turned toward that form of explanation which relied upon the impact or contact of matter with matter. Some, for example, returned to the Greek philosopher Epicurus' interpretation of magnetic attraction which involved the exhalation of a corporeal effluvium from the magnet which, on returning to the magnet, draws the iron with it.

Among the men who returned to the atomism of the ancients in preference to Aristotelianism, were Galileo Galilei and Thomas Hariot. Galileo, of course, is familiar to all as, among many other things, the discoverer of the law of falling bodies. What is less well known is that Galileo was an atomist, and in the same work in which he introduced the law of falling bodies, he described a very complex mathematical atomism, employing infinitely small atoms with infinitely small vacuous spaces among them[2].

Thomas Hariot is a less widely known, but perhaps equally interesting figure. Hariot was a great English astronomer, mathematician and physicist who, because he never published his findings, has been largely forgotten. Among his many accomplishments were the use of a telescope, probably before Galileo[3], the discovery of Snell's law of refraction twenty years before Snell found it[4], and the discovery of the law of falling bodies independently of Galileo[5]. Hariot is important here because he was one of the first in the seventeenth century to use atomism as a *systematic* natural explanation. As he advised his friend Kepler, one must contract oneself into an atom in order to pass through the portals of Nature's door[6].

These new atomists could not, of course, merely resurrect ancient atomism. The new atomic doctrine had to incorporate within it the experimental advances for which it was, in part, revived. At first, the atomic theory was used to explain particular natural phenomena, as Hariot did when he attempted to explain refraction on the basis of atoms and void. Some, like Nicholas Hill and Daniel Sennert, tried to bridge the gap between atomism and Aristotelianism with attempts at synthesis. Finally, others, like the French priest Pierre Gassendi, the English philosopher Thomas Hobbes and the Frenchman René Descartes, built great systems of physics, rich in detail, which attempted explanations of all things.

These three natural philosophers, and especially Gassendi and Descartes, were responsible for the establishment of the mechanical philosophy or the doctrine of matter and motion as the sole basis for scientific explanation. Gassendi was a famous philosopher and astronomer; he is generally considered to be the chief reviver of atomism in the mid-seventeenth century. All three philosophers – Hobbes, Gassendi and Descartes – held that every natural phenomenon is caused by the size, shape and motion of small, subvisible particles. Beyond this general agreement lay important disagreements however. Gassendi maintained the existence of hard, indivisible atoms and the existence of the void or vacuum. Descartes, on the other hand, maintained that the world was a plenum and that there exists no void. Moreover, to Descartes, the corpuscles or bits of matter of which the universe was made were infinitely divisible; there existed no true "atoms." Both these philosophies – the atomistic system of Gassendi and the plenist theory of Descartes – were 1) *mechanical* in that they explained all things by the impact of matter upon matter, and 2) *corpuscular* in that all explanations involved invisible particles or corpuscles. All the major scientists of the mid-seventeenth century were, in some sense, disciples of either Gassendi or Descartes, or, like Robert Boyle, adhered primarily to the common area of agreement between them.

The three natural philosophers just mentioned – Hobbes, Descartes, and Gassendi – were aware of a deep contradiction in the mechanical philosophy. They purported to explain all natural phenomena by the size, shape and motion of invisible particles. Yet these particles or corpuscles were not amenable to direct experience, nor could their motions be found with mathematical rigor. *Physics*, they held, was in consequence *hypothetical* in nature. Unlike mathematics, physics was not, and could never be, rigorous because the particles could not be experienced directly. The term "hypotheses" was used by them in a special sense; it was the function of the physicist to suggest "hypotheses" of detailed mechanisms which were *possible* or *plausible*. He could do little else. These detailed mechanisms were to be limited only by two considerations. First, these mechanisms must be consistent with observed phenomena, and, secondly, they must be self-consistent and lead to no absurd conclusions[7]. In sum, all that the natural philosopher can aspire to is to suggest tentative hypotheses concerning the invisible corpuscles. Hence, the paradigm physics of the mid-seventeenth century, dominated by Gassendi and Descartes, can with justice be termed "the hypothetical physics." Thomas Hobbes best summarized this approach when he wrote:

> In thinges that are not demonstrable, of which kind is the greatest part of natural philosophy, as depending upon the motion of bodies so subtile as they are invisible, ... the most that can be atteyned unto is to have such opinions, as no certayne experience can confute, and from which can be deduced by lawfull argumentation no absurdity ...[8]

II

In the 1660's, there was a reaction against this type of physics. The reaction took place primarily in England, and on a broad front. Most of those who rebelled against the hypothetical physics were inspired by Sir Francis Bacon, and must, in some sense, all be termed "Baconians."

Bacon, who wrote during the first quarter of the seventeenth century, was actually an adherent of the atomic doctrine at an early stage in his career. But Bacon soon abandoned atomism. It is important to examine his reasons. He rejected it, by 1620, as a mere *a priori* construction, lacking what for Bacon was a prime requisite for a physical theory: *certainty*[9]. Bacon proposed to establish *certainty* in science with his new organon. He advocated a path to understanding, in his words "direct from the sense, by a course of experiment orderly conducted and well built up[10]." He did not, however, fall into blind empiricism, as is sometimes alleged. Bacon clearly realized that, again in his words, one first "lights the candle and then by means of the candle shows the way[11]." In less metaphorical terms, one must first arrive at some tentative theoretical understanding in order intelligently to approach the world of experience. In sum, it was from such considerations of method that Bacon was forced to abandon atomism.

Bacon's call for *certainty* in science was echoed by his disciples in the 1660's. The Royal Society, established in the early years of the Stuart restoration, was, in part, the institutionalized protest of the Baconians against the systematizers. The revolt took several forms; there was a spectrum of Baconians opposed to the hypothetical physics. First, there were those who rejected *all* theories and fell back upon elaborated "natural histories" after the fashion of some of Bacon's treatises. Secondly, there were those, like Robert Boyle, who attempted to *test* the great systems of Descartes and Gassendi. Boyle was not satisfied with the *a priori* nature of the systems of the French philosophers, and wished, through experiment, to investigate the manner of their conformity with actual phenomena. Finally, there were those, like Barrow and Newton, who accepted Bacon's demand for certainty and, not finding it in the hypothetical physics, emphasized the necessity for what they called "mathematics" and what today would be called "mathematical physics." This last group is the real subject of this paper.

In order to understand Newton's attitude towards the hypothetical physics, one must first examine the point of view of his teacher and mentor, Isaac Barrow. Barrow was a famous mathematician, classical scholar and Anglican theologian. At the restoration of King Charles, he was appointed professor of Greek at Cambridge, and professor of mathematics at both Gresham College and Cambridge, where he taught Newton. As a mathematician Barrow was very accomplished, and widely acclaimed by his contemporaries.

In a series of lectures given in 1664–65, which Newton almost certainly attended, Barrow mounted an attack on the mechanical philosophers, and offered a new course of action[12]. This new course was the one which was identified with Isaac Newton for the following sixty years.

Barrow deprecated the approach to natural philosophy of the hypothetical physics. What, he asked, do the philosophers offer but *ad hoc* hypotheses?

> And for the Dispatch of every Question [Barrow wrote] or the Explication of a Phaenomenon, a new and distinct Hypothesis is invented. From whence it happens that in what is called and accounted the same science are found hypotheses without number[13].

Barrow was *not*, it should be stressed, attacking the mechanical philosophy in so far as it was based upon matter and motion. He was attacking the hypothetical method of the mechanical philosophers, i. e., the method of remaining satisfied with hypotheses and not certainties.

> No Body surely is so simple [Barrow stated] as immediately to agree or force himself to acquiesce with any of these *Hypotheses*[14].

True science, according to Barrow, must be *certain* science. It was Barrow's aim to end what he called "all Causes of Disputation[15]." The way out of the difficulty was to become not merely a natural philosopher, but a *mathematical* philosopher. Barrow's description of his idea of a mathematician is instructive for it describes the actual course of action which his disciple, Newton, followed:

> Mathematicians, [Barrow wrote] only meddle with such Things as are certain, passing by those that are doubtful and unknown. They profess not to know all Things, neither do they affect to speak of all Things. What they know to be true, and can make good by invincible Arguments, that they publish[16].

Newton's famous reluctance to publish a systematic "theory" of matter, after the fashion of the hypothetical physicists, or to dispute about mechanical causes was not, therefore, merely the result of timidity or innate reticence, but was an essential part of a program to transform natural philosophy from the hypothetical physics of Descartes, Gassendi and Hobbes, to a new, more *certain* science. His guide in these matters was Isaac Barrow.

In order to clarify the distinctions made between the hypothetical physics and the Newtonian approach, an example is in order. Among the most striking cases are the discussions of the expansibility of air of Descartes and of Newton.

In the fourth part of his *Principles of Philosophy*, entitled "Of the Earth," Descartes discusses why air can easily be expanded and contracted. Air, he says, is composed of small particles which are very soft "as small feathers or the ends of very delicate strings[17]." These pliant, feather-like particles are by their very nature easily moved. Consequently the volume they occupy is easily expanded and contracted.

This explanation, though brief, is a good example of the hypothetical method. Descartes had no way of *knowing* whether his ingenious model was, in fact, true. But it was *consistent* with the facts, as far as it went, and was also consistent with his own system. These requirements being satisfied, Descartes rested, assured that his explanation, even if it could not be proved true, could equally not be proved false as well.

Newton, on the other hand, made stricter requirements upon a scientific explanation. One of the best examples of Newton's method is his manuscript *De Aere et Aethere* (*Of the Air and Aether*), written about 1675, but never published[18]. It provides an interesting contrast with Descartes' "hypothesis." First, Newton tries to prove that there exist repulsive forces in nature. He does this, in Baconian fashion, by listing instances or examples of the tendency of bodies in nature to avoid contact. He then insists that he is not concerned with the *cause* of this repulsion; this cause is disputable and not worth the trouble. He concludes, however, that "air is composed of ... particles ... repelling each other with a certain large force[19]." On this basis, Newton intends to demonstrate the properties of air.

According to Newton, "Hooke proved by experiment" that the volume of air is reciprocally proportional to the pressure applied to it [Boyle's Law[20]]. If we assume that there is a force acting at a distance, the intensity of which is inversely proportional to that distance, this relation between pressure and volume of air can easily be derived. Newton provided this derivation in Book II, Proposition XXII of his *Principia Mathematica*, published over a decade later.

The difference between the approaches of Descartes and of Newton is apparent. Descartes was contented with a non-mathematical, qualitative hypothesis. Newton proceeds in a Baconian manner to find from experience that there exist repulsive forces. Then he assumes that these forces vary inversely with the relative distance between air particles. From this assumption, Newton can derive mathematically the *quantitative* properties of air. To be sure, Newton is leaving the qualitative physics of Descartes, and entering the realm of quantitative physics. But he is doing more. He is abandoning the *hypothetical method*, and embracing the method advocated earlier by Bacon and adding mathematical rigor to it.

III

With this background, one can now re-examine the famous controversy over Newton's optical letters in the light of Barrow's program and, as I suggest, Newton's adherence to it. The intricacies of this controversy, about which much has been written, become manifest if one assumes that Newton followed his teacher, Barrow, in rejecting what Barrow termed "hypotheses."

Newton's first optical letter was communicated to the Royal Society and published in its *Philosophical Transactions* for 1672. In it, Newton related the results of his famous prism *experimentum crucis*. From this experiment, Newton cautiously drew several conclusions about the nature of color which we need not go into here. He also suggested ("perhaps") that the experiment proved that light is a *substance* and not a *quality*, i. e., that light is a corporeal body rather than a property of the medium, as both the Aristotelians and the Cartesians had held[21].

Soon after the appearance of the first optical letter, Newton was criticized by a group of scientists who represented varying points of view. These men included Ignatius Pardies, Christian Huygens and Robert Hooke. Pardies, a French Jesuit, was one of the first to reply, discussing what he called "Mr. Newton's very ingenious hypothesis of light and colours[22]." It was, of course, Newton's intention to avoid disputations over "hypotheses." His answer to Pardies quite frankly stated this purpose.

> I do not take it amiss that the Rev. Father calls my theory a hypothesis, inasmuch as he was not acquainted with it. But my design was quite different... I would rather have [my views] rejected as vain and empty speculations than acknowledged even as a hypothesis[23].

His own conclusions, Newton insisted, were not part of the hypothetical physics; they were true and certain properties of light proved by (Baconian) induction, which, according to Newton, was the only path to certainty in science.

In his second reply to Pardies, Newton declared that the best mode of philosophizing is "first to inquire diligently into the properties of things, and establishing those properties by experiments and then to proceed more slowly to hypotheses for the explanation of them[24]." Newton is, of course, using the term "hypotheses" here in a second sense. The various uses by Newton of the term can, however, be easily distinguished in context.

Newton then directly attacked the hypothetical physics. He concluded: "For if the possibility of hypotheses is to be the test of truth and reality of things, I see not how certainty can be obtained in any science[25]." The hypothetical physics of Descartes, Gassendi and Hobbes permitted no *certainty in science*. This was the heart of Barrow's objections and it remained the heart of Newton's objections as well. Newton's physics had henceforth to conform to a quantitative version of Baconian requirements. Yet however plainly Newton expressed himself, his contemporaries did not understand, or perhaps try to understand his point. A case study in discussion-at-cross-purposes is the interchange between Newton and Robert Hooke.

Hooke's critique of Newton's theory clearly demonstrates his lack of appreciation of the proposed Newton-Bacon-Barrow reform of physics. Hooke termed Newton's conclusions "his hypothesis[26]." Thinking primarily in terms of the mechanical philosophy, Hooke saw the essence of Newton's argument in his hint that light is a corporeal substance. Naturally, Hooke insisted that the same phenomena can be explained as well by his own (wave) hypothesis. Newton's argument was, he insisted, one possible, even ingenious hypothesis, but it was only one of many possible solutions.

Newton was, of course, incensed. Hooke had missed his whole point. He was disappointed, Newton stated in his reply, that Hooke was still concerned with mere hypotheses. That light is a material substance is a possible conclusion from the experiments, but it is not a fundamental part of his optical theory. Many hypotheses *could* be advanced, but none was needed. "You see therefore," Newton concluded, "how much it is beside the business at hand to dispute about *Hypotheses*[27]."

Newton's difficulties with Hooke were largely repeated with Christian Huygens. Huygens insisted that until Newton supplied a mechanical "*Hypothesis*" for the origins of colors, he [Newton] had not solved the problem of color[28]. Again Newton had to explain his position. "[T]o examine how colors may be explain'd *hypothetically*," Newton wrote, "is besides my purpose[29]."

The controversy over the optical letters was not, therefore, a controversy over the wave versus particle theory of light. As we have seen, Newton himself was indignant over Hooke's attempt to look at it in this way. Nor was the controversy concerned with a general fear that Newton's views were reactionary, and would lead back to Aristotelianism[30]. The crux of the matter, as Newton saw it, was the rejection of the hypothetical physics for a more certain, more Baconian, more quantitative physics.

Yet Newton did, several times in the course of his career, venture into creating many detailed mechanisms. How is one to explain the apparent contradiction between his anti-hypothetical stand and these very hypothetical constructions? First, one should remember that Newton never *published* these speculations, except in the form of "queries" as in his *Opticks*. Moreover, he often claimed to be reluctant to write down such speculations, and indeed he was. In his famous letter to Robert Boyle in which Newton outlined a complicated and cumbersome aether hypothesis, he (Newton) insisted that he would not even have written down his notions but for Boyle's insistence[31]. With all of Newton's qualifications, it seems hardly fair to dignify his speculations as a "theory of matter."

What of the famous "queries" appended to later editions of his *Opticks*? Here Newton *did* publish some speculations about the constitution of matter. It should be stressed that Newton distinguished clearly between a "query" and a *hypothesis*. For the hypothetical physicists a hypothesis was one *possible* explanation among many of a particular phenomenon. A *query* for Newton was a more or less probable induction from experience. For Newton, a query was the *starting-point* for investigation, leading to an explanation[32]. On the other hand, a hypothesis was the *end-point* of the scientific explanation of the hypothetical physicists.

Newton's assault on hypotheses was not truly an attack on the mechanical philosophy as such. It was an attack on the methodology of the great practitioners of that philosophy, Descartes, Hobbes, Gassendi and even Huygens. Explanations according to the motion of matter were completely acceptable, even desirable, to Newton; however, they had to be arrived at through careful induction from experience. It was the *hypothetical physics*, not the *mechanical philosophy*, which Newton attacked so successfully.

NOTES

1. Johannes Magirus, *Physica peripatetica* (Frankfurt, 1597), pp. 88–90.
2. Galileo Galilei, *Dialogues concerning Two New Sciences*, trans. Henry Crew and Alfonso de Salvio (New York, 1914), pp. 47–67.
3. F. R. Johnson, *Astronomical Thought in Renaissance England* (Baltimore, 1937), pp. 227–28.
4. J. Lohne, "Thomas Harriott, the Tycho Brahe of Optics," *Centaurus 6* (1959), pp. 113–21.
5. See my forthcoming book, *Science and Atomism in England: From Hariot to Newton.*
6. Hariot to Kepler, in Johann Kepler, *Gesammelte Werke*, ed. Max Caspar *et al.* (Munich, 1937–63), XV, p. 368.
7. See René Descartes, *Oeuvres*, ed. Victor Cousin (Paris, 1824), III, pp. 520–21, and Thomas Hobbes, *English Works*, ed. W. Molesworth (London, 1837–45), I, p. 531.
8. Hobbes to Newcastle, in Historical Manuscripts Commission, *Portland Manuscripts* (London, 1891), II, p. 128.
9. See note 5.
10. Francis Bacon, *Works*, ed. J. Spedding, R. Ellis and D. Heath (Boston, 1860–64), VIII, p. 114.
11. *Ibid.*, p. 15.
12. Isaac Barrow, *Mathematical Lectures Read in the Publick Schools*, trans. John Kirby (London, 1734).
13. *Ibid.*, p. 61.
14. *Ibid.*, p. 58.
15. *Ibid.*, p. 239.
16. *Ibid.*, p. 64.
17. Descartes, *Oeuvres*, III, pp. 368–70.
18. Isaac Newton, *Unpublished Scientific Papers*, ed. A. R. Hall and M. B. Hall (Cambridge, 1962), pp. 221–28.
19. *Ibid.*, p. 223.
20. *Ibid.*
21. Isaac Newton, *Papers and Letters on Natural Philosophy*, ed. I. B. Cohen (Cambridge, Mass., 1958), p. 57.
22. *Ibid.*, p. 86.
23. *Ibid.*, p. 92.
24. *Ibid.*, p. 106.
25. *Ibid.*
26. *Ibid.*, p. 111.
27. *Ibid.*, p. 123.
28. *Ibid.*, p. 136.
29. *Ibid.*, p. 144.
30. Cf. Richard Westfall's very interesting "Newton and His Critics on the Nature of Colors," *Archives internationales d'histoire des sciences 15* (1962), pp. 47–58.
31. Newton to Boyle, in Isaac Newton, *Correspondence*, ed. H. W. Turnbull (Cambridge, 1959–61), II, p. 295.
32. A. R. Hall and M. B. Hall, "Clarke and Newton," *Isis* 52 (1961), p. 584.

Centaurus

INTERNATIONAL MAGAZINE OF THE HISTORY OF

MATHEMATICS, SCIENCE, AND TECHNOLOGY

EDITED BY

MOGENS PHIL, A. G. DRACHMANN, OLAF SCHMIDT

AND VILHELM MØLLER-CHRISTENSEN

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MUNKSGAARD · COPENHAGEN

1966