CHAPTER 3: NEWTON'S SYNTHESIS

1. INTRODUCTION

1.1. The Happy Ending

The end of the story, almost invariably told with Newton as the lone hero[1], is very well known. In the summer of 1684, Edmund Halley paid a visit to Newton in Cambridge, and questioned him about his views concerning the latest speculation in London cafés, namely, that the planetary trajectories could be calculated based on the assumption that the sun attracts the planets by a force which diminishes by the square of the distance between the planet and the sun.

To Halley's surprise and delight, Newton replied that he had already done just that. Moreover, his calculations showed that if the "force of attraction" between the sun and each planet is taken to be inversely proportional to the square of the distance between them, the resulting planetary orbit is elliptical, just as Kepler had suggested some seventy years earlier. Unable to reproduce the calculations on the spot, Newton promised Halley he would send them to him. He kept his promise several months later, by sending Halley a short tract— *De Motu Corporum in Gyrum*— which while not exactly answering Halley's question, offered much more in exchange. It was, it turned out, an initial draft of the *Philosophiae Naturalis Principia Mathematica*, which Newton completed in less than two years and the Royal Society published in 1687.

1.2. The Question

There is hardly any doubt that the correspondence with Hooke in 1679-80 dramatically changed the way that Newton pursued Galileo's project; *i.e.* that one cannot understand Newton's work in *De Motu* unless what he learned in this communication is taken into account. With regard to the important question for our purpose here, namely, what precisely did he learn, there is much less of a consensus.

Several answers suggest themselves. The first, stemming directly from the original priority dispute between Newton and Hooke, is that Hooke taught Newton the inverse square ratio between gravity and distance, and that Newton slighted Hooke by not attributing to him the discovery of this law. This dispute was picked up by historians, and for more than a century (since Rouse Ball, and especially since Lohne's rebuttal in "Hooke versus Newton"), the investigation of Hooke's contribution to celestial mechanics has revolved almost exclusively around the question of his eligibility to the title of the discoverer of the Inverse Square Law (henceforth: ISL).

More recently[2], it has been forcefully argued that the change that occurred in Newton's work, which enabled him to compose *De Motu*, and which should most probably be attributed to his encounter with Hooke, is the move from concentration on centrifugal tendencies to a consideration of centripetal forces. In a very preliminary way, which will be qualified later, I shall say that it has been shown that while Newton's early gestures towards understanding planetary motion consisted of attempts to find the forces needed to keep bodies in circular orbits by calculating the force by which they strive to break away, in the years following his exchange with Hooke, his concentration shifted to calculating the relations between hypothetical centripetal forces and the curves into which they would force the planets.

The most general possible answer emanates from the way in which Newton's achievement has come to be perceived following the seminal works by Wilson ("From Kepler's Laws, So-called, to Universal Gravitation") and Westfall (*Force in Newton's Physics*), *i.e.*, as being first and foremost the universalization of gravity. My presentation of it here, as the culmination of 'Galileo's Project,' is firmly within this tradition. And since Newton's success came on the heels of his encounter with Hooke, both Westfall and Wilson have asked whether in fact Newton acquired the concept of universal gravity from Hooke, and if indeed Hooke ever possessed such a concept[3]

1.3. Difficulties

None of these answers is generally accepted as conclusive. Rather, each serves as a focus of debate concerning Hooke's role in the turn that took place in Newton's work in the 1680s. For the most part, the debates revolve around priority, and are characterized by questions such as "What elements in [Newton's] new Synthesis did he borrow from his contemporaries and what were the products of his own insight" (Whiteside, "Newton's Early Thoughts," 129), or did Hooke or "did [Hooke] not hold a conception of universal gravitation" (Westfall, "Hooke and the Law of Universal Gravitation," 245). While these discussions highlight various important aspects of the Hooke-Newton encounter, this chapter does not come to summarize them. Instead, it will attempt to determine what part of the achievements credited to Newton was developed within and in response to his correspondence with Hooke.

Epistemologically, this is a completely different challenge. Attempting to determine whether it was Newton who learned the inverse square law (or the notion of centripetal force, or universal gravity) from Hooke, or vice versa, leads to the question of which protagonist was first to arrive at any of these pieces of knowledge. The following discussion, on the other hand, will concern the question of the skills and theoretical tools employed by Newton and Hooke in forging and fusing these pieces. This inquiry may be conducted without accepting two fundamental presuppositions that underlie the priority debate. Although these assumptions are mentioned briefly in the previous chapters, they are nevertheless significant enough to consider from yet another perspective.

First, the question 'who taught whom' or 'who got there first' assumes that the knowledge in question—ISL or any of the other candidates—has an existence prior to, and independent of, its discovery by the one who taught it to the other. In asking about the skills and tools used to bring about this knowledge, on the other hand, one stipulates that the outcome of the correspondence might have all been new; not only new for one of the interlocutors, but novel a product of the exchange itself. To accept a similar claim about Newton's mature work on celestial mechanics in general is to admit that, as and indisputable as any of it may seem with hindsight, it was all completely contingent upon the historical vicissitudes of its production.

Secondly and connected to this point, the question of priority assumes that *either* Newton *or* Hooke deserves the credit for prior discovery (of the inverse square law, or the notion of centripetal law, or universal gravity). This entails that the alleged discovery is fundamentally an act of an individual. In contrast, in attempting to determine Hooke's contribution toward composing the texts leading to the *Principia*, we allow the possibility that *both* Hooke *and* Newton deserve the credit together. We thus assign primacy to the process of producing knowledge over the end product, and imply that this may be a cooperative process—taking place within the correspondence, between the two men.

1.4. Different Approach

This epistemological turn has some immediate historiographic ramifications, the most obvious being that it makes it all the more desirable to avoid "read[ing] the future into the past, with a sense of elation" (Sabra, 224). The priority question calls for careful dating and authorizing of previous appearances, in different contexts, of ISL, centripetal attraction and universal gravitation. But this antiquarian pursuit is of little value if these elements of Newton's work in the 1680s have no standing of their own, if their meaning and their significance are completely dependent on the historical contingencies of their production and employment. If, as this chapter will suggest, the way Newton uses ISL, centripetal attraction and universal gravitation in *De Motu* and the *Principia* have been established through, and in response to the encounter with Hooke, then the interpretation of these texts gains little from the knowledge of when, before the correspondence, they were first declared, and by whom.

My strategy will therefore be somewhat different. I will attempt to determine the constitution of the new knowledge transmitted and created in the correspondence between Hooke and Newton by comparing Newton's work immediately following the exchange with his work on similar issues before it. Looking back at Hooke's knowledge, I will not attempt to adjudicate his priority claims, but rather to account for his contribution to this cooperative effort. Since Hooke is the main hero of this work, the preliminary comparison will have to be restricted to a relatively small sample of Newton's relevant work. To investigate the immediate outcome of Newton's correspondence with Hooke, I will explore the *De Motu* of 1684 and a manuscript entitled by Herivel "The Kepler-Motion Paper (The Newton Copy)" (henceforth: *KMP*), whose dating is more problematic. If Newton had written anything directly relevant to the question of planetary motion in the 1670s, none of it has survived, so the outcome of the exchange with Hooke will have to be traced by comparing Newton's work of the 1680s to two of his manuscripts from the late 1660s which Herivel entitles "On Circular Motion" (Herivel, 192-198, henceforth *OCM*) and "The Laws of Motion" (Herivel, 208-218, henceforth *LOM*).

2. NEWTON BEFORE AND AFTER

2.1. The Inverse Square Law

The oldest and most heated of the debates mentioned above is the one concerning the credit Newton owed Hooke for first proclaiming the inverse square ratio between gravity and distance (ISL). It is debated today in virtually the same terms used by the two practitioners, yet, like many other hindsight priority disputes and specifically the ones mentioned in previous chapters, it is seriously misguided. The question whether Hooke deserved Newton's recognition for the discovery is misleading—not because the ISL appears in Newton's writing previous to the correspondence with Hooke (as indeed it does)—but because ISL was never 'discovered'. It had been suggested, speculated and hypothesized by different people, for different reasons, in different contexts, to fulfill different goals.

Hooke had applied the ISL already in 1665—much earlier than is usually noted. He certainly did not foresee the priority dispute looming, for he did not even bother to explicitly formulate it. The allusion to ISL comes in the *Micrographia*, in reference to the "*Toricellian*" experiments discussed in the previous chapters. Using the outcomes to calculate the size of the atmosphere, he explains why, in calculating atmospheric pressure, he resorts to counterfactual assumption that the column of air, weighing on his mercury tube, is "a *Cylinder* indefinitely extended upwards:"

> [I say *Cylinder*, not a piece of a *cone*, because, as I may elsewhere shew in the Explication of Gravity, that *triplicate* proportion of the shels of a Sphere, to their respective diameters, I suppose to be removed by the decrease of the power of Gravity] (*Micrographia*, 227. Square parenthesis in the original)

Hooke's succinct remark is an abridgment of the following argument: the atmosphere is a sphere of air enveloping the earth. Each point on earth can be taken as the apex of a cone of air, "indefinitely extended upwards."[4] The volume of a sphere (or a cone) is in "*triplicate* [cubic] proportion" to its "respective diameters," and the same proportion holds true between the volume of the cone and its height. If the air's density is equal at all heights, then the volume of the air is proportional to the cube of the height of the atmosphere. The volume of a cylinder, on the other hand, varies only in simple ratio to its height. However, if gravity decreases in proportion to the square of distance, then "that *triplicate* proportion ... [is] removed," namely, the weight of the air varies with the height of the atmosphere. The atmospheric pressure can therefore be calculated, for convenience sake, as if it were a cylinder of air, rather than a cone supported by each point, and as if gravity were constant, rather than decreasing according to the ISL.

Hooke was so cavalier with this ingenious argument and with the use of ISL for the simple reason that neither was original. Early suggestions that the sun's influence on the planets diminishes by the square of the distance are to be found in medieval optics, and were supported by arguments of the same structure as Hooke's: light is distributed in concentric spheres around its source (the sun, in the case of the heavens). Since there is a set 'quantity' of light, the larger the sphere, the smaller the 'density' of light

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