Gal, Ofer, Meanest Foundation and Nobler Superstructures: Hooke, Newton and the Compounding of the Celestiall Motions of the Planets" (Boston Studies in the Philosophy of Science,229) xii+239 pp., Dordrecht/Boston/London: Kluwer Academic Publishers, 2002

The puzzling title of Ofer Gal's book, "Meanest Foundation and Nobler Superstructures" is part of a remark in Robert Hooke's *Micrographia*, but Gal does not explain what relevance it has concerning the main subject of his book, which is described in the subtitle "Hooke, Newton and the Compounding of the Celestiall Motion of the Planets". After centuries of astronomical observations and theoretical work by Ptolemy, Copernicus, Brahe and Kepler and many other Western and Islamic astronomers, a complete formulation of the physical principles of planetary motion, and a mathematical solution based on these principles was given by Newton in his masterful book, the *Principia* . The importance of Newton's enormous achievement can not be overstated - it was the key event that initiated the 17-th century scientific revolution and culminated with the development of modern science. Hence, it is of considerable interest to understand the historical path which led to this achievement, and countless books and scholarly articles have been devoted to this task. But only recently has some attention been focused on the work of Robert Hooke on “Celestiall Motions”, and on his exchanges with Newton regarding the subject. Hooke was the first curator of the Royal Society and one of the most prolific experimental scientists of all times, but until the end of the 19-th century, his life and work had been nearly forgotten. In the 1660’s Hooke gave a correct formulation of the physical principles of orbital motion and universal gravitation which he published in a short tract entitled *An Attempt to prove the Motion of the Earth by Observations* which Newton also read. Hooke’s considerable achievements are slowly been recognized today (on March 2005, a plaque commemorating Hooke was placed in Webminster Abbey where Newton is buried), and during the past three years over half a dozen books have been devoted to his life and work. It is generally accepted that a correspondence between Hooke and Newton in the Fall of 1679 was of considerable importance to the development of orbital dynamics, and contributed to the formulation of Newton’s ideas on this subject. But there is disagreement regarding what precisely Newton learned from Hooke in this correspondence, and in his book Gal addresses this important issue.

Gal starts his book by describing what he calls Hooke’s ”programme” to account for the planetary motion in terms of terrestial physics, and reviews the 1679 Hooke-Newton correspondence on this subject, and Hooke’s related writings and lectures at the Royal Society. After lengthy digressions on Hooke’s writings on optics, elasticity and horology, which are not well integrated with the main topic of his book, and two rambling ”interludes” on philosophical issues, Gal finally turns his attention to Newton's early manuscripts on orbital motion. Here he makes the startling claim (p. 184) that " representing force driven motion by straight lines or open curves, while reserving the closed orbit to represent force-free motion, expressed a common understanding of the relations between force and motion...", which leads him to the conclusion that "the novelty of *De Motu* [Newton's first draft of the Principia] is thus encapsuled in the willingness to represent forced motions by closed curves" (p. 188). Supposedly, this change of representation occurred as a consequence of Newton's correspondence with Hooke. But there is ample historical evidence in Gal's own book that contradicts both his claim and his conclusion.

Long before his correspondence with Hooke, Newton understood that in the absence of an external force a body moves in a straght line with uniform velocity. This is the principle of inertia introduced by Galileo and Descartes, which Newton had studied during his student days at Cambridge University, and Hooke also had applied in his analysis of celestial motion. Conversely, they understood that the effect of a force acting on a body is to change its velocity. In particular, for constrained motion, as in the case of a ball rolling inside a spherical bowl, both Newton and Hooke recognized that the force acting on this ball is exerted by the side of the bowl. Taking the radial acceleration for the magnitude of this force, Newton calculated its dependence on the velocity and the radius for a circular orbit, and obtained the fundamental relation - that the force is proportional to the square of the velocity, and inversely to the radius (pp. 180-181) which also had been derived earlier by Christiaan Huygens (pp.186-187), and later on by Hooke. In 1669 Newton applied this relation to the motion of the planets around the Sun, assuming that their orbits are approximate circular with the Sun at the center, and having uniform velocities and periods that satisfy Kepler's third law (that the square of the period is proportional the cube of the radius). He then deduced that the gravitational attractive force of the Sun depends inversely with the square of the radius of the planetary orbit. Assuming also that the moon moves in an approximate circular orbit with the earth at the center, he determined from observations the ratio between the gravitational force acting on the moon and the force of gravity at the surface of the earth, and found that this ratio is in near agreement with the result expected from an inverse square dependence of this force. This was Newton's famous moon test (p. 181). This example alone suffices to demonstrate that contrary to Gal's claim and conclusion, quoted above, already ten years before his correspondence with Hooke, Newton had shown that circular orbital motion can be understood by the action of a central force, and that this action accounted for the astronomical observations of the motion of the planets and the moon. In addition, the Dec. 13, 1679 letter of Newton to Hooke, which is only partly described in Gal's book (pp.6-8) demonstrates that Newton had developed an approximate method to evaluate graphically non-circular orbits for general central forces.

Then what did Newton discover as a consequence of his stimulating correspondence with Hooke? Newton himself admitted to Halley that after this correspondence with Hooke he found that Kepler's empirical area law (conservation of angular momentum) was a consequence of the action of central forces such as the gravitational force. This essential result permitted Newton to describe non-uniform orbital motion geometrically by representing time in terms of the area swept by the radius vector of the orbit. The proof of Kepler's area law is the cornerstone theorem in the *Principia*, Proposition 1, Book 1. But Hooke's timely intervention was never acknowledged by Newton, and in his book Gal fails to recognize that this proof was stimulated by the exchange between Hooke and Newton.

Biography

Michael Nauenberg is a professor of physics (emeritus) at the University of California Santa Cruz. He has written several articles on Newton, Hooke and the development of orbital dynamics in the 17-th century. He co-edited a book with Richard Dalitz on *The Foundations of Newtonian Scholarship*,and in collaboration with J.B. Brackenridge, he contributed a chapter on *Curvature in Newton's Dynamics* to the *The Cambridge Companion to Newton* edited by I.B. Cohen and G.E. Smith.