Descartes' *Principia*: Laws of Motion

I. Kepler and Galileo: The Second Post-Copernican Generation

A. The Legacy of *Two New Sciences*

1. Even though others were working along related lines, Galileo's claim to have put forward a new science seems legitimate, for he has marked off a self-contained area

a. Domain of the science: all phenomena near the surface of the earth in which the propensity to fall vertically is the only natural process producing any change of motion (and hence in the absence of air resistance, etc.)

b. Range of the science demarcated by failure of vertical acceleration to remain (essentially) constant

2. But the new science he singles out he also leaves quite incomplete, for the theory he offers, for all its virtues, is but a fragment

a. The theory has six basic principles: (1) propensity to vertical fall is the sole mechanism; (2) its effect is one of uniform acceleration in time; (3) the speed acquired in accelerating through any given vertical height is independent of the path taken, (4) is independent of the weight (and shape) of the moving body, and (5) is just sufficient to restore the body to the height from which the acceleration in question commenced; and (6) this acceleration is not only uniform locally, but has the same universal value everywhere in the vicinity of the earth's surface

b. Major results -- now called "laws" -- are deduced from these principles plus some auxiliary assumptions: (1) the law of free-fall, (2) the law of inclined planes, and (3) the law of projectile motion

c. Nevertheless a fragment because theory fails to extend to pendular motion, deriving the rule for the pendulum -- period varies inversely with the square root of length -- obtained by Galileo from experiment

3. The mathematical theory that Galileo offered was an exemplar, displaying the importance not just of mathematical rigor, but also of a basically "axiomatic" approach

a. Galileo's theory is a question-answering device, with a promise of exactitude, just like theories in astronomy

b. But, unlike theories in astronomy, it united diverse phenomena under a small number of fundamental claims, yielding high "explanatory power" (probably a misleading description)

c. As such, it showed, perhaps for the first time in the history of modern science, how a combination of simplicity, completeness, and exactness -- three factors logically opposed to one another -- can provide compelling evidence for a theory

d. (Though exactness here open to some dispute, and still incomplete)

4. Galileo's new science brought out, again perhaps for the first time, the indispensable role of experiment in developing empirical evidence for theories that idealize

a. Precisely because it makes claims about what would happen in the absence of air resistance, specially contrived experiments are needed in which the effects of such things as air resistance become controlled or minimized
b. The form of experiment which Galileo emphasized involved validation of (theoretically) salient phenomena -- the underlying logic of which is hypothesis testing and falsification
c. He failed to see the much greater evidential potential in another kind of experiment in which some specific result (e.g. the value of g or its equivalent, the distance of fall in the first second) is deduced from a combination of theory and observation -- the underlying logic of which is confirmation through converging (and mutually refining) evidence (a la Horrocks)
d. Mersenne and Riccioli, whether they intended to or not, initiated such an approach, in the process displaying one key virtue of it, viz. increasing refinement of experiments (in response to vagaries)

5. In spite of legend to the contrary, Galileo seems to me to have left us with less than usually suggested on the process of turning data into evidence -- i.e. on the logic of bringing data to bear
   a. Called attention to a special form of theory testing: do predictions derived from mathematical theory hold for certain special, usually highly contrived circumstances in which confounding effects should either be minimal or should largely cancel one another out
   b. Still, his discussions of the role of discrepancies in comparing observations and theories are superficial and, worse, confused, conflating different logics as if they were one
   c. I suspect his shortcomings here initiated a long, still continuing tradition of confusion about evidence in the early stages of theory construction – in particular, the self-evident standing as matters of fact of the announced results of experiments
6. Finally, Galileo left important work to be done, of two sorts:
   a. Develop a more thorough empirical basis for the theory
   b. Extend the theory to pendular motion and other forms of constrained curvilinear motion

B. Kepler and Galileo: Some Contrasts

1. Before turning to Descartes, and a new generation in the history of science, we should consider some contrasts between the two foremost scientists in the preceding post-Copernican generation
2. Both Kepler and Galileo developed mathematical theories -- more specifically, mathematical question-answering devices -- but of radically different sorts
   a. Galileo's theory unifies diverse phenomena under a comparative minimum of basic principles
   b. As such Galileo's theory “explains” various "laws" and regularities -- i.e. gives reasons why they should be considered nomological, namely because they derive from certain fundamental, universal principles
   c. Kepler's orbital theory offers no such unification; his three "laws" are not tied together in the same way as Galileo's "laws" are

3. Kepler insists on an underlying physics where Galileo does not -- indeed, where Galileo even calls the value of proposals about underlying physics into question (Salviati in response to Sagredo)
    a. Kepler turns to underlying physics to show such things as the nomologicality of his "laws"
    b. Galileo achieves this sort of thing through his unified theory; instead of an underlying physics, he has as underlying the constancy and universality of the acceleration of gravity as a basic principle
    c. The question why g -- that is, the distance of fall in the first second -- is constant, or whether it really is or only nearly so, though relevant, does not demand an answer
4. The contrast between Galileo relying on experiment and Kepler on observation is tied to their different logics of idealization
    a. Galileo idealizes because it is the only way he can find to obtain a “science” -- to obtain a theory of the sort achieved
    b. Kepler concludes that his theory is an idealization in order to justify treating it as the first in a sequence of successive approximations
    c. The contrast between the two of them here is probably mostly a reflection of their contrasting observational bases
5. Kepler and Galileo exhibit contrasting logics in evidential reasoning, as revealed by the contrasting role of discrepancies
    a. Any systematic discrepancies place a burden on Kepler, either to revise the theory or give grounds for attributing them to second order (physical) mechanisms
    b. The only burden systematic discrepancies place on Galileo is to dismiss them on such grounds as their not being large enough to falsify the theory
    c. The contrast here becomes even more pronounced when Galileo shifts to success in practice -- showing an instrumentalist bent that Kepler expressly rejects
6. Finally, they exhibit contrasting attitudes toward the "perfectibility" of their respective sciences
    a. Kepler takes perfectibility as a basic goal, insisting on predictive power, with the empirical world as ultimate arbiter
    b. Galileo is prepared to sacrifice perfectibility to gain what we are here calling explanatory power
    c. This contrast -- tension -- has persisted in science ever since

C. In Pursuit of a Truly Empirical Science

1. Contrasts between Kepler and Galileo should not obscure the commitment they had in common to the idea that empirical considerations should somehow be the ultimate arbiter
    a. Both are grappling with the challenge of finding decisive ways of marshalling empirical evidence
    b. Both depart from prior traditions in theory in an effort to allow empirical considerations to be more decisive

2. Empirical "science" itself was scarcely a new thing, for medicine, metallurgy, and chemistry (or alchemy -- more accurately “chymistry) all had long empirical traditions
    a. Galen's treatises on the nature of medical science date from the same period as Ptolemy
    b. The experimental tradition in chemistry and alchemy was thriving in the wake of Paracelsus, a contemporary of Copernicus
    c. Renaissance naturalism had produced Gilbert's work on magnetism
3. The main difference between Kepler and Galileo and these traditions was their greater appreciation of how hard the evidence problems were that they were facing
    a. Appearances can be deceptive, a lesson from Copernicanism and the telescope
    b. Appearances may be compounded out of diverse causes, necessitating special ways of disentangling the causes to obtain evidence pertaining to them
    c. Questions addressed require information that was difficult to obtain -- distance to planets, precise times of fall
4. Galileo and Kepler were not alone in their pursuit of more effective ways of bringing the empirical into science
    a. Francis Bacon had published *The Advancement of Learning* in 1605 and the *New Organon* in 1620, describing a general approach to building knowledge from observation that became especially influential in Britain
    b. Mersenne had published two tracts presenting the "mechanical philosophy" in 1623, followed by *The Truth of the Sciences* in 1625
        (1) Argues that a combination of mathematics and experiment, under the constraints of the mechanical philosophy, can yield useful theoretical knowledge of the world
        (2) Skeptical arguments to the contrary notwithstanding
        (3) Mechanical philosophy put forward by Mersenne in opposition to Renaissance naturalism
    c. Even Riccioli is best viewed as subjecting Galileo's *Dialogue* to strict empirical assessment, with Ptolemy and Aristotle as the “null hypothesis” so to speak
5. Descartes can be viewed as extending and refining Mersenne's views by imposing three requirements on theorizing
    a. The mechanical philosophy: explanation must be carefully distinguished from pseudo-explanation in which understanding is replaced by a mere name
    b. There must be one comprehensive, unified theory of the entire sensible world, for misleading evidence can all too easily develop in support of separate piecemeal theories of a limited range of phenomena
    c. Great attention must be given to the foundations of this comprehensive theory, for error there can undermine everything else
6. These three suggestions had the sound of the voice of reason at the time!