THE NEWTONIAN REVOLUTION – Part One

Philosophy 167: Science Before Newton's *Principia*

Class 8

Descartes' *Principia*: Laws of Motion

October 21, 2014

Philosophy 167: Science Before Newton's Principia

Assignment for October 21

Descartes' *Principia*: Laws of Motion

Reading:

Descartes, Principia Philosophiae, Part II completely.

---- Part III, Articles 1-30.

---- Part IV, Articles 23-26, 133-139, 145-165.

Questions to Focus On:

1. Descartes, in sharp contrast to Galileo, treats the question of whether a vacuum does or can exist as a conceptual issue, and not an empirical issue. How, if at all, does his proof that a vacuum is impossible fail to end the issue?

2. Descartes asserts that there is always an equal quantity of motion in the universe. What does he mean by this "conservation principle"? What evidence does he offer for it?

3. Descartes proposes three laws of motion in Articles 37 to 42 of Part II. How are these laws related to Newton's three laws of motion? What evidence does Descartes offer in support of them?

4. Articles 45 to 53 of Part II lay out "rules" for determining what will happen following the impact of two objects. What is the point of these rules? Are they simply logical consequences of the laws, or do they involve further assertions? How does Descartes propose to reconcile the rules with what would appear to be commonplace counterexamples in our everyday experience -- e.g. in billiards?

5. The basic explanation for planetary motion laid out at the beginning of Part III asserts that the planets are borne along by vortices in an unseen fluid. What grounds does he provide for this? Does he consider it a mere conjecture?

6. The excerpts from Part IV concern Descartes's theories of gravity and magnetism -- theories that look like the most rank sort of unfounded conjecture to us. Why did Descartes look upon them as something other than mere conjecture?

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!

II. Descartes: The Third Post-Copernican Generation

A. Descartes: A Biographical Sketch

1. Descartes was born near Tours in 1596; from 1628 to 1649 he lived in Holland; and he died (from pneumonia) in 1650 in Sweden, where he had moved the year before, accepting an invitation from Queen Christina
    a. He was thus a part of the third post-Copernican generation, along with Mersenne (1588-1648), Gassendi (1592-1655), and Riccioli (1598-1671), not to mention his main rival in mathematics, Fermat (1601-1665)
    b. Kepler and Galileo were already major figures when he was a teenager, and Ptolemaic astronomy was largely a thing of the past, at least in "scientific" circles
2. Descartes received a strict Scholastic education at the hands of the Jesuits at La Fleche (where Mersenne was also schooled a few years earlier)
    a. Received a degree in law in 1616
    b. While in Holland in 1618, met Beeckman, and worked with him on such things as a mathematical relation describing free fall
    c. On November 10, 1619, in a fever-related dream while in Germany, had the vision of a complete new mathematical and scientific system: "Descartes' dream"
3. From 1622 to 1628 he worked on aspects of this system, often visiting Paris, where he became known in intellectual circles
    a. Started *Rules for the Direction of the Mind* around 1619, picking it up again after 1625 and finally abandoning it unfinished in 1628
    b. Whether Mersenne or others saw any of this manuscript is unclear
    c. Descartes did engage in discussions with Mersenne and his circle while in Paris from 1625-1628
4. In his first attempt to publish a comprehensive system, Descartes wrote *Le Monde, ou Traite de la lumiere* and the *Treatise on Man* from 1629 to 1633
    a. When he learns of the trial of Galileo, he withholds them from publication, fearing his proof of Copernicanism in *Le Monde* will lead him into similar problems
    b. Though Mersenne knew of these works, he and his circle apparently never saw them; they were published in 1664
5. Descartes' first major publication was the *Discourse on the Method*, published (in French) in 1637, with the *Geometry*, *Meteorology*, and *Optics* accompanying
    a. Full published title: "*Discourse on the Method of rightly conducting one's reason and seeking the truth in the sciences, and in addition the Optics, the Meteorology and the Geometry, which are essays in this method*"
    b. Originally proposed title: "*The Plan of a universal Science which is capable of raising our nature to its highest degree of perfection. In addition, the Optics, the Meteorology and the*

Geometry, in which the Author, in order to give proof of his universal Science, explains the most abstruse Topics he could choose, and does so in such a way that even persons who have never studied can understand them" (Cottingham, et al)

6. Both the *Optics* and the *Geometry* made major contributions, the latter especially via van Schooten's Latin editions, with commentary (greatly expanding the text), of 1649 and 1659
   a. *Optics* includes the law of refraction, which (like others) he appears to have discovered independently of Snel
      (1) With this law, a theory of geometric optics covering shapes of lenses -- introducing real science into the design of telescopes
      (2) Identifies and explains spherical aberration (mistakenly attributing chromatic aberration to the same thing) and indicates lens shapes for eliminating it
   b. *Geometry* extends classical geometry in ways that legitimate the use of algebraic methods to solve problems
      (1) A primary step, together with the work of Fermat, in forming what we call analytical geometry
      (2) Though not a reduction of geometry to algebra (just the opposite) and no Cartesian coordinates in it
      (3) Rather, it expands the notion of geometric construction beyond compass and straight edge, and then "reduces" algebra to this expanded geometry, thereby legitimating it
      (4) Huygens studied Cartesian geometry under van Schooten in Leyden, and Newton's reading of van Schooten's second edition contributed greatly to his early advances in math, including the calculus -- arguably as much as anything else did
   c. *Meteorology* covers phenomena like lightning, storms, and clouds, but now probably best known for Descartes' account of rainbows (Eighth Discourse)
7. The works that made Descartes most famous were published in the 1640's, appearing initially in Latin, but with authorized translations into French
   a. *Meditations on First Philosophy, with Objections and Replies* in 1641 (2nd ed, 1642); French translation, 1647
   b. *Principia Philosophiae* -- the *Principles of Philosophy* in 1644; French translation, 1647
   c. *Passions of the Soul* in 1649, and working on *Description of the Human Body*, which would have complemented the *Principles*, at the time of his death

B. Descartes' Intellectual Mission

1. While Descartes, as much as Mersenne and Gassendi, was part of an anti-Scholastic movement within Catholicism, he never rejected its goal of a unified, comprehensive philosophy
   a. His concept of education remained that of obtaining a world view, tied to Catholicism
   b. The fault lay not in the goal of Scholasticism, but in the Aristotelian philosophy underpinning it

2. Descartes grew up at a time when skepticism, as articulated in the late 16th century most forcefully by Montaigne, was in full flower
   a. Montaigne's version, an extension of Sextus Empiricus' Pyrrhonism, offered persuasive arguments against all knowledge claims
   b. Descartes appears to have seen his mission in part as one of saving the world -- in particular the Catholic world -- from skepticism
   c. Aligning him at least in spirit with Mersenne's *The Truth of the Sciences* of 1625
3. As a consequence, one demand he placed on himself was to find a method of knowing that is secure from skepticism
   a. How to achieve absolutely secure knowledge, once and for all, including (perhaps with qualifications) knowledge of the sensible world around us
   b. Notice here the contrast with Kepler and Galileo, both of whom were concerned with securing knowledge in certain limited domains, but felt no need to take on the general problem
4. The second demand Descartes placed on himself was to formulate a new, comprehensive, unified philosophy to replace Scholasticism
   a. A total new curriculum for universities -- something he was definitely aiming at
   b. (Galileo too was pushing a new curriculum, but confined largely to natural philosophy)
   c. A total world view, akin in its unity and extent to the teachings of St. Thomas Aquinas
5. One can therefore think of Descartes as emulating Aristotle, who had managed to cover virtually everything known in his philosophical writings
   a. On Descartes' view, it seems, Aristotle had the right conception of what needs to be done, but adopted wrong methods
   b. This time Descartes was going to do it right, in the process ending skepticism and its consequences forever
6. However grandiose this may seem, such a vision was not entirely unique to Descartes at the time
   a. Bacon, Hobbes, Spinoza, and Leibniz were certainly on a similar track, at least up to a point
   b. Indeed, it was a natural response to the state of the intellectual world at the time
   c. The more modest views about our capacities for knowledge that were expressed by Galileo, and subsequently by Gassendi and his followers -- especially the willingness to live with ignorance -- were atypical

C. The Scope and Goals of Cartesian Science

1. Descartes is often said to have wanted to reduce all empirical science to geometry; but this is worse than uninformative
   a. He always distinguished between the domain of mathematics -- the realm of pure possibility -- and the domain of empirical science -- the realm of the actual
   b. Thus the absence of geometry in his *Principia* is not necessarily a sign of its incompleteness

2. For our purposes it is better to think of Cartesian science as a response to skeptical arguments against the possibility of knowledge of the empirical world
    a. The argument from illusion is the most important of these arguments
    b. The challenge it poses is how to distinguish conclusively between veridical and non-veridical perception, and hence how to distinguish veridical perceptual judgments from others
3. Descartes accordingly finds himself obliged to present not just an account of the world around us, but continuous with it an account of perception
    a. The geometry of perspective of Desargues (also part of Mersenne's circle) provides an example of how to put illusion in its place, as are accounts of refraction and of how the eye works
    b. The account of the world and our perception of it should allow inferences from perception either to the real cause, explaining illusion away, or to an identification of what additional information is needed to get to the real cause
    c. Perception itself is a corporeal process (at least up to a point) and hence ought to be a unified, continuous part of any science of the material world
4. So far as I know, this was a novel idea: a single, unified, comprehensive empirical science covering all the material world, including epistemological foundations characterizing veridical perception
    a. Physics, mechanics, optics, etc.; chemistry (e.g. fire), etc.; biology; and physiological psychology, etc.
    b. The overall science able to reconstruct truth out of the vagaries of appearance
    c. The ultimate evidence for the science: save the phenomena, as perceived, while identifying the single reality yielding the vagaries in them, yet staying within the mechanical philosophy
5. One consequence of this program is that Descartes' books within science tend to occur in pairs
    a. *Le Monde* and *Treatise on Man*; *Principia* and the uncompleted *Description of the Human Body*
    b. The *Optics* also exhibits signs of this preoccupation, covering both the physics of lenses and visual perception

D. The Historical Significance of Cartesian Science

1. Even the briefest encounter with the 300 pages of Descartes' *Principia* is enough to reveal that his empirical science consists almost entirely of falsehoods
    a. Unlike everything else we have been reading, it makes virtually no specific lasting contributions to science
    b. Obvious question: why am I having you read garbage
2. Reason: his *Principia* was profoundly influential; whether they agreed with it or not, it was a background in common that everyone else we will be studying shared (until roughly 1780)
    a. Huygens and Newton, in particular, were both strongly affected by it in their youth
    b. But even 120 years later, 80 years after Newton's *Principia*, the greatest figure of that time, Euler, was still insisting on Cartesian-like vortices in astronomy

c. As Voltaire's famous letter of 1728, "On Descartes and Newton," attests, the views of Descartes' *Principia* swept Continental Europe

3. Reason: Descartes was Newton's antagonist -- his *Principia* was written to respond to and to refute Descartes'
   a. Not just to show that Descartes' scientific theories were false, in particular the vortex theory
   b. But also to show that Descartes' whole way of doing science was a mistake, and a different method was needed, as illustrated by Newton's *Principia*
   c. One cannot understand Newton's *Principia* without Descartes' *Principia*
4. Reason: though Newton never openly admits it, many aspects of Descartes' thinking had a profound influence on him
   a. Descartes' way of conceptualizing motion was the principal source of Newton's way -- this in contrast to e.g. Galileo's
   b. Hence to understand how Newton envisaged certain problems, we often need to consider how they would have been formulated within Descartes' framework
   c. (Much the same is true of Huygens, who also rebelled, though not so categorically, against Cartesian science)
5. Reason: Cartesian science was the main source of resistance to Newton's *Principia*, both the knee-jerk and the sustained resistance, explaining why it provoked a 100 year controversy
   a. To understand the conflict over gravitation in the 18th century, one must understand the contrasting conceptions of science offered by Descartes and Newton
   b. This not just a conceptual conflict, but also a conflict about how to achieve empirical knowledge at all
   c. In other words, a conflict about evidential reasoning, and not just about action at a distance
6. Reason: Descartes' conception of science, for better or worse, is still with us, although often hidden somewhat from view
   a. This raises the question, why is this conception of science so compelling, especially in the face of Newton's critiques of it and the now obviously absurd substantive science it led to
   b. What really is wrong with this conception of science? -- this is a question we want to answer by the end of the course

III. Descartes' "Mechanical Philosophy"

A. The Mechanical Philosophy: Two Schools

1. Descartes was the leader of one school of the movement known as the "mechanical philosophy" that came to dominate 17th century natural philosophy
   a. Descartes' chief rival, Gassendi, became the principal leader of the other school, which, through his influence on Boyle, flourished in England in the second half of the century
   b. Mersenne largely neutral between the two

   c. Both schools were a response not just to Aristotelian natural philosophy, but also to Renaissance Naturalism, as illustrated (at its best) by Gilbert's *De Magnete*

2. The thread common to the two was a critique of Aristotelian and Naturalistic explanation as pseudo-explanation
   a. Both of these movements were criticized for positing qualities in objects that only appear to explain, such as heaviness to explain falling and lightness to explain things that rise, as criticized by Galileo
   b. The Naturalists openly acknowledge mysterious qualities, like the special vital spirit in iron producing magnetic phenomena
   c. Moliere's famous satire of "multiplying" qualities -- the dormitive power in opium that causes sleep, with no grasp of the mechanism at all -- probably reflected the influence of the discussion group Mersenne initiated and Gassendi continued after Mersenne died
3. The paradigm of explanation for the mechanical philosophy was the mechanical clock, in which everything could be accounted for in terms of one part in motion, pushing another
   a. Once started, the clock runs through contact of gear to gear, with a spring initiating the motion
   b. Every mechanism is totally comprehensible: no open questions, like how is this able to do that?
4. The only legitimate attributes in explanations are ones universal to all matter, such as occupying space, moving in time, encountering other matter, and producing change of motion through contact
   a. So, for example, if iron has a special magnetical quality, that must be explained in terms of the matter composing it and generic properties of this matter, such as shape
   b. Different shapes, for example, can produce different effects, but the generic category of shape is universal to all matter

      "All the properties which we clearly perceive in it are reducible to the sole fact that it is divisible and its parts movable; and that it is therefore capable of all the dispositions which we perceive can result from the movement of its parts" Part II, Article 23

5. One of the requirements of the mechanical philosophy was no action at a distance, for no explanation could be offered for how such action was effected
   a. E.g. Galileo's critique of Kepler's tidal theory
   b. Any appeal to action at a distance a pseudo-explanation, substituting a mere word for understanding, with the consequence of creating only an illusion of understanding
   c. A corollary: all talk of “attraction” suspect, along with appeals to “virtues” and “powers” that continued to appear throughout the literature in Engand
6. The two different schools of mechanical philosophy split over the question whether a vacuum can exist in nature
   a. Cartesian school: plenists
   b. Other schools: atomists (Corpusculareanism)

B. Descartes on the Vacuum and Atomism

1. Descartes held that the very concept of a vacuum is incoherent, and hence no vacuum is even possible in nature
   a. In the tradition of Aristotle, who argued, e.g., that two things separated by a vacuum are separated by nothing at all
   b. Descartes' approach contrasts with those who consider the issue, do vacuums exist, an empirical question to be resolved by experiments
2. The key premise in Descartes' argument is that the essence of any corporeal (i.e. material) object is extension, where 'essence' means what it is for that sort of object to exist
   a. His argument in the *Principia* and *Meditations* to exclude all other quantities turns on the claim that we can conceive bodies without color etc., but not bodies that do not occupy space (see II, 4)
   b. For him that leaves not even solidity, but only extension; not everyone agreed with this
3. But then the very idea of a vacuum is contradictory, for empty space extended and hence is a body
   a. Anything that is extended is a substance, namely corporeal substance -- (II, 16)
   b. To oppose this argument, one must argue that corporeal objects have some further essential attribute, for only then can one distinguish between empty space and such objects
4. {Galileo, by contrast, considered the issue an empirical one, and endeavored to devise experiments that would distinguish
   a. In 1644 his protegé Torricelli (1608-1647) created the barometer, following his suggestion
   b. In the late 1640's Pascal (1623-1662) conducted compelling experiments using the barometer to show that vacuums exist, which he reviewed face-to-face with Descartes in 1647-48
   c. Boyle followed these with a battery of experiments over the next dozen years
   d. Even so, there were holdouts against the vacuum well into the 18th century -- e.g. Leibniz}
5. Descartes does take the trouble to explain the concept of empty space, viz. as a conceptualization in which dimensions and shape are abstracted away from specific bodies
   a. But this doesn't alter the substantial reality
   b. Indeed, space and place are just relative anyway (II, 13) -- there is no external receptacle
   c. And, at least considered geometrically, motion too is relative

C. The Plenist World View, Versus Ours

1. On the Cartesian world view, then, matter is everywhere: air, liquid, and solid all material, so that differences lie only in such things as sizes, shapes, and movement of parts
   a. Further unseen particles, as defended in II, 7:

      "it is less consistent with reason to imagine something unintelligible, in order to appear to explain rarefaction by a merely verbal device, than it is to conclude, from the fact that bodies become rarefied, that they contain pores or interstices which grow larger and that some new body approaches to fill these pores; even though we may not perceive this new body through any of our senses"

b. As we shall see, Descartes has unseen particles of more than one type, with the smallest indefinitely small by virtue of infinite divisibility

2. A fluid mechanical world view, with the universe filled completely -- i.e. total continuity of contact for all matter, completely continuous, and infinitely divisible

   a. No smallest particles and hence no atoms (II, 34)

   b. Motion does not occur via bodies transferring into empty space, but via closed circuits (II, 33)

3. Gassendi, by contrast, offers a world view, derivative from Lucretius's *De Rerum Natura*, in which atoms ("corpuscles") move around in a vacuum, striking one another

   a. An immense void filled with atoms in motion, touching one another and impacting on one another, with no forces acting at a distance among them

   b. {Galileo was inclined in this direction, though he felt less need for a comprehensive world view}

4. Both of these world views should be contrasted with the one we inherited from Newton, which involves atoms in a void, but with forces at a distance among them

   a. Atoms or corpuscles the basic units of matter, endowed with a small number of fundamental forces, attracting and repelling

   b. This view violates the mechanical philosophy: how do these atoms attract and repel one another from a distance?

5. Cartesian plenism is likely to seem crazy, but this primarily a comment on the difference between the way we conceptualize things and the way it requires

   a. Nothing intrinsically incoherent in this view

   b. With time we could learn to think this way -- indeed, in fluid mechanics we often do

   c. Kuhn's central point applies here: to understand and hence to see why a discarded view in science was once so compelling, we need to look at it from within, and not from without

D. Descartes on Magnetic Phenomena

1. The most obvious challenge confronting the mechanical philosophy was the phenomenon of magnetism, as described phenomenologically in Gilbert's *De Magnete*

   a. He argued that it has a special immaterial quality that enables it to act at a distance

   b. Intellectual honesty demanded an account, which Descartes offers at some length in Part IV

2. Descartes lists 34 qualitative phenomena identified by Gilbert, many of them found through "experiment" -- i.e. intervention -- (IV, 145)

   a. Phenomena involving "magnetic force" -- i.e. "virtutis"

   b. Include all the usual ones: North and South poles, magnetic earth, alignment, attraction, repulsion, declination, etc.

   c. Descartes then claims that all 34 follow from simple compositional feature of the solid matter peculiar to iron

3. Specifically, magnetism is associated with special grooved particles that move in vortices, corresponding to which there are grooved slots in iron, and not in other things, that allow these particles to pass (more or less freely) through them
   a. Left-hand, or right-hand, twisted grooved particles, with corresponding threaded slots that can receive only like particles
   b. Poles, with each kind of particles passing through iron in opposite directions, and then circulating (see Figure in Appendix)
4. Impact of these particles suffices to explain the key "action at a distance" properties:
   a. Oblique impact of particles on slots explains alignment (150, 152)
   b. High velocity of particles when opposite poles aligned causes "attraction" by expelling the air etc. between the magnets, so that air acting behind them pushes them toward one another (153)
   c. Inability of particles to penetrate oppositely threaded grooves explains repulsion through impact (154)
   d. Declination because of vagaries in direction of particles flowing through iron in earth (168) -- vagaries that can be affected by our transferring iron from one place to another
5. Obvious question: why anything but a Rube Goldberg account, manufacturing features as needed
   a. Part of answer: the range of the phenomena covered in an explanation that relies primarily on a simple claim
   b. Another part: basic features of the explanation forced by the mechanical philosophy: must be some sort of unseen particles acting via impact
   c. A third part: no other explanation forthcoming that satisfies the constraints

E. Descartes on Gravity and Weight
1. Part IV covers a huge range of terrestrial phenomena, including various chemical effects like fire
   a. For example Descartes explains the tides in terms of a vortex induced pressure from the moon
   b. But the phenomena of primary note for us are gravity and weight
2. Again, Descartes must give a purely mechanical account of the phenomena of gravity:
   a. Virtually all solid and liquid bodies tend toward the center of the earth
   b. Some bodies are heavier, and more dense, than others
3. Descartes' basic account supposedly based on tendency of heavy bodies to move to center in whirlpools (IV, 20-27): weight from the action of globules (of the second type) in constant vortex motion around the earth
   a. Without them, everything would spin off the rotating earth
   b. These receding heavenly particles "press down and drive below themselves some terrestrial parts into whose places they rise"
   c. Weight then not a quality of bodies at all; in particular, it is distinct from the quantity of matter in any body (23) -- which is simply its volume

4. Density and weight variations arise because of differing compositions of bodies
    a. The more ethereal matter there is in the body, the more that globules can slip through it, and hence the less the pressure they exert, and the less the weight
    b. Less weight for same volume: less terrestrial component, and more ethereal
5. One thing to notice here is that the evidential logic is not so weak as it first appears to be, for Descartes can defend particles of various sorts from independent considerations (III)
    a. He does manage to explain weight and Archimedes' phenomenon, at least up to a point
    b. Furthermore, what else can gravity be if not some sort of pressure, for nothing else is compatible with the mechanical philosophy
6. Newton, as well as Huygens and others, will be trying to devise a mechanical explanation of gravity along somewhat these lines even after Newton's *Principia* is published

IV. Descartes' Laws of Motion

A. Circulation and Conservation of Motion

1. The material in Part II of primary interest to us concerns the so-called Laws of Nature and the Rules on impact that follow them
    a. This section at the end of Part II and the vortex theory in Part III were the most influential, for even corpusculareans (i.e atomists) like Huygens were affected by them
    b. The material in Part IV is of interest to us mostly to display Descartes' approach to the empirical world around us
2. Start with a cautionary note: Descartes on motion is rather more elusive than it at first seems to be, as reflected in recent scholarly disputes about him
    a. Complication: contrast between Descartes' views and what others took him to be saying
    b. Another: contrasts between *Le Monde*, the Latin *Principia*, the French *Principia*, and his subsequent letters and his (subsequently published) conversation with Burman
    c. Another: tendency to read Descartes from modern perspective, viewing him as anticipating modern ideas -- Whig history
    d. {I find myself especially influenced here by Gabbey's contrast between the geometry and metaphysics of motion}
3. According to Descartes, the primary cause of motion is God, who introduced and maintains a fixed quantity of motion in the universe
    a. Basis for the assertion is theological: the constancy or immutability of God
    b. This assertion not one of the laws of motion, but more fundamental than they are; laws concern "the secondary and particular causes of the diverse movements which we notice in individual bodies" (37)
4. This "conservation of total motion" principle appears at first glance to be a forerunner of our conservation of momentum, but this is almost surely a mistaken and misleading idea

a. Quantity of motion: B∗speed, where B represents bulk (Lat. *moles*) or quantity of matter (ultimately, volume for Descartes) and speed is a scalar

b. Our momentum, by contrast, includes an intensive quantity, mass as a measure of quantity of matter, and more important it is a vector quantity -- i.e. it is directional

5. Rationale for the principle: everything surrounded by touching bodies so that any change of place -- i.e. motion -- of one volume requires changes of place of others

   a. The only way to change the total motion is to accelerate a closed circuit

   b. God would not do this

6. Given this rationale, Descartes' claim is more akin to the principle of continuity in fluid mechanics than it is to conservation of momentum

   a. Volume flow rate = v ∗A, where A is normal to v (in units of volume of fluid per time)

   b. Picture a continuous, incompressible fluid flow through a pipe of varying cross-sectional area: v∗A everywhere a constant

   c. Now "sum" across the universe, and have Descartes' principle

   d. Spinoza offers just this line of interpretation (Propositions vii-xi of his *Principles of the Philosophy of Descartes*), and hence not a Whig interpretation at all

7. Not an empirical principle, but led to a serious controversy in empirical science 40 years later about what is conserved in e.g. a closed system

   a. B∗v for the Cartesians, versus $B*v^2$ for Leibniz (and Huygens), both scalar quantities

   b. This dispute worth looking at to see how those in Descartes' wake tried to bring empirical considerations to bear, and how they still depended on non-empirical considerations

B. The First Law of Motion (i.e. Nature)

1. "Each thing, provided that it is simple and undivided, always remains in the same state as far as is in its power, and never changes except by external causes [*causis externis*]" (37)

   Le Monde: "Each individual part of matter always continues to remain in the same state unless collision with others forces it to change that state." (p. 61)

   a. '*Quantum in se est* ' (translated above, "as far as is in its power") is a phrase borrowed from Lucretius's *De Rerum Natura*

   b. The law is a general principle of change, in the same sense that Aristotle's four causes or principles are

   c. But Descartes is ruling out final and formal "causation" for simple, undivided things

2. Descartes distinguishes two states of concern, rest and motion

   "If it is at rest, we do not believe that it will ever begin to move unless driven to do so by some external cause. Nor, if it is moving, is there any significant reason to think that it will ever cease to move of its own accord and without some other thing which impedes it." (37)

   a. Law says it continues to move, but says nothing about how it continues to move

b. Notice the argument for continuing to move: "no significant reason to think that"

3. As this phrase suggests, the law is really a tenet of explanation of change, akin to those put forward by Aristotle, and not as such an empirical generalization

   a. That is, it is indicating which why-questions are appropriate -- e.g. not 'why does that continue to move?'

   b. And it is indicating what sorts of answers are appropriate to these questions -- e.g. 'because that thing impeded it'

   c. Also 'why is that thing moving?' -- 'because it was already moving and nothing has impeded it'

4. This import of the law is illustrated by Descartes' immediate application of it to answer the old Aristotelian problem of why projectiles keep moving after they are thrown (38)

   a. Reason amounts to rejection of question ('why not?')

   "For there is no other reason why things which have been thrown should continue to move for some time after they have left the hand which threw them except that, having once begun to move, they continue to do so until they are slowed down by encounter with other bodies."

   b. Thus rejecting Medieval impetus, and the line of thought offered by Sagredo in the "Third Day" and then carried over into the “Fourth Day”

5. The status of this law is not entirely clear, for Descartes begins by saying that it is a consequence of God's immutability, but then offers no derivation

   a. Spinoza offers a derivation in his *Principles of the Philosophy of Descartes* (II, xiv), but I still do not see why it follows on Spinoza’s account

   b. Descartes' appeal is to metaphysics, with empirical considerations to remove objections

   c. Thus the law is best viewed as a proposed way of conceptualizing motion, built off a meta-physical claim

C. The Second Law of Motion: Circular Motion

1. "Each part of matter, considered individually, tends to continue its movement only along straight lines, and never along curved ones" (39)

   Le Monde: "When a body is moving, even if its motion most often takes place along a curved line and can never take place along any line that is not in some way circular, nevertheless each of its individual parts tends always to continue its motion along a straight line. And thus their action, i.e., the inclination they have to move, is different from their motion." (p. 71)

   a. In the margin statement of the law, he says that bodies moving "in a circle always tend to move away from the center of the circle"

   b. A source of subsequent confusion: are they trying to recede from the center?

2. This law complements the first one by specifying what a state of motion is

   a. Change of direction is a change of state, warranting a why-question

   b. No mention of no change of speed, but can take this for granted from the context

3. First argument for the law appeals to the immutability and simplicity of God

a. God maintains all things, and hence maintains the direction of motion at an instant, which is rectilinear motion

b. I find this argument question-begging, for why not curvilinear directions?

4. Second, empirical, argument is tantamount to a response to this complaint: as a matter of empirical fact, rectilinear

   a. Sling argument, with two claims: stone does not stay on circle, but tends (more) in direction of tangent; and can feel the endeavor of the rock to pull away from our hand

   b. This argument is also a little question-begging, though less so, for why can't the effects be attributed to encounters with other objects?

   c. In short, law again a proposed way of conceptualizing motion

5. Descartes' analysis of circular motion, as in the sling, is of critical importance since it undercuts the "naturalness" of circular motion proposed by Copernicus, Galileo, and even Kepler

   a. The tendency is to go off along a tangent

   b. Insertion in the French edition speaks of an "attempt to pull" that anticipates Huygens' centrifugal force

6. Descartes himself calls attention to the importance of the analysis of curvilinear motion

   "This consideration is of such importance, and will be so frequently used in what follows, that it must be very carefully noticed here"

   a. It sets the question for planetary astronomy: why curvilinear at all

   b. In contrast to, why some curvilinear path other than a circle

D. Comments on the Principle of “Inertia”

1. The first two laws together are often said to be the first statement of the principle of inertia -- i.e. of Newton's first law

   a. An anachronistic claim in some ways, for Descartes expressly rejected Kepler's concept of inertia (tendency to laziness), and Newton doesn't use the term in his statement of the law

   b. The proper claim, then, is more along the lines that Descartes is here capturing the essence of what became known as “the principle of inertia” in the 18th century

2. This essence consists of two distinct parts, one concerning no need for action to continue motion, and the other concerning the specific form of motion that will continue

   a. I.e. contrary to Aristotle, there is no need to invoke a cause to explain why motion continues, but only to explain why motion changes, for motion a state, and only have to explain changes of state; and uniform circular motion requires external cause and hence is not in and of itself eternal

   b. Thus, for example, Kepler's appeal to the Sun's driving the planets in continued motion is being rejected here

   c. I.e. a state of motion consists of a rectilinear direction and a speed

3. Where this principle was first enunciated is a subject of some controversy and confusion

a. *Le Monde*, except that it was not published, and Descartes appears not to have circulated it even within Mersenne's narrow circle

b. Galileo intimates the principle in some of his replies to arguments against the earth's motion in the *Dialogue*, and he offers what seems in retrospect to be an explicit version of it for horizontal motion in *Two New Sciences*; but he also seems to commit himself to a principle of continuing circular motion in the *Dialogue*

c. Gassendi announces the principle in published letter in 1641 (*De Motu impresso a motore translato*), in which he offers various experimental results bearing on Galilean claims (including objects falling from masts and circular arc versus inclined plane times)

"All that has no other aim than to make us understand that motion impressed [on a body] through void space where nothing either attracts or resists will be uniform, and perpetual; ... so that in whatever direction you throw a stone, if you suppose that, at the moment in which it leaves the hand, by divine power, everything besides this stone is reduced to nothing, it would result that the stone will continue its motion perpetually and in the same direction in which the hand has directed it" (translation from Franklin)

(1) A generalization of Galileo: uniform straight-line motion everywhere, not just on the horizontal

(2) Underlying rationale: nothing would disturb the motion of Gassendi's corpuscles (i.e. atoms) unless they were to contact some other corpuscles, and his corpuscles were moving in all directions

d. But elsewhere in the same work (see Appendix) Gassendi speaks of the perpetual continuation of uniform circular motion, seemingly missing the implication of inertia that Descartes stresses

e. *Principia Philosophiae*: the most influential statement of the principle prior to Huygens's *Horologium Oscillatorium* (1673), if not to Newton's *Principia*

4. Gassendi's *De Motu impresso a motore translato* was important for other reasons as well

   a. The principle we call Galileo's principle of relativity -- the motion of objects within the hull of a boat is the same whether the boat is stationary or moving forward uniformly -- was put forward in replying to anti-Copernican arguments in the *Dialogue*

   b. Gassendi announced in the letter that he had carried out experiments confirming it, such as dropping an object from the top of a mast with a boat moving and not moving

5. This is a ninth Galilean principle to be added to the eight from *Two New Sciences* of the last class

6. Gassendi, it should be noted, was far more skeptical than Descartes about our capacity to establish conclusions about unseen processes, mechanisms, and entities

   a. He viewed his corpuscularеanism as forever merely a hypothesis that could never achieve the same status as an observed matter of fact

   b. That view carried over in Locke's writings through Charlton and Boyle, both of whom were very much followers of Gassendi, though Boyle was no less influenced by Bacon

E. Some Issues with the Principle of Inertia

1. Complications, e.g. in the case of Descartes, because he is putting the principle forward in the context of a conceptual scheme that is in some respects at variance with Newton's
   a. Rest and motion are different kinds of state for Descartes, and not just different degrees of a single kind of state
   b. Descartes requires different forces to initiate motion from rest and to change motion
   c. Hence, in some ways a different concept of force involved
   d. And no notion of mass involved, only one of bulk (*moles* versus *massa* in Latin), while our modern notion of inertial motion, if not Newton's, has *mv* equal to a (vector) constant, and of course no distinction about rest versus motion is made in forces effecting changes of motion
2. The logical or epistemic status of the principle of inertia has been a long standing source of concern within philosophy of science
   a. It is scarcely an empirical generalization, from observations
   b. In making a claim about what happens in the absence of (unseen and unknown) external causes, it borders on a definition of what an external cause of motion is -- anything that impedes in such a way as to change speed or direction -- and hence of what a dynamic force is
   c. The principle itself includes no independent way to determine forces, and hence it is hard to find a way to test it in isolation from other claims
   d. Yet it seems empirical, even in Descartes, who appeals to the sling
3. Notice again, however, that whether it is empirical or not, it is first and foremost a proposed way of conceptualizing motion, with important implications for curvilinear motion!
4. My view now is that the principle of inertia was the end product of a several step reconceptualization of motion in which the Aristotelian way of conceptualizing it gradually gave way to a new way of conceptualizing it
   a. Several people, including Galileo and Gassendi, saw unimpeded motion as continuing, in contrast to Aristotle -- i.e. continuing motion requires no explanation
   b. Descartes was the first to emphasize that curvilinear motion has to be something other than unimpeded, which ends up being the most important feature historically
   c. Others, notably Huygens, adopted the principle in extending Galileo's theory of local motion
   d. Modern conceptualization fully clear only after Newton's *Principia*
   e. A gradual process in which no one person gets all the credit for putting it forward, but Descartes has claim to it more than anyone else because of his conclusions about curvilinear motion
5. Finally, let me emphasize once again that formulating and proposing the principle of inertia is one thing, providing compelling empirical evidence for it is entirely another
   a. Kuhn, for one, would question whether one can legitimately say that the Aristotelian conceptualization of motion was wrong and the modern one right

b. Rather, for him they represent two different ways of trying to make sense of the world

c. An important dimension of this course is to stay on the lookout for any subsequent developments that provide evidence for the principle of inertia

F. The Third Law of Motion

1. The statement of the law in *Principia* expands on that in *Le Monde*

"When a body meets another, if it has less force (*vim*) to continue to move in a straight line than the other has to resist it, it is turned aside in another direction, retaining its quantity of motion and changing only the direction of that motion. If, however, it has more force; [sic] it moves the other body with it, and loses as much of its motion as it gives to that other" (40)

Le Monde: When one of these bodies pushes another, it cannot give the other any motion except by losing as much of its own at the same time; nor can it take away from the other body's motion unless its own is increased by as much" (p. 65)

2. Notice what the problem is: how is total motion maintained when local motion changes ("*ubi corpus quod movetur alteri occurrit*")

a. Answer: it depends on, and only on, the local situation

b. Case 1: perfectly elastic reflection, with no change of either $B*v$; in this case the moving body never becomes one at rest (see Spinoza, for example in the Appendix)

c. Case 2: a transfer of motion, with $B*v$ changing in both

3. "Proof" of the first part: change in determination or direction alone does not produce a change in the motion of the body

a. Only changes in local motion have to be explained in order to explain how motion globally preserved

b. If local motion diminished, a compensating increase would have to show up somewhere else, which it doesn't

c. "Proof" here ignores question why both bodies don't change

4. "Proof" of the second part "theological": God maintains in the same way that he created motion, namely by causing "some of the parts to push others and to transfer their motion to these others" (42)

a. Hence follows from immutability of God

b. "Proof" here ignores question why some third body doesn't change, via action at a distance

5. Again notice that Descartes is offering us a way of conceptualizing change of motion, but now with an additional conceptual element, force (*vis*)

a. Either motion is preserved or transferred, with total remaining the same

b. In former, encounter shows up via change in direction, yielding answers to questions arising out of Law II

c. In latter, encounter shows up via transfer of motion from one to the other, yielding answers in response to other questions about change of state of motion

6. Empirical considerations are invoked in the discussion, but only to legitimate talk of unseen forces
    a. Law is not subject to empirical test as such, because it invokes unseen forces observable only through the consequences attributable to them by this law
    b. Hence, taken by itself, with no independent way of determining forces, a way of conceptualizing, and not any sort of empirical generalization

G. The Concept of a Law of Nature

1. Laws of nature a notion from Renaissance naturalism that makes its way into modern science primarily through Descartes' use of 'law' ('*lex*') here
    a. We did not see this term emphasized in Galileo or Kepler
    b. Newton almost certainly adopted it because of Descartes, whether directly or indirectly
    c. Then the term gained its general use in science from Newton's use
2. One feature of the Cartesian concept of a law: so-called natural necessity, supporting counterfactuals, for only God could alter
    a. I.e. "lawlike" in Goodman's sense
    b. This thread runs through all the uses of the term in modern science, and not just the narrower uses more typical of Descartes and Newton
3. Another feature of the Cartesian concept: laws hold universally of all matter, and have a certain bedrock character in the sense that all explanation of change of motion stops with them
    a. All matter conforms to these three laws at all times
    b. There is no possibility of deriving these three from more basic physical principles
    c. Contrast this with Galileo's derivation of the "law" of projectile motion, which explains this "law" by reducing it to more fundamental principles
    d. Explanation stops with these laws in the sense that the only proper sort of answer to the question why matter conforms to them is that this is the way God chose to create the world -- i.e. this is the way God legislated (the tie to Renaissance naturalism)
4. No such bedrock principles in Kepler or Galileo
    a. Galileo's basic claims -- e.g. uniform vertical acceleration near the surface of the earth -- were not put forward as applying to all matter at all times
    b. Nothing akin to these principles in Kepler at all, whose account of planetary motion does not invoke axioms of motion
    c. Descartes is the first place we have seen where the reasoning starts from such fundamental, universal principles
5. A natural question: why is this the first place we are seeing it; answer: Descartes is engaged in a different project from Kepler and Galileo
    a. Notice the title of Part II: "Of the Principles of Material Objects"
    b. Descartes laying out basic rules for all physical explanation, replacing Aristotle's four "causes,"

that is, his four different kinds of answers to “why” questions

6. The bedrock character of the laws raises a special problem that we have been noting in passing: how can one effectively test claims of this much generality
   a. Conceptualization: where explanation stops with brute descriptive fact -- i.e. with a way of describing what is happening
   b. How does one discover empirically where this is, for must describe e.g. motion before adducing any empirical considerations

V. Descartes' Rules of Perfectly Elastic Impact

A. Change of Motion and the Concept of Force

1. Descartes' rules of impact are standardly dismissed as crazy (as evidenced by the Millers' footnotes); still, however infamous they may be, they are historically important
   a. Even Descartes' defenders acknowledge how difficult the arguments for the rules are to follow, and they typically point out that the rules were added to the Latin edition at the last moment, then amplified in sometimes clumsy ways in the French
   b. I occasionally think of the criticism of Descartes here by historians and philosophers who should know better as a case of lesser minds taking comfort from others' mistakes
   c. It is not just that Descartes did not have the luxury of looking the correct answers up in a textbook, as the Millers can
   d. More, it is a matter of Descartes doing something different, which others have not elected to follow him on
2. The problem Descartes addresses is how to determine the force of resistance to motion which, once known, would allow change of motion to be determined via the rules

   In order to determine, from the preceding laws, how individual bodies increase or decrease their movements or turn aside in different directions because of encounters with other bodies; it is only necessary to calculate how much force (*virium*) to move or to resist movement there is in each body; and to accept as a certainty that the one which is stronger will always produce its effect.... This could easily be calculated if only two bodies were to come in contact, and if they were perfectly solid..." (45)

   a. The laws of motion themselves do not determine the outcome, for there are an infinity of before-to-after solutions to the equation, $(B_1 * v_1 + B_2 * v_2)_{before} = (B_1 * v_1 + B_2 * v_2)_{after}$ -- one equation in two unknowns not sufficient
   b. Worse, nothing said in laws about which force is greater, the force impressed on a body by another, or the force to resist
3. Descartes' picture is that of a contest between two forces, one impressed and the other resisting, with the greater dominating
   a. The force of rest -- to resist change from rest to motion -- is taken quite differently from the force to resist a change of motion

  b. The third law says that if the impressed force is greater than the force to resist, a change in motion occurs, with a loss in the impressing body's capacity to cause subsequent changes in motion
  c. Problem then is which force is greater -- indeed, how are we even to measure force
4. Quantity of motion [$\Delta(B*v)$] transferred from one body to another becomes a measure of the force effecting the motion, hence a measure of the amount the impressed force exceeded the force to resist
  a. $\Delta(B*v)$ is like Galileo's proposed measure of percussive force since what happens upon percussive impact is a complete loss of motion
  b. At least it is so long as B is taken to be quantity of matter here, so that neutral between Galileo's weight and Descartes' volume
5. A critical point, all too often ignored: forces themselves cannot be seen, but can only be inferred from change of motion, lack thereof, etc. -- indeed, even in the tradition of statics where the term was used in conjunction with balances and levers
  a. Descartes' problem is that he gives rules for inferring the unseen forces, but only under unobservable conditions
  b. He then gets criticized for not predicting what happens in the observable case -- something he is not even trying to do
6. In short, we need to keep two things separate here: the problem as Descartes poses and solves it and the problem posed and solved by others
  a. The historical significance of Descartes' rules of impact does not lie in his failure to solve a problem posed and solved by others after him
  b. Rather, it lies in the fact that his rules forced others to think through the principles of impact

B. The Rules for Change of Motion After Impact
1. The reasoning behind the first three rules is comparatively transparent
  a. Rule 1: equal bodies at equal speed recoil, with reason given only in French edition -- absence of cause to change motion
  b. Rule 2: if one slightly larger, then both move off at same speed in direction of the larger, for it wins the contest
  c. Rule 3: if same size, but one slightly faster, then it wins the contest, transferring the minimum amount of speed to the other needed to end the contest
2. The next three rules concern what happens when one of the two bodies is at rest
  a. Rule 4: if larger at rest, then never moved regardless of speed of smaller, for the force of resisting motion in a body at rest "increases in proportion to the difference in speeds"
    (1) Which it would if this force is equal to the amount of change of speed involved in raising the at-rest object to the speed of the approaching one

(2) Descartes here speaks of "the resistance to receiving twenty degrees of speed"

b. Rule 5: if smaller at rest, then it loses the contest, with the minimum amount of speed transferred to it as needed to end the contest

c. Rule 6: if same size, then a compromise between the preceding two rules: "the two effects must be equally shared"

3. Finally, Rule 7 generalizes Rules 4, 5, and 6 to the case of objects moving in the same direction, but at different speeds

   a. Contest again, but this time between B_1*v_1 and B_2*v_2; the object with the greater motion wins, where v designates (scalar) speed, not (vectorial) velocity

   b. When impacting body smaller, it recoils, with no change in speed of impacted

4. In a subsequent letter to Clerselier, Descartes enunciates a principle underlying these rules (see Appendix)

   a. A principle of least modal mutation, which together with that of conservation of total motion yields a unique solution

   b. Spinoza states this principle outrightly (Proposition xxiii)

   c. Trouble is that Rule 6 does not conform to this, but instead to a principle of the mean

5. Thus, whether Descartes himself had clear principles underlying the rules is a matter of some controversy, and we can say with some confidence that if he did, they do not appear in print

   a. (Gabbey develops this point at length: pp. 247- 272)

   b. However important it is to understanding Descartes, its main importance historically is that it invites others to reconceptualize the problem here, since they have trouble understanding Descartes' conceptualization

   c. Spinoza's account instructive, for intended to be sympathetic to Descartes (Props. xxiv- xxxvii, as in Appendix)

C. Empirical Problems: Descartes' Defense

1. As Descartes openly acknowledges, "experience often seems to contradict the rules" (53)

   "However, because there cannot be any bodies in the world which are thus separated from all others, and because we seldom encounter bodies which are perfectly solid; it is very difficult to perform the calculation to determine to what extent the movement of each body may be changed by collision with others. Since, {before we can judge whether these rules are observed here or not,} we must simultaneously calculate the effects of all those bodies which surround the bodies in question and which affect their motion"

2. In effect, then, Descartes' reply to the obvious line of empirical objection is that the rules are idealizations

   a. No effects from surrounding medium and perfect elasticity

   b. Rules address encounters between two bodies at a time; in real world many bodies involved in all encounters

3. The surrounding medium can make it possible for a body to be put into motion with very little force
   a. For a small B∗v can augment the large sum B∗v of all the fluid particles impacting an object on one side, thereby overcoming its force to remain at rest (for total bulk of impacting particles will exceed its bulk, bringing Rule 5 into play)
   b. {Descartes will not be the last person who struggles with understanding fluid resistance; the mechanism remained a problem in physics until around 1900!
   c. Descartes himself says that a science of resistance is impossible -- see letter to Mersenne, 13 Nov 1629

      As for the cause of the air resistance, ..., in my view it is impossible to answer this question since it does not come under the heading of knowledge. For the air resistance varies, depending on whether it is hot or cold, dry or wet, clear or cloudy, and numerous other factors. Moreover the same can be said about all the questions you raise about air resistance: the degree of resistance varies depending on whether the weight is made of lead or iron or wood, on whether it is round or square or some other shape, and numerous other factors.}
4. Problem: how can one confirm the rules empirically, for motion of the fluid particles is not directly observable?
   a. I.e. the rules are empirically unfalsifiable
   b. Final sentence in the French text to Article 52:

      "The demonstrations of this are so certain that, even if experience were to appear to show us the opposite, we would nevertheless be obliged to place more trust in our reason than in our senses"
   c. In effect, a claim about no plausible alternative for conceptualizing change of motion under impact, and hence a challenge to others
5. The Rules are not entirely immune to empirical considerations, for they underlie the celestial vortex theory
   a. A possible source of empirical support: the success of the theory based on them to explain celestial phenomena
   b. But this not a defense against internal inconsistency (if this is a legitimate complaint), nor against the claim that there are still better ways of conceptualizing motion under impact
6. The important thing to realize is that what is at issue here is how we are to conceptualize the causal interaction of impacting bodies, and as is so typical of all issues about fundamental conceptualization, it is hard to bring empirical considerations directly to bear
   a. Empirical considerations presuppose a way of describing what is happening, and hence a conceptualization
   b. I.e., just as Kuhn says, empirical considerations are not conceptualization-neutral

D. Relativity of Motion: "Internal" Problems

1. Some have argued that Descartes' Rules are incoherent within his own philosophical system insofar as they violate the relativity of motion principle which he announces in Articles 24 and 25

    a. Idea of relativity of motion -- e.g. as expressed by Galileo -- is that descriptions before and after should be equivalent to one another regardless of which is at rest and which is moving
    b. Regardless of which object observer is on and whether observer can tell whether that object is in motion
2. Descartes' Rules 4, 5, and 6 violate this principle
    a. If sitting on larger body, taken to be at rest, then get a different result for relative motion after than sitting on smaller body, taken to be at rest
    b. Equally so if sitting on a third body which has the same overall motion as one of the other two
3. This line of "internal" criticism of the Cartesian system carried some weight in subsequent years, but it really does seem to be missing Descartes' point
    a. He is perfectly prepared to concede that not all motion is relative from a metaphysical stand-point, for forces of resistance distinguish between bodies at rest and bodies in motion
    b. Motion considered geometrically is only relative; forces are not geometric, but metaphysical
4. As various commentators have pointed out (Gueroult and Gabbey among others), there are two "levels" in Part II, with the first half devoted to a geometric characterization and the second half to a deeper metaphysical one
    a. Forces ultimately determine true, absolute situation, so that can distinguish between bodies at absolute rest and bodies in absolute motion on Descartes' view
    b. Puts him into a position to reject the Tychonic system, as he had in *Le Monde*
    c. (And here anticipating Newton's argument, whether Newton recognized this or not)
5. Last Article of Part II not really a denial of this, for not claiming there that motion as conceived geometrically will suffice to account for all phenomena
6. Questions about relativity of motion, the principle of relativity, and what motions can be distinguished will continue to be of concern as we proceed
    a. Descartes may be subject to criticism here, but the criticism should not be one of flagrant inconsistency
    b. Rather it will have to take the form of claiming that there is (in some sense) a better way to conceptualize motion and its change

E. Descartes on "True" Motion
1. As just noted, early in Part II Descartes introduces a distinction between "motion in the ordinary sense" and "motion properly speaking" that seems to assert the relativity of motion
    a. Article 24: local motion "as commonly interpreted is nothing other than *the action by which some body travels from one place to another*"
    b. Article 25: "what should be understood by movement, according to the truth of the matter…, is *the transference of one part of matter or of one body, from the vicinity of those bodies immediately contiguous to it and considered as at rest, into the vicinity of others*"

2. Notice, however, that the latter asserts something stronger than just that true motion has to be referred to some other body "considered as at rest"
   a. Rather, true motion has to be referred to bodies "immediately contiguous" that are considered at rest and has to consist in no longer being immediately contiguous to those bodies
   b. By contrast, in *Le Monde* contains nothing like this, but only an insistence, contra Aristotle, on limiting talk of motion to cases of change of place:

      The philosophers also suppose several motions that they think can be accomplished without any body's changing place, such as those they call *motus ad formam*, *motus ad calorem, motus ad quantitatem* ("motion with respect to form," "motion with respect to heat," "motion with respect to quantity"), and myriad others. As for me, I conceive of none except that which is easier to conceive of than the lines of mathematicians: the motion by which bodies pass from one place to another and successively occupy all the spaces in between [p. 63]

3. Descartes' new, restrictive notion of true motion shows up again, though seemingly only in passing, at the end of Part II, while discussing the transport of a body by a moving fluid stream
   a. The specific context involves explicating the difference between solid and fluid bodies initiated in Article 54
   b. Following which the principal concern seems to be the transfer of motion between fluids and bodies immersed in them (Articles 56-60) in relation to the Rules -- a topic not raised at all in Galileo's *Two New Sciences*
4. One upshot of this discussion is the seemingly innocuous conclusion reached in Article 61:
   a. *That when an entire fluid body moves simultaneously in some direction, it must necessarily carry along with it any solid body which is immersed in it* -- a conclusion that is asserted to be consistent with Rule 4
   b. An obvious reason for Descartes' including this is to prepare the way for his vortex theory of planetary motion in Part III
5. The very next Article makes an assertion that is not innocuous at all, but on its surface rather extraordinary: *That a solid body, which is carried along by a fluid, is not therefore moving*

   If, moreover, we turn our attention to the true and absolute nature of movement; which consists in the transfer of a moving body from the vicinity of other bodies contiguous to it, and which is equal in both the body which is said to move and the contiguous body away from which [it is said that] it moves, although it is not customary to speak of the two in the same way {and to say that both move}; we will clearly know that a solid body which is thus carried along by the fluid in which it is contained does not, strictly speaking, move as much as it would if it were not carried along by this fluid; for it certainly moves away less from the neighboring particles of this fluid {when it follows its current than when it resists it}.

   a. This conclusion represents something much stronger than just the need to refer all motion to some body considered at rest
   b. For it says that a body carried by a fluid is strictly speaking not moving at all no matter how much it and the fluid surrounding it are moving relative to other bodies considered at rest

6. We shall be returning to this conclusion next week and again when we turn to Newton, who took strong exception to it, in the process initiating his famous discussions of absolute space, time, and motion

Select Sources

Descartes, René, *Le Monde ou Le Traité de la lumière* (1664) facing pages tr. Michael Sean Mahoney, Abaris Books, 1979.

--------, *Traité de l'homme* (1664), French text with Translation and Commentary by Thomas Steele Hall, Harvard University Press, 1972.

--------, *Discourse on Method, Optics, Geometry, and Meteorology*, tr. Paul J. Olscamp, revised ed., Hackett Publishing, 2001.

--------, *La Géometrie*, facing pages tr. David Eugene Smith and Marcia L. Latham, Open Court, 1952.

--------, *Geometria*, Latin tr. with commentary by F. van Schooten, 2nd ed., Amsterdam, 1659.

--------, *Principles of Philosophy*, tr. Valentine Rodger Millar and Reese P. Miller, Reidel, 1983/84.

--------, *Principia Philosophiae*, Elzevier (1644, 1650, 1656, 1664, 1672, 1677); vol. X in *Oeuvres de Descartes*, ed. Charles Adams and Paul Tannery, 2nd ed, Paris, 1974-1986.

--------, *The Search for Truth*, in *The Philosophical Writings of Descartes*, Col. II, tr. John Cottingham, Robert Stoothoff, and Dugald Murdoch, Vol. II, Cambridge University Press, 1984, pp. 399-420.

--------, *The Correspondence*, in *The Philosophical Writings of Descartes* , Vol. III, tr. Cottingham, Robert Stoothoff, Dugald Murdoch, and Anthony Kenny, Cambridge University Press, 1991.

--------, *Epistolae*, Latin tr. Johannes de Raei, 2 vols., Elzevir, 1668.

Spinoza, Baruch, *Principles of the Philosophy of René Descartes* (1663), in *Earlier Philosophical Writings*, tr. Frank A. Hayes, Bobbs-Merrill, 1963, pp. 13-103.

Gaukroger, Stephen, *Descartes: An Intellectual Biography*, Clarendon Press, 1995.

--------, "The Autonomy of Natural Philosophy: From Truth to Impartiality," in *The Science of Nature in the Seventeenth Century*, ed. Peter R. Antsey and John A. Schuster, Springer, 2005, pp. 131-163.

--------, "The foundational role of hydrostatics and statics in Descartes' natural philosophy," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 60-80.

Garber, Daniel, *Descartes' Metaphysical Physics*, University of Chicago Press, 1992.

--------, "Descartes' Physics," in *The Cambridge Companion to Descartes*, ed. John Cottingham, Cambridge University Press, 1992, pp. 286-334.

--------, "Descartes and Experiment in the *Discourse* and *Essays*," in *Essays on the Philosophy and Science of René Descartes*, ed. Stephen Voss, Oxford University Press, 1993, pp. 288-310.

--------, "A different Descartes: Descartes and the programme for a mathematical physics in his correspondence," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 113-130.

Gabbey, Alan, "Force and Inertia in seventeenth century dynamics," *Studies in History and Philosophy of Science*, vol. 2, 1971, pp. 1-67.

--------, "Force and Inertia in the Seventeenth Century: Descartes and Newton," in *Descartes: Philosophy, Mathematics, and Physics*, ed. Stephen Gaukroger, The Harvester Press, 1980, pp. 230-320.

--------, "Descartes's Physics and Descartes's Mechanics: Chicken and Egg?," in *Essays on the Philosophy and Science of René Descartes*, ed. Stephen Voss, Oxford University Press, 1993, pp. 311-323.

Gueroult, Martial, "The Metaphysics and Physics of Force in Descartes" in *Descartes: Philosophy, Mathematics, and Physics*, ed. Stephen Gaukroger, The Harvester Press, 1980, pp. 196-229.

Clarke, D. M., *Occult Powers and Hypotheses*, Oxford University Press, 1989.

--------, "Causal powers and occasionalism from Descartes to Malebranche," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 131-148.

Schuster, John A., "'Waterworld': Descartes' Vortical Celestial Mechanics – A Gambit in the Natural Philosophical Contest of the Early Seventeenth Century," in *The Science of Nature in the Seventeenth Century*, ed. Peter R. Antsey and John A. Schuster, Springer, 2005, pp. 35-79.

--------, "Descartes' *opticien*: the construction of the law of refraction and the manufacture of its physical rationales, 1618-1629," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 258-312.

Bos, Henk J. M., *Redefining Geometrical Exactness: Descartes' Transformation of the Early Modern Concept of Construction*, Springer, 2001.

Dear, Peter, "Circular Argument: Descartes' Vortices and their Crafting as an Explanation of Gravity," in *The Science of Nature in the Seventeenth Century*, ed. Peter R. Antsey and John A. Schuster, Springer, 2005, pp. 81-97.

--------, *Mersenne and the Learning of the Schools*, Cornell University Press, 1988.

Hattab, Helen, "From Mechanics to Mechanism: The *Quaestiones Mechanicae* and Descartes' Physics," in *The Science of Nature in the Seventeenth Century*, ed. Peter R. Antsey and John A. Schuster, Springer, 2005, pp. 99-129.

McLaughlin, Peter, "Force, Determination, and Impact," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 81-112.

Ranea, Alberto Guillermo, "A 'science for *honnêtes hommes'*: *La Recherche de la Vérité* and the deconstruction of experimental knowledge," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 313-329.

McClaughlin, Trevor, "Descartes, experiments, and a first generation Cartesian, Jacques Rohault," in *Descartes' Natural Philosophy*, ed. Stephen Gaukroger, John Schuster, and John Sutton, Routledge, 2000, pp. 330-346.

Gassendi, Pierre, *De motu impresso a motore translato, epistolae duae*, Paris, 1642, (available on-line through ECHO).

Charlton, Walter, *Physiologia Epicuro-Gassendo-Charletoniana: or, A fabrick of science natural, upon the hypothesis of atoms, founded by Epicurus, repaired by Gassundus, augmented by Walter Charleton, Dr. in medicine, and physician to the late Charles, Monarch of Great Britain*, London, 1654.

Lolordo, Antonia, *Pierre Gassendi and the Birth of Early Modern Philosophy*, Cambridge University Press, 2007.

Osler, Margaret J. (ed.), *Atoms*, Pneuma, *and Tranquility: Epicurean and Stoic Themes in European Thought*, Cambridge University Press, 1991.

Dugas, René, *Mechanics in the Seventeenth Century Century (from the Scholastic Antecedents to Classical Thought)*, tr. Freda Jacquot, Central Book Company, 1958.

Damerov, V., Freudenthal, G., McLaughlin, P., and Renn, J., *Exploring the Limits of Preclassical Mechanics: A Study of Conceptual Developments in Early Modern Science: Free Fall and Compounded Motion in the Work of Descartes, Galileo, and Beeckman*, Springer-Verlag, 1992.

Franklin, Allan, *The Principle of Inertia in the Middle Ages*, Colorado Associated University Press, 1976.

Pav, Peter Anton, "Gassendi's Statement of the Principle of Inertia," *Isis*, vol. 57, 1966, pp. 24-34.

Aiton, Eric, *The Vortex Theory of Planetary Motions*, Elsevier, 1972.

Westfall, Richard S., *The Construction of Modern Science*, Cambridge University Press, 1977.

Middleton, W. E. Knowles, *The History of the Barometer*, Johns Hopkins Press, 1964.

Blair, Ann, *The Theater of Nature: Jean Bodin and Renaissance Science*, Princeton University Press, 1997.

Zilsel, Edgar, "The Genesis of the Concept of Physical Law," *The Philosophical Review*, vol. 51, 1942, pp. 245-279.

<u>Credits for Appendix</u>

Slides 4-6: Gaukroger (1995)

Slides 7-9, 21: Descartes (2001)

Slides 10, 11: Descartes (1952)

Slides 12, 14-17: Descartes (1974-1986)

Slide 19: Westfall (1977)

Slides 22-24, 26, 29, 35, 38, 39, 41: Descartes (1983/84)

Slides 27, 28, 34: Descartes (1983/84, 1979)

Slides 25, 37: Spinoza (1963)

Slide 30: Franklin (1976)

Slide 31: Charleton (1654)

Slide 32: Dugas (1958)

Slide 36: Aiton (1972)

Slide 40: Descartes (1979)