The Rise of Classicality

The Clockwork Universe

Centuries before the achievements of Newton and his successors allowed deterministic celestial motions to be predicted and understood in the sense of modern science, the clockwork analogy appeared in works on astronomy, from the late medieval period of Robert Grosseteste (1175-1253) and Nicole Oresme (1325-82) up to Nicholas Copernicus' (1473-1543) epic work of the heliocentric theory, *De revolutionibus.* In the 17th century, the view of a clockwork universe was articulated by René Descartes (1596-1650), Johannes Kepler (1571-1630), and Robert Boyle (1627-1691) in which all evolutions must be cyclic but with orbits initially arranged by a designer. Johannes Kepler (1571-1630) wrote in 1605 that his aim is (Letter to Herwart von Hohenburg, February 10, 1605)

> *to show that the heavenly machine is not a kind of divine, live being, but a kind of clockwork…insofar as nearly all the manifold motions are caused by a most simple, magnetic and material force…*

In Kepler's case, the orbits took the form of a nested arrangement of Platonic solids. The most popular world model in the 17th and 18th centuries was the clockwork universe proposed by Boyle, comparing it to a real clock in Strasbourg Cathedral. The presence of a creator's role in the universe's clockwork continued with Newton, whose General Scholium of the *Principia Mathematica* comments on the designer of this system whose operations it was Newton's honor to give a detailed mathematical description. Newton states in the *Principia*:

> *This most elegant system of the sun, planets, and comets could only proceed from the counsel and dominion of an intelligent and powerful being.*

The prevalent view of an all-embracing deterministic explanation of celestial and terrestrial phenomena based on Newton's achievements eventually emerged, however Newton's writings raised additional issues not associated with what later became accepted as *Newtonian Mechanics*. Though mechanical cause and effect eventually became the business of Newtonian science, the issue of a first cause still remained for Newton himself. In Query 28 of his *Opticks*, Newton maintained [321]:

> *…the main Business of Natural Philosophy is to argue from Phenomena without feigning Hypotheses, and to deduce Causes from Effects, till we come to the very first Cause, which certainly is not mechanical.*

In Newton's *Opticks,* he comments on his two roles for God in the universe, that of creating and sustaining. He argued that only divine intervention could explain why the mutual gravitational attraction of the planets does not destabilize the solar system. In Book III of the *Opticks*, Newton expressed the view that the solar system is unstable and requires intermittent adjustment, to which Leibniz criticized Newton that if God had to intervene in the creation, this would surely demean His craftsmanship [322, p. 147]. By the late 20th century, this issue had been related to deterministically chaotic properties of the solar system with the result that it cannot be predicted beyond about 5 million years [304, p. 245].

Newton had created a theory that produced many features of the solar system such as Kepler's geometrical properties of planetary orbits as a result of the universal law of gravitation. However, Newton noticed that other observed features of the solar system were apparently outside of his system. For example, the planets all rotate in a counterclockwise direction around the sun and the planes of the orbits are nearly coincident. Given such configurations of the planets, their future course could be determined, but why these configurations? This led to considering whether such features were a result of chance or else evidence of design in the world. In Query 31 of the *Opticks*, Newton contrasted the choice versus chance issue regarding motions of planets that orbit the sun in the same direction and nearly identical plane with those of comets whose orbits were at every possible angle to ecliptic plane of the planets:

> *For while Comets move in very excentrick Orbs in all manner of Positions, blind Fate could never make all the Planets move on and the same way in Orbs concentrick, some inconsiderable Irregularities excepted, which may have arisen from the mutuall Action of Comets and Planets upon one another, and which will be apt increase, till this System want a Reformation. Such a wonderful Uniformity in the Planetary System must be allowed the Effect of Choice.*

Although Newton did not make probabilistic arguments in the *Principia*, his attitude in the *Opticks* and in private correspondence was that even if we cannot discover a mechanism for the unexplained regularities, we could be assured that there is such a mechanism [323, p. 273]. After Newton's death, a number of scientists attempted to justify the orientations of the orbits based on probabilistic arguments, including Daniel Bernoulli (1700-1782), Georges Buffon (1707-1788), and Pierre Laplace (1749-1827). Explanations of these issues would eventually require the new concept of angular momentum conservation, which preserves the rotational direction of an initial gas cloud as well as the effects of inelastic collisions that provide a mechanism by which the gas cloud can settle to a state that minimizes mechanical energy while conserving angular momentum. That minimal energy configuration is a flattened disc. As a result of high-resolution astronomy and numerical computations, stars are now believed to form within clouds of gas and dust that collapse under gravity. Over time, the surrounding dust particles stick together, growing into larger rocks, which eventually settle into a thin proto-planetary disk where asteroids, comets, and planets form. Once these planetary bodies acquire enough mass, they dramatically reshape the structure of the original disk, forming rings and gaps as the planets sweep their orbits clear of debris and guide dust and gas into tighter and more confined zones.

This type of understanding can be extended to the scale of galaxies though details from atomic and nuclear physics must be included to fill in all the details and has been made possible only with advances in computer power and computational algorithms. The complexity on this scale now increases, galaxies comprising radiation, normal matter as well as the more recently recognized *dark matter,* which is nonluminous and interacts essentially only via gravitation. The universe is thought to have rapidly expanded during an early *inflationary* era after the Big Bang leading to the growth of tiny fluctuations in the density of matter. Denser regions become gravitationally bound capturing both normal and dark matter. These gases become cooled by the emission of photons resulting from the interactions between electrons, hydrogen, and helium. A galactic disc is thereby formed as the rotating gas contracts and denser regions continue to accumulate matter. Then, occasionally, stars are born as nuclear fusion ignites a clump that is sufficiently dense and massive. After forming a sufficient number of stars, gases become expelled from the galaxies in the form of *superwinds*, leading to a competition between gravitation pulling gases together and violent supernova explosions breaking it apart, enabling galactic formation to be now understood over the entire scale of cosmic time [324] [325].