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<u>'The Swerve' and Probabilism: Parallels in Philosophical and Scientific Thought</u>

Over 20 centuries after the Stoics rejected the Epicurean atomic swerve, quantum physicists grappled with the probabilistic theories of quantum mechanics. This paper aims to identify some parallels between the two events. The first section contextualizes Epicurus atomism and the Stoic rejection of the swerve in the Greek context, while the second traces the transition from classical mechanics to quantum mechanics and the subsequent rejection of probabilism. Finally, the last section discusses the similarities and implications of the comparison. Notably, the Stoic rejection of the Epicurean swerve and the modern rejection of quantum probabilism share several characteristics, particularly regarding the nature of determinism and the role of indeterminacy in the universe.

Greek Context: Democritus, The Swerve, and the Stoics

Atomists like Democritus (b. 460 BCE) described the world as made up of two fundamental components: atoms and void—with atoms as the indivisible component that move within the infinite and nothingness of the void (Berryman). As these 'indivisible' atoms move around in the void, they repel and combine, creating our world as we see it. Although we, and everything we see, is impermanent and the result of atoms clustering into forms referred to as *kosmoi*, atoms are indivisible and act according to fixed laws of nature. Democritus argued that the universe, at its core, was "being," unchanging, essentially deterministic, and governed by fixed laws. This deterministic understanding of the universe had serious implications for the Greek metaphysical understanding of human morality.

Epicurus (b. 341 BCE) also held that atoms and void were the two fundamental components of the universe. In *Letter to Herodotus*, Epicurus describes how atoms of varying shape, weight, and size continually collide with other atoms to form the compound bodies we see and the world of 'becoming' that we perceive (Diogenes §54). In this way, he agreed with Democritus that bodies and our world as we see it are compound structures of atoms in void. However, Epicurus refused to accept that atomism necessitated a deterministic conception of the universe. He sought to "modif[]y and thus preserv[e] atomism" by "saving it from the errors of Democritus" (Hanson 28). If our world were deterministic due to atoms moving in void according to fixed laws of nature, human beings would lack autonomy and responsibility over their actions. Enter: 'The Swerve' or the clinamen. Epicurus proposed that, occasionally and unpredictably, atoms deviate from the 'fixed' laws of nature. He describes how "atoms move continuously for all time, some of them falling down, others swerving, and others recoiling from their collisions" (Epicurus [7]). Epicurus' system disrupted Democritus' determinism by introducing the idea that atoms swerve as a precursor to their collisions and the formation of compound bodies. The element of randomness preserved human freedom and moral responsibility.

Meanwhile, the Stoics rejected the randomness and uncertainty of the Epicurean swerve by claiming it was "unnecessary" (O'Keefe). Within their metaphysics, you can still "effectively and rationally deliberate what to do, even if the outcome of [your] deliberation and the actions that result from it are both causally determined" (O'Keefe). Essentially, causal determination is *not* incompatible with human freedom (O'Keefe). Although they differed in their forms of determinism—with Democritus subscribing to atomistic and causal determinism and the Stoics subscribing to compatibilist determinism, the Stoic rejection of the Epicurean swerve argued for a return to an ultimately deterministic worldview. This response to the randomness of Epicurus' system provides a structure for understanding the widespread rejection of probabilism in quantum mechanics.

Probabilism: Classical Mechanics to Quantum Mechanics

Classical mechanics is a branch of physics that explains the behavior and movement of physical objects larger than atoms and molecules, including in the astronomical realm. On this non-atomic scale, one can predict the behavior of observed phenomena or an experiment. Newtonian mechanics, the foundation of classical mechanics, explains the motions of everyday objects and celestial bodies through the laws of motion and universal gravitation. If we view these laws of motion and gravity as fixed laws, classical mechanics takes on a similar kind of determinism as Democritus' system above. Although Newton and Galileo—two giants of classical mechanics—recognized that classical mechanics does not hold in all physical situations, they could not observe, measure, or experiment with the very small (Greenberg).

It wasn't until the early 20th century that the development of quantum mechanics truly challenged this determinism of classical mechanics (although Boltzmann's interpretation of entropy as statistical in 1890 challenged it somewhat). In 1900, Max Planck proposed the quantization of energy or the idea that energy exists in discrete "quanta" as a response to the problem of ultraviolet catastrophe (Fowler). By theorizing energy as quantized, Planck's experiments directly challenged the classical understanding of electromagnetic waves as continuous (Kragh). Energy quantized according to particular spectral distributions, which introduced considerations of probabilities (Kragh). Although Planck did not say the universe was, at its foundations, probabilistic, his theory laid the foundation for quantum mechanics and its probabilistic theory.

Einstein, de Broglie, Bohr, Heisenberg, and Schrödinger continued from Planck's quantization hypothesis. In 1905, Albert Einstein proposed his Nobel-Prize-winning hypothesis that light is quantized into particles called photons, which introduced a degree of probabilism as the emission of an electron could not be predicted with absolute certainty. In 1924, Louis de Broglie hypothesized that electrons exhibit wave-like and particle-like properties and that the behavior of particles is inherently uncertain. Also in the 1920s, under the name of The Copenhagen Interpretation, Werner Heisenberg posited his *uncertainty principle* that described how "explaining and classifying has become conscious of its limitations, which arise out of the fact that by its intervention, science alters and refashions the object of investigation" (Sleator). Similarly, Bohr's *principle of complementarity* led to the "realization that particle and wave behavior are mutually exclusive, yet that both are necessary for a complete description of all phenomena" (Sleator). These experiments on the subatomic level and the accompanying hypotheses regarding the physics of the very small, introduced and embraced a degree of probabilism and randomness into our conception of the universe.

While Bohr and Heisenberg embraced probabilism, many 20th-century quantum physicists did not. Among the list above, Einstein, de Broglie, and Schrödinger refused to accept the absolute probabilism of quantum mechanics. Einstein's famous quote, "God does not play dice with the universe," describes his belief that some underlying variables must determine the outcomes of quantum events; it could not simply be probabilistic (Baggott). This attitude towards probabilism, the uncertainty, and the randomness of the universe, shares characteristics with the Stoic rejection of the Epicurean swerve.

Rejection of The Swerve and Quantum Probabilism

Both Epicurus' swerve and quantum probabilism introduce randomness into the universe. While the Stoic rejection of the swerve arises from a different context and motivations than the 20th-century physicists' rejection of probabilism, both groups share a joint discomfort with that indeterminacy and randomness. The philosophical commitment to a rationally ordered cosmos drives the Stoic rejection of the swerve, while the scientific aspirations of a complete and determinist theory of physical reality drive the rejection of quantum probabilism. The swerve and probabilism prompt the question: what is randomness? A comparison between classical and quantum definitions of randomness may highlight another similarity between the Stoic rejection of randomness and the modern physicists' rejection of probabilism. Classical randomness refers to random events due to insufficient information—essentially, the unknowns. Quantum randomness, however, represents truly random events—the unknowables—which violate determinism. In a way, Epicurus' swerve represents an early type of *quantum* randomness. Lucretius (b. 99 BCE), a disciple of Epicurus, described the "infinitesimal degree" of these random swerves (Evangelidis 6). This very slight nature of the swerve and the description of atoms as perpetually in motion create an image of the uncertain nature of vibrating atoms (Evangelidis). Similarly, Heisenberg's uncertainty principle indicated that quantum particles are constantly in motion—vibrating, one might say. The Greek and modern acceptances of the randomness inherent in quantum-level vibration represent a breathtaking recognition of the limits of human knowledge. In an increasingly complex world, we should aim to carry this sense of humility and openness into our scientific and intellectual pursuits.

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