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A NEW PERSPECTIVE BY K. STRANG

Uncertainty and Heisenberg

Cause and effect

Heisenberg was certain that his Uncertainty Principle (UP) would mark him out as the driving force behind the discontinuous particle interpretation of quantum mechanics. David C. Cassidy in his essay *Heisenberg and the Quantum Revolution* [Science and Society, Routledge, 2001] gives an account of how the UP upset the accepted mechanical view of cause and effect.

‘For the young Heisenberg, the uncertainty principle constituted the culmination and completion of the quantum revolution, a revolution that incorporated his commitments to foundations that he himself had helped to lay. And, as if to silence any objection to this point of view, he concluded his published paper with several claims that went far beyond mathematics and thought experiment. With the Dirac-Jordan transformation theory, he declared, the quantum formalism is complete and unalterable; the uncertainty relations are true and irrefutable, because they are a direct consequence of the formalism. All previous and future experimental observations of atomic phenomena are thus subsumed under this interpretation. Moreover, he argued, although quantum physics contains a basic statistical element, that element is not a property of nature itself. It enters because of the disturbance caused by the physicist’s attempt to observe nature. Finally, he presented his first explicit statement on a most profound consequence of uncertainty—a challenge to causality. The causality principle requires that every effect be preceded by a unique cause. This idea had served for over a century as a basic assumption of practically every form of rational research. The French mathematician Laplace is credited with perhaps the simplest definition of causality as applied to Newtonian mechanics: if the position and momentum of a particle are accurately known

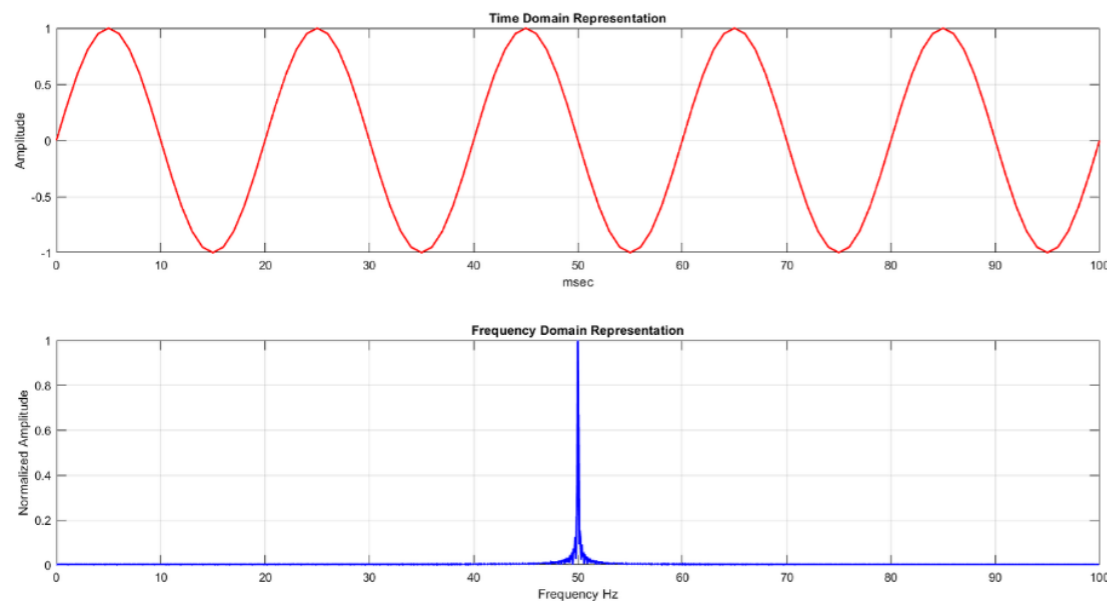
at a given moment, then, with a knowledge of all the forces acting on the particle, its motion is fully determined by the mechanical equations for all future time. The uncertainty principle, Heisenberg asserted, denies this: “In the strict formulation of the causal law—if we know the present, we can calculate the future—it is not the conclusion that is wrong but the premise.” The initial values of the momentum and position cannot be measured simultaneously with absolute precision. As such, one can calculate only a range of possibilities for the position and momentum of the particle at any future time. Only one possibility will result from the actual motion of the particle. The causal connection between present and future is lost, and the laws and predictions of quantum mechanics become merely probabilistic, or statistical, in nature.

To my mind, this does not herald in a brave new world. In classical mechanics, in order to calculate the momentum (mass times velocity) of a classical object, such as a car, *two* positions are needed, and the time taken to move from one to the other or the distance between the two positions. It is quite impossible to determine the momentum from one position alone. Equally the converse is true: if a car is travelling at a known momentum along a road, its position will constantly change. It does not prevent the physicist from making predictions as to the position, given a constant speed and direction. The prediction cannot be absolutely certain because the car could break down. In addition, classical physics can involve estimates with a tolerable level of inaccuracy, by rounding numbers up etc

There are two further arguments supporting the UP: (i) that in the very process of taking the measurement (i.e., shining a laser on the electron) the scientist alters the position or momentum of the electron; and (ii) that the uncertainty can be adduced mathematically by the Fourier transform noted in Figures (a) and (b) below. Both these arguments fail because their premise is that the object of study is a particle rather than a standing wave.

The Fourier transform is claimed to underpin the UP. If a function is a basic sine wave as in Figure (a) then the Fourier transform looks like Figure (b). The sine wave in Figure (a) is infinitely wide while the vertical line in Figure (b) is infinitely narrow. Therefore, if the wave function for a particle's position is wide, the momentum will be its Fourier transform which is narrow. This indicates that increased knowledge of the former results in decreased knowledge of the latter.

Figures (a) and (b)



If one considers the wave version of quantum mechanics, as opposed to the particle version, one is no longer dealing with position and momentum but frequency. The most natural interpretation of two images above is a description of a change in frequency which I believe was the original intention of mathematician and physicist, Joseph Fourier (1768–1830).

Bohr's Criticism

Bohr's criticism of Heisenberg's 1927 paper in stressing the particle view as the only possible one, and ignoring Bohr's complementarity principle which stressed the equal validity of the wave interpretation, caused a meltdown:

'Heisenberg vehemently disagreed. Insisting on the primary use of particles and discontinuity, he absolutely refused Bohr's suggestion that he withdraw his paper, which he had in the meantime sent to press. Heisenberg could not tolerate extensive

use of waves or of wave-mechanical notions, nor could he fail to publish his own major contribution to the interpretation debate. The subsequent battle with Bohr grew so intense that Werner reportedly burst into tears during one meeting and even managed to wound the usually unflappable Bohr with some sharp remarks. [ibid]

Unfortunately Bohr's equivocation on the particle-wave debate, muddied the waters further, not only in physics but into other subjects. In 1994 a professor of physics at New York University, Alan Sokal submitted an essay, *Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity* to a cultural studies journal for publication. The essay was complete gibberish but was published and is referred to as the 'Sokal Hoax'. There is a full account of this together with articles by Mara Beller and Paul Boghossian in the scientific papers section of my website.