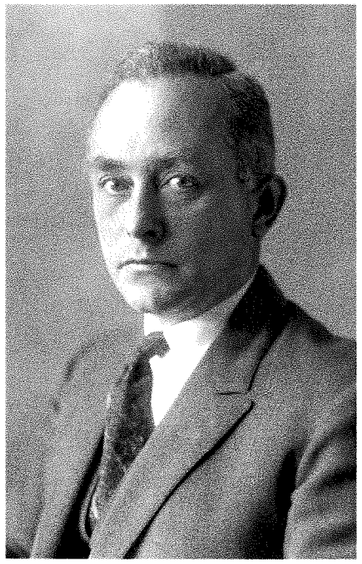
Gregor Schiemann

God Does Not Play Dice

Einstein's Still Topical Critique of Quantum Mechanics

There is hardly a remark by Einstein as famous as his statement that God does not play dice. Not only is it included in many portrayals of Einstein's life and work, it has even provided the title for a number of books on issues of modern physics and mathematics. The popularity of the sentence stands in notable contrast to the rather private context from which it originates. Einstein did not so much elucidate his comment in his writings on physics as he implemented it in his correspondence, and even more frequently in oral discussions with other physicists. The subject was the "statistical interpretation" of the atomic theory established in the 1920s known as "quantum mechanics." There is much to suggest that Einstein directed this remark against a view represented by this interpretation and still held in physics today: the belief that in the world of the very small, there are no causes for the spatial-temporal occurrence of individual events.



Max Born, around 1931

For a long time Einstein's critique was held to be reactionary in the face of the innovations and successes of quantum mechanics. Einstein, thus the general opinion, was a representative of an antiquated worldview, whose proximity to Spinoza's determinism made it irreconcilable with the worldview of modern physics. In the last decades, however, scholars have expressed misgivings about this opinion, which deserve to be taken seriously. Einstein's views on modern quantum mechanics (the same quantum mechanics still valid today) have piqued renewed interest on the part of many scholars.

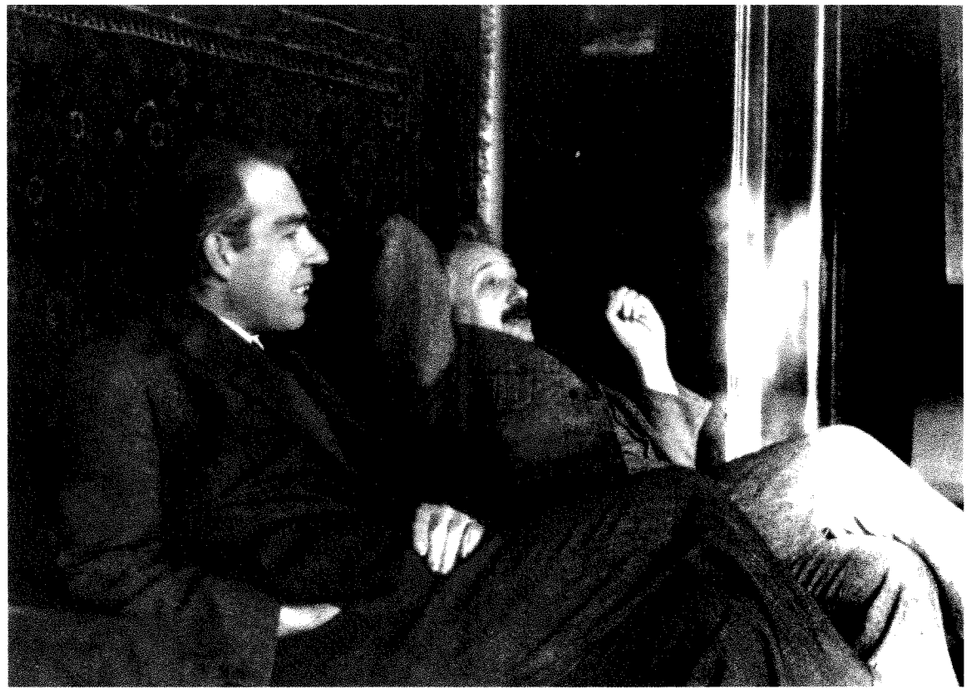
The shift in the attitudes of scholarship to Einstein's arguments with quantum mechanics throws another light on his God who does not play dice. The more recent works emphasize that Einstein's critique of statistical interpretation is not the expression of an untenable view of physics, but rather refers to future potential developments of atomic theory, which still remain to be achieved. This also gives new meaning to the sentence about God not playing dice.

Similar to the manner in which Einstein left this remark unexplained, however, his entire position on quantum mechanics has not remained unambiguous. His dice metaphor provides latitude for opposing points of view. On the one hand it can be linked with recent results of research; on the other it points unchangingly to the reactionary elements in Einstein's thought. I will turn first to these latter elements, and then look at the opposing interpretation, which picks up on recent results.

Isn't Chance at the Root of Natural Phenomena?

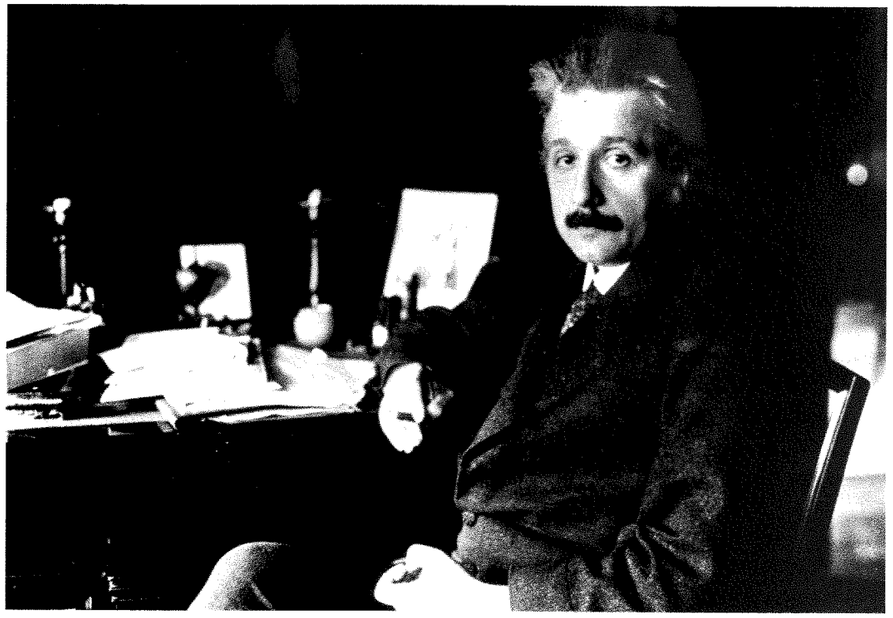
If one looks more closely at the subject of his criticism, it is not surprising that Einstein's critique of statistical interpretation seemed antiquated to his contemporaries. The interpretation he rejects picks up on perhaps the most revolutionary finding in the atomic physics of the past century: The individual events of atomic physics which have been measured – e.g. radioactive decay and the deflection of particle beams – can be predicted statistically, but not with precision. The point of time when a radioactive atom emits a certain particle, for instance, is chance in the mathematical sense; in principle, the point in time is arbitrary. Only the probabilities of emission can be calculated, and with a large number of particles this can result in a high precision of predicted measurement values.

Probabilities were introduced to physics long before quantum mechanics. They already played a key role in the atomic theories of 19th century classical physics, with which Einstein was extremely well acquainted. Statistical assumptions about the motions of the invisible atoms, distributed by chance, were used to explain measurable heat phenomena with classical theories. An increase in the temperature of a gas, for instance, was traced back to an increase in the average velocities of the gas atoms. It was believed that the knowledge about the motion of individual atoms, while not available at that time, would be obtained in the future. Why should it not be possible to determine the state of motion of an atom exactly and specify all causes that led to this state? The dice metaphor stands for this consideration. If the conditions of the motions of a rolled dice were known well enough, it would be possible to predict how the dice would fall. This would then reveal how chance is produced according to causal laws. Formulated as a paradox, chance would lose any element of chance. But God already has this knowledge. Thus what humans see as a roll of the dice is, from a divine perspective, not chance at all.



Niels Bohr and Albert Einstein in Leiden, at the end of 1920s (photo: Paul Ehrenfest)

The statistical interpretation of quantum mechanics asserts the inapplicability of such ideas to the field of the smallest dimensions. According to this interpretation, mathematically calculated probabilities are not an expression of ignorance about the state of atomic objects, but rather a characteristic of their state. All his life Einstein disagreed with this, because, in his view, one of the tasks of a theory is to give causes for the phenomena it



Albert Einstein in the library on Haberlandstrasse, 1929

describes. One had to leave open the possibility of later providing a deterministic foundation for the formulation of any physical theory.
With this view Einstein falls back on the ideas of 19th century classical physics and on the world-view associated with it, of a strict system of natural laws, which is effective on a fundamental level and does not provide any room for coincidental events. In this sense his remark that God does not play dice refers to an outdated agenda for the deterministic explanation of nature.

Or Are Dice Not at the Root of Chance?

More recent history of science research has shown, however, that Einstein's critique is not exhausted in its backward-oriented, problematic elements. In 1986 Arthur Fine presented significant arguments to this end in his highly regarded book *The Shaky Game. Einstein, Realism and the Quantum Theory*. According to Fine's analyses, Einstein does not object to the mathematical formalism of quantum mechanics, but rather to its conception as a complete theory in need of no further elaboration.
Einstein links his rejection of statistical interpretation's claim to integrity with the conviction that microphysical phenomena require a new kind of theory. In his view, the basic conceptualization of quantum mechanics should not be improved through minor corrections, but rather replaced by another "point of departure." Late formulations from the 1940s and 1950s suggest that he believed atomic theory would not be applicable in the future because of the still existing structural analogies and contextual relationships to classical physics. With this Einstein wanted to turn the tables on the critique directed against him: not his search for a realistic and causal theory of microphysics, but rather quantum mechanics in its present form would be far too bound up with a traditional conceptualization.
His previous rejection of what he called the "interference explanation" could also speak for a thrust in this direction. It goes back to Werner Heisenberg and is still quite influential even today. According to this interpretation, the acausal character of measurements in atomic physics is a result of the fact that the measurement process inevitably and uncontrollably interferes with the objects it is supposed to measure. What is dubious about this assumption is the tacit prerequisite that the objects had classically definable local and pulse characteristics before their interaction with the measurement apparatus. Accordingly, the acausal character would not appear until after the fact and (in contrast to "statistical interpretation") not belong to the nature of the objects. By rejecting the interference explanation, Einstein intuitively – thus one could perceive his critique – abandons the attempt to ground the assertion of microphysical processes' supposedly undeceivable acausality by linking it back to ideas of classical physics.

Werner Heisenberg, around 1958 (photo: Fritz Eschen)

From this perspective, his comment that God does not play dice appears in another light. The metaphor of playing dice expresses the conviction that coincidences are brought forth by nature, which is itself causally composed, in analogy to classical physics. If the conditions of the movements of the dice could be recorded exactly, then it would be possible to recognize the causes from which the results of each roll of the dice necessarily must proceed. Similar considerations can be related to the interference explanation: if interference through measurement could be minimized, then the deterministic basic structure of nature would be revealed. But God does not play dice. If the observable atomic coincidences are based on anything, it cannot be of anything like a dice game, whose causes can be researched in principle.
Today it remains unclear whether the contingency of atomic phenomena is part of their nature or whether it results from a process that is perhaps not coincidental. Einstein's comment and its effect have made a great contribution to keeping us aware that the solution of this problem is one of the tasks of future physics.

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