DOES GOD PLAY DICE WITH THE UNIVERSE?

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Throughout his life, Einstein repeatedly claimed that God does *not* "play dice", as he put it, with the universe. What did he mean? And why did he say it?

A philosophical disagreement about physics.

He said it because he found himself in profound disagreement with many of the most outstanding and influential physicists of his time: physicists like Neils Bohr, Werner Heisenberg and Max Born who had adopted what came to be known as the "Copenhagen interpretation" of the then-new field of quantum mechanics.

His disagreements with them were philosophical. Just as he rejected their claim that experimental results in quantum mechanics implied that nothing exists unless it is being observed by a conscious human being, so also he disagreed with their claim that these results implied that the so-called "deterministic" philosophy of Newtonian mechanics was false.

DETERMINISM VERSUS INDETERMINISM

Most of us believe that, as we put it, "things don't just happen", i.e., that events don't occur without being *caused* to occur. And outside quantum mechanics, every other branch of science – physical, biological, medical, social, psychological, etc. - shares that assumption.

Einstein believed that this assumption was justified. He believed, more generally, that the universe was *deterministic* in the sense that every event that occurs is caused by other events in such a way that the causing events bring about their effects, or in other words, "determine" the effects they will have.

Our ancient ancestors, and superstitious people to this very day, shared the belief that every event that occurs is ultimately caused by a god or gods. But as a scientific world-view gradually took hold, educated people came to believe in natural, rather than supernatural causes, of the changes they saw in the universe around them. Tsunamis, for example, don't occur because the gods are angry. Rather they are caused by ("determined" by) other events such as earthquakes, landslides, and asteroid impacts. And the same with everything else that happens: computer glitches, physical and mental diseases, and so on.

Sir Isaac Newton's deterministic mechanics.

The foremost example of this deterministic world-view was Newtonian physics. Newton's laws of motion provided causal explanations for the behaviour of all physical objects in the universe, from the way billiard balls interact, to the way the moon revolves around the earth, and the planets revolve around the sun.

Newton showed that the position and the momentum of an object such as the moon at any given time "determines" its position and momentum at any subsequent time (provided, of course, that some other object doesn't interfere with it). Subject to the non-interference proviso, the position and momentum of the moon at a given time – its "initial state" - *determines* the position and momentum of the moon at every subsequent time, whether or not we know this initial state. And if, in addition, we also *know* its initial state, then making use of Newton's laws of motion, we can *predict* the moon's future states. This fact, of course, together with other facts about the position and momentum of the earth as it revolves around the sun, is what makes it possible to construct tide tables for years, decades, and even centuries in the future.

Newtonian mechanics was, and still is, highly successful when it comes to describing the mechanisms governing the behaviour of largish, "macrophysical", objects.

But early in the 20^{th} century, physicists investigating the behaviour of extremely small objects, such as subatomic particles, found that they could not apply Newton's laws to the description of what was going on at this "microphysical" level.

Thus was born the new physical theory known as quantum mechanics.

THE REJECTION OF NEWTONIAN DETERMINISM.

The failure of Newton's laws at the microphysical level was one of the consequences of Max Planck's discovery that energy comes in multiples of little packets called "quanta". It turned out that attempts to make precise simultaneous measurements of the position and momentum of microphysical objects was impossible. To the extent that one's measurement of an electron's position was precise, one's measurement of its momentum would be correspondingly imprecise. And vice versa.

This meant that one simply could not predict with certainty where the electron would be when one next attempted to measure it. One had to content oneself with making estimates of where it would *probably* be, not where it would *certainly* be.

Heisenberg's "indeterminacy" principle.

Werner Heisenberg gave this discovery a name. He called it "The Indeterminacy Principle", or sometimes "The Uncertainty Principle". And he, along with the majority of quantum physicists – those belonging to the so-called Copenhagen School – concluded that the behaviour of the fundamental constituents of matter is therefore not deterministic but *indeterministic*. In their view, events at the microphysical level occur "randomly", "by pure chance" – meaning that they aren't determined by any causes whatever.

Thus in a letter to Einstein in June 1927, Heisenberg wrote:

> I believe that indeterminism, that is the nonvalidity of rigorous causality, is *necessary*, and not just consistently possible.

And Neils Bohr expressed the same view when he wrote:

> The renunciation of the ideal of causality in atomic physics . . . has been forced upon us . . .

EINSTEIN'S CRITICISMS OF ALLEGED INDETERMINACY IN THE QUANTUM WORLD.

Einstein disagreed strongly with this conclusion. In his view, the inference was fallacious: those who argued this way were guilty of confusing two senses of the word "determinism".

Two kinds of determinism: causal and predictive.

As Einstein implicitly realised, it is important to recognise the difference between two deterministic claims:

(a) Causal determinism.

Causal determinism says that every event is caused by, and hence determined by, previous events. Someone who believes in causal determinism is making what philosophers call an "ontological" claim, i.e., a claim about the nature of *reality* in itself.

(b) Predictive determinism.

By way of contrast, predictive determinism says that if causal determinism is true, and if – *in addition* – we have knowledge about the causes of an event and the laws of nature that govern the occurrence of that sort of event, then we can have knowledge of (i.e., predict) future events. Someone who believes in predictive determinism is making what philosophers call an "epistemological" claim, i.e., a claim about our *knowledge* of reality.

Einstein agreed with the Copenhagen interpretation that predictive determinism was unachievable when dealing with microphysical events. He agreed, that is, that we can't make the measurements that would allow us to make precise predictions of what is going to happen at that level.

But, he argued, that doesn't mean that causal determinism is false. It doesn't mean that events at the microphysical level occur by pure chance without any causes whatever.

A matter of logic.

The logic of the matter is clear. Predictive determinism, as defined above, clearly implies causal determinism since the concept of causal determinism is included within the definition of predictive determinism. But causal determinism does not imply predictive determinism since the concept of causal determinism does not include anything about knowledge or predictability. Hence, from the falsity or failure of predictive determinism at the quantum level, it does not follow that causal determinism is false.

On this matter of logic, Einstein was completely correct while his opponents were guilty of fuzzy thinking leading to fallacious inferences.

The concept of chance in dice games.

The point that Einstein was making can be illustrated by considering a dice game where, by virtue of our ignorance of the precise position and momentum of the die at the time it is thrown, we can't predict exactly how it will fall but must, at best, make estimates as to where it will *probably* fall.

The case of roulette is especially complicated since our ignorance extends not only to the state of the ball at the time it is thrown, but also to the state of the roulette wheel itself – its position and momentum at that time. This is a clear-cut case of a so-called game of "chance".

Yet no one doubts that there are causal mechanisms governing the fall of the ball and where it will end up on the wheel as it spins. Indeed, in 2004 a group of gamblers in a casino used electronic devices to make instantaneous measurements of all these mechanisms with a fair degree of precision. As a consequence they were able to improve their chances of winning by calculating a more limited range of probabilities for the die falling on a particular section of the roulette wheel.

In Einstein’s view, the bettors’ uncertainty as to where the ball would finish up is simply a result of their lack of knowledge, not a result of a lack of causal mechanisms for its final position.

By way of analogy, he would argue that the uncertainty involved in Heisenberg’s Uncertainty Principle is simply a result of lack of knowledge. In particular, the statistical probability estimates found in quantum physics are simply a result of our lack of knowledge (because of imprecise measurements) of the initial states of atomic and subatomic particles, not a result of a lack of causal mechanisms for the way these particles behave.

As he put it:

> I still believe in the possibility of a model of reality - that is, of a theory which represents things themselves and not merely the probability of their occurrence.
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> I am . . . firmly convinced that the essentially statistical character of contemporary theory is solely to be ascribed to the fact that this theory operates with an incomplete description of physical systems.

Einstein’s supporters.

Einstein wasn't alone in believing that quantum mechanics would eventually go beyond a mathematical description of probabilities and find an explanation in the form of deeper causal mechanisms. His views were shared by several other great physicists of the time: Max Planck, Erwin Schrodinger, Louis de Broglie, and - much later – David Bohm.   Louis de Broglie expressed their common viewpoint aptly when he wrote that he expected a time to come when:

> . . . we will be able to interpret the laws of probability and quantum physics as being the statistical results of the development of completely determined values of variables which are at present hidden from us. . . . The idea of chance . . . comes in at each stage in the progress of our knowledge, when we are not aware that we are on the brink of a deeper level of reality which still eludes us.

De Broglie was claiming that the concepts of randomness and chance are purely *epistemological* ones, having to do with our knowledge - or, rather, our lack of it - and should not be taken as having *ontological* import, i.e., as having any implications for the nature of the world itself. He held that the idea of chance has to do with our ignorance of how things really are rather than a failure of causality in the world itself.

The defenders of quantum indeterminacy held that the estimates of chance that are reflected in the probabilistic mathematics of quantum mechanics are due to a failure of causality in reality, not just a failure in our knowledge. The concept of chance, in their view, is an ontological one, not just an epistemological one. In effect, they were saying that the way the universe itself behaves at the atomic level is as if there were a god who was playing dice with it.

This was what Einstein was denying when he said that God does *NOT* play dice with the universe.