State Defendants' Response to Gonzales Plaintiffs' Motion for Preliminary Injunction

Exhibit AA

Einstein's Parable of Quantum Insanity

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SEPTEMBER 23, 2015 | 5 MIN READ

Einstein's Parable of Quantum Insanity

Einstein refused to believe in the inherent unpredictability of the world. Is the subatomic world insane, or just subtle?

BY FRANK WILCZEK & QUANTA MAGAZINE

The Sciences

From Quanta Magazine (find original story here).

"Insanity is doing the same thing over and over and expecting different results."

That witticism—I'll call it "Einstein Insanity"—is usually attributed to Albert Einstein. Though the Matthew effect may be operating here, it is undeniably the sort of clever, memorable one-liner that Einstein often tossed off. And I'm happy to give him the credit, because doing so takes us in interesting directions.

First of all, note that what Einstein describes as insanity is, according to quantum theory, the way the world actually works. In quantum mechanics you can do the same thing many times and get different results. Indeed, that is the premise underlying great high-energy particle colliders. In those colliders, physicists bash together the same particles in precisely the same way, trillions upon trillions of times. Are they all insane to do so? It would seem they are not, since they have garnered a stupendous variety of results.

Of course Einstein, famously, did not believe in the inherent unpredictability of the world, saying "God does not play dice." Yet in playing dice, we act out Einstein Insanity: We do the same thing over and over—namely, roll the dice—and we correctly anticipate different results. Is it really insane to play dice? If so, it's a very common form of madness!

Einstein Insanity: We do the same thing over and over—namely, roll the dice—and we correctly anticipate different results. Is it really insane to play dice? If so, it's a very common form of madness!

We can evade the diagnosis by arguing that in practice one never throws the dice in precisely the same way. Very small changes in the initial conditions can alter the results. The underlying idea here is that in situations where we can't predict precisely what's going to happen next, it's because there are aspects of the current situation that we haven't taken into account. Similar pleas of ignorance can defend many other applications of probability from the accusation of Einstein Insanity to which they are all exposed. If we did have full access to reality, according to this argument, the results of our actions would never be in doubt.

This doctrine, known as determinism, was advocated passionately by the philosopher Baruch Spinoza, whom Einstein considered a great hero. But for a better perspective, we need to venture even further back in history.

Parmenides was an influential ancient Greek philosopher, admired by Plato (who refers to "father Parmenides" in his dialogue the *Sophist*). Parmenides advocated the puzzling view that reality is unchanging and indivisible and that all movement is an illusion. Zeno, a student of Parmenides, devised four famous paradoxes to illustrate the logical difficulties in the very concept of motion. Translated into modern terms, Zeno's arrow paradox runs as follows:

1. If you know where an arrow is, you know everything about its physical state.
2. Therefore a (hypothetically) moving arrow has the same physical state as a stationary arrow in the same position.
3. The current physical state of an arrow determines its future physical state. This is Einstein Sanity—the denial of Einstein Insanity.
4. Therefore a (hypothetically) moving arrow and a stationary arrow have the same future physical state.

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5. The arrow does not move.

Followers of Parmenides worked themselves into logical knots and mystic raptures over the rather blatant contradiction between point five and everyday experience.

The foundational achievement of classical mechanics is to establish that the first point is faulty. It is fruitful, in that framework, to allow a broader concept of the character of physical reality. To know the state of a system of particles, one must know not only their positions, but also their velocities and their masses. Armed with that information, classical mechanics predicts the system's future evolution completely. Classical mechanics, given its broader concept of physical reality, is the very model of Einstein Sanity.

With that triumph in mind, let us return to the apparent Einstein Insanity of quantum physics. Might that difficulty likewise hint at an inadequate concept of the state of the world?

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Einstein himself thought so. He believed that there must exist hidden aspects of reality, not yet recognized within the conventional formulation of quantum theory, which would restore Einstein Sanity. In this view it is not so much that God does not play dice, but that the game he's playing does not differ fundamentally from classical dice. It appears random, but that's only because of our ignorance of certain "hidden variables." Roughly: "God plays dice, but he's rigged the game."

But as the predictions of conventional quantum theory, free of hidden variables, have gone from triumph to triumph, the wiggle room where one might accommodate such variables has become small and uncomfortable. In 1964, the physicist John Bell identified certain constraints that must apply to any physical theory that is both local—meaning that physical influences don't travel faster than light—and realistic, meaning that the physical properties of a system exist prior to measurement. But decades of experimental tests, including a "loophole-free" test published on the scientific preprint site arxiv.org last month, show that the world we live in evades those constraints.

Ironically, conventional quantum mechanics itself involves a vast expansion of physical reality, which may be enough to avoid Einstein Insanity. The equations of quantum dynamics allow physicists to predict the future values of the wave function, given its present value. According to the Schrödinger equation, the wave function evolves in a completely predictable way. But in practice we never have access to the full wave function, either at present or in the future, so this "predictability" is unattainable. If the wave function provides the ultimate description of reality—a controversial issue!—we must conclude that "God plays a deep yet strictly rule-based game, which looks like dice to us."

Einstein's great friend and intellectual sparring partner Niels Bohr had a nuanced view of truth. Whereas according to Bohr, the opposite of a simple truth is a falsehood, the opposite of a deep truth is another deep truth. In that spirit, let us introduce the concept of a deep falsehood, whose opposite is likewise a deep falsehood. It seems fitting to conclude this essay with an epigram that, paired with the one we started with, gives a nice example:

"Naïveté is doing the same thing over and over, and always expecting the same result."

Frank Wilczek was awarded the 2004 Nobel Prize in physics for his work on the theory of the strong force. His most recent book is A Beautiful Question: Finding Nature's Deep Design. Wilczek is the Herman Feshbach Professor of Physics at the Massachusetts Institute of Technology.

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FRANK WILCZEK is a theoretical physicist at the Massachusetts Institute of Technology. He won the 2004 Nobel Prize in Physics for his work on the theory of the strong force, and in 2012 he proposed the concept of time crystals.

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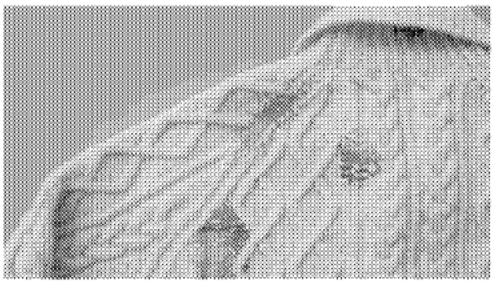

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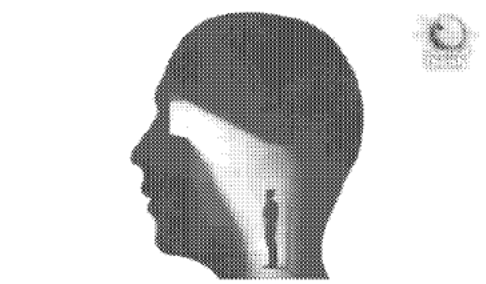

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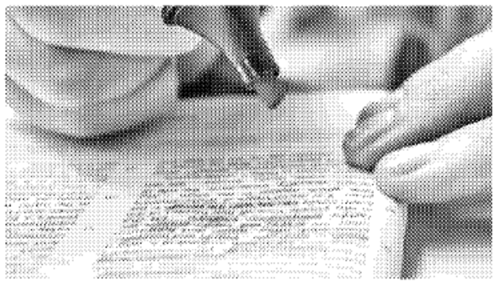

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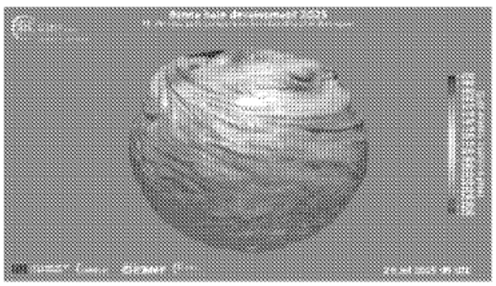

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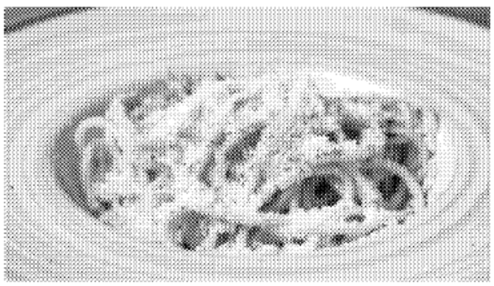

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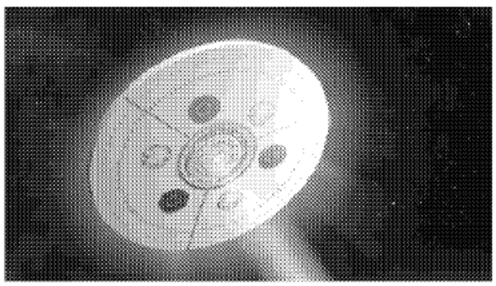

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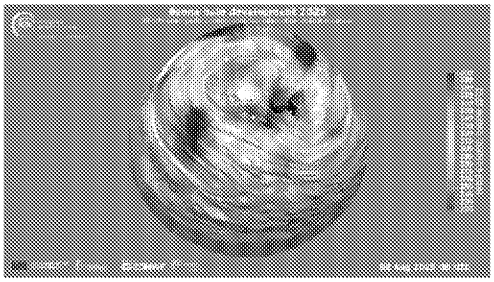

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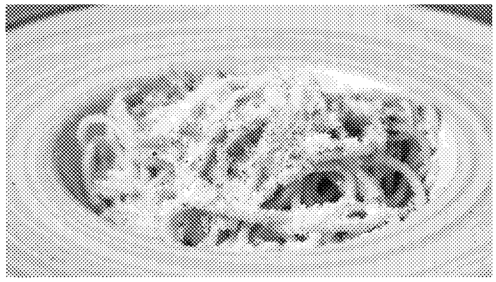

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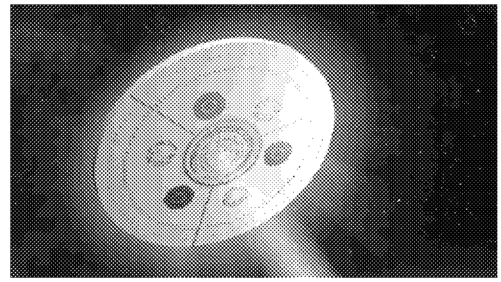

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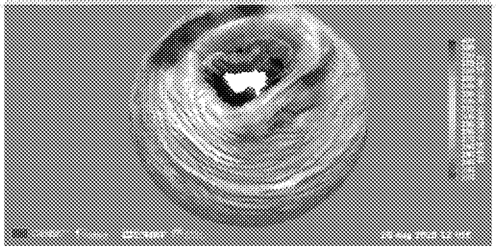

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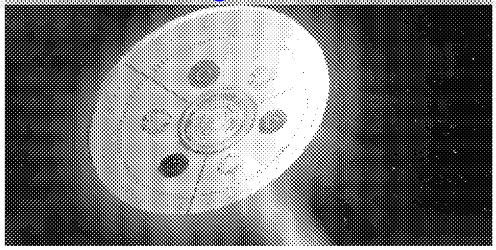

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