Does God Play Dice with the Universe?

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Summary: Is the world basically determined or random? Einstein had one view, Heisenberg the other. A new result from theoretical physics on this age-old philosophical question turns the tide in Einstein's favour.

Einstein did not like fuzzy physics, which brought him into conflict with people like Heisenberg, whose uncertainty principle says that the universe has basic indeterminacy. Relativity rules our world in the large, with laws which are precise. Quantum mechanics appears to rule the world in the small, with inbuilt randomness. While Bohr and others attempted to bridge the gap through arguments about complementarity, Einstein remained convinced that God (or whatever other rational thing underpins physics) does not play dice with the universe. The tide of opinion has run against Einstein for a century, but results on higher dimensions than the four of spacetime have recently swung the flow in his favour.

Imagine that you are given a jigsaw puzzle depicting Einstein. It is of the standard sort, printed on thin cardboard. As you put it together, you note that the pieces do not fit very well. But you persevere, and after a while have it completed. You step back to have a look: you see Albert's bushy hair, his lined face, and the spaniel eyes which seem to be trying to impart knowledge. You step closer, and notice the gaps between the pieces of the jigsaw. Attempting to improve the picture, you push some pieces closer together, only to find that elsewhere the spaces become wider. No matter how you try to make the image coherent, there are always places where the pieces do not match.

Quantum mechanics is like this. No matter how you try, there is always a fuzziness to nature on the small scale. It is measured in the case of particles by Planck's constant, h. Consider a typical particle, described by its mass, and its position and speed in ordinary (three-dimensional) space. The product of the mass and speed is the momentum, which you know from school is a conserved quantity. So is the particle's energy, which is based on its mass. Now imagine that one particle interacts with another (it might be when two particles collide in an accelerator). Let us focus on one particle in the interaction. In general, it changes its location in space over some time interval, so that its momentum changes, and possibly also its mass. Analysing the data, you find something odd: if the momentum is known well, then the position is known poorly, and vice versa. You cannot fix both things! Indeed, the product of the change in the momentum and the change in position cannot be fixed to better than an accuracy given by Planck's constant *h* (see above). The same applies to the product of the change in mass and the timescale of the experiment. In the language of four-dimensional spacetime, there is a kind of inbuilt graininess in our picture of the small-scale world.

Einstein hated this. He developed special relativity (a theory of the movements of objects in space and time), and general relativity (a theory of how the movements of objects are affected by masses or accelerated in spacetime). Both theories are overwhelmingly beautiful in concept and in complete agreement with observation. However, they do not contain the fuzziness law – or Heisenberg's uncertainty principle – which we outlined above. Denying inderminacy was not a popular view in the 1920s and 1930s, when quantum theory underwent a rapid development. This was largely due to the idea that a point-like particle could be replaced with a spread-out wave. Such a concept agreed with the fuzziness of the Heisenberg picture. It was formalized in the theory of wave mechanics, wherein the de Broglie wavelengths characterized the momenta of a particle and the Compton wavelength characterized its mass. These physical quantities were linked to the three directions of ordinary space and the "other" axis of time, in a theory which was compatible with the spacetime introduced by Einstein. Nevertheless, the latter remained

deeply skeptical that the laws of nature were founded on uncertainty, and hoped for a better resolution of the physics of the small and large scales. Recently, it appears that physicists have found the answer to Einstein's headache. It is based on the idea – which is mathematically simple but conceptually challenging – that we should go outside spacetime.

To see what is involved here, let us return to the jigsaw puzzle of Einstein which we considered above. But now, we replace the badly-fitting cardboard one with a precisely-machined one where the pieces are solid blocks. That is, we now have a jigsaw of the type produced by quality manufacturers of children's toys: the pieces are cut from a thick plank, so they plop into place exactly, with negligible gaps and no ambiguity. From a distance, we still see Einstein's face as before. But closer, we now find it hard to discern the lines between the pieces of the jigsaw. In fact, given a good-enough saw, the pieces might fit together so perfectly that we could not discern the gaps. So far, so good. But a pecuniary parent might wonder if he/she has to pay more for the second (thick) jigsaw compared to the first (thin) one. The answer is NO, provided the two jigsaws contain the same amount of material. This can be the case, if the gaps in the first jigsaw are balanced by the thickness of the second jigsaw. In the translation of this analogy to physics, the balance is connected with the laws of conservation (see below). The important thing is that the effects of Heisenberg uncertainty in four-dimensional spacetime are equivalent to the physics that takes place in the direction along the fifth dimension. In the conventional interpretation there is uncertainty, while in the new interpretation there is determinism.

This is a remarkable result. But it depends on the assumption that there is (at least) one extra dimension to the world, in addition to the ones of ordinary space (length, breadth, height) plus time. Is it reasonable to extend spacetime this way, even in principle?

The majority of theoretical physicists at present would answer this question in the affirmative. The basic reason is that extra dimensions provide the best framework for unifying the forces of physics. These are gravity (as described by Einstein's theory of general relativity), and the interactions of particle physics (as described by Maxwell's equations for electromagnetism, plus other so-called gauge fields for the weak and strong forces, which are responsible respectively for radioactivity and nuclear reactions). The unification of these four forces in one encompassing account is a kind of physics shangri-la. However, the number of dimensions needed to achieve it is not known. And the fact that we do not directly observe the extra parts is a problem, usually circumvented by assuming that they are very small and so have not been revealed yet by accelerator experiments. This, though, may change soon when the new particle collider begins operation at CERN. It may also be possible to observe the effects of extra dimensions in the gravitational domain, if approval is given for STEP (Satellite Test of the Equivalence Principle).

In the meantime, physicists are working out the consequences of various dimensionalities, including 10D supersymmetry and 11D supergravity. The case of $N = 5$ is of special importance, however. It is the basic extension of the $N = 4$ theory of general relativity due to Einstein, and the low-energy limit of the higher-dimensional theories espoused by particle physicists. A new review of higher-dimensional physics, with extensive references to the Einstein versus Heisenberg issue, is the book *Five-Dimensional Physics* (P.S. Wesson, World Scientific, Singapore, 2006). The author takes the view that if higher dimensions are valid, then common sense suggests that we look first at 5D.

In application to Heisenberg's uncertainty principle, the line of argument is fairly straightforward: We formulate the 5D laws of conservation, expecting that they are very close to the 4D ones typical of conventional physics, and isolate the bits which constitute the difference. As regards the laws of motion of a particle, the bits "left over" are perforce considered to be anomalous from the viewpoint of a 4D observer. It is these anomalous bits which we have been discussing, and which mimic the behaviour we conventionally ascribe to Heisenberg's uncertainty relation. The calculations leading to this interpretation are what physicists euphemistically refer to as "tedious" (for which, read "boring"). The main component of the analysis is the isolation of a fifth force, which is connected to the fifth dimension. It augments the usual 4D relations, which comprise the equations of motion in the three directions of ordinary space, plus the conservation of energy which is associated with the time direction of spacetime. It is interesting to note that essentially equivalent results for the fifth force were arrived at by people working independently and using different approaches. One approach is that of Donam Youm, at CERN in Geneva and ICTP in Trieste (see e.g. Physical Review D62, 084002, 2000). Another approach is that of Paul Wesson and collaborators, at U. Waterloo and Stanford U. (see e.g. J. General Relativity and Gravitation, 32, 451, 2004). It is heartening that separate lines of inquiry should agree, at least at the level of the equations.

Physically, the new research has a Picasso-like elegance to it. The product of the small changes in momentum and position (due to the nudge from the fifth dimension) has a value which is invariant. This means, in the language of tensor calculus, that the quantity has the same value, irrespective of how we choose to measure it. In our case, the numerical value of the invariant is just Planck's constant h. That is, there is Heisenberg-like indeterminacy in 4 dimensions, but it can be calculated if we use the more potent physics of 5 dimensions.

Numerically, $h = 6.6 \times 10^{-34}$ kg m^2/sec to good accuracy. Alternatively, $h = h / 2\pi$ is close to 1×10^{-34} kg m^2 / sec and is easier to remember. The latter defines the unit of spin or angular momentum for elementary particles. The units of Plank's constant are momentum $\times$ distance, or energy $\times$ time. It is these combinations which underlie the traditional 4D view that h sets an intrinsic accuracy for the microscopic world.

Philosophically, the implications of the new research in 5D are profound. There are thousands of articles and hundreds of books in print discussing the question of whether the universe is completely determined by its laws or is open to a basic level of uncertainty. The two people usually associated with this question are Einstein and Heisenberg. However, the subject has been commented on during the last century by nearly all noteworthy physicists. And, of course, by those most profligate of reasoners, the "real" philosophers. The latter have been arguing for millennia about whether or not we have free will. Their discussion in the last century has usually revolved around Heisenberg's uncertainty relation, which appears to leave open a gap of freedom in the laws of physics, which might conceivably be filled by the willful action of the human mind. In this regard, Roger Penrose of Oxford U. has recently proposed that the small perturbations of a quantum-indeterminate world are amplified in some fashion to macroscopic acts by the human brain. That is, even though the basis is obscure, we are still somehow in control of our actions. This is a neat idea. However, the new results we have outlined above substantiate the view of Einstein rather than that of Heisenberg. The randomness which we codify via the uncertainty principle is merely the small part of a deterministic five-dimensional universe, which we only partly understand because we observe things from a four-dimensional perspective.

In a way, if you feel free to read this sentence or not, you are indirectly testing if the world has four dimensions or five.