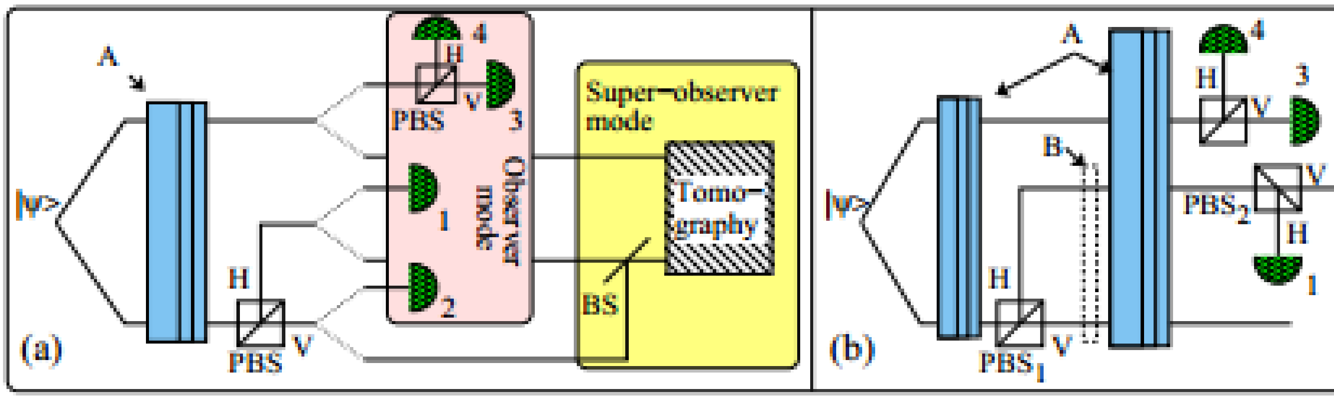

Quantum Experiment Shows How Time 'Emerges' from Entanglement

Time is an emergent phenomenon that is a side effect of quantum entanglement, say physicists. And they have the first experimental results to prove it

- The Physics arXiv Blog in The Physics arXiv Blog

When the new ideas of quantum mechanics spread through science like wildfire in the first half of the 20th century, one of the first things physicists did was to apply them to gravity and general relativity. The result were not pretty.

It immediately became clear that these two foundations of modern physics were entirely incompatible. When physicists attempted to meld the approaches, the resulting equations were bedeviled with infinities making it impossible to make sense of the results.

Then in the mid-1960s, there was a breakthrough. The physicists John Wheeler and Bryce DeWitt successfully combined the previously incompatible ideas in a key result that has since become known as the Wheeler-DeWitt equation. This is important because it avoids the troublesome infinites—a huge advance.

But it didn't take physicists long to realise that while the Wheeler-DeWitt equation solved one significant problem, it introduced another. The new problem was that time played no role in this equation. In effect, it says that nothing ever happens in the universe, a prediction that is clearly at odds with the observational evidence.

This conundrum, which physicists call 'the problem of time', has proved to be thorn in flesh of modern physicists, who have tried to ignore it but with little success.

Then in 1983, the theorists Don Page and William Wootters came up with a novel solution based on the quantum phenomenon of entanglement. This is the exotic property in which two quantum particles share the same existence, even though they are physically separated.

Entanglement is a deep and powerful link and Page and Wootters showed how it can be used to measure time. Their idea was that the way a pair of entangled particles evolve is a kind of clock that can be used to measure change.

But the results depend on how the observation is made. One way to do this is to compare the change in the entangled particles with an external clock that is entirely independent of the universe. This is equivalent to god-like observer outside the universe measuring the evolution of the particles using an external clock.

In this case, Page and Wootters showed that the particles would appear entirely unchanging—that time would not exist in this scenario.

But there is another way to do it that gives a different result. This is for an observer inside the universe to compare the evolution of the particles with the rest of the universe. In this case, the internal observer would see a change and this difference in the evolution of entangled particles compared with everything else is an important a measure of time.

This is an elegant and powerful idea. It suggests that time is an emergent phenomenon that comes about because of the nature of entanglement. And it exists only for observers inside the universe. Any god-like observer outside sees a static, unchanging universe, just as the Wheeler-DeWitt equations predict.

Of course, without experimental verification, Page and Wootter's ideas are little more than a philosophical curiosity. And since it is never possible to have an observer outside the universe, there seemed little chance of ever testing the idea.

Until now. Today, Ekaterina Moreva at the Istituto Nazionale di Ricerca Metrologica (INRIM) in Turin, Italy, and a few pals have performed the first experimental test of Page and Wootters' ideas. And they confirm that time is indeed an emergent phenomenon for 'internal' observers but absent for external ones.

The experiment involves the creation of a toy universe consisting of a pair of entangled photons and an observer that can measure their state in one of two ways. In the first, the observer measures the evolution of the system by becoming entangled with it. In the second, a god-like observer measures the evolution against an external clock which is entirely independent of the toy universe.

The experimental details are straightforward. The entangled photons each have a polarisation which can be changed by passing it through a birefringent plate. In the first set up, the observer measures the polarisation of one photon, thereby becoming entangled with it. He or she then compares this with the polarisation of the second photon. The difference is a measure of time.

In the second set up, the photons again both pass through the birefringent plates which change their polarisations. However, in this case, the observer only measures the global properties of both photons by comparing them against an independent clock.

In this case, the observer cannot detect any difference between the photons without becoming entangled with one or the other. And if there is no difference, the system appears static. In other words, time does not emerge.

"Although extremely simple, our model captures the two, seemingly contradictory, properties of the Page-Wootters mechanism," say Moreva and co.

That's an impressive experiment. Emergence is a popular idea in science. In particular, physicists have recently become excited about the idea that gravity is an emergent phenomenon. So it's a relatively small step to think that time may emerge in a similar way.

What emergent gravity has lacked, of course, is an experimental demonstration that shows how it works in in practice. That's why Moreva and co's work is significant. It places an abstract and exotic idea on firm experimental footing for the first time.

Perhaps most significant of all is the implication that quantum mechanics and general relativity are not so incompatible after all. When viewed through the lens of entanglement, the famous 'problem of time' just melts away.

The next step will be to extend the idea further, particularly to the macroscopic scale. It's one thing to show how time emerges for photons, it's quite another to show how it emerges for larger things such as humans and train timetables.

And therein lies another challenge.

Ref: arxiv.org/abs/1310.4691 :Time From Quantum Entanglement: An Experimental Illustration

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