The Royal Society of Edinburgh

Does God play dice?

Professor Miles Padgett

Report by Peter Barr

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Shedding light on light…

Albert Einstein would have had some tricky questions to ask at the recent RSE lecture on the wonders of quantum mechanics by Professor Miles Padgett of the University of Glasgow. And he may even have conceded that he got it wrong about one of the most mind-boggling issues in physics…

As Professor Padgett himself said at the start of his lecture, if you think you understand quantum mechanics, you clearly do not. The greatest minds in physics have been grappling with some of the basics for decades, and often come to opposite conclusions, but that is just part of the fun.

According to *Ockham's Razor*, quoted by Padgett at the end of his lecture, scientists should seek the simplest explanation for what they observe, but even the sub-topics in Padgett's talk sounded scary: wave-particle duality, wave interference for single particles, and the role of the observer in determining outcomes. And Professor Padgett's challenge was to help his audience understand some of the most difficult subjects in physics by shedding light on light…

One question that scientists have asked over the years is whether light is particles or waves. And the answer appears to be "both."

Padgett explained that when two beams of light overlap, we see interference effects, the same as with waves made of water. When two crests meet, the lightwave gets bigger. When troughs meet, the lightwave gets smaller. And when crests and troughs meet, they cancel each other out. Thus, light appears to travel in waves.

However, Einstein won the Nobel Prize (and in the process fuelled the birth of quantum mechanics) by proving that light, under certain conditions, also behaves like streams of particles – concentrated "packets" of what we call photons.

Although it is "bizarre," most physicists are happy to accept this wave-particle duality, and Padgett suggested that the answer depends on the question you ask – whether you emphasise the wave-like or the particle properties of light. In addition, said Padgett, the two "opposing" theories are simply the models we use to describe the behaviour of light. The truth lies much deeper…

To explore the question further, physicists have set up variations on an experiment which Padgett presented as a kind of "video umpire" in cricket, except that instead of bowling a ball at a wicket, you fire a single photon at a photon detector. The challenge is how to predict where the photon will land, just like the projection of a cricket ball which tells you if the ball would hit the wicket or not, based on measuring speed and angle of rotation, etc. "When does the photon *decide* where to land – as it leaves the source or when it is observed?" And what constitutes an observation? Is the outcome determined by observation – like some kind of telekinesis? Is the outcome undecided until the system is observed?

In Padgett's words, the photon says either: "I know where I'm going but the answer will be hidden from you till I get there." Or: "I don't know where I'm going but I will decide when you observe me."

Does this mean the photon can think for itself and determine the outcome – like some kind of intelligent cricket ball? Do the photons somehow communicate with each other, to deceive the observer?

Einstein and Danish physicist Neils Bohr had two rival theories to explain where the photon would land. Einstein said the outcome was predetermined by "subtleties in the initial state of the photon hidden from the observer," or what is called the "hidden variable" theory, while Bohr claimed that the outcome is only determined at the moment of observation. Einstein therefore leaned towards "predetermination" and Bohr to "random chance," leading to Einstein's famous remark that "God does not play dice with nature" – and inspiring the title of Padgett's lecture.

Modern experiments with polarisation have started to settle the argument, Padgett explained. Every photon seems to "flip a coin" to decide its polarisation – for example, vertical or horizontal, or an angle of 45º (left or right). "What polarisation should I be?" asks the photon. "And when do I decide?" When the photon passes through a polarised filter, it either passes through the filter, changing its angle of polarisation, or it doesn't pass through at all.

In one experiment, two photons are fired off simultaneously in opposite directions, begging the questions: What is their polarisation? How does one photon relate to another, and how do they affect each other's polarisation?

According to the work of French physicist Alain Aspect, the orientation is only decided at the moment we measure it. Furthermore, the measurement of either photon instantaneously determines the state of the other – something called "quantum entanglement" or "spooky action at a distance."

So Einstein was wrong…

Turning to his own research, Padgett also talked about "angular momentum," and introduced a wholly new dimension to the argument by describing how shining a light on a wall both moves the wall back and rotates it. He concluded: "We have shown that measuring the angular position of one photon defines the angular momentum of the other. It seems as if God does indeed play dice with angles."

What it all comes down to, Padgett suggested, is the quest for understanding. If we can understand the photon and the way it behaves, we can begin to understand the other mysteries of physics, much like *The restaurant at the end of the universe*, when author Douglas Adams suggested that from "one small piece of fairy cake," we can extrapolate the whole of creation.

In addition, said Padgett, if photons "throw dice" to decide what will happen, the same may also be true when it comes to microscopic systems. "Is there a chance," he asked, "to show quantum entanglement with living systems?"

During the Q&A session that followed, Padgett had to wrestle with some challenging questions. For example, instead of measuring photons which are vertical or horizontal, or 45º (left or right), what about the other angles? Padgett thought for a moment then revealed that in fact the most interesting photons had an angle of 22.5º or 67.5º – the angles of greatest divergence. Another question touched upon the issue of "long photons," and whether the photon reached the detector while still being linked to its source, thus interfering with the "twin" photon opposite. How would this affect results? Is the entanglement between the photons themselves or between the source and the detector?

Finally, one member of the audience asked how all this affects our daily lives. Padgett said he had a stock answer to this – secure communications, based on "quantum cryptography," or the properties of photons and their complex interactions, which guarantee security by telling us when someone is listening in.

So next time you turn on the light, think about quantum entanglement. It may be a brilliant idea…