Fireworks erupt over quantum nonsense

WHAT if you constantly change the ingredients in your raw batter, but the baked cake is always lemon? It sounds like something from a surrealist film, but equivalent scenarios seem to play out all the time in the mathematics of the quantum world.

Nobel prizewinner Frank Wilczek and colleague Alfred Shapere say we can't ignore the absurdity of the situation any longer. It's time to get to the bottom of what is really going on, and in the process cement our understanding of the fundamental nature of the universe.

They are part of a broader call to arms against those who are content to use the maths behind quantum mechanics without having physical explanations for their more baffling results, a school of thought often dubbed "shut up and calculate".

"I don't see why we should take quantum mechanics as sacrosanct," says Roger Penrose of the University of Oxford. "I think there's going to be something else which replaces it."

Einstein's widely accepted theory of special relativity states that nothing can travel faster than the speed of light. But the phenomenon of quantum entanglement seems to flaunt that speed limit by allowing a measurement of one particle to instantaneously change another, even when the two are widely separated. Einstein famously called this "spooky action at a distance".

"It's very disturbing," says Wilczek of the Massachusetts Institute of Technology. "It bothered Einstein. It should bother everybody."

To underline what they mean Wilczek and Shapere of the University of Kentucky in Lexington, examined a quantum system affected by a key aspect of special relativity: simultaneous events might not look simultaneous to all observers.

If two fireworks go off at exactly the same time in neighbouring towns, a spectator will be able to see both simultaneously. To an observer moving from one town to the other, one firework will seem to explode first. What holds true for you depends on your frame of reference – that is, it's relative.

If you have three fireworks, you'd think there should be six possible orders in which the events can occur, depending on an observer's reference frame. Surprisingly, that is not how it works mathematically. Even if there is some reference frame where all events are simultaneous, the calculations only work if you swap the order of two at a time (arxiv.org/abs/1208.3841).

The team then applied this test to the quantum world. When particles are entangled, they share a "wave function". Physically measuring one of the particles "collapses" all the possibilities encoded in the wave function into a single value, instantly affecting any entangled partners.

Based on the new maths, if you apply special relativity to three entangled photons, you can set up calculations where photon C affects photon A, or C impacts B, but never where C collapses both A and B. All three photons still appear to react instantly, but the wave functions that describe the situation can appear radically different depending on your reference frame, creating a mathematical paradox. "That's the tension: how can you have such large effects on the mathematical objects without physical consequences?" Wilczek says.

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What is more, he thinks quantum experiments that show physical paradoxes might not be far off. "This is my secret agenda: I'm not sure that there aren't real paradoxes that arise in more exotic situations than people have considered to date."

Lisa Grossman ■

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Pretty, from any point of view