

Topos Or Not Topos

According to Christopher Isham, rephrasing quantum physics in terms of topos theory may lead to quantum gravity. What was the question again?

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FQXi Awardee: Christopher Isham, Imperial College

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Christopher Isham, now 63, has scaled back his teaching and outreach activities. Not that he dislikes the challenge of explaining theoretical physics to 16-year-olds. On the contrary: Isham has a great interest in young people.

But the Imperial College professor suffers from a neurological disease, which renders him less mobile than he would like. He now walks only with sticks, and works mostly from home. Coming to grips with the failure of your physical body is a sobering condition for a physicist with a strong interest in philosophy and theology.

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- Christopher Isham

Like many of his colleagues, Isham wants to reconcile the two pillars of 20th-century physics: General Relativity and quantum theory. But unlike the majority of theoretical physicists, Isham believes the answer can be found in a new mathematical language called topos theory.

Introduced by the German mathematician Alexander Grothendieck, topos theory – unlike regular philosophy and theology – is able to handle concepts that can be partially true, instead of just true or false. But topos theory can be frustratingly hard to explain, says Isham. “I could give a seminar on topos theory here at Imperial College, but not many people would understand it.”

Isham believes that’s the main reason why most physicists show little interest in the idea. Indeed, Nobel physicist Gerard ‘t Hooft of Utrecht University in the Netherlands says he doesn’t expect too much from the new approach.

But Isham copes with critiques of his method in the same way he manages his emergent disability: by moving full speed ahead. With a US\$75,000 grant from The Foundational Questions Institute, as well as a US\$15,000 Mini-Grant from FQXi, he hopes to further develop topos theory as a new tool for theoretical physicists.

Uniting the Very Big and the Very Small

For more than half a century, physicists have been trying to develop a theory that describes both the very large and the very small. “It’s an unusual situation [in] that it takes so long,” says Isham. “Finding a theory of quantum gravity is a huge conceptual challenge.”

The universe on large scales obeys Einstein’s theory of General Relativity, which describes gravity. By contrast, the universe on the tiny scale of elementary particles is explained by quantum physics, which deals with uncanny dualities, uncertainties and superpositions.

So far, every attempt to combine the two into an overarching theory of ‘quantum gravity’ has come up empty-handed, or filled with meaningless infinities. Without a working theory of quantum gravity, it’s impossible to fully understand the big bang that gave birth to our universe, for example, or the properties of black holes.

Further, since the exotic realm of quantum gravity can’t be probed by current particle physics experiments, says ‘t Hooft, the quest for this scientific Holy Grail is today carried out solely by theorists.

“String theory and loop quantum gravity are currently the two main programs” attacking this problem, says Isham (see box), “but personally, I think they’re both wrong. In my opinion, quantum theory needs to be changed.”

Topos to the Rescue?

According to Isham, the necessary change might come through topos theory. “This is not a quantum gravity theory in itself,” explains Isham, “but a set of tools to build new theories. It’s a deep and beautiful mathematical framework – a new kind of logic that we could try to apply to the physical world.” Isham’s hope is that the new approach will lead to a reformulation of quantum theory, which would pave the way for a decent theory of quantum gravity, without ugly infinities.



TOPOS THEORIST
Christopher Isham with
his daughter Nicola

According to mathematical physicist Robbert Dijkgraaf of the University of Amsterdam, the topos approach could yield unexpected results, since it provides a fundamental way of describing quantization. “But it’s a very long shot to solve the problem of quantum gravity,” he notes.

't Hooft is even more skeptical. "Our biggest problem is how to formulate our questions," he says. "What exactly do you want to know, and which questions are you able to answer? Isham believes another mathematical language may help, but I don't think so. It sounds a bit as if describing the world in German is better than in Chinese."

But Isham is convinced that looking at the world in a new way will yield surprising new insights. "Most scientists are arrogant," he says. "They tend to think that particles and forces is just all there is to be said about reality. But I do think there are profound mysteries in the world."

Jung, Telepathy, and the Dancing Wu-Li Masters

Isham's somewhat mystical view of reality dates back to when he was a 13-year-old boy. Ever since, he says, "the work of Carl Gustav Jung, who wrote about how the human psyche is related to the world, has appeared fundamental to me." (Jung once remarked to physicist Wolfgang Pauli that our next great development of understanding would involve the mutual embracement of human psychology and quantum physics.)

According to Isham, his strong interest in philosophy and theology has never conflicted with his scientific work.

"There's a lot out there that's not part of mainstream science," he says, "like telepathy, for instance. I try to keep an open mind, and it enables me to take part in interesting meetings on the twilight zone between physics and religion."

There's nothing wrong with keeping a certain philosophical attitude in theoretical physics, says 't Hooft. Indeed, his work on the deterministic nature of reality has far-reaching implications for

our ideas about free will. "But philosophy can't be the only thing," he adds. "Every now and then you need to get your hands dirty" with real physics.

When philosophy is invoked in physics, laypeople may sense a scientific vindication for a whole range of crackpot ideas about putative links between quantum physics and mysticism. "That's inevitable," says 't Hooft. Still, Isham is lenient towards new-age bestsellers like Gary Zukav's *The Dancing Wu-Li Masters* and, more recently, Lynne McTaggart's *The Field*. "They do contain valuable truths," he says, "albeit from different perspectives than science provides."

Dijkgraaf believes Isham is walking on thin ice in his exchange with philosophers and theologians. "Their interest in these fundamental questions is definitely authentic," he says, "but it's tremendously difficult to really get the scientific message across. You have to be very careful that others really understand what you're trying to tell them. That's why most physicists choose not to leave their ivory towers."

Isham recognizes the reservations of many of his colleagues, but, he says, "most of them are benignly tolerant of my activities." Says Dijkgraaf: "That's probably because he is a well-respected member of the community."

Whether or not topos theory – or Jung's ideas about the human psyche – will play a role in the quest for a theory of quantum gravity remains to be seen. But, says Isham, maybe we encounter conflicts because we're not looking in the right way.

"I can't tell whether or not this will turn out to be useful in the end," he acknowledges, "but what I can tell is that my recent work has been the best in my career."

Two Roads to Quantum Gravity

No one knows how to merge quantum mechanics and General Relativity in a successful theory of quantum gravity. However, two approaches have received a lot of enthusiasm from theorists: string theory and loop quantum gravity.

Why is it so difficult to unite quantum theory and relativity? The main problem is that, according to General Relativity, spacetime is continuous, while in quantum mechanics everything is discrete and quantized.

Some physicists have tried to solve this issue by proposing that elementary particles are in fact tiny, one-dimensional strings, as opposed to dimensionless point particles. From a theoretical point of view, string theory looks promising, although the idea only works in ten or eleven dimensions, for which there is no observational evidence.

Moreover, the theory appears to yield an almost infinite number of solutions, and according to some skeptics, proving or falsifying it on the basis of experiments is therefore inherently impossible.

But other physicists think that extra dimensions are not necessary. Instead, spacetime itself may be quantized at an extremely small scale. In their theory, known as loop quantum gravity, there really is a smallest possible distance. Like string theory, today loop quantum gravity has no experimental backing.

At present, it's hard to tell which approach holds the best cards. Indeed, both theories might well be approximations of the same final theory of quantum gravity.

Or, as Christopher Isham would say, they might both be wrong.