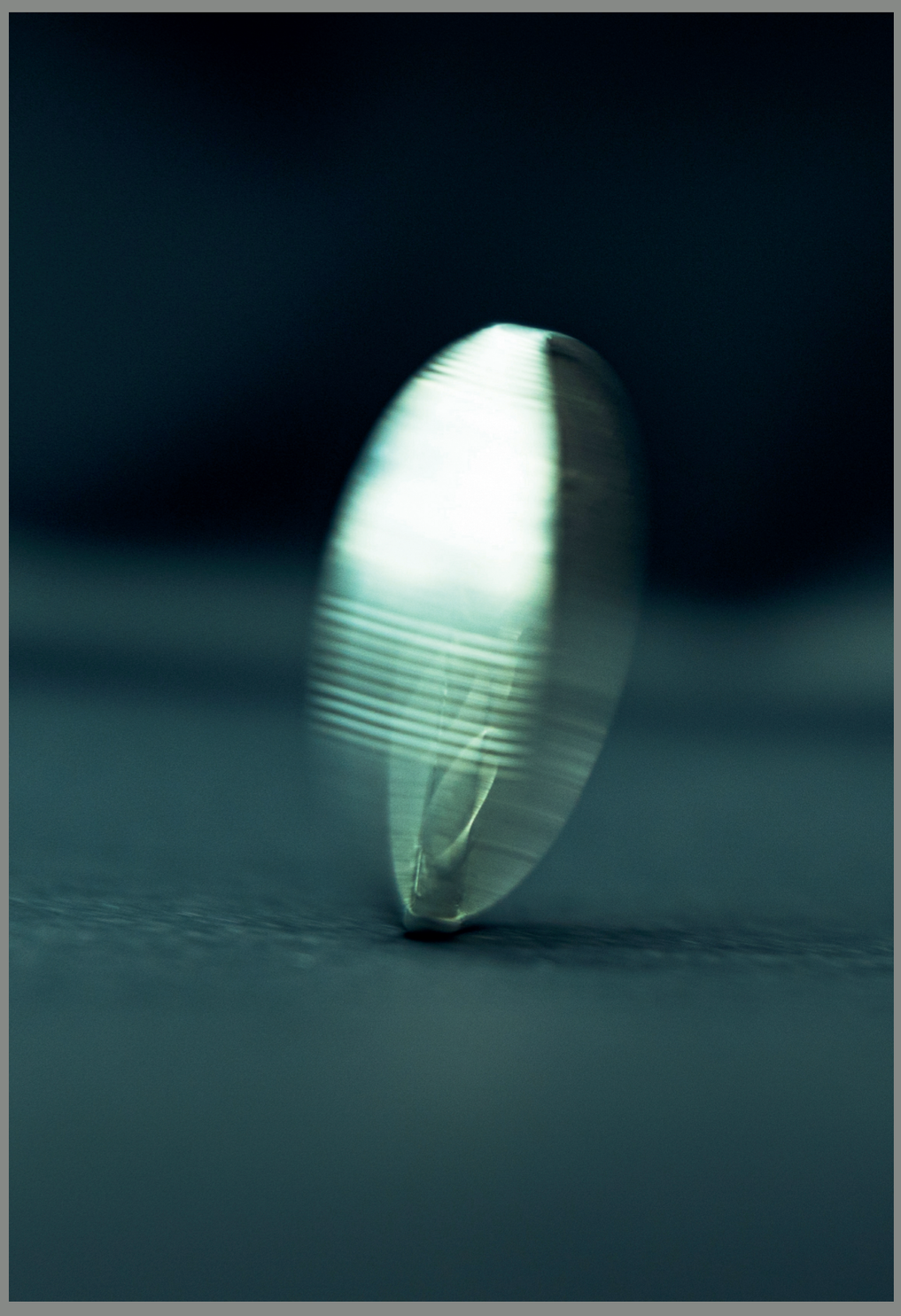
$$|\psi\rangle = a|0\rangle + b|1\rangle$$

Superposition

The world is not what you think

In the 1850s when physicists were exploring the behaviour of gases they realised there were too many molecules to be able to describe their individual behaviours - 27 million trillion molecules in just 1cm³. Instead, the physicists worked out the probabilities that particles would behave in particular ways, and this was an accurate description of what they actually did. It's a bit like spinning lots of coins. You can predict half will be heads and half tails without knowing their individual behaviour.

But then in 1926, Max Born made an extraordinary leap of imagination, suggesting probabilities were not just useful mathematical tricks, they actually determined the behaviour of the subatomic world. This idea helped develop descriptions of quantum physics such as the Copenhagen interpretation, which sees quantum probabilities as fundamental properties of nature. It also meant quantum systems could exist in a superposition of different states at the same time, only collapsing into a single state when measured. It's a bit like a coin that's both heads and tails when it's spinning, and only becomes one or the other when it stops.



How do we know it's true?

Pairs of particles can be created so they have 'entangled' properties. When those properties are measured, there is a high probability they will match, no matter how far apart the particles are.

Einstein thought this could only be possible if the description of quantum physics was incomplete. He suggested there might be hidden information that predetermined the behaviour of entangled particles.

In 1964, physicist John Bell came up with a way of testing this idea. Experiments carried out in the 1970s and 1980s following Bell's instructions found entangled particles behaved in ways that could not be explained by hidden information, and that behaviour matched the predictions of quantum physics. It seemed quantum physics was real.

Why does it matter?

Quantum phenomena such as superposition and entanglement are now being exploited in technologies such as quantum computers and quantum encryption. They also underpin technologies such as MRI scanners.

But it isn't just about new technologies. Quantum physics also challenges how we see ourselves.

Classical physics was often understood to be strongly deterministic - one thing inevitably leading to another - and this raised philosophical questions about predictability and free will. Quantum physics introduced fundamental probabilities and randomness into the description, challenging the idea that nature can always be predicted with certainty.

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$$|E(a,b)-E(a,b')+E(a',b)+E(a',b')|\leq 2$$

The Bell Inequality

The Superposition art installation

16 aluminium panels have had intricate patterns of holes meticulously cut through them. They are both precise and elusive. Each one represents a discrete event, a rupture, but together they combine to form constellations of lines, waves and circles. This echoes the wave-particle duality of quantum physics, in which quantum objects display both particle-like and wave-like behaviour.

The two sides of the panels, whilst apparently different, are actually mirror images of the same pattern, each one an echo of the other.

When someone approaches, the panels start to spin and everything changes. The holes tunnel through space, and the two faces merge to conjure a new symmetrical, 3D superposition of art. Not one side or the other, but both at once. When the spinning stops, the patterns separate again into front and back, their symmetry broken. The patterns revert to simple holes again - really there is nothing there.

The installation builds on the idea of the spinning coin as an analogy for superposition in quantum physics, in which quantum systems can exist in different possible states at the same time, until they are measured and collapse into a single state.

Each panel has an identical twin, and when the twins stop spinning they show the same sides half the time and different sides half the time.

But here's the trick. One of the pairs shows the same side three quarters of the time. This is more often than you would expect from two independent systems. In fact, when they stop in the same position they always show the same side, but when they stop in different positions the correlation disappears. Could there be a connection between them, like identical twins who somehow know how the other feels?

The Bell inequality identified a similar correlation in the behaviour of entangled particles, and when this was found experimentally it was generally accepted as proof that the weird world of quantum physics was real, no matter how strange it seemed.



About Gregor Harvie

Scottish artist Gregor Harvie uses his creative practice to tackle the most complex and fundamental questions of our time. He works collaboratively with experts to create bodies of work that are highly analytic and deeply poetic. For this installation Gregor collaborated with physicist Dr Neel Mackinnon, supported by Professor Stephen Barnett and Professor Sarah Croke from the Quantum Theory Group at the University of Glasgow. Technical support was given by Claire Neilan.

The installation was commissioned by the Quantum Arc, supported by the Scottish Funding Council. It received additional funding from the Institute of Physics and the opening event was supported by the Centre for Doctoral Training in Applied Quantum Technologies at the University of Strathclyde.

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