https://doi.org/10.1038/s41567-022-01886-4

The split of the century

This month, we celebrate the hundredth anniversary of the iconic experiment by Otto Stern and Walther Gerlach — a milestone in the development of quantum mechanics.

Persistence, intuition and a certain dose of luck are only some of the elements that can determine the success of any scientific endeavour. Among the many efforts that marked the early age of quantum physics, maybe none embodies the combination of those three ingredients better than the experiment that Otto Stern (pictured) and Walther Gerlach conducted in 1922[1] to test one of the most baffling predictions of the 'old quantum theory' — space quantization.

Following earlier foundational works on blackbody radiation and the photoelectric effect by Max Planck and Albert Einstein, Niels Bohr stunned the physics community in 1913 with his atom model describing electrons circling around a dense nucleus in orbits with quantized energies and angular momentum. Shortly after, Arnold Sommerfeld refined the model and provided another crucial contribution: not only do electrons have a quantized angular momentum, but the orientation of their orbits is also restricted to specific angles. This is what people at the time dubbed *Richtungsquantelung*, which translates to space — or direction — quantization.

Ironically, Stern did not believe in space quantization at all. He was one of the many shocked by Bohr's ideas, to the point of pledging to abandon physics if "this nonsense of Bohr should in the end prove to be right"[2]. Thus, after learning of space quantization in 1919, he put his mind to finding a way to disprove it.

His first intuition was that, according to the Bohr–Sommerfeld model, the motion of the outermost electron in an atom should produce a net magnetic moment, which could be probed in a magnetic deflection experiment.

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The experimental apparatus, which Stern realized together with Gerlach at the University of Frankfurt, comprised a collimated beam of silver atoms travelling through an inhomogeneous magnetic field before hitting a glass slide.

If the quantum theory was correct, space quantization should have induced the discrete splitting of the beam by an amount dependent on the angle between the field and the magnetic moment of the atoms. This would result in the formation of two separate lines of silver atoms on the slide, as opposed to the random and continuous distribution predicted by classical theory.

To modern eyes, the experimental setup might look rather simple today, and variations of it appear routinely in undergraduate physics laboratory courses. But it was no easy task in 1921, when vacuum pumping and molecular-beam technologies had just been developed. The fragility of the instruments required constant repairs that could delay action for days, and the slightest misalignments could cause hour-long experimental runs to fail. On top of that, the devastating economic crisis that hit Germany at the time made it hard to secure funding for the experiment, which in the end came from rather unorthodox sources — including a generous cheque by Henry Goldman, who had just retired from Goldman Sachs.

After months of unsuccessful trials, when Stern accepted a position at the University of Rostock and moved away from Frankfurt, the duo shook hands and decided to give up. But Gerlach continued the experiment on his own, and on 7 February 1922 he observed the beam splitting and the forming of two lines on the slide with a 0.2 millimetre separation. In a mix of surprise and excitement, Gerlach wrote an eloquent telegram to Stern: "Bohr was right after all." He also attached the now famous photograph of the splitting to a postcard that he sent to Bohr on the same day, congratulating him on the success of his theory.

Although the results proved unequivocally that the atoms did not behave classically, their agreement with the predictions of Bohr and Sommerfeld was a spectacular coincidence. The observed splitting seemed to confirm the exact value of the orbital angular momentum predicted by the theory, which was precisely equal to the reduced Planck constant $\hbar$. But in fact, silver atoms have no orbital angular momentum, and the correct interpretation of the findings relies instead on the half unit of electron spin, whose existence would not be postulated until 1925[3]. The gyromagnetic ratio, which was also unknown at the time and that for an electron is approximately 2, is the missing factor that turns the $\hbar/2$ into $\hbar$.

Despite the original misinterpretation, it is hard to overstate the influence that the Stern–Gerlach experiment had in the development of modern physics. In retrospect, it demonstrated the existence of the electron spin — an impressive feat, especially as the experimenters themselves had no idea what it was. But the setup also became a prototype for a new class of experiments that did not rely on spectroscopic methods to investigate quantum matter. Modern-day researchers still work on extensions of the Stern–Gerlach experiment, for example, as full-loop interferometers for tests of quantum gravity[4]. Even 100 years after the publication of their results, the legacy of Stern and Gerlach still has much to offer.

Published online: 6 December 2022

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