Quantum Spin, Bicycle Rims & a Century Old Conundrum

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If you ever visit Fysicum in Lund, take a left at the main entrance and follow the corridor to a flight of stairs. At the bottom of these stairs to your right is an unassuming door, as plain as the wall around it. Behind the door you will find a miscellany of rubble, nothing of note at first glance, but look closely next to the wall, beneath that pile of electronics. There you will find it, a forlorn tube with a humble exterior. It may not look like much, but entombed within its casing lies a mystery that has been dormant for just over a century.

In 1922, on the cusp between classical and quantum physics, Otto Stern and Walther Gerlach performed an experiment which showed the true quantum nature of the atom. They used some silver, an oven and a pair of magnets, all inside an evacuated tube. The silver was heated in the oven to a gaseous form and escaped through a small slit, thereby creating a narrow atomic beam. This beam was then aimed between the two magnets and towards a small detector plate behind them.

From a classical perspective, each atom is essentially a tiny bar magnet pointing in some random direction, the technical term for this being the *magnetic moment*, which is closely related to the quantum spin of the particle. This means that each atom will have a distinct interaction with the magnetic field; they will all be rotated and shoved differently. As such, the pattern on the detector should show an even distribution. However, what Stern and Gerlach saw when they put the plate under a microscope was something entirely different: All atoms had been pushed either left or right, seemingly by the same amount, leaving a blank region in the middle of the plate. Each and every one of them had apparently aligned its magnetic moment either perfectly with or exactly against the magnetic field. How did this happen? To this day this remains an open question known as the measurement problem.

Nowadays, the Stern-Gerlach setup might seem archaic, but even the most modern instruments sometimes need to rely on simple solutions. One such example is the time-of-flight spectrometer, which employs an even magnetic field to guide particles in a helical motion towards a detector. This device measures the 3D momentum of the particle to an extraordinary precision, and so one would think everything has to be precisely aligned for it to work. However, the ingenuity of this design shifts all the requirements for precision from the geometry of the device to the electronics. This means that the specifications on the construction of the spectrometer is not as strict. In fact, standard bicycle rims have been successfully used as scaffolding for the magnetic coils.

The burning question is this: Can the Stern-Gerlach effect be combined with such a spectrometer? If so, then a new type of device could be created, one that not only measures the momentum but the magnetic moment and, indirectly, the spin as well. The hope is that this machine can be built and that it will serve as a bathyscaphe for quantum physics, finally allowing a glimpse of the bottom of the murky depths first probed over one hundred years ago.

The first step is to build this new device, not physically, but digitally, which is what was done for this project. There are still some challenges ahead, but simulations have shown that this spectrometer can be constructed and operated within realistic parameters. Perhaps those murky depths will be visited sooner rather than later?