THE STERN-GERLACH EXPERIMENT

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A NEW PERSPECTIVE BY K. STRANG

The Stern-Garlich Experiment

This experiment carried out in around 1922 was designed to disprove the quantisation of spatial orientation of the electron. Sommerfeld had concluded that not only could electrons inhabit certain quantised energy levels but their orientation must also be quantised. In 1925 the results of the experiment were also appropriated to prove the existence of 'spin' or the fourth quantum number. See the table below:

QUANTUM NUMBERS	VALUES	DESCRIPTION
n	The principle quantum number may be any positive whole number and describes the energy level	The size of the orbital or energy
ℓ	The orbital or angular quantum number can take a whole number value from 0 to n - 1	the shape of the orbital
m_ℓ	The magnetic quantum number with ($2\ell+1$) different values between $-\ell$ to $+\ell$	the orientation of the orbital
m_s	for each combination of the above three numbers there are two possible values of the spin quantum number +1/2 -1/2	spin

Otto Stern was unhappy with Sommerfeld's approach as it defied classical mechanics and electrodynamics. He teamed up with Walther Gerlach who was an experimental physicist, to design an experiment to demonstrate that quantisation of spatial orientation was incorrect.

Angular Momentum and the Magnetic Dipole Moment General

Angular momentum is the description of motion that is not in a straight line but involves rotation or other periodic motion eg a pendulum. If a steady electric current is moving in a circle around a wire it creates a magnetic field and also responds to any externally applied magnetic field by deflecting or changing the direction of the current and this is termed a 'magnetic dipole moment' An example without the looped wire is a compass needle. The needle experiences a torque aligning it with the magnetic field.

If a charged particle is moving at constant speed around a circle it will have angular momentum quantum number ℓ and a magnetic dipole moment, quantum number m_ℓ. It is found by experiment on atoms that these are proportional to each other.

The Electron

The electron cannot be observed orbiting the nucleus. Nevertheless it is argued that because many atoms have angular momentum and magnetic dipole moments, if an experiment can show that the magnetic dipole moment is 'quantized' in the atom ie. is not a continuous property but a discrete property then the angular momentum of the electron will also be quantised. This is already a stretch.

The S-G experiment (1) on the third quantum number

The experiment involved neutral silver atoms being fired through an inhomogeneous magnetic field and detected on a screen. The structure of the silver atom is important for the later analysis of 'spin' as it has 47 electrons filling 4 energy levels 2,8,18,18 and 1 single electron in its highest energy level. When the silver atoms are fired through the inhomogeneous magnetic field it was thought they would be detected as a continuous smear but were in fact localised in two places. This was conclusive 'proof' that Sommerfeld was correct and the orientation of electrons were quantised. The problem is that the atomic number m_ℓ can only take odd values (there should have been three or five smears) and secondly the single electron has an angular momentum of zero which cannot be quantised.

The S-G experiment (2) on 'Spin'

Rather than let the experiment go to waste, it was argued a few years later that the results must be the effect of some other type of (intrinsic) momentum belonging to the electron which was christened 'spin angular momentum' or 'spin' for short. This reasoning was used to support the two Dutch physicists, Samuel Goudsmit and George Uhlenbeck who had come up with the idea of 'spin' in 1925 and on presenting it to their professors Ehrenfest and Lorentz had been dismissed as non-sense. When it became clear that this idea could also support Pauli's Exclusion Principle by providing a fourth quantum number, it became entrenched in particle physics.

The standard explanation summed up in an Open University text book [Quantum Mechanics and its Interpretation, Book 2 p72] as to why electrons are not used in the experiments, is as follows:

'There are formidable practical difficulties in [using electrons] . . . electrons would be strongly deflected by the magnetic fields in a S-G apparatus, simply because they are moving charged particles. Such a deflection would overwhelm the much more delicate

deflection due to the magnetic dipole moment of an electron in an inhomogeneous magnetic field and prevent us from observing effects directly associated with spin.'

Then the rational for using silver atoms:

' . . . the electrons in a silver atom are arranged in such a way that the magnetic dipole moments of all but one of the electrons is cancelled out. The remaining electron has no orbital angular momentum (ℓ = 0) so there is no orbital contribution to its magnetic dipole moment. This means that the magnetic dipole moment of a silver atom can be regarded as being due to the spin of a single electron.'

This is supposed to account for the two smears on the detector screen and represents the two values of 'spin' +1/2 and -1/2.

An alternative explanation from wave mechanics might be that the two smears on the detector indicates a wave with a motion flip-flopping between crest and trough and this is the reason for the two values or an interference patterns where there is an amplification and a cancelling out of waves and troughs of the stream of atoms.

'The Stern-Gerlach experiment is undoubtedly one of the great achievements of experimental physics, but it raised many issues about the fundamentals of quantum physics. Stern pointed out that, if space quantisation was a real physical effect, it should give rise to birefringence, or double refraction, in materials since there would be a difference in the refractive indices along and perpendicular to the magnetic field direction. Such an effect had never been observed.' [Malcolm Longair, *Quantum Concepts in Physics*, CUP 2013, p154]

So, not only is 'spin' questionable but also the quantised orientation. Once again, experiments heralded as conclusive are anything but that. See the section of the website on 'Magic Particles' which covers the experiments to prove Bell's Inequalities and the additional material 'Compton Scattering' in the 'Einstein's Other Blunder' section.