(a) Electron Spin

The existence of spin was confirmed experimentally by Stern and Gerlach in 1922 in which a beam of silver atoms was allowed to pass through an inhomogeneous magnetic field. Stern and Gerlach used silver atoms in their experiment. Silver atoms have 47 electrons with electron configuration $[\mathrm{Kr}]4d^{10}5s^{1}$. Forty-six of them fill completely the $n=1,2,3$ and 4 levels. The last electron is an n = 5 electron with zero orbital angular momentum (a 5s state). The only possible angular momentum is the intrinsic angular momentum of the last electron. Thus, a magnetic dipole moment is also that of the last electron (the nucleus has much smaller dipole moment and can be ignored).

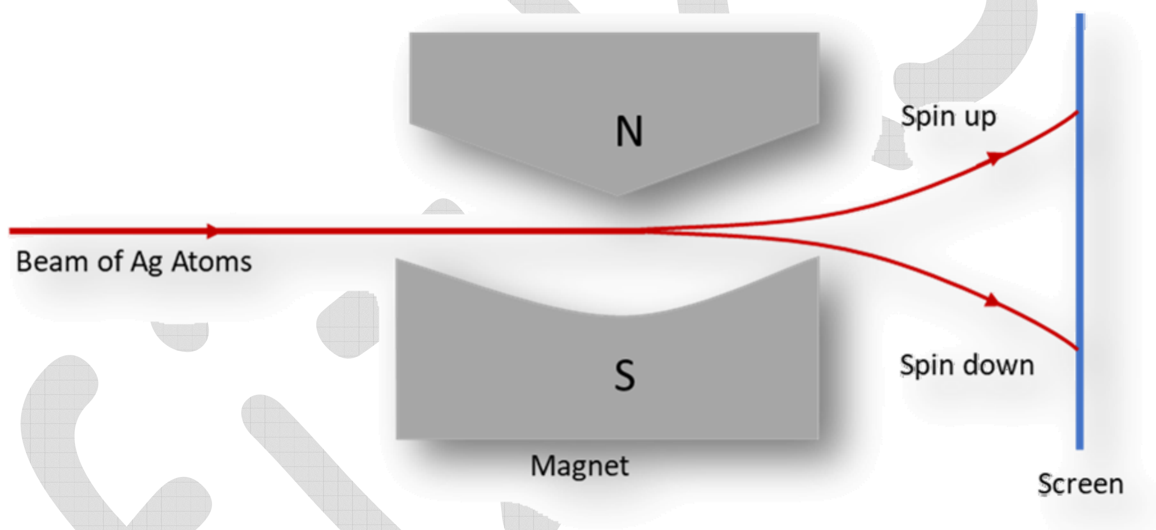

Figure: Apparatus for Stern-Gerlach experiment: when a beam of silver atoms passes through an inhomogeneous magnetic field, it splits into two distinct components corresponding to spin-up and spin-down.

If the magnetic field points mostly in the positive z direction, and the gradient is also in the positive z-direction, then classically we must see on the screen a *continuous* band that is symmetric about the undeflected direction. According to Schrödinger's wave theory, however, if the atoms had an orbital angular momentum l, we would expect the beam to split into an *odd* (*discrete*) number of $2l+1$ components. If the silver atoms were in its ground state, its total orbital angular momentum would be zero: $l=0$ (since the fifth shell electron would be in a 5s state), there would be only one spot on the screen, and if the fifth shell electron were in a 5p state $(l=1)$, we would expect to see three spots. Experimentally, however, the beam behaves according to the predictions of neither classical physics nor Schrödinger's wave theory. Instead, when the inhomogeneous magnetic field was on, the beam of silver atoms split into two parts, one deflected up and the other deflected down as a result *it splits into two distinct components.*

In 1925, Uhlenbeck and Goudsmit proposed an explanation for the splitting of Silver beam the Stern-Gerlach experiment. They postulated that the electron possesses an intrinsic angular momentum, referred to as "Spin", and which, unlike the orbital angular momentum, has nothing to do with the spatial degrees of freedom. This intrinsic angular momentum gives rise to a magnetic moment in the electron that interacts with magnetic fields. The electron spin and the related magnetic moment are quantized such that there are only two possible discrete values. This quantization of the magnetic moment is what leads to the deflection of the beam of silver atoms either up or down in the inhomogeneous magnetic field.

Here, it is very important to understand that the term "electron spin" is an inappropriate name. We should not imagine electron as a tiny ball of charge spinning about its axis. The surface of the electron would have to be rotating at greater than the speed of light in order to produce a magnetic moment the size of that measured for the electron. The spin, an intrinsic degree of freedom, is a purely quantum mechanical concept with no classical analogy. Unlike the orbital angular momentum, *the spin cannot be described by a differential operator*.

While Uhlenbeck and Goudsmit's postulate of the existence of an intrinsic angular momentum for the electron provided an explanation of the Stern-Gerlach experiment, there was no solid theoretical framework for their postulate. However, in 1928 Paul Dirac developed a relativistic version of quantum mechanics. Using his relativistic equation, Dirac was able to derive the existence of electron spin and show that the properties of electron spin were in accord with Uhlenbeck and Goudsmit's postulate and the results of the Stern-Gerlach experiment.