Longitudinal Spin Transfer to the Λ Hyperon in Semi-Inclusive Deep-Inelastic Scattering

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The nuclei of atoms consist of protons and neutrons, more generally referred to as nucleons. The nucleon is a composite object too. It contains tiny (or *point-like* constituents known as quarks and gluons which are continuously moving inside the nucleon.

An important property of the nucleon is its *intrinsic spin*, which is equal to 1/2 in units of $\frac{h}{2\pi}$, where h represents the Planck constant. How do the quarks and gluons conspire to produce an overall spin of 1/2? This question has been vigorously addressed by theoretical and experimental physicists over the past two decades.

In the *naive* Constituent Quark Model the nucleon is a simple object consisting of only three quarks. Thus, the proton consists of two "up" quarks (u quark) and one "down" quark (d quark), i.e. it has a uud configuration. Similarly the neutron has a udd configuration in this model. As the quarks are also spin-1/2 particles, the spin of the proton can be explained by assuming that the two u quarks in the proton are aligned parallel to the proton spin, while the d quark has an opposite spin orientation. For the neutron the two d quarks would be aligned along and the u quark opposite to its instrinsic spin direction.

The experimental data, however, did not confirm this simple picture. Experiments in which high energy polarized electrons (or muons) are scattered from polarized proton targets revealed that only 30% of the nucleon spin can be attributed to the quark spin. Hence, there must be other carriers of angular momentum in the proton, and although not directly measured sofar it is commonly believed that this must imply that the gluons are polarized and/or that both gluons and quarks may have a non-zero orbital motion in the proton. Similar conclusions have been obtained for the neutron.

Given the non-trivial spin structure of the proton and the neutron, it is of interest to consider the spin structure of other composite spin-1/2 particles, i.e. other baryons. In this respect the Λ^0 baryon is particularly interesting, as it is the lightest baryon containing a different type of quark. Apart from a u and d quark the Λ^0 baryon contains a so-called strange quark s. In fact, baryons containing one or more s quarks are alsno known as hyperons and the Λ^0 particle is the lightest hyperon. As the Λ^0 hyperon is not stable - having a life time of only 2.6×10^{-10} s - it is not possible to scatter polarized electrons from a target consisting of Λ^0 particles. Therefore, another probe of the Λ^0 spin structure must be found.

One possibility is to try to measure the polarization of Λ^0 hyperons that are produced in reactions initiated by a polarized quark. If this polarized quark becomes a constituent of the formed Λ^0 baryon, the produced Λ^0 baryon may obtain the same spin orientation if the original quark is an important source of angular momentum of the Λ^0 particle. This polarization of the Λ^0 can be measured due to the parity-violating nature of Λ^0 decay. If the Λ^0 hyperon decays into a proton and a negative pion, the proton is preferentially emitted along the spin-direction of its parent. By measuring the number (N^+) of protons emitted along the Λ^0 spin direction and the number (N^-) emitted in the opposite direction, one can evaluated the asymmetry $\frac{N^+-N^-}{N^++N^-}$ which is directly proportional to the polarization of the Λ^0 hyperon. If, for example, the Λ^0 hyperon is fully polarized, i.e., all Λ^0s are produced with the same spin orientation, the measured asymmetry will be maximal and equal to $\alpha = 0.642$. Here, α is the so-called Λ^0 decay parameter known from other experiments.

Now, the question is where to take a polarized quark from that could be used to produce a polarized Λ^0 hyperon? There are several options. One is the decay of a Z^0-boson formed in collisions of electrons and positrons, each acelerated to an energy of about 46 GeV. The Z^0-boson happens to decay with a high probability into one strange quark and one antiquark, which are both highly polarized. The polarized strange quark will find u and d quarks in the debris of the collision enabling the formation of a Λ^0 hyperon. By measuring the polarization of the produced Λ^0 one can measure the transfer of polarization from the strange quark to the Λ^0 hyperon. Such experiments have been performed in the previous decade at the LEP collider of CERN. The analysis of the data obtained in these measurements confirmed the basic structure of the Λ^0 hyperon as predicted by the Constituent Quark Model, i.e. it was found that the spin of the Λ^0 hyperon is mostly carried by the strange quark s. The question remained whether the u and d quarks also contribute to a certain extent to the spin of the Λ^0 hyperon. Information on the latter issue could not be reliably derived from the CERN data.

The second method to produce polarized Λ^0 hyperons from polarized quarks is more sensitive to the role of u and d quarks. In this case high-energy *polarized* leptons (i.e. electrons, positrons or μ-mesons) are scattered from a proton target (hydrogen). In the scattering process the lepton emits a high-energy longitudinally polarized photon. This photon will only interact with a quark in the proton target if the quark has a spin-orientation opposite to that of the photon. As the proton is mostly consisting of u quarks, the scattering process described above predominantly singles out polarized u quarks. In a similar way as was discussed above for the CERN experiments, the produced quark will interact with other quarks produced in the collision, leading to the formation of various baryons. By searching for Λ^0 hyperons produced in such lepton-induced experiments, one can study the probability that the polarization of the original u quark is transfered to the Λ^0 hyperon. Such a measurement was carried out by the HERMES experiment at DESY. It was found that the produced Λ^0 hyperons were mostly unpolarized, i.e. hardly any spin had been tranferred from the polarized u quark to the Λ^0 hyperon. This result is also consistent with the Constituent Quark Model. It should be noted, however, that other mechanism (involving the initial production of heavier hyperons decaying into a Λ^0 baryon, for instance) may play a role in the interpretation of the data as well. The results obtained in the HERMES experiment, however, provide important constraints on our understanding of both the Λ^0 spin structure and the reaction mechanism involved.