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MEMORANDUM

To: Susan S. Silbey

From: Peter Fisher

Subject: Notes on quarks and the Ω^-

Date: Thursday, March 31, 2016

This memo reviews some of the ideas of the quark model of nuclear matter with particular attention to the pivotal role of the Ω^- baryon whose discovery in 1964 established the model and led to the idea of color charge.

Physics catagorizes our universe by dividing into it length scales: starting at the size of the visible universe (10 billion light years) and ending with subnuclear structure (below 1 fermi or 10^{-15}m). The Periodic Table describes atomic structure (10^{-10}m) formed by electrons in motion around nuclei. The Table of the Isotopes describes nuclear structure (a few 10^{-15}m) comprised of protons and neutrons. The Quark Model, developed in the 1960's by Gell-Man, Zweig, Ne'eman and others describes the structure of nuclear matter (below 10^{-15}m) whose particles are composed either of three quarks (called baryons) or a quark and an anti-quark (called mesons) bound together by the strong interaction.

Experiments by Kendall, Friedman and Taylor in the mid-1970's established the physical reality of quarks. Before then, quarks were a calculational tool for predicting the properties of nuclear matter. The original model contained three kinds of quark, up (u), down (d) and strange (s). Each quark has a mass, charge, spin and isosopin. The charge defines the electrical interactions of the quark, the spin defines the magnetic interactions and the isospin defines the strong and weak interaction properties. The specification of mass, charge and isospin, referred to as quantum numbers, uniquely specifies a type of quark. The spin is a dynamical quantum number (like position or momentum) and may assume one of two possible values.

For the bound states of three quarks, the baryons, there are eighteen combinations when rearrangements are taken into account (for example, uus is the same particle at suu), each corresponding to a unique baryon. Gell-Mann et al. studied the decay of the baryons and used ideas of group theory to further separate the baryons into a group of eight (the octet) and ten (the decuplet), shown below in Fig. 1.

This early quark model had a problem: the Pauli Exclusion Principle requires that no two quarks in the same baryon may have the same set of quantum numbers. Two identical quarks in the same baryon could assume two different spin states, so a proton (uud) or neutron (udd) would be allowed. According to the model, baryons with three identical quarks like the Δ^{++} (uuu) or Δ^- (ddd) would not exist because, since there are only two spins states, there would be two quarks in the same state. However, both the Δ^{++} and Δ^- observed in the 1950s.

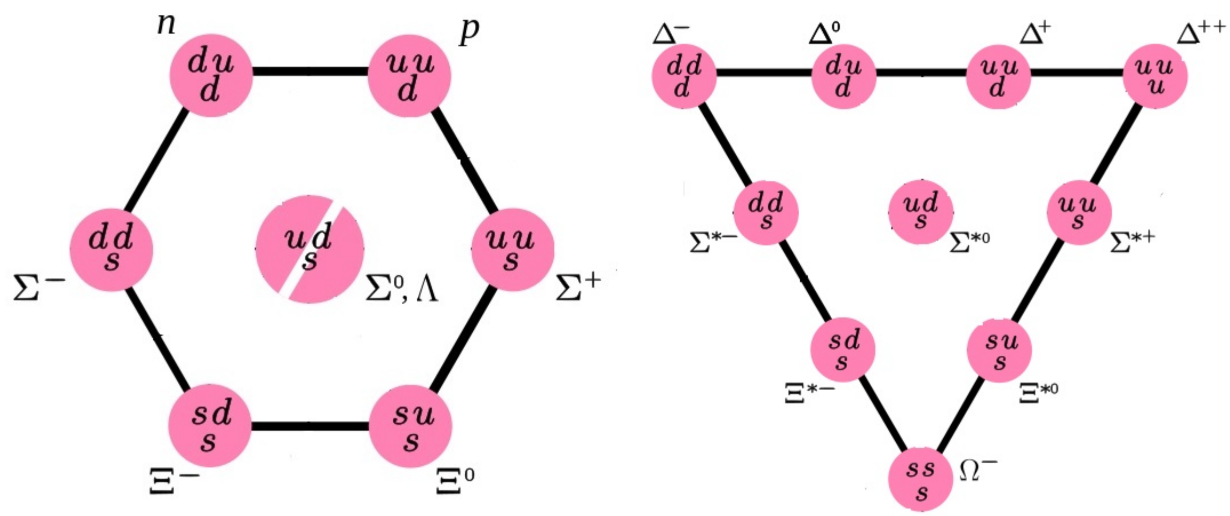

Figure 1: Baryon octect (left) and decuplet (right)

Theorists developed a number of modifications to the Quark Model to explain the three quark states. One model postulated an additional quantum number called color charge that could take on three possible values (called red, green and blue), allowing, for example, the three u quarks in the Δ^{++} to assume three different color charges. The Quark Model with color charge then predicted a bound state of three strange quarks, sss called the Ω^-. Observing the Ω^-would support the new idea of color charge.

The Brookhaven National Laboratory bubble chamber, operating the the new Alternating Gradient Synchrotron, caught a picture of Ω^- shown below in Fig. 2, along with its decay sequence. Observation of the Ω^- put color charge on the map and in the early 1980's, Wilzcek, Politzer and Gross developed a theory of strong interactions called Quantum Chromodynamics, now well established as the theory of the strong interaction.

Three more quarks have been observed since 1964 and the quark model has had to expand to fit them. The heaviest, the top quark, decays before it can form a baryon, but the other quarks form particles. Fig. 3 shows a part of the new periodic table for nuclear particles.

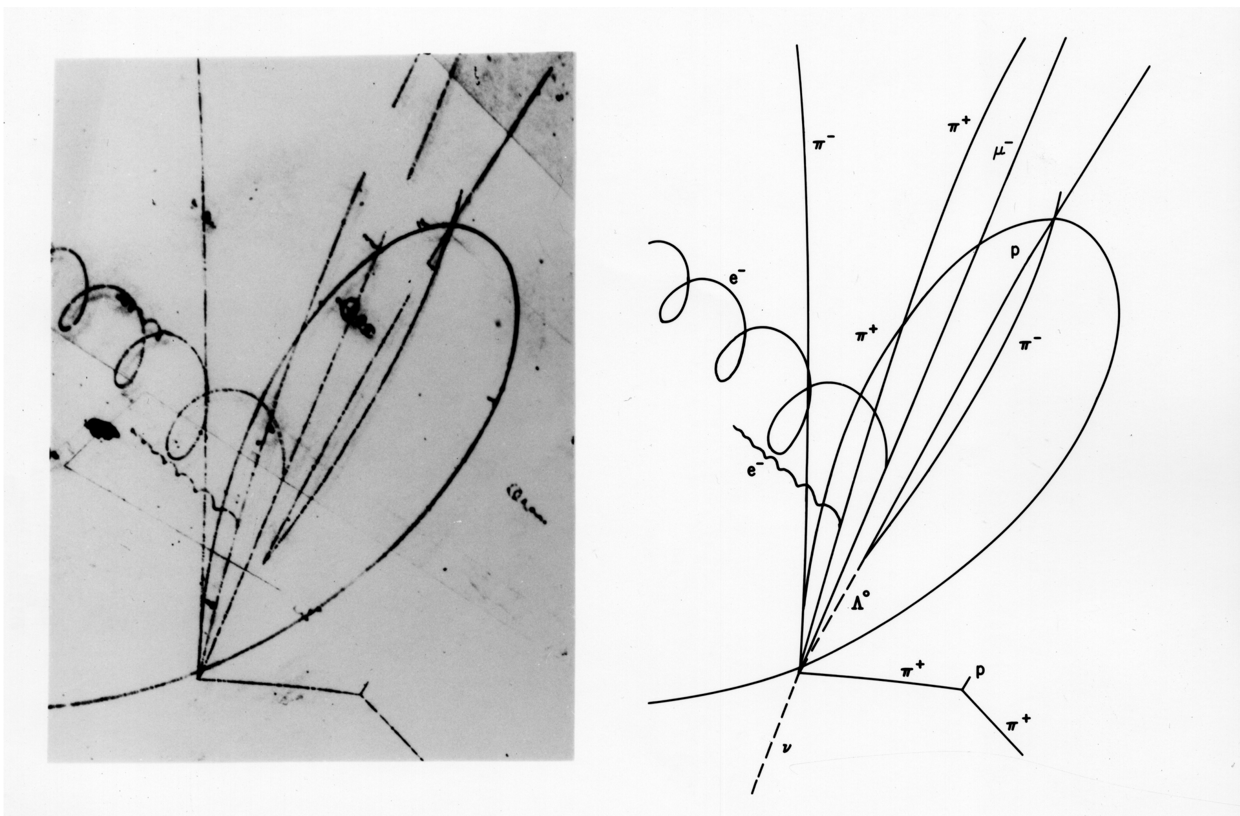

Figure 2: Bubble chamber photograph of the Ω^- decay products.

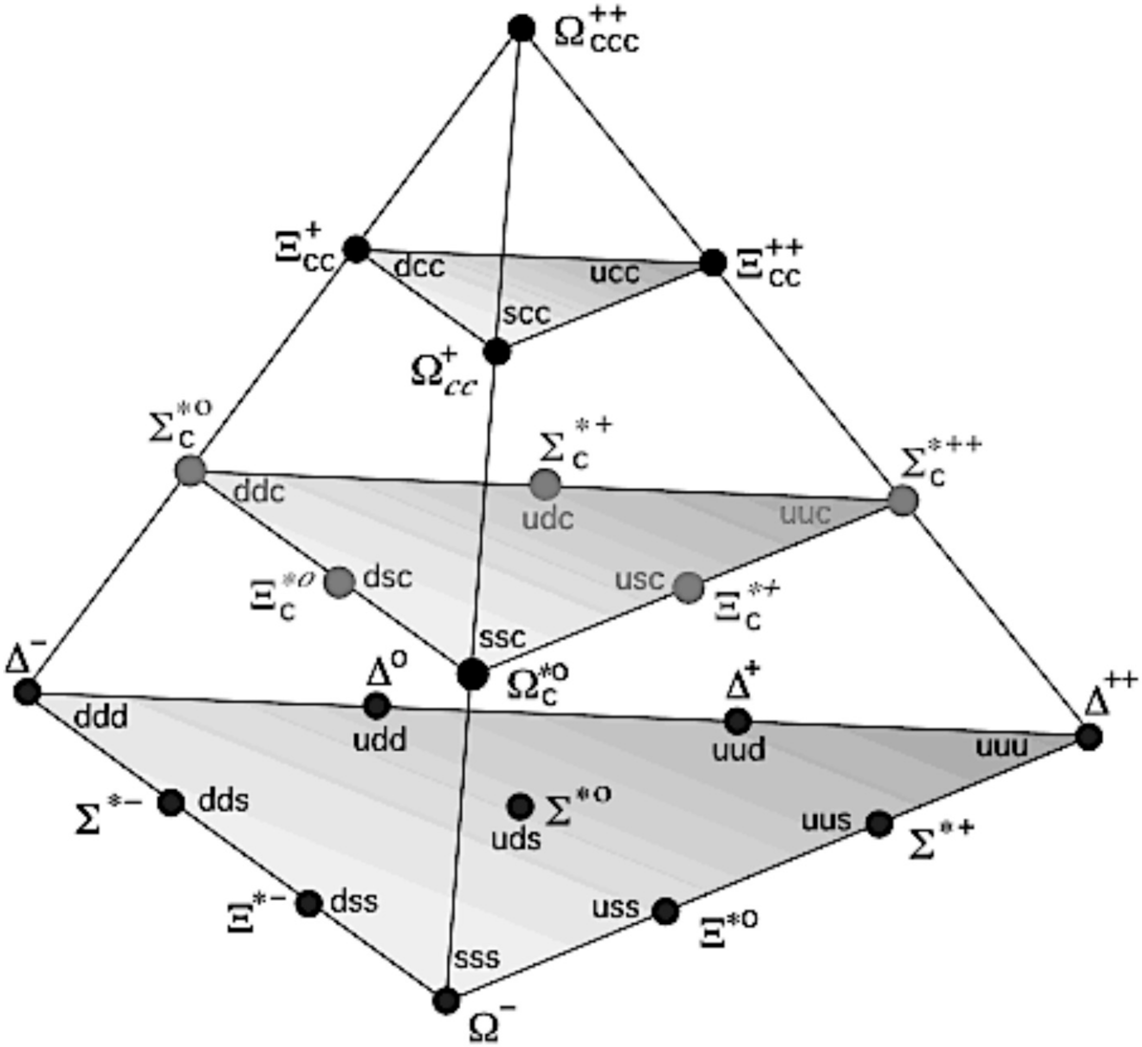

Figure 3: A 20plet of baryons using four types of quark.