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1 The Quark Parton Model

In 1964, Gell-Mann and Zweig, against all experimental result, suggested that the fundamental triplet does exist and it contains three so called quarks. The quarks are the building blocks of the baryons and mesons and they cant be found in isolation. The quarks come with three different flavours: up(u), down(d) and strange(s) and their antiparticles. This set of three quarks corresponds to the fundamental SU(3) representation. The quantum numbers of quarks with their antiparticles are given in Table 1. The quarks carry electric charges $\pm\frac{2}{3}$ and $\pm\frac{1}{3}$ of the electron charge, which has never been observed before.

Quark	Spin	Parity	e_q	I	I_3	S	B
u	1/2	+1	+2/3	1/2	+1/2	0	+1/3
d	1/2	+1	-1/3	1/2	-1/2	0	+1/3
s	1/2	+1	-1/3	0	0	-1	+1/3
$\bar{u}$	1/2	-1	-2/3	1/2	-1/2	0	-1/3
$\bar{d}$	1/2	-1	+1/3	1/2	+1/2	0	-1/3
$\bar{s}$	1/2	-1	+1/3	0	0	+1	-1/3

Table 1. Quarks in the Quark Model with their quantum numbers and electric charge n units of electron charge

Baryons are obtained by as a combination of three quarks(qqq) and mesons by combining a quark and an antiquark ($q\bar{q}$). From the rules for combining representation of SU(3) one can show the patterns of baryons and mesons[1]:

$$q\bar{q} = 3 \otimes 3 = 1 \oplus 8$$

$$qqq = 3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$$

The constituent quark model describes a nucleon as a combination of three quarks. According to the quark model, two of the three quarks in a proton are labeled as having a flavor "up" and the remaining quark a flavor "down". The two up quarks have fractional charge $+\frac{2}{3}e$ while the down quark has a charge $-\frac{1}{3}e$. All quarks are spin $\frac{1}{2}$ particles. In the quark model each quark carries one third of the nucleon mass.

Since late 1960, inelastic scattering experiments were used to probe a nucleon's excited states. Performed experiments suggested that the charge of the nucleon is distributed on a pointlike constituents of the nucleon. The experiments at the SLAC used high energy electrons scattered by nucleons, where virtual photon is the mediator between the target nucleon and coulomb scattering of an electron. The four-momentum, Q, of the virtual photon serves as a measure of the resolution of the scattering and may be formulated as:

$$d = \frac{\hbar c}{Q} = \frac{0.2 \text{ GeV} \cdot \text{ fm}}{Q}.$$

The electron scattering data taken during the SLAC experiments revealed a scaling behavior, which was later defined as Bjorken scaling. The inelastic cross section was anticipated to fall sharply with Q^2 like the elastic cross section. However, the observed limited dependence on Q^2 suggested that the nucleons constituents are pointlike dimensionless scattering centers. Independently, Richard Feynman introduced the quark parton model where the nucleons are constructed by three point like constituents, called partons.

Shortly afterwards, it was discovered that partons and quarks are the same particles. In the QPM the mass of the quark is much smaller than in the naive quark model. In the parton model the inelastic electron nucleon interaction via the virtual photon is understood as an incoherent elastic scattering processes between the electron and the constituents of the target nucleon. "In other words, one assumes that a single interaction does not happen with the nucleon as a whole, but with exactly one of its constituents."[2] In addition, two categories of quarks were introduced, "sea" and "valence" quarks. The macroscopic properties of the particle are determined by its valence quarks. On the other hand, the so called sea quarks, virtual quarks and antiquarks, are constantly emitted and absorbed by the vacuum.

The inelastic scattering between the electron and the nucleon can be described by the two structure function, which only depend on x_B Bjorken scaling variable - the fraction of nucleon four-momentum carried by the partons.

It was experimentally shown, that the measured croos section of inelastic lepton-nucleon scattering depends only on x_B, as it was mention above it is reffered as scaling. If there where additional objects inside the nucleon beside the main building partons, it would introduce new energy scale. The experimental observation of scaling phenomenon was the first evidence of the statement that the quarks are the constituents of the hadron. The results which were obtained from MIT-SLAC Collaboration(1970)are presented below on Figure 1 and 2 [2] [3] . It clearly shows the structure function dependence on x_B variable and independence of the four-momentum transfer squared.

Figure 1. Scaling behavior of $\nu W_2(1/x_B) = F_2(1/x_B)$ for various Q^2 ranges.

Figure 2.Value of $\nu W_2(Q^2) = F_2(Q^2)$ for $x_B = 0.25$.

The quark parton model predictions are in agreement with the experimental results. One of those predictions is the magnet moments of baryons. For example, the magnet moment of the proton should be the sum of the magnetic moments of the constituent quarks according to the naive quark model [4]:

$$\frac{e}{2m_p}\mu_p = \Sigma_{i=1,2,3} < P_{\frac{1}{2}}|\frac{e_q(i)\sigma_z(i)}{2m_p(i)}|P_{\frac{1}{2}} >$$

Assuming that the masses of light non-strange quarks are just one third of the total nucleon mass $m_d = m_u = \frac{m_p}{3} = \frac{m_n}{3}$ and expressing the magnetic moment in units of $\frac{e}{2m_p}$ we get the following result $\mu_p = 3$, which agrees with the findings of experiment. In addition, the quark parton model predictions of magnetic moments of the other baryons are compared with the experimental results below in Table 2. As it can be observed, it is in agreement with the experiment within the accuracy of 20 - 25 %.

Particle	Prediction (MeV/c^2)	Experiment (MeV/c^2)
p	930	937
n	1230	1232
Λ	1110	1116
Σ^+	1377	1384
Σ^-	1377	1384
Ξ	1329	1318
Ξ^0	1529	1533
Ξ^-	1529	1533

Table 2. Magnetic moment of baryons in units of nuclear magnetons ($\frac{e}{2m_p}$). [4]

The Quark Parton Model was succesful explaining the mass of baryons. The baryon masses can be expressed in the quark model using the de Rujula-Georgi-Glashow approach:

$$m_B = \Sigma_i m_q(i) + b\Sigma_{i\neq j}\frac{\sigma(i)\sigma(j)}{m_q(i)m_q(j)}$$

The difference between the actual experimental results and the predictions is in order of 5 -6 MeV. On the other hand, the similar formula for meson masses fails. The difference in meson mass case, between the experiment and calculation is approximately 100 MeV. This can be explained, by calculating the average mass of the quark in a baryon and meson [4] :

$$< m_q >_M = \frac{1}{2}(\frac{1}{4}m_\pi + \frac{3}{4}m_p) = 303MeV$$

$$< m_q >_B = \frac{1}{3}(\frac{1}{2}m_N + \frac{1}{2}m_\Delta) = 363MeV$$

Particle	Prediction (MeV/c^2)	Experiment (MeV/c^2)
N	930	937
Δ	1230	1232
Σ	1178	1193
Λ	1110	1116
Σ^*	1377	1384
Ξ	1329	1318
Ξ^*	1529	1533
Ω	1675	1672

Table 3. Baryon mass predictions compared with experimental findings. [4]

References

[1] Close, F.E. (1979). *An Introduction to Quarks and Patrons.* London, UK: Academic Press Inc. LTD.

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[4] Anisovich, V.V., Kobrinsky, M.N., Nyiri, J., & Shabelski, Yu. M. (2004). *Quark Model and High Energy Collisions.* World Scientific Publishing Co. Pte. Ltd.