Leptonic behavior of constituents of baryons.

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Abstract

The striking results that the same expression relating mass to the magnetic moment and to flux quantization applies to baryons and to leptons indicate that the theoretical interpretation of this finding must be the same for all these particles, with little (or no) participation of other than electromagnetic(quantum) effects. The generation of leptons and baryons seems quantitatively associated to the excitation of "dressed" particles states with (rest) energies *describable* in terms of interactions between "anomalous" magnetic moments and a self-magnetic field, as proposed by Barut in his theory for the muon.

Introduction

The present paper goes deeper into the analysis introduced in previous publications by the author[1,2] on the subject of the origin of Mass. In our recent analysis of data for leptons and baryons[2] it was possible to show that leptons and baryons can have their masses described by the same expression as a function of their magnetic moments, supposing as valid a model in which gauge invariance imposed to the problem converges to magnetic flux quantization. The inverse dependence of mass upon the alpha constant is obtained from this analysis.

Several authors have reported the dependence of the rest masses of particles upon the inverse of the alpha constant. Barut [3-5] was able to obtain such result considering that heavy leptons are actually “dressed” electrons. Barut initially considers an electron subject to an additional interaction term between its self magnetic field and a magnetic moment, the radiative reaction term attributed to relativistic effects. The radiative reaction term is proportional to the α constant, which gets introduced in the analysis.

The quantization of the problem is carried out by taking the Dirac equation and inserting in it a current containing a convective reaction term proportional to the momentum *p*.

$$[\,(\gamma - \alpha_2\, p)p - m_e]\psi = 0 \qquad (1)$$

Here γ is a Dirac matrix associated with velocity(in c =1 units) and m_e is the electron mass. The results of Barut´s work in which we are most interested can be obtained simply by taking a scalar form of equation 1. Replacing γ by 1 and recognizing that the parameter α_2 (to be determined) should be of order α(small) one immediately obtains a second order equation for the allowed values of mass if one takes p as simply proportional to the dressed particles mass m. Imposing that the quantity between square brackets is null leads (in the limit of small α_2) to two values for m: $m_1= m_e$, and $m_2= 1/\alpha_2 - m_1$. The theory therefore predicts the existence of a heavier particle in addition to the electron. The parameter α_2 (and thus m_2) is obtained in the following way. One can consider one of two possible interpretations for the heavier particle(the muon). Either it is an ordinary lepton of g=2 and mass m_2, or it is a “dressed” electron with the electron mass m_e and a different value of g-factor, g_d , to be determined. The dressing effects are those from self-interaction with its own electromagnetic field. The “anomalous” factor corresponds in the classical picture to a magnetic moment, which interacting with the magnetic self-field alters the mass (= rest energy interpreted as magnetic energy) towards the much greater value m_2. Barut argues from a comparison with a classical relativistic rotating particle that such dressed state would have the quite small value of $g_d = 4\alpha/3$ in suitable units. The values of α_2 and m_2 are obtained by turning magnetically identical the two interpretations for the muon, that is:

$$\frac{2}{{}^{1}/_{\alpha_2} - m_e} = \frac{g_d}{m_e} \qquad (2)$$

One immediately obtains from this simplified calculation the usually reported value for the muon mass: $m_2 = (3/2\alpha)m_e$ (which differs from Barut´s much more detailed calculation by about 0.7%).

In fact our previous work obtains exactly this result by going straight towards the core of the problem, which is the association of self magnetic energy with the rest energy, in a way similar to that adopted by Post many years ago[6]. For this purpose the work of Saglam and collaborators [7] becomes quite relevant. These latter authors have found out from a classical spin-top model that a magnetic moment of one leptonic or nuclear magneton corresponds to one quantum of flux. This leads to a direct method for obtaining the “anomalous” self-interacting magnetic energy for any lepton or baryon, as discussed in [2].

Our previous work begins with the concept of gauge invariance and consequent flux quantization associated with the zitterbewegung intrinsic motion of fundamental particles. We then associated the magnetodynamic energy of the motion with the rest energy of a particle[1,6]. The main result of such phenomenological analysis was eq. (3) of [2]:

$$\frac{mR^2}{\mu} = \frac{nh}{2\pi ec}$$

As explained in [2] , R can be taken proportional to μ. Inserting the definition for R into (1) and using the definition of the fine structure constant alpha, $\alpha = e^2/\hbar c$, we rewrite this latter equation in the form:

$$\frac{2c^2\alpha}{ne^3} m = \frac{1}{\mu} \tag{3}$$

It can immediately be noticed that if n and μ are proportional to each other, eq. (3) would produce an inverse dependence of m with the alpha constant, as reported in the literature.

Application to Leptons and Baryons

A.O.Barut [8,9] proposed an alternative theory for the inner constitution of baryons and mesons, in which the basic pieces would be the individual, *stable* unit-charge particles, namely the proton and the electron (and in addition, the neutrino). After so many years, evidence has accumulated in support of the quark model as far as the inner structure of baryons is concerned. However the fact that the decay products of baryons are unit-charge particles is an important result which is explored in the analysis that follows. Barut proposed also that the short range strong interactions between such internal constituents would be magnetic in nature. Although we do not develop such proposal in detail, the present model , whose main result is eq. (3), follows similar lines as the energies involved are magnetodynamic. The application of eq. (3) requires a quantum-theoretical method for a precise determination of the values of n, the number of flux quanta, which is not available. In ref. [1] a tentative method of calculation based on the possibility of adding the contributions from each quark individually was proposed. However, the strict determination of these numbers would require the knowledge of the proper topological properties of each baryon and how to sum individual contributions from its constituents. Topological details would certainly have an effect on these numbers, which might even be half-integers.

However, there actually exists a semiclassical treatment that offers a way to deal with this issue[7]. Self-magnetic field effects produced by the intrinsic (spin) motion of a particle would impose also a simultaneous cyclotron rotation. Both effects taken together produce magnetic flux across the orbit, which leads to the conclusion that *one fundamental magneton (either Bohr´s, or leptonic, or nuclear) of magnetic moment produced by an* *elementary unit of charge is related to exactly one quantum of magnetic flux trapped inside the orbit*[7]. The derivation is valid for unit-charge leptons and the proton. That is, considering that *flux conservation* is followed in the decay of baryons, even in the absence of knowledge about how to impose flux quantization to quarks one might concentrate only on the unit- charged final products of the decay. From the standpoint of the present analysis this establishes a scaling criterion to convert the experimental values of the magnetic moment for particles (in nuclear or leptonic magneton units) into a number of flux quanta *n*. Ideally, this implies for the baryons that the ratio $n/\mu(\text{n.m.}) \rightarrow 1$. Consistently with what is expected from [7], in Table 1 we notice that the magnetic moments for the baryon *octet* in the last column are ordered in almost integer, small numbers of nuclear magnetons. Considering that the magnetic moments should be proportional to the number of flux quanta trapped in the zitterbewegung motion, we take for *n* the integer or half-integer number which is closest to the observed magnetic moment in nuclear magneton units. The results for the leptons and baryon octet are displayed in Table 1. All the magnetic moment data for the baryons (octet and decuplet) come from [10]. Table 2 presents the data for the baryon decuplet particles.

Analysis: The Effect of Spin on Mass Determination.

Figure 1 shows the plot of eq.(3) and the lower straight solid line should be followed for a perfect agreement with theory. We observe that eq. (3) describes very well the data available for leptons (solid triangles) and the octet of baryons (circles) with the values of *n* in Table 1. Relativistic corrections are apparently very similar (or absent)for all these spin-1/2 particles. When we plot the data for the decuplet (open triangles) we notice a quite revealing distribution of the points, forming a second line parallel to the lower straight line shifted by a factor of 1.7. This is a very important result, which indicates the influence of spin on this analysis.

The following heuristic interpretation seems applicable in this case. The baryons of the decuplet are spin-3/2 particles. The spin angular momentum is given by the product of the frequency of rotation times the moment of inertia of the particle(such simple picture persists even in a detailed field-theoretical treatment of the angular momentum problem in the internal rest frame of reference of an electron[8]). In this case the frequency is the zitterbewegung rotation frequency $2mc^2/\hbar$ which is proportional to mass, while the moment of inertia is proportional to the mass and to the square of the mass (energy) distribution range ρ^2. Therefore, if one picks a point on each line of Figure 1 at the same value of the abscissa μ, the ratio between the values of m^2 for the octet and the decuplet particles is 1/3 in view of the ratio between the spin angular momentum values, assuming that ρ should be about the same since it is associated with the magnetic energy density spatial distribution due to the zitterbewegung charge motion. Since n should also be the same for same values of μ we immediately conclude that the theoretical ratio between the ordinates (m/n) of these two points is $\sqrt{3}=1.73$, with the octet line below the decuplet line, shifted by the logarithm of this number, a behavior that is generally followed by the experimental data in the Figure. The pair of real particles in Figure 1 which comes closer to strictly following this condition is that formed by the neutron(n) and the decuplet hyperon Ω^- (cf. data on the Tables and the Figure). They have practically the same magnetic moments and their rest masses differ by 77%, which is very close to the theoretical value 73%. The agreement is poorer (points below the upper line)for the most unstable decuplet particles (meanlives of about 10^{-24} sec.)since the values of ρ should vary markedly when compared to the much more "stable" octet particles(meanlives of 10^{-11} sec. or longer). Miller´s calculations [11] display the full *superposition* of the charge density of quarks – and thus smallest possible ρ – in stable nucleons. It is thus expected that unstable particles are spread in larger regions since their constituents would not fully superimpose during their extremely short lives, and thus the mass of unstable particles can lay below the upper line in the Figure since the angular momentum is compensated by the increase in ρ.

It must be pointed out that most of the data for the magnetic moments for the decuplet are theoretical and vary according to the parameters adopted in the calculations [10]. In recent years there have been reports about the surprisingly small influence of quarks on the spin of nucleons, which has been experimentally determined[12]. Gluons have been suggested as the main responsible for spin. The results in Figure 1 indicate that the origins of the rest energy in leptons are the same as in baryons with a strong influence of spin. Since the fully quantum electromagnetic model of Barut seems applicable our results (including the value of spin) are consistent with very little (or none) influence of strong forces attributable to quarks. The whole treatment requires arguments based upon EM theory only.

Detailed investigations have been carried out to gather and interpret experimental data for mesons and baryons[13-14]. A dependence of mass with the inverse powers of α has been reported. We see from eq. (3) and Figure 1 that an inverse relation with α indeed is part of our results, since following [7] the ratio n/μ is essentially the same for all baryons. The differences are theoretically related to the particular representations of SU(3) to which each of them belong. In particular, eq. (3) applied to the nucleons produces the same expression for mass as that obtained by MacGregor, which writes it as a function of the electron mass and the alpha constant only[13].

Conclusions

We have applied the previously developed magnetic energy model for the origin of particles [2] to the entire baryons octet and decuplet. The theoretical expression eq. (3) fits well the octet particles and leptons. The shift between the plots for the decuplet as compared to the octet of baryons can be quantitatively attributed to the greater spin. The analysis in this paper reinforces the perception that geometrical or topological effects dominate the problem of mass determination, and thus the consideration of magnetic effects in the subnuclear scale is essential, as proposed by Barut, among others.

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Table 1: Data utilized in Figure 1 for leptons and the octet of baryons. Following [7], the values of *n* are chosen as the integer or half-integer numbers that follow as close as possible the sequence in the last column for the baryons, in order to fit theory to data. The magnetic moments are from ref. [10]. A leptonic magneton (l.m.) refers either to the Bohr magneton for the electron or to the same formula with the muon mass replacing the electron mass. All magnetons refer to unit(elementary)-charge particles. One needs to convert mass to grams, magnetic moments to erg/gauss (all CGS units).

part	Rest energy(MeV)	n	(Abs)Magnetic moment(n.m. or l.m.)
e	0.511	1	1
muon	105.66	1	1
p	938.27	3	2.79
n	939.56	2	1.91
$\Sigma +$	1189	2.5	2.46
$\Sigma 0$	1192	1	0.85 (theor.)
$\Sigma -$	1197	1.5	1.16
$\Xi 0$	1314	1.5	1.25
$\Xi -$	1321	1	0.65
Λ	1116	0.5	0.61

Table 2: Data utilized in Figure 1 for the decuplet of baryons. Following [7], the values of *n* are chosen as the integer or half-integer numbers that follow as close as possible the sequence in the last column, in order to fit theory to data. The magnetic moments are from ref. [10](only the first and last are experimental results; the others are theoretical). The Δ^0 particle is not included since its (theoretical) moment is zero. One needs to convert mass to grams, magnetic moments to erg/gauss (all CGS units).

part	Rest energy(MeV)	n	(Abs)Magnetic moment(n.m.)
Δ++	1230	4	4.52
Δ+	1234	3	2.81
Δ–	1237	3	2.81
Σ +	1379	3	3.09
Σ 0	1380	0.25	0.27
Σ –	1382	2.5	2.54
Ξ 0	1525	0.5	0.55
Ξ –	1527	2	2.26
Ω –	1672	2	2.02

Figure 1: Plot of eq. (3). Solid triangles are leptons, solid circles represent the baryon octet, and open triangles the decuplet. The upper line is a factor of 1.7 above the lower line, which corresponds to perfect agreement with eq. (3). This shift is attributed to the ratio 3 between the spin of the decuplet and octet particles, which shifts the scales for each plot by a factor of √3 (see text).