The Periodic variation of Baryon masses as a function of their Magnetic Moments, and the Stability of the Proton.

Osvaldo F. Schilling

Departamento de Física, Universidade Federal de Santa Catarina, 88040-900, Florianópolis, SC. Brazil. email: osvaldo.neto@ufsc.br

Abstract: The analysis of *tabulated* data for all baryons of the octet and decuplet reveals that, due to quantum interference of closed current paths in the femtometer scale, *The masses of spin ½ baryons, in proton mass-units, are simple periodic functions of their magnetic moments, in nuclear magneton-units.* The analysis shows that currents have either a simple ring form (the neutron case) or a closed winding shape(the proton case), depending on the amount of magnetic flux enclosed/linked by the current. We argue that the stability of the proton is promoted by this particle winding currents ability to enclose/link *a total integer* (three) number of magnetic flux quanta, something not achieved by the neutron in a planar ring current path, which only links but does not enclose enough flux.

keywords: Quantum interference, Regularization techniques, Magnetic flux quantization.

1) **Introduction, and discussion of the theory in previous work**.

In recent years the author has carried out investigations on the possible application of electrodynamics in the theoretical analysis of Particles properties, like in the determination of their masses, and their relation to magnetic flux confinement inside the Particle. This led to the association of the origin of Particles to a topological transition(to a current loop-state) starting from plane waves in an environment at 10^{13} K (possibly Big Bang conditions) [1,2]. In view of the amount of data available, the analysis has been concentrated on the baryons of the octet and decuplet.

Quantitative agreement between models and data has been achieved adopting a relativistic circular ring of currents model for the baryons[1], in which is included the concept (introduced by Asim Barut in the 1970s [3]) that a proton-state(with mass m_p)surrounded by a cloud of mesons, neutrinos, and electrons is taken as a fundamental element present in all baryons. It is inevitable to notice the potential similarity of this problem to the one of determining the dynamic properties of currents flowing around a conventional superconductor ring, which is confirmed by this investigation.

The ring model is explicitly developed to represent spin ½ particles, since elements of such quasi-proton can circulate in two opposite directions in the ring plane. Making reference to details available in

previous publications[1], a Dirac equation is written for the ring-shaped distribution of charge that models a Particle. The propagation of momentum around the ring (of encircling perimeter L) takes place by local elemental displacements, like in a vibrating string. Bohr-Sommerfeld quantum conditions impose a continuity of phase around the ring that introduces an infinite number of vibrating modes (indexed as k), given by the momenta $p_k = 2\pi\hbar k/L$. The fundamental state is obtained by summing up over these modes. This sum diverges, but the converging part of the solution can be isolated by applying a Regularization ("Reg" below) procedure that extracts the diverging parts, which are associated to the surrounding infinite environment[1]. The Dirac equation and its solution include a magnetic gauge field A , which introduces an amount of magnetic flux ϕ arrested inside the ring and produces a magnetic moment μ. The flux $\phi = A\ L$ is defined in numbers n of magnetic flux quanta $\phi_0 = hc/e$, which is *linked* by the current ring and is associated with the magnetic moment. It will be necessary to define an additional amount of flux $\Delta\phi$ (and associated number of flux quanta Δn) fully *concealed/enclosed* in a possible closed whirling/winding path of the current, so that its magnetic field has *no external effect* upon the measured μ.

The solutions of the Dirac hamiltonian provide energies which are associated with the rest energies Mc^2 of the baryons, through the expression (s → -1)[1]:

$$Mc^2 = U_0 + \text{Reg} \sum_k c\{(p_k + e(\phi+\Delta\phi)/Lc)^2 + m_p^2 c^2\}^{-S/2} \qquad (1)$$

for each baryon of mass M. Here U_0 is the parent state energy of the environment the loops originate from, and is obtained by comparing theory with the mass data for the baryons in the Tables. Equation (1) can be rewitten in dimensionless form. Here the dimensionless parameters are $m' = m_p/m_0$, where $m_0 = 2\pi\hbar/cL$, and $u_0 = U_0/m_p c^2$:

$$M(n)/m_p = u_0 + (1/m')\text{Reg} \sum_k \{(k+n+\Delta n)^2 + m'^2\}^{-S/2} \qquad (2)$$

The second term on the right of (2) corresponds to an internal correlation energy that turns the ring states energetically favorable as compared to the parent state, so that a condensation into ring form takes place. This would be the picture of ring-like Particles formation from a Parent state. The Regularization of the second term in (2) results in(s→ -1, and k + are the positive integers):

$$\text{Reg} \sum_k \{(k+n+\Delta n)^2 + m'^2\}^{-S/2} =$$

$$= \frac{2\sqrt{\pi}}{\Gamma\left(\frac{1-s}{2}\right)} \left(\frac{\Gamma\left(-\frac{s}{2}\right)}{2m'^{-s}} + 2\pi^{-\frac{s}{2}} \sum_{k+} \left(\frac{k}{m'}\right)^{\frac{-s}{2}} K_{\frac{s}{2}}(2\pi m' k) \cos(2\pi k n + \delta) \right) \quad (3)$$

which must be multiplied by $(\pi^{\frac{2s-1}{2}} / \Gamma\left(\frac{s}{2}\right)) \Gamma\left(\frac{1-s}{2}\right)$ and inserted in (2) to give the masses (see ref. 1 for details of the Regularization method). One immediately realizes that the $M(n)$ are periodic functions of n, where phases $\delta = 2\pi k \Delta n$ represent breaks in phase continuity through the list of baryons(see below). It must be pointed out that the Modified Bessel function K in (3) decays very fast with the argument and thus the only term of the sum that actually contributes is $k = 1$ (which defines $\delta = 2\pi \Delta n$).

2) The inclusion of J=3/2 particles data in the analysis.

The baryons magnetic moments data adopted in this analysis come from the first and last columns in Table 3.2 of ref[4], and is presented in Tables 1(baryon octet) and 2 (baryon decuplet).

Only the octet particles are spin J= ½ particles. To include more data in the analysis, one needs to obtain also values of mass for the decuplet (J=3/2) particles in an *hypothetical* spin ½ state. The infuence of

magnetic properties on mass is also an important issue. These properties are represented by a number of flux quanta n , and by μ, the magnetic moment.

Firstly, in our previous publications a parameter n is defined for spin ½ particles through the equation[1] (α is the fine-structure constant)

$$n = (2c^2\alpha/e^3) \mu m. \qquad (4)$$

Such definition (based upon Post´s cited work below) is *useful* for discussion and associates an n to the available tabulated data, but neglects quantum interference and is strictly applicable when all the magnetic flux produces a magnetic moment. Assuming initially that this is the case, we notice that m on the right side is proportional to the ratio n/μ, which contains the magnetic part of the mass in the form of a ratio. In planar ring current paths n and μ should be proportional to each other, since magnetic flux inside a loop of radius R is given by $2\pi\mu/R$. The spin should not affect R, and thus we come to the useful conclusion that *magnetic effects on mass should not change for excited spin states* like J= 3/2(that is, depending on spin, n and μ might vary but would keep their proportionality ratio, and thus *net magnetic effects* would essentially remain unaltered under spin variation). This particular point is confirmed by Corben's[5] detailed Particles data analysis, in which baryons and mesons in different spin states are

shown to obey simple relations of the kind "J proportional to M^2 + constant", where J and M (mass) are in dimensionless units. This is no surprise since spin is indeed a global(nonlocal) property related to Mass [6,7]. It is thus consistent with Post´s and Corben's work that the increase in mass of the observed decuplet particles as compared with the octet particles can be attributed to the greater spin and not to any net changes in magnetic contribution in (4). This will be explored in the analysis below.

Values for n from (4) are relevant for discussion. To obtain suitable values for n in the *decuplet from eq.(4) and spin ½* we then proceeded as follows, imposing consistency with Corben´s work. Firstly we recognize from inspection of the tabulated magnetic moments that each of the Δ(including the nucleons N), Σ, and Ξ families of particles has in the decuplet 3/2 spin state a particle with a magnetic moment which is very close in absolute value to the moment of a particle of same family in the octet ½ spin state. This indicates that hypothetical ½ spin state decuplet baryons may be assumed to have the same masses as the octet baryon particles of same family. In addition, the decuplet spin 3/2 magnetic moment may be attached to the proposed octet particle provided n/μ remains unchanged, for consistency with Corben´s analysis. Therefore, from this reasoning one concludes that n is obtained for this state by inserting in (4) the octet particle mass and the

respective tabulated spin 3/2 magnetic moment, since this would keep the ratio n/μ unaltered by spin change.

This is applied to the Δ, Σ, and Ξ families of decuplet particles, but the particle Ω is a special case. It does not have a tabulated octet spin ½ version for comparison. Therefore, firstly mass for the hypothetical spin ½ state of the decuplet baryon Ω is obtained by subtracting from the spin 3/2 mass the overall *averaged mass excess* of all decuplet particles over the octet masses, which is 244 MeV/c^2 . Then, the value of *n* is determined as for the other particles.

The masses for the ½ spin versions of the decuplet Particles are called *transformed masses* m_t and are shown in Table 2, and are actually the same as the octet particles masses. Then, as said, values of *n* are obtained from eq (4) adopting the transformed masses to simulate spin ½ for decuplet particles, alongside the available values of μ for the decuplet, which we assume as good since values of *n* are chosen to keep the same n/μ ratios under spin change. Albeit not fully rigorous, through eq.(4) and ref. [5] we justify the utilization of the magnetic moments of the decuplet particles for the hypothetical octet particles, since these data are needed for the mass calculations below.

The Tables show that the obtained ratios n/μ are close to unit in dimensionless units for many Particles, which is the expected result for

a circulating ring path of current. However, the Tables also show there are "jumps" in the values of n , which can be attributed to the presence of an extra flux Δn, not related to a magnetic moment, and phase displacements in eq. (3) are expected. Flux penetration through weak-links are usually associated with these jumps in superconducting current paths[8]. However, such effect is not considered in the perfect-ring circuit model calculations adopted, which resulted in the simple cosinusoidal expressions (2)-(3) with $\delta = 0$. Since μ might be considered the unperturbed version of the parameter n (cf. eq. 6 of ref.[6], taking $s = 1$ there), we take $n = \mu$ in eq.(3), and associate the breaks to the parameters Δn and δ. By proceeding this way the plot in Figure 1 reveals a relevant new result.

Analysis.

Figure 1 clearly displays the periodic behavior of eqs. (2)-(3) in the fit of the data. The dashed line is a perfect cosine($\delta = 0$) and fits data up to $\mu = 2$. It is particularly interesting to note that calculations in [4], Table 3.2, predict the null magnetic moment of the Δ^0 particle, which agrees with the dashed $\delta=0$ curve close to $M/m_p = 1$(red point on the Figure at $\mu=0$). This would be the only particle with null magnetic moment predicted by the present model, and the calculations in [4] agree on this prediction.

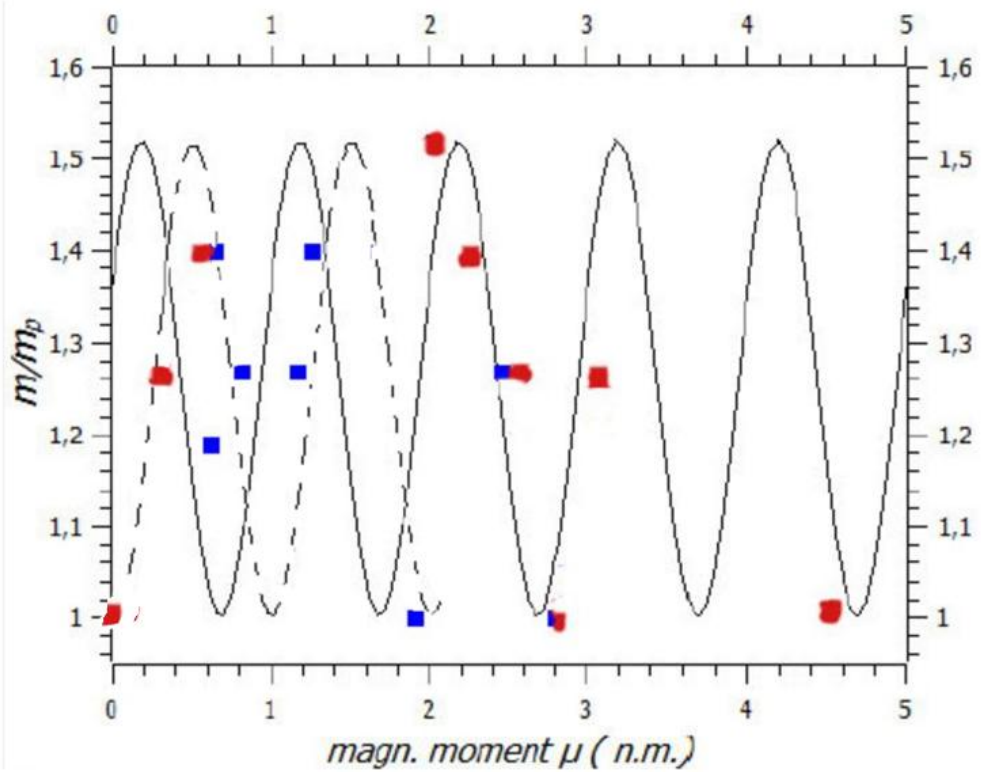


Figure 1: Plot of the ratio M/m_p from Tables 1(blue points) and 2 (red points, m_t adopted for Table 2 data) using the magnetic moments in the Tables in place of *n* in eqs. (2-3). The phase-displaced cosine curves are the plot of eqs.(2-3) with μ in place of *n* (cf. ref. [6]). One notices the good fits obtained if two curves with $\delta=0$ and $2\pi/3$ are adopted in the fits, one (dashed) below and the other(solid) above $\mu=2$. <u>Note that proton and neutron are not fitted by the same curve</u>.

For magnetic moments μ between about 2 and 5 magnetons, the (solid) fit curve is a phase-displaced cosine, with $\delta=2\pi/3$, which corresponds to additional flux not related to magnetic moment.

Indeed, at $\mu \approx 2$ there is a jump of the magnetic flux calculated from eq.(4) (cf. data for particles n and Ω on the Tables), with *essentially no increase in magnetic moment*, which appears as a jump in mass in the Figure. This is a strikingly revealing feature. In a rather detailed heuristic analysis, Post [8] described exactly this kind of effect, attributing it to a closed winding path of the current superposed to the ring path (like for instance in a trefoil-shaped current path [9]). This would allow an increase of the confined magnetic flux with little effect on the magnetic moment.

In both curves in Fig. 1 the dimensionless parameters are $m' = 0.36$ and $u_0 = 2.5$ ($m' = m_p/m_0$, where $m_0 = 2\pi\hbar/cL$, and $u_0 = U_0/m_p c^{2.}$), which slightly correct numbers obtained in previous publications(a ½ factor is included here in the k=0 additive tern in (3) as compared to the expression in ref. [1]). The u_0 parameter corresponds to $U_0 = 2340$ MeV, which is consistent with the peak position in the plot of cosmic rays protons flux analyzed in previous work[2].

The Stability of the Proton.

This analysis reveals a remarkable difference between the proton and the neutron, which are fitted by different curves. This may be

responsible for the stability of the proton not being shared by the neutron.

For simplicity, let's consider the fit provided by the two curves in the figure as accurate enough for a quantitative analysis. It is indeed a remarkable feature of the presently discussed theories that the proton and neutron are fitted by two *different phase-displaced curves* , corresponding to very different current paths in the two particles. The phase displacement δ of about $2\pi/3$ for the proton curve corresponds to an additional amount $\Delta n = \delta/2\pi = 1/3 \approx 0.3$ flux quanta, concealed in a winding closed current path. Such extra flux *would not exist* in the neutron case, with $\delta=0$. In fact, such extra flux when added to that from $n = \mu = 2.8$ for the ring path allows the proton to just reach the quantum stability condition that requires the net magnetic flux through these paths to be confined *in integer numbers* of flux quanta, that is, $n + \Delta n \approx 3$ in this case. The neutron, with total flux $n = \mu = 1.9$ does not reach the full stability condition. In fact the proton is the only observed spin 1/2 baryon that simultaneously bears the least mass(greatest internal correlation energy[1]), and conceals an *integer* number of magnetic flux quanta, a condition required for stability in lossless closed circuits, and thus would be the only stable baryon.

Further Analysis and Conclusions.

The periodic dependence of energy of currents (here determining the rest masses of baryons) as a function of trapped flux in a ring or tube-shaped superconductor was described theoretically by Byers and Yang[10](cf. their Theorem 1), as a consequence of quantum interference of currents circulating around the trapped flux. The present work shows that existing tabulated data can be organized to display a similar periodic effect happening inside baryons. The tendency for the current loop *reach a stable state in which the enclosed flux is quantized* is also the object of their analysis(their Theorem 4), and we have here the example of the proton particle stabilized at a quantized flux content state.

In conclusion, this paper divulges the following results, immediately obtainable from tabulated data: *the masses of spin ½ baryons, in proton mass-units, are simple periodic functions of their magnetic moments, in nuclear magneton-units*. There is evidence of changes in the topology of currents, which would include closed winding paths as flux increases [8, 9]. The establishment of a closed winding current path (absent in the neutron) seems related to the stability of the proton being achieved at just 3 confined flux quanta.

Results are in accordance with predictions by Byers and Yang[10] for the periodic behavior of the energy of currents in multiply-connected superconductors trapping magnetic flux.

Acknowledgment

The author is grateful to Dr. Indranu Suhendro for his interest on this Research.

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Table 1: Baryon octet data(magnetic moments μ from ref. [4]). According to eq.(4) (gaussian units): $n = 1.16 \times 10^{47} \mu m$. Theoretical (T) values of μ in [4] are indicated. Other values are experimental

	abs μ (n.m.)	μ(erg/G) x 10^{23}	m(Mev/c^2)	m(g) x 10^{24}	n eq.(4)
p	2.79	1.41	939	1.67	2.73
n	1.91	0.965	939	1.67	1.9
Σ^+	2.46	1.24	1189	2.12	3
Σ^0	0.82(T)	0.414	1192	2.12	1
Σ^-	1.16	0.586	1197	2.12	1.5
Ξ^0	1.25	0.631	1314	2.34	1.7
Ξ^-	0.65	0.328	1321	2.34	0.9
Λ	0.61	0.308	1116	1.98	0.7

Table 2: Baryon decuplet data <u>in a spin ½ state</u> (magn. moments μ from ref. [4]). According to eq.(4): $n = 1.16 \times 10^{47}\ \mu\, m_t$ (gaussian units). See text for the definition of m_t.

	abs μ (n.m.)	μ(erg/G) x 10^{23}	m_t(Mev/c^2) (**see text**)	m_t(g) x 10^{24}	n
Δ^{++}	4.52	2.28	939	1.67	4.4
Δ^{+}, Δ^{-} Δ^{0}	2.81,2.81 0(T)	1.42	939	1.67 1.67	2.8 , 2.8
Σ^{+}	3.09 (T)	1.56	1189	2.12	3.8
Σ^{0}	0.27 (T)	0.136	1192	2.12	0.33
Σ^{-}	2.54 (T)	1.28	1197	2.12	3,1
Ξ^{0}	0.55 (T)	0.28	1314	2.34	0.76
Ξ^{-}	2.25 (T)	1.14	1321	2.34	3,1
Ω^{-}	2.02	1.02	1428	2.54	3