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LINEAR MASS RULES AND HADRONIC SHELLS: THE BARYONS

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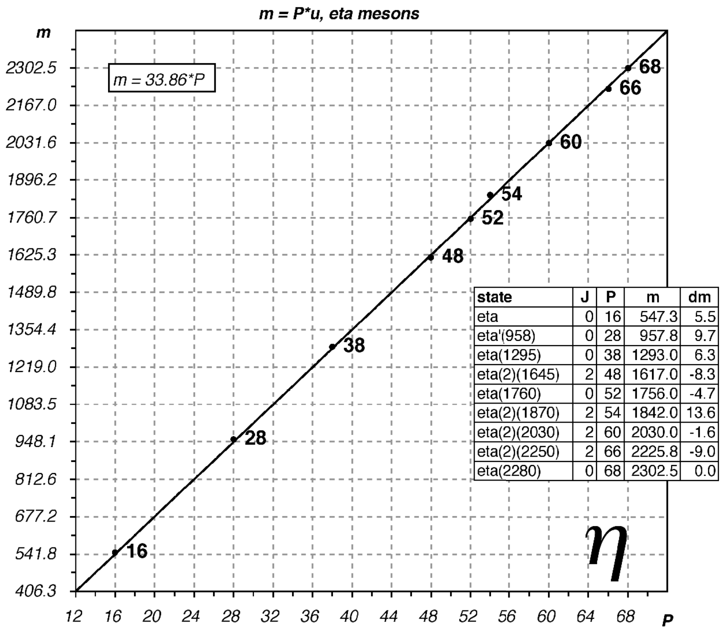
Abstract

The meson mass system is multilinear. This result, combined with a stability analysis of the meson spectrum indicative of shell structure, implies that meson shells are geometrically similar to nuclear shells. In addition, the meson mass rules suggest solid-phase bound states on an fcc lattice, possibly with stable leptons as constituents. The preliminary baryon mass systematics shows compatible linear quantization rules, while the baryonic shell sequence corresponds to a lower constituent density, and starts only at shell 3. The baryonic number might be related to a different lattice organization.



state	J	P	m	dm
eta	0	16	547.3	5.5
eta'(958)	0	28	957.8	9.7
eta(1295)	0	38	1293.0	6.3
eta(2)(1645)	2	48	1617.0	-8.3
eta(1760)	0	52	1756.0	-4.7
eta(2)(1870)	2	54	1842.0	13.6
eta(2)(2030)	2	60	2030.0	-1.6
eta(2)(2250)	2	66	2225.8	-9.0
eta(2280)	0	68	2302.5	0.0

Figure 1: *Mass multiplicity plot for the η mesons: $m_{\rm i} = u * P_{\rm i}$, with the mass unit u and the even integer multiplicities $P_{\rm i}$ obtained by minimization.*

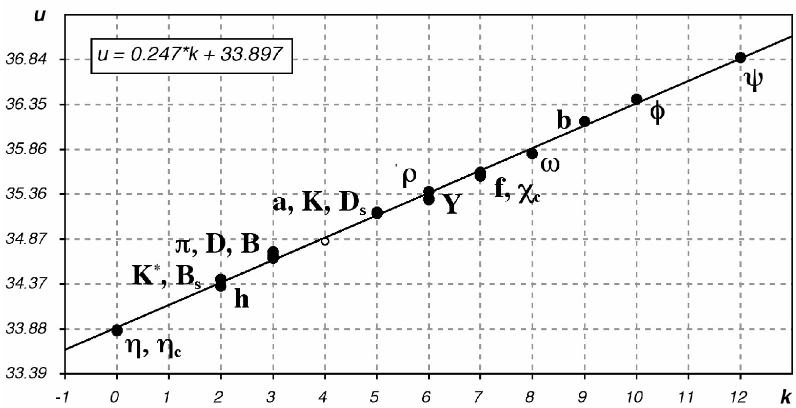


Figure 2: *Meson mass unit grid $u_{\rm k} = u_0 + k * du, k =$ [0..12]; q-qbar asymmetric families with labels above the line, q-qbar symmetric below.*

1 State of the art

The cognitive landscape of particle physics is patchy. Quarks define an accurate and mysterious CKM chemistry and a plausible but incomplete classification scheme, and their identification with the constituents seen in deep-inelastic scattering experiments is problematic. The quark model is still schematic as in the days of Gell-Mann, and the masses of hadrons cannot be derived from quark masses and binding energies. Even more surprisingly, no comprehensive hadronic mass rules are yet part of the accepted body of knowledge.

The standard model is not really satisfactory, and the trend is to go "beyond" it by adding more rather than looking elsewhere. The approach of the present author is to attack the problems of mass rules and hadron models with an open mind, by analyzing the hadron spectrum in the hope of extracting new or not well established regularities which may suggest alternative viewpoints.

2 Mass rules and the mesons

The mass of a bound state is its more fundamental parameter, corresponding to its total energy, and it is surprising that with so many hadron masses, and so many phenomenologists over so many years, there are no established mass rules. Few authors research this field, and publishing such results is problematic: "there are no mass rules, and if you think you found one, you are a crackpot!". Actually the rules are linear and have been known for more than 50 years, although in an approximate formulation.

Y. Nambu observed in 1952 that meson masses are even multiples of a mass unit u of about 35 MeV/c^2, baryons (and also unstable leptons) odd multiples, so that mass differences among similar particles are quantized by 70 MeV/c^2 [1]. M. H. Mac Gregor studied this property extensively [2, 3] and few other authors mentioned it also. Recently this rule has been reassessed by the present author for all the mesons listed by the PDG, grouped by quark composition and J^{PC}, with evaluation of its significance by Montecarlo [4, 5].

This analysis shows that the rule is statistically significant separately for each group and with slightly different values of u (see for example the η mesons in fig.1). For certain groups u is linearly spin dependent, and the different base values of u for the various meson groups are linearly quantized on a grid of 12 intervals, and are strongly correlated with the quantum numbers (fig.2).

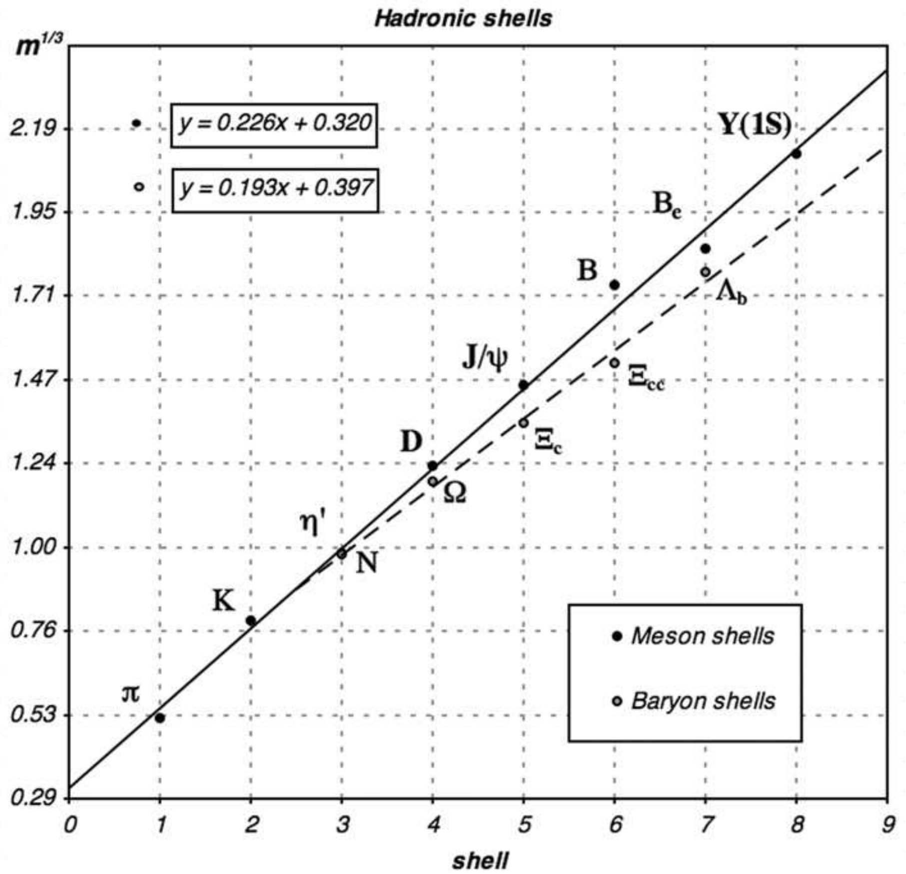


Figure 3: *Hadronic shells, expressed as the cuberoot of the mass (in GeV/c^2) versus shell number. Compared to the mesons, the baryonic shells start only at shell 3, and grow with a lower slope.*

3 Hadronic shells

In atoms and in nuclei, stability is organized with shells, which can be expressed with alignments of the 1/3 power of the total number of constituents of the most stable configurations. Atomic shells show as the cube root of Z for the inert gases charted vs the shell number. Nuclear stability is related mostly to the neutronic magic number series, but with a derived sequence based on the atomic number A = Z + N, stability can be expressed in a similar way [6].

Through the linear mass rules mentioned previously, hadrons can be probed for shell organization. By analyzing the distribution of particle lifetimes as a function of the mass, stability peaks are recognized separately for mesons and for baryons [6], and indeed the cube roots of their masses follow two distinct alignments (fig.3). Postulating that one 35 MeV/c^2 mass unit corresponds to one constituent, the mass and the number of constituents are proportional, giving a strong indication that hadrons may be shell structured.

4 Meson shells

The mesonic shells expressed with the number of constituents are geometrically very similar to nuclear shells: the shell population sequences are almost identical, doubly-magic-equivalent states are present only up to shell 3, and there are also clear indications of sub-shells [7]. The mesonic shell sequence is correlated with the quark composition up to b-bbar in shell 8, and no states are present around the mass values of the hypothetical subsequent shells.

In this context the mesonic mass quantization patterns are compatible with solid-phase partonic bound states on an fcc lattice, with light spin-1/2 partons of charge 0, +1 and -1 coupled anti-ferromagnetically with positive binding energy [7]. Given these constraints, a possible choice for the constituents in agreement with these results (and the only one with non-fictitious particles), are the stable leptons, as proposed by A. O. Barut in a different context, with short-distance electromagnetism acting as the strong interaction [8].

In this unconventional scenario, suggested by the results extracted from the whole meson spectrum, in first approximation there is no dynamic in the bound state, nor any need for color. Mesons are unstable elastic crystals of stable leptons, and at least half of the mysterious parameters of the standard model are no longer needed [7]. What about the baryons?

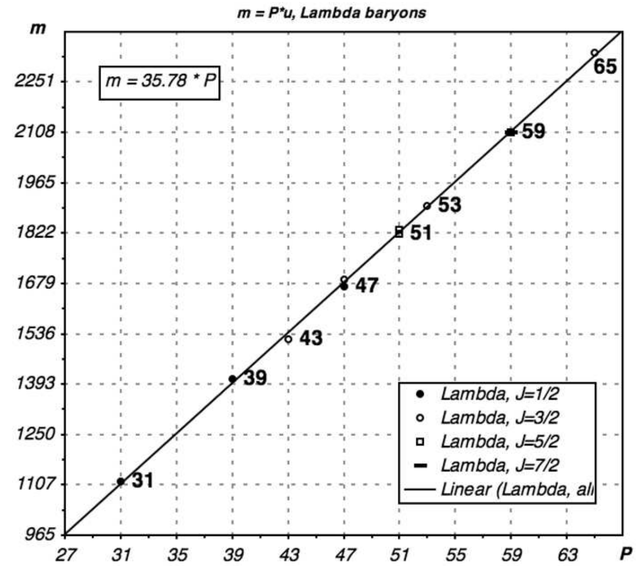


Figure 4: *Mass multiplicity plot for the* Λ *baryons:* $m_{\rm i} = u * P_{\rm i}$*, with the mass unit* u *and the odd integer multiplicities* $P_{\rm i}$ *obtained by minimization.*

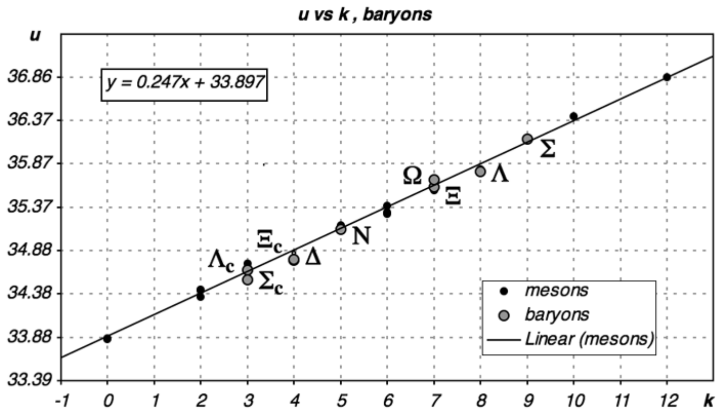


Figure 5: *Baryon mass units plotted on top of the meson grid* $u_{\rm k} = u_0 + k * du, k$ *= [0..12] of fig. 2. Only positions 3,4,5 and 7,8,9 are occupied, respectively by unflavored or charmed baryons, and strange ones.*

5 Baryon mass rules

The same automatic analysis procedure used for mesons can be applied to the baryons, fitting the masses with odd multiples of the same mass unit after grouping the states by quark composition and J^{PC}. For certain baryon families, such as the N and the Δ, the PDG record of each state must be carefully inspected to detect possible mergers of separate states which are close in mass. The complete analysis with all the fits and their statistical significance will be published separately in an extensive report [9]. The results show that the baryon mass rules are very similar to the mesons, but for the odd rather than even multiplicity.

For certain baryon families u is spin dependent with the same coefficient as the mesons. The graph of fig.4 is the multiplicity fit for the Λ baryons, showing no spin dependence. The resulting mass units for the various baryon families can be charted on the same u-grid as the mesons, and show a remarkable pattern (fig.5). Unflavored and charmed baryons occupy positions 3,4 and 5 on the grid, while strange baryons sit at locations 7,8 and 9. Also an amazing sequence of equally spaced Θ^+ baryons [10] (of which only one is listed by the PDG and considered dubious), follows the same periodicity rule with a mass unit of 35.89 MeV/c^2 sharply on mark 8 of the u-grid [11].

6 Baryon shells

By comparing the meson and baryon shell plots from fig.3 it appears that the first baryonic shell is number 3, and that the constituent density of baryonic shells is lower than the mesonic ones. These clues, and the odd mass multiplicity of the baryons, indicate that the baryon lattice organization is different, centered, less dense and also such that only at shell 3 and above the structures are cohesive. Various possible solutions compatible with the constituent count of the various shells are currently being investigated. The radial charge density distribution of the proton and the neutron [12], and the shape of the p-p elastic cross-section [13] also indicate that the nucleon is structured in three layers.

This line of research is incomplete, and a lot remains to be done. If it were to be confirmed, particle physics would loose much of its mysterious aura, and become more structural, along the lines of nuclear physics.

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