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Quarks for Hadrons and Leptons

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The simplest, naive, model for a unified description of leptons and hadrons consists in postulating, besides the usual quarks p, n, *h*, a fourth quark, with very heavy mass and very high binding to pairs like $\bar{p}n$ and $\bar{p}\lambda$. In a SU(4) scheme the fourth quark has a quantum number charm which may be taken as proportional to the lepton number. Muons would be distinguished from electrons by the occurrence of a λ-quark instead of a n-quark in their structure. The forces among these quarks would have to be such as to give leptons an almost point-like structure at the experimentally known energies as well as absence of strong interactions at these energies. However, one would expect the display of strong interactions by leptons at extremely high energies.

O modelo mais simples, ingênuo, para uma descrição unitária de leptons e hadrons consiste em postular, além dos quarks usuais p, *n*, **5** um quarto quark *l*, dotado de massa muito grande e forte ligação a pares do tipo $\bar{p}n$, $\bar{p}\lambda$. Em um esquema SU(4), o quarto quark tem um numero quântico "charm" que seria proporcional ao número leptônico. Muons se distinguem de elétrons pela ocorrência do quark λ em lugar do quark n. As forças entre os quarks deveriam ser tais a dar aos leptons uma estrutura puntiforme as energias conhecidas bem como ausência de interações fortes entre leptons e entre leptons e hadrons. Contudo, seria de esperar que os leptons apresentassem interações fortes a energias extremamente elevadas.

This paper is a report on an attempt made a few years ago by the author to formulate a unified model of quarks for hadrons and leptons. The model has several difficulties, the most important one being the implication that leptons would be expected to display strong interactions; and that the incorporation of lepton and hadron quarks into a multiplet would lead to a violation of the laws of conservation of baryon and lepton numbers.

These difficulties seem now to be less discouraging than in the past. One finds experimentally that the ratio of the cross section for electron pair annihilation into multihadrons to the cross section for electron pair annihilation into a muon pair increases with the energy[1], which is perhaps an indication that at very high energies electrons have strong interactions. On the other hand, the possible violation of the laws of conservation of lepton number and of baryon has recently been proposed by Salam and Pati[2].

Our argument is based on a comparison between the muon-electron mass difference:

$$m_u - m_e \sim 105 \text{ MeV} \tag{1}$$

and the $K^{*-} - \rho^-$ mass difference:

$$m(K^{*-}) - m(\rho^-) \sim 116 \text{ MeV}, \tag{2}$$

the mass difference between K^- and π^- being about three times the above number:

$$m(K^-) - m(\pi^-) \sim 354 \text{ MeV}. \tag{3}$$

Now, what distinguishes the K* from the p-meson and the K^- from π^- is the replacement in the latter of a n-quark by a A-quark. That is, one has, in the Gell-Mann model

$$K^- \sim (\bar{p}\uparrow\lambda\downarrow),$$
$$\pi^- \sim (\bar{p}\uparrow n\downarrow)$$

and

$$K^{*-} \sim (\bar{p}\uparrow\lambda\uparrow),$$
$$\rho^- \sim (\bar{p}\uparrow n\uparrow).$$

One would expect the factor *3* between the numbers (2) and (3) to result from the spin-dependance of the forces between quarks.

This comparison suggests that perhaps the Gell-Mann quarks are also somehow constituents of leptons and that a muon might result from an electron structure by the replacement of a n-quark by a A-quark.

The simplest approach to this idea is then to naively postulate, besides the usual quark triplet, a fourth one, l say, with spin 1/2, zero charge and all quantum numbers zero except a lepton number L = 1. In this scheme, a SU(4) model based on the quartet:

$$q = \begin{pmatrix} p \\ n \\ \lambda \\ l \end{pmatrix},$$

with the following quantum numbers:

	B	L	Q	Y	SPIN	ISOSPIN
p	1/3	0	2/3	1/3	1/2	1/2
n	1/3	0	−1/3	1/3	1/2	1/2
λ	1/3	0	−1/3	−2/3	1/2	0
l	0	1	0	0	1/2	0

would lead to a structure for the electron of the form:

$$e^- \sim (\bar{p}\, n\, l) \tag{4}$$

then,

$$\eta_+ \mid +b, l\rangle = e^{i\alpha} \mid b + \frac{1}{3},\ \mathrm{I}-\mathrm{I}),$$

where η_+ means $(\eta_9 + i\eta_{10})/2$ or $(\eta_{11} + i\eta_{12})/2$ or $(\eta_{13} + i\eta_{14})/2$.

The particle classification would lead to structures of bosons with non vanishing baryonic and leptonic numbers. Thus the pseudoscalar meson multiplet contains:

a) an octet of mesons with L = B = 0,
b) a triplet of lepto-antibaryonic bosons, L = 1, B = −1/3,
c) a triplet of baryo-antileptonic bosons, L = −1, B = 1/3,
d) a SU(4)-singlet, B = L = Q of the form

$$\frac{1}{\sqrt{12}}\,(\bar{p}p + \bar{n}n + \bar{\lambda}\lambda - 3\bar{l}l),$$

e) a SU(4)-singlet, B = L = Q of the form

$$\frac{1}{\sqrt{4}}\,(\bar{p}p + \bar{n}n + \bar{\lambda}\lambda + \bar{l}\,l).$$

The 15 bosons are contained in the matrix:

$$M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} + \frac{\eta_{15}}{\sqrt{12}} & \pi^+ & K^+ & (\bar{l}p) \\ \pi^- & -\frac{\pi^0}{\sqrt{12}} + \frac{\eta_8}{\sqrt{6}} + \frac{\eta_{15}}{\sqrt{12}} & K^0 & (\bar{l}n) \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 + \frac{1}{\sqrt{12}}\eta_{15} & (\bar{l}\lambda) \\ (\bar{p}\,l) & (\bar{n}\,l) & (\bar{\lambda}l) & -\frac{3}{\sqrt{12}}\eta_{15} \end{pmatrix}$$

whereas a muon would appear like:

$$\mu^- \sim (\bar{p}\,\lambda\, l). \tag{5}$$

Similarly, an electron-type neutrino would be of the form:

$$\nu_e \sim (\bar{n}\, n\, l),$$

whereas a muon-type neutrino would be like:

$$\nu_\mu \sim (\bar{n}\lambda\, l).$$

If we call η_j the fifteen traceless 4 x 4 hermitian matrices which generate the SU(4) group, three of them commute among themselves, $\eta_3, \eta_8, \eta_{15}$. The charge Q is defined as

$$Q = \frac{1}{2}\left(\eta_3 + \frac{1}{\sqrt{3}}\eta_8\right) = \begin{pmatrix} 2/3 & & & \\ & -1/3 & & \\ & & -1/3 & \\ & & & 0 \end{pmatrix},$$

the baryon number is

$$B = \frac{1}{2\sqrt{6}}\left(\frac{3}{\sqrt{6}}\, I + \eta_{15}\right) = \begin{pmatrix} 1/3 & & & \\ & 1/3 & & \\ & & 1/3 & \\ & & & 0 \end{pmatrix}$$

and the lepton number:

$$L = \frac{\sqrt{6}}{4}\left\{\frac{1}{\sqrt{6}}\, I - \eta_{15}\right\} = \begin{pmatrix} 0 & & & \\ & 0 & & \\ & & 0 & \\ & & & 1 \end{pmatrix}$$

(equal to the negative charm).

It follows from the commutation rules for the η's that B and L do not commute with η_a for a = 9, ... 14; if $|b, l\rangle$ is as eigenstate of B and L

$$B\,|\,b, l\rangle = b\,|\,b, l\rangle, \qquad L\,|\,b, l\rangle = l\,|\,b, l\rangle\,.$$

In order to obtain the possible structure for leptons one has to consider the reduction of 4 x 4 x $\bar{4}$ which gives:

$$4 \times 4 \times \bar{4} = 36 + 20' + 4 + 4$$

and the SU(3) contents of the resulting multiplets are

$$\begin{array}{l} \underline{36} : \underline{6} ; \underline{15}, 3 ; 8, 1 ; \bar{3} \\ 20' : 3 ; 6, 3 ; 8 \\ 4 : 3 ; 1. \end{array}$$

Besides the construction of objects like

$$\frac{1}{2} (\bar{p}pp) - \frac{1}{3} \frac{1}{2} \bar{n} (np + pn) + \frac{1}{2} \bar{\lambda} (\lambda p + p\lambda) + \frac{1}{2} \bar{l} (lp + pl),$$

which seem not to exist (as well as the lepto-baryonic objects in the pseudoscalar meson classification) one gets the following one

$$e^- = \frac{2}{12} \bar{p} (nl + ln),$$

which could be identified with the electron;

$$\mu^- = \frac{5}{12} \bar{p} (\lambda l + l\lambda)$$

which could be the negative muon. And the corresponding neutrinos:

$$\nu_e = \frac{1}{3} \bar{n} (nl + ln) - \frac{1}{6} \left\{ \frac{\bar{p}}{2} (pl + lp) + \right.$$
$$\left. + \frac{\bar{\lambda}}{2} (\lambda l + l\lambda) + \bar{l} l l \right\};$$
$$\nu_\mu = \frac{5}{12} \bar{n} (\lambda l + l\lambda).$$

However, other particles – perhaps heavy leptons – could exist according to the model, such as:

$$E^+ = \frac{5}{12} \bar{n} (pl + lp),$$

a positively charged electron-like lepton;

$$M^+ = \frac{5}{12} \bar{\lambda} (pl + lp)$$

a positively charged muon-type lepton;

$$N_\mu = \frac{5}{12} \bar{\lambda} (nl + h)$$

another neutra1 muon-like particle.

An immediate consequence of this model is that electrons and their neutrinos would be related to the pion-triplet whereas muons and their neutrinos would be associated to the K-doublet:

$$\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \sim \begin{pmatrix} \bar{n} & \lambda & l \\ \bar{p} & \lambda & l \end{pmatrix}$$

$$\begin{pmatrix} E^+ \\ \nu_\mu \\ e^- \end{pmatrix} \sim \begin{pmatrix} \bar{n} & p & l \\ \bar{p} & p & l \\ \bar{p} & n & l \end{pmatrix}$$

Correspondingly, there would exist a doublet of the type:

$$\begin{pmatrix} M^+ \\ N_\mu \end{pmatrix} \sim \begin{pmatrix} \bar{\lambda} & p & l \\ \bar{\lambda} & n & l \end{pmatrix}$$

On the other hand, in the conjugate representation $4 \times 4 \times 4$ there will occur wave functions like $\bar{p}\, n\, \bar{l}$ and $\bar{p}\, \lambda\, \bar{l}$ which are antileptons, with however the same electric charge as the structures (4) and (5) respectively. One is therefore free to identify the negative muon with $\bar{p}\, L\, \bar{1}$ instead of with $\bar{p}\, \lambda\, 1$ and the latter would be a heavy lepton M^-.

In this scheme the quark 1 would be very heavy and would have a very strong interaction with a pair quark-antiquark such as $\bar{p}p$, $\bar{p}n$ so as to make the electron mass and structure much smaller than the pion mass and radius. The higher mass of muons would result from the occurrence of a L-quark.

This naive model predicts the existence of spin 3/2 leptons, the structures of which are similar to the coupling of a l-quark with a p-meson structure and a K*-structure.

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Calcul du Spectre des Photons Gamma Atmosphériques entre 1 et 1000 MeV

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The energy spectrum of atmospheric gamma-rays at 4 g/cm^2 has been calculated for cut-off rigidities of 4.5, 10 and 16 GV. The processes considered for the production of these gamma-rays were the .n^0 decay plus the bremsstrahlung from prirnary, secondary like splash and re-entrant albedo electrons. The calculations indicated that the spectrum could be fitted to a power law in energy, with the exponencial index varying from 1.1 in the energy range 1 – 10 MeV, to 1.4 in the energy range 10 – 200 MeV and 1.8 in the energy range 200 – 1000 MeV. These results will be discussed.

O espectro de raios gama de origem atmosférica a 4 g/cm^2 foi calculado para a região de rigidez magnética de 4.5, 10 e 16 GeV. O processo de produção de raios gama considerado foi a desintegração dimesôes neutras, o n^o e o freiamento de eletrons primários, secundários como albedo e eletrons reentrantes. O cálculo indica que o espectro pode ser melhor aproximado por uma função em potência da energia com índices exponenciais variando entre 1.1 no intervalo de energia de 1 a 10 MeV, 1.4 no intervalo de energia de 10 a 200 MeV e 1.8 no intervalo de energia de 200 a 1000 MeV. Estes resultados são discutidos neste trabalho.

1. Introduction

Le fond continu du rayonnement γ atmosphérique entre 1 et 1000 MeV a plusieurs origines. Les réactions du type $p+p \rightarrow \pi^0 \rightarrow 2\gamma$ sont une source de photons dont l'intensité maximale se situe aux environs de 70 MeV, ce qui conduit compte tenu des dégradations en énergie dues a l'effect Compton a générer des photons y d'énergie inférieure à une vingtaine de MeV; il en est de même des rayons y dûs aux desexcitations de noyaux comme ^{16}O et ^{14}N (PUSKIN[1], LING[2]). Cependant, la source principale est l'émission créé par le freinage des électrons secondaires dans le champ des noyaux atmosphériques; ces électrons sont dûs a de nombreaux processus dont les principaux sont: