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STRANGE HADRONS IN LATTICE QCD

G. Martinelli

INFN - Laboratori Nazionali di Frascati

C. Omero

Istituto di Fisica dell'Università di Trieste

G. Parisi

Università di Roma II, Tor Vergata

and

R. Petronzio

CERN - Geneva

A B S T R A C T

We make a Monte Carlo simulation to extract the values of the masses of some strange mesons and baryons within lattice QCD. Squared meson masses depend linearly upon quark masses and a splitting with the correct sign, but still too small, of the Σ - Λ baryons is observed.

It is with the deepest regret that we report here the tragic death of our dear friend and collaborator Claudio Omero

We report on an analysis of strange hadron spectroscopy in the framework of lattice QCD which constitutes an example of a case where hadrons are made of quarks with sizeably different masses ¹⁾.

In Ref. 2) it was shown that, for values of the hopping parameter K ³⁾ between 0.145 and 0.150, at $\beta=6$, the masses of mesons and baryons made of degenerate quarks could be well fitted by the following expressions :

$$m_M^2 = A_M \frac{1}{K} + B_M \quad (1)$$

$$m_B = A_B \frac{1}{K} + B_B \quad (2)$$

The above expressions were used to extract the values of the masses of the pseudoscalar and vector mesons and of spin $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons.

Also, in the case of a meson built up of different quarks, like the K and K^* mesons, an approximate prediction can be made with the parameters of Eq. (1), using its following generalization

$$m_M^2 = \frac{A_M}{2} \left(\frac{1}{K_1} + \frac{1}{K_2} \right) + B_M \quad (3)$$

where K_1 and K_2 are related to the masses of the two different flavours.

In this letter we present a more refined study of the unequal mass case using eight gauge field configurations out of the thirty-two generated in Ref. 2).

Up to cubic terms in $1/K_1, 1/K_2$, the form of Eq. (3) can be modified as follows :

$$m_M^2 = \frac{A_M}{2} \left(\frac{1}{K_1} + \frac{1}{K_2} \right) + B_M + C_M \left(\frac{1}{K_1} + \frac{1}{K_2} \right)^2 + D_M \left(\frac{1}{K_1} - \frac{1}{K_2} \right)^2 \quad (4)$$

It is clear that the last term in the above equation cannot be detected by an analysis involving quarks having the same mass. For the baryons, Eq. (2) can be modified by the presence of terms which vanish when $K_1 = K_2$ already at a linear level :

$$m_B = \frac{A_B}{3} \left(\frac{2}{K_1} + \frac{1}{K_2} \right) + B_B + C_B \left(\frac{1}{K_1} - \frac{1}{K_2} \right) + O \left[\left(\frac{1}{K} \right)^2 \right] \quad (5)$$

coefficient C_B is related to the D/F ratio of the standard analysis of SU(3) mass breaking.

We make a fit with Eqs. (4) and (5) to the masses of mesons and baryons constructed with quark propagators computed for different values of K .

We have concentrated the analysis on K, K^* mesons and on $\Sigma, \Lambda, \Lambda_{\text{singlet}}$ baryons; the $L=1$ mesons have not been investigated because of our poor present understanding of their behaviour already in the degenerate quark mass case, as discussed in Ref. 2).

We report in the Table the results for the K meson as a function of K_1, K_2 and give, for comparison, the result of the fit of Eq. (3): the remarkable agreement of the fit with the measured values excludes the relevance of the additional quadratic terms of Eq. (4) in the range of quark masses considered. We found similar results for the K^* meson.

For the baryons we have measured the ratio G_Σ/G_Λ where G_Σ, G_Λ are the Σ and Λ like correlation functions measured as a function of the time distance :

$$\frac{G_\Sigma(t)}{G_\Lambda(t)} = \frac{\int d^3x \langle \Sigma_\delta(x) \Sigma^\delta(0) \rangle}{\int d^3x \langle \Lambda_\delta(x) \Lambda^\delta(0) \rangle} \sim \text{const.} + (m_\Lambda - m_\Sigma)t \quad (6)$$

$t \text{ large}$

$\Sigma_\delta(x)$ and $\Lambda_\delta(x)$ are operators carrying the same quantum numbers of the corresponding baryons :

$$\Sigma_\delta^+(x) = (S^A(x) \mathbb{C} \gamma_5 u^B(x)) u_\delta^c(x) \epsilon_{ABC} \quad (7)$$

$$\begin{aligned} \Lambda_\delta^0(x) = & \left[2 (u^A(x) \mathbb{C} \gamma_5 d^B(x)) S_\delta^c(x) - \right. \\ & \left. - (d^A(x) \mathbb{C} \gamma_5 S^B(x)) u_\delta^c(x) - (S^A(x) \mathbb{C} \gamma_5 u^B(x)) d_\delta^c(x) \right] \epsilon_{ABC} / \sqrt{6} \quad (8) \end{aligned}$$

$\mathbb{C}$ is the charge conjugation matrix. The operators in Eqs. (7) and (8) reduce to the standard SU(6) wave functions in the non-relativistic limit.

The linear fit of Eq. (6) gives :

$$m_{\Sigma} - m_{\Lambda} = (0.012 \pm 0.006) \bar{a}^{-1} \quad (9)$$

For $\bar{a}^{-1} = 1.42 \text{ GeV}^{-1}$ we get

$$m_{\Sigma} - m_{\Lambda} = (18 \pm 9) \text{ MeV} \quad (\text{exp} \sim 77) \quad (10)$$

One should first observe that the systematic errors due to the contamination of excited states are expected to be larger than in the case of the proton and Δ^{++} analyzed in Ref. 1). There, a more sophisticated method was used to extract the values of the masses from the behaviour of the baryon propagator which also takes into account the effects of the opposite parity hadrons propagating backwards in time. Second, the numerical value we have got has the correct sign but is definitely smaller than the experimental one. This phenomenon is also common in the case of p - Δ splitting which again turns out to be underestimated within our experimental conditions. We believe that this general trend of underestimating the spin-spin effects can be mainly ascribed to the too coarse grain of our lattice. Incidentally, for the ratio of Σ - Λ over Δ - p splitting extracted with the same procedure, we get

$$\frac{m_{\Sigma} - m_{\Lambda}}{m_{\Delta} - m_p} = 0.18 \quad (\text{exp: } 0.26) \quad (11)$$

which is much closer to the experimental value than each of the two mass differences taken separately. For the Λ singlet baryon, because of the form of the corresponding operator involving many terms with alternating signs, it was impossible, with our statistics, to extract a value for the mass with a reasonable error.

To summarize, the mesons are very well fitted by an expression linear in the quark masses and their masses are in good agreement with the experimental values; for the baryons, the presence in the linear fit of non-symmetric terms with the correct sign is established and a systematic tendency to underestimate spin-spin effects is observed. For the analysis of the data, we have applied the method discussed in Ref. 2) and we have spent about one hour of CDC-7600 CPU time.

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TABLE : The measured value of the pseudoscalar (P) meson as a function of K_1 , K_2 is compared with the linear fit of Eq. (3); the parameters of the fit are $A_P = 0.713$, $B_P = -8.918$.

$m_P^2 a^2$ (measured)	$m_P^2 a^2$ (linear fit)	K_1	K_2
0.99 ± 0.15	0.99	0.145	0.145
0.81 ± 0.15	0.82	0.1475	0.1475
0.66 ± 0.15	0.66	0.150	0.150
0.90 ± 0.15	0.90	0.145	0.1475
0.83 ± 0.16	0.82	0.145	0.150
0.74 ± 0.15	0.74	0.1475	0.150

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