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ABSTRACT

The lowest mesons made up of a light quark and a strange quark produced from a K beam show a good agreement with expectations of the quark model. This good agreement leads to the prediction of the light isoscalar and isovector states and the isoscalar $s\bar{s}$ states. Except for one mystery The X(1590) the 2^{++} states seems to be well described by the expected ideally mixed $q\bar{q}$ states up to 2.0 GeV. Above 2.0 GeV a new degree of freedom seems to be excited with respect to the breakdown of the OZI rule in production of 2^{++} resonances that decay into $\phi\phi$. This is to be contrasted with the situation for the 0^{++} isoscalar states which seems to show a new degree of freedom for its mesons in its ground state. One might conclude that since the 0^{++} glueball is predicted by lattice calculations to be degenerate with the $s\bar{s}$ 0^{++} meson, that the very unusual assortment of isoscalar 0^{++} mesons are due to glueball mixing.

THE $q\bar{q}$ SPECTRUM FOR STRANGE MESONS

Results presented at this conference[1] dealing with strange mesons masses with $J^P = 0^+$ and 2^+ can be compared to the quark model[2] (see Table I). In Table I,

TABLE I

J^P	Mass (MeV)	Quark Model Mass (MeV)
2^+	1431± 2	1430
2^+	1973± 26	1940
2^+	2050± 30	2170
0^+	1429± 7	1250
0^+	1940± 22	1910

the ground state of 0^{++} p-wave $q\bar{q}$ state is off by 180 MeV which is 60% of its total measured width. When one compares the p-wave $q\bar{q}$ systems one finds that the 0^{++} mes[illegible] re most sensitive to mass shifts coming from the tensor term and the

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spin-orbit interaction. In perturbation theory the masses of the p-wave $q\bar{q}$ spectrum are given by[2]

$$\begin{aligned}
M(2^{++}) &= M_0 + .25S - .20T + L,\\
M(1^{++}) &= M_0 + .25S + T - L,\\
M(0^{++}) &= M_0 + .25S - 2.0T - 2.0L,\\
M(1^{+-}) &= M_0 - .75S,
\end{aligned}$$

where S arises from the contact term, T arises from the tensor term, and L from the spin-orbit interaction. The perturbative calculation has shifted the 0^{++} meson mass with a numerical strength of two for the tensor and spin-orbit terms. In the $c\bar{c}$ spectrum where perturbation theory should work the tensor has the value of 20 MeV and the spin-orbit has the value of 34 MeV. The above set of equations can well describe the isovector light states (M_0 = 1275 MeV) and the strange states (M_0 = 1395 MeV) if one uses S = 73 MeV, T = -20 MeV, and L = 12 MeV. Giving $b_1(1235)$ = 1220 MeV, $a_1(1260)$ = 1261 MeV, $a_2(1320)$ = 1309 MeV, $K_0^*(1430)$ = 1429 MeV, and $K_2^*(1430)$ = 1429 MeV. This mass formula perdicts a 0^{++} light quark isovector $a_0(1310)$ which could easily lie under the $a_2(1320)$ in $K\bar{K}$ and $\pi\eta$ final states.

The experts would not like the tensor term to be negative but the splittings in the p-wave sector seem to have the 2^{++} at the same mass as the 0^{++}. Let us assume for the rest of the paper that the strange mesons as observed in Ref. 1 are the $q\bar{q}$ states of the quark model once all relativistic corrections are done right. With this definition the light isovectors and ideally mixed isoscalars are then easily calculated using a mass squared splitting of .3 GeV^2 (see Table II).

TABLE II

J^P	Strange Mass (MeV)	Light Mass (MeV)	$s\bar{s}$ Mass (MeV)
2^+	1430	1321	1531
2^+	1970	1890	2040
2^+	2050	1975	2122
0^+	1430	1321	1531
0^+	1950	1870	2025

THE 2^{++} MESONS AND THE QUARK MODEL

The PDG table[3] gives 4 non-strange 2^{++} mesons below 2.0 GeV [$f_2(1270)$, $a_2(1320)$, $f_2'(1525)$, and $f_2(1720)$]. In this conference it is clearly shown that $f_2(1720)$ is really the $f_0(1720)$.[4] In the full listings of mesons PDG[3] gives three additional isoscalar 2^{++} mesons that are seen below 2.0 GeV [$f_2(1565)$, $f_2(1810)$

and $f_2(1920)$]. All but the $f_2(1565)$ have a place in Table II. Thus we have seen the $\ell = 1$ and $\ell = 3$ $q\bar{q}$ light quark isoscalar [$f_2(1270)$ and $f_2(1920)$] and the light quark radial excited $\ell = 1$ isoscalar [$f_2(1810)$] plus the strange member of the three systems [$K_2^*(1430)$, $K_2^*(1980)$ and $K_2^*(2050)$] plus the $s\bar{s}$ member of the $\ell = 1$ isoscalar [$f_2'(1525)$]. Table II predicts two more $s\bar{s}$ states above 2.0 GeV the $f_2(2040)$ and the $f_2(2120)$. In Ref. 5 three 2^{++} states are seen decaying into $\phi\phi$. The strange feature of these three 2^{++} states is that they are produced by $\pi\pi$ scattering which is an OZI forbidden process.

Lattice gauge calculations predict that the 2^{++} glueball has a mass around about 2.4 GeV,[6] which is very close to the value predicted by the flux tube model.[7] One can easily imagine that the glueball degree of freedom breaks down the OZI rule because of its flavor singlet properties and then by mixing with the two $s\bar{s}$ 2^{++} states in this mass region leaves one with three $\phi\phi$ resonances that are not ideally mixed.

The $f_2(1565)$ is an extra $I = 0$ 2^{++} state.[8] The $f_2(1565)$ has a very small coupling to $\pi\pi$ final state[9] (less than 14%), so if we assume that the $f_2(1565)$ is made up of a light multi-quark state that decouples from $\pi\pi$ one can use the work done by J. Rosner[10] to determine the mixing of the $f_2(1565)$ with the $f_2(1270)$. Rosner assumed in his paper that the $f_2'(1525)$ which is an $s\bar{s}$ state plays no role in the mixing. The only change in his arguments about mixing deals with the decay of the light multi-quark state into $K\bar{K}$. It is reasonable to assume that the decay into $K\bar{K}$ from a system of many light quarks is suppressed. This fact then constrains the mixing angle to be small and thus the decay into $\pi\pi$ has to be fundamentally suppressed and not suppressed by mixing.

C. Dover[11] calculated the deeply bound $N\bar{N}$ quasinuclear states and finds a 2^{++} $I = 0$ state which has a 10% branching ratio to $\pi\pi$. Using Rosner's arguments this state must not mix with the $q\bar{q}$ 2^{++} states. This seems reasonable since we are dealing with a $3q3\bar{q}$ state mixing with a $q\bar{q}$ state. This same type of non-mixing between $q\bar{q}$ and $3q3\bar{q}$ states was noted in the 3π 1^{++} $I = 1$ channel.[12] This non-mixing makes $\pi\rho$ scattering orthogonal to $\pi\varepsilon$ scattering. The $f_2(1565)$ is at the same mass as the $f_2'(1525)$ but the quark content is totally different, one being six light quarks and the other being two strange quarks. The only mixing state of the system is the $\pi\pi$ channel which is 10% of the width in one and 2% in the other. These small couplings lead to very small mixing.

If a quasinuclear state explains the $f_2(1565)$ then there should also be a $I = 0$ 0^{++} state at 1150 MeV and $I = 0$ 1^{--} state at 1280 MeV.[13] The problem of not finding the two lower states could be overcome if the $f_2(1565)$ is really the $f_0(1565)$ and be the lowest of the $N\bar{N}$ quasinuclear states predicting that the 1^{--} lies at 1600 MeV and the 2^{++} lies at 1700 MeV. One should look at $p\bar{p} \to \pi^+\pi^-\pi^0$ or $3\pi^0$

in flight with good enough acceptance that one can do an isobar analysis[14] using the two angles of the three pion production plane with respect to the beam axis and the Dalitz plot varibles. Both $f_2(1565)$ and $f_0(1565)$ isobars should be tried in the analysis.

THE 0^{++} MESONS AND THE QUARK MODEL

The PDG table[3] gives 5 non-strange 0^{++} mesons below 2.0 GeV [$f_0(975)$, $a_0(980)$, $f_0(1400)$, $f_0(1590)$, and $f_2(1720)$]. In this conference it is clearly shown that the $f_2(1720)$ is really the $f_0(1720)$.[4] In the full listings of mesons PDG[3] gives three additional non-strange 0^{++} mesons that are seen below 2.0 GeV [$f_0(1240)$, $a_0(1320)$, and $f_0(1525)$]. In Table II $a_0(1320)$ and $f_0(1525)$ are predicted, however that leaves four f_0 states to go into the one $f_0(1321)$ spot and an extra a_0 state. The $f_0(975)$ and the $a_0(980)$ are states made up out of $2q2\bar{q}$ [15] and thus would not go into Table II.

The $f_0(1525)$ which fits into Table II so nicely comes from the reaction $K^-p \rightarrow K^0_sK^0_s\Lambda$.[16] This paper clearly shows that there is an important s-wave under the $f_2(1525)$ but due to the fact that this D-wave resonance is so strong the mass and the width of the s-wave are uncertain. It certainly is possible that the mass could be 1590 Mev, or that the $f_0(1400)$ and the $f_0(1720)$ which both decay into $K\bar{K}$ could add together and thus account for the s-wave under the $f_2(1525)$.

Lattice gauge calculations predict that the 0^{++} glueball has a mass around about 1.6 GeV [6] which is very close to the value predicted by the flux tube model.[7] One can easily imagine that the glueball is placed near the 0^{++} p-wave $s\bar{s}$ state and thus causes the formation of two states shifted up and down in mass compared to 1530 MeV [$f_0(1450)$ and $f_0(1720)$]. Under this scheme there should be a $f_0(1320)$ mainly going to $\pi\pi$. The S-wave $\pi\pi$ mass spectrum shows a bump at this mass but detailed fits are always infulenced by the $f_0(1450)$ rapid phase motion. Another problem of this scheme is the $f_0(1590)$ which decays into $\eta\eta$ [17] and $\eta\eta'$.[18] Ref. 19 is able to fit the $\pi\pi \rightarrow \eta\eta$ and $\pi\pi \rightarrow \eta\eta'$ 0^{++} data by using the $f_0(1400)$ and $f_0(1720)$ thus making it possible not to have a $f_0(1590)$. In these proceedings Yu. Prokoshkin[20] has reported observing a $f_0(1720)$ going to $\eta\eta$ but only at high t which is not π-exchange. This observation fits into the scheme that the $f_0(1590)$ is made up of two states, because at low t one sees both $f_0(1400)$ plus $f_0(1720)$ [creating the $f_0(1590)$], while at high t one only sees the $f_0(1720)$.

Another possiblity is that the glueball so messes up the expected structure that one ends up with three evenly placed 0^{++} states about the glueball mass [$f_0(1400)$, $f_0(1590)$, and $f_0(1720)$].

Detailed coupled channel analyses of the $\pi\pi$ scattering channels ($\pi\pi \to \pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$) along with production reactions ($J/\psi \to \gamma\pi\pi$, $\gamma K\bar{K}$, $\gamma\eta\eta$, $\gamma\eta\eta'$ and $pp \to p\pi\pi p$, $pK\bar{K}p$, $p\eta\eta p$, $p\eta\eta' p$) is the only way to establish the spectrum of 2^{++} and 0^{++} particles. Some examples of this type of study are given in Refs. 19 and 21.

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