THE $\eta(1440)$, $f_1(1420)$, AND $f_1(1510)$

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The first observation of $\eta(1440)$ was made in $p\overline{p}$ annihilation at rest into $\eta(1440)\pi^+\pi^-$, $\eta(1440) \to K\overline{K}\pi$ (BAILLON 67). This state was reported to decay through $a_0(980)\pi$ and $K^*(892)\overline{K}$, with roughly equal contributions. The $\eta(1440)$ was also observed in radiative $J/\psi(1S)$ decay to $K\overline{K}\pi$ (SCHARRE 80, EDWARDS 82E, AUGUSTIN 90). There is now evidence for the existence of two pseudoscalars in the $\eta(1440)$ region, which we call η_L and η_H. The η_L around 1410 MeV decays mainly through $a_0(980)\pi$ (or direct $K\overline{K}\pi$). The η_H around 1475 MeV decays mainly to $K^*(892)\overline{K}$.

The simultaneous observation of two pseudoscalars is reported in three production mechanisms: π^-p (RATH 89); radiative $J/\psi(1S)$ decay (BAI 90C, AUGUSTIN 92); $\overline{p}p$ annihilation at rest (BERTIN 95,97, CICALO 99). All of them give values for the masses, widths, and decay modes in reasonable agreement. However, AUGUSTIN 92 finds η_L above η_H.

In $J/\psi(1S)$ radiative decay, the $\eta(1440)$ decays into $K\overline{K}\pi$ through $a_0(980)\pi$, and hence, a signal is also expected in the $\eta\pi\pi$ mass spectrum. This was indeed observed by MARK III in $\eta\pi^+\pi^-$ (BOLTON 92B), which report a mass of 1400 MeV, in line with the existence of the η_L decaying to $a_0(980)\pi$. This state is also observed in $\overline{p}p$ annihilation at rest into $\eta\pi^+\pi^-\pi^0\pi^0$, where it decays into $\eta\pi\pi$ (AMSLER 95F). The intermediate $a_0(980)\pi$ accounts for roughly half of the $\eta\pi\pi$ signal, in agreement with MARK III (BOLTON 92B) and DM2 (AUGUSTIN 90).

One of these two pseudoscalars could be the first radial excitation of the η', with the $\eta(1295)$ being the first radial excitation of the η. Ideal mixing, suggested by the $\eta(1295)$ and $\pi(1300)$ mass degeneracy, would then imply that the second isoscalar in the nonet is mainly $s\overline{s}$, and hence couples to $K^*\overline{K}$, in agreement with the η_H. Also its width matches the expected width for the radially excited $s\overline{s}$ state (CLOSE 97, BARNES 97).

An investigation of the $K\overline{K}\pi$ and $\eta\pi\pi$ channels in $\gamma\gamma$ collisions was performed (ACCIARRI 01G) . Their analysis leads to an η_H signal in $K\overline{K}\pi$, but η_L is not observed in $\eta\pi\pi$. Since gluonium production is presumably suppressed in $\gamma\gamma$ collisions, the ACCIARRI 01G results suggest that η_L has a large gluonic content (see also CLOSE 97B). The gluonium interpretation is, however, not favored by lattice gauge theories, which predict the 0^{-+} state above 2 GeV (BALI 93).

Let us now deal with 1^{++} isoscalars (see also our article in the previous issue of this *Review*). The $f_1(1420)$, decaying to $K^*\overline{K}$, was first reported in $\pi^- p$ reactions at 4 GeV/c (DIONISI 80). However, later analyses found that the 1400–1500 MeV region was far more complex (CHUNG 85, REEVES 86, BIRMAN 88). A reanalysis of the MARK III data in radiative $J/\psi(1S)$ decay to $K\overline{K}\pi$ (BAI 90C) shows the $f_1(1420)$, decaying into $K^*\overline{K}$. Also, a $C = +1$ state is observed in tagged $\gamma\gamma$ collisions (*e.g.*, BEHREND 89).

In $\pi^- p \to \eta\pi\pi n$ charge-exchange reactions at 8–9 GeV/c, the $\eta\pi\pi$ mass spectrum is dominated by $\eta(1440)$, and $\eta(1295)$ (ANDO 86, FUKUI 91C), and at 100 GeV/c ALDE 97B report $\eta(1295)$ and $\eta(1440)$ decaying to $\eta\pi^0\pi^0$ with a weak $f_1(1285)$ signal and no evidence for $f_1(1420)$.

Axial (1^{++}) mesons are not observed in $\overline{p}p$ annihilation at rest in liquid hydrogen, which proceeds dominantly through S-wave annihilation. However, in gaseous hydrogen, P-wave annihilation is enhanced, and indeed, BERTIN 97 report $f_1(1420)$ decaying to $K^*\overline{K}$.

The $f_1(1420)$, decaying into $K\overline{K}\pi$, is also seen in pp central production, together with $f_1(1285)$. The latter decays via $a_0(980)\pi$ and the former only via $K^*\overline{K}$, while $\eta(1440)$ is absent (ARMSTRONG 89, BARBERIS 97C). The $K_S K_S \pi^0$ decay mode of $f_1(1420)$ establishes unambiguously C=+1. On the other hand, there is no evidence for any state decaying to $\eta\pi\pi$ around 1400 MeV, and hence, the $\eta\pi\pi$ mode of $f_1(1420)$ must be suppressed (ARMSTRONG 91B).

We now turn to the experimental evidence for $f_1(1510)$. Two states, $f_1(1420)$ and $f_1(1510)$, decaying to $K^*\overline{K}$, compete for the $s\overline{s}$ assignment in the 1^{++} nonet. The $f_1(1510)$ was seen in $K^- p \to \Lambda K\overline{K}\pi$ at 4 GeV/c (GAVILLET 82) and at 11 GeV/c (ASTON 88C). Evidence is also reported in $\pi^- p$ at 8 GeV/c, based on the phase motion of the 1^{++} $K^*\overline{K}$ wave (BIRMAN 88).

The absence of $f_1(1420)$ in K^-p (ASTON 88C) argues against $f_1(1420)$ being the $s\overline{s}$ member of the 1^{++} nonet. However, $f_1(1420)$ was reported in K^-p, but not in π^-p (BITYUKOV 84), while two experiments do not observe $f_1(1510)$ in K^-p (BITYUKOV 84, KING 91). It is also not seen in radiative $J/\psi(1S)$ decay (BAI 90C, AUGUSTIN 92), central collisions (BARBERIS 97C), nor in $\gamma\gamma$ collisions (AIHARA 88C), although, surprisingly for an $s\overline{s}$ state, a signal is reported in 4π decays (BAUER 93B). These facts leads to the conclusion that $f_1(1510)$ is not well established (CLOSE 97D).

Assigning the $f_1(1420)$ to the 1^{++} nonet, one finds a nonet mixing angle of $\sim 50°$ (CLOSE 97D). However, arguments favoring $f_1(1420)$ being a hybrid $q\overline{q}g$ meson or a four-quark state were put forward by ISHIDA 89 and by CALDWELL 90, respectively, while LONGACRE 90 argued for a molecular state formed by the π orbiting in a P-wave around an S-wave $K\overline{K}$ state.

Summarizing, there is rather convincing evidence for $f_1(1420)$ decaying to $K^*\overline{K}$, and for two pseudoscalars in the $\eta(1440)$ region, η_L and η_H, decaying to $a_0(980)\pi$ and $K^*\overline{K}$, respectively. The $f_1(1510)$ is not well established.

References

References may be found at the end of the $\eta(1440)$, $f_1(1420)$, and $f_1(1510)$ Listings.