an important threshold, which suggests that they may be bound states of a meson pair. Examples include the $f_0(980)$ and $a_0(980)$ (close to the $K\overline{K}$ threshold), the $f_1(1420)$ (above $K\overline{K}^*$, thus not a bound state but perhaps a threshold enhancement), the $f_0(1525)$ and $f_2(1520)$ ($\omega\omega$ and $\rho\rho$), the $f_J(1710)$ ($K^*\overline{K}^*$), and the $\psi(4040)$ ($D^*\overline{D}^*$). Many suggestions for such mesonium candidates, involving both light and heavy quarks and binding mechanisms, have appeared recently (WEINSTEIN 90, DOVER 91, BARNES 92, DOOLEY 92).

It should be emphasized that no state has been identified unambiguously as a glueball, hybrid, or multiquark state. The candidates we discuss below are chosen because they are difficult to interpret as conventional $q\overline{q}$ states. Note, however, that we do not see it as our task to discuss theoretical interpretations of the candidates; rather, we merely catalogue the observations of possible relevance.

The scalar-meson sector: The established isoscalars with $J^{PC} = 0^{++}$ are the $f_0(980)$, $f_0(1300)$, $f_0(1370)$, and $f_0(1590)$; the $f_J(1710)$ is an established isoscalar whose spin may be 0. In the quark model, one expects two 1^3P_0 states and one 2^3P_0 ($u\overline{u}+d\overline{d}$)-like state below 1.8 GeV. Thus, there are too many well-established scalars to find a place in the quark model. From further dynamical arguments related to the production or decay, it is very likely that both the $f_0(1590)$ and the $f_J(1710)$ are non-$q\overline{q}$ resonances.

It should, however, be noted that for scalar resonances with strong S-wave thresholds, naive quark model expectations, in particular ideal mixing, must be strongly broken by unitarity. Thus, the physical scalar $q\overline{q}$ spectrum can be very much distorted from naive expectations. Another problem is that mass determinations of a very broad resonance like the $f_0(1300)$ or the $K_0^*(1430)$ are always somewhat dependent on the model and background assumptions. For a detailed discussion of this sector, see our "Note on S-wave $\pi\pi$, $K\overline{K}$, and $\eta\eta$ Interactions."

The $f_0(1590)$, seen in π^-p reactions at 38 GeV/c (BINON 83, BINON 84C, ALDE 87, ALDE 87B), has a peculiar decay pattern for a $q\overline{q}$ state:

$$\pi^0\pi^0 : K\overline{K} : \eta\eta : \eta\eta\prime : 4\pi^0 =< 0.3 : < 0.6 : 1 : 2.7 : 0.8$$

The scalar glueball and the ${}^3P_0$ $s\overline{s}$ state are both expected near this mass, so we may here be seeing the effects of more than one resonance.

The $f_J(1710)$ (whose spin is uncertain) has been seen mainly in "gluon-rich" $J/\psi(1S)$ radiative decay, where it is copiously produced. In central production, the WA76 experiment (ARMSTRONG 89D) on 300 GeV/c pp interactions n sees a structure at the same mass, but favors spin 2. The $f_J(1710)$ has not been seen in hadronic production ($K^-p \to K\overline{K}\Lambda$) (ASTON 88D), nor in $\gamma\gamma$ fusion. The ratio of the branching fractions in $J/\psi \to \omega f_J$ and $J/\psi \to \phi f_J$ suggests important nonstrange and strange components in this state.

The pseudoscalar sector: The established isoscalars with $J^{PC} = 0^{-+}$ are the η, $\eta\prime(958)$, $\eta(1280)$, and $\eta(1440)$ [which may be two pseudoscalar resonances $\eta(1410)$ and $\eta(1490)$; see the "Note on the $\eta(1440)$"]. In the $q\overline{q}$ model, we expect two 1^1S_0 and two 2^1S_0 pseudoscalars in the 500–1800 MeV range.

Identifying the $\eta(1280)$ with the 2^1S_0 ($u\overline{u}+d\overline{d}$) state seems natural, but it is more problematic to assign one of the two peaks in the $\eta(1440)$ region to the 2^1S_0 $s\overline{s}$ state. The $\eta(1440)$ is observed in $s\overline{s}$-depleted reactions like $\pi^-p \to \eta\pi\pi n$ (ANDO 86) and $\pi^-p \to a_0(980)\pi p$ (CHUNG 85, BIRMAN 88), and is not seen in the $s\overline{s}$-enriched channels like $K^-p \to K^*(892)\overline{K}\Lambda$ (ASTON 87). The fact that ANDO 86 sees the $\eta(1440)$ bump and the $\eta(1280)$ with similar intensities argues for these states being of a similar nature, *i.e.*, radial excitations of the η and $\eta'(958)$. However, as there are suggestions of two resonances in the $\eta(1440)$ structure, the experimental situation remains confused and the nature of the $\eta(1440)$ is not well understood.

The axial-vector meson sector: The $q\overline{q}$ model predicts a nonet that includes two isoscalar 1^3P_1 states with masses below about 1.6 GeV. Three such 1^{++} states are known, the $f_1(1285)$, $f_1(1420)$, and $f_1(1530)$, which suggests that one of these is a non-$q\overline{q}$ meson. The $f_1(1420)$ is the most likely candadate; see CALDWELL 89 and the "Note on the $f_1(1420)$." The proximity of the $K\overline{K}^*$ threshold suggests this may be a dominantly $K\overline{K}^*$ mesonium resonance or threshold enhancement (LONGACRE 90, TORNQVIST 91).

The tensor meson sector: The two 1^3P_2 $q\overline{q}$ states are very likely the well-known $f_2(1270)$ and $f_2'(1525)$. There are several other states, which have been suggested as $J^{PC} = 2^{++}$ non-$q\overline{q}$ candidates: the $f_2(1430)$, $f_2(1520)$, $f_J(1710)$, $f_2(1810)$, $f_2(2010)$, $f_2(2300)$, and $f_2(2340)$.

The $f_2(1520)$ is observed by the ASTERIX collaboration (MAY 89) in $p\overline{p}$ P-wave annihilation at 1565 MeV in the $\pi^+\pi^-\pi^0$ channel. Its mass is better determined in the $3\pi^0$ mode by the Crystal Barrel (ANISOVITCH 94) to be 1520 MeV, close to the $\rho\rho$ and $\omega\omega$ thresholds. It has no place in a $q\overline{q}$ scheme, since all nearby $q\overline{q}$ states are already occupied.

Similarly, the $f_J(1710)$ could be composed of $K^*\overline{K}^*$ and $\omega\phi$ (DOOLEY 92), since it lies close to these thresholds. Note that before 1991, the spin of the $f_J(1710)$ was believed to be 2, and that the subsequent spin-0 determination (CHEN 91) has not been confirmed. As already mentioned, in central production WA76 still favours spin 2 for their 1720-MeV structure.

Of the heavier states, the $f_2(1810)$ is likely to be the 2^3P_2 and the three f_2's above 2 GeV could possibly be the 2^3P_2 $s\overline{s}$, 1^3F_2 $s\overline{s}$, and 3^3P_2 $s\overline{s}$, but a gluonium interpretation of one of the three is not excluded. These three f_2 resonances have been observed in the OZI-rule-forbidden process $\pi p \to \phi\phi n$ (ETKIN 88), which has been cited as favoring the gluonium interpretation.

A similar $\phi\phi$ mass spectrum is seen by ARMSTRONG 89B in the Ω spectrometer. The DM2 and MARK-III collaborations see threshold, $\phi\phi$ production, but favor $J^P = 0^-$, not 2^+.