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Some rare tensor-meson decays and the implications for the $K^{**}(1420) \to K^*(890)\pi\pi$ transition*

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A model with dominant TVV interaction, supplemented by experimental information from related processes, predicts the yet-unreported decay $K^{**}(1420) \to K^*(890)\pi\pi$ to have a width of 7.5 MeV. A characteristic feature of the model is that the pion pair comes out predominantly in an isotopic spin $T = 1$ state.

During the last few years, several groups have reported measurements of the strong decays $A_2 \to \omega\pi\pi$ and $f \to 4\pi$, the latter proceeding at least partially as $f \to \rho\pi^+\pi^-$. Although unfavored by phase-space limitation in comparison with the two-body decays of the tensor mesons, these decays turn out to be relatively frequent, the world average being[1]

$$\Gamma^{\text{exp}}_{(\text{av})}(A_2 \to \omega\pi\pi) = 8.6 \pm 1.8 \text{ MeV},$$
$$\Gamma^{\text{exp}}_{(\text{av})}(f \to \pi^+\pi^-\pi^+\pi^-) = 6.2 \pm 1.5 \text{ MeV}. \tag{1}$$

In a recent paper,[2] a theoretical analysis of these decay modes was presented. The principal conclusion is that the TVV coupling appears to play the dominant role in this type of transitions, the major contribution to the decay amplitudes arising through the $T \to V + V \to P + P + V$ chain. A generalization of the TVV interaction to an SU(3)-symmetric form would then imply the occurrence of similar transitions of the strange tensor meson $K^{**}(1420)$, i.e., $K^{**}(1420) \to K^*(890)\pi\pi$ decays of appropriate strength. In this note, we work out the expectations for the $K^{**} \to K^*\pi\pi$ transitions, arriving at a predicted rate of 7.5 MeV when the average experimental width for $A_2 \to \omega\pi\pi$ is used as input.

A survey of the reported[1] K^{**} experiments reveals that the $K^{**} \to K3\pi$ transitions have not been analyzed in the past for the detection of the modes suggested here. Two recent experimental analyses, which had sought this mode, give figures differing by an order of magnitude. With limited statistics, Goldberg concludes[3] that the $K^{**-} \to K^{*-}\pi^+\pi^-$ process occurs at a rate of 4 ± 1.3 MeV. On the other hand, preliminary results from the Amsterdam-CERN-Nijmegen-Oxford collaboration give[4] $0.6^{+0.3}_{-0.6}$ MeV for this decay.

Since we address ourselves to K^{**} decays deriving from a TVV vertex, we have to consider as possible modes $K^{**} \to K^*\pi\pi$, $K^{**} \to \rho K\pi$, and $K^{**} \to \omega K\pi$. However, while the first mode has approximately 250 MeV of phase space available, the other two have only a margin of a few MeV and hence will be considerably inhibited and of no practical interest. In the rest of this note, we therefore restrict our analysis to the $K^{**} \to K^*\pi\pi$ modes only. To be specific, let us consider the decays of K^{**+}; there are three channels available:

$$K^{**+} \to K^{*+} + \pi^+ + \pi^-, \tag{2a}$$

$$K^{**+} \to K^{*+} + \pi^0 + \pi^0, \tag{2b}$$

$$K^{**+} \to K^{*0} + \pi^+ + \pi^0. \tag{2c}$$

Unlike the $A_2 \to \omega\pi\pi$ decay, where the two pions are emitted in an isotopic-spin state $T = 1$, the pion pair in the (2a) transition can be in both $T = 0$ and $T = 1$ states, whereas in $K^{**+} \to K^{*0}\pi^+\pi^0$ we have again a pure $T = 1$ pion pair.

We now summarize the approach used in Ref. 2 to deal with the $A_2 \to \omega\pi\pi$, $f \to \rho\pi\pi$ decays and then proceed to use the information extracted thereof for the $K^{**} \to K^*\pi\pi$ decays. The amplitude for $T + V \to P + P$ is calculated by including the contributions from direct (s) and exchange (t, u) channels. The direct-channel contribution is dominated by an intermediate vector meson, while the t and u channels involve the exchange of pseudoscalar and vector mesons. The couplings needed are then of the TVV, VPP, TVP, VVP, and TPP types. Except for the first one, these couplings are well known from the strong decays of tensor and vector mesons.[5] In Ref. 2, the amplitude for $T + V \to P + P$ is calculated in the Born approximation and in a dual model. The comparison of the calculated transition rate with experiments permits the determination of the only unknown coupling of the models, the TVV-interaction constant. In both models the contribution of the vector-meson exchange in the s channel is then by far the dominating one and the value of the TVV coupling is only slightly model-dependent. Thus, for the presentation of this paper, we shall use the simpler Born approximation.

The most general TVV vertex has five independent couplings, defined as follows:

$$\langle T(l)\,|\,V_1(p_1),V_2(p_2)\rangle=\frac{g_{TV_1V_2}}{\mu}\,\tau^{\mu\nu}\left[\alpha\epsilon^{(1)}_{\mu}\epsilon^{(2)}_{\nu}+\beta_1(\epsilon^{(1)}\cdot p_2)\epsilon^{(2)}_{\mu}p_{1\nu}+\beta_2(\epsilon^{(2)}\cdot p_1)\epsilon^{(1)}_{\mu}p_{2\nu}+\gamma(\epsilon^{(1)}\cdot\epsilon^{(2)})p_{1\mu}p_{2\nu}+\delta(\epsilon^{(1)}\cdot p_2)(\epsilon^{(2)}\cdot p_1)p_{1\mu}p_{2\nu}\right]. \quad (3)$$

$\tau^{\mu\nu}$, $\epsilon^{(1)}_{\mu}$, $\epsilon^{(2)}_{\mu}$ are the polarization tensor and vectors of the tensor and vector mesons, respectively. μ is the pion mass, the $g_{TV_1V_2}$ coupling being thus dimensionless. Various models have been discussed in the literature for the $\alpha, \beta_1, \beta_2, \gamma, \delta$ coefficients. Generally, they have been determined either from considerations of strong-interaction dynamics[6] or from gauge-invariance constraints,[7] with quite similar results. Adopting the first approach as the more appropriate for our case, one has[6]

$$\alpha=p_1\cdot p_2,\quad \beta_{1,2}=-\left(1+\frac{2p_{1,2}^{\;2}}{l^2}\right),\quad \gamma=3,\quad \delta=-4/l^2. \quad (4)$$

The comparison of the decay rate of $A_2\to\omega\pi\pi$, as calculated in the Born approximation, with the experimental value (1) gives then

$$g_{A_2\rho\omega}^{\;2}/4\pi\cong 2.7. \quad (5)$$

We are equipped now to handle the calculation of the $K^{**}\to K^*\pi\pi$ modes along the same lines. Here the contributions come from vector mesons in the s channel and from pseudoscalar, vector, and tensor mesons in exchange channels. The diagrams pertaining to the calculation of the $K^{**+}\to K^{*+}\pi^+\pi^-$ decay are depicted in Fig. 1. Assuming SU(3) symmetry and canonical mixing for the TVV couplings, one has from Eq. (5) $g_{K^{**+}K^{*+}\rho^0}=\frac{1}{2}g_{A_2\rho\omega}=\pm 2.95$. The other couplings (except TTP) are taken from experimentally measured rates as follows[8]: $|g_{\rho\pi\pi}|=5.9$, $|g_{K^{*+}K^0\pi^+}|=4.6$, $|g_{K^{**+}K^0\pi^+}|=0.43$, $|g_{K^{**+}K^{*0}\pi^+}|=0.26$; the $K^{**+}K^{**0}\pi^+$ coupling is related by SU(3) to the calculated[2] value of the $A_2 f\pi$ coupling, $g_{K^{**+}K^{**0}\pi^+}=(1/\sqrt{2})g_{A_2 f\pi}$. Since the relative phases of the various contributions are unknown, we present first the rates calculated from each exchange separately, for the $T=1$ part of the two-pion state only. One obtains

$$\Gamma^{s(T=1)}_{(V)}(K^{**+}\to K^{*+}\pi^+\pi^-)=2.5\text{ MeV}, \quad (6a)$$

$$\Gamma^{t,u(T=1)}_{(V)}(K^{**+}\to K^{*+}\pi^+\pi^-)=4.3\times10^{-3}\text{ MeV}, \quad (6b)$$

$$\Gamma^{t,u(T=1)}_{(P)}(K^{**+}\to K^{*+}\pi^+\pi^-)=0.6\times10^{-3}\text{ MeV}, \quad (6c)$$

$$\Gamma^{t,u(T=1)}_{(T)}(K^{**+}\to K^{*+}\pi^+\pi^-)=1.3\times10^{-3}\text{ MeV}. \quad (6d)$$

The contributing terms were then combined with various choices for the relative phases, and we find that the rate given by the TVV contribution alone is never affected by more than 12%. Hence, we can take only the s-channel part for a reliable estimation of the rates. In this approximation, the $K^{**+}\to K^*(\pi\pi)^{T=0}$ mode vanishes and one has

$$\Gamma(K^{**+}\to K^{*0}\pi^+\pi^0)=2\Gamma^{(T=1)}(K^{**+}\to K^{*+}\pi^+\pi^-). \quad (7)$$

With this approach, the decay rate comes out to be

$$\Gamma^{(T=1)}(K^{**+}\to K^{*0}\pi^+\pi^0+K^{*+}\pi^+\pi^-)=7.5\text{ MeV}. \quad (8)$$

The distributions $d\sigma/d\sqrt{t}$ and $d\sigma/ds$, where $t=(p_{K^*}+p_\pi)^2$ and $s=(p_{\pi_1}+p_{\pi_2})^2$, are presented in Fig. 2.

Contributions to $K^{**}\to K^*(\pi\pi)^{T=0}$, although small, arise in our model via t and u exchanges (Fig. 1). The couplings required for their calculation are known and the rates for each exchange separately are

$$\Gamma^{(T=0)}_{(V)}(K^{**+}\to K^{*+}\pi^+\pi^-)=3.0\times10^{-3}\text{ MeV}, \quad (9a)$$

$$\Gamma^{(T=0)}_{(P)}(K^{**+}\to K^{*+}\pi^+\pi^-)=0.82\times10^{-3}\text{ MeV}, \quad (9b)$$

$$\Gamma^{(T=0)}_{(T)}(K^{**+}\to K^{*+}\pi^+\pi^-)=1.3\times10^{-3}\text{ MeV}. \quad (9c)$$

The upper limit for the $T=0$ decays arising from maximal positive interference is

$$\Gamma^{(T=0)}(K^{**+}\to K^{*+}\pi^+\pi^-)\le 0.014\text{ MeV},\qquad \Gamma(K^{**+}\to K^{*+}\pi^0\pi^0)\le 0.007\text{ MeV}. \quad (10)$$

Thus, under the assumptions of this model, the

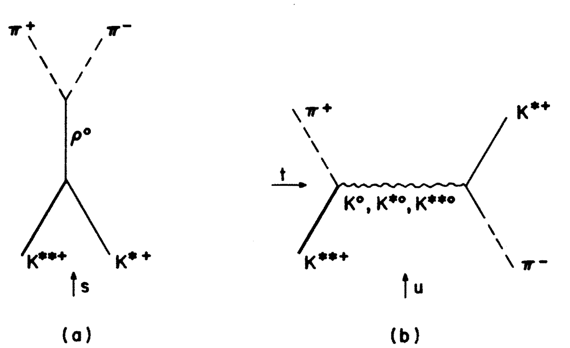

FIG. 1. The diagrams contributing to the $K^{**+}\to K^{*+}\pi^+\pi^-$ amplitude.

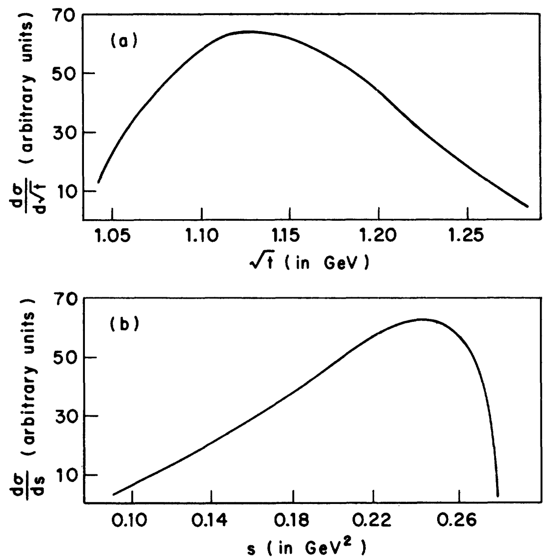

FIG. 2. Calculated effective mass distributions for the decay $K^{**+}\to K^{*0}\pi^+\pi^0$. (a) $d\sigma/d\sqrt{t}$, where $t=(p_{K^*}+p_{\pi^+})^2$, (b) $d\sigma/ds$, where $s=(p_{\pi^+}+p_{\pi^0})^2$.

amount of $T=0$ in the pion pair of the decay is less than 1%.

Before concluding, we add a few remarks:

(I) In our calculation, the possible contribution of intermediate axial-vector mesons has been ignored. There seems to be increasing evidence[9] for the existence of two strange axial-vector mesons with masses 1300 MeV and 1400 MeV, which decay also into $K^*\pi$. However, it has been pointed out in Ref. 2 that if the TAP coupling is mainly responsible for the observed $T\to VPP$ decays [through an intermediate $(A)P$ state], its strength would have to be[10] of the order of 100. Since this appears unreasonable, and also since its predicted differential distribution appears to be invalidated in the $A_2\to\omega\pi\pi$ decay,[2] we assume that it does not play a major role in these decays.

(II) The treatment presented here neglects possible final-state interactions. Their inclusion will most probably affect the rates of the decays leading to $T=0$ pion pairs. One way of taking this into account would be the inclusion of a $K^{**}\to K^*\epsilon\to K^*\pi\pi$ term in the decay amplitude. The measurement of the $(\pi\pi)^{T=0}/(\pi\pi)^{T=1}$ ratio in these decays is therefore of particular interest. However, from previous experience, the final-state interaction is not expected to enhance the $T=0$ rates [Eqs. (9)] by more than one order of magnitude, which would still leave them relatively small.

(III) The rate predicted in (8) is based on a TVV-coupling strength (5), derived from the world average for the $A_2\to\omega\pi\pi$ rate (1). However, the latter is obtained from widely divergent experimental results, ranging from 20 MeV[11] (see Ref. 11) to 5 MeV[12] (see Ref. 12). The calculated $K^{**}\to K^*\pi\pi$ rate would then vary accordingly.

To summarize, our main results are the expectation of a significant $K^{**}\to K^*\pi\pi$ mode of approximately 7.5 MeV and a small value for the $(\pi\pi)^{T=0}/(\pi\pi)^{T=1}$ ratio in this decay. Their experimental probing is feasible and would throw light on the validity of the picture we suggest for the $T\to VPP$ decays in terms of a dominant TVV interaction. Should the experimental rate be very different from the calculated one, it could imply a sizable breaking of SU(3) symmetry or that a quite different mechanism is at work in these decays.

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