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Regge spectroscopy of charmed mesons*

J. Finkelstein
Department of Physics, Columbia University, New York, New York 10027

Stephen S. Pinsky
Department of Physics, Ohio State University, Columbus, Ohio 43210
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The implication of assigning the newly discovered particles to Regge trajectories is discussed. The Ademollo-Veneziano-Weinberg relation is used to determine the trajectory parameters and exchange degeneracy is used to predict a tensor particle at 2264 MeV and an axial-vector particle at 2140 MeV.

The discovery of new heavy mesons produced in e^+e^- annihilation has recently been announced.[1,2] In this note we will explore the assignment of those mesons to Regge trajectories and the consequent predictions of other mesons lying higher on those same trajectories. Our analysis will be independent of any detailed quark model of the new mesons, but will turn out to be reasonably consistent with the quark-model calculation of Ref. 3.

We begin by assuming that the particle detected in the $K\pi$, $K\pi\pi$, and $K\pi\pi\pi$ modes at 1870 MeV[1,2] (we take the average mass of the charged and neutral states), which is denoted by D, is a pseudoscalar. The peak in the recoil spectrum to the D observed at 2010 MeV we will assume represents a vector particle denoted by D^*. These two assignments together with the relationship between the vector and pseudoscalar trajectories proposed by Ademollo, Veneziano, and Weinberg[4] (AVW) enable us to determine the parameters of the Regge trajectories.

The version of the rule proposed by AVW that is relevant to us can be stated as

$$\alpha_V(m_P^2) = \tfrac{1}{2}\,, \tag{1}$$

where α_V is a vector trajectory and m_P is the mass of the appropriate pseudoscalar particle. This rule is empirically extremely successful, as can be seen in the two examples $\alpha_\rho(m_\pi^2) = \frac{1}{2}$ and $\alpha_{K^*}(m_K^2) = \frac{1}{2}$. In our case the rule becomes

$$\alpha_{D^*}(m_D^2) = \tfrac{1}{2}\,. \tag{2}$$

Using $m_D = 1870$ MeV, the vector assignment of the D^* $[\alpha_{D^*}(m_{D^*}^2) = 1]$ and a linear trajectory, we determine the slope of D^* trajectory to be 0.92 GeV^{-2}. We note that this value is quite consistent with the value of the slope of most well-established Regge trajectories. For example, the ρ trajectories in a recent charge-exchange experiment[5] were found to have a slope of 0.93 GeV^{-2}, though different determinations vary somewhat.[6] This is considerably different than the value of 0.33 GeV^{-2} that one obtains by placing the $\psi(3100)$ and the $J^P = 2^+$ $\chi(3550)$ on the same linear trajectory. If we are willing to believe a linear extrapolation of the D^* trajectory to vanishing invariant mass we obtain an intercept of -2.72; thus the trajectory takes the form

$$\alpha_{D^*}(s) = -2.72 + 0.92 s\,. \tag{3}$$

The next highest particle on the D^* trajectory is, if we assume weak exchange degeneracy, a tensor particle which we denote by D^{**}. Using the trajectory of the D^* given in Eq. (3) we find $m_{D^{**}} = 2264$ MeV. This value is slightly below the value of 2330 MeV predicted in Ref. 3. By comparison with decays of known tensor mesons we would estimate the partial width of $D^{**} \to D\pi$ at about 1 MeV and that of $D^{**} \to D^*\pi$ at about 0.3 MeV. The full width would therefore be in the 2–3 MeV range since there is relatively little phase space for multipion final states. These estimates are sensitive to the assumed mass of the D^{**}; for example, $m_{D^{**}} = 2.33$ GeV implies a partial width of $D^{**} \to D\pi$ of 2.4 MeV.

Even though exchange-degenerate Regge analysis is less reliable for unnatural- than for natural-spin-parity trajectories, it is amusing to consider that if the D trajectory were parallel to the D^* trajectory given in Eq. (3) it would pass through unity at a mass of 2141 MeV and give rise to an axial-vector meson D_A^* at that mass. A peak at just about this mass is in fact seen in the missing-mass spectrum reported in Ref. 1; however, this peak has an alternative explanation[3] as a reflection from $D_V^*\bar{D}_V^*$ production. While perhaps both effects are present, the $D_A^*\bar{D}$ has the advantage over the other mode of being an s-wave decay.

It can be observed that two-body thresholds seem to be closely associated with particles or at least with prominant structure in the e^+e^- annihilation cross section. Compare the $D\bar{D}$ threshold at 3.74 GeV with the ψ' at a mass 3.68 GeV, the $D\bar{D}_V^*$ threshold at 3.88 GeV with the possible structure at 3.95 GeV, and the $D_V^* \bar{D}_V^*$ threshold at 4.02 GeV with the structure at 4.03 GeV. There is also the analogous case of the $K\bar{K}$ threshold at 0.99 GeV to be compared with the ϕ at a mass of 1.019 GeV. With our speculation on the masses of the D^{**} and D_A^* we note that the $D^{**}\bar{D}$ and $D^*\bar{D}_A^*$ thresholds are at 4.13 GeV and 4.15 GeV, respectively, close to the structure in the e^+e^- cross section at 4.1 GeV, and the $D^{**}\bar{D}_A^*$ threshold is at 4.4 GeV, in agreement with the structure at 4.4 GeV. There also appears to be an interesting parallel between the A_1 and the D_A^* since both are closely associated with kinematic enhancements. The A_1 is suspected to be associated with a Deck effect in the $\rho\pi$ channel. Similarly, we estimate the D_A^* to have about the same mass as a kinematic reflection of $D^*\pi$.[3] It may in fact be that these are dual descriptions.

Note added in proof. The rate for $D^{**} \to D\pi$ was calculated from the rate for $K^{**} \to K\pi$ assuming that the rate varies as $p^5/(m_{D^{**}})^2$.

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