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AN ω-MIXING MODEL FOR THE PRODUCTION OF NONHADRONIC ψ's*

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ABSTRACT

We develop a simple, plausible model for the photoproduction and hadronic production of the $\psi(3100)$ under the assumption that this state is not a hadron. In particular, we find the cross section

$$\sigma(\gamma N \to \psi N) \lesssim 3 \text{ nb} \quad .$$

Experimental results in this range will not unambiguously determine whether the ψ is a hadron.

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The discussion of the production of the $\psi(3100)$ and $\psi(3700)$ in hadron-induced and photon-induced experiments has been flawed by the necessity of making strong and somewhat prejudicial assumptions about the nature of the new narrow states. In particular, the experimental analysis of photoproductic on nuclear targets[1-3] is presently being phrased only in terms of the usual vector dominance model[4] which provides a reasonable description of ρ, ω, an ϕ photoproduction,

$$\frac{d\sigma}{dt}(\gamma N \rightarrow VN) = \frac{\alpha}{4}\frac{4\pi}{\gamma_V^2}\frac{d\sigma}{dt}(VN \rightarrow VN) . \tag{1}$$

The assumption underlying the extension of this description is that the ψ is a strongly interacting particle with a substantial amplitude for elastic scatterin off nucleons. A measurement of ψ photoproduction with appropriate attention given to nuclear effects can be used in the vector dominance formula to infer value of $\frac{d\sigma}{dt}(\psi N \rightarrow \psi N)$. In addition, the optical theorem and an assumption about the phase of the amplitude can give $\sigma_{tot}(\psi N)$. If one believes in hadronic models for the ψ which lead to quite low values of $\frac{d\sigma}{dt}(\psi N \rightarrow \psi N)$,[5,6] observation of a few nanobarns of cross section can be made consistent with the vecto dominance hypothesis.

It is a much more difficult problem to understand at what level data on photoproduction can be said to test whether the ψ is a hadron. One way to do this is to construct a model for the production of ψ's which does not require that they interact strongly and study the implications of this model for photoproduction.

From the fact that the ratio of the cross sections $\sigma(e^+e^- \rightarrow \text{hadrons})$ and $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ are significantly different on and off resonance,[7] we know tha the $\psi(3100)$ and $\psi(3700)$ must have a direct coupling to hadrons. That is, they cannot couple only through the photon. In the direct interaction there is substantial evidence that the $\psi(3100)$ acts as an $I^G=0^-$ meson.[8] The information on the quantum numbers of the $\psi(3700)$ is less complete but the decay $\psi(3700) \rightarrow \psi(3100) + 2\pi$ is consistent with $I^G = 0^-$ for $\psi(3700)$ as well. Although the assignment of hadronic quantum numbers to these states suggests that they are hadrons it is not conclusive. In particular, if there exists a massive vector meson approximately degenerate in mass with the $\psi(3100)$ as suggested by dual models or the Generalized Vector Dominance model[9] then the two particles could mix through a weak, semiweak, or electromagnetic interaction and the nonhadronic ψ would assume the quantum numbers of the legitimate hadron.

While there are many possibilities, this kind of speculation does suggest a simple model for the production of ψ's. If we assume that the production of the ω-like hadron which mixes with the ψ is related to the production of the $\omega(783)$ continued in the external mass, we can estimate ratios of cross sections involving ψ's from the measured ratios of similar cross sections involving ω's, as indicated in Fig. 1. The only uncertainty lies in the theoretical estimate of the mass continuation.

In the context of our model, the exclusive cross sections for $pp \rightarrow pp\psi$ and $pp \rightarrow pp\omega$ are related by

$$d\sigma(pp \rightarrow pp\psi) \cong h^2 \, d\hat{\sigma}(pp \rightarrow pp\omega) \qquad (2)$$

where the notation $d\hat{\sigma}$ implies that the amplitude for $pp \rightarrow pp\omega$ is continued in the mass of the vector meson from m_ω to m_ψ and h is the parameter describing the mixing of the ψ with the vector meson. While, in principle, this continuation requires a careful theoretical estimate and can involve new dynamic principles, it is consistent with our quest for simplicity that we input the minimum number of detailed assumptions. One feature of the physical amplitude which must be important in doing this continuation is the so-called "leading-particle-effect". The physical amplitude is found experimentally to be damped in the longitudinal momentum transfer between initial- and final-state protons. As we increase the effective mass of the ω in $pp \to pp\omega$ at finite energies we increase the minimum-momentum-transfer between protons. This suggests that the cross section is much smaller. Because the mass extrapolation is large the suppression can be substantial. One estimate of the suppression uses an analytic approximation to phase-space integrals weighted to insure the leading particle effect.[10] At $p_{LAB} = 28.5$ this calculation suggests a factor of 40 suppression for the integrated cross section,

$$\hat{\sigma}(pp \to pp\omega)\Big|_{\substack{m_\omega = m_\psi \\ p_{LAB} = 28.5}} \cong \frac{1}{40}\,\sigma(pp \to pp\omega) \qquad (3)$$

The same calculation indicates that the cross section $\hat{\sigma}(pp \to pp\omega)$ should rise by a factor of 3 from $p_{LAB} = 22$ GeV/c to 28.5 GeV/c. The <u>inclusive</u> cross section $pp \to \psi$ + anything is observed experimentally to rise a factor $\cong$ 10 between these two energies.[11] While a substantial portion of the growth can be attributed to the opening up of other exclusive channels, we must also be careful to assign a considerable uncertainty to the theoretical value of the suppression factor. A calculation based on the bremsstrahlung model for ω production[12] gives a factor 1/200 for the suppression at $p_{LAB} = 28.5$ GeV/c.

Our estimate for the coupling constant h in Eq. (2), based on the experimental data[13] and the suppression factor of 1/40 as in Eq. (3) is

$$h^2 \cong 3 \times 10^{-4} \qquad (4)$$

This value can be given more physical meaning by noting that the width of the heavy mesons is given by

$$\Gamma_V \cong h^{-2}\,\Gamma_\psi = 250\ \text{MeV} \ . \tag{5}$$

We find this value to be quite reasonable. For example, a calculation of the width of an ω with mass around 3 GeV using simple phase space[10] normalized to the width of the $\omega(780)$ gives $\Gamma_V \cong 300$ MeV, approximately equally divided in the 3π, 5π, and 7π channels. If we require reasonable values of this width to be between 0.1 and 1 GeV, then

$$7 \times 10^{-5} < h^2 < 7 \times 10^{-4} \ , \tag{6}$$

corresponding to suppression factors between 8 and 80. We note in passing that the recently discovered structure at SPEAR with mass approximately 4100 MeV may be a candidate for the vector meson.

The ω-mixing model predicts substantially larger cross sections for the production of ψ's in π-beams. In particular, 2-2 amplitudes such as $\pi N \to \psi N$ need not exhibit as strong a suppression in the mass of the vector meson as do $2 \to 3$ amplitudes. In these processes, an estimate of the kinematic suppression involves fitting an exponential e^{Bt} to the peripheral peak of the cross section and allowing for the increased minimum momentum transfer, t_{min}, necessary to produce the ψ in comparison with the ω. However, we also expect the value of B to vary with the mass of the vector meson in agreement with the generally observed decrease in the slope parameter with increasing mass in other hadronic and photonic experiments. We estimate this slope can decrease by a factor of two in changing from the ω to the ψ mass.

For example, using $B = 5$ and $\sigma(\pi^- p \to \omega n) \cong 50\,\mu b$ at 14 GeV/c, we estimate

$$\sigma(\pi^- p \to \psi n) \cong 3 - 30\ \text{nb} \tag{7}$$

at this energy. One exclusive channel which can be reliably estimated by taking a ratio is $\sigma(\pi p \to \pi\psi p) \cong 0.3$ nb at $p_{LAB} = 28.5$, using

$$\frac{d\sigma(\pi^\pm p \to \pi^\pm \psi p)}{d\sigma(pp \to p\psi p)} \cong \frac{d\sigma(\pi^\pm p \to \pi^\pm \omega p)}{d\sigma(pp \to p\omega p)} = 0(1) \tag{8}$$

since the kinematic constraints on the mass-extrapolations on the ℓ.h.s. of (8 should approximately cancel.

We now turn to photoproduction where we can estimate the expected cross section using

$$\frac{d\sigma}{dt}(\gamma p \to \psi p) \cong h^2 \frac{d\hat{\sigma}}{dt}(\gamma p \to \omega p) . \tag{9}$$

With our value for h^2 and experimental data on ω photoproduction[15] we predic

$$\sigma(\gamma p \to \psi p) \cong 0.3 - 3 \text{ nb} \tag{10}$$

neglecting t_{min} effects as is reasonable at the upper range of SLAC energies a well as at Fermilab. An experimental cross section substantially in excess o this amount is in disagreement with our simple model--a fact which might the be interpreted as requiring a strong interaction for the ψ and some component the usual vector dominance type.

It should be made clear that Eq. (10) estimates the pseudoelastic contribu tion to $\gamma p \to \psi p$ where the incident photon is presumed to couple to an ω which then scatters diffractively into a massive ω-like particle which mixes with the This production channel should exhibit all the features commonly associated with diffractive dissociation.[16] As discussed previously, we expect $d\sigma/dt$ to exhibit a t-dependence which is less steep than in $\gamma p \to \omega p$. When the experiment is performed on nuclear targets there should also be a sharp peak assoc ated with the coherent production on the nucleus. This nuclear coherence doe not itself imply that the ψ is a hadron any more than it implies the photon is a hadron--it only means both the γ and ψ couple to hadrons.

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exhibit a t-dependence which is less steep than in $\gamma p \to \omega p$. When the experiment is performed on nuclear targets there should also be a sharp peak associated with the coherent production on the nucleus. This nuclear coherence does not itself imply that the ψ is a hadron any more than it implies the photon is a hadron--it only means both the γ and ψ couple to hadrons.

We might also expect a substantial contribution at high energy to inclusive photoproduction of ψ's from an intermediate reaction of the form $\rho p \to \omega +$ anything, as indicated in Fig. 2, since, in the usual vector dominance model, the coupling of the γ to ρ is 9 times stronger than its coupling to ω. Simple model calculations indicate that the inclusive photoproduction of ψ at Fermilab energies should be about an order of magnitude larger than the exclusive channel $\gamma p \to \psi p$.[17] This would imply a rise in the inclusive cross section with energy.

The experimental measurements on photoproduction now being carried out at various laboratories[1-3] may clarify things. As we see above, it is important to separate the elastic component as cleanly as possible.

It is instructive to compare our use of the ω-mixing model for the $\psi(3100)$ to another case involving an $I^G=0^-$ meson where we do not expect it to apply. If, in spite of the fact that the $\phi(1019)$ is known to be a hadron, we assume it couples only by mixing with the ω, we would predict for example

$$\frac{\sigma(\pi^- p \to \omega n)}{\sigma(\pi^- p \to \phi n)} \cong \left.\frac{\sigma(\gamma p \to \omega p)}{\sigma(\gamma p \to \phi p)}\right|_{\omega\,\mathrm{mixing}} \tag{11}$$

Not surprisingly, this prediction is badly violated by the experimental data where the ratios above are respectively[18]

$$\frac{\sigma(\pi^- p \to \omega n)}{\sigma(\pi^- p \to \phi n)} \cong 280$$

$$\frac{\sigma(\gamma p \to \omega p)}{\sigma(\gamma p \to \phi n)} \cong 4 \tag{12}$$

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13. We take the approximation $\sigma(pp \rightarrow pp\psi) \cong \left(\frac{1}{3} - \frac{1}{2}\right)\sigma(pp \rightarrow \psi + x)$ at this energy From Ref. 11 we take $\sigma(pp \rightarrow \psi + x) \times b_{\psi \rightarrow e^+e^-} \cong 10^{-34}\ \mathrm{cm}^2$ where $b_{\psi \rightarrow e^+e^-} \cong \frac{1}{15}$ from Refs. 7 and 8. The value of $\sigma(pp \rightarrow pp\omega)$ of $60\ \mu b$ was obtained from P. L. Connolly et al., BNL 11980 (1967). (unpublished). The main source of uncertainty is the ratio of the exclusive and inclusive

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16. See, for example, D.W.G.S. Leith, in Proceedings of the SLAC 1974 Summer Institute in Particle Physics (SLAC Report 179), Martha C. Zipf, ed., Vol. 1, p. 1.
17. For example, we can estimate the contribution of $\rho N \to \psi$ + anything from the measurement of $nN \to \psi$ + anything in Ref. 3 of $\gtrsim$ 400 nb. Models suggest that ρ's should be a better source of ψ's than neutrons so that when we multiply by $\alpha\pi/\gamma_\rho^2 \cong 1/330$ to get a value for photoproduction we calculate several nanobarns.
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FIGURE CAPTIONS

1. This demonstrates the basic feature of the ω-mixing model. The ψ couples to other hadrons only through the ω.
2. Mueller-Regge diagram for the inclusive process $\gamma p \to \psi + x$ in the ω-mixing model.

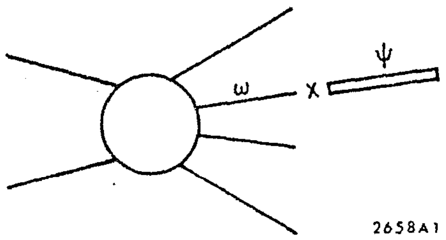

FIGURE 1

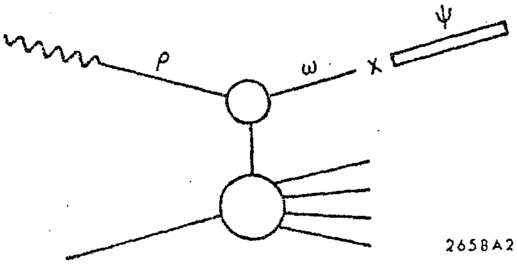

FIGURE 2