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The New Vector Mesons and Photon Total Cross Sections

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ABSTRACT

Using vector dominance arguments we estimate the contribution of $c\bar{c}$ vector mesons to total photon-nucleon cross sections. We find this contribution to be non-negligible in the Fermilab energy range. We also discuss possible contributions from vector mesons made of hypothesized heavier quarks.

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INTRODUCTION

Total photon cross sections on protons and complex nuclei has been a subject studied with much interest. These cross sections exhibit a somewhat hadron-like character in the multi-GeV range. The cross sections on protons exhibit diffractive characteristics. The forward scattering amplitude is predominantly imaginary and the total cross sections vary slowly with energy. Published measurements exist up to photon laboratory energies of 18 GeV.[1] The cross sections using complex atomic nuclei as targets show the additional hadronic characteristic that they are not proportional to nuclear mass number A. Rather the total cross sections are proportional to A^n with n slightly less than unity.[1] These characteristics are suggestive of a vector dominance picture[2] as a method of interpreting the results of the measurements. The photon scattering amplitudes are related to vector meson scattering amplitudes which are deduced from photo-production data or alternatively related to directly measurable scattering amplitudes through quark model considerations.

The new generation of proton accelerators has permitted the creation of tagged photon beams with energies up to the order of 200 GeV. This makes it possible to measure photon total cross sections over a greatly extended energy range and as it turns out with considerably better accuracy (roughly half a percent) than previous measurements at lower energy made with photons from electron machines.

Our specific objective here is to calculate in as simply a fashion as possible a reliable estimate of the contribution of the ψ/J particles to photon total cross sections using the vector dominance picture. Since these particles will only contribute for photon energies above 10 or 15 GeV it may be that one has an unexpected increase in photon total cross sections in the Fermilab energy range, presumably due to charm. We then can ask whether one may have further contributions from even heavier quarks such as those that may be associated with the newly discovered upsilon particles.[3]

PHOTON TOTAL CROSS SECTIONS AND ψ PARTICLES

According to the vector dominance picture,[2] neglecting off-diagonal meson-meson couplings the total photon-proton cross section

$$\sigma(\gamma p) = \alpha \sum_{V} (g_V^2/4\pi)^{-1} \sigma_V \quad . \qquad (1)$$

Here α is the fine structure constant, σ_V is the vector meson-nucleon total cross section and $(g_V^2/4\pi)^{-1}$ is the photon-vector meson coupling strength squared at zero photon mass. The sum is over all vector mesons that couple to the photon. To evaluate the sum in (1) we must know three sets of facts: (a) the spectrum of vector mesons, V, (b) the vector-meson nucleon total cross sections, σ_V, and (c) the photon-vector meson coupling constants g_V. We call the contribution of the ψ particles to $\sigma(\gamma p)$, $\Delta\sigma_c(\gamma p)$.

The spectrum of these latter particles, presumed to involve $c\bar{c}$ quarks in a spin 1 relative s-state configuration is shown in Table I.[4] Their masses to a good approximation are given by

$$N = \frac{1}{3}c(M^3 - M_\psi{}^3) \qquad (2)$$

with N = 0, 1, 2, 3 and c = 0.161(GeV)$^{-3}$. We assume below that higher mass states have masses which for our purposes can also be described by (2). We note in this connection, that to a good approximation, the charmonium picture using a pure linear potential in the relative $c\bar{c}$ radial space coordinate r leads to[5]

$$N \propto (M^2 - M_0{}^2) \qquad (3)$$

i.e. implicitly to a linear Chew-Frautschi plot, since there is a virtual degeneracy of even or odd spin states in such a potential.[5] We have then from (2) the experimental level density

$$\rho(M) = \frac{dN}{dM} = cM^2 \qquad (4)$$

whereas equation (3) would lead to $\rho(M) \propto M$ which is the density of states of the old lighter mesons.

For the vector meson-nucleon total cross sections we make the assumption that all mesons made of the same type of quarks have the same total cross section. There is ample evidence that this is reasonable even for states of different spin, e.g. the cross sections of pions, ρ and ω mesons are very similar. There is also experimental information on total cross sections of unstable particles from coherent production of resonances with hadrons incident on complex nuclei.[6] These results also tend to support the assumption of equal cross sections for mesons made of the same quarks.

We now address ourselves to the question of the coupling constants g_V at zero mass. Vector dominance gives information on the coupling constants $g_V(M_V)$ at the mass of the vector meson M_V in terms of the leptonic width for decay of the vector meson, Γ_{ee}^{V}. Specifically

$$\frac{g_V^{\,2}(M_V)}{4\pi} = \frac{\alpha^2 M_V}{3\Gamma_{ee}^{V}} \quad . \tag{5}$$

Values determined experimentally are listed in Table II.[4,7] Extrapolation to zero mass is a problem since we require $g_V = g_V(0)$. Photoproduction of these vector mesons on both hydrogen and complex nuclei provides this information in principle. Determination of these coupling constants at zero mass exist for ρ, ω, ϕ. It is of importance that a series of measurements on photoproduction of ψ particles be carried out on complex nuclei in the future in order to determine $g_V = g_V(0)$ and σ_V. Lacking this information we assume that for a family of vector mesons made of the same quarks we can use formula (5) to yield <u>the ratios</u> of coupling constants g_V at zero photon mass. Further we find empirically that within the ψ family, taking data for the ψ particles from Table II that to within 10%

$$\left(\frac{g_V{}^2(M_V)}{4\pi}\right)^{-1} \propto \frac{1}{M_V{}^4} \quad . \tag{6}$$

We have, in this connection, summed the leptonic widths for the $\psi'(3.685)$ and $\psi'(3.772)$[7] since it is this sum presumably that represents the strength for a pure s-wave radial excitation of the c-$\bar{c}$ system. We assume that the proportionality result (6) is valid for g_V at zero photon mass. We write then

$$(g_V{}^2/4\pi)^{-1} = (g_\psi{}^2/4\pi)^{-1}\left(\frac{M_\psi}{M_V}\right)^4 \tag{7}$$

where V is a c-$\bar{c}$ vector meson with s-state spatial configuration, on its mass shell.

It follows then that for total c.m. energy $\sqrt{s} > M_\psi + m_p$, where m_p is the proton mass, converting the sum in equation (1) over radial excitations of ψ particles to an integral, and using equation (4) for the density of vector meson states, that the contribution to the photon-nucleon total cross section from c$\bar{c}$ vector mesons is

$$\Delta\sigma_c(\gamma p) \simeq \alpha\left(\frac{g_\psi{}^2}{4\pi}\right)^{-1} \sigma_\psi\left[1 + M_\psi{}^4 \int_{M_{\psi'}}^{\infty} \frac{\rho(M)dM}{M^4}\right]$$

$$= \alpha\left(\frac{g_\psi{}^2}{4\pi}\right)^{-1} \sigma_\psi\left[1 + cM_\psi{}^3 \cdot \frac{M_\psi}{M_{\psi'}}\right] \quad . \tag{8}$$

We have here approximated the sum over radial excitations by an integral. This is practical from some value of M_V on since presumably the higher excitations have fairly broad widths. For our purposes (8) is adequate.

It is of interest to evaluate the contribution of $\Delta\sigma_c(\gamma p)$ to $\sigma(\gamma p)$ numerically. Data for photoproduction of $\psi(3.095)$ on hydrogen yields $(g_\psi^{\ 2}/4\pi)^{-1}\sigma_\psi^{\ 2}$ through the vector dominance relation

$$\left.\frac{d\sigma(\gamma,\psi)}{dt}\right|_{t=0} = \alpha(g_\psi^{\ 2}/4\pi)^{-1}\sigma_\psi^{\ 2}/16\pi \quad . \tag{9}$$

We can then write

$$\Delta\sigma_c(\gamma p) = 16\pi\frac{1}{\sigma_\psi}\left[\frac{d\sigma(\gamma,\psi)}{dt}\right]_{t=0}\left(1 + cM_\psi^{\ 3}\frac{M_\psi}{M_{\psi'}}\right) \quad . \tag{10}$$

This yields the value $8.0/\sigma_\psi$(mb) in microbarns at photon laboratory energy of 161 GeV using photoproduction data from reference (8) which gives $(d\sigma/dt)_{t=0} = (82 \pm 10)\text{nb}/(\text{GeV})^2$. There is one determination of σ_ψ from incoherent photoproduction data at 20 GeV[9] yielding $\sigma_\psi = 3.5 \pm 0.8$ mb. Even with this high value we find $\Delta\sigma_c(\gamma p) \simeq 2.3$ microbarns. Using the rule $\sigma_V \propto 1/m_q^{\ 2}$ where m_q is the mass of the quark q and V is made up of $q\bar{q}$ we would have $\sigma_\psi \sim 1.6$mb and $\Delta\sigma_c(\gamma p) \simeq 5$ microbarns. We see then that the ψ family contributes, via vector dominance, a few percent to the photon-nucleon total cross section $\sigma(\gamma p) \sim 115$ μb in the Fermilab energy range.

POSSIBLE CONTRIBUTION OF THE UPSILON

Following these considerations we now attempt to estimate the contribution to the total cross section of Υ particles[3] assuming they are made of $Q\overline{Q}$ where Q is a heavy quark with mass ~5GeV. For the ground state of $q\overline{q}$ systems it is found empirically[10] that the vector dominance couplings

$$\left(\frac{g_V^{\,2}(M_V)}{4\pi}\right)^{-1} \tilde{\propto} \frac{1}{M_V} e_q^{\,2} \tag{11}$$

where e_q is the charge of quark q. It follows, assuming this relation valid at zero photon mass, and using equation (8) that

$$\Delta\sigma_Q(\gamma p)/\Delta\sigma_c(\gamma p) \simeq \frac{e_Q^{\,2}}{e_c^{\,2}} \frac{\rho_\Upsilon(M_\Upsilon)}{\rho_\psi(M_\psi)} \frac{\sigma_\Upsilon}{\sigma_\psi} \tag{11}$$

$$\simeq \frac{1}{10} \frac{e_Q^{\,2}}{e_c^{\,2}} \frac{\rho_\Upsilon(M_\Upsilon)}{\rho_\psi(M_\psi)} \quad . \tag{11a}$$

We have taken $\sigma_V \propto 1/M_V^{\,2}$ here and $M_\Upsilon = 9.5$ GeV. e_Q and e_c are the charges of the Q and c quarks. The density of states of the Υ vector mesons is expected to be perhaps twice[11] that of ψ' s at low excitation so that $\Delta\sigma_Q(\gamma p)$ could be as large as a microbarn at $E_\gamma \sim 160$ GeV if $e_Q = e_c$.

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REFERENCES

[1]D. O. Caldwell, et al., Phys. Rev. D7, 1362 (1973). This paper contains references to older measurements. For preliminary results at higher energies see "Photon-Hadron Interactions: Recent Results at Fermilab," T. Nash, presented at European Conference on Particle Physics, Budapest, Hungary, July, 1977. FERMILAB-Conf-77/61-Exp. 2021.00.

[2]J. J. Sakurai, Ann. of Phys. 11, 1 (1960).

[3]"Observation of a Dimuon Resonance at 9.5 GeV in 400 GeV Proton-Nucleus Collisions," S. W. Herb, et al., FERMILAB-Pub-77/58-EXP.7100.288, July 1977 (submitted to Phys. Rev. Lett.).

[4]G. J. Feldman in Proc. of Summer Institute on Particle Physics, SLAC Report No. 198, November 1976, pp. 81-126.

[5]J. F. Gunion and R. S. Willey, Phys. Rev. D12, 174 (1975).

[6]See, for example, C. Bemporad, et al., Nucl. Phys. B42, 627 (1972).

[7]"Observation of a Resonance in e^+e^- Annihilation Just Above Charm Threshold" P. A. Rapidis, et al., SLAC-PUB-1959, June 1977. (Submitted to Phys. Rev. Letters).

[8] "Photoproduction of the $\psi(3.095)$ and $\psi'(3.684)$ at FNAL Energies"
J. S. Sarracino, Ph.D. Thesis U. of Illinois at Urbana-Champaign, 1976.
See also T. Nash, et al., Phys. Rev. Letters 36, 1233 (1976).

[9] R. L. Anderson, et al., Phys. Rev. Lett. 38, 263 (1977).

[10] See J. D. Jackson, Proc. of Summer Institute on Particle Physics, SLAC Report No. 198, November 1976, pp. 147-202.

[11] E. Eichten and K. Gottfried, Phys. Lett. 66B, 286 (1977).

TABLE I

N	0	1	2	3
M(GeV)	3.095	3.684	4.05	4.414
$M^3 (GeV)^3$	29.65	49.99	66.4	85.98

TABLE II

V	ρ	ω	ϕ	ρ'	$\psi(3.095)$	$\psi'(3.684)$	$\psi'(3.772)$	$\psi''(4.05)$
$\frac{1}{4\pi} g_V{}^2 (M_V)$	2.5	18	15	17	12	31	53	31