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DETERMINING MESON RADIATIVE WIDTHS FROM PRIMAKOFF EFFECT MEASUREMENTS *

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ABSTRACT

We suggest that the measurement of vector meson radiative decays $V \to P\gamma$ in Primakoff effect experiments on nuclei should be reanalyzed including isovector hadronic exchange. Its inclusion invalidates the assumption, made in data analyses, of A-independence of the strength of the strong production amplitude and could well remove the disagreement between theory and experiment for $\Gamma(\rho \to \pi\gamma)$ and $\Gamma(K^{*o} \to K^{o}\gamma)$.

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The outstanding problem in the radiative decays of the generic kind V (vector) $\rightarrow$ P (pseudoscalar) + γ and P $\rightarrow$ V + γ has been to understand the measured rates (1) $\Gamma(\rho \rightarrow \pi\gamma) = 35 \pm 10$ KeV[1,2] compared to the nonet symmetry (or naive quark model) expectation of $\simeq$90 KeV, and (2) $\Gamma(K^{*o} \rightarrow K^o\gamma) = 75 \pm 30$ KeV compared to the nonet symmetry value of $\simeq$210 KeV. Considerable theoretical effort[3,5,6] has been made in attempts to understand these anomalously low rates in broken symmetry schemes. One may say in summary, that it is not difficult to fit $\Gamma(K^{*o} \rightarrow K^o\gamma)$ in a broken symmetry scheme but it is not possible to understand the low value of $\Gamma(\rho \rightarrow \pi\gamma)$ simultaneously with the measurement[7] of $\Gamma(\eta' \rightarrow \rho\gamma)/\Gamma(\eta' \rightarrow \omega\gamma)$, which proves to be a strong constraint.[5] The best one can do in the schemes of Edwards and Kamal[3] is to obtain $\Gamma(\rho \rightarrow \pi\gamma) \simeq 70$ KeV.

The purpose of this letter is to propose a mechanism which, when incorporated in the data analysis, could raise $\Gamma(\rho \rightarrow \pi\gamma)$ [and $\Gamma(K^{*o} \rightarrow K^o\gamma)$] to higher values consistent with the quark model expectations.

Both $\Gamma(\rho \rightarrow \pi\gamma)$ and $\Gamma(K^{*o} \rightarrow K^o\gamma)$ have been measured in Primakoff effect[8] experiments on various nuclei at Brookhaven National Laboratory with a pion beam of momentum 22.7 GeV/c and a $\overline{K}^o$ beam of momentum 8 to 16 GeV/c, respectively. At these momenta the coherent Coulomb production in P + (A,Z) $\rightarrow$ V + (A,Z) interferes with the coherent strong production. The experiment measures $d\sigma/dt'$ for the coherent V-production. The Coulomb production amplitude[9-11] is built up of the coherent contribution from the Z protons. In the data analyses[1,2,4] the strong production amplitude has been assumed to be generated by ω-exchange. This isoscalar natural parity (1^-) exchange gives an amplitude with the same Lorentz structure as that from the Coulomb production, and A times the elementary amplitude $P + n$ (or p) $\rightarrow V + n$ (or p). The strong production amplitude with ω-exchange has a form[2,9,10]

$$F_{nucleus} = A \frac{\vec{h}\cdot\vec{q}_\perp}{q_\perp} F_{strong} \quad . \tag{1}$$

F_{strong} can be found in Refs. 2, 9, 10; $-t' = q_\perp^2$ and $\vec{h}$ is proportional to $\sqrt{C_0}\ (\vec{\varepsilon}\times\vec{k})$, where $\vec{\varepsilon}$ is the V polarization vector, $\vec{k}$ is the incident momentum in the laboratory system, and $\sqrt{C_0}$ measures the strength of the elementary production amplitude on a nucleon. The normalization of $\vec{h}$, which is of no consequence to us, is so chosen that in the absence of any nuclear or coulomb absorption one has[2] $\frac{d\sigma}{dt'} = C_0 A^2 q_\perp^2$.

In the data analyses,[1,4] $\frac{d\sigma}{dt'} \alpha \left|F_{Coulomb} + e^{i\phi} F_{nucleus}\right|^2$ was fitted varying the phase ϕ and C_o to get the best fit to the data. <u>An essential criterion for the goodness of the fit was that C_0 should not depend on the nucleus.</u>[1] Gobbi, <u>et</u> <u>al</u>.,[1] however, do have a solution for $\Gamma(\rho \rightarrow \pi\gamma)$ with the rate varying from a low of 57 ± 6 Ke V for Ag to a high of 77 ± 5 KeV for U with $\phi = 90^o$ and C_0 decreasing monotonically from 3.4 ± 0.2 mb/GeV^4 for the lightest element (Cu) to 1.8 ± 0.3 mb/ GeV^4 for the heaviest (U).

If ω-exchange were the only natural parity exchange then the above criterion of constancy of C_0 with A would be appropriate. However, a variation of C_0 with A would be expected if an isovector natural parity exchange were contributing. A candidate is A_2-exchange with $I^G = 1^-$ and $J^P = 2^+$. It produces an amplitude with the same Lorentz structure as the ω-exchange, but because it is an isovector the amplitude is proportional to (Z-N) rather than A,N being the neutron number. For lighter nuclei this effect will be small but it will grow in importance with A. If the A_2-exchange amplitude interferes with the ω-exchange amplitude one should expect an effect on C_0 of the form

$$C_0(N,Z) = C_0(N{=}Z) \left| 1 + \delta \frac{Z-N}{A} \right|^2 \qquad (2)$$

where δ measures the amount of interference. For $\delta \simeq 1$ the departure from unity can be quite large. The correction factor is 0.84 for Cu; 0.76 for Ag; 0.62 for Pb and 0.60 for U. This variation of C_0 is in the same direction and of the same size as that needed by Gobbi et al.[1] to make their solution for $\Gamma(\rho \to \pi\gamma)$ acceptable.

The physics is somewhat more involved. The importance of the A_2-exchange relative to the ω-exchange depends on their relative phases and sizes. For exotic reactions ($K^+p \to K^{*+}p$, $\pi^+p \to \rho^+p$) one expects approximate ω-A_2 exchange degeneracy to give largely a real amplitude and a null relative phase between the ω- and A_2- amplitudes for production on a nucleus. For nonexotic reactions ($\bar{K}^o p \to \bar{K}^{*o}p$, $\pi^-p \to \rho^-p$) the amplitudes are rotating and have significant real and imaginary parts (see for example, Fig. 12 of Ref. 13 for amplitudes calculated with absorption effects included). The actual phase varies from reaction to reaction.

The sizes are determined mainly by the coupling strengths. The ω-amplitude is proportional to $g_{\omega\rho\pi}\, g_{\omega NN}$ where $g_{\omega NN}$ is the vector coupling constant. Similarly, the A_2 contribution is proportional to

$4m_N \; g_{A_2\rho\pi} \; g_{A_2NN}$ ($4m_N$ coming from conventions). The meson coupling $g_{\omega\rho\pi}$ calculated from $\Gamma(\omega \rightarrow \pi\gamma)$ [12] together with vector meson dominance is $g_{\omega\rho\pi} \simeq 16 \text{ GeV}^{-1}$. $g_{A_2\rho\pi}$ is calculated to be $\simeq 10 \text{ GeV}^{-2}$ from $\Gamma(A_2 \rightarrow \rho\pi)$.[12] The coupling $g_{\omega NN}$ is accurately measured by the C-odd contribution to the NN total cross section, while g_{A_2NN} is well determined by the value of $\frac{d\sigma}{dt}(\pi^- p \rightarrow \eta n)$ in the forward direction, where only the nonflip amplitude contributes. From the detailed analysis of Ref. 13 we find $g_{\omega NN} \simeq 12$ and $g_{A_2NN} \simeq 7$. Thus the ratio of the sizes of the two contributions is of order

$$\frac{A_2}{\omega} \simeq \frac{280}{192} \simeq 1.5 \tag{3}$$

for the basic reaction on a nucleon.

In practice absorption corrections will alter the individual phases and magnitudes and an appropriate general form for $d\sigma/dt'$ in $P + (A,Z) \rightarrow V + (A,Z)$, is

$$\frac{d\sigma}{dt'} \; \alpha \; \left| F_{Coulomb} + e^{i\phi} \, A \, F_{\omega} + e^{i\delta} \, (N-Z) F_{A_2} \right|^2 \tag{4}$$

Clearly the advantages one gains by going to the heavier nuclei are offset by the theoretical uncertainties. Simple analysis can be done for $N \approx Z$ nuclei only.

The remarks on the importance of the A_2-exchange for heavier nuclei will also apply to the measurement[4] of $\Gamma(K^{*o} \rightarrow K^o\gamma)$.

In summary the data analyses for $\Gamma(\rho \rightarrow \pi\gamma)$[1,2] and $\Gamma(K^{*o} \rightarrow K^o\gamma)$[4] are suspect for heavier nuclei insofar as one cannot assume the constancy of the strength of the strong production amplitude with A. Reliable analysis can be done only for the light nuclei with $N \approx Z$. Indeed, for Cu, Gobbi *et al*. have $\Gamma(\rho \to \pi\gamma) = 66 \pm 8$ KeV for $\phi = 90^{\circ}$. At Fermi Laboratory energies (150 to 200 GeV/c) one will get a cleaner separation of the Coulomb and strong production peaks with little interference and our remarks will not apply. However, the disadvantage of going to higher energies is that the Coulomb peak shifts closer to the zero of t' and the data analysis will have accompanying uncertainties.

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