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PHASES IN VECTOR MESON PHOTOPRODUCTION*

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ABSTRACT

We calculate the phase of vector meson photoproduction on nuclei using the optical model. The predicted relative phase between ρ^{o} and ω^{o} appears to disagree with experiment.

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Although the experimental situation remains unsettled, there have been suggestions[1] for some time that the "coherent" amplitude for omega-meson photoproduction, $f_{\gamma p \to \omega p}$, has a large real part near the forward direction. (By the coherent amplitude, we mean that part of the amplitude which is spin nonflip and isospin independent, i.e., the part which can add up coherently on a nuclear target. In particular, the pion exchange contribution is excluded.) A large real part, or worse, a totally real amplitude, would be difficult to understand within the context of the vector dominance model, wherein $f_{\gamma p \to \omega p}$ is simply a constant, $g_{\gamma\omega}$, times the ω-nucleon elastic amplitude:

$$f_{\gamma p \to \omega p} = g_{\gamma\omega} f_{\omega p \to \omega p} \tag{1}$$

The constant $g_{\gamma\omega}$ must be real by time reversal invariance, and we expect $f_{\omega p \to \omega p}$ to become predominantly imaginary at high energy. In any simple diffraction model, also, one would expect $f_{\gamma p \to \omega p}$ to be mainly imaginary, regardless of vector dominance. We would like to point out that it is possible to determine whether or not $f_{\gamma p \to \omega p}$ and $f_{\omega p \to \omega p}$ indeed have the same phase, as predicted by (1), by studying the phase of coherent ω photoproduction on nuclei. That phase is accessible through the interference of the leptonic decay modes of ρ^0 and ω^0.[1,2]

The multiple scattering or optical model theories of scattering on a nucleus yield the fundamental relation among forward coherent amplitudes

$$f_{\gamma A \to \omega A} = \left(f_{\gamma p \to \omega p} / f_{\omega p \to \omega p}\right) f_{\omega A \to \omega A} \tag{2}$$

in the limit of sufficiently high energy that the effect of minimum momentum transfer can be neglected. This equation does not depend on assuming vector dominance. It can be derived from the multiple scattering viewpoint as follows: $f_{\omega A \to \omega A}$ corresponds to a sum of terms in which the ω elastic scatters off

$1, 2, \ldots, A$ nucleons in the nucleus; while $f_{\gamma A \to \omega A}$ corresponds to the same sum except for replacement of the first elastic scattering by a $\gamma p \to \omega p$ transition, provided that the momentum transfer to the nucleon involved in this scattering is negligible. (We assume for simplicity that scattering from neutron and proton are identical.) In the optical model formalism, the coherent nuclear photoproduction amplitude at impact parameter b is given by

$$f^{(b)}_{\gamma A \to \omega A} = f_{\gamma p \to \omega p} \int_{-\infty}^{\infty} dz\, \rho(z, b) \exp(i\Delta_0 z) \exp\left(i \int_z^{\infty} dz'\, \rho(z', b) \frac{2\pi}{k} f_{\omega p \to \omega p}\right)$$

$$= \frac{f_{\gamma p \to \omega p}}{f_{\omega p \to \omega p}} \frac{k}{2\pi} \int_{-\infty}^{\infty} dz\; \rho(z, b)\; \frac{2\pi}{k} f_{\omega p \to \omega p} \exp(i\Delta_0 z) \tag{3}$$

$$\times \exp\left(i \int_z^{\infty} dz'\; \rho(z', b)\; \frac{2\pi}{k}\; f_{\omega p \to \omega p}\right) .$$

In Eq. (3), $\rho(z,b)$ is the density of nucleons, and $\Delta_0 = \left(m_\omega^2/2k\right)$ is the minimum momentum transfer required to produce the ω. In the limit of high energy, Δ_0 goes to zero, and the quantity following $f_{\gamma p \to \omega p}/f_{\omega p \to \omega p}$ becomes equal to the ω-nucleus amplitude at impact parameter b. Thus we can write Eq. (3) more suggestively, after summing over b, as

$$f_{\gamma A \to \omega A} = \frac{f_{\gamma p \to \omega p}}{f_{\omega p \to \omega p}}\; f^{(\Delta_0)}_{\omega A \to \omega A} \tag{4}$$

where $f^{(\Delta_0)}_{\omega A \to \omega A}$ becomes the ω-nucleus elastic scattering amplitude as $\Delta_0 \to 0$. Our essential point is now to remark that the phase of $f_{\omega A \to \omega A}$ is guaranteed to be nearly pure imaginary for a large nucleus, regardless of the phase of $f_{\omega p \to \omega p}$. Intuitively, this is because a large nucleus will almost completely absorb ω's and therefore appear to be a "black disk" with a purely absorptive amplitude. Therefore, the phase of $\gamma A \to \omega A$ on a big nucleus at high energy essentially tells us the phase of $f_{\gamma p \to \omega p}/f_{\omega p \to \omega p}$.

For a finite nucleus at finite energy, the phase of $f_{\gamma A \to \omega A}$ may differ from pure imaginary either due to $f_{\gamma p \to \omega p}/f_{\omega p \to \omega p}$ or due to $f^{(\Delta_0)}_{\omega A \to \omega A}$. Equation (3), however, allows us to calculate $f^{(\Delta_0)}_{\omega A \to \omega A}$ given $f_{\omega p \to \omega p}$. Representative results for the phases are shown in Fig. 1, calculated with a uniform density model for the nucleus of radius (1.3 Fermi) $A^{1/3}$. We show ϕ_A, the phase of $-i\, f^{(\Delta_0)}_{\omega A \to \omega A}$ in the forward direction, as a function of ϕ, the phase of $-i\, f_{\omega p \to \omega p}$; with Im $f_{\omega p \to \omega p}$ chosen so that $\sigma_{\omega p} = 30$ mb. If vector dominance holds, then ϕ_A is directly the phase predicted for the nuclear photoproduction. We have not considered phases larger than 60° in magnitude for $f_{\omega p \to \omega p}$, since such phases would correspond to absurdly large real parts for a forward elastic scattering amplitude. Although the optical model and a uniform density sphere are undoubtedly over-simplified, we can draw certain general conclusions. Note first that the assumption of a large phase for ωp elastic scattering does not lead to a large phase for $f^{(\Delta_0)}_{\omega A \to \omega A}$ even on carbon, due to the damping of the phase by the rescattering effects.

Measurements[1,2] of $\gamma C \to \ell^+ \ell^- C$ (ℓ stands for electron or muon) have been reported which seem to indicate a large relative phase between the ρ and ω — on the order of 100°.[3] At the same time, measurements for the ρ production phase on carbon[4] seem to show the ρ production to be predominantly imaginary (as expected by vector dominance). These results then imply that $f_{\gamma A \to \omega A}$ has a very large phase. A phase of 100° for $\gamma A \to \omega A$ would certainly be in contradiction with simple vector dominance and diffraction dissociation models. In fact, what Fig. 1 shows is that even a phase of $30^\circ - 40^\circ$ on carbon would indicate serious difficulties. It then would appear that confirmation of the experimental results would be disastrous for even the qualitative predictions of simple diffraction production.

The figure also indicates that at low energies, Δ_0 has a large effect on the phases, and on heavy nuclei can even reverse the trend for the phase to be small. At high energy, however, a large ωp scattering phase leads to a small phase on lead. Thus from the point of view of theory, the simplest experiment is at high energy on a large nucleus, where ρ and ω production should be pure imaginary and relatively real if vector dominance holds. If vector dominance does not hold, such a measurement then gives the phase of $f_{\gamma A \to \omega A}/f_{\omega A \to \omega A}$; and similarly for ρ.

If it does in fact turn out that $f_{\gamma A \to \omega A}$ is not close to pure imaginary, then we would be forced to face two possibilities. Either something is wrong with vector dominance and simple diffraction dissociation, or with the simple coherent production formalism. With regard to the latter it is possible that anomalous real parts arise in the production of unstable particles, as a result of on-mass shell scattering of the particles into which they decay.[5] We are presently investigating this question. The electromagnetic mixing of ρ and ω should change the effective phase of the ω by $\lesssim 10^{\circ}$.[6]

Finally, it is also worth noting that while the results for the ρ^{0} phase on carbon are consistent with vector dominance, they do not set very stringent limits on the production phase on the nucleon. For example the result of Asbury et al.[4] $\phi_A = 15 \pm 25^{\circ}$ at 2.8 BeV corresponds to $\phi = 9^{\circ}\,{}^{+41^{\circ}}_{-37^{\circ}}$, as can be seen from Fig. 1.[7]

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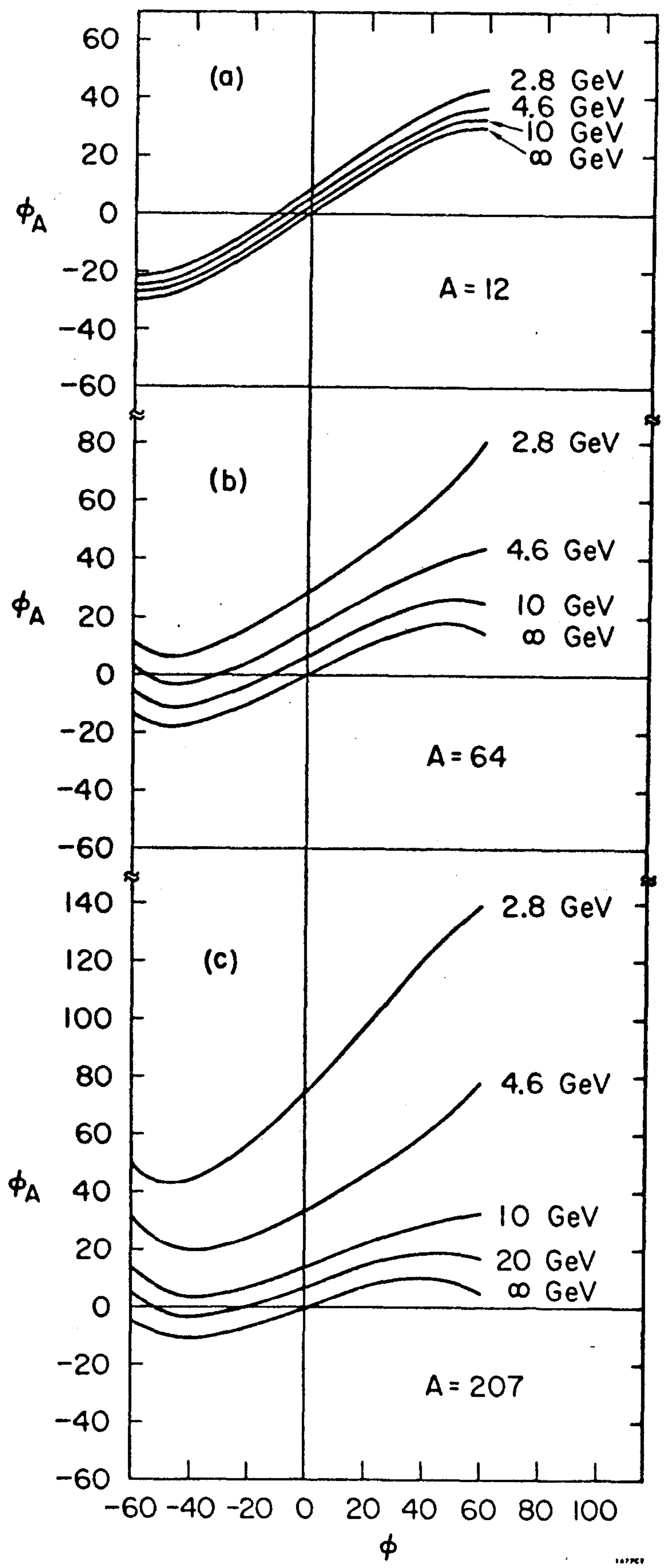

Fig. 1 ϕ_A, the phase of $-i\, f^{(\Delta_0)}_{\omega A \rightarrow \omega A}$, as a function of ϕ, the phase of $-i\, f_{\omega p \rightarrow \omega p}$ for various energies, and various nuclei. ϕ_A is the phase predicted for $\gamma A \rightarrow \rho A$ and $\gamma A \rightarrow \omega A$ by the vector dominance model.