Determination of the ω-γ Coupling Constant and the ω-N Scattering Amplitude*

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Forward ω photoproduction from complex nuclei and interference in the $\pi^+\pi^-$ decay mode of ω, ρ^0 photoproduced from complex nuclei are analyzed to determine the ω-γ coupling constant and the magnitude and phase of the ω-N scattering amplitude. Values obtained are $\gamma_\omega^2/4\pi = 7.6_{-1.1}^{+1.8}$; $\sigma_{\omega N} = 25.3 \pm 7.8$ mb; $\tan^{-1}\alpha_\omega = -28° \pm 16°$.

While there is now reasonable agreement between the values of the ρ^0-γ coupling constant $\gamma_\rho^2/4\pi$ as determined by e^+e^- colliding beams[1] and as determined from ρ^0 photoproduction on complex nuclei,[2,3] the situation for the ω-γ coupling constant $\gamma_\omega^2/4\pi$ is not so clear. The colliding-beam result of the Orsay group[4] is $\gamma_\omega^2/4\pi = 3.7 \pm 0.7$. We have interpreted our experiment on ω photoproduction on complex nuclei[5] to yield the value 7.3 ± 1.0, a factor of 2 discrepancy. In arriving at this result, we made the assumption that the ρ^0- and ω-nucleon scattering amplitudes had the same magnitude and phase, as suggested by the quark model. A subsequent experiment by Biggs *et al.*[6] on interference in the e^+e^- decay mode of ρ^0-ω photoproduced from carbon suggests that the phase difference may be as large as 80°. In this Letter we analyze jointly the results of our experiment[7] on interference in the $\pi^+\pi^-$ decay mode of ρ^0-ω photoproduced from carbon, aluminum, and lead, and our previous experiment[5] on photoproduction of ω mesons from complex nuclei, to determine $\gamma_\omega^2/4\pi$ and also the magnitude and phase of the ω-N elastic-forward-scattering amplitude.

Diffractive photoproduction of vector mesons V from complex nuclei is well described by the vector-dominance assumption, with the use of the optical model to describe V-nucleus scattering. Neglecting nuclear-correlation effects, the production amplitude can be written

$$A_{\gamma V} = A_0 \int_0^{+\infty} d^2b \int_{-\infty}^{+\infty} dz\, \rho(b,z) e^{iq_\parallel z} e^{i\vec{q}\cdot\vec{b}} \times \exp[-\tfrac{1}{2}\sigma_{VN}(1-i\alpha_V)\int_z^{+\infty} \rho(b,z')dz']. \quad (1)$$

Here σ_{VN} is the vector-meson-nucleon total cross section, α_V is the ratio of real to imaginary parts of the forward V-N scattering amplitude, $\vec{b}$ is the impact-parameter vector, z is the coordinate in the forward direction, $q_\parallel = m_V^2/2E_\gamma$, and $\rho(b,z)$ is the nuclear-density distribution. A_0 is the production amplitude on a single nucleon and by vector dominance can be written

$$A_0 = (\alpha/16\gamma_V^2)^{1/2}\sigma_{VN}(i + \alpha_V). \quad (2)$$

We use the same nuclear-density distributions as in our earlier[2,5] work. Since we are principally interested in differences between ρ^0 and ω, minor inaccuracies in this model will cancel.

The data to be utilized are listed in Table I. They consist of 0° ω-photoproduction cross sections from five elements, taken at 6.8 GeV, and ω-ρ^0 phase differences from three elements, taken at 8.0 GeV. Three parameters appear in the description of ω photoproduction: $\gamma_\omega^2/4\pi$, $\sigma_{\omega N}$, and α_ω. χ^2 contours of fits to the photoproduction cross-section data alone are shown in Fig. 1. It is apparent that none of the three parameters are well determined. However,

Table I. Zero-degree ω-photoproduction cross sections and ω-ρ^0 phase differences in the 2π decay mode.

Element	$d\sigma/dt$ (mb/GeV^2)	$\Delta\varphi_A^{\omega\rho}$ (deg)
Be	0.44 ± 0.03	...
C	0.72 ± 0.06	94.0 ± 4.8
Al	2.9 ± 0.3	80.4 ± 5.4
Cu	10.2 ± 0.9	...
Pb	47.5 ± 4.4	79.6 ± 6.3

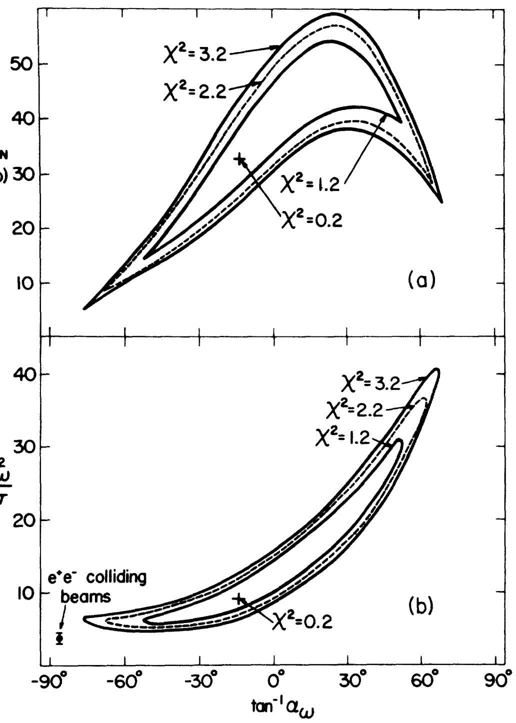

FIG. 1. χ^2 contours of fits to ω photoproduction from complex nuclei (a) in the $\sigma_{\omega N}$-$\tan^{-1}\alpha_\omega$ plane and (b) in the $\gamma_\omega^2/4\pi$-$\tan^{-1}\alpha_\omega$ plane. Also shown is the value of $\gamma_\omega^2/4\pi$ obtained by e^+e^- colliding beams, Ref. 4.

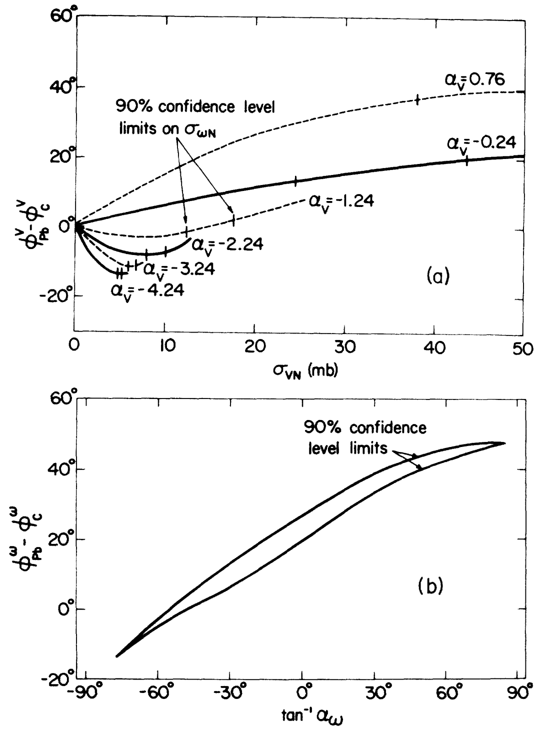

FIG. 2. (a) Calculated difference of the V-nucleus scattering phase between carbon and lead, $\varphi_{\text{Pb}}{}^V-\varphi_{\text{C}}{}^V$, as a function of σ_{VN}, for several α_V. For $V=\omega$, the measured ω-photoproduction cross sections limit $\sigma_{\omega N}$ to the region between the vertical bars, at the 90% confidence level. (b) Calculated limits on the lead-carbon phase difference in ω-nucleus scattering, as a function of $\tan^{-1}\alpha_\omega$. $\sigma_{\omega N}$ has been restricted to the region allowed to it by the ω-photoproduction cross-section data.

fairly strong relations among the parameters are determined. Further, a lower bound on $\gamma_\omega^2/4\pi$ is obtained which is only marginally consistent with the Orsay[4] value.

The ω-ρ^0 phase differences listed in Table I are the sum of the phase differences in ω-ρ^0 photoproduction and in the decay $(\omega$-$\rho^0)\to 2\pi$. In the vector-dominance approach, *all the A dependence* of this phase difference comes from the A dependence of the phase difference of ω-ρ^0-nucleus scattering. This phase difference is readily calculated from Eq. (1), and is described by four[8] parameters: α_ω, α_ρ, $\sigma_{\omega N}$, and $\sigma_{\rho N}$. In our analysis, we assume that these parameters change negligibly between 6.8 and 8.0 GeV. We also take $\alpha_\rho=-0.24$ and $\sigma_{\rho N}=27$ mb as given, thus introducing no additional free parameters.

The calculated A dependence of the V-nucleus forward-elastic-scattering phase is shown in Fig. 2(a), where the lead-carbon phase difference is plotted as a function of σ_{VN} and α_V. This figure can be qualitatively[9] understood as follows. For transparent nuclei ($\sigma_{VN}\to 0$ or $A\to 0$) the V-nucleus scattering phase is equal to the V-nucleon scattering phase, $\pi/2-\tan^{-1}\alpha_V$. For opaque nuclei ($\sigma_{VN}\to\infty$ or $A\to\infty$) the V-nucleus scattering amplitude is purely diffractive, with a phase $\pi/2$, independent of α_V. Thus, for a finite value of σ_{VN}, the phase difference between an "infinite-A" nucleus and a "zero-A" nucleus is just $\tan^{-1}\alpha_V$. There is a range of σ_{VN} where carbon and aluminum are rather transparent, and lead is fairly opaque.

As can be seen in Fig. 2(a), the lead-carbon phase difference depends upon σ_{VN}, at fixed α_V. Consider now $V=\omega$, and impose a restriction between $\sigma_{\omega N}$ and α_ω as given by the ω-photoproduction data; i.e., restrict $\sigma_{\omega N}$ and α_ω to the region of $\chi^2-\chi^2_{\text{min}}<3$, in Fig. 1. With 90% confidence, $\sigma_{\omega N}$ and α_ω lie in this region. The vertical bars on the fixed-α_V curves of Fig. 2(a) indicate the limits of this region. Within these limits, the prediction of the lead-carbon phase difference depends little on $\sigma_{\omega N}$, as is shown in Fig. 2(b). Note that the lead-carbon phase difference is roughly linear in $\tan^{-1}\alpha_\omega$, with a constant of proportionality near $\frac{1}{2}$. Similar results hold for the lead-aluminum phase difference.

$\varphi_A{}^V$, the phase for a single vector meson, cannot be directly compared with our ρ^0-ω interference experiment.[7] Rather one must consider the ω-ρ^0 difference $\Delta\varphi_A{}^{\omega\rho} = \varphi_A{}^{\omega} - \varphi_A{}^{\rho}$. Using the assumed values for α_ρ and $\sigma_{\rho N}$, we calculate the A dependence of the ρ^0-ω difference, and find

$$\Delta\varphi_{\mathrm{Pb}}{}^{\omega\rho} - \tfrac{1}{2}(\Delta\varphi_{\mathrm{Al}}{}^{\omega\rho} + \Delta\varphi_{\mathrm{C}}{}^{\omega\rho}) = (2.25)^{-1}(\tan^{-1}\alpha_\omega - \tan^{-1}\alpha_\rho) \pm 2.5°. \quad (3)$$

The $\pm 2.5°$ error reflects the uncertainties in $\sigma_{\omega N}$ and $\sigma_{\rho N}$. Inserting the measured values of $\Delta\varphi_A{}^{\omega\rho}$ from Table I yields the value[10] of $-17° \pm 17°$ for $\tan^{-1}\alpha_\omega - \tan^{-1}\alpha_\rho$. Assuming $\alpha_\rho = -0.24$, we obtain $\tan^{-1}\alpha_\rho = -30.5° \pm 17°$.

The ω-photoproduction cross sections of Table I can now be reanalyzed, along with the additional piece of datum, $\tan^{-1}\alpha_\omega = -30.5 \pm 17°$. Reminimizing χ^2 yields the fitted values[11] $\sigma_{\omega N} = 25.3 \pm 7.8$ mb; $\gamma_\omega{}^2/4\pi = 7.6^{+1.8}_{-1.1}$; and $\tan^{-1}\alpha_\omega = -2.8° \pm 16°$. Allowing for a $\pm 10\%$ overall normalization uncertainty in the ω-photoproduction cross sections, $\gamma_\omega{}^2/4\pi$ is greater than 5.2 at the 97.5% confidence level.

There have been two ρ^0-ω interference experiments[6,12] in the e^+e^- decay mode, which have been interpreted to yield values of $\tan^{-1}\alpha_\omega - \tan^{-1}\alpha_\rho$. Note that their method (absolute phase from a single-nucleus leptonic decay) is very different from ours. Biggs *et al.*[6] obtain $-80^{+30°}_{-38°}$ at 3.6 GeV, and Ting and collaborators[12] obtain $-21^{+25°}_{-20°}$ at 5.1 GeV. Theoretical expectations based on the quark model or on "common sense" are that the phase difference should be small. The value for $\sigma_{\omega N}$ obtained here is in excellent agreement[2,3] with $\sigma_{\rho N}$, as is expected from the quark model. Including the new information gained in the interference experiment[7] changes $\gamma_\omega{}^2/4\pi$ very little; it is still a factor of 2 larger than the storage-ring value.

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[8]To a good approximation, it is sensitive only to $\alpha_\omega - \alpha_\rho$ and $\sigma_{\omega N} - \sigma_{\rho N}$.

[9]This simple picture neglects the nonzero longitudinal-momentum transfer $q_{\parallel}$. All numerical results are based on Eq. (1), which includes $q_{\parallel}$.

[10]This value implies an aluminum-carbon phase difference of 1°, as compared to $14° \pm 7°$. The large observed difference is not anticipated; we attribute it to a statistical fluctuation. If either the carbon or aluminum phase is used alone, rather than their average, the result changes by one standard deviation.

[11]The errors shown allow for correlations among the parameters.

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