Photoreactions on Nuclei and Vector-Meson-Dominance Breaking*

G. V. Bochmann
McGill University, Montreal, Canada

(Received 14 September 1971)

Within a coupled-channel optical model, calculations of photon-nucleus total cross sections and π^+ photoproduction on nuclei at high energy are presented and compared with experimental data. The question of the validity of vector-meson dominance (VMD) is discussed. It is found that the fair agreement between theory and experiment in a recent paper by Bochmann, Margolis, and Tang can be greatly improved if one uses experimental two-body amplitudes and allows for deviations from the VMD model for the production reactions $\gamma p \to \rho^0 p$ and $\gamma p \to \pi^+ n$.

The multi-GeV total cross-section measurements of photons on nuclei and the incoherent photoproduction of ρ^0 and π^+ mesons on nuclei provide interesting tests of the vector-meson-dominance (VMD) model. In a recent paper,[1] calculations of these processes were presented using eikonal methods. The values of the two-body amplitudes for those calculations were determined from experiments within the framework of VMD. A reasonable agreement was found between the measured cross sections and the calculations. However, within the experimental uncertainties, some discrepancies seemed to be present. The aim of this paper is to point out these difficulties, and to show[2] that one finds excellent agreement with the experimental values if the two-body amplitudes are determined from experiments without the constraints of VMD. A similar approach for the photon-nucleus total cross sections has also been used by Mennessier and Nachtmann.[3]

Results of Ref. 1 for photon-nucleus total cross sections and π^+ photoproduction are shown in Figs. 1 and 2. The experimental uncertainties are still fairly large, and it is not possible to say if any additional assumptions are necessary to describe the experimental data. However, we note some apparent difficulties:

(a) The ratio of photon total cross sections on nuclei and nucleons, respectively, indicates that for heavy nuclei the calculated values are too low (Fig. 1, full lines).

(b) The theoretical result for the effective number $N_{\rm eff}$ of incoherent π^+ photoproduction (Fig. 2,

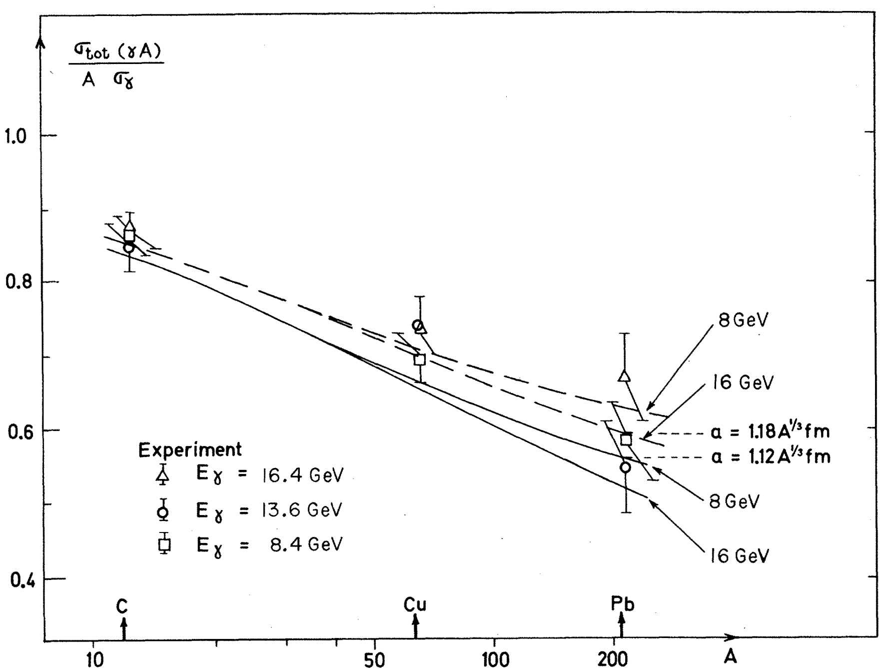

FIG. 1. Photon-nucleus total cross sections: Data from Ref. 5 are compared to theoretical calculations. The nuclear parameters are the same as in Ref. 1. The effect of a change in the nuclear radius from $R = 1.12A^{1/3}$ fm to $R = 1.18A^{1/3}$ fm is shown for $A = 208$ at $E_\gamma = 8$ GeV. Full lines: two-body amplitudes from Ref. 1; Broken lines: two-body amplitudes without the VMD constraints.

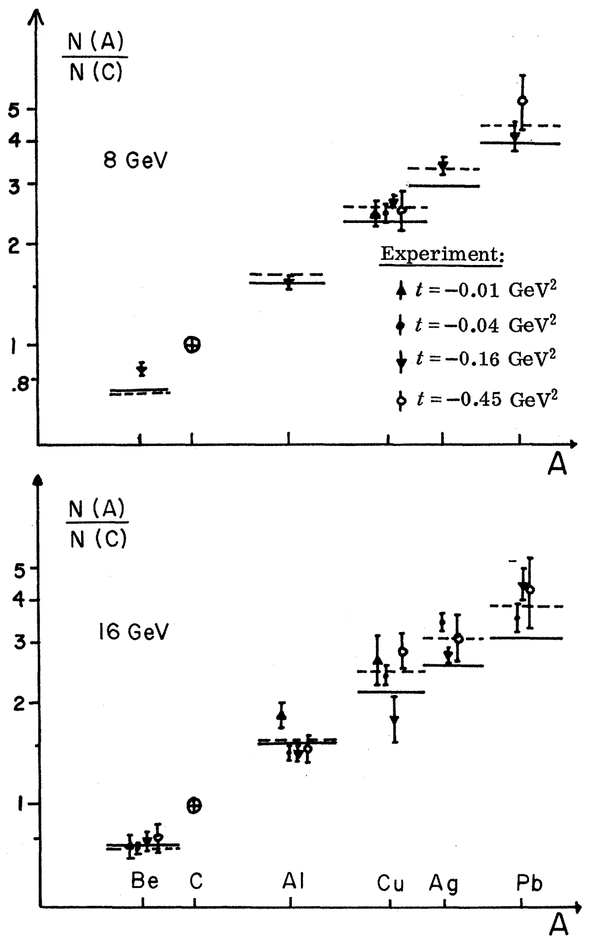

FIG. 2. Incoherent π^+ photoproduction: The values of N_{eff} are given for different nuclei normalized to the value for carbon. The full lines are calculations from Ref. 1. The broken lines are calculations without the VMD constraints. The experimental data are taken from Ref. 4.

full lines) is too low for heavy nuclei.

(c) The calculations for π^+ photoproduction predict too strong an energy dependence, as already noticed by Boyarski *et al.*[4]

(d) There are several methods to determine the ρ^0 total cross section on nucleons σ_ρ, which give slightly different results.

In Ref. 1 the total cross section σ_ρ was determined from measurements of ρ^0 photoproduction on nucleons and the value of the VMD coupling constant $\gamma_\rho^2/4\pi$. We have now determined the value of σ_ρ from measurements[5,6] of the photon-nucleon total cross section σ_γ using the VMD relation

$$\sigma_\gamma = \tfrac{1}{4}\alpha \sum_{V=\rho,\omega,\phi} \left(\frac{\gamma_V^2}{4\pi}\right)^{-1} \sigma_V \, .$$

These values of σ_ρ are listed in Table I.

TABLE I. Photon-nucleon cross sections. The parameters for the two-body amplitudes are listed as functions of the incident photon energy. The values (i) of σ_ρ are determined from the values of σ_γ with $(\gamma_\rho^2/4\pi)^{-1} = 0.5$ and a 16% contribution (Ref. 4) to σ_γ from the vector mesons ω and ϕ. The values (ii) are determined from ρ^0 photoproduction on nucleons with $(\gamma_\rho^2/4\pi)^{-1} = 0.5$ as explained in Ref. 1.

Incident energy E_γ in GeV	5	8	16
σ_γ in μb (a fit to experimental data from Refs. 5 and 6)	124	117	111
σ_ρ in mb (i)	28.5	26.8	25.5
σ_ρ in mb (ii)	25.2	24.2	23.6

The difficulties mentioned above disappear if one allows for breaking of the VMD model in the production reactions $\gamma p \to \rho^0 p$ and $\gamma p \to \pi^+ n$. For ρ^0 photoproduction we describe the amount of breaking with the factor λ, which is defined by the equation

$$\frac{d\sigma}{dt}(\gamma p \to \rho^0 p)_{t=0} = \lambda^2 \frac{1}{16}\left(\frac{\alpha}{4\pi}\right)\left(\frac{\gamma_\rho^2}{4\pi}\right)^{-1} \sigma_\rho^2 (1+\beta^2) \, .$$

For $\lambda = 1$ we have the usual VMD model. The phase $\beta = (\text{Re} f)/(\text{Im} f)$ is taken from Ref. 1. The value of λ can be determined by comparing the values of σ_ρ obtained from ρ^0 photoproduction on hydrogen (see Ref. 1 and Table I) and from photon total cross-section measurements (see Table I). We find λ to be essentially energy-independent with a mean value of $\lambda = 0.9$. This means the ρ^0 photoproduction amplitude $f_{\gamma\rho}$ is 0.9 times smaller than predicted by VMD.

For π^+ photoproduction, the validity of the VMD model is discussed in the literature.[7,8] By comparing experiments of π^+ photoproduction with ρ production by pions on protons, it is found[8] that the amplitude $f(\rho p \to \pi^+ n)$ is about 0.7 times smaller than predicted by VMD. We have used this value for the calculations presented here.

We now come to the calculation of the photon total cross section and the π^+ photoproduction on nuclei. In both cases, the VMD-breaking two-body amplitudes affect the cross sections in a similar way: The contribution of the two-step process [Figs. 3(b) and 4(b), respectively] decreases in ratio to the one-step process [Figs. 3(a) and 4(a), respectively]. Since the two-step amplitude interferes destructively with the dominating one-step amplitude, the effective nucleon number increases appreciably.

We note that the calculations of incoherent ρ^0 production on nuclei of Ref. 1 are not affected by these considerations.

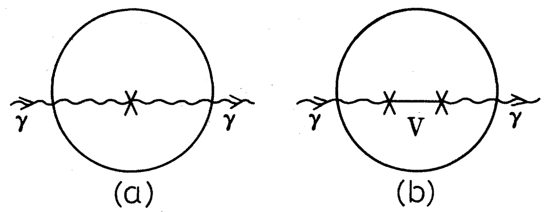

FIG. 3. Diagrams from photon forward elastic scattering on nuclei: (a) one-step elastic scattering of the photon on a nucleon, (b) two-step process with vector-meson production and photon regeneration.

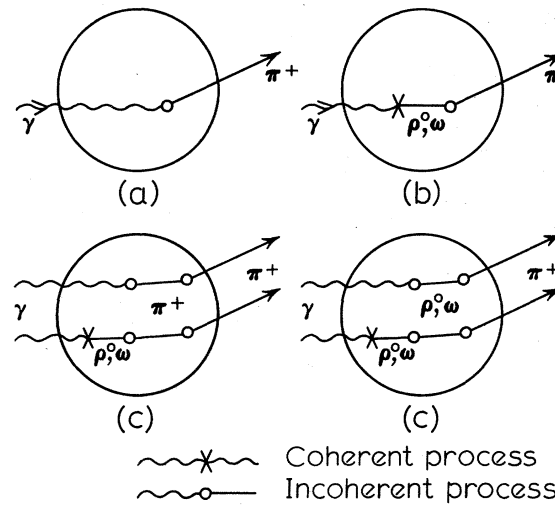

FIG. 4. Diagrams for incoherent π^+ photoproduction on nuclei: (a) one-step process, (b) two-step process with intermediate vector meson ρ or ω, and (c) processes with two incoherent steps.

We have redone the calculations of Ref. 1 using experimental two-body amplitudes. We include the contributions to the cross section from one-step and multi-step processes, as shown in Figs. 3 and 4. The two-body amplitudes are determined as discussed above. The results of these calculations are shown in Figs. 1 and 2 (broken lines), and they exhibit good agreement with the experimental data.

We note that these new results are not sensitive to the value used for the ρ-meson coupling constant $\gamma_\rho^2/4\pi$. Only the ρ-nucleon total cross section depends on this value, and it is shown in Ref. 3 that the photon-nucleus total cross section is insensitive to σ_ρ.

We come to the conclusion that the VMD model, together with the eikonal methods used, provide a reasonable description of the photoreactions on nuclei described above.[1] However, if we allow for breaking of VMD, and use the measured two-body production cross sections, we find that the calculations for photoreactions on nuclei (photon-nucleus total cross sections and incoherent π^+ photoproduction) show a better agreement with the experimental data. Even though the experimental uncertainties are large, these results indicate that the deviations from the VMD model, as they seem to be observed in two-body reactions, are really present.

It is a pleasure for me to thank Professor B. Margolis for encouragement and many fruitful discussions in relation to the work presented here.

---

*Work supported in part by the National Research Council of Canada.

[1]G. V. Bochmann, B. Margolis, and C. L. Tang, Phys. Rev. Letters 24, 483 (1970).

[2]See also G. V. Bochmann, Ph. D. thesis, McGill University, 1971 (unpublished).

[3]G. Mennessier and O. Nachtmann, Phys. Letters 34B, 309 (1971).

[4]A. M. Boyarski *et al.*, Phys. Rev. Letters 23, 1343 (1969).

[5]D. O. Caldwell *et al.*, Phys. Rev. Letters 23, 1256 (1969). See also D. O. Caldwell *et al.*, *ibid.* 25, 609 (1970).

[6]H. Meyer *et al.*, in *International Symposium on Electron and Photon Interactions at High Energies, Liverpool, England, 1969,* edited by D. W. Braben and R. E. Rand (Daresbury Nuclear Physics Laboratory, Daresbury, Lancashire, England, 1970).

[7]D. Schildknecht, in *Proceedings of the International Seminar on Vector Mesons and Electromagnetic Interactions, Dubna, U.S.S.R., 1969* (Joint Inst. Nucl. Res., Moscow, U.S.S.R, 1969).

[8]R. Diebold and J. A. Poirier, Phys. Rev. Letters 22, 906 (1969).