Comments on the Radiative Decay Width of the ρ^-†

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Our reported measurement of the radiative decay width $\Gamma(\rho^- \to \pi^- + \gamma) = 35 \pm 10$ keV appears anomalously low when compared with the basic unbroken SU(3)-symmetry theoretical prediction. Further comments concerning our method of analyses and our results are provided in hope of removing recent confusion. The analysis provides the phase of the transition as well as the amplitude, and a plea is made for theoretical effort on this phase.

Several new phenomenological comparisons of the radiative decay widths of the nonet of vector mesons have been published.[1-4] New compilations of the experimental measurements of the radiative widths have been compared with predictions based on some form of the SU(3) symmetry scheme. The most striking feature of the comparisons appears to involve the ratio $\Gamma(\omega^0 \to \pi^0 + \gamma)/\Gamma(\rho^- \to \pi^- + \gamma)$. While the unbroken SU(3) prediction for this ratio is $\approx 9:1$, the measured value[5,6] is $(870 \pm 50\text{ keV})/(35 \pm 10\text{ keV}) \cong 25:1$. No attractive theoretical scheme for reconciling theory and experiment has yet been advanced.[7]

Our previous Letter[5] on the reaction $\pi^- + A \to \rho^- + A$ is based upon an experiment and analysis which are more fully described in the thesis of Strawczynski.[8] The Letter provides more sharply drawn final conclusions. The primary purpose of the present Comment is to clarify whatever confusion has been engendered by the fact that the conclusions from the earlier unpublished theses were weaker and more tentative.[9] In order to avoid further confusion, let it be clearly understood that the analysis we describe below is that used in Ref. 5.

The primary data analysis provides the coherent cross section $d\sigma(\pi^- + A \to \rho^- + A)/dt$ versus t for six different targets (C, Al, Cu, Ag, Pb, and and U). There are three fundamental quantities which are extracted from the subsequent analysis: (1) The amplitude for coherent Coulomb dissociation of the π^-; (2) the coherent strong-interaction amplitude (ω^0 exchange); and (3) the intrinsic relative phase of the two amplitudes (φ). The square of the Coulomb amplitude can be written as the radiative decay width $\Gamma(\rho^- \to \pi^- + \gamma)$ times a factor containing some t and A dependence; this latter factor is calculated by the optical-model technique. Similarly, the square of the ω^0-exchange amplitude is written as C_0 times another t- and A-dependent term which is also calculated with the aid of an optical model. Implicitly then, C_0 can be interpreted as the intensity of ρ^- production by ω^0 exchange that would be directly extracted from data taken with a hydrogen target. The optical model has fixed parameters; these parameters include the mean nuclear radius and shape and the $\rho^- N$ total cross section. The latter has been set equal to the $\rho^0 N$ total cross section (26 mb) as determined by similar optical-model analyses of $\gamma + A \to \rho^0 + A$ experiments.[10] The uncertainties quoted in the final results reflect the uncertainties in the optical-model parameters.

If one examines the integrated cross section versus Z,[5] it is clear that the observed process is neither pure Coulombic (rapid Z increase, approaching Z^2) nor pure strong (slow, saturating increase with Z). This observation is supported by an examination of the t dependence for the individual target data. The experimental data (with the exception of the low-Z data, i.e., for carbon) are of intermediate character. It is more sharply peaked at small t than is predicted on the basis of pure coherent strong production, but it is not as sharply peaked as would be the case for pure Coulombic production. Despite these observations, if the yield for high-Z elements (Pb, U) were to be ascribed *entirely* to Coulombic pro-

TABLE I. Results of the fits to the angular distributions.[a]

Element	Γ (keV)	C_0 [mb/(GeV/c)^4]	χ^2 per degree of freedom	φ (deg)
U	34 ± 4	2.4 ± 0.3	10/9	0
Pb	22 ± 3	2.7 ± 0.3	17/11	
Ag	15 ± 4	3.3 ± 0.3	11/8	
Cu	17 ± 4	3.4 ± 0.2	11/6	
U	77 ± 5	1.8 ± 0.3	12/9	90
Pb	64 ± 4	2.1 ± 0.2	16/11	
Ag	57 ± 6	3.2 ± 0.2	7/8	
Cu	66 ± 8	3.4 ± 0.2	10/4	
U	114 ± 7	5.8 ± 0.7	42/9	180
Pb	103 ± 6	5.2 ± 0.4	47/11	
Ag	106 ± 16	5.9 ± 0.9	19/8	
Cu	139 ± 14	5.8 ± 0.2	35/6	
U	32 ± 4	4.7 ± 0.4	10/9	270
Pb	26 ± 3	4.3 ± 0.8	16/11	
Ag	28 ± 5	4.0 ± 0.3	8/8	
Cu	41 ± 7	3.9 ± 0.2	10/6	
All elements fitted simultaneously	34 ± 4	4.9 ± 0.2	···	256 ± 6

[a]Reproduced from Ref. 8.

duction, a value of $\Gamma(\rho^- \to \pi^- + \gamma) \approx 50$ keV results. A larger value of Γ can only be supported by the data analysis if there is a measure of destructively interfering strong production amplitude. The results of separate, three-parameter fits to the four elements of highest Z are given in Table I. Approximately one quadrant of φ values centered about $\varphi = 180°$ can be clearly rejected on the basis of unacceptable χ^2 values. Plots of these fits are given in the thesis and readily confirm this judgment.[8] On this basis only, an upper limit of $\Gamma = 80 \pm 10$ keV can be established.[11] But the large value of Γ simultaneously implies a *set* of C_0 values. Consider the entries for $\varphi = 90°$. Although the fits are individually acceptable, C_0 for C and Al is more than twice the value implied by the Pb and U fits.

The C data have an effectively negligible Coulomb component and thus provide C_0 relatively unambiguously. If all the data are simultaneously fitted, a much more restricted solution is provided. Our published conclusions were and are $\Gamma(\rho^- \to \pi^- + \gamma) = 35 \pm 10$ keV, $C_0 = 4.0 \pm 1.0$ mb/GeV,[4] and $\varphi = 270° \pm 45°$. The uncertainties were increased to accommodate our appraisal of the systematic uncertainties. The above value of C_0 is in excellent agreement with the value extracted from $\pi + p \to \rho + N$ experiments.[12] As noted earlier, if we allow C_0 to vary with target element, a larger value of Γ is possible. This is equivalent to an assertion that our optical model for the A dependence of the ω^0-exchange process is uncertain by a factor of 2. It is our considered judgment that this is not the case. We believe that the basic optical-model formulation is on sound theoretical footing for this type of coherent process and that the uncertainty of the model is truly reflected by the uncertainties produced by our knowledge of the phenomenological parameters noted earlier.

The unpublished thesis[8] from which Table I was extracted was completed half a year earlier than the publication.[5] At the earlier juncture we had not yet decided to rule out the analysis solution which provided a set of C_0 values. We were still gaining experience with optical-model fits to other coherent channels; our analysis of the $\Gamma(\Delta^+ \to p + \pi^0)$ decay width was not completed.[13] We were quite aware of the anomalous implications of our measurement and were not disposed to precipitous conclusions. We are surprised that anyone claiming to have read the thesis and the previous Letter could find all of this so perplexing.[9]

We conclude with the observation that a theoretical calculation of the phase angle φ might prove to be extremely interesting.

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[5]B. Gobbi *et al.*, Phys. Rev. Lett. 33, 1450 (1974).

[6]The width $\Gamma(\omega^0 \to \pi^0+\gamma)$ is taken from V. Chaloupka *et al.*, Phys. Lett. 50B, 1 (1974).

[7]There is little doubt that improved measurements on the processes $\rho^- \to \pi^- +\gamma$, $K^{*0} \to K^0+\gamma$, and $K^{*-} \to K^- +\gamma$ with use of the Coulomb dissociation technique and beam energies in excess of 100 GeV can and will be forthcoming. The accuracy of the existing results obtained at lower beam energies has been restricted by the complication engendered by the interference between Coulomb and strong amplitudes. At the higher energies now available, the Coulomb amplitude will markedly dominate the strong amplitude for large Z, and the extraction of accurate radiative widths will result. Accurate values for C_0 and φ (see text for definitions) should also be provided.

[8]L. Strawczynski, Ph.D. thesis, University of Rochester, 1974 (unpublished).

[9]Several of the theoretical papers cited above contain incorrect inferences concerning our work. The author of Ref. 4 incorrectly gives our result as 50 ± 25 keV and quotes Refs. 1 and 2 as justification.

[10]H. Alvensleben *et al.*, Phys. Rev. Lett. 24, 786 (1970); H. J. Behrend *et al.*, Phys. Rev. Lett. 24, 336 (1970).

[11]The reader may wonder why the solutions for $\varphi=90°$ correspond to larger Γ than that given by setting $C_0=0$. The underlying explanation is that some destructive interference is implied for $\varphi=90°$. This is caused by Coulomb phase shifting which must be included in the analysis. Coulomb phase shifting decreases with increasing impact parameter. The strong-interaction amplitude corresponds to impact parameters equal or less than the nuclear radius. The Coulomb dissociation amplitude contains contributions from substantially greater impact parameters and consequently lags in phase. The manner in which Coulomb phase shifting is introduced into the optical-model analysis is entirely straightforward.

[12]See Ref. 5 for discussion and references.

[13]We submit that our experiment features an unusual number of checks and controls. These are briefly noted in Ref. 5. Of particular interest is the fact that the identical experimental apparatus was also used to measure the coherent reaction $p+A \to \Delta^+ +A$ under almost identical beam conditions. [B. Gobbi *et al.*, Phys. Lett. 58B, 219 (1975).] The subsequent optical-model analysis gave results in excellent agreement (± 8%) with the prediction based on $\gamma+p \to \Delta^+ \to p+\pi^0$ experimental data. This result can be equivalently expressed by the statement that the measurement provides a value of $\Gamma(\Delta^+ \to p+\gamma) \approx 600$ keV, in excellent agreement with published values.

Reply to "Comment on 'Resonance Raman Scattering and Collision-Induced Redistribution Scattering in I_2'"

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We demonstrate that neither laser broadening nor inelastic collisional broadening plays a dominant role in the data of our recent experiments as has been suggested, and again we conclude that our results can only be explained by redistribution emission resulting from phase-changing processes.

In a recent Letter[1] we reported temporal and frequency measurements on the re-emitted light following slightly off-resonance monochromatic excitation of molecular iodine. We interpreted our data as clear evidence for collisional redistribution—an effect predicted some years ago[2] but not previously observed. This process is one in which a molecule undergoes a collision resulting in a change of phase but it remains in the same quantum state, i.e., it is a pseudoelastic collision. Similar observations were subsequently made in atomic sodium by Carlsten and Szöke.[3]