Photon interactions below 9 MeV in Ba and Ce

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Elastic scattering of monoenergetic tagged photons from natural barium and cerium targets was measured at 135° for excitations between 4.5 and 9.0 MeV. The data were used to infer the respective total absorption cross sections below neutron emission threshold, and the results are compared with (γ,n) measurements and with the predictions of a quasiparticle-phonon calculation in ^{140}Ce. The low energy dipole absorption is found to be generally consistent with an extrapolation of the tail of the $E1$ giant resonance, and to be substantially underestimated by the quasiparticle-phonon theory.

In heavier nuclei, away from closed shells, it is expected that the low energy distribution of $E1$ transition strength will tend to be governed by the tail of the giant dipole resonance (GDR).[1,2] Near closed shells, however, it is likely that the detailed energy dependence of the electric dipole strength will be strongly influenced by the fragmentation of the one-photon states that are found near the neutron emission threshold.[3] In particular, nuclei in the region about doubly closed ^{208}Pb show little indication of a GDR tail at subthreshold excitations.[4] The gross distribution of $E1$ strength in these nuclei, however, is found to be very much the same from nucleus to nucleus, which suggests that underlying simple 1p-1h core excitations may be dominant. The theoretical work of Soloviev *et al.*[3] indicates that the situation may be similar for the single closed shell $N=82$ nuclei in that the $E1$ strength function near threshold is predicted to be only slightly influenced by the GDR. This prediction can be tested by an examination of the photon absorption cross section inferred from elastic photon scattering.

A second reason for interest in subthreshold measurements of photon elastic scattering in the $N=82$ region concerns the question of the giant magnetic dipole resonance. Outside of the Pb region, the Ba and Ce nuclei are expected to exhibit the best examples of strong localized spin-flip $M1$ transition strength.[5] This $M1$ strength is likely to constitute substantially less than 10% of the total dipole ($E1+M1$) scattering below threshold, and the extraction of quantitative $M1$ strength distributions from asymmetries measured with tagged polarized photons as discussed in Ref. 6 will require an accurate determination of the unpolarized elastic scattering cross section.

In the present experiment, elastic scattering of tagged monoenergetic photons from natural barium and cerium targets was measured at 135° for excitations between 4.5 and 9.0 MeV. The details of the photon tagging technique and the experimental procedure are the same as have been described in Ref. 4. Specific information about the Ba and Ce targets is given in Table I. The observed average photoelastic differential cross sections for barium and cerium are shown in Figs. 1 and 2. The error bars correspond to statistical uncertainty only, and the systematic error is estimated to be less than about 8%, as discussed in Ref. 4. The total elastic cross section scale corresponds to a dipole angular distribution.

Both cross sections exhibit considerable structure. Collateral nuclear resonance fluorescence (NRF) measurements[7,8] tend to indicate, however, that this structure is not due to individual strong nuclear transitions. In the work of Ref. 8, the largest NRF transitions were found to have strengths $\Gamma_0^2/\Gamma \lesssim 2$ eV, and seem to show only modest correlation with the structure in the cross sections of Figs. 1 and 2. No NRF resonances were observed above about 7.2 MeV excitation nor could resonances with ground state widths of less than a few tenths of an eV be resolved by the NRF method. Strength discrepancies where NRF resonances were observed can be accounted for by contributions to the tagged photon scattering from levels with individual ground state widths that are below the sensitivity of the NRF technique.[4]

A reasonable estimate of the total photon absorption cross section below threshold can be deduced from the measured average elastic cross section.[9] The analysis assumes that the ground state widths follow a Porter-Thomas distribution, and depends rather weakly on the ratio of the average level spacing, $\bar{D}$, to the average total radiative width. For both barium and cerium, $\bar{D}$ was obtained from a standard backshifted Fermi-gas level density formula[10,11] with the parameters $a=15.0$ MeV^{-1} and $\Delta=1.35$ MeV taken from Ref. 11. The average total radiative width, $\Gamma_{\gamma T}\sim 0.8$ eV, was estimated from neutron

TABLE I. Target composition.

Target	Isotope	Abundance	(γ, n) threshold (MeV)	atoms/b
Ce	140	88.5%	9.1	0.0199
	142	11.1%	7.2	
Ba	138	71.7%	8.6	0.0233
	137	11.3%	6.9	
	136	7.8%	9.1	
	135	6.6%	7.0	

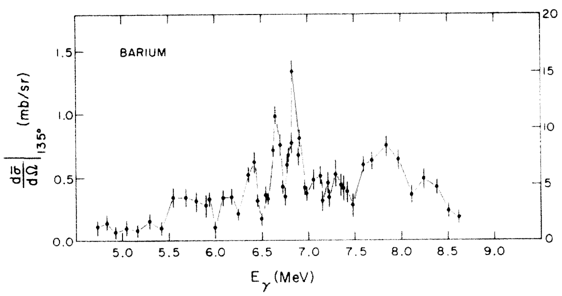

FIG. 1. Elastic tagged photon scattering cross section for natural barium.

capture data reported in Ref. 12.

The inferred total photon absorption cross sections below threshold in barium and cerium are shown in Figs. 3 and 4. In Fig. 3, the results of the present work (solid lines) are compared with (γ,n) data from Saclay[13] (open circles). The dashed curves are an extrapolation to lower energies of the Lorentz lines that were fit to the (γ,n) data over the peak of the GDR.[13] In both cases, the general trend of the absorption cross section below threshold seems to be quite consistent with the extension of the Lorentz line at least down to excitations of 5 or 6 MeV. The cross section inferred from the elastic photon data has a tendency to lie above the line, but this tendency is also seen in the (γ,n) data even well above the threshold region.

Also shown in Fig. 3 are cross section points derived from very high resolution threshold photoneutron measurements in ^{138}Ba and ^{140}Ce (plus signs).[14,15] In this threshold work, individual transitions were observed over excitation intervals of 50 keV at 8.6 MeV in Ba and 40 keV at 9.1 MeV in Ce. Only transitions with photon widths greater than about 15 meV were resolved. In the present work, total ground state strengths were obtained from the respective reported resolved strengths[14,15] and from the strength resolution limit by assuming that the photon ground state partial widths follow a Porter-Thomas distribution. Both $E1$ and $M1$ strengths were combined to produce the threshold total dipole cross sections indicated by the plus signs in Fig. 3. The threshold data are quite consistent with both the higher energy (γ,n) data from Saclay and the present subthreshold measurements.

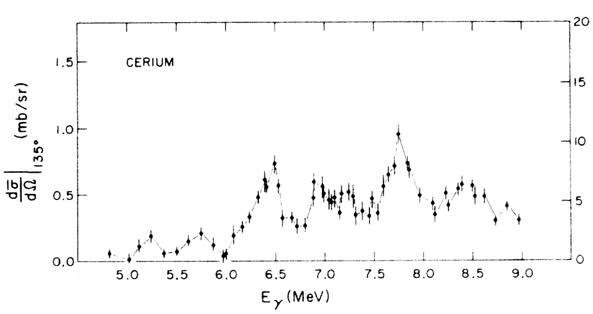

FIG. 2. Elastic tagged photon scattering cross section for natural cerium.

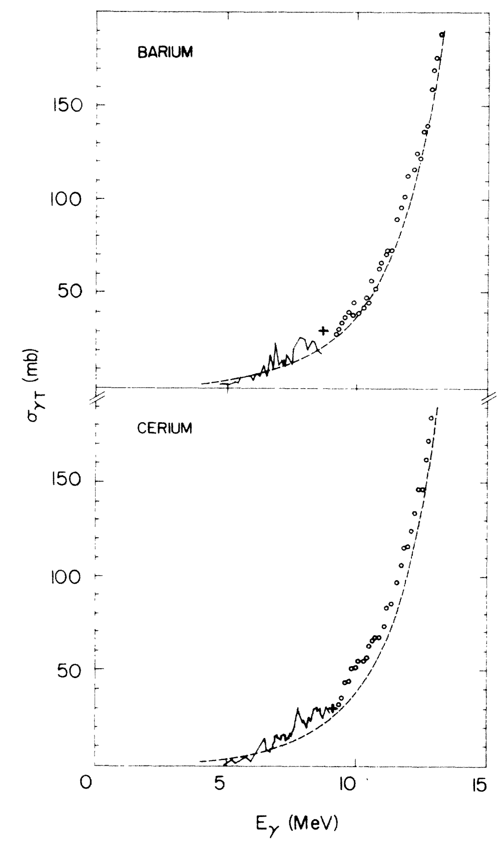

FIG. 3. Inferred total absorption cross sections for Ba and Ce from the present work (solid lines) compared with (γ,n) data from Ref. 13 (circles). The dashed curves are Lorentz-line fits to the respective GDR's (Ref. 13). Also shown (plus signs) are cross sections derived from very high resolution threshold photoneutron measurements in ^{138}Ba (Ref. 14) and ^{140}Ce (Ref. 15).

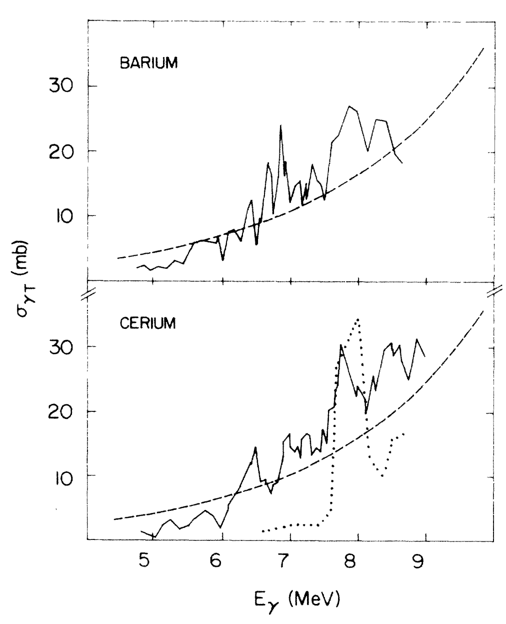

FIG. 4. Inferred total absorption cross sections for Ba and Ce from the present work (solid lines) compared with the predictions of the quasiparticle-phonon model of Ref. 3 (dotted line). The dashed curves are the Lorentz lines of Ref. 13.

In Fig. 4, the total absorption cross sections below 9 MeV are compared with the distribution of $E1$ strength that was calculated in Ref. 3 for ^{140}Ce using the quasiparticle-phonon model (dotted line). In general, the calculation predicts substantially less electric dipole strength than is indicated by the present work.[16] This suggests that the influence of the GDR at low excitations is in fact considerably greater than has been accounted for by the model. The calculated peak at 8 MeV excitation corresponds well in both location and magnitude to large individual peaks in both the Ce and Ba cross sections. The presence of this peak in the theoretical work is attributed to a relative reduction in the amount of one-phonon state fragmentation that occurs in nuclei near closed shells. It is likely that much of the more pronounced structure that is found in the experimental measurements can be related to locally fragmented "core" states. This observation is also supported by the similarity between Ba and Ce in the details of the respective structure seen at excitations of 6.5, 6.9—7.2, 7.9, and 8.3 MeV.

It is useful to compare the inferred total absorption cross sections shown in Fig. 4 with similar plots from the Pb region which are given in Fig. 5.[4] The congruence of the distribution of the low energy total absorption in ^{206}Pb, ^{208}Pb, and ^{209}Bi is evident, and in each case the trend of the cross section lies well away from and below the extrapolated GDR tail. It may be that only in nuclei near the Pb double closed shell do the one-phonon states really dominate the distribution of low energy electric dipole strength. Away from Pb, the tail of the GDR appears to have a strong influence even in nuclei with single closed shells. In the $N = 82$ nuclei, the primary effect of the one-phonon states near threshold seems to be to produce a strong modulation on the extrapolated trend of the GDR.

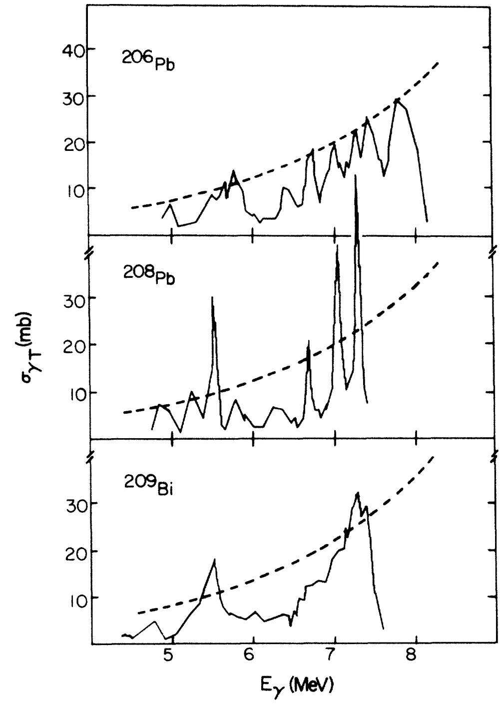

FIG. 5. Inferred total absorption cross sections for ^{206}Pb, ^{208}Pb, and ^{209}Bi from the elastic scattering data of Ref. 4. The dashed curves are the GDR Lorentz lines of Ref. 17.

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