for proton energies of 150 to 500 MeV.

In summary, we draw the following conclusions from our 400-MeV $p+^{208}$Pb results: (1) A KMT optical potential for which the real central part has a radial form closely resembling that of the matter density, as is derived with use of free N-N amplitudes, does not give correct analyzing powers. (2) Improved prediction of analyzing powers seems to require that the potential does not simply vary linearly with matter density. Such potentials arise naturally in Brueckner-Hartree-Fock or Dirac-Hartree models, and such models may be necessary to explain elastic scattering of protons at 400 MeV. (3) The positions of maxima and minima in the cross-section angular distribution depend sensitively on the rms radius of the neutron density, but not on a density-dependent modification to the effective N-N interaction. Whatever the deficiencies in the KMT model turn out to be at 400 MeV, it is possible that they do not affect neutron radius determinations; our result for the rms neutron radius of ^{208}Pb is within a standard deviation of that obtained at 800 MeV, and significantly lower than the prediction of the density matrix expansion model.

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Investigation of the Fission Decay of the Isoscalar Giant Quadrupole Resonance in ^{238}U by Electron- and Positron-Induced Fission

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The controversial results for the fission decay of the isoscalar giant quadrupole resonance in ^{238}U have been investigated by electron- and positron-induced fission experiments ($E_e = 10-35$ MeV). The measured cross-section ratio σ^-/σ^+ and absolute cross sections were analyzed with use of available distorted-wave Born-approzimation virtual-photon spectra. Within this analysis no fission decay of the giant quadropole resonance could be detected, in contrast to a recent inclusive electrofission work.

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The isoscalar giant quadrupole resonance (GQR) in heavy nuclei[1] has been observed in various hadron- and electron-induced reactions[2-4] at an excitation energy of $\approx 65A^{-1/3}$ MeV. However, a number of controversial experiments have been recently reported on the fission decay of the GQR in actinide nuclei. In Table I the results for ^{238}U are summarized. Arruda Neto *et al.*[5] extracted a high fission branch, exhausting ≈ 70% of the energy-weighted sum rule (EWSR), from inclusive (e,f) experiments by means of the virtual-photon concept. This leads to a fission probability of the GQR of ≈ 80% and ≈ 40% in the energy ranges of 6.5 to 8.5 and 9 to 12 MeV, respectively.[6] These conclusions are challenged by $(\alpha,\alpha'f)$ coincidence experiments of van der Plicht *et al.*,[4] who deduced an upper limit for the fission probability of the GQR of only ≤ 11%, which is below the fission probability of the underlying continuum. Very recent $(\alpha,\alpha'f)$ measurements performed at a higher α energy ($E_\alpha = 152$ MeV) by Bertrand *et al.*[7] resulted in nearly equal fission probabilities of the GQR and the continuum [(25 ± 10)% and (21 ± 8)%]. Shotter *et al.*[8] observed some structure in $(^6\mathrm{Li},{}^6\mathrm{Li}'f)$ coincidence spectra, but failed in extracting a quantitative fission probability. Besides these hadron-induced reaction data also electrodisintegration experiments contribute to these controversial results. Absolute cross-section measurements of Aschenbach, Haag, and Krieger,[9] analyzed in the frame of the virtual-photon concept as was Arruda Neto's data, indicate a negligible fission decay of the GQR and disagree with the absolute values reported by Arruda Neto and Berman.[6] From a very recent $(e,e'f)$ coincidence study[10] performed at Illinois a strength of ≈ 13% $E2$ EWSR was observed in the fission channel of the GQR. At Stanford a strength of 25% EWSR was found in the same reaction.[11] However, both $(e,e'f)$ and hadron-induced experiments could not separate possible $E0$ contributions.

This controversial experimental situation clearly shows that the decay properties of the GQR in actinide isotopes are an open problem. However, the knowledge of the GQR fission probability as compared to the statistical decay of the giant dipole resonance should provide interesting information on the coupling between the collective phenomena of giant resonances and fission. Therefore we performed measurements of electrofission cross sections with improved techniques by using both electron and positron beams of the Giessen linac. Our aim was to clarify the existing discrepancies and in addition to test the inclusive (e,f) experiments and their analysis within the virtual-photon concept.[12,13]

The electrofission cross section is given as a sum of folding integrals over the photofission cross section of the multipolarity λL and the corresponding virtual-photon spectrum:

$$\sigma_e(E) = \sum_{\lambda L} \int_0^E \sigma_{\gamma f}{}^{\lambda L}(E_\gamma) N^{\lambda L}(E, E_\gamma) \frac{dE_\gamma}{E_\gamma}. \qquad (1)$$

The virtual-photon spectra can be calculated in the distorted-wave Born approximation (DWBA). They strongly depend on the multipolarity.[13] In particular one finds that the intensity of $E2$ spectra is much higher than that of $E1$ spectra. Furthermore the ratio of $E2$ spectra for electrons and positrons is considerably larger than the corresponding $E1$ ratio. Therefore it is—at least in principle—possible to extract $E2$ strength either by measuring absolute electroinduced and photoinduced cross sections or by determining the ratio of electron- and positron-induced cross sections. Arruda Neto and Berman[6] used the first possibility and compared their absolute electrofission cross section σ_e with calculated ones $\sigma_{\mathrm{calc}}{}^{E1}$ [see Eq. (1)], assuming that the experi-

TABLE I. Results from investigations of the fission decay of the GQR in ^{238}U.

Reaction	$E2$ EWSR in the fission channel (%)	Fission probability P_f (%)	Reference
$(\alpha,\alpha'f)$		≤ 11	4
$(\alpha,\alpha'f)$	(50 ±15)	25 ± 10	7
$(^6\mathrm{Li},{}^6\mathrm{Li}'f)$		≥11	8
(e,f)	65 ±7	80 ± 10 (< 8.5 MeV)[a]	6
		40 ± 10 (9 – 12 MeV)[a]	
(e,f)	≈0		9
$(e,e'f)$	13.4±2.6 (< 11.7 MeV)[a]		10
$(e,e'f)$	≈25 (< 11 MeV)[a]		11

[a]Integration interval.

mental photofission cross section $\sigma_{\gamma f}$[14] is purely $E1$. An analysis of the difference $\sigma_e - \sigma_{\text{calc}}^{E1}$ yields the $E2$ photofission cross section. It should be emphasized that two absolute cross sections (σ_e and $\sigma_{\gamma f}$), measured at two different laboratories, are needed in this procedure.

As we pointed out in our previous papers[15,16] the measurement of the cross-section ratio σ^-/σ^+ for electron- and positron-induced reactions represents a more reliable method to detect $E2$ strength from electrodisintegration experiments, since in this quantity the absolute scale of the photoinduced cross section is nearly canceled. Furthermore, only relative electroinduced cross sections have to be measured; no absolute calibrations are necessary.

The electrofission experiments were performed at the Giessen linac. The irradiation facility was similar to that used in our previous measurements[16] and will be described in detail in a forthcoming paper.[17] The beam current was measured absolutely by a calibrated Faraday cup directly connected to the vacuum system. A system of beam profile and position monitors and removable scintillators enabled an optimal beam adjustment. The fission fragments were detected by two large-area (113 cm^2) parallel-plate detectors.[18] The detectors, placed at $\pm 90°$ with respect to the beam, each covered a solid angle of $\approx 15\%$ of 2π. The targets could be displaced in order to check

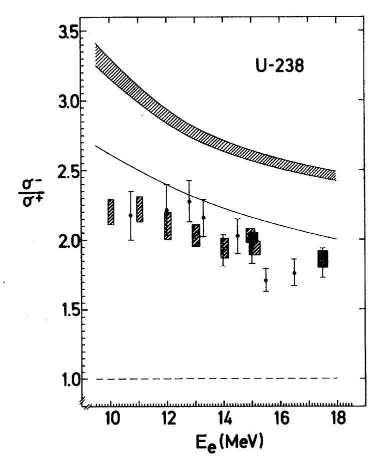

FIG. 1. Ratio σ^-/σ^+ as a function of bombarding energy E_e. Hatched rectangles: results for a thick target; full rectangles: results for a thin target; full points: previous results (Ref. 16) taken with track detectors; broken line: plane-wave calculation; full line: DWBA calculation for a pure $E1$ excitation; hatched area: DWBA prediction including the $E2$ strength of Ref. 6.

the negligible background from neutron-induced fission. Small corrections were made for bremsstrahlung-induced fission.

Figure 1 shows our results for the cross-section ratio σ^-/σ^+ as obtained for a thick (2.8 mg/cm^2) and a thin target (200 μg/cm^2), respectively. For comparison our previous data,[16] measured with track detectors, are also plotted. The full curve represents the calculation with use of the available DWBA virtual-photon spectra[13,19] and the photofission cross section as measured by Caldwell *et al.*[14] The hatched, curved area is the DWBA prediction with the assumption of an $E2$ strength as reported by Arruda Neto and Berman[6] ($65 \pm 7\%$ of EWSR). Our results are in disagreement with the conclusions of Arruda Neto and Berman. The data points are even slightly below the pure $E1$ curve.

This raises the question on the accuracy of the calculated virtual-photon spectra and their approximations. Small changes ($\approx 5\%$) in the scale of the $E1$ virtual-photon spectra result in an agreement of our data with a pure-$E1$ calculation. Unfortunately no conclusive tests of the virtual-$E1$-photon spectra exists with an accuracy better than 10%–20% since the investigated (e,n) and (e,f) reaction data[13,16,20,21] were analyzed with the assumption of a pure $E1$ excitation. However, a possible $E2$ contribution to the absorption cross section would increase the electroinduced cross sections considerably. The $E2$ spectra were only checked in the low-energy region (6–7 MeV) with an accuracy of $\pm 20\%$ (Ref. 22).

As a further test we performed absolute electrofission cross-section measurements, since the results reported in the literature so far differ considerably. In the absolute measurements we used a thin target (200 μg/cm^2), where the bremsstrahlung production and the absorption of fragments are negligible. The target thickness was measured by α spectroscopy. Because of absolute calibrations our results have a systematic error of $\approx 6\%$. With use of a coincidence technique the efficiency of the detectors could be controlled on-line. We restricted ourselves to an energy range ≤ 35 MeV since at lower energies finite-size effects in the calculated virtual-photon spectra are negligible and furthermore the assumed extrapolations for the photofission cross sections for energies E_γ above ≈ 18 MeV do not affect considerably the conclusions (see Ref. 9).

Figure 2 shows our data and the results of previous electron-induced fission experiments. The hatched areas represent the $E1$ prediction using

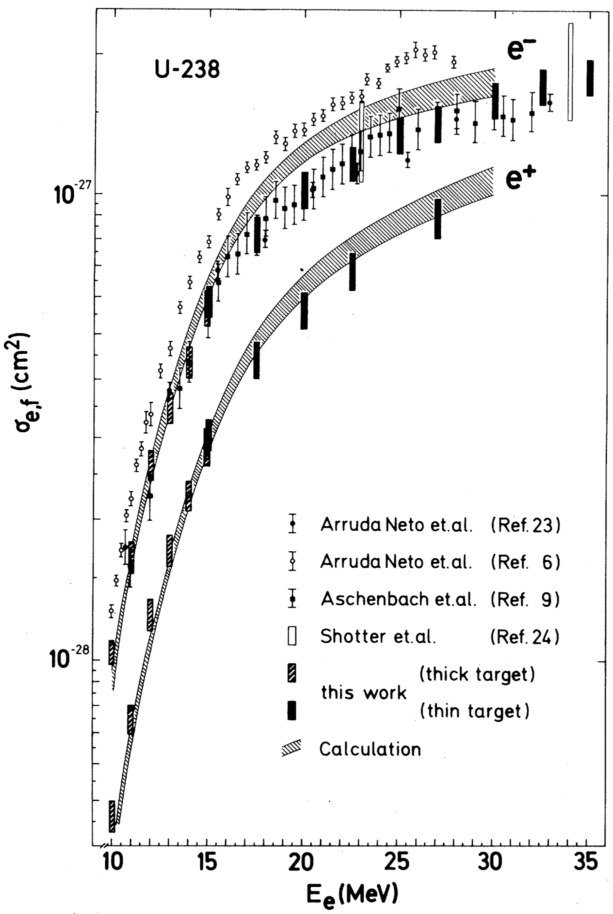

FIG. 2. Comparison of absolute electron- and positron-induced fission cross sections for ^{238}U. The error bars of the present results include both systematic and statistical errors. (Hatched areas: DWBA calculation for a pure $E1$ excitation including the systematic uncertainties in the $\sigma_{\gamma f}$ values of Ref. 14.)

the absolute photofission cross sections of Caldwell *et al.*[14] The data given by Arruda Neto and Berman[6] lie above this curve. From the difference, these authors extracted an $E2$ strength of $\approx 70\%$ of the EWSR. In contrast, our electron cross sections are considerably lower than results of Arruda Neto and Berman.[6] They are in good agreement with Aschenbach's[9] values and the older data of Arruda Neto *et al.*,[23] which both were obtained with a technique completely different from our method. The results reported by Shotter *et al.*[24] are affected with a systematic error of $\pm 20\%$ and are not conclusive in this energy range. Our electron results are slightly lower than the $E1$ calculation, similar to the σ^-/σ^+ ratio (see Fig. 1).

The positron-induced cross sections are in fair agreement with the $E1$ curve. This seems to be reasonable in view of the smaller Coulomb distortions of the positron virtual-photon spectra (see Ref. 13).

Summarizing, our measurements of the cross-section ratio σ^-/σ^+ and of absolute cross sections for electron- and positron-induced fission of ^{238}U do not confirm the data and conclusions of Arruda Neto and Berman.[6] With use of the DWBA-virtual-photon analysis, no fission decay of the isoscalar GQR could be detected. However, in our point of view an upper limit for the fission decay of the GQR with a strength of 20%–30% of the EWSR cannot be excluded from such inclusive electrodisintegration experiments, when taking fully into account the uncertainties of the present virtual-photon spectra.

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