[7]J. Blocki, J. Randrup, W. J. Swiatecki, and C. F. Tsang, Ann. Phys. (N.Y.) 105, 427 (1977).
[8]P. G. Zint and U. Mosel, Phys. Rev. C 14, 1488 (1976).
[9]A. J. Sierk, in Proceedings of the Symposium on Heavy-Ion Elastic Scattering, Rochester, New York, 1977 (unpublished), p. 306.
[10]W. Greiner, in *Proceedings of the International Conference on Nuclear Reactions Induced by Heavy Ions, Heidelberg, Germany, 1969* (North-Holland, Amsterdam, 1970), p. 748.
[11]G. R. Satchler and W. G. Love, Phys. Lett. 65B, 415 (1976).
[12]K. T. R. Davies and J. R. Nix, Phys. Rev. C 14, 1977 (1976).
[13]J. R. Birkelund and J. R. Huizenga, Phys. Rev. C 17, 126 (1978).
[14]P. David, J. Bisplinghoff, M. Blann, T. Mayer-Kuckuk, and A. Mignerey, Nucl. Phys. A287, 179 (1977).
[15]P. R. Christensen and A. Winther, Phys. Lett. 65B, 19 (1976).
[16]J. B. Ball, C. B. Fulmer, E. E. Gross, M. L. Halbert, D. C. Hensley, C. A. Ludemann, M. J. Saltmarsh, and G. R. Satchler, Nucl. Phys. A252, 208 (1975).
[17]J. G. Cramer, R. M. DeVries, D. A. Goldberg, M. S. Zisman, and C. F. Maguire, Phys. Rev. C 14, 2158 (1976).
[18]Y. Eisen and Z. Vager, Nucl. Phys. A187, 219 (1972).
[19]S. E. Vigdor, D. G. Kovar, P. Sperr, J. Mahoney, A. Menchaca-Rocha, C. Olmer, and M. Zisman, Bull. Am. Phys. Soc. 23, 615 (1978).
[20]K. T. R. Davies and A. J. Sierk, J. Comp. Phys. 18, 311 (1975).
[21]B. B. Back, O. Hansen, H. C. Britt, and J. D. Garrett, Phys. Rev. C 9, 1924 (1974).
[22]P. Möller and J. R. Nix, Nucl. Phys. A229, 269 (1974).
[23]S. E. Larsson, Phys. Scr. 8, 17 (1973).
[24]L. G. Moretto, S. G. Thompson, J. Routti, and R. C. Gatti, Phys. Lett. 38B, 471 (1972).
[25]A. H. Wapstra and K. Bos, At. Data Nucl. Data Tables 19, 175 (1977).

Remeasurement of ^{40}Ar and ^{84}Kr Excitation Functions Leading to the Same Compound Nucleus, ^{158}Er

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Excitation functions were redetermined for the reactions ^{118}Sn(^{40}Ar, 5–6n)$^{153-152}$Er and ^{74}Ge(^{84}Kr, 5–6n)$^{153-152}$Er, at two accelerators. Data obtained at the two accelerators agree. The new energy values are, however, different from those published earlier, and no significant differences occur between the (Ar,xn) and (Kr,xn) reactions leading to the same product nucleus. Thus, special mechanisms, such as pre-equilibrium neutron emission and angular-momentum windows, are not needed to interpret the new data.

Recent measurements and calculations of the slowing down of energetic heavy ions in matter have indicated large discrepancies between experimental and calculated stopping powers, and even between different calculations, for ions such as argon and krypton.[1,2] These discrepancies are pertinent to questions of current interest in heavy-ion nuclear physics, such as the mechanism of complete fusion reactions, because, in many instances, degrader foils have served to vary the beam energy in excitation-function measurements. In particular, experiments designed to study the formation of erbium compound nuclei in bombardments with ^{40}Ar and ^{84}Kr have indicated systematic differences in the threshold and peak excitation energies of (Ar,xn) and (Kr,xn) reactions leading to the same radioactive residual nucleus.[3] For the ^{84}Kr reactions, mechanisms such as pre-equilibrium emission of neutrons and a reduced probability of complete fusion at low angular momenta (the l-window effect) were invoked to explain these differences.[3-6] However, in this early work,[3] the range-energy values of Northcliffe and Schilling[7] had been used to calculate the energies of the beam after it had passed through several absorbers. Consistency checks had been run, using different initial beam energies with appropriate absorbers to obtain the same expected energy on target, but no direct energy-loss measurements had been made.

To resolve the question of possible differences between (^{40}Ar, xn) and (^{84}Kr, xn) reaction mechanisms, we have redetermined the excitation functions for ^{153}Er and ^{152}Er, with special attention given to the measurement of the beam energies on target. These experiments are timely because recent measurements of evaporation-residue cross sections and γ-ray multiplicities in the erbium region did not indicate serious differences between Ar- and Kr-induced reactions: The data for both projectiles were consistent with a complete-fusion mechanism, with no cutoff at low-l waves.[8]

As described below in detail, all of the cross-section determinations reported here have been related to direct measurements of energy losses in different absorbers. In some instances, energies were determined concurrently with cross sections. In others, recent energy-loss measurements were used to construct empirical range-energy curves or to correct the energy values obtained from published range-energy compilations.

Irradiations were performed at the accelerator ALICE in Orsay and at the SuperHILAC in Berkeley, California. Helium-gas-jet systems were used at both laboratories to collect and assay the α-radioactive nuclei produced in the reactions ^{118}Sn(^{40}Ar, 5–6n)$^{153-152}$Er and ^{74}Ge(^{84}Kr, 5–6n)-$^{153-152}$Er.

At ALICE, the energy of the extracted krypton beam was measured by magnetic analysis: The magnetic field was determined with a nuclear-magnetic-resonance probe, and the radius, with beams whose energies were determined by the proton-recoil technique.[9] The energy losses in nickel absorbers were derived from the corrections[1] determined with the proton-recoil system to the Northcliffe-Schilling stopping powers. The largest energy loss in the absorbers was 85 MeV, with the beam energy degraded in steps from 393 ± 4 MeV to 308 MeV.

At the SuperHILAC, a time-of-flight system (TOF)[10] determined the krypton beam energy (620.1 ± 1.4 MeV) and the energy losses in foils of nickel, aluminum, and titanium to be used in measuring the excitation functions. A solid-state detector was calibrated by placing it directly in the attenuated beam behind the TOF system. For the actual cross-section measurements, this calibrated detector with its associated electronics was moved to the gas-jet chamber, where it was placed periodically in the attenuated beam behind the absorber foils to monitor the beam's energy and spread.

At ALICE, the ^{118}Sn(^{40}Ar, xn) excitation functions were remeasured in the energy range 170–230 MeV. The beam energy, 259 ± 2 MeV, was determined with the calibrated magnetic analysis system, as described above. Energy losses in the nickel absorbers used were obtained from the empirical corrections[1] to the Northcliffe-Schilling values for ^{40}Ar.

The validity of these corrections was verified at Orsay in experiments in which excitation functions were measured for the ^{40}Ar + ^{164}Dy reaction in conjunction with measurements of the energy of the beam on target. ^{40}Ar beams of four different energies were successively obtained from the accelerator. Then for each energy beam, two cross-section measurements were made, one with no absorber and one with a thin Ni foil, to avoid large energy losses in the degrader foil. Thus, in all, eight sets of cross sections were determined,[11] with the energy of each set being measured by the proton-recoil technique. It should be noted that these data agree[12] with excitation functions recently obtained at Unilac, where energies were measured by TOF.[13]

We made no measurements at the SuperHILAC of energy losses of ^{40}Ar in absorber foils. However, we did determine the energy of the extracted ^{40}Ar beam, 286 ± 2 MeV, by TOF prior to studying several target-projectile systems, including ^{40}Ar + ^{118}Sn and ^{40}Ar + ^{164}Dy. The SuperHILAC energy scale for the ^{164}Dy data had been previously computed with the Northcliffe-Schilling tables.[14] Comparison of the new Orsay excitation functions for ^{40}Ar + ^{164}Dy with the SuperHILAC data led to corrections in the latter energy scale; these same corrections were applied to the data for ^{40}Ar + ^{118}Sn.

Figures 1 and 2 show the remeasured relative cross sections for (^{84}Kr, 5–6n) and (^{40}Ar, 5–6n), respectively, plotted versus laboratory energy. The closed points were measured at the SuperHILAC, and the open points, at ALICE. In each figure, for ease of comparison, the peak of the 5n excitation function has been set equal to 1000, and the other experimental points normalized accordingly. It is apparent that the Berkeley and Orsay data are in good agreement, especially in the independently determined laboratory energy scales, and in the shapes of the excitation functions. This agreement is especially striking in view of the fact that the beams extracted from the two accelerators had considerably different energies: For ^{84}Kr, the measured energies at

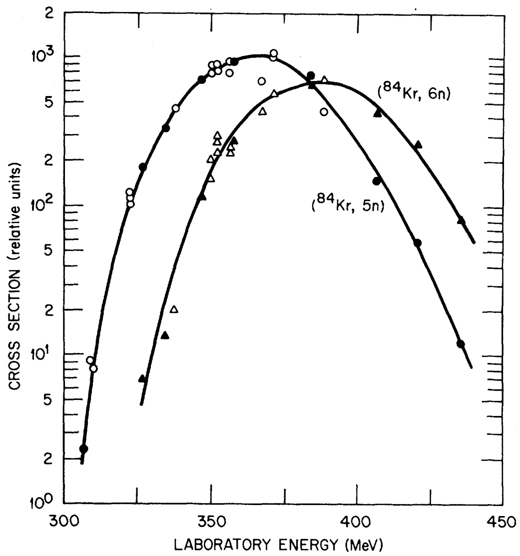

FIG. 1. Relative excitation functions for the reaction ^{74}Ge(^{84}Kr, 5–6n)$^{153-152}$Er vs laboratory energy. The open points were measured at the accelerator ALICE, and the closed points, at the SuperHILAC.

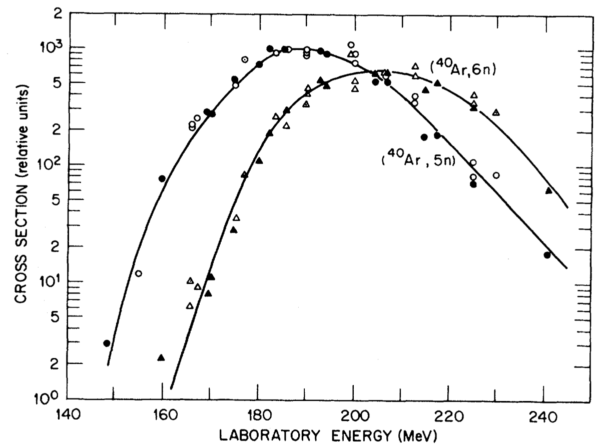

FIG. 2. Relative excitation functions for the reaction ^{118}Sn(^{40}Ar, 5–6n)$^{153-152}$Er vs laboratory energy. The open points were measured at the accelerator ALICE, and the closed points, at the SuperHILAC.

ALICE and the SuperHILAC were 393 and 620 MeV, respectively; for ^{40}Ar, the corresponding energies were 259 and 286 MeV.

The energy scales in Figs. 1 and 2 differ from those calculated earlier[3] with the aid of the Northcliffe-Schilling tables, with the new excitation functions having been shifted to lower laboratory energies. This shift is small for ^{40}Ar, ~4 MeV, but is considerable for ^{84}Kr; for the (Ke, 5n) reaction, it is ~20 MeV at the peak, and ~35 MeV at the threshold, of the excitation function.

In Fig. 3, we compare the data for ^{40}Ar and ^{84}Kr for each residual nucleus, ^{153}Er and ^{152}Er, plotted versus excitation energy. The ordinate scales are the same as in Figs. 1 and 2. Strictly speaking, here one should compare reaction probabilities, $P_{xn} = \sigma_{xn}/\sigma_R$, instead of cross sections, σ_{xn}. However, we want to avoid the use of theoretical values of the total reaction cross section, σ_R, in presenting our data. Besides, the emission of five and six neutrons occurs well above

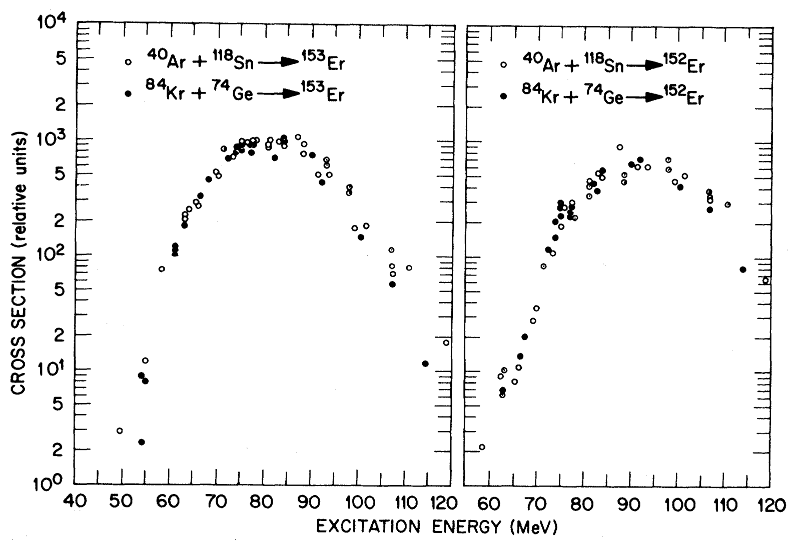

FIG. 3. Relative excitation functions plotted vs excitation energy for the production of ^{153}Er and ^{152}Er, compared for ^{40}Ar- and ^{84}Kr-induced reactions.

the Coulomb-barrier threshold, so that the ratio of total reaction cross sections for ^{40}Ar and ^{84}Kr is constant, to within ~15%, for $E^* \gtrsim 60$ MeV. The relative cross sections are thus proportional to the reaction probabilities. We see that for both $5n$ and $6n$ emission, there are no significant differences between the data obtained with the Ar and Kr beams, in terms of the reaction thresholds and the peaks of the excitation functions [the (Ar, xn) curves appear to be wider than the (Kr, xn) curves, with full widths at half maximum of 28 and 24 MeV, respectively.] We therefore conclude that the independence hypothesis of compound-nucleus formation and decay is valid for ions as heavy as ^{40}Ar and ^{84}Kr. Special mechanisms, such as pre-equilibrium neutron emission and angular-momentum windows,[3-6] are not needed to interpret our new data.

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[1]R. Bimbot, S. Della Negra, D. Gardes, H. Gauvin, A. F. Fleury, and F. Hubert, Nucl. Instrum. Methods 153, 161 (1978).

[2]R. L. Hahn, K. S. Toth, R. L. Ferguson, and F. Plasil, to be published.

[3]H. Gauvin, Y. LeBeyec, M. Lefort, and R. L. Hahn, Phys. Rev. C 10, 722 (1974).

[4]M. Lefort, Phys. Rev. C 12, 686 (1975).

[5]C. Cabot, H. Gauvin, Y. LeBeyec, and M. Lefort, J. Phys. (Paris), Lett. 36, 289 (1975).

[6] M. Lefort, J. Phys. (Paris), Colloq. 37, C5-57 (1976).

[7]L. C. Northcliffe and R. F. Schilling, Nucl. Data, Sect. A 7, 233 (1970).

[8]H. C. Britt, B. H. Erkkila, P. D. Goldstone, R. H. Stokes, B. B. Back, F. Folkmann, O. Christensen, G. Fernandez, J. D. Garrett, G. G. Hagemann, F. Plasil, R. L. Ferguson, M. Blann, and H. Gutbrod, Phys. Rev. Lett. 39, 1458 (1977).

[9]R. Bimbot, S. Della Negra, D. Gardes, H. Gauvin, and B. Tamain, Rev. Phys. Appl. 13, 393 (1978); R. Bimbot, D. Gardes, H. Geissel, and K. H. Schmidt, Z. Phys. A 286, 327 (1978).

[10]H. C. Britt, B. H. Erkkila, P. D. Goldstone, R. H. Stokes, F. Plasil, R. L. Ferguson, and H. H. Gutbrod, in ANL Report No. ANL/PHY-76-2, Proceedings of the Symposium on Macroscopic Features of Heavy Ion Collisions, Argonne, Illinois, 1976, edited by D. G. Kovar (unpublished), p. 491; and to be published.

[11]B. Lagarde and Y. LeBeyec, to be published.

[12]W. Reisdorf, private communication.

[13]K. H. Schmidt, P. Armbruster, W. Faust, S. Hofmann, G. Münzenberg, W. Reisdorf, H. G. Clerc, W. Lang, D. Vermeulen, H. Ewald, and K. Güttner, Z. Phys. A 284, 431 (1978).

[14]Y. LeBeyec, R. L. Hahn, K. S. Toth, and R. Eppley, Phys. Rev. C 14, 1038 (1976).

Parity of Bound $J=1$ Levels in ^{208}Pb

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The parities of four bound $J=1$ levels in ^{208}Pb that are strongly excited by γ rays were determined by observing the elastic scattering of plane-polarized photons. The levels at 5.51, 7.06, 7.08, and 7.33 MeV are excited by electric dipole radiation, and therefore have negative parity. The 1^- assignment for the 7.06-MeV level is of particular significance because this level had previously been thought to contain about 36% of the $M1$ strength in ^{208}Pb.

The energies of magnetic dipole excitations in ^{208}Pb and their one-particle, one-hole structure are particularly important because these features are sensitive indicators of the poorly known spin-dependent part of the effective nucleon-nucleon interaction in nuclei (the Migdal parameters g_0 and g_0').[1] This interaction affects a variety of nuclear-structure problems and is related to the nuclear-matter density at which a pion condensate would be expected.[1] The single-particle model predicts only two one-particle, one-hole spin-flip states that would be strongly excited by magnetic dipole radiation in ^{208}Pb; the proton $h_{9/2}$-$h_{11/12}^{-1}$ state would have an unperturbed energy of about 5.57 MeV while the neutron $i_{11/2}$-$i_{13/2}^{-1}$ state would have an energy of about 5.85 MeV.[2]

